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MINUTES OF PROCEEDINGS
L. S. S. 2/3
OF
LONDON —
 THE INSTITUTION
OF
 CIVIL ENGINEERS;
 WITH OTHER
 SELECTED AND ABSTRACTED PAPERS.
 VOL. CIV.

EDITED BY
 JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. ciii., p. 254, line 3, the No. should be "877" and not "8771."

" " " 6, for "609" read "600."

" p. 350, line 4, in the denominator of the fraction for "mile" read "mille."

" p. 496. Attention has been directed to the fact that the problems, with their solutions, contained in the abstract, "Self-Induction and Capacity," by P. Boucherot, were discussed and published by Mr. T. H. Blakesley, M. Inst. C.E., in 1885.

" p. 514, line 5, for "shape of the brick cylinders" read "shape of the cylinders."

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1890-91.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

13 January, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

M. CARNOT, President of the French Republic, was elected by
acclamation an Honorary Member.

It was announced that the following Associate Members had
been transferred to the class of

Members.

HENRY RICHARD CARLETON, B.A., B.E.
HENRY JAMES COLES.
WILLIAM SANTO CRIMP.
WILLIAM CROSS (Newcastle-on-Tyne).
JOHN REGINALD HARDING.

GISEBERT KAPP.
WILLIAM OLIVER EVELYN MEADE-
KING.
EDMUND PENNY.

and that the following Candidates had been admitted as

Students.

GORDON ALLEN.
LEWIS BROWN BAGOT.
OSWALD BARKER.
FRANCIS EDWARD BENEST.
CHARLES MARCUS BLES, B.Sc.
JAMES LORD BOWNESS.
JOHN DU VALLON BRUNTON.
RALPH GEORGE CARTE.
JOHN ROBERT CHAMPION.
GEORGE FINDLATER CLEMENTS.
STAMFORD VAIR CLIREHUGH.
EDWARD FRANKLYN ELLIOT.

GEORGE GONSALVES.
EDWARD LONG GROVE.
HECTOR FREEMAN GULLAN.
CHARLES THOMPSON JOHNSON.
NAGENDRANATH MITRA.
REGINALD FREDERICK ERNEST RIDG-
WAY.
HENRY FRANCIS RUSSELL.
LEOPOLD HALLIDAY SAVILE.
ERNEST WILLMOTT SLOPER.
NORMAN MCLEOD RAMSAY WILSON.

The Candidates balloted for and duly elected were as

An Honorary Member.

The Right Hon. LORD RAYLEIGH, M.A., D.Sc., F.R.S.

Members.

ANTONIO DE CARVALHO PAES DE AN- DRADE.	FREDERICK MARGARSON HYNES.
WILLIAM BUCHANAN.	LOUIS JOHN MCKENZIE LOWE.

Associate Members.

DOUGLAS ALLPORT, Jun., Stud. Inst. C.E.	WATKIN HALL.
WILLIAM ARNOT.	HENRY JOHNSON.
EDWARD NEVILL BANKS.	SIDNEY COOKE LEWIS, Stud. Inst. C.E.
CHARLES FREDERICK BECHER, B.A., B.E.	JOHN DA VINCI LOUCH.
HORACE SAMUEL BOND.	ALFRED LUNN.
HENRY JOHN BRIDGEWATER.	JAMES GILBERT STEVENSON MACINTYRE, Stud. Inst. C.E.
WILLIAM ALOYSIUS CASHMAN, B.E., Stud. Inst. C.E.	JAMES PORTER MAGINNIS.
HENRY VINE CHAMPION.	PERCY EDWARD MITCHESON.
NEVILLE BROOKES DAVIS, Stud. Inst. C.E.	ROBERT EDWARD PEAKE.
HAROLD DEANS, B.A., Stud. Inst. C.E.	ALFRED BARNES PICKARD.
FRANK WILLIAM DODD, Wh.Sc.	DAVID PRICHARD.
ANDREW DUNCAN, Stud. Inst. C.E.	LOUIS EDGAR ROBERTS.
JOHN DUNN FERGUSON.	WILLIAM CHARLES CLIFFORD SMITH.
THOMAS FRAZER.	FREDERICK CHENERY SUGGATE.
HENRY COLTHURST GODWIN.	JOHN WULSTAN TWINBERROW, Stud. Inst. C.E.
	EDWARD VENNING.

Associates.

THOMAS BLISSETT.	CAPTAIN JAMES DALLAS, R.E.
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(Paper No. 2490.)

“Auxiliary Engines in connection with the Modern Marine Engine.”

By WILLIAM HENRY ALLEN, Assoc. M. Inst. C.E.

ONE of the most striking features in the development of the marine engine has been the introduction of auxiliary engines. Formerly not only was the whole of the propelling power derived from one engine, but all the arrangements for dealing with the steam were concentrated in it; whereas in the present day the work is

divided among a number of separate and highly specialized machines, each having its own definite function, upon the due performance of which depends the working of the whole.

The year 1840 marks an epoch in the history of the marine engine, when the inverted-beam, or side-lever, engine took substantial form. An interesting extract from a specification of that time reads: "Boilers to be proved by water-pressure to not less than 14½ lbs. at bottom of boiler, and shall be capable of generating sufficient steam at not less than 7 lbs. pressure to fill the cylinders for eighteen double strokes per minute with the passages open."

Then followed the oscillating and the horizontal engines, and these were the principal forms of marine engine in vogue up to the year 1860, both having low-pressure steam, scarcely ever reaching 50 lbs. per square inch. Later on the fact was recognized that high-pressure steam was more suitable and economical, and probably the Paper read before the Institution by Mr. Alfred Holt, in 1877,¹ had considerable influence on the minds of marine engineers. Since the before-mentioned date the overhead form of compound engine, with initial pressures of from 80 to 100 lbs. and expanding either in two or in three cylinders, has been adopted, and from about the year 1884 to the present time the triple-expansion engine has been the accepted form.

With higher pressures came the necessity for a surface-condenser, and thus began the separation of the condensing-plant and the introduction of circulating-engines. Now, most large main engines consist simply of the cylinder frame-work and ordinary working parts; the air-pump, circulating-pump, reversing-engine, feed-pump, and the turning-engines, being entirely separate from the main engines. The advantages which this arrangement possesses are manifest, as it would be almost impossible to construct large engines such as are now made, running at from 850 to 900 feet piston-speed per minute, and occupying such small compass, unless the condensing-power were separate.

CIRCULATING-PUMP ENGINE.

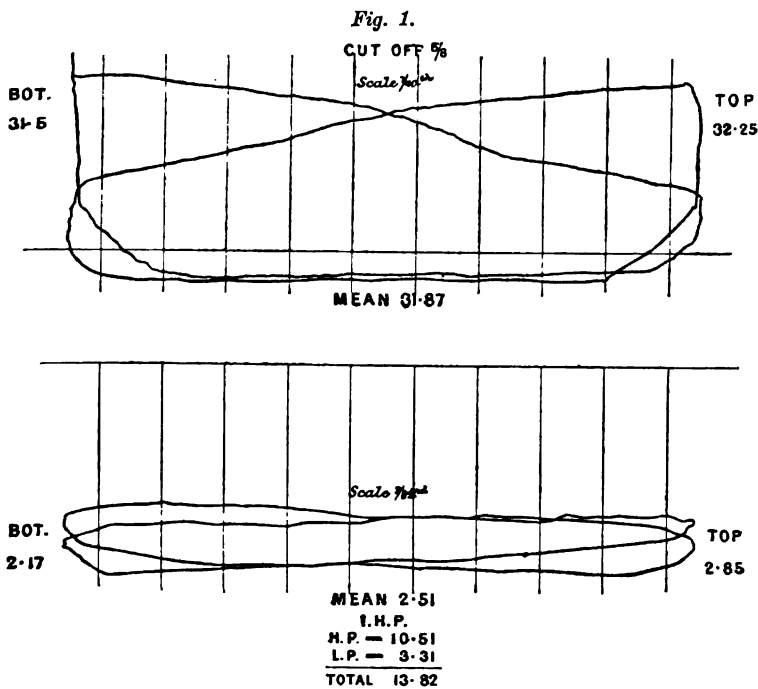
The earliest auxiliary introduced into the engine-room was the circulating-pump engine in combination with the surface-condenser. One of the first fleets of steamers on which this

¹ Minutes of Proceedings Inst. C.E., vol. li. p. 2.

arrangement was adopted was that of the White Star Line, including the "Oceanic" and two sister ships, the former of which made her maiden voyage in 1871. Several difficulties occurred owing to makers of centrifugal-pumps advocating engines running at speeds which were not justified by experience. The result was that some of the earlier centrifugal-pumps had to be withdrawn and replaced by others containing larger disks for lower speeds. The mistake was probably due to the fact that the custom on land had been to work centrifugal-pumps by belts at an extremely high rate of speed, no direct-acting pumping-engines having then been properly designed, but as soon as it was recognized and corrected no further difficulty was experienced. When the "Arizona" was built in 1878, lower speeds and more suitable engines were adopted, and the auxiliary engines of this boat, after a period of twelve years, are still in good working order. The form of circulating-engine adopted for driving these pumps was in harmony with the design of the main engines, namely, the inverted cylinder, with cast-iron standard and columns, and this type has been used in all the largest steamers until it reached its maximum size when the "Umbria" and "Etruria" were built. The large circulating-pumps on board the "Umbria" and "Etruria" are shown in Plate 1, Fig. 1. They are 20 inches in diameter, and are each capable of discharging 9,000 gallons per minute at a speed of 110 revolutions, being driven direct by engines having cylinders 15 inches in diameter by 12 inches stroke, taking steam from the main boilers at 110 lbs. pressure and exhausting into condensers. The main engines indicate close upon 15,000 HP., requiring 1.2 gallon per indicated HP. when the engines are developing their full power. This may be taken as the fixed type of circulating-engine since 1884.

Subsequently, when steam-pressures were increased to 150 lbs. in triple-expansion engines, it was thought desirable that the circulating-pumps should have compound engines, to effect greater economy. The first large boats fitted on this principle with triple-expansion main engines were the "Aller," "Trave," and "Saale," of the North German Lloyd, the circulating-engines of which are shown in Fig. 2. These consist of two 16-inch pumps, each driven by twin engines having cylinders 8 inches and 16 inches in diameter by 10 inches stroke, capable of circulating water for condensing the steam of engines of 7,000 HP. at 120 revolutions. Each pump delivers at this speed 4,000 gallons per minute, which gives a quantity of about 1.1 gallon per indicated IIP. It will be readily seen that with

the full boiler-pressure of 150 lbs. the cylinders of these engines are far too large for the ordinary work of circulating; but in explanation of their capacity it should be pointed out that as it was usual to connect the centrifugal pumps with the bilge, it was necessary to make the engines not only sufficiently powerful for circulating, but also capable of working against a head equal to the depth of the bilge. For this reason the compound engines had to be designed for nearly three times the power which would otherwise have been sufficient. The diagram, *Fig. 1*, is taken from



INDICATOR DIAGRAMS OF CIRCULATING ENGINES, S.S. "ALLER."
STEAM 150, VACUUM 28, REVOLUTIONS 130.

these engines, and it will be seen that the power required for circulating is only 13.82 indicated HP., whereas the engines are capable of indicating 90 HP. when dealing with the full capacity of the pump and total depth of bilge of 25 feet. This fact gave rise to the question as to whether a more efficient form of engine could not be devised, which would be large enough for bilge-purposes, and yet economical in its action when circulating. Accordingly the same form of engine which was used in the

"Umbria" has been employed in the new Hamburg American steamer "Normannia," also the Castle Line "Dunnotar Castle," Fig. 3; but instead of using the steam from the boiler at a pressure of 160 lbs. for driving the circulating-engines, it is taken out of the high-pressure steam-receiver, and having done its work of circulating, is passed into the low-pressure steam-chest of the main engines. Thus a form of expansion has been obtained which is economical in the use of steam as well as in the first cost of the engine, while for the purpose of pumping the bilge, when the main engines are stopped, an auxiliary steam-pipe connects the engine with the main boilers.

The quantity of water generally used for circulating-purposes has of course decreased with the reduction of water evaporated per indicated HP. per hour. Thus, with from 25 to 30 lbs. per indicated HP. per hour the circulating-engines were required to give as much as 15 to 20 lbs. of water per minute for surface condensing, while with the triple-expansion engines, which use only 15 to 18 lbs. of water, the regular quantity seldom exceeds 10 lbs. It will be seen, therefore, that the "Arizona," indicating 6,000 HP., required 13 lbs. of cooling water per HP. per minute; the "Umbria," of 15,000 HP., built in 1884, 12 lbs.; and the "Aller" class, built in 1886, triple-expansion, indicating 7,000 HP., required 11 lbs.; and in the "Normannia," built in 1889, there are two engines indicating 13,000 HP. which use about the same quantity. It is found that the quantity of condensing-water is a matter of some consideration, as a difference in temperature above or below the normal point is detrimental to good working. Should the surface not be enough, or the condensing water be insufficient in quantity, then the vacuum obtained will be lower than that desired; whereas, on the other hand, if the circulating pumps deliver too much water the condensed steam is reduced to a temperature below that at which it is economical to return it to the boiler.

So far as the Author knows, no experiments have been carried out on the condensing-plant of marine engines, and consequently the data for regulating the size of the machine must be those obtained from practice. The Author has found the friction of the condenser-tubes, together with the velocity of entrance, as well as the friction of the circulating-pipes themselves, to be equivalent to a head of from 5 to 10 feet; that is to say, that in calculating from the speed of the centrifugal pump, as well as the quantity of water known to be delivered at this speed, from 5 to 10 feet is the range of pressure against which it is necessary to work.

Comparing the quantity of water discharged with the indicated HP., the efficiency at this head, and with the moderate number of revolutions at which they are operated, has been found to be 50 per cent. This result was with a velocity of water of from 9 to 10 feet per second through the circulating-pipes, which accords with the common practice in the merchant service. In the Navy much higher velocities have been used, in some instances 15 feet per second, but the effect of this must be to considerably diminish the duty of the centrifugal-pump. The above efficiency must be considered fairly good when the large range of power for which the engines are constructed is taken into consideration.

Safety of working in this department of a twin-screw marine engine is in a large measure assured by cross-connecting the circulating-pumps, so that in case of emergency either of them could be employed for condensing the steam from both engines. This method, which has been recently carried out in the new mail boats "Empress of India" and two sister vessels for the Canadian Pacific Railway Company, is shown in Plate 1, Figs. 4 and 6. In this ship, which is divided by a longitudinal bulkhead in the usual way, the circulating-pumps are attached to both condensers by cross-connecting with a system of valves. Each pump is provided with two engines, either of them being powerful enough to supply its own condenser, and the two together capable of working the pump at a sufficiently accelerated speed to provide water for both condensers. This method has also the advantage of keeping down the area of the cylinders for circulating, while still retaining full power for bilging.

The Author recommends that for steamers having horse-powers ranging from 6,000 upwards, the speed of the centrifugal-pumps for circulating-purposes should not be less than 150 revolutions per minute, a lower speed only adding to the weight and bulk without having any advantage. In some instances the Author has noticed that the main engines, with strokes of 5 or 6 feet, have been travelling at a higher number of revolutions than the comparatively small centrifugal pumping-engines, with strokes of only 10 to 12 inches, which is an evident anomaly. As it is quite possible to make such engines work with certainty at 150 or 180 revolutions per minute, there can be no reason why the above-mentioned speed should not be adopted. These remarks apply only to the Mercantile Marine, for in the Navy the question is somewhat different; there the engines are only required to develop their maximum power on trial trip or on special occasions, and the pumps can then be readily worked up to 250 to 300 revolutions

per minute; while the normal speeds, when the engines are only indicating half power, will fall under 200 revolutions.

The custom of duplicating auxiliary engines seems now to have entirely fallen into disuse, past experience having proved it to be a totally unnecessary practice, not only increasing the first cost, but necessitating the carrying of so much dead weight to no purpose. If the circulating-engines are well made, there is no more occasion to duplicate them than the main engines.

Probably no better instance can be given of the regular running of ships with single circulating-pumps, than that of the New Zealand Steamship Company's fleet of the "Tongariro" class, 4,500 HP., fitted with single 15-inch pumping-engines in 1883, Fig. 5. These vessels have been running ever since without any break-down or stoppage.

There has been considerable difference of opinion as to whether centrifugal pumps should be made entirely of gun-metal, or of cast-iron, or with cast-iron casing and gun-metal disk. The Author's experience with cast-iron disks and casings is entirely in their favour, as, in many cases which have come under his observation, the pumps have shown no sign of corrosion after being at work for fifteen years. On the other hand, centrifugal-pumps made with gun-metal disks and cast-iron casings, have shown considerable pitting in the latter, after being at work for a few years, no doubt from galvanic action set up by the contact of the salt water with the two different metals.

In connection with centrifugal-pumps several instances have come under the Author's notice where circulating-pumps have given considerable trouble through a reduction in the area of the suction-pipes, valves, and gratings. As a centrifugal-pump, in order to work with advantage, should have its full area of pipe kept open all through the system, it becomes necessary that the inlet should in every case be quite free, and that nothing should be allowed to enter the pipes which would be likely to choke the passage, such as seaweed or other matter. This has frequently occurred through neglect, and too much care cannot be taken to prevent it.

SEPARATE AIR-PUMP ENGINES.

The practice of entirely disconnecting the air- and feed-pumps from the main engines, and working them by their own steam cylinders, has not been universally adopted, but there are several

instances of such separate sets of engines giving great satisfaction. A diagram of one of these is shown in Fig. 7. In it the air-pumps are below, and are worked direct from the cross-heads, the steam-cylinder being inverted. On either side are placed feed- bilge- and sanitary pumps, the machine being thus thoroughly balanced in all its movements. A crank-shaft is employed, having ordinary connecting-rods, with flywheels at each end, so that the motion is tolerably steady. One of the best examples of this kind of work is to be found in the s.s. "Normannia" of the Hamburg-American line. In this case the cylinders are not triple-expansion, but receive their steam from the high-pressure steam-chest of the main engines, and exhaust into the low-pressure steam-chest of the same, thus using the steam expansively and without much loss. The arrangement shown is extremely compact in itself, and the system is very convenient in engine-rooms provided with twin engines, where space is limited, and there is not room for the air-pumps to work in the ordinary way.

The advantage which this class of auxiliary engines possesses consists in the fact that the pumps can always be started before the main engines, and thus by the use of separate centrifugal-pumps in addition, a vacuum can be produced ready for the first stroke of the main engine. This method has also been employed where new engines of larger size have been introduced into old boats, in which lack of space has compelled the designers to seek some other way of working the air-pumps than by having them connected with the main engines, as, for instance, in the London and North Western Railway Company's boats "Lily," and "Violet."

AUXILIARY COMBINED PUMPING-ENGINES.

For creating a vacuum in the auxiliary condenser, the combined air-pump and centrifugal-pump, shown in Fig. 8, is a useful appendage in the marine engine-room. By increasing the diameter of the disk of the centrifugal-pump, the revolutions can be reduced so that the air-pump can be made to run without any difficulty. The maximum speed for which these pumps have been made to run is 250 revolutions per minute.

FANS FOR FORCED DRAUGHT.

The keen competition which now exists among steamship companies, and the consequent demand for higher speeds, has

made it almost a necessity to employ artificial draught in order to provide sufficient air to burn the required quantity of coal on a reduced grate-area. A trial of induced draught by jet-nozzles not having met with the success which was anticipated, the method seems now to have been more or less discarded. The different methods of applying forced draught which have come under the Author's notice are the closed ashpit system with cold air, the closed ashpit system with hot air, the air being passed through tubes in the smoke-box, the closed stoke-hold system, as universally employed in the Navy, and the open stoke-hold system, in which the fans are employed for assisting the draught. In all cases the centrifugal-fan appears the best means of providing the necessary air-pressure.

The Author believes that the first application of fans for forced draught was made by the late Mr. Thornycroft, on one of the early experiments with fast-running boats. During the last eight years the adoption of fans in mail steamers and in the Navy, has gradually become universal, the Author alone having fitted as many as six hundred sets during the last five years. The first fleet of steamers of any size in constant service fitted with fans was the City of Dublin Mail Steam Packet Company's line, running between Holyhead and Dublin; forced draught was introduced on these in 1883, and it has since been applied to each of the Company's steamers, eight fans being placed in the first and each succeeding vessel. The use of these machines has led to the shortening of the passage by at least half an hour, and has in every way rendered steaming more easy.

The success of this work gave an impetus to forced draught in coasting steamers, and it has been applied in nearly every instance to new passenger vessels, as well as to a number of old vessels at present working round the coast. The several fleets of steamers which have been fitted by the Author with direct-acting fans during the last six years are as follows:—The boats running between Belfast and Glasgow, the Liverpool and Isle of Man boats (4), Liverpool and Llandudno (2), Holyhead and Dublin (4), City of Dublin Steam Packet Company's (5), London and North Western new steamers (2), Great Western boats, running between Weymouth and the Channel Islands (3), Brighton and South Coast boats running between Newhaven and Dieppe (2), Chatham and Dover boats running between Dover and Calais (3), and the Netherlands Steamship Company's boats running between Queenborough and Flushing (4). From this list it will be seen that all the principal lines of passenger steamers running from

England to neighbouring shores have been fitted with fans for forced draught.

Fig. 10 shows the form of fan and engine supplied to the City of Dublin Steam Packet Company's boat "Ireland," there being four fans of a diameter of 7 feet 6 inches, each capable of delivering 50,000 cubic feet of air per minute for a HP. of 6,000.

Fig. 11 represents eight sets of 7-foot fans driven direct, as fitted on the passenger steamer "Mona's Isle," for the Isle of Man service, each set of which is capable of delivering 40,000 cubic feet of air per minute.

The above refer to coasting or channel steamers only. Forced draught, however, has by no means been confined to coasting steamers, as recently all the Atlantic liners, as well as some boats trading to Australia, have been equipped with assisted-draught fans of various kinds.

Fig. 12 shows the form of fans employed in the China line of steamers of 3,000 HP. They were made of rather large diameter, for giving only light pressures in the stoke-hold, so that they might run from Liverpool to China without stopping, and without fear of accident. They are 6 feet 6 inches in diameter, and are capable of delivering 20,000 cubic feet of air per minute, and fitted with tandem engines, having cylinders 7 inches and 12 inches diameter, by 7 inches stroke. They have been at work for the last six years, and the owners are adding duplicate sets to their new fleet. A convenient method of fixing fan-engines to bulkheads is shown in Fig. 9, being one of five in the p.s. "Adder."

The application of fans, however, may have a twofold purpose, namely, to enable more coal to be burnt in a given time, and also to reduce the temperature of the stoke-hold, which is always a desirable object.

Fig. 13 shows a set of fans which have recently been placed by the Author on the "Majestic" and the "Teutonic" for this purpose, and have been the means of considerably increasing the speed of these vessels. They are above deck, and are used for providing air for the forced draught below. They are 7 feet 6 inches in diameter, and each is capable of delivering about 50,000 cubic feet, making in all 200,000 cubic feet of air delivered per minute in each vessel. The fans are driven by engines having cylinders $6\frac{1}{2}$ inches and 13 inches diameter, by 8 inches stroke, with 180 lbs. of steam taken direct from the boiler. They run at 250 revolutions per minute, and work steadily without vibration. The last and probably most important example

of the introduction of forced draught into the Atlantic steamers, is that of the s.s. "Normannia," 13,000 HP., the stoke-holds of which are provided with twelve sets of single inlet fans, each driven by a tandem compound engine of economical form. When it is considered that the weight of these twelve fans is only 6 tons, and the advantages obtained by the reduction in the weight of the boilers are taken into account, as well as the accelerated speed, it will be seen how great a benefit arises from the introduction of forced draught when used for moderate pressures. At present there is no general consensus of opinion on the subject of forced draught, and it would appear that every system requires a different quantity of air and a different pressure; but as regards quantity, it is safe to take as a liberal allowance 260 cubic feet of air per lb. of coal, although, considering the waste there is sometimes in leakage, and through outlets where the air will probably find vent instead of through the fire, it may be prudent, under some circumstances, to add considerably to this amount. As an example of the different conditions which may be met with, it may be stated that on one vessel of 8,000 HP., the Author fitted fans capable of delivering 200,000 cubic feet of air per minute, and in another, indicating 13,000 HP., the fans provided 130,000 cubic feet per minute only, with equally good result.

At present the pressures for forced draught vary from $\frac{1}{2}$ inch of water upwards, according to the system, but, until further progress is made in high-pressure boilers, the Author is of opinion that a pressure exceeding $\frac{3}{4}$ inch of water in the ashpit is not advisable, involving, as it does, leakage in the tubes, and other troubles. Experiments, both in England and abroad, show that the large variation in the quantity of air required in the different systems makes it almost impossible to give any proper rule. An instance of this may be found in the introduction of forced draught in the Queenborough and Flushing boats, the fans supplied to the last few steamers being 18 inches less in diameter than the earlier ones, with equally good results. It may be observed that these fans are employed only for assisted draught. Considerable benefit, however, has been obtained with even these small fans, particularly when the wind is abaft the funnel, as it is then that the stokers find the greatest difficulty in maintaining their pressure. The same may be said about the steamers which travel in the trade-winds, many of which are being supplied with fans for providing air when going with the wind.

All the fans above mentioned are driven direct from their own engines, and are under the control of the engineer. Belt-

driven fans are not suitable for steamship purposes, it being impossible to work a high-speed belt properly when it is placed longitudinally with the ship, which is generally the most convenient arrangement. This, together with the proximity of dust and grease, renders the system an unsafe one. Seeing how readily engines and fans combined can be fitted into any corner, it is evident that direct driving is the best.

There now is no difficulty in making large fans to run true within $\frac{1}{16}$ inch in their diameter as well as sideways, for sizes up to 7 feet or 8 feet diameter. Considerable reduction has also been effected in the weight. The first large fans, constructed by the Author in 1885, were 7 feet 6 inches in diameter, and weighed 28 cwt. each. By improvements in the construction, the present form, which is capable of working at higher speeds, and against heavier pressures, weighs only 16 cwt. This decrease in weight is not only a gain in itself, but assists greatly in keeping down vibration.

All fans for high-speed engines should be bolted down to a substantial foundation. To bolt a high-speed fan against a thin plate bulkhead without supports will, in a great measure, tend to increase vibration, and will possibly fracture the base-plate. Experiments on this subject clearly show that solidity of foundation is essential for engines of this class.

It having been suggested by leading authorities that a central diaphragm would add considerably to the efficiency of the fan, the Author carried out a series of experiments on the subject, and satisfied himself that no benefit accrued from its introduction. It would at first sight appear that the two currents of air meeting in the centre would tend to destroy each other in a measure, but the trials proved that bosses having curved entrances to about the diameter of the inlet were in every way as efficient as if the diaphragm had been carried right through.

The speed of fans depends upon their diameter and the amount and pressure of air required, but as it is limited by the maximum rate at which quick-running engines can be driven without excessive wear and tear, a speed of from 250 to 350 revolutions per minute may be regarded as the safest and most satisfactory for engines running on long voyages. The efficiency of the combined fan and engine is not high, the maximum obtained by the Author in experiments on fans of from 4 feet 6 inches to 6 feet in diameter suitable for steamship purposes, being only 42 per cent. As, however, the power required for driving fans on large ships is but a small proportion of the whole, it is highly desirable to keep up the areas of the cylinders, so that, in the event of the

steam-pressure dropping, they may be sufficiently large to maintain the full speed required by the fan until it is restored. For calculating the areas of the cylinders an efficiency of 35 per cent. would ensure the engines being of ample power.

With regard to the velocity of the air, a good practice in calculating the diameter of fans is to allow from 40 to 50 feet per second in the suction-orifice, when working at the speed mentioned above. This would permit a considerable margin in the capacity of the fan in case it should be required to give a large volume or a higher pressure at any time.

The arrangement of the pipes leading from the fan to the closed ash-pit is of great importance. In several ships to which fans made by the Author have been fitted on board by the builders, the whole of the pipes had to be removed when the trials were made, no pressure being obtained in the ash-pit, although a water-gauge indicated 4 inches at the fan. This was entirely absorbed by friction, for it must be remembered that the pressures are at all times light, and will take very little to annul them. The pipes should be of ample diameter and the bends should be made with easy curves, all angles and Z-pieces being avoided.

The value of fans on board ships can only be appreciated by those who have gone to sea with and without them. When used for forced draught not only are the owners benefited by a result in many cases exceeding their expectations, but the comfort of the stokers is increased. If owners were to consider this more they would soon be convinced of the advantage of attending to the comfort and well-being of those engaged in the engineering department.

The Author infers from questions put to a number of engineers that general opinion is in favour of the use of the fan, which has now rendered it easy to maintain the steam-pressure, and has put an end to the constant pricking and slicing which tended more than anything to knock up the stokers.

REVERSING-ENGINES.

At about the same time as centrifugal pumps were introduced, the auxiliary engine employed for the purpose of operating the reversing-links of the main engines came into use. The form which was usually employed at first, and which is now common in small steamers, is that known as the "roundabout" engine (Fig. 15). It consists of an ordinary reciprocating engine having

a cylinder of from 5 inches to 8 inches diameter, working the ordinary wheel motion. The crank on the second shaft is connected either to the weigh-shaft of the main engines, or to the links themselves, and arranged so that the links may be reversed ahead and astern. The reversing action takes place by turning the steam into exhaust by the ordinary central valve. For engines up to 1,500 indicated HP. where there is plenty of room, this arrangement answers the purpose well. Some engineers also prefer this plan on account of its being very suitable for heating up the main cylinders before leaving port by starting the reversing-engine at slow movement, when it will admit a small volume of steam on both sides of the main piston, by the fact of the reversing engine bringing the links backwards and forwards from ahead to astern; also the engineer can leave the engine working in perfect safety, which cannot be done so well by any other system. While this form has generally been adopted for small engines, it has been almost entirely superseded in large engines during the last ten years by one in which the action is direct. This is known as the hydraulic reversing-engine, and is shown in Fig. 14. It consists of a steam-cylinder, the movement of the piston of which is controlled by a hydraulic oil-cylinder. This gives an exceedingly smooth motion to the weigh-shaft, and renders the engines capable of being controlled with ease, and what is often of great importance in an emergency, it is also much quicker in its action than the roundabout gear. Fig. 14 shows the reversing-engine as applied to the Pacific mail steamers "Orizaba," "Oroya," "Oruba" and "Oritava"; it is bolted direct on to the back column of the main engine, the handle for operating the steam- and oil-valves being carried to the platform at the front. These reversing-engines are always fitted with automatic cut-off gear, which renders their adoption a matter of considerable convenience for the engineer in charge; for the movement of the small hand-lever which controls the steam-valve is followed by the motion of the reversing-engine only so far as is necessary, the automatic gear cutting off the steam and oil at the required position, so that when the engineer is called upon either to put his engine to full speed ahead, or half speed astern, or any other point, he knows that the links of the main engine will correspond to the position in which he places the handle. The automatic cut-off controlling-gear consists of a set of differential wheels and levers which are positive in action; they are either connected to the weigh-shaft or to the cross-head of the reversing-engine, and by links and levers to the valves on the reversing-engine. The operation of altering or reversing the position

of the links having been accomplished, the hydraulic cylinder takes upon itself the function of a locking gear, its valve preventing oil from passing from one side to the other, and so securing the piston in the required position. The action known as thrusting of the link-blocks is greatly lessened by the solid way in which the oil cylinder acts upon them. The hydraulic cylinder having a tail-end piston-rod has consequently the same capacity at each end, and the only leakage therefrom, which would be from the gland, is made up by the accumulator, Fig. 14. This accumulator is in connection with the hand feed-pump, which is a necessary adjunct to the reversing-engine, in order that the engines may be reversed by hydraulic power as well as by steam, as explained hereafter. It consists of a small cylinder with leathern piston pressed by a steel spring, the piston-rod passing through the top of the cylinder, and thus forming an index to its position inside. When any leakage occurs in the oil-cylinder of the reversing-engine, the piston of the accumulator follows the leakage and so keeps up the same pressure throughout the whole system. The fact is immediately made known to the engineer in charge by the piston-rod of the accumulator, which is visible, having fallen, and it is at once made good by a few strokes of the hand-pump. Hence, if the hydraulic cylinder is properly looked after, the reversing-engine can be regarded with confidence as a means also of holding the links firmly in position when the engines are worked at full speed.

This engine can be readily used for reversing the main engines by hand, with the small hydraulic hand-pump connected with it. While steam is down the hydraulic gear can be used to reverse the main engines, as is often necessary when in port, thus making the arrangement very complete. The diagram Fig. 14 shows the reversing-engines of the Royal Mail paddle-steamer "Ireland," sailing between Holyhead and Dublin. Some idea of the power of these engines will be gained from the size of this reversing-engine, the steam-cylinder of which has a diameter of $32\frac{1}{2}$ inches, with a stroke of $43\frac{1}{2}$ inches, the operating piston-rod being as much as 4 inches in diameter. The motion of the reversing-engine is generally communicated to the weigh-shaft of the main engines by side rods, which can be arranged in the ordinary way, or with a slot-link between the hydraulic cylinder and the steam-cylinder.

Small reversing-engines are now being generally used in river-tugs. The difference between the work of reversing the main engines by hand and that of actuating the starting-valve of the

reversing-engine is thoroughly understood by those in charge of such craft.

It is somewhat difficult to indicate a rule for determining the size of starting-engines, owing to the power required for reversing the main engines varying with the system of valves employed, piston-valves taking considerably less power to reverse than ordinary slide-valves; but to enable comparisons to be made it may be mentioned that for compound engines indicating 6,000 HP., with steam-pressures of 100 lbs., the Author has fitted starting-engines with cylinders 20 inches diameter by 24 inches stroke, the main engines in this instance having piston-valves in the high-pressure cylinder, and D-valves in the low-pressure cylinder. For engines of 7,000 HP. of the triple expansion type, having piston-valves for the high-pressure and intermediate cylinders and D-valves for the low-pressure cylinder, reversing-engines are provided having cylinders 20 inches diameter by 33 inches stroke. For engines of smaller power, say 5,000 HP., reversing-engines having cylinders 14 inches diameter by 20 inches stroke have sufficed. It is well, however, to have them larger than is actually required when working with the full boiler-pressure, as it is important that they should be sufficiently powerful to reverse the engines in port when only the donkey-boiler may be at work with a pressure of 80 lbs.

A further extension of the use of this form of steam and hydraulic power has been made in the engine-room since the introduction of high-pressure steam. Instead of employing the ordinary screws for lifting the valves on the main steam-pipes, this is done by small steam- and hydraulic-gear placed on the steam stop-valve, or connected therewith from any part of the engine-room by the necessary levers, rendering the work of opening this large valve exceedingly easy.

ELECTRIC-LIGHT ENGINES AND DYNAMOS.

These are among the latest additions to the engines placed under the care of the sea-going engineer, but they have come into use so rapidly that it is now the regular practice to fit up cargo-steamers as well as passenger-steamers with electric light. The difference in the comfort of a ship going to sea with electric light on board as compared with the use of oil-lamps can only be judged by those who have had experience with both. A paper on this subject was read before the Institution by Mr. Jamieson in

1884,¹ since which time considerable advances have been made in perfecting the dynamo and engine for ship work. In the interim, nearly every variety of engine has been tried—turbine, three-cylinder, rotary, single- and double-acting, open and closed, high and low speed; but the general opinion appears to be that the double-acting engine, specially constructed for driving dynamos, is the form which, in the future, will find the most favour for marine work.

At present electric-light machinery may be classed under two heads—namely, that specially suitable for Admiralty purposes, the highest economy and efficiency being the principal points in the specification, and that appropriate for ordinary merchant steamers, where a good sound practical engine and dynamo are looked for before economy, except probably in the best Atlantic liners, where compound engines of economical form may be found.

The question as to whether dynamos should be driven direct from engines or by rope-gearing has, the Author thinks, been settled by the general adoption of the direct-working machine; and, when it is considered how desirable it is to dispense with any belting or gearing, where, as on board ship, oil, grease and water are sure to be present, the advantages of direct-driving become apparent.

The engine used for Admiralty work is shown in Fig. 16, from which it will be seen that it is of the compound form with twin engines. This form was constructed by the Author in 1885, and a drawing of the same was exhibited with Mr. Kapp's paper on dynamos.² The twin form is equally advantageous both for high and low pressures, and single or compound engines, the effect being for one engine to entirely balance the other, which at high speeds is most essential. As an instance of the endurance of engines of this class, the Author may point to three sets of his dynamos and engines fitted on H.M.S. "Devastation" in 1884; which have been working constantly and regularly without stoppage, except when they have been changed over, at 300 revolutions per minute, with the full voltage and current. On the dismantling of this ship recently, in order to introduce triple-expansion engines, the dynamos and engines were transferred, with an ordinary overhaul, to another vessel of low steam-pressure, and this after six years of hard and continuous work.

The speed of Admiralty engines for electric lighting is now

¹ Minutes of Proceedings Inst. C.E., vol. lxxix. p. 1.

² *Ibid.*, vol. lxxxiii. p. 154.

fixed at 320 revolutions per minute. The diagram represents a dynamo capable of giving off 400 amperes at the regulation pressure of 80 volts when running at 320 revolutions, the engine having cylinders 8 inches and 14 inches diameter by 8 inches stroke.

The Admiralty basis for testing engines of this class is a steam-pressure of 100 lbs. per square inch, exhaust being made into the atmosphere, and at this pressure in engines made by the Author the consumption of water is 33·7 lbs. per HP. hour of output at the terminals of the machine. This form of engine and dynamo is a considerable improvement upon the earlier types. Until 1888 the quantity of water generally taken with open engines was as much as from 40 to 42 lbs. per electrical HP. hour.

Probably the British Admiralty has had more experience in dynamo-driving for steamships than any foreign government or private firm. Beginning many years ago with alternate-current machines driven by belt off the capstan, the high speeds of dynamos were brought down until they overlapped those of the engines. Some of the latter were tried at first at 800 revolutions per minute, of the three cylinder and rotary form; then the speed was gradually reduced to 250 revolutions for double-acting, and 350 to 400 for single-acting engines, until finally, at the present time, the question is settled in favour of the twin double-acting engine running at a speed of 320 revolutions per minute.

The Author is of opinion that progress has been largely accelerated by the close specifications issued by the Admiralty, without which latent ability would not have been developed and such great improvements effected in so short a time. The economy of engines and dynamos has been improved both by increasing the efficiency of the dynamo and by reducing the quantity of water required by the engine itself. Naturally, with a higher pressure of steam, combined with the use of the condenser, considerable reduction can be made on the above figure of 33 lbs.; but it will be readily understood that as all engines are tested at Portsmouth on the lines specified above, a comparison can only be properly made under those conditions. It will also be seen that these engines have in themselves certain qualifications which give them an advantage over closed engines, namely, accessibility, simplicity, and economy, combined with the all-important one of durability. It must not be forgotten too that the twin engine with cranks at opposite angles—such as is exclusively used at the Admiralty—has the advantage of working with considerably less vibration than the single-cylinder engine.

For the mercantile marine, however, an altogether different class of engine seems to be required. With the exception of some of the largest liners, nearly all vessels are now being fitted with single-cylinder direct-acting engines and dynamos, the object of the owners being to secure a machine which will run constantly without repair or breakdown, and one which can be readily understood by ordinary marine engineers, and repaired by them when necessary.

The type of engine and dynamo usual in the mercantile marine is shown in Fig. 17. The engine is of the inverted single-cylinder form connected direct to the dynamo without belting, and the whole is so constructed that any part can readily be removed. The essential features of this class of engine are:—working parts balanced as far as possible—low pressures on the bearings, obtained by large surfaces—and accurate workmanship.

It may be mentioned that the practice for merchant vessels has hitherto been to work engines of this class at a speed probably higher than experience would justify. The Author is of opinion that for engines capable of lighting boats requiring 200 to 400 lights, a speed of 270 revolutions per minute is one which can be maintained and relied upon without danger of breakdown, and at the same time it admits of a fair size being given to the engine and dynamo without excessive weight and space being occupied.

GOVERNOR.

One of the most useful additions lately made to direct-acting sea-going dynamos is that of the fly-wheel governor. Until this improvement was effected it was necessary as a rule to watch the engine and dynamo in order to regulate its speed. It is absolutely necessary for marine work that the governor should be driven from the engine without the use of belting, as it seems impossible to keep belting from slipping, owing to the unavoidable splashing of oil and water. The usual practice when this occurs has been to take the belt off the governor, and work the engine without it, a man standing by the stop-valve to regulate the voltage from time to time. This is now obviated by the improvements which have been made in direct-acting governors. The Admiralty specifications require that the speed shall be capable of regulation by hand while the engine is running, for which purpose the fly-wheel governor is inapplicable, and the ordinary ball and spring form

is generally employed, provided with hand-regulation. It is a further condition in the Admiralty specifications, that the momentary increase of speed and voltage, when the whole load is instantaneously thrown off, should not exceed 25 per cent. of the normal.

For all ordinary purposes of merchant steamers, however, these conditions are not necessary, and a governor which will maintain a steady voltage independent of the steam-pressure, and the current given out by the dynamo, is one which finds most favour. The fly-wheel governor holds the eccentric in suspension, and regulates the stroke of the steam-distribution valve in accordance with the work given out by the machine, and in the event of the full load being suddenly thrown off, prevents the speed of the engine from being increased more than 3 per cent.

DYNAMOS.

The ship-lighting dynamo has been greatly improved of late, and the drum-wound armature machine, Fig. 16, is one which has been found to work satisfactorily. The armature consists of a cast-iron hub mounted on a steel spindle, having laminated plates for the core, the whole being drum-wound on the outside. Every part at all likely to get out of order is visible, and can be readily repaired by those who have charge of the machine.

The voltage at which the Author has found it most convenient to work in merchant ships is 60 volts, which is suitable for glow-lamps as well as for projectors.

It will be borne in mind that most of the auxiliary engines placed on the lower platform have to work in temperatures varying from 90° to 120°, and hence it becomes necessary that the dynamo used for shipwork should heat as little as possible above such a normal temperature. The Author's experience is that dynamos can be readily made with the cooling surface, and the rate of development of heat so proportioned that neither armature nor field magnet rise more than 50° Fahrenheit beyond the temperature of the surrounding air after a run of six or seven hours. At the above temperature, therefore, there can be no difficulty in making engines and dynamos to fulfil their duties in as efficient a way as any of the other machinery in the engine-room.

Bearing in mind that the electric-light engine has generally to work harder and longer than any other in the ship, the light being required both when in port and when at sea, the matter of

economy is of some importance. This will no doubt have further consideration at the hands of shipowners. The efficiency of ordinary ship-lighting dynamos, with double-acting engines, is considerable, reaching in some cases as high as 83 per cent. It will be observed from the Table in the Appendix that the efficiency of dynamos of the ordinary mercantile form is over 81 per cent. This result has been obtained from a number of machines of similar size. The curve, Fig. 2, shows the efficiency of engine and dynamo combined, from no load to full load.

The above description of auxiliary engines does not by any means exhaust the list of those which are to be found in the marine engine-room of the present day, as mention should be made of the present form of feed-pump, which is generally of the duplex pattern, without fly-wheel; also the evaporator with Weir's hot-water feed-pump; the refrigerating-apparatus, which has generally the horizontal compound engine, with air-pumps opposite to the same; the steering-gear which is sometimes placed in the engine-room; the small engine for turning the engines round when in port; the distilling-machinery; the air-compressors, when the cabins are ventilated by nozzles; and the ash-hoists. The Paper has, however, extended so far that it would be impossible to embody all the details of these engines, and the Author has therefore preferred to confine himself to the four classes which have come within his own experience.

The Paper is accompanied by drawings, from which Plate 1 and *Figs. 1 and 2* have been prepared.

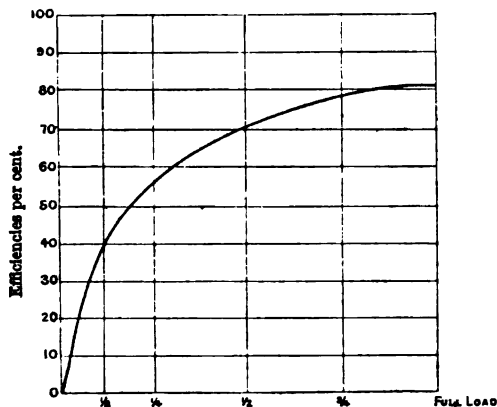
APPENDIX.

COMBINED EFFICIENCY OF ENGINE AND DYNAMO.

Proportion of Full Load.	Loss in Engine, Dynamo-shaft and Bearings.	Loss in Dynamo.	Losses in Engine and Dynamo combined.	Output.		E.H.P.	I.H.P.	Combined Efficiency.
				Volts.	Amp.			
Engine with dynamo unexcited	5.5							
Engine with dynamo excited	5.5	3.79	9.29	81.0				
Per Cent. 12.8	5.5	3.80	9.30	80.00	55	5.89	15.19	Per Cent. 39.0
24.5	5.5	3.85	9.35	82.50	102	11.25	20.60	54.5
48.5	5.5	4.02	9.52	82.50	203	22.40	31.92	70.0
72.0	5.5	4.57	10.07	80.50	306	33.10	43.77	76.5
100.0	5.5	5.36	10.87	80.25	429	46.10	56.97	81.2

Losses expressed in HP.

Fig. 2.



Curve showing efficiency of Combined Engine and Dynamo.

Discussion.

Mr. Allen. Mr. W. H. ALLEN said that the Paper was entirely of a practical nature. He regretted that he had not been able to add the result of experiments; but those who knew the marine world would know the difficulty of getting ships for the purpose. He had supplied many such engines, but had never been able to get an opportunity of testing them. The committee of a kindred Institution were now engaged on this subject, and he hoped they would be successful in getting boats for the purpose of carrying out their investigations. He hoped that the Paper would afford scope for good discussion.

Mr. Willans. Mr. P. W. WILLANS said he had not had much to do with auxiliary engines for marine work, except those connected with dynamo driving; but as the Author had devoted a good deal of the Paper to that branch of the subject, there were a few points to which he should like to call attention, especially as the somewhat important question had been raised with regard to the relative advantage of single- and double-acting engines, with the design and manufacture of the former of which he had been connected for some time. Marine work was of a very peculiar nature, and manufacturers had usually no opportunity of learning anything as to the efficiency of their engines after they had once been fixed on board ship. They knew very little more about them in five years' time than they did at the outset; so that whatever tests they wished to apply must be made before the engines went on board. In addition they had to do with a curious class of men in those who drove the auxiliary engines. It was not as though the chief engineer had to deal with them—they were often in the hands of inexperienced men. It did not matter much what class of men they were, whether skilled or not; in fact, his own experience had shown him that the best men to drive engines for electric lighting were gardeners. What was wanted was men who were capable of doing what they were told, and willing simply to carry out their instructions. Such difficulties as he had encountered in connection with closed engines on board ship he had very rarely met with on land. They had been almost entirely of two kinds. First, difficulties caused by the enormous quantity of water found in auxiliary steam-pipes on board ship; and secondly, difficulties due to the imperfect understanding of the use of

the oil-chamber in which the cranks ran, and to carelessness in Mr. Willans. not seeing that the lubricating mixture was replenished and in proper order. The first of the two difficulties mentioned above, viz., water, had been met in his case by the use of steam separators and by a more efficient system of escape-valves, so that it was now found possible to discharge suddenly into the steam-pipe of an engine running at 400 revolutions per minute a cubic foot of water, without any bad result. The second, viz., the quality of the lubricating mixture in the crank chamber depended solely on those in charge of the engines. On land practically no difficulties of this kind were now experienced, and by degrees, as the advantages of this system of lubrication both in economy of oil and of attendance were realized, he had no doubt that it would be more generally adopted on board ship. He could think of no course more likely to lead to this result than the use of open double-acting engines for the hard and continuous work of electric lighting at speeds of 320 revolutions, such as Mr. Allen appeared to advocate. The Author had spoken of the "single-acting closed engine," as though the two things were inseparable; but in reality the one was a question of principle, and the other, of convenience. For continuous work beyond a certain speed, he did not think that any one would recommend a double-acting engine. He was not speaking of occasional work; but for steady work, such as electric-lighting installations on land, and also on board ship, there was a speed at which double-acting engines were not applicable. The only question was, what was that speed? Closing up an engine was another question altogether. There were a number of different points to be considered, and there were certain advantages in having it open, and certain others in having it closed. His own reason for usually closing his engines was that there was nothing to be done to them, no adjustment of the bearings being required. This being the case, it was better to run the machine in a bath of oil rather than let it splash the oil in all directions. On the other hand there was a possibility of neglect. If the lubricant was run out of the chamber containing the cranks, &c., they were in a worse position with a closed than with an open engine. He had learnt by experience that it was very dangerous on board ship to put a cock anywhere if he did not desire it opened at intervals. If a stoker saw one, for instance, on the crank-chamber of a closed engine, he said to himself, "This cock would not be here unless it was wanted." The result was that sooner or later he opened it when the engine was running and let the oil out; and the consequences were not pleasant.

Mr. Willans. Sometimes even worse things than that were done. He had known, for instance, a case where an engine used for driving a capstan in a North Sea trawler had been opened up, and in which the only sign of lubrication in the crank-chamber was herring-bones, and scales, and salt water; and, although that might be taken as an extreme case, he had known others in which (in what ought to have been efficient hands) the lubricating mixture used had been hardly more effective, although perhaps less original in its nature. Those who were familiar with his engines would remember that there was an air-cushion to keep the pressure in one direction on the crank-pin. On one ship—and that not a North Sea trawler, but one of the largest ships in the Navy—the cock on the air-cushion cylinder was connected by a pipe to the bilge and kept open for hours together, under the impression that it was a drain-cock. This was the class of difficulty with which he had had to contend on board ship. He was at the present time constructing a number of single-acting open engines for use in the English Navy under Admiralty conditions, so that the matter could hardly be considered to be definitely settled in favour of double-acting engines for the Navy. The Author had not, however, contented himself with the statement that there were things to be said on both sides, but had said (referring to double-acting open engines), "It will also be seen that these engines have in themselves certain qualifications which give them an advantage over closed engines, namely, accessibility, simplicity, and economy, combined with the all-important point of durability." He then pointed out that the twin engine with cranks at opposite angles had the advantage of working with considerably less vibration than the single-cylinder engine. But this, although apparently included among the advantages of open double-acting engines, was not an advantage over the single-acting closed engine, which was usually made in the same way. He would take the Author's first four points—durability, economy, simplicity, and accessibility. First, as to durability. The Author's figures showed what he had found the best speed at which to drive double-acting engines. Speaking of circulating-pumps, he gave an account of the gradual slowing-down of the engines driving them. Beginning at speeds which were "not justified by experience," they came down to 100 and 120 revolutions, and the Author himself put 150 to 180 as the speed at which it was "quite possible to make such engines work with certainty." It would be instructive to consider what, at that speed, these engines had to do. Taking the only case for which the Author gave

diagrams, namely, that of an engine capable of developing 90 indicated HP. when pumping out the bilge, but doing in ordinary every-day work about 13 HP. The low-pressure cylinder under these conditions worked at a mean pressure of little over 2 lbs., and the high-pressure cylinder being about one-fourth the area of the low-pressure, the power developed in it was equal to 7 lbs. or 8 lbs. on the low-pressure; that was to say, the whole work of the engine was equal to 10 lbs. per square inch on the low-pressure cylinder. Was this "hard and continuous work?" He was afraid that engineers could not be content with that amount of work from an engine. Again, the Author had referred to the engine of the "Devastation" as having run for a very long time, and done "hard and continuous work." He believed that during the whole of the run referred to, there was 15 lbs. pressure in the steam-pipe, the engine exhausting into the atmosphere. They were working at that as a maximum, but it was only such work as a double-acting engine ought to do easily for reasons well known to those who had studied the problems connected with the inertia of the reciprocating parts. In comparison with that case he would like to mention two or three instances of single-acting engines with which he had been connected. The first to which he would refer was a fan-engine which had been working at the Woodthorpe colliery, near Sheffield, for some five years. It had run as much as nine months without being stopped, and it was locked up by itself at night. His partner, being down there on one occasion, asked to be allowed to see the engine. He was told that the man had gone home and had taken away the key. That was an engine indicating 100 HP. and running at 300 revolutions, the mean pressure on the pistons being 30 lbs., as compared with the Author's 10 lbs. It was regularly left running by itself in that way, and the bearings were oiled twice a week. The next case was that of a compound 80 HP. engine working with 40 lbs. mean pressure (referring all to the low-pressure cylinder), driving a dynamo for the electrical deposition of copper. Being a single-acting engine the bearings were as usual fitted up slack, and at starting and stopping when the engine was running slowly the slack of the bearings could be heard. After it had been away five or six months, the people wrote in alarm to say that at stopping there was a noise which they could not account for. He sent a man to see what was the matter, and it was found that there was, as they said, a thump on the bearings when they stopped; but the point was that it was five months after the engines had been started, and it was the first time they had been

Mr. Willans, alarmed, for it was the first time they had stopped. He assured the owners that it would not happen until they stopped again; and, for anything he knew, the engine had been going ever since. Many electric-lighting stations had been started of late with insufficient plant, the demand for light coming on very quickly. The result was that at some of them the engines had been run far beyond their intended power. At the Kensington Court station, for instance, two 80 HP. engines had been running for more than two years without any examination or overhaul of the bearings. At the end of that two years, after working generally at full power, and during the times of greatest demand up to 100 HP., which required 50 lbs. mean pressure, referring all as before to the low-pressure cylinder—four or five times as much as that the Author had spoken of—they were still going on without any repairs to their bearings, just the same as at first. He wished in this discussion to be sure that they were considering engines doing the same kind of work, especially in comparing notes as to durability. Next, as to economy, the Author gave figures for water-consumption in the case of some of his engines for the Navy. They were employed to drive dynamos having an output of 400 amperes at 80 volts, and he gave the consumption of steam as 33·7 lbs. per electrical HP. per hour; but he did not say whether this result was obtained at his own works or at Portsmouth. Mr. Willans would compare with this the figures obtained in the case of the last six central-valve engines of the same power supplied to the Navy about six months ago. Three of these were running at about 390 revolutions and they gave a mean of 29·2 lbs. per electrical HP. per hour, the pressure of steam being 100 lbs. The other three were working (owing to the dynamos) at speeds of about 440 revolutions, and were consequently less fully loaded; the consumption in these was on the average 30·4 lbs. These figures were obtained during the tests at his own works. The average consumption of these six engines at Portsmouth came out $\frac{1}{6}$ lb. more than in his trials at Thames Ditton. The steam at Portsmouth contained when it reached the engines much more moisture than he had noticed elsewhere, and in two of the trials there were leaks in the pipes, &c., which brought up the average, so that the slight difference was easily accounted for; but he would take 29·5 lbs. as a figure which was constantly reached by his engines with fairly dry steam at 100 lbs. pressure non-condensing. Comparing this with the results obtained by the Author, 33·7 lbs., he found that for such work as incandescent lighting in the Navy, a saving of about 90 tons of coal a year

would be effected in the case of his single-acting closed engine Mr. Willans, running continuously, as against the Author's double-acting open engine under the same conditions. Comparing it with the good substantial commercial engine with a single-cylinder, in the case of which 42 lbs. per electrical horse-power would probably be a fairly low estimate, the saving in running continuously would be something like 270 tons per annum. He asked, therefore, what became of the claim of superior economy? Mr. Allen might say that a part of this economy was due to the higher speed, to which he would reply that 400 revolutions was too much for a double-acting engine of this size for electric lighting, and that therefore the comparison was a perfectly fair one. With 130 to 140 lbs. pressure the consumption of steam per electrical HP. per hour was usually about 24 lbs.; and with condensing engines using high pressure it could be reduced to 18 lbs. per hour. The question of economy of coal was frequently overlooked on board ship in the case of the auxiliary engines. It was too often regarded as a small percentage of the total and therefore unimportant, but if any one were to say that because the coal used in London was a large quantity as compared with that used in an electric-light station, economy in electric-light stations was of no importance, he would not be listened to for a moment. The economy of fuel, although not the only thing to be considered, was of great importance on board ship as well as on land. The cost of coal was not, however, the only expense in running an engine—oil was used as well. The Author was silent on this point, but open engines, running at 320 revolutions, required a good deal of it. In the case of some of his 200 HP. engines running at Kensington Court and driving dynamos direct at 350 revolutions, the engineer, Mr. Miller, informed him that the daily consumption of oil for the bearings was half-a-pint for a run of from twelve to sixteen hours. It was very desirable that the Author should give particulars of the oil used in his 50 HP. engines at 320 revolutions. With regard to attendance, Mr. Willans thought it was hardly necessary to argue the point, as it was now generally admitted that with the single-acting engine, not requiring its bearings adjusted, much less attendance was necessary. As to the mechanical efficiency, he had put in a Table a few figures relating to engines driving dynamos by most of the best known makers, whose machines had been tried at his works. The first was one of the Navy engines running at 32·8 electrical HP., which gave 82·6 efficiency, or Electrical HP. at a full load. That was a machine considered Indicated HP.

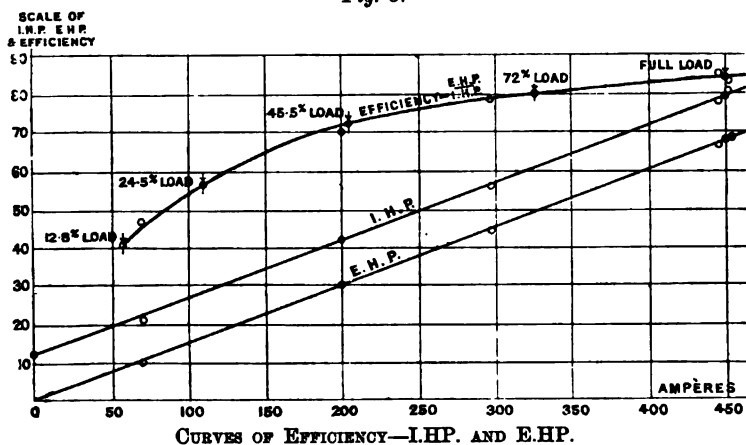
Mr. Willans.

EFFICIENCIES AT VARIOUS LOADS OF WILLANS AND ROBINSON'S ENGINES COMBINED WITH VARIOUS MAKERS' DYNAMOS.

Engine No.	1,105	998	996	986	1,001 1,002 983	960	969	951	993	968	677
Dynamo maker	Latimer Clark	Siemens	Goolden	Crompton	Johnson and Phillips	Chamberlain and Hookham	Elwell Parker	Crompton	Mather and Platt	Siemens	Siemens
Full load in Elec- trical HP. . . }	32.5	60.8	62.0	67.0	68.0	68.8	81.0	148.3	149.0	242.0	44.25
100 per cent. load . . }	82.6	84.0	85.1	84.5	83.1	83.3	83.1	85.8	84.0	85.9	82.3
72 per cent. load . . }	80.2	78.5	80.0	80.3	..	..	78.5	81.0	77.0	81.0	79.8
45.5 per cent. load . . }	71.0	71.0	71.9	72.2	..	..	67.5	73.1	69.5	72.8	75.3
24.5 per cent. load . . }	59.9	59.9	58.1	56.9	..	..	54.8	58.9	54.9		
12.8 per cent. load . . }	44.8	42.0	40.5	40.4	..	..	40.4	42.2	40.0		
Percentage Efficiency.											

ably smaller than that spoken of by the Author. The figures given Mr. Willans were not chance cases, but were representative ones, the full power varying from 32 to 160 electrical HP., and the efficiency rising in some cases to 86 per cent. It might be interesting to point out that if an engine was very fully loaded, a higher efficiency was necessarily obtained at the lighter loads; for they worked in the better part of the curve, so that it was important to know in comparing light-load efficiencies how heavily an engine was loaded. Fig. 3 showed the way in which he usually set out the results. The electrical HP. was represented by the lower diagonal line, and the indicated HP. by the upper one; the efficiency curve showed the electrical HP. divided by the indicated HP. If the

Fig. 3.



Engine, No. 966; Crompton Dynamo, No. 2,035; constant volts, constant speed, observed points=0.

curve was carried out by increasing the power the efficiency would be slightly increased, and bring the quarter load further to the right, and so into the better part of it. That partly accounted for the differences in efficiency at the light loads shown by the Table in some cases, the more heavily loaded engine, other things being equal, coming out better at light loads. He had observed that the Author gave his figures for efficiency for ordinary commercial engines. In comparing them with those given in Mr. Willans' Table, which were all for compound engines, it must not be forgotten that although the dynamo might in such cases be slightly inferior to those constructed to pass Admiralty tests, yet this would be at least compensated by the reduced friction of

Mr. Willans, the single-cylinder engine employed. He always found that his simple engine gave a rather higher mechanical efficiency than his compound engine when used for equal loads, the increased economy in steam per electrical HP. in the latter being realized in spite of this mechanical disadvantage. With respect to the two other claims made by the Author for his engines—accessibility and simplicity—it was impossible to judge of the simplicity, as the details given were so meagre that no opinion could be formed one way or the other; he could not for a moment agree, however, that they were necessarily more simple in construction than closed single-acting engines, and they certainly were not so easy to drive and to adjust. He did not see how such engines could be simpler to work than those in which the cranks, connecting-rods, and valve-gear, could be all lubricated once a day through one oil-hole, and in which the bearings never needed small adjustments. As to the general question of speeds, he ventured to say that if double-acting open engines of 50 or 60 HP. were used in the future, in the merchant service or the Navy, they would be run at much lower speeds than 320 revolutions per minute, and that even then their use would entail greater bulk and weight (especially for the dynamo), and increased first cost, together with reduced economy in every respect as compared with well-designed single-acting engines, the working parts of which could be run at a comparatively high speed in a bath of oil. There was one other point; the Author, in referring to the question of governing, mentioned that one of the greatest improvements on board ship was that of fly-wheel governors. With that Mr. Willans quite agreed. In marine engineering, where they ought not to want any adjustment in speed, it was impossible to have too powerful a governor; but on land, where very often everything turned on being able readily to vary the rate at which the engine was running, it was doubtful what would be the best thing to do. He found that electricians wanted more and more a variable speed for electric-lighting engines, and in fewer instances an absolutely constant speed, unless it was in stations where the alternating current was used. On board ship, where dynamos could be compounded, they ought to have the speed constant, and the more powerful they could make the governor, and the less accessible while running, the better it would be. He found no difficulty in regulating the speed within 2 per cent. and 3 per cent. by means of a governor on the crank-shaft (not a fly-wheel governor) in cases where the weight of the fly-wheel was not limited by other considerations.

Mr. F. E. DUCKHAM said the Author had dealt very fully with Mr. Duckham. the question of machinery for applying forced draught to steamships. The great point to be considered with respect to such inventions was whether they were commercially successful. During last session Mr. White, the Chief Constructor of the Navy, in a Paper read before the Institution of Naval Architects,¹ gave some particulars with reference to the use of forced draught on board Her Majesty's ships. He there stated that on the "Howe," whereas by natural draught they attained 8,200 indicated HP. and 15·9 knots speed, when using forced draught they obtained 11,600 indicated HP. and 16·9 knots speed, an increase of 40 per cent. in the HP. and of 6 per cent. in the speed. Then with reference to the "Medusa," natural draught gave an indicated HP. of 6,300 and 18 knots speed; which under forced draught was brought up to 10,000 indicated HP. and a speed of 19·9 knots. These results were obtained on trial trips, but it was of the utmost importance to the commercial world to know, not what took place on a trial trip, when everything was worked up to the highest point of efficiency for the time being, but what had been the result of voyages of ordinary steamships, out and home, with and without forced draught; so that they might get some accurate means of comparing the effect of the two systems on steamers of the ordinary type. It had, moreover, been found that great damage had been done to the boilers by forced draught, and orders had been issued in some quarters that it was only to be used in cases of emergency and for short periods. This circumstance made it more necessary to consider how far it was applicable for commercial purposes. It had been said that marine boilers gave way probably because of the intense heat in their furnaces; but it must not be forgotten that there was intense heat also in the fire-box of locomotives, where however the draught instead of being forced was induced by the exhaust of steam into the funnel. That led to the question whether the present type of marine boiler was the correct one, and whether to use forced draught with these boilers was not like trying to make an old-fashioned tool do for present-day purposes. He remembered Mr. Yarrow referring in that Institution to the water-tube boiler introduced by him. He had since seen it at work, and was considerably impressed with its efficiency and simplicity. It was a first-rate thing for torpedo-boats. Mr. Yarrow had not designed it for large sea-going vessels, but he believed it was a departure from the present style of marine boilers that might lead eventually

¹ Transactions of the Institution of Naval Architects, vol. xxxi. p. 12.
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Mr. Duckham to the satisfactory application of forced draught. Mr. Duckham had lately been engaged in various experiments as to the transmission of grain by the medium of air, and found that induced draught or suction utilized the power employed far more efficiently than air under pressure. Some years ago, when the telegraphs were taken over by the Government, a series of experiments were made as to the relative efficiency of compressed-air and of a vacuum for the transmission of messages, and a Paper by Mr. Preece was read before the Institution,¹ showing that there was a great advantage to be obtained by working the tubes under suction instead of pressure for the purpose in question. The advantage was not constant in amount, but was greatest between the higher pressures and greater vacuums, and diminished as atmospheric conditions were approached. He was not prepared to say if that reasoning was directly applicable to the question of the small pressure of draught which would be used for the furnaces of marine boilers. There was one other point in relation to the auxiliary engines of steam-ships. He might be thought foolish for saying that the greater number of vessels which were lost at sea were lost because they were not enabled to keep themselves afloat, nevertheless it was a melancholy fact. It might be taken in round numbers that the effective HP. of the boiler, if suitably employed, would enable a vessel to throw out something like half a ton of water a minute for each HP. Taking the vessel referred to by the Author, with 13,000 HP., it should, under such circumstances, be able to pump 6,500 tons a minute. The ship would need to be cut in two to admit the quantity of water which such power could discharge, but if they took one vessel with another, it would be an exception to find that they had sufficient pumping appliances to throw 20 or 30 tons of water a minute. This left a large margin of power unapplied. It was important that artificial draught and marine boilers should be improved upon, and whatever could be done in the direction of economizing coal, and reducing the weight of the boiler, so that the vessel should be able to carry a larger quantity of freight, would be a great commercial advantage, although the question of the ship's pumps was more important in relation to the loss of property and life at sea.

Mr. Terry. Mr. S. H. TERRY said the Author, in speaking of forced draught on the "Majestic" and "Teutonic," seemed to imply that the air by which the furnaces were kept going was supplied

¹ Minutes of Proceedings Inst. C.E. vol. xxxiii. p. 34, and vol. xliii. p. 87.

entirely by the four fans which he had built for those ships, Mr. Terry. He would like to ask more precisely what work the Author's fans were doing in connection with the forced draught of the ship, because he was under the impression that there were fourteen fans and engines supplied by the firm with which he was connected, Messrs. Bumsted and Chandler, which were used for that purpose. He would like to know whether those fans had been taken out, or whether the Author's fans were not really doing quite another work, namely, ventilating the stokeholds. From the Paper it might be implied that these fourteen fans were not in existence. He had been informed by the engineer of one of those ships that only a Chandler engine or fan could endure the temperature in which those fans were working, for they were down in the casing immediately round the boilers. They did not get much of the credit for the work, because they were not seen by the passengers at all. He would also like to know whether about the time that the increase of speed took place, when the Author's fans were put in, it was a fact that the screws of the "Teutonic" were altered, and whether their being put to a rather different pitch might not have something to do with altering the speed of the ship. He might mention that the Chandler fan and engines had been running on these ships at a speed of 350 revolutions per minute, each being capable of supplying some 16,000 cubic feet of air, or in all 224,000 cubic feet of air per minute in each ship. There were 3 inches of water-pressure in the fan-casing; but that was very much reduced by the time it reached the closed ash-pits, in consequence of the friction in the air-trunks. In addition to the forced draught, three other Chandler engines were employed in each ship in ventilating the refrigerating chambers, and the screw tunnels. He was entirely in accord with Mr. Duckham as to improving the pumping-arrangements on board ship. It was a matter in which he had taken interest for some years. As long ago as 1880, on the occasion of the loss of the "American" off Cape Palmas on the African coast, he began a correspondence, which was followed up by others, in 'The Engineer' and 'Engineering' on the subject of fitting ships with more powerful pumping machinery. It seemed an anomaly that a large vessel should be dependent upon her crew, and in some well-known cases of shipwreck on her passengers, to assist in working the pumps. Of course the whole power thus available was nothing in comparison with what could be applied if the steam in the boilers could be brought to bear on proper pumps. It was evident that

Mr. Terry since the date he alluded to, progress had been made in that direction, and the pumping engines were now nearly always connected with the bilge. He did not claim to have originated the idea of doing so, but merely stated that he was one of those who brought prominently forward the necessity of increasing the pumping power on board ship. It was not, however, of much use fitting powerful pumping machinery unless the pipes and valves were large enough to pass the water that a centrifugal pump would draw, and he had known cases in which pumps and engines and steam-pressure had been good, but the pipes had been so restricted in area that they were unable to carry the water, and there was no chance of working at full power. With regard to the use of auxiliary engines on board ship, he felt convinced that the engine of the future, for fan-driving, and for dynamos and centrifugal pumps, would be single-acting, either compound or triple-expansion, for this type had been proved to be the only one which could run continuously at anything like the speed requisite for direct-driving without knocking, or undue wear and tear. On this head he might state that his firm had received most satisfactory accounts from the superintending engineers of the fleets of the following steamship companies, in which their engines and fans and engines and dynamos had been almost continuously used: namely, the British India Company, dynamo-driving; Messrs. Herskind and Wood, under Mr. Fothergill's system for fan-driving for forced draught; the White Star Company; the Peninsular and Oriental Company; on the Carron Company's fleet, for electric lighting; and numerous other companies which he need not mention. In some cases the engines had been running for six years, and were as good as when put in, although making 400 and 500 revolutions per minute for several weeks at a time, and taking steam at pressures up to 180 lbs. to the inch. In numbers of steamships he could name, the electric-light engines and centrifugal-pump engines of the double-acting open (direct-driving) type made nearly as much noise as the main engines of the ship, which were exerting a hundred times more power, and it was unsatisfactory alike to the engineer, the passengers, and the crew, to have the efforts made to produce a quiet engine-room frustrated by the knocking of auxiliary engines, which in cases he had come across, were audible all over the ship. As regards steam yachts the silence of the electric-light engines was of great importance. Yachts were now largely used by professional and business men to recruit their energies. Every steam-yacht owner wanted the electric light, but unless single-acting engines

were used it could only be obtained (in harbour when the main Mr. Terry engines were standing) at the sacrifice of quietude. Railway companies were frequently and properly accused of conducting their traffic with a needless amount of noise, produced by whistles, escaping steam, vacuum-brake ejectors, careless shunting, &c., and he expected that at no distant date we should become too highly civilized to tolerate barbarous and unnecessary sounds. Most people were accustomed to think of a ship, except during bad weather, as the abode of peace and quietude, but this would be a thing of the past if engines making a knocking and hammering were used, and on this account therefore he felt convinced that the single-acting high-speed engine was the standard type of the future for auxiliary purposes.

Mr. REGINALD BOLTON said the Author had shown illustrations Mr. Bolton. of a number of applications of small engines to various purposes on board steam vessels. These engines were distributed about the ship at different distances from the source of power—namely, the boiler. There were others which were not described, such as the steam-winch, capstans, windlasses, and so on, amounting in some of the larger vessels to a considerable number. The engineer of the "Arizona" told him that he had under his charge in that vessel as many as seventy steam-cylinders—quite a conglomeration of material for losing power, if he might put it in that way, as well as for doing necessary duties. He was convinced that in a vessel of that kind the power should be distributed in the most economical way possible, and if details of the working of those small engines in the various parts of the ship could be obtained some means of improvement might be found. In addition to losses in the engines there were losses in the pipes, which must be considerable in large vessels. The only criterion they had of the amount of steam used by these small engines was that the donkey-boilers of cargo-steamers were being made larger and larger. A case recently came before his notice where a cargo-boat of moderate dimensions had to have a donkey-boiler put in equal in size to one of the main boilers. That evidently indicated considerable losses in the small engines. Amongst those which had been described by the Author there was one which seemed to show an efficiency superior to that of the others. It had been stated that the efficiencies of the fan-engines were very low, and the Author did not bring forward figures as to the pumping-engines, but he did so with reference to electrical-driving engines, and both he and Mr. Willans agreed that as much as 80 to 82 per cent., and as Mr. Bolton was informed, even up to

Mr. Bolton. 84 and 85 per cent. had been reached by engine and dynamo combined. It appeared, therefore, that if electrical driving was ever to come into use anywhere, it would be suitable on board ship, where a distribution of power was required, and where under present conditions, an immense amount was wasted. If the dynamo and engines were of such a size as to be able to supply a number of these smaller machines with the power which was required, the losses should not be greater than they were at the present moment. The efficiency of the motor already stood as high as 80 per cent., and would probably be made even greater. They had therefore to deal with an efficiency in the electrical producing plant of 80 to 82 per cent. together with a loss in transmission which might be said to be 1 to 2 per cent. of that amount, and an efficiency of the motor of 80 per cent. He could only say that this was superior in its results to the present state of things. Taking as an example the steam-winch, which was some hundreds of feet from the boilers in most vessels:—Before it could be started, the whole of the pipe had to be heated, which involved an amount of loss which must be serious. When it did start, they had two small cylinders, 7 inches by 10 inches or 8 inches by 12 inches, working with a cut-off in some cases three-fourths and in some seven-eighths of the stroke, throwing the steam out of the ship's side in a manner familiar to any one who visited the docks. It would be an improvement if these small engines scattered about the ship and connected by long lines of steam-pipes could be done away with, and electrical motors used in their place. He put forward this suggestion with diffidence, but it appeared to find some confirmation from the figures which the Author and Mr. Willans had laid before them as to dynamo-driving.

Mr. Siemens. Mr. A. SIEMENS wished to say a few words in the same sense as the last speaker as to the disadvantages of the present auxiliary engines, many of which were arranged so as to take their steam-supply from the main boiler, as well as from the donkey-boiler, and had their exhaust connected with the main condenser, and as an alternative, with the open air. This arrangement naturally led to most of the auxiliary engines being much too large for their work, and to their being fitted with a multitude of pipes in which the working of the ship caused constant leaks, giving frequent employment to the fitters on board. The same remarks applied to hydraulic pipes. He hoped to exhibit a complete set of auxiliary engines driven by electric-motors for ships' use at the coming Naval Exhibition, when he

should be in a position to speak more fully. The principal difficulty connected with employing the electric motor, as, for instance, in the case of a winch, was that the winch had to exert the pull on the rope without actually moving. The consequence was that an excessive current would pass through the armature of an ordinary motor, and it would probably be damaged. That was the chief reason why electric motors had not sooner been employed in such auxiliary engines, because the danger of damaging the armature through a sudden stoppage could not be avoided. He thought they had overcome that difficulty, and they intended to exhibit a fan, a winch, a capstan, and a machine for closing watertight doors of an ironclad. The way in which these auxiliary engines would be worked was that there would be one main auxiliary engine, so to speak, which would drive the dynamo machine with the best efficiency, and under the immediate eye of the engineer. All the other motors could be practically left to themselves, proper precautions being taken, so that no excessive current could reach the armature. With regard to the lasting qualities of the motor, he thought he could cap Mr. Willans' remarks about the gardener, by saying that at Sir William Siemens' place at Tunbridge Wells there was an electric-motor for pumping water into the house, which was worked for six hours on three days of the week; it had been used ever since 1878 or 1879; it had only been looked after by a gardener, and it never gave any trouble. There was no reason whatever why all electric-motors should not be equally manageable, if only proper care was taken to make them large enough, and to prevent an excessive current reaching the armature.

Mr. PREECE said Mr. Siemens had omitted to mention perhaps the most important point in favour of the introduction of electric-motors on board ship in preference to small steam-engines. Speaking particularly of one large man-of-war, which he saw a short time ago at Malta, he found that there were no less than eighty-six engines on board, and the ship was permeated all over with steam-pipes. He was told that in hot countries those pipes added some 10° or 15° to the already unbearable temperature of the country, and as the commander of the ship stated, electricians could not confer a greater boon on the navy than by the introduction of electric-motors which would enable them to remove the steam-pipes, and thus lower the temperature of the ships, which were in some cases absolutely ovens.

Professor GEORGE FORBES had noticed a slight misinterpretation of the results given by the Author and Mr. Willans, which

Professor
Forbes.

Professor
Forbes.

Mr. Bolton introduced, and which might lead to a misunderstanding. Mr. Bolton mentioned the 80 per cent. efficiency, or greater, which had been referred to as the efficiency of the engine and dynamo combined, and proceeded to say there was 1 or 2 per cent. loss in the mains, and there would be then an 80 per cent. efficiency in the motor. It was over-looked that the 80 per cent. efficiency of the steam-engine and dynamo combined was to be taken as the ratio of the HP. developed electrically by the dynamo machine to the indicated HP. Therefore, when they were dealing with a motor the efficiency was not 80 per cent., because the steam-engine had nothing to do with it. It was probably more like 92 or 93 per cent. That was a point that added very considerably to the total efficiency of the system, beyond what Mr. Bolton had spoken of. He agreed with what had been said by Mr. Preece as to the enormous value of electrical transmission on board ship by means of wires instead of steam-pipes. At the same time, since the engines that had been spoken of chiefly as being benefited by the use of electricity happened to be the steam-winch and the capstan, he might point out that there was a rather serious trouble, in some services, connected with the employment of electricity for those two purposes, though not for the machinery in the body of the ship. Any one who had, like himself, crossed the Atlantic at that period of the year, with a strong north-westerly wind, and the temperature below zero, would remember how, for several days before reaching port, it was necessary to keep the steam on the engines of the winches and capstan, in order to prevent the accumulation of ice, which might interfere with the working of them when they arrived in port. That was the difficulty that must occur, and which he felt to be almost insuperable when ships were trading in temperatures where there was likely to be a large accumulation of ice over certain parts of the machinery.

Mr. Kapp.

Mr. GISEBERT KAPP said that several speakers appeared to think it was an easy thing to put an electric motor on board ship, and to use it for the purposes mentioned with the highest possible efficiency. It seemed, however, that one important effect was lost sight of: the high efficiency of 92 per cent. was quite attainable in 100 HP. machines when steadily running at the normal speed, but with a machine that was turned on and off they could not get anything like as much. The electric motor was very efficient if it had a full or half load, and could run at a full and constant speed. On board ship, however, what was wanted was to give a half turn of the winch and then stop; it was nothing but stopping and starting,

and under such conditions an electric motor was just as bad as a Mr. Kapp. slipping belt; the current went through, but produced little motion. He was afraid that for intermittent work of that kind they could hardly introduce electricity at present; they must first of all find a way of gearing motors running at a constant rate, by apparatus permitting a variable speed to be communicated to the capstan or winch, or whatever was being driven. There were other purposes on board ship for which motors might be used with great advantage; they could drive pumps, ventilators and various other machines. He did not wish to throw cold water upon a subject as to which he was himself an enthusiast, namely, the transmission of motive power by electricity; but on the other hand, he did not think it was right to let members run away with the idea that it could be done very easily. He wished to ask the Author about a passage in which he stated, speaking of the amount of cold water which must pass through the tubes of the condenser, that there was a particular quantity which was the best. He could understand one limit which the Author had given when he said, "Should the surface not be enough, or the condensing-water insufficient in quantity, then the vacuum obtained will be lower than that desired;" but the other he could not quite understand, namely, when he continued, "On the other hand, if the circulating-pumps deliver too much water, the condensed steam is reduced to a temperature below that at which it is economical to return it to the boiler." That was in a manner opposed to the well-known thermo-dynamic law, which stated that the greater the difference of temperature at which they worked, the more economical was the process; whereas they were now told they must not have too good a vacuum. He would ask the Author whether there was really such a point below which they must not go. With regard to the governor, he quite agreed with what Mr. Willans had said, as to its being adjustable for land engines. They were generally compelled, or they found it at any rate exceedingly convenient, to use at central stations shunt-wound dynamos which gave rather a higher pressure when lightly loaded and a lower pressure when fully loaded, even when the speed remained constant. The speed, however, would slightly vary, and he did not know of any governor which would keep an engine absolutely constant under great variations of load, so that the imperfection of the governor increased this variation of electric pressure. The engine ran a little faster with a light load, and the dynamo itself gave more pressure with a light load. The Author's firm had been perfectly successful in providing a governor adjust-

Mr. Kapp. able while running, in two steam-dynamos made to his specification, and in which it was one of the conditions that the governors should not allow the engines to hunt. He was pleased to say that the engine had fulfilled both conditions in a very satisfactory manner.

Sir, Frederick
Bramwell.

Sir FREDERICK BRAMWELL said with regard to an ordinary winch for the purpose of unloading a cargo, Mr. Kapp need not be alarmed as to the necessity of stopping and starting. The common practice was to keep the winch running constantly, and simply by holding on the fall or slacking out the fall, to make the winch raise or even lower, and to regulate the pace of lowering, although it was always running in the lifting direction.

Mr. Cowper.

Mr. CHARLES E. COWPER said that the system of forced draught was a matter of great interest, since theoretical considerations tended to point to it as a possible direction in which to obtain more economy in the use of steam, as well as a greater production from a given plant. The manner in which the Author had stated the advantages obtained by the use of forced draught might be satisfactory, from a commercial point of view, but it appeared to an engineer very crude and unsatisfactory. He told them that in the case of the "Majestic" and also in that of the "Teutonic" forced draught had been the means of considerably "increasing the speed of the vessel." Now it was obvious that the speed of a vessel depended upon the speed at which the screw was driven by the engines, and that again depended on the supply of steam by the boilers. It was the work of the boilers that was actually affected by the forced draught. It would be of interest if the Author could give them some figures with regard to the increased evaporation, showing how it affected the economy; and, further, as to the condition of the boilers, and whether they were at all injured by the heavier firing.

Mr. Beaumont.

Mr. W. W. BEAUMONT thought Professor Forbes intended to warn engineers generally that they might be misled with regard to some remarks which had fallen from Mr. Bolton as to the efficiency of electric motors. But he told them that the efficiency might be 90 per cent. instead of the 82 per cent. as on Mr. Willans' diagrams. So far as a motor was concerned, that of course was quite correct; that was to say, a motor might give as mechanical HP. 90 per cent. of the power electrically represented by the current supplied to it; but the generator and engine, not having an efficiency at the very outside of more than 86 per cent., the 90 per cent. efficiency for the motor would be reduced to $0.86 \times 0.9 = 77.4$ per cent. at the best, and in many cases it would

only be about 70 per cent. which could be calculated upon or Mr Beaumont. obtained in motors even of considerable size. He thought Professor Forbes had intended to complete his explanation in this way.

Mr. H. W. RAVENSHAW said that, with steam donkey-engines, Mr. Raven- there was a great loss from the condensation of steam in the pipes, shaw. which would be almost entirely obviated by the use of electro-motors. He had employed a high-speed double-acting open engine for electrical testing, and on measuring the consumption of coal and oil, found that, when giving about 20 brake HP. for ten hours, it used 10 cwt. of coal, costing 4s. 6d., and 1½ gallon of oil, costing 5s. 3d. The cost of oil with improved lubricating arrangements had been since reduced to about 3s. 6d. These figures showed the necessity of providing efficient means of lubrication for this class of engine.

Mr. G. B. OUGHTERSON, while regretting that Mr. Brotherhood Mr. Oughterson. was not present to take part in the discussion of this question, desired to say a few words on the subject of forced draught. Mr. Brotherhood had had considerable experience in this matter, having supplied upwards of eight hundred fan-engines for that particular purpose. The Author had said "at present there is no general consensus of opinion on the subject of forced draught, . . . but as regards quantity, it is safe to take as a liberal allowance 260 cubic feet of air per pound of coal." Now 260 cubic feet of air would weigh about 21 lbs., and inasmuch as competent authorities gave 18 lbs. as the quantity actually necessary for the proper combustion of 1 lb. of coal under forced draught, he considered 260 cubic feet to be far from a liberal allowance. The Author somewhat qualified his statement by adding, that considering the waste through leakage, &c., it might be prudent, under some circumstances, to add considerably even to the liberal allowance he mentioned; but Mr. Oughterson's experience was, that with forced draught in closed stokeholds, they would have to add considerably to, in fact, would have to go to nearly double the quantity that the Author had stated. It might be that the Author had calculated the quantity of air necessary for forced draught on the same basis as that on which he had estimated the yield of fans which were mentioned in the Paper as having been fitted on the "Majestic" and "Teutonic." These fans, 7 feet 6 inches diameter, running at 250 revolutions per minute, were said to be capable of giving out 50,000 cubic feet of air per minute; but taking a moderate percentage of the fan-tip velocity as that of the air through the inlets, and given a perfectly free delivery, he thought it would be found that the quantity

Mr. Oughterson. of air delivered ought to be very much in excess of that stated in the Paper. The Paper went on to state that "it having been suggested by leading authorities that a central diaphragm would add considerably to the efficiency of the fan, the Author had carried out a series of experiments on the subject, and had satisfied himself that no benefit whatever accrued from its introduction . . . but the trials proved that the bosses having curved entrances to about the diameter of the inlets were in every way as efficient as if the diaphragm had been carried right through." He fancied the "leading authorities" to whom the Author referred were the same as those who had suggested the diaphragm to Mr. Brotherhood; and so far as his memory served him, it was never a question of carrying the diaphragm "right through," but of carrying it far enough to cause the two opposing currents to diverge; and it appeared to him, that having extended the bosses to about the diameter of the inlets, the Author had done all that was intended. With regard to electric-light engines, he might speak with some little authority, seeing that about eleven hundred of Mr. Brotherhood's engines had been supplied for the purpose of driving dynamos. Some of these had been at work for periods far longer than that mentioned in the Paper, during which the Author's double-acting engine was fitted on H.M.S. "Devastation," and were working, he had every reason to believe, most satisfactorily. He agreed with Mr. Willans, that the closed single-acting engine had scarcely had fair play. Double-acting open engines appeared to be, for the moment, in greater request, and manufacturers were therefore more or less forced to meet this demand, but the single-acting closed engine was susceptible of numerous applications, and in many cases found its place where it would be impossible to apply a double-acting engine, and it could be worked with marked economy as regards fuel and oil. Mr. Brotherhood had at his works two of his 3-cylinder single-acting compound engines, which had been running since 1884, each giving out about 22 HP. with 100 lbs. initial steam-pressure, one making 750 revolutions, and the other 650 revolutions per minute: these engines had cost very little for repairs, and were practically in as good order as when they were started. Another of a similar class had been at work since 1885, running at 600 revolutions, and with the exception of new piston-rings, had never had any repairs done to it. Altogether, he thought that the single-acting closed engine, whether of the Brotherhood type, or of the Willans type, had in many instances great advantages. He had thought it well to call attention to what, rightly or wrongly,

appeared to him to be a misconception with regard to the quantity of air required for forced draught, but his observations must be taken as referring exclusively to the closed-stokehold system, and not to the closed-ashpit system, as of the latter he had no experience. Some reference had been made as to the failure of certain boilers under the action of forced draught. To his knowledge, the mail steamers on the Dover and Ostend route, built and engined by Messrs. Denny and Co., of Dumbarton, two and a half years ago, and working with forced draught on the closed-stokehold system, had been doing service constantly and well with a pressure of from $1\frac{1}{2}$ inch to 2 inches of water in the stokeholds; each steamer was fitted with four Brotherhood engines and fans, the fans being 5 feet in diameter.

Mr. W. H. ALLEN, in reply, said it would be almost impossible to have a Paper read in that Institution upon high-speed engines, or the economy of water-consumption, or on any kindred subject, without Mr. Willans taking part in the discussion. They all knew what he had done, both in practice and in theory, and his writings should be studied by all young men. He was sorry to hear the apology that Mr. Willans had to make as to the men necessary for working the engine; doubtless it was owing to the fact that many mishaps had occurred, for although his engines were so well known and gave universal satisfaction on land, they did suffer from *mal de mer* as soon as they got to sea. Whatever might be the reason, he had come across a number of them which, from one cause or another, gave considerable trouble. He believed it was due principally to the abundance of water which was always to be found in steamships. Since Mr. Willans supplied his first engines to the Navy years ago, they had no doubt been very much perfected. In reference to the low speed of the circulating engines, to which he had called attention, namely, 150 revolutions a minute, it must be remembered that while dynamo-driving was one thing, circulation was quite another. The ship depended for its very existence on the main engines. It did not much signify if a light went out, but for the circulating engines to stop was a serious matter, and superintending engineers did not see their way to go beyond the present number of 130 to 140 revolutions. He had raised it to 150, and thought they could afford to work at that speed without any possibility of a breakdown. With regard to, the long run of one of Mr. Willans' engines, it so happened that Mr. Allen had had an exactly similar experience. Some of his engines on the "Devastation" had been working for many weeks without change over. Mr. Willans asked

Mr. Allen whether the experiments with regard to the water consumption were made at Portsmouth or in their own works. The figures he had given were obtained at Portsmouth. The rules there were extremely rigid and well understood, and it would have been foolish to make any experiments in their own works, and expect them to be improved at Portsmouth. Mr. Willans pointed out that his engines had proved more economical by 29·5 to 33·7. Every engine-maker must give way to Mr. Willans as having introduced the most economical design, but the economy depended upon the increased speed at which that particular form could be driven. Mr. Willans' engines gave a consumption of 29·5 lbs., with 440 revolutions, whereas his (Mr. Allen's) engines, with 33 lbs. only, travelled at 320 revolutions. That must be taken into consideration in comparing their respective values. He was very glad to see the Table that Mr. Willans had brought forward, because it was a proof that they were not so far behind with the double-acting engine. Mr. Willans had claimed an efficiency of 82·3, whereas Mr. Allen's firm had reached in their trial with ordinary mercantile engines 81·2, so that they were only 1 per cent. under Mr. Willans under the same circumstances; with a speed of 440 revolutions against their 320 with engines of 44 indicated HP.

Mr. Willans. MR. WILLANS remarked that those figures were obtained three years ago; at present the efficiency was about 1 per cent. higher.

Mr. Allen. MR. ALLEN said in that case they were 2 per cent. behind Mr. Willans. It should further be noted that the high efficiency of 85·9 per cent. on the Table was obtained with engines of much greater power, namely, 240 HP. With regard to the governor, he had only given one example, namely the fly-wheel and governor, which he had spoken of in the Paper as applicable to marine work, but they also had a variable governor, which would almost equal it in point of precision. There could be no doubt that, as Mr. Duckham had said, forced draught was a commercial success. In no case that he knew of had there been a failure. On the Inman Line the best paying steamer was the "Ohio," which was fitted with forced draught, and the "City of Paris" at the present moment was undergoing a change for the same system. He thought that the term forced draught was misapplied at the present moment, and that assisted draught was a better expression to use. In the paddle-steamer "Victoria," running between Dover and Calais, the speed of the boat with natural draught was 15 knots, and under forced draught 19 knots, with a pressure of

about $2\frac{1}{2}$ inches. At that speed the boilers began to give considerable trouble, and were voted by no means a success. But by reducing the speed of the fans one-half, getting a pressure of $1\frac{1}{2}$ inch, they obtained 18 knots without any trouble whatever to the boilers or machinery; so that in that instance natural draught gave 15 knots, assisted draught 18 knots, and higher forced draught 19 knots, showing the advantage of assisted draught as against forced draught for commercial success. He was afraid that Mr. Terry had commenced with the wrong paragraph of the Paper, and had omitted to notice that in which he said with regard to the fans on the "Teutonic," "The application of fans, however, may have a two-fold purpose, namely, to enable more coal to be burnt in a given time, and also to reduce the temperature of the stokehold, which is always a most desirable object." The Paper went on to show that fans had been introduced into the "Majestic" and "Teutonic" under those circumstances. What were the circumstances? To burn more coals in a given time, and to reduce the stokehold temperature—not as forced draught. The orifice by which the air was taken to the stokehold was too small for ventilating purposes, and also for supplying forced draught; consequently they fitted large fans for the purpose of supplying the stokehold with air in order to feed the fans below. Sufficient coal could not be burnt before they were furnished with this assisted draught. Coming to the observations of Mr. Bolton and of Mr. Siemens on the same subject, he had not lost sight of the fact that electricity might form an important agent in the auxiliary machinery of ships in the future. With regard to Mr. Terry's statement that the single-acting high-speed engine would be the standard type of the future, the Author was of a different opinion. The same observations had been made regularly for the last ten years by advocates of this engine, but results went to show that the single-acting engine was as far off universal approval as ever. At the present moment it was not accepted by the Royal Navy in any form at all, after every consideration had been given it, and in the mercantile marine, from the Author's own knowledge, of a very extended character, he could safely say that fifty double-acting engines were in use to one of the other type, so that until the single-acting engines could be radically improved, and the difficulties which had hitherto accompanied the working of them had been overcome, the Author felt sure that the double-acting engine would still retain its position in the marine world. It was not to be supposed that it could not be made to run quietly, for when constructed of proper material, with ample bearing

Mr. Allen.

Mr. Allen. surfaces, and accurate workmanship, coupled with a careful distribution of steam, this form could be relied upon for silent and constant working as well as any other. Mr. Preece mentioned that in one of the ships of the Royal Navy at Malta they had eighty-six engines on board. That would not bear comparison with the mail boats, as probably seventy of those were idle during ordinary times. On the "Normannia" there were thirty-six auxiliary cylinders which were necessarily always at work to assist the main engines. That gave rise to the question whether some other means could not be devised of concentrating these small engines under one head. Electricity was the only thing they could think of. At present they were endeavouring to see how far that would assist in driving the fans themselves. He did not know whether it would be applied to driving pumps, although that might be done later on. A serious obstacle prevented the introduction of electricity for that purpose at present: while it enabled them, by increasing the speed, to reduce the diameter of the fans considerably, and thus to make them occupy a smaller space in the ship, there was this one objection to it, viz., the extremely high prime cost. In the case of the "Normannia" they found that the increased cost of a set of motors and fans, together with generating plant, would be something like £3,000 over and above that of the present system. Every shipowner shook his head directly that was mentioned by way of experiment or otherwise. The poor duty obtained from the small fan-engines would be balanced to a great extent by the large generating plant being confined to one small central station, so that it was quite likely it would come into use when they had better motors to assist them. With regard to Mr. Kapp's remarks as to the reduction of temperature in the condenser, it was well known to all marine engineers that they would rather have a poor vacuum, so long as they could keep up the temperature of the feed-water. Mr. Ravenshaw's remarks with regard to the consumption of oil in double-acting engines were scarcely consistent with well-known experience. The Author found that an ordinary dynamo-engine, indicating 60 HP., would usually work for six hours, with a consumption of oil of nine pints. With reference to Mr. Oughterson's criticism, the quantity given of 260 cubic feet of air required per lb. of coal was one which he had worked with for years past, and never found to fail. All ships were not alike; some had enclosed stokeholds, some were poorly made, and the leakage was considerable. When he had that figure before him he had in his mind that they were

dealing with new ships. With regard to the quantity which Mr. Allen. Mr. Oughterson imagined had been discharged by the 7-foot 6-inch fan, that gentleman omitted to mention the pressure. In the case he had given, the pressure should be $1\frac{1}{4}$ inch, and he did not think the discharge would then be more than 50,000 cubic feet. That was the result of a number of experiments he had made, extending over several years.

Correspondence.

Mr. E. A. COWPER found no reference in the Paper to the proper Mr. Cowper. shape of a fan-casing. He would, therefore, beg to call attention to the fact that it ought to be an Arithmetical Spiral, as stated in his remarks on Mr. R. Briggs's Paper on Rotary Fans.¹

Mr. W. WARREN said the Author did not claim to have com- Mr. Warren. pletely enumerated the many classes of auxiliary engines used on board ships, but had confined himself to those of which his firm made certain special types. Incidental reference, however, was made by Mr. Siemens and others to the use of electric motors for driving winches and the like. All were familiar with that most useful but imperfect machine, the winch, with its excessive waste of steam and its noisy spur-gearing—which latter was endured with a forbearance difficult to understand when it was remembered how differently these things were worked in America with almost noiseless friction-gear. Better than this, however, and what he particularly wanted to refer to, was the hydraulic system of working cargo, which besides being perfectly noiseless, enabled light or heavy goods to be handled much more rapidly than with steam-winches. This application of hydraulic power, apart from some difficulties in the use of it in very cold climates, was a perfectly ideal system, concentrating all the machinery into one place under the eye and control of the engineers. The new steamers of the British India Steam Navigation Company, the Messageries Maritimes, and a few others running to Australia and elsewhere, were all fitted with hydraulic cranes, with wire-ropes instead of chains, making all the movements so quietly that ordinary conversation could be carried on during cargo-working.

Mr. C. HUMPHREY WINGFIELD agreed with the Author as to the Mr. Wingfield. necessity for easy curves in the air-passages to and from the fans, but thought that the excessive loss of pressure referred to on

¹ Minutes of Proceedings Inst. C.E., vol. xxx. p. 297.

Mr. Wingfield. pp. 15, 16, might have been partly due to the delivery-pipes being small. If the air-way through the firebars and coal was large as compared with the section of the fan delivery-pipe a considerable fall in pressure must ensue. Perhaps the Author would give his views as to the proper diameter of fan and of air-pipes for a given size of grate with a definite pressure of undergrate blast. He thought the Table in the appendix required some little explanation. For instance, how was the 5.5 "loss in engine, dynamo-shaft and bearings" arrived at? Was it measured directly by a dynamometer between the engine and the dynamo while the latter was in full work, or was it measured by friction cards, or otherwise, when the engine was unloaded? It was so remarkably constant that it looked as if some assumption had been made; being the same when the engine ran free as when it was indicating 56.97 HP., and this in a Table where the indicated horse-power was worked out to two decimal places! Professor Thurston had stated, as a result of some trials with non-condensing engines, that the horse-power per revolution wasted in friction by a given engine of this type was independent of the load. On the other hand some careful experiments by Walther-Meunier and Ludwig¹ showed the horse-power wasted per revolution by a condensing engine increased slowly with the load. Professor Thurston's results showed, therefore, that a friction-card taken when the engine was running free gave a true measure of the wasted horse-power at that speed whatever load might be afterwards put on. The other experiments showed the contrary to be the case. If the Author had tested this point it would be of great interest to hear his conclusions. He desired to ask whether 9.29 should not be put in the indicated horse-power column as well as in the fourth column, and 5.5 in the second line of horse-power column, as otherwise he could not understand how these quantities were arrived at. Perhaps the Author would also state whether in estimating the losses in the dynamos the figures represented merely the electrical horse-power due to the current passing through the shunt-coils, or whether the waste power which generated Foucault currents in the pole-pieces, &c., was estimated and allowed for. It would seem that this should be added to the figures for loss in the dynamo.

Mr. Allen. Mr. ALLEN stated, in reply to Mr. Warren's remarks, that while hydraulic arrangements had been improved and introduced into a number of vessels for some time past, instead of mechanical means

¹ Bulletin de la Soc. Ind. de Mulhouse, vol. lvii. p. 140.

for raising, lowering, steering, and so on, it was clear that in the future electricity would supersede the former power. In answer to Mr. Wingfield, he was unable to deal briefly with the question as to the proper diameter of fans and air-pipes for a given size of grate, owing to the fact that every system required a different volume and pressure, but he hoped to collect particulars on this head later on. With regard to Mr. Wingfield's remarks upon the Table of efficiency, the 5·5 HP. (which was the loss in the bearings of the dynamo-shaft) was carefully calculated from several diagrams taken while the engine was running light, and with the brushes lifted from the machine; and it was assumed that the HP. wasted in friction was the same at full load or any part of the load. In answer to the question whether 9·29 HP. should not have been put in the Indicated HP. column as well as in the fourth column, the Author pointed out that the 9·29 HP. was entirely lost, and did not represent any useful work. It should be explained that the losses in the dynamo given in the third column, represented the whole power lost over the armature and field-magnets, and that it increased from light load to full load.

20 January, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Paper by Mr. W. H. Allen, on "Auxiliary Engines in connection with the Modern Marine Engine," occupied the evening.

LIST OF MODELS, &c.
EXHIBITED AT THE MONTHLY RECEPTION.

13 January, 1891.

Exhibitor.	Objects.
W. H. ALLEN, Assoc. M. Inst. C.E.	Centrifugal pump. Electrical gear for first-class cargo-steamers. Engine and dynamo. Single-inlet fan and engine.
W. ANDERSON, D.C.L., M. Inst. C.E.	Magazine rifle and component parts.
Sir W. G. ARMSTRONG, MITCHELL & Co.	Model of floating steam-crane at the Liverpool Docks.
Sir B. BAKER, K.C.M.G., M. Inst. C.E.	Electric motor. Model of the Forth Bridge. Model of a steam ferry-boat.
SYD. W. BARNABY, M. Inst. C.E.	Model of first-class twin-screw torpedo-boat.
J. WOLFE BARRY, M. Inst. C.E.	Model of the Barry Docks, Cardiff. Model of the Tower Bridge.
WILLIAM BASHALL, Assoc. M. Inst. C.E.	Case of samples of patent metallic packing for high-pressure engines.
LORD BRASSEY, K.C.B., Assoc. Inst. C.E.	Albums (four) of photographs of scenery in Australia and New Zealand.
CAIRD & RAYNER	Evaporator for marine boilers.
J. G. CHANDLER, Assoc. M. Inst. C.E.	Set of models of beam-engine and pumping-plant.
THOS. COATES	Model of steam fire-engine.
Sir JAS. N. DOUGLAS, M. Inst. C.E.	Electric lighthouse-lamp with pair of large fluted carbons. Set of Douglas lighthouse-burners, oil and gas. Small air-engine for rotating the lantern at St. Catherine's Lighthouse.
J. & E. HALL	Photographs of refrigerating machinery.
JOHN HASTIE & Co. . . .	Model of safety after-steering gear.
HIGGINSON & Co. . . .	Model of steam ash-hoist. Model of steam quarter-master (combined hand and steam steering-gear).
JOHN KIRKALDY, Assoc. M. Inst. C.E.	"Compactum" Distiller. Drawing of fresh-water distilling and feed make-up machine on the S.S. "Lombardia" of the Royal Italian Navy. Drawing showing arrangement of heating and evaporating machinery in a mercantile steamer. Drawing of machine combining surface-condenser, feed-heater, and feed make-up as fitted to a triple-expansion engine.

Exhibitor.	Objects.
V. DE MICHELE, Assoc. M. Inst. O.E.	Model of reversing-gear.
C. A. PARSONS & Co. . . .	Turbo-electric generator, with armature.
NAPIER PRENTICE	Armature.
	Power-motor.
	Magnetic cut-out and fuses.
E. S. PRESTON, Assoc. M. Inst. C.E.	Model of improved tail-board for tip-carts.
R. C. RAPIER, M. Inst. C.E. .	Model of sluices proposed to be erected on the River Thames at Richmond.
T. RICHARDSON & SONS . . .	Model of Morison's No. 3 evaporator for marine boilers.
ERNEST SCOTT & MOUNTAIN .	Gun-metal casting of a fan-impeller.
	Model of magnetic-separator.
	Triple distilling feed-pump.
SIEBE, GORMAN & Co. . . .	Model of cold-air refrigerator and store.
JOHN L. THORNYCROFT & Co.	Model of guard-boat for defence of submarine mines.
	Model of shallow-draft patrol-steamer.
	Tubular boiler.
W. H. TOPHAM, Assoc. Inst. C.E.	Armstrong shell dug out of No. 3 dock at Buenos Ayres after the revolution.
FRANCIS WISWALL, Assoc. M. Inst. C.E.	Model of movable weir.
A. F. YARROW, M. Inst. C.E.	Model and photographs of sea-going torpedo-boat.
	Photograph of an Argentine first-class torpedo-boat.
	Photograph of second-class torpedo-boat.
	Photograph of gun-boat for service on the Zambesi.

27 January, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2491.*)

"Machine-Stoking."

By JOHN FREDERICK SPENCER, M. Inst. C.E.

STEAM engineering includes three distinct processes:—1. The combustion of fuel and the production of heat. 2. The generation of steam by transmission of the heat produced by combustion. 3. The disposal of the steam generated for motive- or heating-purposes. Except only in the references to evaporation-trials and efficiency, the present Paper is limited to the first of these, viz., the combustion of fuel and the production of heat.

It would not be in accordance with the purpose or the scope of this communication to discuss the chemical theory of combustion. The heat-unit values per lb. of fuel burnt to carbonic acid and carbonic oxide, 14,133 and 4,452 respectively, and the supply of air required for their formation, 141 and 76 cubic feet, are well known; and both in machine- and hand-stoking the conditions, which these figures give, have to be met in order to effect perfect combustion. Experience has proved that with hand-firing sometimes an amount of oxygen is found in the waste gases leaving the boiler flues, equal to the whole quantity required for the complete combustion of the fuel. Such excess of air-supply is due to the difficulty of mixing the carbon and the oxygen perfectly; and this difficulty is diminished by machine-stoking. The inequalities of hand-firing arise mainly from two causes, namely, admitting air at the wrong time and place, and adding fuel according to the pressure gauge, without regard to the requirements of perfect combustion. It may be admitted that with a uniform evaporative duty (such as exists in many mills under careful supervision, and in water-works, where there is competent engineering superintendence) the deficiencies of hand-firing may be lessened, but they cannot be removed.

Machine-stokers are of two distinct types, called respectively coking- and sprinkler-stokers, both being supplied with coal from a hopper. In the coking-stoker the fuel is fed slowly on to the dead-plate, movable bars being provided for carrying it forward at a rate intended to be proportionate to that of the combustion required. In the sprinkling system the fuel is more or less evenly distributed on the grate by fans, beaters, or shovels, with or without movable bars. In both systems with moving bars it is claimed that when the fuel arrives at the forward end of the bars there is nothing left but ash and clinkers, which drop into a space provided for them, and from which they are removed through the ash-pit.

The Author proposes, after giving a brief sketch of the history of the subject, to describe at length one of the most successful machines of each type, selecting for the purpose the well-known coking-stoker of Messrs. T. and T. Vicars of Liverpool and Earlstown, and illustrating the sprinkler type by the equally well-known machine of Mr. E. Bennis of Bolton.

It is no matter of surprise that James Watt included a machine-stoker among his many inventions. The James Watt stoker of 1785 was worked by hand, and consisted of two sets of bars one behind the other, the fuel being fed at the door end, and pushed forwards as it ceased to smoke, the smoke from the fresh fuel passing over and through the more advanced combustion at the bridge-end of the grate. Mr. C. Wye Williams, referring to the original specification says, "these words of Watt, 'through, over, or among a body of hot, glowing coals,' have led more men astray, and occasioned more waste of money, loss of time, and misapplication of talent, than almost any other false light of the day."¹ Mr. Williams points out that as the air passing through the coke or glowing coal near the end of the bars is exhausted of its oxygen by contact with the hot fuel—which oxygen has combined with the carbon to form carbonic acid—the only possible effect of endeavouring to prevent smoke by this method, will be that some of the carbonic acid will be reduced to carbonic oxide by taking up a second charge of carbon, thus causing the loss of a considerable quantity of heat. It is, however, evident this loss cannot occur if, in the system condemned, provision is made for a supply of oxygen to meet the full demands of the carbon present in all stages of the combustion.

In 1816 Dowson invented a machine-stoker for feeding upwards by a piston, so as to keep a hot fire on the top. Some thirty

¹ "The Combustion of Coal and the Prevention of Smoke," by C. Wye Williams, 1854, p. 37.

patents have been taken out on this system by Juckes, Beeby, Frisbie of New York, and others. Frisbie's method of feeding by three horizontal screens was the only one which was much used, and none of these inventions have been sufficiently successful for permanent adoption.

In 1822 the two systems of coking and sprinkling were applied, by Brunton and Stanley respectively, to externally-fired boilers. Brunton introduced both the pushers for feeding and the movable bars, and he has been followed by nearly 200 specifications for various modifications of the coking machine. Among these inventors were Juckes, in 1841, and Bodmin, in 1843; the Juckes stoker being well known and largely introduced. The coal was fed from a hopper on to a moving chain-grate, the feed being regulated by a drop-shutter. It was only suitable for under-fired boilers, was deficient in power, not economical, and the maintenance was costly, but it was efficient as a smoke-preventer. The attempt by Taylor and others in 1873-4 to adapt this stoker to Lancashire boilers was not successful.

In 1866 and 1869 Howarth and Horsfall invented a coking-stoker with hollow fire-bars, fed with water from the boiler. The bars were stationary, and the coal was carried along by a saw worked by an eccentric; but frequent leakage led to its failure, although it was successful when in working order.

Brunton's system was meanwhile being modified in many important particulars by Normand in 1856; Wilson and Smith 1863; Vicars and Smith in 1867, 1868. In 1879 and 1889 Messrs. T. and T. Vicars introduced their most recent improvements in the coking-stoker.

To complete this brief historical record of machine-stoking it is necessary to return to the year 1822, when the sprinkler-stoker was introduced by John Stanley, his drawing representing the machine as applied to the wagon-boiler. The fuel from the hopper was thrown on the fire by three beaters or vanes fixed on a revolving shaft, and working in a case under the hopper. These stokers were fitted to many furnaces, and various modifications were made by Church, W. and J. Galloway, Robert Newton, Rye and others. As in the case of the coking-stokers, the change from external to internal-firing operated against the success of the sprinkling system. In 1870 an American named Dilwyn Smith, in Liverpool, although not an inventor or mechanic, saw the advantages of machine-stoking, and having obtained the aid of Mr. G. F. Deacon, M. Inst. C.E., Mr. Thomas Henderson, well known as a maker of sprinkler-stokers, and Mr. Edward Bennis,

the inventor and maker of the machine of that type selected for this Paper, succeeded in 1872-4, in producing an adaptation of the Stanley stoker to the Lancashire and Cornish boilers, which was fairly successful, although somewhat costly, and not fitted with movable bars.

During the introduction of the Dilwyn Smith stoker, Mr. Bennis made a series of tests at the works of Messrs. Jackson Brothers, Wharf Foundry, Bolton, with a view to ascertain the advantages of combining the movable bars with the sprinkling system. Mr. C. Wye Williams had expressed the view that an even distribution of fuel, allowing free mixing of the air, combined with a self-cleansing bar, would produce the most perfect system of combustion that could be realized. At this stage of the progress of the sprinkling system many of its advocates, and notably Mr. Bennis, held this view, and believed that the sprinkler-stoker was specially adapted to cases where there was a deficiency in evaporative duty. Mr. Bennis's experiments in 1874 confirmed the advantage of the movable bars, and also led to one of the special features of his machines, namely the distribution of the fuel over different portions of the fire-grate in succession. This was included in his specification dated April 1875, and in June of the same year Mr. Proctor claimed certain special mechanism for varying the distribution. A costly litigation ensued, and both inventors are now actively manufacturing machine-stokers very similar in character as to distribution of the fuel, but differing in the important items of the movable bars and the disposal of the clinkers and ashes.

In consequence of the more active combustion in the sprinkling, as compared with the coking system, there arose a greater necessity for protecting the movable bars from the intense heat, and in cases where this protection has not been secured, the wear has been severe. Mr. Bennis claims to have succeeded in combining with the sprinkler-stoker a system of movable bars that can be regulated to suit any rate of combustion. Mr. Bennis also provides a supply of steam underneath and in front of the dead-plate by means of a $\frac{1}{4}$ -inch or $\frac{3}{8}$ -inch pipe, perforated with holes $\frac{3}{16}$ inch in diameter, and so drilled that jets of steam and air are blown along and between the line of fire-bars; the effect of this minute expenditure of steam being to prevent the adhesion of clinker to the bars, and also, according to the inventor, to act as an aid to combustion.

Mr. Proctor has introduced various improvements in sprinkler-stokers since 1875, and one firm has forty-six furnaces fitted with his machines.

COKING-STOKERS. (ILLUSTRATED BY THE VICARS MACHINE-STOKER.)

Figs. 1, 2 and 3, Plate 2, show the new and improved mechanical stoker and smokeless furnaces of Messrs. T. and T. Vicars, applied to a Lancashire boiler 28 feet long, 7 feet 6 inches diameter, having two flues each 2 feet 9 inches diameter. Small bituminous fuel is deposited in the large hopper shown in Fig. 1, and by its own weight falls into four boxes—two for each furnace—from whence it is gradually pushed into the fire-places, by alternately reciprocating plungers (Fig. 3), falling first on to a perforated dead plate 12 inches long, where it ignites, and thence on to the fire-bars. Each plunger receives its motion from a bell-crank lever connected with an eccentric and a strap, deriving its movement from the cam-shaft. This shaft, with its necessary fittings, is shown in Fig. 2. The hopper for this size of boiler will hold from 10 cwt. to 12 cwt.

The bars have a peculiar reciprocating motion, being moved slowly forward simultaneously, but returning in two sections. Figs. 4 show how the connection is made between the bar and dog-shaft for each furnace. These connecting pieces are technically called upper and lower keys, and transmit a reciprocating movement from the dog-shaft to the bars. Here one set of the bars, namely those attached to the leading or upper key, is seen to be drawn away from the end of the grate to the maximum distance, viz., 4 inches. The alternate bars have a low seat in front as shown in Fig. 4, c, resting upon a lower cross-bearer attached to the lower keys, and the latter, having just been respectively released by a heart-shaped cam from their resisting pawl (which is provided to prevent the lower keys from coming forward with their bars before the due time), are about to be drawn away from the end of the grate also, the same maximum distance, viz., 4 inches. Thus the bars receive their alternate motion. There are two hardened-steel dogs, and one heart-cam connected with each set of keys, and two sets of keys to each furnace or flue.

The bars having been brought backward, as shown in Fig. 1, and the cam-shaft having continued its intermittent motion, the leading dogs are brought into contact with the stroke-bar, Fig. 4, b. The positions of the other dogs at this point are seen on the left (Fig. 4, a); they do no actual work during the forward movement of the bars—and so, against the resistance of the stroke-bar pawl, which is attached to the upper

keys, the latter are pushed forward, and they drive before them the whole of the bars. The low-seated bars receiving this motion at the same time from the cross-bearer of the top bars, shown in Fig. 1, draw their connected keys after them, the latter conveniently sliding over their resisting pawls, which act only in the backward stroke of the top bars and upper keys. In this way the burning mass of fuel is gradually but slowly carried forwards.

Such unconsumed fuel as reaches the end of the fire-bars, is discharged, together with the clinker and ash refuse, into the flue, wherein a bank is thus formed acting as a bridge to close the end of the ash-pit, and on which the combustion of the precipitated fuel is in due course completed, Fig. 1. The clinker and ash are removed from the combustible matter at the back, and drawn out from underneath at intervals varying from three to twenty-four hours according to the quality and quantity of coal consumed, no opening of the fire-door being necessary for this cleaning; sufficient, however, is left in the back, or on the bottom of the flue to form a close bank against the admission of cold air through the bars and into the combination chamber (Fig. 1). A small quantity of steam is allowed to blow upon the end of the bars from a jet, and tends to keep them and the bearers cool.

The supply of fuel is regulated with facility by a simple mechanical arrangement (Fig. 2), consisting of a quadrant and clicks. The stroke or travel of the bars may be adjusted to any length less than 4 inches, by altering the position of the stroke-bar from that shown in Fig. 4, and pushing it inwards. When the 'resisting click is in the first tooth of the draw-bar, the part for contact with the dog falls outside the circle of motion made by the latter, and this being so the bars remain at rest; but between these two positions they may be made to move, and the fuel fed, according to the work required from the boiler. The formation of clinker is prevented by this method of moving back alternate bars at the same time, and the admission of air under them is also rendered uniform. The whole machine stands on strong girders bedded on the ground, which relieve the front plate of the boiler from any strain.

The driving-power is supplied by a shaft which may be placed either above or below the stoker, and on which are fixed two eccentrics, each actuating a ratchet-wheel and pawl, Fig. 2, and thus communicating to the dog-shaft the intermittent motion referred to. The eccentrics on the driving-shaft are so fixed that the latter does not bear the strain of the whole machine at any one

time, one dog-shaft being at work while the other is at rest, so that the boiler has a constant supply of fuel. Hand-firing may be easily resorted to by opening the large door between the plungers (Fig. 2).

The driving-shaft has a constant rate of from 18 to 20 revolutions per minute, and the dog-shaft being regulated entirely by the arrangement already referred to, can be made to revolve at any speed up to 3 or 4 revolutions per minute, and needs little or no lubrication. Smoke is entirely prevented, inasmuch as no coal is allowed to pass on to the bars without first mixing with the perfect combustion already going on, and any smoke resulting from the mouth of the fire is completely consumed before it has left the grate.

SPRINKLER-STOKERS. (ILLUSTRATED BY THE BENNIS MACHINE.)

In this arrangement, as applied to the ordinary Lancashire boiler, a hopper is placed directly above the centre of each furnace, so as to leave room for glass water-gauges and steam-gauge between them, and so that each fire may be independent of the other. Underneath this hopper is a throwing apparatus or stoker, consisting of a cast-iron box B, with a shelf C inside. On this shelf a pusher-plate D slides, being actuated by the lever L, which receives its motion from the scroll-cam H.

The scroll-cam is made in two parts, so that it may be closed or opened by hand-nuts on the long end. The effect of this arrangement is, that the motion of the pusher-plate D can be exactly regulated, and the fuel at each stroke measured with great accuracy. The pusher-plate D, being drawn back by the lever L, as much fuel falls in front of it as fills up the blank space left by its withdrawal; it then moves forward again, the coal being propelled before it so as to fall over the edge of the shelf C, in front of the shovel S, ready to be thrown on the fire.

The throwing-apparatus consists of a V-shaped shovel S, resting on the bottom of a cast-iron box B. This shovel S is hinged to the lever or shovel-arm M, which latter is screwed on to the side of the box, so as to obtain sufficient length of stroke without making the shovel deep. On the side of the shovel-arm is a projection against which the tappet T presses so as to draw back the shovel-arm and shovel, against the pressure of the throwing-spring P. It will be seen that in Fig. 6 it is drawn under the shelf C right away from the fuel. As the tappet releases the arm M, it darts forward, and the shovel S strikes against the

heap of fuel, scattering it over the fire with more or less force according to the distance to which it has been previously drawn back.

The tappet T is made with four different-sized lifts, so that in one revolution of the shaft O four throws of varying strength will be given. These throws are so adjusted that the first sends the fuel on to the front part of the bars near the fire-door; while the next charge is thrown nearly to the end of the bars, and is scattered all across the fire over a space about 2 feet in length; the third throw distributes the fuel just beyond the first, and the fourth beyond that again. The object of this particular arrangement is to give time for the consumption of the suddenly liberated hydro-carbons before a fresh charge of fuel is added, thus preventing smoke, and producing perfect combustion.

Projecting from the shovel-arm M is the short lever F, to the end of which is attached a hardened steel pin G. Two springs work on this pin, being attached at their farthest end to rocking wing-nuts with hardened ends. When the tappet T lifts the shovel-arm M, the lower spring is drawn into tension, and the top spring is practically free from load. On the tappet releasing the shovel-arm, the latter bounds forward and reverses this position, coming almost at once to the point of rest. This arrangement gives perfect control over the distribution of the fuel, as by a turn of the wing-nut, the tension of the driving-spring may be sufficiently increased to throw the coal 1 foot or 2 feet further. Below each stoker is a fire-door A, usually 10 inches deep and 16 inches wide, so as to afford ample space for stoking by hand at night. This door is constructed to admit a small quantity of air, which passing through a perforated plate, is forced over a second plate, and then down close to the fire, where it discharges itself in small streams through a grid, keeping the outside of the door quite cool.

In the Bennis Camel-Furnace (Plate 2, Fig. 6), the fire-bars are usually about 5 feet long from the dead-plate to the end. At the front there is a depression about 3 inches deep, and then a slope 12 inches long and rising 3 inches. Beyond this the upward slope is only about 1 in 48, but at the farther end of the bars it increases to 1 in 6. Thus the end of the fire-bar is much higher than the front, and the clinkers and ashes have to ascend this hill to the clinker-chamber, in which they lie until all their heat is given up and they are drawn out dark and cold. This movement of the fuel is effected by the whole of the bars being pushed forward a distance of $1\frac{1}{2}$ inch by the pressure against

the bottom projection on the bar U of the cam-bar E, and by the washer-cams W (which are strung upon it, and are set at slightly varying points) bearing against the top projection on the bar at I. The bars are brought back to the front in series, so that only one in eight returns at the same time, leaving the clinker and fire $1\frac{1}{2}$ inch further forward for each complete revolution of the cam-shaft. The non-production of smoke is secured in this arrangement by the varying throw, combined with a continually clean fire; the supply of fuel being adjusted to the draught, so that the highest results as to production of steam and economy of fuel are secured.

An important point in stoking apparatus is wear and tear, and in this machine the minimum is secured, as follows:—The gearing bracket Z, Fig. 5, Plate 3, is enclosed in covers to prevent dirt and dust reaching the bearings, and all the working parts therein run in oil. All the cams, tappets, and other wearing parts are deeply chilled, and the wearing part on the shovel-arm is of hardened shear-steel.

When machine-stokers are fitted with hoppers filled by hand the only labour saved as compared with hand-firing is that of slicing and raking the fires; but where there are several boilers in a range a more important economy can be effected by raising the coal with a Jacob's ladder or elevator, and then conveying it in an overhead trough by a screw or tray-chain to each hopper as required (Fig. 7). The elevators and conveying-screw are driven from an over-head shaft, which may be the one used for driving the machine-stokers. In some cases this conveying-plant is also employed for removing the ashes and clinkers.

In many machine-stokers a crushing-mill was formerly placed under the hopper and over the feeding gear, to allow large coal to be used, but this provision is now seldom introduced, preference being given to the smaller and cheaper coals which possess good calorific value but are not available for hand-firing without loss of evaporative duty. If, however, machine-stoking should be more generally adopted, it might be found necessary to have this crushing-gear either in the machine or at the collieries.

Machine-stokers are generally worked by a small engine. For this purpose a 6-inch cylinder is ample for a range of twelve 7-foot Lancashire boilers, and estimating the average coal consumption for these boilers at 60 cwt. per hour, the fuel required for driving the machine-stoker would not exceed $\frac{1}{2}$ cwt. per hour. To this must be added the loss of steam in the grate-jets. By a careful experiment made by Mr. Bennis, in 1882, it was

found that at 82 lbs. pressure the weight of steam escaping through sixteen holes each $\frac{1}{8}$ -inch in diameter was 35 lbs. per hour. Supposing that these steam-jets only served to keep the bars clean and cool, there would be a charge on the boiler fuel of about 2 per cent., but experience has proved that a higher duty can be realized with than without the jets.

The advocates of machine-stoking contend that the following advantages result from its adoption:—(1) Prevention of smoke; (2) Economy of fuel; (3) Increased and more uniform evaporative duty; (4) Economy of labour, when combined with conveying plant.

1. *Prevention of Smoke.*—With the certain prospect of more strict legislature to reduce the smoke nuisance, its abatement is of great importance to the steam-user and the public. It is generally held that to prevent the emission of hydro-carbons in smoke, there must be on the same grate a green and a hot fire, a rapid and a slow combustion. With hand-firing this is only possible by keeping an intense fire near the bridge and a green fire near the dead-plate, or by the “alternate-side firing” system advocated by Mr. C. Wye Williams. There is also a great tendency to rely on the deficient supply of air being rectified by the split-bridge. It has been stated that it is not necessary to have machine-stoking to prevent smoke, as it can be sufficiently reduced by careful hand-firing. This statement is possibly true as applied to cases where there is specially intelligent supervision, but it is untrue as regards average steam-users and their stokers. Nor is the split-bridge a reliable remedy, unless the extent of air-admission can work in harmony with the stoking. It is true that Mr. Parkinson’s application of the split-bridge has, when fairly tried, greatly reduced the emission of smoke; but this success is not independent of “careful hand-firing.” The great advantage claimed for a machine-stoker as a smoke-preventer, is that it is always working under Mr. C. Wye Williams’ essential conditions of a green and a bright fire on the same grate, much better localized than with “alternate-side firing,” when it is quite possible for the gases to escape on the green side without combining with the oxygen on the hot side. With movable bars, machine-stoking is something more than a greatly improved system of combustion tending to smoke-prevention. It is an efficient remedy for smoke-pollution, and is the only system not dependent on that *rara avis* an educated stoker. Finally, with machine-stoking, one great cause of smoke in hand-firing is generally absent, namely, the frequent use of the slice and poker to rouse

the fire and to clean the bars. An observer outside a mill where the boilers are hand-fired, can count the firing and stoking times by the emission of smoke from the shaft. In machine-stoking it is only at long intervals that the door is opened, and then for a much shorter time.

2. *Economy of Fuel.*—With reference to the economy due to the use of a cheaper coal in machine-stoking than is possible with hand-firing, the testimony is overwhelming, and is rarely contested; but it is not so generally known that, owing to the more perfect combustion in machine-stoking, the cheaper coal often realizes also a higher evaporative duty per lb. of fuel.

In June, 1890, two careful trials of ten hours each were made at the Royal Paper Mills, Wandsworth, on a Lancashire boiler 7 feet 5 inches in diameter, and 30 feet long, with two 2-foot 9-inch flues, with the following results:—

	Hand-Fired.	Vicars Machine Stoker.
Grate-area	33 square feet	22 square feet.
Quality of coal (small)	Welsh	Bituminous
Price per ton	15s.	13s.
Coal per hour	6·4 cwt.	5·3 cwt.
Water per hour	502 gallons	533 gallons.
Water per lb. coal	7 lbs.	8·98 lbs.
Cost per 1,000 gallons evaporated	9s. 4·75d.	6s. 5·5d.

The fact that three firms alone have between them, either working or on order, 340 coking-stokers is strong evidence in favour of machine-stoking.

The testimony in favour of sprinkler-stokers is equally satisfactory, as is shown by the following trials of Bennis stokers, one made under the direction of Mr. L. E. Fletcher, M. Inst. C.E., and the other under the direction of the Author.

Messrs. ARMITAGE and RIGBY, Warrington.

Date, June and July, 1888.

Boiler, Lancashire, 7 feet by 27 feet; two 2-foot 9-inch flues.

Working pressure, 75 lbs. per square inch.

Temperature of feed-water, 55°.

	Hand-Firing.	Machine-Stoking.
Duration of trial	56 hours	35 hours
Coal consumed per hour	730 lbs.	917 lbs.
Water consumed per hour	450 gallons	677 gallons
Water evaporated per lb. of coal	6·18 lbs.	7·37 lbs.
Coal used (slack) 4s. 6d. to 5s. 7d. per ton	..	..

There was a second trial on June 18th and 19th with almost identical results. Mr. L. E. Fletcher, in his report to Messrs. Armitage and Rigby, concludes in these words:—"It is clear that in these trials the mechanical-firing had a decided advantage as compared with hand-firing, the duty obtained from the boiler with it being much higher, the water evaporated per lb. of coal much greater, and this with fuel lower in price."

The other competitive test with hand-firing was at the Middlesex Hospital, on a boiler of marine type, with one 2-foot 9-inch furnace-tube. To meet the demand for greater heating-power a Bennis stoker was ordered by the Author on the advice of the late Mr. Inglis, M. Inst. C.E., of Bolton, and previously to its being fitted, several careful hand-fired evaporative trials were made in September, 1889, with best large Welsh coal, the maximum duty realized being 195 gallons per hour, and 7·622 lbs. of water per lb. of coal—a poor result, due chiefly to heavy firing and deficient air-supply and draught. After the sprinkler-stoker was fitted a number of tests were made, with the following results:—

	Water Evaporated		Temperature of Feed.	Quality of Coal
	Per Hour.	Per lb. of Coal.		
1889.				
October 25 . .	310 gallons	8·38	206°	Welsh small and small rough Hartley. Welsh small.
November 1 . .	284 „	9·71	186°	
October 31 . .	190 „	10·178	193°	

The test on the 31st of October was in order to ascertain the consumption of fuel with the same evaporative duty as when hand-fired. With hand-firing the speed of air in the ash-pit, as measured

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by an anemometer, was 400 feet per minute; but with the stoker it was 750 feet. It is a general result of machine-stoking to largely increase the supply of air, and this may be partly due to the disturbance of the fuel by the movable bars and the absence of a thick fire.

3. *An increased and more uniform Evaporative Duty.*—The Author considers that greater evaporative duty may be expected with sprinkler- than with coking-stokers, the coking system having been chiefly adopted where the boiler-power is ample. There are cases, however, as at the Southwark and Vauxhall Waterworks at Hampton, where a Vicars' stoker consumes nearly 30 lbs. of coal per square foot of grate-surface. The automatic supply and progression of the fuel gives great uniformity of evaporation.

4. *Economy of Labour.*—This may be and is realized by machine-stoking, as the system permits the automatic supply of fuel to the hoppers. Mr. Campbell, of Perth, informed the Author that in a range of eight boilers with conveyors, one man had been saved.

In the mercantile steam navy machine-stoking is hardly known, only a few vessels being fitted with Henderson's movable self-cleansing fire-bars. It would save the loss of cleaning fires, and give a larger increase of evaporative duty than forced combustion by fans, and with much less injury and inconvenience. An increased duty of at least 10 per cent. from a ton of coal might be obtained with the employment of less highly-skilled labour. In addition to these advantages, all classes of cheap coal would be available for steam-ships, and smoke would be prevented—a great boon for the passenger traffic.

The number of furnaces fitted with machine-stokers and working at the present time is approximately as follows:—

COKING-STOKERS.

Juckles and others, old style	300	
Vicars.	2,500	
Sinclair, McDougall, and others	600	
Friable, Beeby, and others	200	
	<hr/>	3,600

FAN AND SPRING SPRINKLER-STOKERS.

Stanley beater, or fan machines	20	
Dillwyn Smith and Henderson	1,500	
Whittaker, Hodgkinson, Carver Newton, } Rye, Leech, and others	1,000	
Bennis	5,000	
Proctor	4,000	
	<hr/>	11,520
Total		<hr/> 15,120

This would represent about 8,000 boilers out of an estimated total in the United Kingdom at the present time of 140,000, or only 5·7 per cent. fitted with machine-stokers, and it has taken nearly seventy years to achieve this limited success. It is estimated that out of the 140,000 boilers in the United Kingdom, about one-half are to be found in the three counties of Lancashire, Yorkshire and Cheshire, and about the same number—70,000—are under inspection by the Manchester Steam-Users Association and the several Boiler Insurance Companies. Possibly, if statistics could be obtained of the percentage of boilers working at the present approved high pressure, or of the percentage of compound or triple-expansion stationary engines, the result would be somewhat analogous to that of the stokers. In two large Boiler-Guarantee and Insurance Associations there are approximately 1,010 boilers fitted with machine-stokers, or about 8 per cent. of the total number under the inspection of these associations.

The tendency of all boiler-inspection is highly conservative, its chief aim being to ensure safety, and in some cases, good dividends. Its best work is repetitive, and that is opposed to progress and improvement, so that both in reports and circulars it is necessary to remember this and read between the lines. Machine-stokers are suffered, but not recommended, and this alone has affected them adversely.

The Paper is accompanied by the drawings from which Plates 2 and 3 have been prepared.

Discussion.

Mr. Cowper. Mr. E. A. COWPER did not think the Author had given as much credit to mechanical stokers as they deserved, but on the contrary had been rather modest in claiming their advantages. To show that, he would take the case of steam-boilers in London, as local circumstances often greatly affected the proper treatment of steam-power. He made a great many experiments about fifty years ago on a steam-boiler with and without forced draught, using several kinds of American anthracite, as well as different sorts of English coal. He found that with a few alterations in the furnace, narrower bars, and a change to a cheaper fuel, namely, "Leases Main" in place of Hartley, he saved one-third of the total cost, and that without using forced draught. He tried letting in steam (perhaps in rather too great a quantity); but the general effect was to shift the heat, so to speak, further along the flue, in consequence of the production of hydrogen and carbonic oxide from the action of the water on the fuel and the subsequent burning of those gases some 6 or 8 feet further on. That had the effect, to a certain extent, of consuming the smoke, not necessarily by preventing the formation of it, but by giving a higher temperature at the particular point where they wanted the hydrocarbons to burn. He thought it was very likely that the small jets of steam now introduced were not extravagant, and answered the purpose sufficiently well. Since that time he had made numbers of boilers, and found that when the air-admission was properly arranged, a little care in the stoking, namely, putting the fresh coal on the dead-plate and front of the fire, and then pushing it forward from time to time, would practically prevent smoke if the draught was properly regulated. He always admitted a certain quantity of air per square foot of grate when the boiler was not required to be forced, and in order to increase the supply of steam he let in a little more air by putting a screw through the fire-door, so that it would not shut within a $\frac{1}{2}$ inch or $\frac{3}{4}$ inch. That was a rough-and-ready means of preventing smoke. In Liverpool and some other places they said the best plan was to give the stoker sixpence a week extra at the end of the quarter if no complaint had been made of smoke during that time. That was found to be a very successful remedy. He had a number of Vicars' stokers

at work in and about London, and they answered well on the Mr. Cowper. whole, although, of course, there was a certain amount of wear and tear, as was the case with all machines working in the dirt. In arranging a mechanical stoker inside the tube of a boiler, it was advisable to line the bottom half of the tube for a short distance with curved bricks, forming an incline sloping down forward into the ashpit, so that any live coal that fell over the end of the bars might lie on the brickwork, and not on the bottom plates of the tube, which might be injured by it. He wished to call particular attention to the fact that in London people insisted on having their coal screened, and refused to take small coal and dust, which was consequently a drug in the market. It could be got at from 9s. 6d. to 11s. per ton, and with a good mechanical stoker would burn quite as well as coal at 20s. or 21s., which meant that they got the fuel at half price. The result was that the cost of power, with a good high-pressure expansive condensing-engine, from a farthing per HP. per hour with large coal was reduced in many cases to half a farthing per HP. per hour with small coal. He had an early opportunity of handling one of the Bennis stokers and of observing how it could be adjusted so as to make it throw the coal to a distance of three, four, five or six feet if they wished it. The saving in cost of fuel in places where large coal was dear and small coal was cheap, was so great that he wished much more attention was given to the matter in London. In some localities where it would be necessary to break up the coal in order to get it small, the economy would not be so great. As to the saving in labour, it was necessary to put up lifting-apparatus and conveying-apparatus in order to deliver the coal just where it was wanted into the hoppers. He might add that it was very dangerous work for men to throw coal up to a high level, as it strained them, and often produced rupture.

Mr. E. N. HENWOOD said the plan of firing boilers by the Mr. Henwood. mechanical stoker was no doubt very clever, but in his opinion the use of liquid fuel would altogether put coal out of the market. He had a vessel fitted on his plan. The fuel was either a residue from coal or gas-tar, known as creasote or green-oil, or *astathi*, the residue from crude Russian petroleum. The evaporation derived from that boiler working at 60 lbs. pressure was over 30 lbs. per lb. of fuel. He also fitted it, in 1887, to a steam yacht of his own, the "Ruby," which was running for several months on the Thames, and was viewed by a great number of people including a representative from Lloyd's, from the Admiralty, the Board of Trade Surveyor, and other gentlemen. There was no trace whatever of smoke on any

Mr. Henwood. occasion, and no stoker was required. In the Caspian and the Black Seas several vessels had been running with liquid fuel.

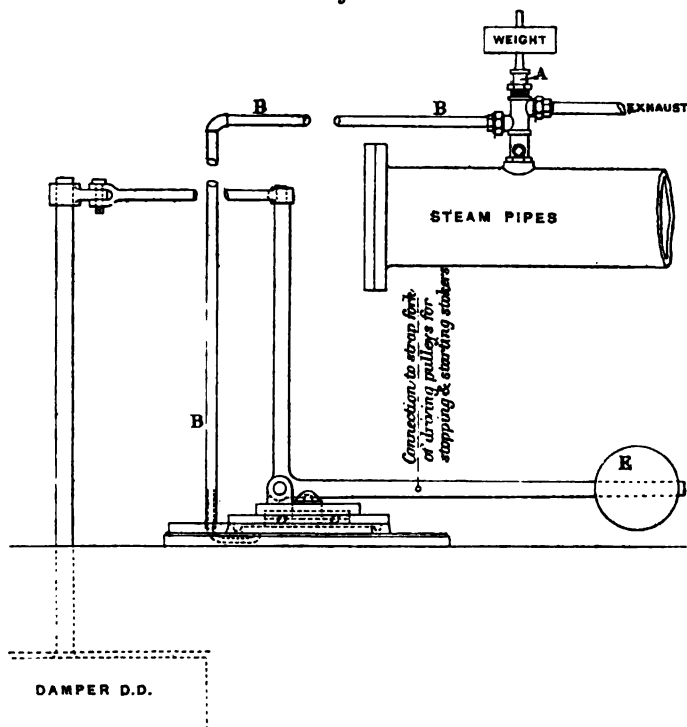
Professor Kennedy. Professor ALEXANDER B. W. KENNEDY remarked that further information was desirable on one or two points. The matter of the economy of fuel in the use of a machine-stoker was of the first importance. In all the illustrations given, with one exception very poor fuel was used. In that one case, with good Welsh coal they got on the whole a very fair evaporation, but nothing remarkable or more than could be obtained with ordinary stoking. In the other instances poor coal was used, so that they were brought back to the point which Mr. Cowper had emphasised, and which was of great importance, viz., that it was perhaps possible by the use of machine-stokers to get smokeless combustion with a much cheaper fuel than would otherwise be used. Obviously, if the poor fuel was only half the price of Welsh coal, and if it could be made to do the same work with equal absence of smoke and with only an increase of 50 per cent. in weight, it was cheaper to use it. He should like to know a little more on that point, and also the actual value of the fuel employed in the particular experiment cited. With regard to the small steam-jet used both with the Vicars and with the Bennis stokers, he had not himself made measurements of either, but any one who had had experience of the use of steam-jets in furnaces would know that they were apt to be a serious snare. A small hole in a boiler with 120 lbs. pressure in it got rid of a large amount of steam. He did not mean to say that the figures given in the Paper were not quite right in this particular case, but he had been the means of disappointing so many gentlemen who had systems involving the use of steam-jets, by insisting on the measurement of the steam used in them, that he thought it only fair to say a word about it. Any one who had works or stations of any kind in London, was obliged to use some means for preventing smoke, whether he got a good economy out of it or not. In his own case, at an electric-lighting station not very far distant, he was at present simply using good Welsh coal and good hand-stoking. They did not get any smoke, and the economy was as great as could be obtained under similar conditions from the boiler, under any system of firing. Perhaps some one could state whether these machine-stokers were adaptable to the case of work which was varied quickly. Every one knew that if a fog came on, a London electric lighting station might have its load increased four- or five-fold in ten minutes. He would like to know to what extent they could rapidly work

up the combustion in one of those boilers, or reduce it again if required. He did not know whether the economy of labour alluded to was a misprint, but surely it must be something more than the Author had stated when he said that Mr. Campbell, of Perth, in a range of eight boilers saved one stoker. If that was all, the saving was very small. In cases where he had tested boilers and stokers of that kind and obtained thoroughly good results, he had not found that the amount of air used differed much from that required with good hand-stoking, nor that the composition of the furnace gases taken from the chimney was very different. The Author very properly hinted that there were a good many small places where stoking was carelessly done in which the advantages of machine-stoking might possibly be obtained. With reference to a remark made by the last speaker as to the evaporation due to oil, he believed the figure he mentioned was 40 or 50 per cent. in excess even of the theoretical value of most oils.

Mr. W. LINTON ESKRIGGE was in a position to answer the question as to the power of the stoking machine to raise steam quickly, and to let it down when it was not required. A manufactory in Lancashire with which he was connected had sixteen sprinkler-stokers at work, and he could therefore speak from practical experience. They had adopted a regulator which acted in the following way. The damper being wide open, the steam gradually rose, either because of the firing, or because some portion of the work was shut off, until at last the pressure reached the desired amount, usually 100 lbs., and lifted the small safety valve A. When this occurred, the escaping steam acted with the full pressure in the boiler on the column of water contained in the pipe BB, and raised the bellows CC, thereby partially closing the damper DD, and at the same time throwing the belt driving the machine stoker on to the loose pulley, and stopping the steam-jets under the bars. As soon as the pressure fell to 100 lbs., or just under, the weight E opened the damper, started the stoker, and turned on the steam-jets. This action was so sudden and complete that as much as one-third of the work was often thrown off without causing the steam-pressure to vary more than 2 or 3 lbs. In that way a regular pressure was maintained, which, as practical people knew, was of great importance in cotton-spinning. The stokers were all of the same type, and the automatic action of the regulator was perfect. As an old member of the Stockport Corporation, he might state that for twenty or thirty years they had a sub-committee formed from the

Mr. Eskrigge. Nuisance Committee to take the smoke question in hand. A Bill was passed by which they were not allowed to make more than ten minutes of dense smoke. When he became a member of a Cotton-spinning Company, having to put in new boilers, the Directors decided to try if it were possible, by fitting them with automatic stokers to make a practically smokeless chimney. After much consideration they fixed upon the "sprinkler-stoker" as

Fig. 1.



being the best. The Medical Officer of Health, who supported this decision, watched the chimney for some weeks, and not seeing any smoke issuing therefrom, came to the conclusion that the "works" must be stopped, and wrote to ask the reason why. With regard to another case in which the machine-stoker was applied in the town, the inspector gave up visiting the factory, as there was no smoke. They had gone to great expense in this matter of smoke-consumption, and having first put in eight

stokers, they had now added eight more. With regard to the economy of fuel effected, in October, 1877, they were using 88 tons of coal per week, and they reduced the consumption to 76 tons of common slack, which to-day was worth 7s. 10½d. At that time it was worth 5s. 10½d.

Mr. E. BENNIS said machine-stokers on the sprinkler system produced more steam per minute than any hand-firing in the world. If the self-cleaning bars were efficient, the moment each charge of fuel was thrown on, it burst into flame; in fact, the fire-box was continually full of flame. The steam-regulator made by his firm, to which Mr. Eskrigge had referred, acted partially by closing the damper, and entirely stopping the machine-stoker as soon as the small safety-valve was lifted; the damper being only left sufficiently open to keep the fire up. Taking 80 lbs. as a common pressure in Lancashire, as soon as the steam rose above 80, the damper was nearly closed and the machine stopped. As soon as it fell, say to 79½, the work would begin again automatically, and the fire being red all over, directly the new fuel fell on it, the flame burst out with great vigour. Where steam was taken irregularly, the apparatus would keep stopping and starting again; but where the demand was more regular it would run for perhaps half-an-hour, then stop for a short time, and go on again. Cotton mills seldom threw off at any one time above 7½ per cent. of the power employed, and in them the steam-pressure could be kept from varying more than ¼ lb. In some works, however, they put on or off 40 per cent. of the entire power, but even with this variation in the demand the pressure could generally be kept within about 3 lbs. Supposing that at such a factory the boiler-pressure were 80 lbs., they would set the regulator to 77 lbs., and rarely indeed would any steam blow to waste. It was most important that the regulator should be connected with the stoker as well as the damper, in order to keep the steam steady. His own machine was a shovel-stoker, throwing the fuel on the fire in consecutive zones; but it was open to him to make coking stokers as well. The reason he had not done so was, because the boilers in Lancashire, Yorkshire and Scotland were generally heavily fired. In London the practice was to have a good many boilers, and to fire them more easily. With the Bennis stoker on an ordinary-sized grate, 56 lbs. of small coal per square foot of grate per hour was being consumed night and day. When he first went into the business of machine-stoking, it was considered that a furnace which consumed 20 to 23 lbs. per square foot of grate per hour was doing very well. He was now testing hand- and machine-

Mr. Bennis. firing at one of the most important steel-works in Scotland, where by putting three men to fire one boiler, they burned nearly 50 lbs. of fuel per square foot of grate per hour.¹ He had guaranteed to beat the evaporation by hand-stoking by 30 per cent. with his machine. An important point in machine-stoking was whether the machine could burn the same class of small fuel, largely in use in the north for hand-firing, with economical results. This was what they had to do in Lancashire. In London machine-stokers were highly favoured because the users could buy the best fuel in the country, viz., small north-country coal, at half the price of good Welsh coal. Again and again, with small north-country coal, he had equalled or beaten the results obtained by hand-firing with best Welsh coal, thus saving the whole difference in cost. He could not do this in every instance, because the journey from Newcastle deteriorated the small fuel, and sometimes it had been lying in the yard for a considerable time. But whenever they got the small north-country coal fresh, they were able to obtain as good results by using it with the machine, as hand-firing would give with the best Welsh coal. Welsh large coal did not deteriorate quite so fast; but in London hand-firing had not done as well ton for ton or hour for hour with it as his machine-stoker had with north-country small fuel. It had been stated in the discussion that nearly all the tests had been made at low evaporation per lb. of fuel. That was necessarily so, because nearly every one who adopted stokers used common small coal. He had a case at Mr. Rich's mills at Stroud where 11 lbs. of water was evaporated per lb. of fuel by hand-firing, and 12½ lbs. per lb. of the same class of small-coal with the machine-stoker, showing that the machine would do more work with the same fuel than hand-stoking. The same remark would apply to a properly run coking-stoker as to economy, but not as to increased production of steam per hour. In his experience, as the result of careful testing under independent inspection, coking-stokers were more applicable to lightly fired boilers, and by means of them better economy was secured than by hand-firing. But shovel-stokers could be used for heavy firing. He found that, provided there was no considerable raking of the

¹ The correct weight of fuel consumed per square foot of grate worked out to 47 lbs. per hour, and not 50 lbs. as stated. The machine-stoker consumed 70 lbs. per square foot of grate per hour—the grate however being much smaller. The guaranteed work—30 per cent.—was accomplished with an increased consumption of only 15 per cent. in the boiler.

fires, the greater the consumption per hour, the greater the economy. On the contrary, in working by hand-firing it had been found that light firing produced the most economical results. A machine-stoker of the shovel type, from the regularity of its action, produced a more intense heat when urged up to its full power. As an illustration of this, he would mention that he was now conducting a week's test at an important Lancashire paper-works where seven boilers were ordinarily used. He had at first tried six, but that morning he had reduced the number to five, having found that the machine-stoker was making too much steam, and even now there was more than was necessary. The reason was partly that stated by the Author, and partly also because the regular and intense fire being always clear from smoke, produced a greater heat in the boiler tubes, and the water took it up more rapidly. Again, when the flue gases reached the economizer they did not carry so much smoke with them, and the pipes did not get clogged up, so that a greater heat was attained there, as well as round the boiler. At the paper-works spoken of, the additional result obtained in the economizer was not equal to that attained in the boiler itself. The water leaving the economizer was only 30° hotter with machine-firing than during the previous hand-firing test when seven boilers were being used; so that there was an increase in the work of the economizer of 14 per cent., whereas each boiler was doing 40 per cent. more. The flue-gases entered the economizer at an average temperature of 750°, and left it at 450°, losing 300° in raising the water from 210° to 240°. Recurring to the low evaporation of 7 or 8 lbs. per lb. of fuel, the fact must be taken into consideration that most firms endeavoured to use cheap coal. Frequently 2s. to 4s. per ton was saved in country places where, as the boilers were heavily fired, the mill-owners were compelled to use good coal for hand-firing. At the Palmer mills mentioned by Mr. Eskrigge, from 8 to 12 tons of coal was saved per week out of 96 tons, in addition to obtaining a considerable increase of power. It might be said that the machine-stoking had decreased the number of boilers used. That was so; but the three boilers were doing more work than the four formerly did by hand. Frequently with machine-firing 30 to 40 per cent. extra work was done on a given range of boilers, while the labour to the men was lessened. With regard to gas-firing, he had made an exhaustive series of tests at the Bilston Steel Works with Mr. Lithgoe, and the conclusion come to was, that no gas-firing could compete with the direct combustion of coal in the boiler, because it was not economical to carry on two

Mr. Bennis. processes when the same result could be obtained by one. He formerly shared the popular belief among engineers, that when carbonic acid gas was passed over coke fires, carbonic oxide was largely produced. His opinion now was that this was an error, as in no case had he been able to detect carbonic oxide in considerable percentage in flue-gases from boilers, and Mr. Fletcher had shown in his numerous experiments that carbonic oxide could rarely be got out of boiler-chimneys. They might, of course, find a trace; but the gas was so inflammable that if there was any air present it would burn. Under these circumstances he was unable to account for the fact, having made a good many experiments with coke-firing, that they could not get the same evaporative duty per lb. of coal, nor the same work out of a boiler by coke-firing, even with a steam-blast. Of course in steel-works where they had short chimneys and great pressure, the carbonic oxide would come out of the top of the chimney and burn there, but he was speaking of boiler-fires. Mr. Fletcher, who had made a great many more experiments than he had, said that only where there was dense black smoke did any carbonic oxide escape from chimneys.

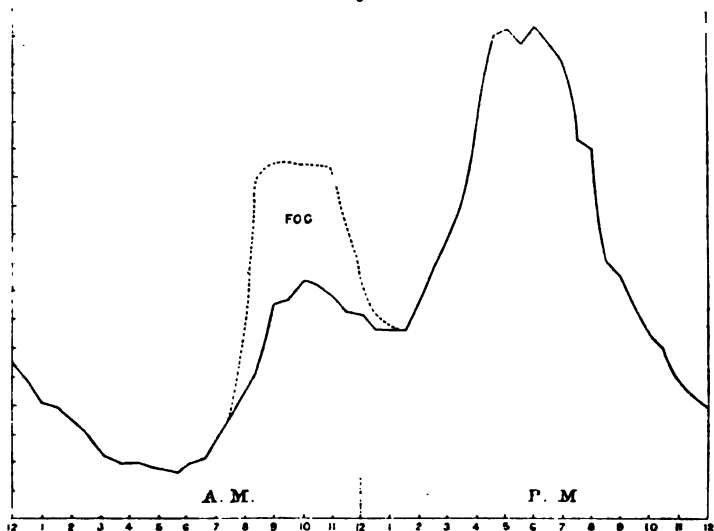
Mr. Sugden. **MR. THOMAS SUGDEN** said one thing that appeared to him peculiar in the two systems of stoking was the length of the fire-bar, which was shortest in that machine in which apparently it ought to be longest. The coking-stoker, where part of the surface of the grate was taken up by the coking, had a very short bar, while the sprinkler-stoker, where the whole of the fire-bar was available for making steam, had a much longer one. He should like to know the reason of this. With short fire-bars the heat was too much localised, and would have rather a detrimental effect upon the boiler from being confined to such a limited space. With respect to the windage and the admission of air to support combustion, the Author stated that the moving-bar kept the spaces open, and in consequence a much greater velocity of air escaped through. He imagined that this greater velocity of air was due rather to the grate-surface, which, in all mechanical stokers, was much smaller than in an ordinary furnace. In the ordinary Lancashire boilers the grate-surface would be 6 or 7 feet long at the least. In Bennis's stoker the bars were 5 feet, and in the Vicars about 3 feet 6 inches long, so that in burning the same amount of fuel the necessary quantity of air would have to pass through a smaller area, and consequently the velocity must be greater. He preferred this explanation to that given by the Author, namely, that the bars were always clean. In the Vicars's stoker there

was a steam-jet to cool the end of the fire-bars, and in the other Mr. Sugden. stoker the steam-jet was used to keep them clean and cool; but he should think that they required an account of the smaller grate surface that the draught should be assisted. Most people, in putting up mechanical stokers, would find that unless they had a very good draught they would not work so well, because with a limited grate-surface a stronger current of air was needed; so that possibly they might not get the same result unless they employed some kind of forced draught. In his experience one of the great difficulties about mechanical stoking was that of constructing the machinery, and also of keeping it in order. Making fire-bars 5 or 6 feet long was a serious matter, and in most instances they did not last a great while—sometimes not more than a few weeks. In addition to this there was a natural prejudice on the part of firemen against mechanical stoking, because they thought it would do away with skilled labour and make their positions worse. It was necessary that people who put on mechanical stokers should consider that when men were determined that a machine should not work it was very rarely indeed that it was found to go satisfactorily. He had with him the results of some experiments which he had made with the coking-stoker, extending over a period, in one instance, of seventy-four days, and in another instance of fourteen days. By hand-firing during fourteen days, 159 tons of coal at 15s. 3d. a ton. were burnt. That quantity of coal forced 2,375,176 gallons of water into the main against the constantly accumulated pressure of 720 lbs. per square inch. When mechanical stokers were fixed for the same boilers, the result was that 492 tons of coal burnt, at 11s. 3d. a ton, forced 10,146,583 gallons of water into the main under the same conditions. In this case mechanical stoking just saved the difference in the price of the coal, or about 25 per cent. The evaporative tests in both instances were nearly the same.

Mr. W. H. PREECE wished to emphasise one point raised by Mr. Preece. Professor Kennedy, because it introduced a problem that was exercising the minds of electrical engineers, and compelling them to call in the aid of the mechanical engineers, and especially of those who advocated mechanical stoking. The variation of load during a day of twenty-four hours was a very serious item, and he would put it before them in the shape of a diagram. The horizontal line, *Fig. 2*, represented the day, starting from midnight, and the load of the apparatus in the central station, that was to say, the HP. converted into the electrical energy supplied to the district, was measured upon the

Mr. Preece. vertical lines, which might represent any amount of power they chose, say 1,000 HP. At twelve o'clock at night there were still a few dissipated gentlemen found out of their beds, and a certain amount of light was used, which dwindled down to something very small at four o'clock in the morning. At that hour there was always somebody wanting light, and busy men like engineers were commencing to rise. At times on dull mornings they required light at the breakfast table, and the load mounted. Then breakfast being over, having read the newspaper and gone to business, the load fell again, and at twelve o'clock it reached

Fig. 2.



a minimum. At that time of the year between three and four o'clock in the afternoon there commenced a very sudden rise—shops, offices, places where business was transacted required light; and not satisfied with light in their business places, they required light when they went home and dressed for dinner, at which time between seven and eight o'clock at night there was the maximum power required at the station. When they had gone to the theatres the load descended at a rapid rate until it reached, at the end of the diagram, about the same value which it had at the commencement, twenty-four hours previously. This was an illustration of the way in which the load of a central electric-lighting station might vary. From four o'clock until six

there was a sudden rise from about 50 or perhaps 100 HP. up to Mr. Preece. 1,000 HP. Of course, at the present moment, he was dealing with electric lighting, because the public generally were not yet educated to the use of small motors. When they did become so educated the diagram would be rather modified. Electrical engineers had watched with a good deal of interest these mechanical stokers. In the new Post Office, when they introduced pneumatic tubes the boilers were fitted with mechanical stokers, and they found the variation of load was very much of the same character. Naturally when the business man got to his office at about eleven o'clock he sent messages away with great rapidity up to twelve o'clock, and if he were to draw a curve indicating the variation of the telegraphic service, the maximum point would come at twelve o'clock midday, instead of late in the evening. It was quite impossible to get that sudden rise of work by means of the mechanical stokers, and they were obliged to remove them. He had had a good deal to do with electric-lighting stations, but there was only one central station that he knew of in this country where mechanical stoking had been introduced, viz., at Newcastle,¹ and they were watching its performance with a good deal of interest. It had only been running a few months, so that nobody could tell at present what the result would be. He would call the special attention of those who were dealing with mechanical stoking to the question of the great rise between the hours of four and six o'clock shown on that diagram. The effect of a fog in the morning would be to cause a sudden increase of the load in the morning, as in the case he had mentioned of the pneumatic tube.

Mr. J. F. SPENCER, in reply, said the great care with which Mr. Spencer. Professor Kennedy always made his experiments warranted the supposition that a very efficient set of men were employed as stokers. One of the chief reasons for bringing forward the Paper was that good stokers were very few. The bulk of the work carried on in the country was done by men who were seldom faithful to their duty, and it was undesirable to depend upon a system where the majority of those who had to carry it out were so inefficient. The necessity of mechanical stoking arose mainly from the circumstance that it was so hard to get what was called careful hand-firing. The difficulty at sea at present was to obtain efficient firemen, and if the system of mechanical

¹ He had afterwards learnt that they were used in the central stations in Liverpool.

Mr. Spencer, stoking in a modified and perhaps better form could be applied to the Navy and mercantile marine, the advantage would be simply immense.

It was noticeable that every defence of hand-stoking omitted reference to the importance of the "uniformity" in the production of heat, which was the special characteristic of machine action as contrasted with hand-work. As a striking illustration of the value of economical arrangements that could not be materially altered by the man in charge, reference might be made to the greatly increased average economy of steam-power which resulted from having an unalterable expansion, as in the differential cylinders of compound or triple-expansion engines, in place of a cut-off gear regulated by ignorant and often incapable men. With regard to Professor Kennedy's remarks as to the economy of labour, in Perth, it amounted to one-third; and the steam-user would not consider that "very small"; the circumstances, however, in that case, were not specially favourable. With reference to the anemometer tests in the ash-pit it was not implied that the supply of air was increased in the ratio of the figures given, but that the draught was made much greater by the adoption of machine-stoking, giving, in fact, an increase in evaporative duty of upwards of 40 per cent., with inferior coal. The following table of actual tests made by Mr. Bennis formed the basis of the Author's estimate of the weight of steam used for twelve boilers:—

OUTFLOW OF STEAM INTO THE ATMOSPHERE (1882).

Boiler Pressure.	Supply-Pipe.	Distance from Boiler.	Exit Holes.	Lbs. Steam Used.	Velocity. Feet per Second.
Lbs.	Inch.	Feet.	Inch.		
82	$\frac{1}{2}$	6	16 of $\frac{1}{8}$	342	1,300
82	$\frac{1}{2}$	6	16 „ $\frac{1}{8}$	916	1,200
82	$\frac{1}{2}$	6	16 „ $\frac{1}{8}$	255	950
81	$\frac{1}{2}$	6	16 „ $\frac{1}{8}$	722	850
82	$\frac{1}{2}$	3	1 „ $\frac{1}{2}$	5,370	1,150

It was a matter of regret that so little reference was made in the discussion to coking-stokers, and it might be fairly assumed that whether the coking or the sprinkler type of machine should be adopted would depend to a great extent on the special circumstances of each case. If the attention of engineers and

steam-users could be directed to the importance of substituting these machines for human stokers the results might prove as important in economizing the production of steam, and in purifying the atmosphere of the manufacturing towns, as those derived from the use of increased pressure and engines of improved construction.

Correspondence.

Mr. F. COLYER noticed that the Author stated that the Juckes' furnace "was deficient in power and not economical," and that "the attempt to adapt this stoker to Lancashire boilers was not successful." Speaking from personal experience he might state that he had used these furnaces largely for nearly thirty years. They had been most successfully applied to Cornish and Lancashire boilers, and also on a large scale to brewery coppers; in the case of boilers, they had been employed inside the tubes as well as under the shell. For coppers they had been used by him in sizes of from 15 to 54 square feet, and in boilers from 15 to 40 square feet. The saving effected in the cost of coal was from 20 to 25 per cent., allowing for the wear and tear of the furnaces. In experiments and tests made by him some years ago, using two 35 nominal HP. Lancashire boilers, 1 lb. of common slack coal evaporated 10½ lbs. of water. These experiments were made at a large sugar-house, and were spread over a period of one week; the coal bill at this place at the end of the year, taking into account the number of hours the boilers were worked, showed a saving of at least 25 per cent. He also carried out some tests at one of the largest breweries in Burton-on-Trent, where these furnaces were applied under brewing-coppers, and found that with the commonest slack and dust from a Midland Colliery, the saving in cost of coal was 30 per cent. As to the evaporative power in this case, repeated tests were made with two coppers worked side by side, into each of which sixty barrels of water were put, one of them being heated by an ordinary hand-fired furnace with large coal, and the other by a Juckes' furnace with common slack. The water in the copper heated by the Juckes' furnace was boiled in two-thirds of the time required in the case of the one heated by an ordinary fire. He could quote many similar instances where experiments had fully established

Mr. Colyer. the large economy of this type of furnace. One of the largest breweries in London had used Juckes' furnaces for about forty years, and they still had twenty-two large ones at work and found them the most economical furnace for the purpose. Nearly all the large brewers, both in London and Burton, employed them, and during a long experience he had never known them to fail. He had many times successfully applied these furnaces inside the tubes of Cornish and Lancashire boilers, the tubes being from 2 feet 6 inches to 3 feet in diameter, and found that the economy was as great as when they were placed under the shells of other boilers of like type. He was aware that there were failures some years ago in the cotton districts, where the furnaces were constructed by inexperienced people and were badly made, but in this case the manufacturer should take the blame. The fact that for forty years they had been and were still largely used was the best answer to the Author's statement. There were several other furnaces not named, that had been extensively used for the prevention of smoke, such as Copeland's, where the coal was introduced under the fire. The objection to this method was not any want of economy, but because only those kinds of coal could be used that would cake together. The Paper might have been entitled "A description of Vicars' and Bennis' Machine-stokers," but Mr. Colyer considered that there were others of the same type, equally good, which should have been described if prominence was to be given to any particular class. There was nothing novel in either of the furnaces described. Jets of steam were used under the fire-bars upwards of twenty years ago and were still employed by many people. He fully endorsed Professor Kennedy's statement that the expenditure of steam in the jets described was more than many people supposed; it probably cost more than any saving effected by the increased draught or the preservation of the bars. Pans of water placed under furnace bars would prevent them from burning out rapidly, and would also help the draught when it was sluggish, and this plan involved no expenditure of steam. The evaporation per lb. of coal by Vicars' furnace, viz., 8.98 lbs. water, was far behind that effected by Juckes' furnace, which would evaporate from 10 to 11 lbs. of water per 1 lb. of fuel of the same quality. He had lately seen near Glasgow Juckes' furnaces working under water-tube and other large boilers with great economy, the heating power and easy way in which steam could be kept up being all that could be desired. If they could be used with advantage where the coal was so poor and so cheap it was surprising that many large firms did not apply them.

He might state that he had no interest in either Juckes' or any Mr. Colyer other furnace. He had refrained from entering into any particulars of other good furnaces for the prevention of smoke because they were not named in the Paper. It was to be regretted the Author did not treat his subject more fully and generally instead of confining himself practically to the description of two out of many machines of this class. With reference to the remarks of Professor Kennedy and Mr. Preece, there was no difficulty in working any of the good mechanically-fired furnaces, where the demands for steam were not regular, as the speed could be adjusted to suit and the motion of the bars stopped if necessary. There was no doubt that furnaces of this class supplied a more regular amount of steam than hand-fired furnaces, and that there was a great advantage in working with a thick and even fire, and in not having to open the fire doors and let in cold air to the top of the furnace where it was not required, and where much damage was done to the plates of the boiler. The most severe test of this kind was in the case of a brewery copper, where the fire had to be entirely drawn immediately the wort was sufficiently boiled, and then quickly returned to the furnace in order to boil the next quantity. In the case he had referred to one-third of the time was saved by the use of Juckes' machine. He had also had other cases, where steam wharf-cranes were employed, and where the demand was intermittent. Machine-furnaces had been found in practice to be the best, and by far the most economical and efficient in every case where they had been intelligently applied.

Mr. G. D. DENNIS remarked that he had had long experience in Mr. Dennis. the management of hand-fired boilers, and one of the largest private electric-lighting stations was now under his superintendence, where there were four double-flued boilers 30 feet by 7 feet 6 inches. Two of these had been fitted, by his advice, with Vicars' mechanical coking-stokers. So far they had given every satisfaction, and as much steam could be obtained from these two boilers, with small-coal costing 10s. 6d. per ton, as from the other two using best Nottinghamshire steam-coal at 18s. 6d. per ton and firing by hand. These machine-stokers would meet a sudden call quite as quickly as hand-fired boilers, and they only required to be tried under such conditions as existed at electric-lighting stations to be generally adopted. They had given no trouble, and the chimney was always clean. More coal could be burnt with them than by hand-firing, and with this advantage, that

Mr. Dennis. the mechanical stokers always put the coal in the right place, viz., on the dead-plate end of the furnace, thus causing all the products of the early combustion of the fuel to pass over the incandescent mass. Arrangements were being made to fit the other two boilers with machine-stokers of the same make.

Dr. Proell. Dr. R. PROELL was convinced that apparatus of this kind was capable of giving good results with respect to economy of steam and smokeless firing, and he found no difficulty in accepting the Author's figures with regard to those points. But it was doubtful whether it would also be possible to keep the machine constantly in good working order. The separate parts would suffer a good deal from the strong heat radiated by the furnace and would soon warp to such an extent as to become useless. Mechanical stokers would not be very largely taken up in Germany. In that country the greatest stress was laid on the thorough training of the stokers in special schools for firemen. In this way the people learnt what were the conditions of economical and smokeless firing, and the boiler-makers also on their side were urged to build furnaces in which these conditions could be realized. Systematic practical experiments with various kinds of boilers had shown that it was actually possible to obtain an economical and almost smokeless combustion with hand-firing. That was the conclusion to which he had been led by his own experience. If in England the system adopted with respect to the teaching of the firemen was different, then there might be scope for mechanical stokers. But besides these things the quality of the coal and the nature of the demand for steam had to be taken into account. If the former coked very much and the latter was variable, then the machines would not behave so well as they were otherwise capable of doing.

Mr. Reynolds. Mr. EDWARD REYNOLDS hoped that the question of the application of machine-stoking to marine purposes would be raised. The chief difficulty appeared to be that a steam-ship did not average a level floor, and that in consequence, one side of the bars became bare when machine-stokers were used; considering, however, that circular furnaces were almost universal, and that such variations of weather as would make a permanent change in the average list of the ship were not sudden, it would appear to be perfectly practicable to make an automatic device whereby the position of the bar-frames, &c., in the circular flue might be adjusted to suit the average list of the ship on its course, and this having been provided for, the

makers of machine-stokers would find an enormous field open Mr. Reynolds. to them.

Mr. SPENCER, in reply to the correspondence, observed that Mr. Mr. Spencer. Colyer's reference to brewers' coppers, to which the Jukes furnace had been applied, was quite outside the scope of the Paper, which was limited to steam engineering, and Mr. Spencer did not consider it necessary to discuss the success of such application of the system. In support of his statements about the Jukes furnace, so much objected to by Mr. Colyer, he would give the following reasons :—

1. One firm alone fitted upwards of one thousand Jukes furnaces, of which only about one hundred continued in use after three years, and at the present time it was doubtful if one remained.

2. Eight or ten firms made Jukes furnaces for steam-boilers, and yet discontinued the manufacture. It was hardly to be supposed that they all made the grates faulty.

3. The Author, in visiting the Midland districts in 1882 and 1889 for the purpose of seeing various machine-stokers in operation, did not meet with or hear of a single Lancashire or Cornish boiler working with a Jukes grate.

4. Mr. Colyer did not give the name of any steam-user now working a Jukes grate in a Lancashire or Cornish boiler.

5. The estimated number of Jukes and similar grates now working, as stated in the Paper, which was believed to be in excess of the truth, proved that the experience of fifty years had not been in favour of their general adoption.

6. In 1886 some competitive trials between a Jukes and a Bennis furnace were made at the Bolton Iron and Steel Works with results unfavourable to the former, in which the fire-grates were under the boilers.

The chain-grate was a step in the right direction, but it was practically out of the market now. Mr. Colyer's objection to the omission of particulars of other machine-stokers was hardly reasonable. The title of the Paper was "Machine-Stoking" and not "Machine-Stokers," and in order to illustrate the two types it was but just to select those most generally adopted.

In answer to Dr. R. Proell, no doubt the question of wear and tear was most important in machine-stoking, and the arrangement that was least complicated had the greatest chance of permanent success. The Author was much impressed with the simplicity and efficiency of a coking-stoker at Oldham, shown to him by

Mr. Spencer. Mr. Herbert Fletcher, of Bolton, an ardent advocate of smokeless furnaces. Dr. Proell's belief in an educated human smokeless and economical stoker was a most delusive one. With regard to Mr. Edward Reynolds' suggestion, the automatic device for obviating difficulties due to the list or roll of a steamer had been fully proved to be unnecessary with machine stoking at sea.

3 February, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

WILLIAM BARRINGTON, JUN.
SIDNEY HOWARD FARRAR.
SINGLETON GOODWIN.
JOHN WYKHAM JACOMB HOOD.
CHARLES LOXTON JACKSON.

JOHN ARTHUR DAYRELL LLOYD.
PERCY RICKARD.
EDWARD BLAKEWAY SMITH
ROBERT HENRY FREDERICK STUART.

and that the following Candidates had been admitted as

Students.

CHARLES SPENCE ANGUS.
JOHN CALDER, Wh. Sc.
HAROLD CORDEROY, B.Sc.
ERNEST GRAY COUTTS.

WILLIAM HARVEY EBBS.
GEORGE ADAM HART.
GODFREY WILSON MOORE.
HENRY HAWKINS MYBURGH.

The candidates balloted for and duly elected were as

Members.

FREDRICK ATTOCK, Assoc. Inst. C.E.
ALFRED PANCOAST BOLLER, M.A.
ALEXANDER BREBNER.
MARSHAL CRESSWELL.
ROBERT CRICHTON.
GEORGE ROBERT MOYLE FIELD.
WILLIAM SUTCLIFFE MARSH.

SAMUEL REA.
JAMES DIX SCHUYLER.
WILLIAM BELLHOUSE SCOTT.
WILLIAM POWELL SHINN.
MATTHEW STIRLING.
FREDERICK WILLIAM WALKER.

Associate Members.

JAMES ARMER.
CLAUDE WILLIAM ATKINSON, A.K.C.,
Stud. Inst. C.E.
HENRY CUTHBERT BARNARD, Stud.
Inst. C.E.

ROBERT BARNES.
CHARLES WILLIAM JOHN BEARBLOCK,
Eng. R.N., Stud. Inst. C.E.
GEORGE ARTHUR BECKS, Stud. Inst.
C.E.

Associate Members—continued.

WILLIAM CAMERON BORROWMAN, Wh. Sc.	LUCIEN ALPHONSE LEGROS, Stud. Inst. C.E.
ARTHUR CROMPTON BROWN.	SYDNEY LE GROS, Stud. Inst. C.E.
BENJAMIN JOHN ELDER BRUCE.	JOHN GEORGE LIVERSIDGE, Eng. R.N.
GEORGE CUNNINGHAM BUCHANAN, Stud. Inst. C.E.	SAMUEL ERNEST LUCAS.
GILBERT CLARK.	WILLIAM THEODORE LUCY, Stud. Inst. C.E.
DAVID COE.	GEORGE EDWIN JAMES MCMURTRIE.
PERCY BARBY GUSTAV OTTO CROWE.	ERNEST ALFRED WILLIAM PHILLIPS.
AUGUSTINE CAMPBELL DAVISON, Stud. Inst. C.E.	JOHN PIDGEON.
SYDNEY THORNTON DOBSON.	FRANCIS JOSEPH PIGOTT, Stud. Inst. C.E.
EDMUND ROBERT DYMOND, Stud. Inst. C.E.	WILLIAM EDWARD PRICE.
FREDERICK CHARLES FAIRHOLME, A.K.C., Stud. Inst. C.E.	JAMES FRANCIS READE.
CHASEMORE PHILIP GATES, Stud. Inst. C.E.	JOHN EDWIN ROGERSON, B.A., Stud. Inst. C.E.
CHARLES ERNEST VERE GOUMENT.	JOHN THOMAS HORNSBY SAMPLE, Stud. Inst. C.E.
PHILIP HAMMOND.	EVELYN FRANCIS SANDERS, B.E.
HERBERT WILLIAM HARPER.	RICHARD WILLIAM SMITE.
ROBERT JOHN HARRISON.	WILLIAM SMITH.
WILLIAM HARSTON.	CHARLES ARTHUR STRUTT.
FRANK HOWARTH, Stud. Inst. C.E.	CHARLES ROBERT TREWHELLA, Stud. Inst. C.E.
HERBERT WILLIAM HUGHES.	WALTER FRANCIS AINSLIE WADHAM, M.A., Stud. Inst. C.E.
CHARLES FREWEN JENKIN, B.A., Stud. Inst. C.E.	CLAUD ROBERT WATSON.
	WALTER WILSON, Stud. Inst. C.E.

As an Associate.

ERNEST MONCREIFF PAUL, Lieut. R.E.

(*Paper No. 2497.*)

"Electric Mining-Machinery, with Special Reference to the Application of Electricity to Coal-Cutting, Pumping, and Rock-Drilling."

By LLEWELYN B. ATKINSON, A.K.C., and CLAUDE W. ATKINSON, A.K.C., Assoc. MM. Inst. C.E.

THE employment of electricity in mines for pumping, hauling and coal-cutting, is a subject which has already received some attention in Papers read at the meetings of the more strictly mining Institutions. The Authors have been, during the last four years, constantly connected with the applications of electricity to mining, and have spent a considerable amount of time underground, both in making experiments, and in teaching those who would have to take charge of the Electrical Machinery. They propose in the present Paper to show in what way the conditions of mining work differ from those of other industries, and how the problem has been dealt with, illustrating the subject by describing some of the machinery now in actual use.

The principal uses to which electrical power is likely to be put in coal- and metalliferous mines, and in quarries, are the driving of pumps, of hauling and underground winding-machines, of coal-cutting machines, of drilling-machines, both rotary and percussive, and in certain cases of fans for subsidiary ventilating purposes. It will be unnecessary here to dwell at any great length on the question of the relative merits of different methods of transmitting power in mines, practical experience having shown that compressed-air is almost the only rival to electricity, although in particular instances other systems are still in use for certain purposes. Compressed-air has one advantage, on which much stress has been laid, namely, that the exhaust product is in itself a valuable assistance to ventilation; but from circumstances that will presently be described, it would appear that the method of ventilating a mine by first compressing air, transmitting it under pressure, and then expanding it, is the most costly that can be devised. If power must be spent in ventilation, the best way to do it is to deliver a given volume of air, with the proper difference of pressure between the intake and the up-

cast. In using compressed air, in order to keep the machinery as small as possible, and at the same time to limit the expense of the piping, it is necessary to work at as high a pressure as is feasible. On the other hand, increase of pressure, which in a steam engine conduces to greater economy and efficiency, is, in the case of compressed air, the one item which reduces the efficiency.

The following Table¹ gives the result of experiments made some years ago by Messrs. J. Fowler and Co., of Leeds, who have had considerable experience with air-compressors.

GROSS EFFICIENCY OF COMPRESSED AIR IN THE TRANSMISSION OF POWER.

Air-pressure. Lbs.	Efficiency = $\frac{\text{Brake HP. of Motor.}}{\text{I. HP. of Compressing Engine.}}$
	Per Cent.
40·0	25·8
34·0	27·1
28·5	28·5
24·0	34·9
19·0	45·8

The above results are borne out by the experiments made more recently by Professor A. B. W. Kennedy, F.R.S., M. Inst. C.E., on the transmission of power by compressed air in Paris on the system introduced by Mr. Popp.² These experiments show that the brake HP. of the motor (10 HP.) is 31 per cent. of that of the engine driving the air-compressor if the air is not heated before it is used in the motor. If the air is heated and expanded before passing into the motor this efficiency is increased to 45 per cent. In mining work it is generally difficult to do this, and consequently engineers are content if they can obtain the lower result.

The great advantage of heating and expanding the air before passing it into the cylinder was so far realized by Mr. Frederick Hurd, in 1872, that he devised an arrangement for placing a heating apparatus inside the valve-chest, in which the oxygen for the combustion of the fuel (a mixture of coke and scrap-iron) was supplied by the air working the motor. By this means the possibility of exploding fire-damp is completely overcome, and the formation of ice is avoided.

¹ "On Compressed-Air Machinery for Underground Haulage." By Mr. William Daniel. Proceedings of the Institution of Mechanical Engineers, 1874, p. 210.

² See Report of the British Association, 1890.

In practice 40 lbs. or 50 lbs. is about the pressure now adopted for working compressed-air machinery, although in the case of rock-drills, where lightness, portability of the machines, and smallness of the connecting hose, are of greater importance than efficiency, 70 to 90 lbs. per square inch is frequently used. The final result, however, of experiments at these pressures, agrees with that already given, namely, that it is impossible with compressed-air to transmit to the distant motor more than from 20 to 30 per cent. of the power expended in the engines, and probably, taking due account of the friction and loss in the piping, which, however, is not often excessive, the average efficiency of compressed-air as applied to mining work would be below 20 per cent. In the case of electrical transmission of energy, except when distributed into very small units, there is little difficulty in obtaining 50 per cent. of the power expended in the engine, and there are cases in which no less than 75 per cent. is transmitted without any extraordinary precautions being adopted.

These figures are frequently contradicted by the advocates of compressed-air, but after the precise particulars which have been published of experiments with electricity, and in view of the scanty information obtainable as to actual trials of compressed-air, the onus lies with its advocates to show that the results which can be obtained in regular working by this method exceed those already given. In addition to this lower efficiency, which means not only a greater expenditure of coal but also a large increase in the dimensions of the engine, and consequently in the price of the generating-plant, there is the cost of laying and maintaining the connecting-pipes. To make the matter clearer, a simple case has been chosen, and Table II, Appendix, prepared, showing the comparative economy of these two methods of transmitting power.

It must be borne in mind that the size of the cable plays a large part in determining the efficiency of the electric transmission of power. In the case of steam, compressed-air or hydraulic transmission, the losses in the pipes are frequently neglected, as they are usually small. This cannot be done with electrical plant, first, because the cost of the copper conductors forms a considerable item in the whole, and it is therefore desirable to have them as small as possible under the particular circumstances of each case, and secondly, because, unless the cables are proportioned to the power to be transmitted, they may become heated and damaged by the current passing through them.

In dealing with dip-draining pumps the Authors have given a Table showing the loss of power in the cable in two particular cases, with small machines, but they think that a similar Table dealing with large machinery and varying sizes of cable may be of interest. They have, therefore, in Table I, Appendix, given the losses in each part of an electrical pumping system, first, with a pump delivering 350 gallons per minute against a vertical lift of 900 feet and a pipe line 1,800 yards long of 6-inch pipes, and secondly, with a similar pump delivering 200 gallons per minute to a height of 480 feet through the same pipe line. It will be seen that an efficiency of 67 per cent. can be readily obtained even when transmitting nearly 100 HP. to a distance of more than 2 miles, and without any attempt being made to get specially good results, the whole plant being such as can be worked by unskilled men.

The results given, are, it is true, now recognized to a large extent as being, in the abstract, correct statements of the facts; but in the minds of the owners and managers of collieries and mines, there still exists a doubt as to when they are justified in adopting the use of electricity. One of the most important points which has been raised in this connection, and which was brought very strongly to the front in the discussion on a Paper by Mr. Blake Walker,¹ read at a meeting of the Midland Institute of Mining Engineers, is the question "of the safety, or otherwise, of an electric motor in a coal-mine, in view of the fact of the explosive nature of the gases existing in some parts of most mines."

The problem resolves itself into two parts—First: Will a motor, working under ordinary and satisfactory conditions, be likely to cause an explosion, assuming that it is placed in the positions where motive power is usually required in mines? Secondly: Is it possible under what may be termed extraordinary, but perfectly realizable conditions, to produce an explosion under similar circumstances?

A variety of opinions on the subject have been given, and some experiments have been tried bearing upon it, and the Authors consider that the following may be taken to be a correct summary of the results obtained.

In the case of an ordinary motor working up to, say, 500 volts, having the brushes properly adjusted upon the commutator,

¹ Transactions of the Midland Institute of Mining Engineers, vol. xi. p. 317. "Electricity as a Motive Power," with special reference to its application to mine-locomotives, December 1889.

no sparking can be perceived, but if from wear of the contacts during long runs, or variation in the load, slight sparking should occur, it is produced in contact with large masses of a highly conducting metal (copper), with the result, that the rise of temperature is not sufficient to fire explosive mixtures of coal-gas and air, or ordinary marsh-gas and air. The temperatures required to explode these gases at ordinary pressures may be taken to be, for a mixture of 1 volume of coal-gas, with 5 volumes of air, or for a mixture of 1 volume of marsh-gas with 9·4 volumes of air, from 900° to 1,100° Centigrade.

Copper combines with oxygen in air so as to produce oxide of copper at about 700° Centigrade, and as under normal conditions the formation of this oxide is not observed, either on the collector or on the point of the brush, this fact may be taken as further evidence that the temperature there existing is not sufficient to fire an inflammable mixture of gases. It may be said then, that under normal conditions, an electric motor is not a dangerous machine to use even in an atmosphere charged with considerable quantities of explosive gases; but having shown this, it may be admitted that supposing a brush, for example, is worn so far that it ceases to be in contact with the commutator, or supposing it to become seriously displaced from its proper position, an amount of sparking may ensue, which will cause a temperature sufficiently high to oxidize the copper of the brushes, and farther, to ignite inflammable mixtures. The question then arises, how is it possible to obviate the danger which may arise from this cause?

The Authors, having devoted considerable attention to this matter, have adopted the methods illustrated in Figs. 1, 2, 3, 8, &c., as a means of excluding from the armature the atmosphere in which the machine is working. It should be taken as an axiom that the machine will not normally be placed to work in an explosive mixture; but that what has to be guarded against is, in the case of a motor which perhaps is not attended to for some hours at a stretch, the accumulation of such gases in its neighbourhood during this time. Moreover, where a motor is in use at the coal-face or in a heading, means should be adopted to allow the machine to be stopped if, in the working of the coal, or from the fall of a roof or other reason, an inrush of fire-damp should take place, before this explosive gas has had time to come in contact with the commutator and brushes.

To effect this purpose, the Authors have adopted the practice of enclosing, either the whole armature together with the commutator and brushes, or when this is inconvenient, the commutator

and brushes only, in a casing which is air-tight, or practically so. It has been objected to this plan, that although it may be feasible in the case of small motors, it is impracticable with machines of any size, owing to the diminished ventilation of the armature and commutator. The Authors have, however, adopted the method with success for a motor which has developed up to between 40 and 45 HP., and with no greater difficulty than in the case of one as small as 1 HP. In the winding of field-magnets, it is now recognized that any desired temperature of working may be obtained by allowing well-defined amounts of external cooling-surface for the dissipation of the heat developed. This proportion, for a final temperature of 70° F. above the atmosphere, may be taken as 2·3 square inches per watt to be dissipated.

The armatures of ordinary dynamos and motors are constructed to revolve in contact with the air, and the continual cooling thus obtained allows the surface for each watt to be dissipated for the same rise of temperature, to be diminished to about 0·7 square inch. In the case of the Authors' mining motors, it is only necessary to revert to the basis adopted for the field-magnets, that is to say, to allow a cooling-surface on the exterior of the armature-casing of the proportions which would be adopted for a stationary magnet-coil, in order to obtain the same result as to temperature. The armature revolving inside quickly brings the contained air to the same temperature, and this, being in rapid movement, conveys the heat to the external casing, from the surface of which it is dissipated by radiation and convection. It is true that to obtain a proper proportion between the cooling-surface and the heat generated, it has been necessary to be careful as to the magnetic and electrical design of the armature, but with these precautions, the Authors have found that the temperature of the armature of these enclosed motors at the end of a long run does not exceed that of the field-magnets.

Having thus disposed of the objection which has been raised by electrical engineers to this method, it remains to consider the question from the point of view of the mining engineer. The argument of the mining engineer is that if these casings should become filled with an explosive mixture and ignited, the result would be as disastrous as if they did not exist. The answer to this objection is as follows:—Seeing that under certain sections of the Coal Mines Regulation Act it is not allowable to work where the proportion of explosive gas exceeds about 1 in 30, it is not likely that any electric motor will be

placed in such a position as to be run continuously in an explosive atmosphere for a longer period, at the outside, than two or three hours. The casings with which they are provided are tightly fitted at all the joints, many of them being packed with rubber, and it is not likely that an inflammable mixture could penetrate to a dangerous degree within that time. Should there, however, be any leakage into the covers, as soon as the proportion of marsh-gas in the air reaches 3 or 4 per cent., combustion will take place quietly, producing carbonic-acid gas, which will tend to prevent explosion.

If, however, it is required to work for long periods in such an atmosphere, the Authors would provide means for the introduction into the armature of an inexplusive mixture. The simplest method of producing this result would be to attach to the motor a steel cylinder containing carbon dioxide under pressure, and to connect this with the armature-casing by a pipe which should allow a slow but constant stream of this gas to reach the interior of the casing. The efficacy of this method may be judged when it is pointed out that the presence of 14 per cent. of carbonic acid gas in the most explosive mixtures of fire-damp renders them absolutely unflammable. The Authors consider that this method of protecting the armature and commutator, and preventing the ingress of an explosive mixture, is generally more satisfactory than that of enclosing the commutator and brushes only as mentioned before. Conditions may, however, arise which render this latter method desirable. In that case the point to be aimed at is to produce a cover which shall give a similar protection to that afforded by a safety-lamp, and allow the ingress of the explosive atmosphere, but prevent the egress of flame. In order to do this it is necessary that the volume of the enclosed gases should be small, and that the passages through which the flame can escape should be of sufficient length, and the metal surfaces close enough together to cool it below the point of combustion. If the commutator were enclosed by a cylindrical case or otherwise, so that the volume of gas was small to begin with, yet as it wore away the space would increase to an undesirable extent. The Authors have therefore designed methods by which it can be contracted and the volume of gas kept constant. But the brushes are not the only part which should be protected, for if a wire on the armature should break, or the insulation give way, or if anything should get between the armature and the pole-pieces, sparking might occur, and such a contingency should be provided for.

There now remains the question of the switches connected with the motor, which will, of course, develop a spark on opening the circuit, when the current is flowing. This, in the opinion of the Authors, is a more serious difficulty than the former one, and they have endeavoured to meet it in two ways, namely, by diminishing, as far as possible, the tendency to sparking, and by arranging a switch which, even in the event of a spark, would be safe under any conditions likely to occur. The first idea that occurs is that by using a shunt-wound dynamo as a generator and a shunt-wound motor, the self-induction in the circuit is so far diminished that little sparking is likely to occur. But for many purposes, the conveniences arising from using a series-wound motor, as will presently be pointed out, are such that this method is in general to be abandoned, although the principle underlying it may be adopted. The reason of the diminished sparking with the shunt-wound dynamos and motors is, that the self-induction of the cable circuit is insignificant, and that of the armatures is also small, whilst the circuits of the magnetizing coils in both dynamo and motor, which have large coefficients of self-induction, are always closed through the armature. Thus, although on breaking the circuit the current in the magnet-coils tends to continue, it has a path of discharge through the armature of low resistance and of small self-induction. The Authors have therefore adopted the following plan: In the case of a series-wound dynamo they have provided a resistance-coil of small self-induction, which is always connected to the ends of the magnetizing coil, so as to form a path through which a current in the latter may continue, even when the main circuit is broken. In the same way, they have arranged the switch in such a manner that before breaking the circuit the coil of the magnets is short-circuited. By this means, the act of breaking the circuit reproduces the conditions which exist in the case of a shunt-wound generator and shunt-wound motor, and the only sparking which results is that due to the self-induction of the line and armatures. In order further to diminish this, the switch itself has, on its lower side, a resistance coil connected to the several points with which it makes contact, the wire being large enough to carry the current for the short time during which the switch is passing over them. By this means, even when the generator is short-circuited, the current is so far diminished that if the switch be moved slowly over the contacts, it is less than what has been termed the critical magnetizing current of the dynamo. The result is that by the time the circuit is open the series-wound dynamo has practically ceased to excite itself, the

electromotive force and current are very small, and the sparking practically nil.

As an additional safeguard, the switch itself is constructed in the form of an air-tight box, which, in the same manner as the commutator covering, will exclude an explosive mixture for many hours. Although the Authors have never tried the experiment, they have reason to believe that the amount of gas which could be possibly contained in the switch is not sufficient, should it ignite, to blow the cover off; while the surface of contact between the cover of the base and the cylindrical hole, through which the handle passes, are sufficiently long to cool the escaping gas below the temperature of ignition. This switch is illustrated in Fig. 19. These precautions, which have been carried out successfully in practice, are, in their opinion, amply sufficient to meet all objections on the point of safety in connection with the application of electric motors to mining work.

Having so far dealt with the general question of the applicability of electrical power for mining machinery, and having indicated the methods adopted by the Authors in their designs, it is proposed now to illustrate the application of these principles by some actual examples. Full descriptions have been already given of the application of electric power to mining work under conditions analogous to those existing in ordinary power transmission installations above ground; for instance, Mr. A. Snell, Assoc. M. Inst. C.E., has elaborately described a large pumping plant working at Normanton,¹ and, in a paper previously mentioned, by Mr. G. Blake Walker,² the application to locomotive work of accumulators has been fully discussed. The Authors, therefore, propose to confine their attention to two or three illustrations of the use of electrical power, both in fixed plant and in machinery which is constantly moving from place to place whilst at work. For this purpose they have selected some dip-draining pumps, which are portable but are fixed whilst working; and they propose also to describe electrical coal-cutting machinery, electric coal-borers and electric rock-drills, as examples of constantly moving plant.

The earliest example of the application of electricity in mining work was its adoption by Mr. W. B. Brain, for draining a certain part of the Trafalgar colliery in the Forest of Dean.³ An ordi-

¹ National Association of Colliery Managers, September 28, 1889.

² Transactions of the Midland Institute of Mining Engineers, vol. xi. p. 317.

³ Proceedings of the South Wales Institute of Engineers, vol. 13, p. 277.

nary horizontal pump was driven by a belt from the motor, which was fixed upon a permanent bedplate. The arrangement has worked well, and given satisfaction; but, in the opinion of the Authors, the use of belts in coal-mining work, unless under very exceptional conditions, is entirely out of the question, owing to want of space and the difficulty of keeping them in good working condition in dirty and wet situations.

In Figs. 1, 11, and 12, Plates 4 and 5, are illustrated two dip-draining pumps, a horizontal and a vertical form, designed by the Authors, and constructed by Messrs. W. T. Goolden and Co. In each case three-throw ram-pumps are used, the reason being that it is important in using electric motors that the load should be as regular as possible throughout the revolution. The pumps are mounted upon a bed-plate, which is extended to carry the motor. The motion is communicated from the motor-shaft to the pump-shaft by gearing. This method of reducing the speed is perhaps more noisy than the use of belts, but in practical working this is not of much importance; and, provided that the armature is properly constructed for the purpose, ample strength being given, and proper materials being used to avoid the result of the jar or shock, gearing may be confidently recommended. It requires no adjustment, and is so compact that the whole machine is self-contained, whilst, when the pinion on the motor, which is subjected to the greatest wear, is worn out, it can be replaced in a few minutes at a trifling cost.

Table III, Appendix, gives the data of one pump of each of these patterns, and shows the relative efficiency of the various parts, together with the size of rams. The gross efficiency is not very high, owing largely to the power used being small. But it was specially intended to produce a durable machine, suited for the rough conditions under which it was likely to be worked, and adapted also to be handled by persons who have not the necessary knowledge to keep any delicate mechanism in adjustment. These considerations necessitated the adoption of a large clearance for the armature, ample space for insulation, &c., all of which tended to diminish the efficiency. The motors, it will be observed, are of the Authors' enclosed type, the field-magnet coils being lagged with steel to prevent mechanical damage. These machines have, in some cases, run for many weeks, day and night together, with no attention beyond an occasional feeding up of the brushes and lubrication. This form of pump is well adapted for mines where the electric light is already installed, and in this connection attention may be drawn to a point which is

worthy of note. In the use of electricity for motive power and for lighting, it has often been objected that the variations in the load upon the motor cause a considerable alteration in the lights upon the same main at some distance from the dynamo. The remedy for this is simple. By employing a well-governed engine, and compound-wound dynamo, the electrical pressure at the terminals of the generator may be kept constant; if then, a separate pair of mains is run for the motors, the pressure on the wires feeding the lamps is constant, whilst any variation at the terminals of the motor is not a matter of importance. These electrical pumps appear to meet every requirement of practical mining work, and have replaced steam and hydraulic pumps with considerable advantage.

Turning to the application of electricity to movable machinery, the Authors have for the last four years been constantly engaged in the design of electrical coal-cutting plant, and the results of the work done in this direction will now for the first time be published.

Although this use of electric power has only recently become an accomplished fact, it is interesting to note that the idea presented itself to Mr. Henry Wilde, F.R.S., of Manchester, one of the earliest pioneers in the development of the dynamo machine, as long ago as 1873, when he described the application of electric power to coal-cutting machines of various forms, in a provisional patent taken out by him in that year.

It was in 1887, so far as the Authors know, that the first machine was built for the purpose of cutting coal by electricity. It had a cutter of the bar type revolving on its own axis, a form which it appears was first introduced by Mr. Grafton Jones, and was driven by a motor designed for the purpose, and made by Messrs. W. T. Goolden and Co. (Fig. 6). The original experiments were conducted at the collieries of Messrs. T. and R. W. Bowers, and the conception of thus employing electricity is due to Mr. F. Mori, Electrician, of Leeds, and Mr. J. Blackburn, manager to Messrs. Bowers. Considerable difficulties were, as was natural, found in adapting power to conditions so novel, and so outside all ordinary experience; and, in order to obtain full information as to the obstacles to be overcome, the Authors devoted a good deal of time to practically working at the coal-face the various machines that have been constructed. These difficulties have been twofold: namely, electrical and mechanical. Fig. 6, Plate 4, shows one view of the original machine designed by Mr. J. Blackburn, containing the motor arranged to fit it. This was a three-coil

vertical motor, adapted to work in a horizontal position, one of the side coils being removed. It was of 6 HP., and was driven by a dynamo having a normal output of 10 HP., the motive power being the engine of a hauling-machine, situated at the bottom of the shaft. The distance between the dynamo and the motor was about a mile.

The original dynamo and original motor were both compound-wound, the series-coils on the motor consisting of sufficient turns of thick wire to nearly saturate the magnets with the large current developed on first closing the switch; but when running at a normal load this series-coil had little influence on the magnetization, which was then affected by the shunt-windings; so that the regulation as to speed was almost as good as if the winding had been simply shunt. This arrangement is convenient as giving a good starting power, and at the same time ensuring satisfactory speed regulation; but in the case of coal-cutting machines the Authors have a decided preference for a series-wound dynamo and series-wound motor, for reasons previously described, namely, that when the motor is being stopped, by the insertion of a proper resistance, the electromotive force may be reduced nearly to zero before breaking the circuit; and further, if it is desired to handle the cables or to disconnect them, or to handle any part of the circuit of the machine after it is stopped, there is no liability to a shock should the insulation at any other point be defective. This is of great importance in a motor intended to be used by inexperienced miners, who are easily frightened, even by a moderate shock, so that they neglect to adjust the brushes, &c., even if they are not so far afraid that they will not work the machine at all. This first plant, which is still working satisfactorily, was, it will be noted, practically unprotected from dirt, dust, or explosive gases, and it was in connection with this that the Authors first devised their system of enclosed motors.

The next machine built by Messrs. Goolden is shown in Fig. 15, Plate 5, and in that case, as it was desired to cut into the coal at a height which was suitable for using direct driving without the intervention of gearing, the armature-shaft itself was made to carry the cutter-bar. The opinion, however, which the Authors now hold is, that although this method of working is quite feasible, it is on the ground of expediency not desirable. It is difficult to construct armatures with shafts large enough to carry the strain put upon them by a cutter-bar of the description used without cramping the space for wire and insulation.

Figs. 10, 13, 14, and 16, Plate 5, show still later developments of this class of machinery, in which the cutter-bars are mounted on a separate shaft, and driven by steel double helical gear-wheels. The point to be noted is the combination of the electrical structure with the more strictly mechanical framework, thus providing the greatest amount of strength and electrical power with minimum weight and size. The dimensions of the heading along the coal-face are generally so small that it is only by great compactness that the use of these coal-cutting machines is rendered possible.

Fig. 9, Plate 4, shows in plan the general method of working. The machine, mounted on its wheels standing on the rails laid along the face, is adjusted by means of the turn-table and worm-gear, so that the cutter-bar points along the heading; the current is switched on, and the bar, revolving rapidly on its axis, is turned through an angle of 90° so as to enter the coal. The worm-gear and table being then locked, the machine is drawn along, by means of a winch and wire-rope, cutting its way as it goes. Automatic methods of winding have been devised, but that of pulling in by hand is probably the simplest in the end, and has the advantage of enabling the man at the winch to tell whether the machine is cutting in hard or soft material, and accommodate the rate of movement accordingly. Automatic winding-gear is usually arranged to work at a fixed speed, which must necessarily be that at which the machine will cut in the hardest material to be dealt with, so that with softer material the progress is obviously less than it need be.

The Authors have suggested an automatic winding-gear intended to obviate this objection. It consists of a ratchet-and-pawl motion, the pawl being under the control of an electro-magnet. Since the load on the motor is accurately measured by the current flowing through it, the magnet can be so adjusted, that if the load should exceed the desired limit, the pawl would be lifted out of gear, and the feeding stopped until the machine had eased itself again to its normal load, when the pawl would commence to feed it forward.

All the motors used for these coal-cutting machines are entirely enclosed as to every working part. The field magnets are lagged in steel coverings, the switches with their resistance frames are placed in iron boxes, and from the outside it would be difficult to see that the machine was an electric motor. Furthermore, precautions have been taken to thoroughly enclose the gearing, and all bearings and their parts into which grit can obtain access, and the system of lubrication is such that the oil

passes from the armature-shaft to the cutter-shaft and thence is drained into the gear-box, which has an oil-tight joint, so that the gear eventually revolves in oil.

Fig. 16, Plate 5, shows a particular arrangement of machine, which was required to cut at any height from 9 inches to 33 inches from the road-level. This was effected by bolting to one of the pole-pieces a casting with two segmental slots. The cutter-bar was carried in a support moving on these slots, and by these means could be raised and lowered to any height, remaining at the same time in fixed relation to the armature-shaft from which it is geared.

It is interesting to point out to electrical engineers how the somewhat difficult problem of arranging this machine, so as to avoid the magnetic short-circuiting of the poles, has been met. The leakage from such extended pole-pieces is considerable, but not nearly so excessive as might at first sight be thought.

Several forms of armature have been tried in these machines, with both "drum" and "Gramme" windings, and the Authors are of opinion that on the whole, the "Gramme" armatures are best adapted for the work; the reason being that it is very difficult to secure the wire across the ends of a drum-winding in such a manner as to ensure their being positively driven, and in the absence of such positive driving it seems only to be a question of time when the insulation will become abraded by the excessive vibration. One form which has been much used in these machines is shown in Fig. 10. The armature-core is deeply notched to receive the coils, and when these have been wound in place the whole is covered with a layer of annealed charcoal-iron wire. By this means a notched armature, giving a low magnetic resistance in the air-space, is obtained, whilst the production of eddy-currents and consequent heating of the polar horns is avoided, and the armature is of a form which can be handled and laid on the ground, if necessary, without any damage occurring to the wire or its surface.

It soon became evident that the ordinary brushes used on dynamos and fixed motors were useless, owing to the excessive vibration to which the machines were subjected, whilst various forms having butt-contacts, in which the brush was pushed forward by springs, gave rise, both with metallic and with carbon blocks, to excessive heating, due, as far as can be ascertained, partly to the friction on the commutator, and partly to the inferior electrical contact thus obtained.

Brushes of a type which has been successfully used in launch and tramway work, and was originally designed by Mr. Holroyd Smith, composed of blocks of metal carried by light steel fingers or springs, were also tried with similar results, and finally the Authors have adopted various forms in which the necessary elasticity is given either in the brush itself, or in a light steel back, there being however no movable hinge or knuckle which would allow it to chatter as a whole on the commutator.

The chief mechanical problem in connection with these coal-cutting machines has been : First :—What is the best form of gear to use ? and Secondly :—What is the best form to give to the cutter-bars and cutters ? As to the gear, the Authors have tried chains of every description and strength, and have had to abandon them all ; they have also tried phosphor bronze gearing of ordinary forms, but have finally adopted, as working more smoothly and with less noise, and giving a maximum of strength, cast steel double helical wheels, shrouded nearly to the pitch line. By mounting one of such a pair of wheels in a manner free to slide to a small degree upon its shaft, the perfect alignment of the wheels is secured and the running leaves little to be desired.

Although the several machines illustrated in this Paper have been made to cut above the floor-level, at heights specially suited to each particular case, so as to work in the bands of shale or dirt and thus save the coal, yet the form with a bar-cutter is eminently suitable for cutting at the level of the floor itself, and the Authors have designed machines for this purpose, the rails being laid directly on the surface thus formed. The form of cutter most usually adopted in such cases is that of a large disk or wheel with the tools fixed into its periphery. This disk is carried on a bracket projecting from the side of the machine, and is caused to revolve by a pinion gearing into teeth either cut in its horizontal surface, or into teeth formed on its periphery, the teeth of the pinion being then made sufficiently long to allow the tools to cut clear at the bottom. The tools are spread out so as to cut the material clear of the disk.

Machines on this principle have been used with considerable success in several places, but the Authors consider the bar cutter is to be preferred for several reasons.

First, there is a considerable amount of difficulty in making a machine with a disk cutter to turn round so as to cut its own way under the coal, and in fact in most cases this is done by hand.

Secondly, when the tools are blunt, they have to be taken out and replaced by sharp ones while the disk remains in the coal,

a matter of some difficulty in the confined space and with the small amount of light available. With a bar-cutter, on the other hand, since the bar is only held by four bolts at the coupling, it is turned out of the coal and a fresh one with a complete set of new cutters substituted, the other being sent to the bank to be reground.

Thirdly, if the coal or roof is at all tender there is a great tendency for it to fall as soon as it is undercut; to avoid this, wedges are inserted in the groove to keep it up, but the distance from the front of the cut to the back of the disk is considerable, and as a consequence the coal often falls before it can be wedged; this of course jams the cutter, which then has to be dug free, involving a loss of time. Now with a bar-cutter the wedges can be inserted close behind the bar, only a few inches from the front of the cut, and the coal supported, so that even if it falls it cannot jamb the cutter.

Fourthly, a bar cutter can be made to bare to a greater depth, as much, for instance, as 5 feet.

Fifthly, in order to make an electric motor of sufficient power while the weight is kept small, it is necessary to run it at a fairly high speed, and therefore, to keep the gearing compact, the cutter must also run at a high speed. This is easily attained without any disadvantage with a bar-cutter, but is quite impossible with a disk-cutter, where the speed of the tools would be so great as to seriously heat and soften them. In practice the Authors run the motors at about 700 revolutions per minute, while the cutter makes about 500 revolutions per minute. On the other hand, the disk-cutters will draw more of the fine coal out of the groove than the bars will, but this advantage is not sufficient, in the Authors' opinion, to compensate for the disadvantages enumerated above.

The cutter (Fig. 17, Plate 5) consists of a long bar, either taper or parallel, fitted with a coupling to unite it to the shaft of the machine, and having arranged on it a series of steel tools. The bar, revolving on its axis, acts like a long milling tool, each set of cutters sawing its way through the material. The form used in the coal-cutting machine known as the "Economic" was a parallel bar, having holes in it, into which were fitted steel nibs secured in place by set screws. Some years ago Mr. Grafton Jones suggested the threading of star-shaped disks on to a square or polygonal bar, with a nut at the end to hold them in place. The cutter used by Messrs. Bowers in the first machine tried at their colliery, Fig. 18, Plate 4, was upon this principle. A series of

star-shaped cutters made of cast steel having an hexagonal hole in the centre, were threaded on to a steel shaft, and secured by a nut at the end, the nut having cutters screwed into it, so as to clear itself. The result was satisfactory except so far as the wear of the points was concerned. In fairly soft or friable coal, it is doubtful whether they can be much improved; but in coal which contains much dross or is hard, the cutters are soon blunted, and the power required to drive the machine becomes excessive. After some experiments, in conjunction with Mr. Hans Renold, of Manchester, the form shown in Fig. 17, Plate 5, was devised.

The object in view was to provide a bar which would admit of cutters being used of a much higher grade of steel than was possible with the star-shaped castings previously mentioned: which should have more metal for removing heat from the point of the tool, thus preventing its softening and wear: and which should take, if possible, less power, and at the same time give a more steady cutting action, and remove the debris which it formed. To effect this, the bar is drilled with a series of holes, each of which is placed in a direction nearly at 90° to the next adjacent one, but differing so far from a right angle that one complete turn is made in the length of the bar; by arranging the cutter in this manner, a left-handed spiral is produced having a pitch equal to the length of the bar, which serves to equalize the cutting action, and also a right-handed spiral, which has a pitch equal to about $\frac{1}{2}$ of the length of the bar, and forms as it were a corkscrew to draw the dirt out of the cut. These holes are tapered to about 1 in 30, and pieces of round steel are turned to fit them, the heads being shaped to form the cutter, the exact nature of which depends on the material to be cut.

The proper form to give these tools is a question to which considerable attention has been devoted. Square-shaped, flat-faced tools were tried, of such a width as to overlap one another and remove the whole of the material; it was found, however, that the power required was excessive. Both square and pointed tools of various widths were then tried, with the result that the form indicated in Fig. 17 has been found to be, on an average, the best. This cutter is of a V-shape, and is placed in the bar with a gauge, so that the surface farthest in the coal is set in such a direction as to clear itself. The edge nearest the machine slopes across the cut, so that when the tool has entered to a depth of about $\frac{1}{4}$ to $\frac{1}{2}$ inch, a wedging action commences, and the ridge of coal left between two succeeding cutters is split off. By this means only about a quarter of the total quantity removed is

actually cut away, the remainder being broken off by a splitting action, and the power required for working the machine has been reduced to one-quarter of what it was. Various speeds for operating the bar have been tried, but for fairly hard coal from 400 to 500 revolutions per minute is enough, although in soft and friable coals a higher speed may be adopted. The diameter over the points of the cutters varies from about 5 inches at the front of the cut to about 3 inches at the back. The tools when blunt are driven out with a hammer, and ground on an ordinary stone in a tool-holder, in which they are set in a taper hole, the holder being mounted eccentrically, so that in grinding the proper backing is given. These cutters are made of an exceedingly high quality of steel, which is tempered dead hard, so that it will easily scratch glass.

The average length that can be cut without changing the bar may be taken in hard coal to be about 40 yards, though as much as 80 yards, in hard gritty coal, has been effected without any stoppage. The blunting of the tools, however, when the edge is once really gone, proceeds rapidly, and out of proportion of the work done, and it is bad economy to force the amount cut to too great an extent. One man or boy attends to the winch, one man follows the machine, spragging and putting up props, whilst a third devotes his attention to the cutter itself, and to clearing the road in front of it.

The amount cut by the machine varies according to the nature of the seam, and the experience of the men working it; but it may be taken that on the average, all stoppages being included, 20 to 30 square yards per hour may be cut in fairly hard coal. As a matter of actual maximum performances, the following results may be cited. At Lord St. Oswald's colliery at Nostell, 55 yards were bared to an average depth of 3 feet 8 inches in seventy-five minutes, and lengths up to 20 yards, where the road is clear for running without stopping, have been often cut to this depth at the rate of a yard a minute. And at Messrs. T. and R. W. Bowers' collieries, where a less powerful motor is used, 110 yards have frequently been bared to a depth of 3 feet 6 inches in four hours. The length of cutter-bar usually adopted is from 3 feet 6 inches to 3 feet 9 inches, but it is a matter of interest that in a trial at Messrs. Briggs & Co.'s collieries at Normanton, a bar of 5 feet in length was used, cutting underneath to that depth, an amount exceeding considerably the best performance of any previous machine.

The actual HP. developed by the motor has varied in different

cases from 6 HP. to nearly 15 HP., but in the Authors' opinion, it is a mistake to reduce too far the power available, and 10 or 12 HP. would seem to be a fair average amount for working rapidly and effectively, with a reserve enabling obstacles to be overcome, without straining the machinery.

Table IV., Appendix, gives the relative cost of cutting by machine and hand-labour in certain cases; but, although trials have extended over some time, it is perhaps too early to speak of what will be the ultimate saving effected by the use of these machines. Great difficulties have had to be overcome, apart from the electrical and mechanical problems, in the prejudice of the men, and in the resistance which they offer to the introduction of labour-saving machinery; and this has reached such a pitch in some cases that the miners have actually declined to work the machines, or to remove the coal which has been cut by them. These obstacles will disappear in time, but at present they form an element which has to be considered in estimating the cost of coal-cutting by electric power.

ELECTRIC BORING- AND ROCK-DRILLING MACHINERY.

An early example of the use of electricity in mining was the employment of the electric motor for working rock-drilling plant. This part of the subject has, although apparently simple, proved to be one of the most difficult to deal with; the reasons of this being—first, that the amount of power required is small, and, therefore, the advantage gained by electricity not so noticeable; secondly, that very powerful and complete drills, particularly percussive drills, are in the market; and, thirdly, that the use of machine-drills is generally resorted to in cases where the necessity for at once carrying out the work is very pressing, so that the contractors are less willing to try any experimental plant.

Drilling-machines may be divided into two classes: (1), rotary, and (2), percussive. Fig. 7, Plate 4, illustrates a form of rotary drill, complete with its own electric motor, and mounted upon trolley-wheels, applicable for use for coal or ironstone boring. The motor, the framework of which is made in one with the bed, is a small $\frac{3}{4}$ -HP. enclosed mining-motor, of the Authors' design. The revolving drill-bar has a thread cut along its length working through a nut which is free to revolve except in so far as it is held by an adjustable brake-band. The result of this is that if the brake be slack no feed is imparted to the drill; if the brake be

tightened, so as to prevent the nut revolving, a feed of $\frac{3}{16}$ of an inch per revolution, or any intermediate amount, may be given.

The power is taken from the motor-shaft by bevelled gear, giving a reduction in speed of $1\frac{1}{2}$ to 1; it is then transmitted by the vertical shaft and through a worm-gear to another pair of bevels. The total reduction in speed is from 1,600 revolutions per minute to 50 revolutions on the drill-spindle. This drill will bore a hole 2 inches in diameter in hard coal at a speed of 12 inches per minute.

It will drill in slate at the rate of about 3 inches per minute, but the principal difficulty in dealing with material as hard as slate is to procure a sufficiently satisfactory fixing to the roof and sides to prevent the whole drill from shifting and getting a cross strain upon it. It is therefore principally recommended to be used for coal or ironstone, where rapid sinking through moderately hard material is required. The drill takes about 10 amperes of current, at a pressure of 110 volts. Some experiments made to determine the power actually developed, through all the gearing and on the drill-shaft, show that the ratio $\frac{\text{mechanical power on drill-shaft}}{\text{electrical power}}$ is about 40 per cent.

For dealing with harder rock, diamond-drills, working in a similar form of machine, may be used, but the cost of maintaining diamond-drills is so heavy that in general little economy is effected by their use. Percussive rock-drills, therefore, are generally used for this purpose. The use of percussive rock-drills driven by electricity has, so far, been limited, one of the principal difficulties being the construction of a really suitable percussive action, driven by a rotary motion. Fig. 8, Plate 4, indicates the arrangement devised by the Authors for driving an Ingersoll rock-drill, by means of an electric motor. In order to diminish the weight of the drill, it is separate from the motor, which is mounted on a trolley, the connection between the two being made by a length of about 8 feet of flexible shafting.

The drill itself is well known. It consists of a bar lifted by a crank motion, connected to the driving handle by a ratchet and pawl, in such a manner that after the drill has been lifted by the connecting-rods against the pressure of a spring, as soon as the dead point on the top centre is passed, the spring forces the drill forwards, over-shooting the driving handle, which gears again as soon as the blow is expended. Two blows, or nearly so, are therefore given for each turn of the handle, which is designed to make sixty revolutions per minute.

The driving-wheel is geared into a bevel pinion which is carried by an adjustable frame or quadrant and driven direct by the flexible shaft. The speed reduction is in the ratio of ten to one.

The motor, which is of the pattern previously described, and is entirely enclosed, is mounted on a trolley, and has a fibre pinion driving a gear wheel, which gives motion to the flexible shaft. The speeds are as follows:—Motor, 1,500, flexible shaft, 600, drill wheel, 60. This plant may be taken to represent the present position of electric percussive-drilling, but the Authors have been for some time engaged upon effecting the design of a new machine, doing away entirely with a separate motor, giving a direct percussive action and reducing the total weight to a considerable extent. The experiments upon this drill are not yet complete, and therefore, for the present, it will only be mentioned.

DYNAMO FOR TRANSMITTING POWER.

Figs. 4 and 5, Plate 4, show in section a class of dynamo well adapted for use in transmitting power for electric mining-work, with pressure up to 1,000 or 1,500 volts.

The bed is of cast-iron, and a block in the centre of it forms the connecting yoke of the magnets, which are of the "inverted" type, and stand upon it. The magnet cores are of rectangular section, and are made of wrought-iron. The pole-pieces are of cast-iron, or in some cases are forged in one with the magnet-bars. The armature, which by preference, is of the "Gramme" type of winding, is composed of a number of thin sheets of charcoal-iron, insulated from one another by paper, mounted upon a phosphor-bronze spider, which is notched into the plates, and firmly keyed upon a stout steel shaft. The magnet may be shunt- or compound-wound, but in the case of transmitting power from a dynamo to a single motor, is preferably series-wound. The commutator is composed either of phosphor-bronze or of hard-drawn copper, insulated with mica. The brush-holders are of a special type, enabling the brushes to be fed through the holder and adjusted by a feeding-screw at the back, thus doing away with the necessity of loosening any bolts or nuts. This is valuable in case of long runs extending over nights and days together, such as often occur in mining work.

Special point is made in these machines of the ample clearance given to the armature in the pole-piece gap; $\frac{3}{8}$ of an inch a side is usually adopted, thus allowing room for wear in the bearings,

and, for the expansions which inevitably take place, and obviating the annoyance and delays caused by the armature rotating against the pole-pieces. The shaft and bearings are of large dimensions, compared with ordinary dynamos, for similar reasons, and the precautions thus taken of providing ample margins, not only in the mechanical factors, but also in the electrical design, have contributed largely to the success and freedom from accident which has marked the working of these machines in mining experience. Several of them have been running for periods extending over two or three years, in the hands of persons quite unacquainted with electrical matters, without any breakdown or repairs being necessary, and with very small wear upon the commutators.

SUMMARY.

The instances described will be sufficient to show that:—

A. Electrical power is destined to become an important factor in mining mechanics, on account of—

1. The greater facility with which it can be used with machines which require to be moved from time to time as the work advances.
2. The great economy in first cost, and reduced cost of working owing to its efficiency being higher than that of compressed-air, or any other medium of power-transmission.
3. The smaller cost of maintaining the cables, as compared with piping, on shifting floors in roadways, etc.

B. That the methods described are sufficient to obviate all objections to the use of electric motors in coal-mining, either by excluding inflammable gases, or by constructions which allow of their safe combustion.

C. That the experiments, trials and practical work, extending over four years, show that—

1. Electrical pumps may be used with advantage and economy for mine-draining.
2. Electrical coal-cutters can replace hand-labour, with saving in cost, and increased production of coal.
3. Electrical drilling-machines are available in place of machines worked by hand or compressed-air.

While doubtless, on all these points, opinions may to some extent differ, and the particular methods adopted may be subjected to criticism, the Authors hope that the subject they have

brought forward will be found of interest to the members of the Institution.

The electrical details of many of the machines described are due to Mr. H. W. Ravenshaw, Assoc. M. Inst. C.E., who has used considerable skill in adapting them to meet the conditions required. The Authors also have to express their thanks to Messrs. W. T. Goolden & Co., for placing drawings and results of tests at their disposal, as also to Mr. R. Hancock for his kind assistance in connection with the preparation of the drawings illustrating this Paper, from which Plates 4 and 5 have been prepared.

APPENDIX.

TABLE I.

Size of Cable.	Brake HP. of Engines.	HP. Lost in Dynamo and Belting.	Per Cent. of Total HP.	HP. Given out by Dynamoe.	Volts at Dynamos.	Volts at Motors.	Distance in Yards, Dynamos-Motors.	HP. Lost in Cables.	Per Cent. of Total HP.	HP. Put into Motor.	HP. Lost in Motor.	Per Cent. of Total HP.	HP. Lost in Pipes.	Per Cent. of Total HP.	HP. Absorbed in Friction in Pump and Gearing.	Per Cent. of Total HP.	Useful Work done in Raising Water.	Per Cent. of Total HP.
2. 19/12	200	20.0	10	180.0	670	550	3,800	32.0	16.0	148	15	7.5	16	8.0	22	11.0	95.2	47.8
2. 19/14	224	23.0	10	201.0	750	550	3,800	53.0	23.5	148	15	6.7	16	7.1	22	9.7	95.2	42.7
2. 19/14	256	25.0	10	231.0	860	550	3,800	83.0	32.5	148	15	5.8	16	6.2	22	8.5	95.2	37.1
2. 19/14	192	19.0	10	173.0	644	550	1,800	25.2	13.1	148	15	7.8	16	8.0	22	11.0	95.2	49.6
2. 19/16	209	21.0	10	188.0	698	550	1,800	40.0	19.0	148	15	7.2	16	7.6	22	10.6	95.2	45.6
2. 19/17	216	22.0	10	196.0	730	550	1,800	45.0	22.0	148	15	6.8	16	7.4	22	10.2	95.2	44.0
1. 19/14	72	7.0	10	65.0	674	550	3,800	12.0	16.6	53	8	11.2	3	4.2	13	18.0	29.1	40.5
1. 19/16	88	8.3	10	74.6	774	550	3,800	21.6	25.8	53	8	9.6	3	3.6	13	15.5	29.1	35.0
1. 19/14	67	7.0	10	60.0	618	550	1,800	6.6	9.8	53	8	12.0	3	4.5	13	19.3	29.1	43.5
1. 19/16	70	7.0	10	63.2	656	550	1,800	10.2	14.6	53	8	11.5	3	4.3	13	18.5	29.1	41.6
1. 19/17	73	7.3	10	65.6	680	550	1,800	12.6	17.2	53	8	11.0	3	4.2	13	17.8	29.1	40.0

TABLE II.

System.	Brake HP. of Steam-Engine.	Brake HP. of Motor.	Distance from Engine to Motor in Yards.	Size of Cable or Pipe.	Price of Engine and Dynamo or Compressor.	Price of Cable or Pipe.	Price of Motor.	Total Cost of Plant, without Erection.	Efficiency.
Electric . . .	15.4	10	2,000	Ins. $\frac{1}{8}$	£ 210	£ 192	£ 95	£ 497	Per Cent. 65
Compressed air .	33.3	10	2,000	4	130	700	63	893	30

TABLE III.

Pattern of Pump.	HP. on Belt.	HP. at Terminals of Dynamo.	Volts at Dynamo.	Size of Cable.	Distance in Yards, Dynamo-Pump.	HP. Lost in Cables.	Per Cent. of Total HP.	HP. Lost in Motor.	Per Cent. of Total HP.
Vertical .	3.3	2.95	100	7/15	560	0.56	17.0	0.35	10.6
Horizontal	2.9	2.57	175	7/18	2,000	0.98	33.8	0.23	7.9

Pattern of Pump.	HP. Lost in Pump and Gearing.	Per Cent. of Total HP.	HP. Lost in Pipes.	Per Cent. of Total HP.	HP. in Water Delivered.	Per Cent. of Total HP.	Height Water is Forced.	Gallons per Minute.	Gross Efficiency Transmission.	Size of Rams.
Vertical .	0.6	18.2	0.165	5.0	1.260	38.4	170	24.3	43.4	Ins. 3
Horizontal	0.47	16.2	0.600	20.7	0.288	10.0	19	50.0	30.7	3½

TABLE IV.

RELATIVE COST OF CUTTING COAL BY MACHINE AND BY HAND-LABOUR.

Thickness of seam	3 feet.	
Cost of cutting, filling, &c., by hand		2s. 6d.
Saving of coal by machine	20 per cent.	
Tons bared per shift	160 tons.	
Labour, steam, cutters, interest and depreciation at 15 per cent.		0s. 3d.
Cost of filling after machine, taking up floor, laying rails, &c.		1s. 3d.
Total cost by machine		1s. 6d.
Saving over hand-labour		1s. 0d.
Saving in coal		0s. 6d.
Total saving by machine		1s. 6d.

Discussion.

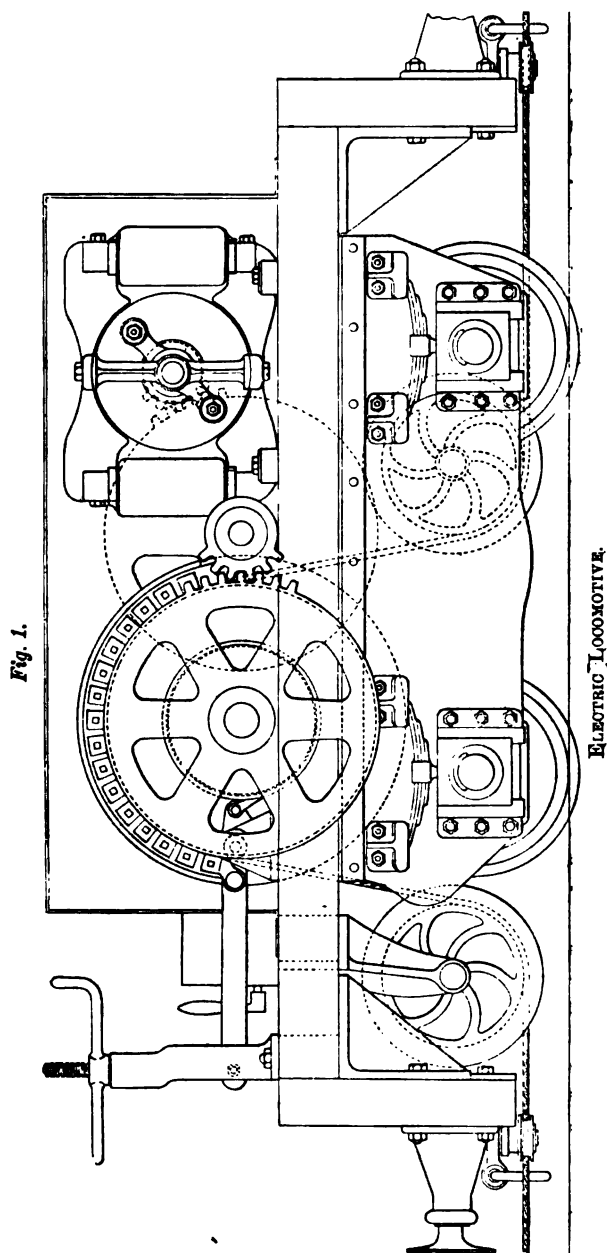
Sir John Coode. Sir JOHN COODE, President, hoped that the question of safety with regard to the use of electricity in coal mines as compared with other methods of conveying power would occupy a prominent place in the discussion. It was a most important point, and should be fully debated.

Mr. LL. Atkin-
son. Mr. LL. ATKINSON desired before the discussion commenced to call attention to one of the cutter-bars on the table which was not described in the Paper. In order to avoid the grinding of the steel points and the expense of renewing the steel cutters, the latter were permanent and had chilled-iron points inserted in them which were nearly as hard as steel, and when worn out could be thrown away, being inexpensive. They had not had much experience with that form, but thought that it would lead to a considerable economy in the item of grinding cutters. He had been told several times lately that although the question of sparking on the motors had been treated in the Paper, they had not dealt with what would be likely to happen should the roof fall, or should the cable be broken from some other cause. The reason was that, although they had devised a mode of getting over the difficulty, it was so novel, that their experience of it did not justify them in placing it before the Institution. The form of the cable, however, was such that even should it be absolutely torn asunder by the breaking of the roof, there would be practically no sparking, and an arc was impossible. That, he thought, removed the remaining objections to the use of the electric cables in fiery coal pits.

Mr. Snell. Mr. ALBION T. SNELL said that during the past four years great progress had been made in the use of electricity in mining, and the General Electric Power and Traction Company, Limited, with which he was connected, had from the first been identified with the work. In 1889, in a Paper read before the Association of Colliery Managers at Wigan, he had described in detail several of the plants then at work,¹ and in 1890 at Sheffield, in a Paper entitled, "The Electrical Distribution of Energy over Extended Areas in Mines,"¹ he reviewed the whole subject and discussed the various methods of applying electricity. He then advocated the use of over-compounded dynamos and series or shunt-wound motors, so as to make the system applicable for both lighting and power, and also

¹ In the Library of the Institution. Tracts 8vo., vol. 488.

Mr. Snell.



Mr Snell. to make it comparable to steam or compressed-air in point of adaptability. Since then his Company had laid down a number of installations, both at home and abroad, for hauling, winding, pumping, fan-driving and lighting, &c., with invariable success, and they had now in hand several which involved rock-drilling, coal-cutting, and pumping, as well as lighting. Before discussing the Paper he wished to draw the attention of the Institution to a new system of electric haulage for use on stiff brows in mines, by means of a cable or rope, fixed at either end and lying parallel to the road. The energy was supplied through wires above or beside the track. The system was introduced by Messrs. Immisch and Walker, and was the property of the General Electric Power and Traction Company. The cable was passed over a sprocket-wheel or a friction-clutch geared in a suitable manner to an electric-motor on a small trolley, the whole forming a light and compact electric-locomotive, *Fig. 1*, not depending for its grip on the friction between the wheels and the rails, but getting a direct pull on the fixed rope. The principle was similar to that employed for working floating bridges and barges. At the Wharncliffe Silkstone Collieries a brow about 500 yards long had been equipped in this manner, and the locomotive had been working successfully for about three months. The inclination of the road averaged 4 inches to the yard, and the rolling load was approximately 4 tons. The trolley carried a 10-HP. electric-motor, and weighed about 20 cwt.; which was unnecessarily heavy for that particular work. It ran in a headway of about 4 feet 3 inches, and the current was supplied by an overhead wire. The objection that had been raised with regard to sparking did not apply in this case. The motor as a whole was protected by a cast-iron covering. The rope was made of steel, and was about $1\frac{1}{4}$ inch in diameter. The friction-clutch was made by Barraclough of Barnsley. Experiments showed that a cable would give more satisfactory results than a rope on account of "slip" and consequent wear and tear. The work was previously done by five horses; but the strain was found to be so heavy that it was deemed advisable to change them every six months and put them to lighter work. The chief advantage of the system lay in the great tractive effort of the trolley in proportion to its weight—a point of considerable importance in mines with small headways and lightly laid roads. It was expected that the method would be applicable to many cases of underground haulage, but more especially to short and steep lengths on roads of otherwise moderate grades, where horses could be used for the greater part of the distance. Amongst the many interesting

points referred to in connection with the application of electricity Mr. Snell. to mining, was the risk of igniting gas. As far back as 1888, when speaking on the subject before the Midland Mining Institute,¹ he gave it as his opinion, that under normal circumstances the sparks at the brushes of a motor would not readily fire gas, owing to their having a low temperature by reason of the large masses of metal in contact with them. His opinion was combated by several leading mining experts, and he therefore decided to make experiments to determine the point at issue. With that view he procured a wooden box about six feet long, with an internal cross-section of about a square foot. One end was blocked up and the other had a hinged door, so as to make an easy outlet for the probable explosion. In the centre a small motor and a gas-indicator were placed. Ordinary coal-gas was admitted from the closed end until the gauge registered an explosive mixture. The motor was then started, and the experiment watched through a glass window in the side. From time to time the sparking was increased by changing the position of the brushes, and the mixture of gas and air was varied through all ranges. It was found that even with excessive sparking the gas did not explode until the commutator and brushes had become heated to a far greater extent than ever obtained in ordinary machines. It followed that although under normal conditions a motor would be unlikely to ignite gas, yet if by any means the brushes and commutator became heated beyond a certain point, the exact temperature of which was not ascertained, the sparks would fire an explosive mixture of gas and air. It was unsafe to place an unprotected motor in an explosive mixture; and he did not think that under the ordinary mining regulations such an absurdity would ever happen, but it by no means followed that even in fiery mines a properly arranged motor should not be installed. He had had a considerable acquaintance with the mines in England, Scotland, and Wales during the past four years, and had noted the conditions of ventilation in both "long wall" and "pillar and stall" working; and he thought that by proper attention to details electricity might be safely employed in almost every colliery. The point to consider was the way in which the danger from sparking should be provided against. Obviously the best method was to have ample ventilation with a large reserve of power, so that in the event of "blowers," the draught could be increased. If the "faces"

¹ Transactions of the Midland Institute of Mining Engineers, vol. xi., 1888, p. 347.

Mr. Snell. were well swept with plenty of fresh air, and the goaf properly packed and looked after, no danger need be apprehended from electricity. But the motor itself could be protected in such a way that it would not fire gas. If it were fixed, say at a pumping or hauling engine, it could be boxed in and supplied with fresh air from the "intake." This arrangement did away with any sudden risk, and there would be ample time to stop the engine driving the dynamo, even if the men omitted to switch off the motor before withdrawing; and assuming a large "blower," working up against the main air-way, the gas would not make much headway against the relatively high velocity of discharge from the small orifice of the motor-casing, which would be farther increased by the heat of the machine. In the event of the ventilation being reversed through a fall (a very rare case), the heat of the motor would probably check the foul air until the current was shut off. He, personally, was inclined to lay the utmost stress on the necessity of providing ample ventilation by well-designed fans rather than trusting to any safety device in the motor itself; for in the latter case there would be the risk of faulty construction or accidental damage, and the personal equation of the attendants must always be an important factor. Roughly speaking, there were two main lines on which motors might be protected; first, by enclosing the whole of the armature, and secondly, by covering the commutator and brushes only. In the former case the volume of air enclosed was so large that, assuming an explosion, the cover would most likely be damaged and the outside gas fired. In the second case the volume of gas enclosed might be made too small to do any harm; but certain mechanical difficulties were involved, and as the armature was not shielded from external damage, a short circuit on the winding might, at any time, cause sparking in the unprotected area. He looked upon both the methods as good when the extent of the protection was properly understood. Messrs. Davis and Stokes' device of an inverted commutator increased the facility with which the fiery area could be limited. But the mechanical difficulties involved in the handling of the machine were considerably increased, and the armature, as a whole, was not covered in any way. The inventors endeavoured to treat the motor as a safety-lamp, the key of which was entrusted to the attendant, and so arranged that the motor could not work without the key ring being properly fixed in position. The idea was worthy of consideration, and no doubt would attract the attention of mining engineers; but it remained to be proved whether so complicated an arrangement was workable in a coal-pit. His Company was

building a 25-HP. motor with an inverted commutator and internal brushes, but there would be some little difficulty in adjusting the latter, which he hoped to get over by using carbon brushes. Another question of importance with electrical work in mines was the installation of the mains. Too much stress could not be laid on the necessity for care in selecting the cable, and on the need of good honest work in erecting and jointing. In no other class of installation did badly designed or careless work so soon tell its own tale. He had used all classes of insulation for underground mains and had laid cables in both wet and dry mines. Speaking generally, it appeared that lead-covered cables, protected by an outer serving of braided and ozokerited hemp, were the most durable for wet pits, and should always be used in the shafts. They were also suitable for the main roads and levels, where the mains might be regarded as permanent; but for rough roads with falling roofs, or heaving floors and sides, he preferred an insulation of vulcanized rubber well served with braided hemp, as being more flexible. In all cases the ultimate success of the installation would depend largely on the method of erection, and the care given to details. In some roads he had buried the cables, in others carried them on insulators, and in many had simply cleated them to the props. In the shafts they should always be encased in strong wood troughing so as to protect them from falling stones, &c. The risks to be expected from the mains were two-fold. There was the very remote chance of an explosion, in the event of a cable being broken when transmitting energy; and there was also a possible chance of a bad "short-circuit" or "earth" causing trouble by firing timber. Considerable emphasis had been laid on each of these points by eminent mining authorities, who seemed, however, to base their opinions on theory rather than on actual experience. So far as he knew, the leakage of an electrical conductor had never caused any difficulty more serious than a short delay; and although he had seen timber charred in a pit top by a short circuit, yet there was no chance of a fire, because the electrical instruments showed immediately that a leakage had occurred, and the engineer in charge was at once on the alert. Indeed, the ease with which the supply of energy was governed and noted, formed one of the chief recommendations for the use of electrical power in mines. Electrical plant really entailed less trouble than steam- or air-machinery, and the men only required to get accustomed to it to appreciate its many advantages. It would not be out of place to say a few words on the possible limits of the use of electricity in mining. Evidently nothing was to be gained by it if the power could be transmitted

Mr. Snell. conveniently and economically by steam or rope; but whenever the distance became considerable these methods were more costly, as well as more troublesome, than either electricity or compressed air was. The Authors and himself were in agreement on that point, their experience coinciding with his own. But there were particular instances where electricity would always be preferred on account of the small space occupied by the cable and motor, as well as the little attention required, and the ease with which the plant could be shifted. And whenever water-power was available, electricity would prove the cheapest form in which energy could be transmitted. He had an extended experience in both main- and dip-pumping by electricity, and found in all cases a considerable gain in net efficiency over that obtainable by compressed air. At St. John's colliery, Normanton, electricity had been substituted for compressed air for main haulage, and main- and dip-pumping, with the result that the original boilers and engines had given rather more than twice the useful effect previously obtained. In Bohemia his Company had successfully transmitted by electricity the energy of natural water-power for winding, pumping, fan-driving, and lighting. They had several convenient forms of portable motors for coupling to Ingersoll percussion and rotary drills in somewhat the same way as those shown by the Authors. They were now building a new coal-cutter which he thought would do good service, being portable and at the same time powerful.

Professor Lupton. Professor ARNOLD LUPTON remarked that as a mining man he viewed the Paper with the greatest possible interest, and felt personally much indebted to the Authors for having brought so many valuable machines into the Institution. He happened to live in the neighbourhood where, he believed, the first electrical coal-cutter in the country was set to work, and had had the opportunity of seeing it in action on several occasions. He had made a study of coal-cutting machines. In 1865 he remembered going to a pit in Yorkshire about nine o'clock at night to start a coal-cutting machine, one of several introduced about that time. Since then a great many had been made and much inventive skill had been applied to their construction and design. That which he saw in 1865 was a pick machine. There had been rotary machines, and machines working with revolving bars, the same as the Blackburn cutter-bar, and the Goolden cutter-bar mentioned by the Authors. He had seen most of these, and they all seemed in his opinion to do their work well; and if they did not prove a commercial success it was not the fault of the inventors or makers, but was probably owing to some insuperable difficulty in the task

they were set to overcome. Twenty years ago he had been in a pit and had seen the machine worked by compressed air holeing at the rate of a square yard per minute. With the aid of a Richards' indicator he measured the exact HP. required to do the work. Some of the electrical coal-cutters, he believed, had equalled if not beaten that performance, but there was one thing to be said for those compressed-air machines to which he referred, namely, that some of them were still in use. He believed there was a colliery in Yorkshire where a great many rotary machines were at work successfully, and there was another where the pick-machine, invented more than twenty-five years ago, was employed. There was one point that he should like to mention. The Paper stated that the cutter-bar holed for a certain distance 5 feet under the coal, and that this could not have been done in any other way. Twenty years ago he saw a pick-machine that holed 5 feet under without difficulty, so that although the machine described in the Paper might be a good one and do its work well, it was not in that respect the pioneer. It was evident that the revolving cutter-bar lent itself to deep holeing with great advantage. He also thought that Messrs. Goolden, as far as he might venture to criticize their work, had introduced considerable improvements in the shape of the cutters. With reference to the question of safety in the use of these machines, the mines of this country might be roughly divided into fiery and non-fiery. The non-fiery were those in which gas might perhaps be found sometimes, but ordinarily speaking it was never seen, and blowers were never heard of. In those non-fiery mines there was a great opening for the use of electric machines. The Authors and also Mr. Snell had given much time and attention to the question of making a motor so that electricity might be safely used for the transmission of large amounts of power in fiery mines. Those devices might be clever. He thought that a coal-owner would not be likely to choose a manager who would get a dangerous machine into the pit and then cover it over to lessen the danger, but he would prefer one who kept as far as he possibly could away from any unnecessary risk. Therefore, without saying that the arrangements would not answer the purpose for which they were intended, he ventured to prophesy that in the course of the next twenty-five years those machines would not be introduced into fiery mines, and that for several reasons. In the first place, in the fiery mines of this country, as a rule coal-cutters were not wanted. The coal was frequently got by the gas, which blew it off, and the need for deep

Professor
Lupton.

Professor
Lupton.

holeing was not so great as in those mines where there was less gas, and the coal was often harder to cut. That led to another question—why should an electric coal-cutter or any other electric machine be used? As stated by the Authors, there was this strong reason, that the work could be accomplished with one-half the power, for a great deal less capital outlay, and for a much smaller working cost. Then it was supposed that a colliery owner would say to his manager, “Why do you ask me to put down expensive compressed-air plant when the thing can be done so much more cheaply by electricity? and if you cannot keep the mine free from gas I must get some one else that will.” That was the dilemma in which a manager might be put if such statements as those in the Paper with regard to difference in the economy of electricity and compressed air obtained currency in the colliery districts. He should like to ask what evidence there was that electrical transmission of power was any more economical than compressed-air transmission of power? The Authors had quoted a Paper by Mr. Daniel, which was read in 1874, but they must remember that that was sixteen years ago, and although compressed air was not a novelty at that time, it was only about twenty-five years since it began to be employed to any extent in the mines of this country. There were gentlemen in the room who had seen it fifty years ago or more; indeed, he believed it was used in the last century. But twenty-five years ago there were only one or two spots in the kingdom where it could be seen in use. Since 1874 he believed there had been some improvements in the construction of air-compressing machinery. He should like to say that because in a colliery they did not have a very economical engine, it did not follow that one could not be made. At an average colliery were not they consuming three or four times as much fuel per horse-power as they all knew to be necessary? And was it likely that if they were not very careful about economy of fuel for a steam-engine, they would be much more so in the case of an air-compressing engine? He did not think that the instances of want of economy in individual air-compressors and motors in a colliery were any proof of what could be done by the system. It should not be forgotten with regard to those electrical machines, that the highest intelligence of the country, the utmost mechanical and scientific knowledge that the century had brought forward, was given to the production of them, whereas most of the air-compressing machines were made by mechanics who did not study the thing beforehand, but simply took the order and carried it out as cheaply as they could, and

nobody knew whether the machine was bad or good unless some scientific man discovered that it was not giving such a good result as was expected by the happy and ignorant owner. *Fig. 2* was a diagram from an air-compressor. It would be observed that there were some zigzags on the top line, showing a pressure 15 lbs. higher than that in the receiver. It was not an economical

Professor
Lupton.

Fig. 2.

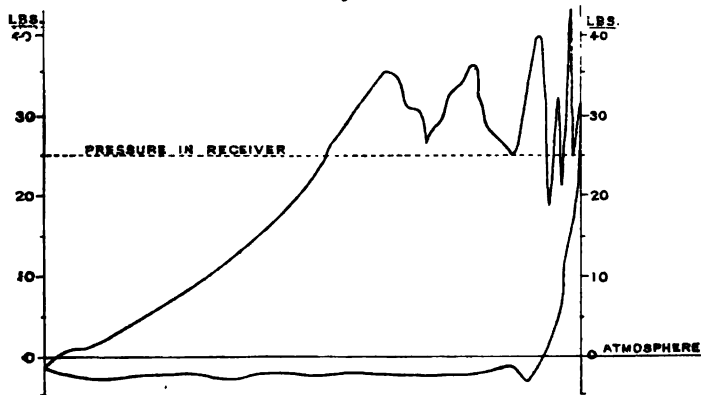
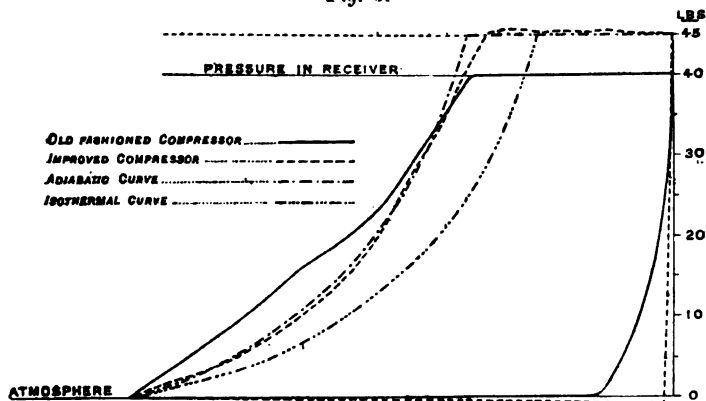
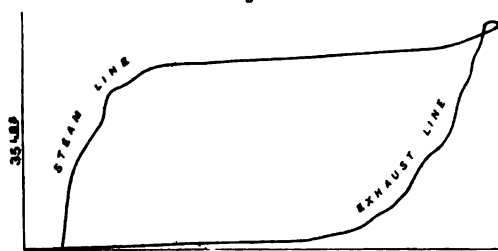


Fig. 3.

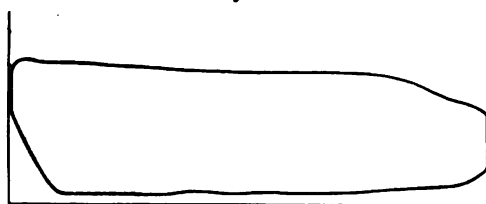


machine. In *Fig. 3* the full black line was taken from Mr. Daniel's Paper, showing the compression line. Comparing that with the curve given by the improved compressor, it would be seen that there was a great deal less waste power in the latter, the reason being that in the one upon which Mr. Daniel experimented the air as it entered the compressor was

Professor Lupton. warm. The consequence was that the delivery was 25 per cent. short of what it should have been, and all the results that Mr. Daniel had given were 25 per cent. less than they might have been, simply through the heating of the inlet air. That difficulty had now been overcome. As much depended on the economy of the motor as on that of the compressor. *Fig. 4* was a diagram taken from a compressed-air engine before it was properly adjusted. The air was not admitted to the cylinder until about one-eighth of the stroke had been made; then the exhaust was not opened until about one-tenth of the return stroke had been made. The result

Fig. 4.

CONSUMER'S ENGINE BEFORE ADJUSTMENT.

Fig. 5.

CONSUMER'S ENGINE AFTER ADJUSTMENT.

was a diagram as bad as it could possibly be. By slightly altering the valve a diagram was obtained, with a proper cut-off and a proper exhaust, very much reducing the air-consumption (*Fig. 5*). They had been told what compressed-air could do, but the diagrams from the air-compressors had not been given. It had been said, "You can only get 20 per cent." because there were some bad examples. He would suggest that there should be a competition between the electricians and the advocates of compressed-air, each working a steam-engine, the power of which was to be taken to a distance of 10,000 yards, and used in lifting water to a given height.

In Table II the Authors had referred to the transmission of

power to a distance of 2,000 yards with a cable of seven wires, No. 16 gauge. Mr. Brain, in the Forest of Dean, had used a cable of exactly the same length of nineteen wires, No. 16 gauge, for the transmission of the same HP., and he lost 20 per cent. of the power by the friction in the main. It was true that Mr. Brain used one-half the voltage that the Authors proposed. If they had 10 per cent. loss of the power put into the main they would still require a cable of nineteen wires, 16 gauge. The result was that the cost would be £100 more for the cable, without any insulators or fixing, than had been stated by the Authors in Table II. The cost of 4-inch pipes for compressed air had been given as £700. A 3-inch pipe would be ample for the HP. delivered, and if they took off £200 from the cost of the pipe, and put £100 on the cost of electric mains, the figures would be materially altered. He should like to know what was the price of the coal-cutting machine mentioned by the Authors as compared with that of a compressed-air coal-cutter. The Paper did not give any means of comparison, excepting with regard to the pumps. He had been told by a great authority that a small motor, say 2 or 3 HP., could not be worked at much more than 100 volts. He was also told that it was impossible to take electricity any great distance in a mine at a less voltage than 500 to do the work economically. Therefore, in order to drive several small motors in the mine at a distance from the shaft, they must have a transformer, which with continuous-current electricity absorbed at least 20 per cent. of the power. How did that affect the economy of the two methods? Then there was another equally important matter. Supposing a motor or twenty motors in a mine, all driven off one set of cables charged with electricity at a constant voltage; the motor was fixed to run at a given speed, and all the gearing was so arranged. It might be wanted to work a pump which had a constant load and therefore required a constant torque; the motor must always have a constant number of amperes in it to make it go. Suppose they desired to make it run at half speed; how could that be done? He had consulted a number of electricians who said, "Put in resistance." A resistance to reduce the speed to one-half absorbed half the power, and then what became of the economy? He had nothing to say against electrical machines, and he wished them all success; but when he heard statements that were not in accordance with his own experience, he thought he was justified in asking for some further explanation.

Mr. ALBERT GROTHE said that two years ago he visited several mining camps in the Western States of America with the object of

Mr. Grothe. making himself acquainted with the application of electricity to mining work, and he ventured to think that a short account of what he saw would not be out of place. The direct impulse for the journey was given by a difficulty arising out of some mining operations in Mexico, which would only be thoroughly appreciated by those who had to take up and continue old deep workings in mines. Professor Lupton had laid some stress upon the supposed fact that there was no advantage, economically speaking, in the use of electricity over compressed air. Those who had experience of both knew better. But apart from the question of economy there was that of expediency, and many of the workings of which he was speaking were ill adapted to the ordinary means of transmission of power. Often there was no room for pump-rods or for steam- or air-pipes, and in such cases the flexible electric wire, so easily placed in position, so easily lengthened as occasion required, and so little in need of repair, offered great advantages irrespective of that of more economical working. In seeking the information desired he naturally turned his eyes to the United States for the obvious reason of proximity; but apart from that there was the important consideration that the Americans were far ahead of them in the application of electricity to the objects of daily life and industry. For every electric motor in use in this country three years ago there were said to be fully six hundred in the United States. He believed that there had been an advance in England since then, and that the disproportion was not now so great; but if they considered that at the end of August last there were in the United States two hundred and fifty-eight railroads, having a length of track of 1,927 miles, over which three thousand and twenty-four cars were run by electric motors, they would agree with him that the Americans were still ahead of this country. In the fifth-rate city of New Orleans electric power was delivered from house to house like water. There was, at the time to which he referred, a show-place on the Feather River near Oroville, California. The river there made a big bend 18 miles long, which at the narrowest part was only between $1\frac{1}{2}$ mile and 2 miles across. The gravel was said to contain a large quantity of pay gold, and a company was formed for the purpose of washing and amalgamating it. A tunnel was driven across the shortest distance of the bend, and motors were placed at the lower end, so that the whole river was turned through the tunnel; and while thus supplying motive power for the different operations, left the river-bed itself bare and accessible. The hydraulic power was converted into electricity,

which was led the whole 18 miles along the bend to perform the Mr. Grothe. work which had to be done in connection with the operations. Unfortunately he had not been able to inspect this important plant in operation, as on his arrival the work had been stopped, and the machinery was in process of removal, not, he was told, on account of any failure of the electric appliances, but because the river-bed did not contain gold in paying quantity. He mentioned the circumstance to show how, in that country, large enterprises were often started on the spur of the moment, without sufficient foundation for ultimate success. In Virginia City, Nevada, the water which had spent its energy in driving a silver mill was taken through pipes down a shaft which communicated with the great Sutro Tunnel, and was made to act through $\frac{1}{2}$ -inch nozzles, with a head of 1,630 feet upon six Pelton waterwheels of 40 inches diameter, and each connected with a dynamo. The electricity thus generated at the bottom of the shaft was conveyed back to the mill on the surface where it drove six electric motors of 60 HP. each at a nominal expense, thus saving 360 HP. which formerly were absolutely wasted. At Aspen, Colorado, there was at that time only a small plant consisting of several hoisting engines driven by two dynamos of 27 HP. It worked so well that large additions had since been made, and there were now three dynamos for sixty arc-lights each, four others supplying an aggregate of 2,500 incandescent lights, and two power dynamos, one requiring about 60 and the other 120 HP. These drove several motors at a distance of about two miles at points underground to which it would have been most inconvenient to convey power by the older methods of transmission. In all those places, however, he missed one thing which had been mentioned by the Authors, namely the drill, and he also failed to find an electric sinking-pump. He understood the Paper to deal with the application of electricity to mining operations, and certainly miners would admit that a sinking-pump and a drill were among the most important mining appliances, and ought not to be left out when it was a question of the employment of electricity for such a purpose. The great difficulty was that so far electricity only gave a rotary motion, and to convert that rotary motion into a reciprocating one was not easy, at any rate while maintaining the special character of the drill. They had an application shown to them which was no doubt good in its way, but for practical work he certainly should not depend upon the machine which he saw before him. It would be necessary to have a drill which was capable of making something like 500 or 600

Mr. Grothe, strokes a minute, not one which would be satisfied with 50 or 60, and with which no practical work could be done. He had recently driven a tunnel at the rate of 60 feet a week, which would have been impossible with such a tool. He had seen a similar thing in San Francisco, where instead of compressing a spring the piston moved in a cylinder containing air, which brought it forward in contact with the rock every time it was pulled back and released. In connection with this important subject mention ought to be made of a new reciprocating electro-magnetic engine by Mr. Van Depoele, which was described at the September meeting of the American Institute of Mining Engineers in New York. The leading idea was based upon the fact that an iron bar held near the open end of a coil of copper wire or solenoid, would be sucked into the solenoid the moment a current was sent through it, and that it would be released when the current was broken, and either drop out by its own weight or might be expelled by springs. The employment of springs in tools of this kind did not commend itself to the practical miner, but it would be observed that the inconveniences inseparable from their use were much less in connection with a reciprocating motion than they would be with a rotary one, and possibly a double solenoid, alternately attracting and releasing the iron bar, would enable the inventor to dispense with springs altogether. A further point of interest in connection with this new machine was that currents rising and falling in closed circuits were used, instead of alternating ones. This not only prevented the possibility of sparks being produced but provided for the regulation of the speed of the engine according to the work it had to do. He was glad to see that the Authors were on the track of a really useful instrument; and he assured them that as soon as they had produced it he should be very happy to put it into practice. There was still a wide field for the application of electricity to mining-industry and even domestic purposes, and he did not agree with those who thought that this power was yet too incompletely known to permit its use with safety. He maintained that as much was known about this particular form of energy as of any other, including the oldest of all—animal power. They could not grasp the mysterious nature of a horse any more than that of the electric current, but, if anything, had the latter under better control, and could apply it with greater precision. What they needed was not so much a greater knowledge of electricity as a greater readiness on the part of consumers to make use of it, and they were specially indebted to the Authors for having brought the subject before them.

Mr. EMERSON BAINBRIDGE said the immediate point before them was the comparison instituted by the Authors between compressed-air and electricity. They had however gone a little farther, and had become exponents of a certain mode of cutting coal by machinery. He was now cutting about 1,000 tons per day by machinery, and therefore had some experience in that direction. Professor Lupton had spoken of a colliery manager being naturally disinclined to apply electricity underground in places where there was any chance of danger. They had not to consider this or that mode of providing an apparently efficient safeguard against a possible spark in a motor, but to bear in mind that they were dealing with human beings, in the dark and underground, and of a class that could not be trusted to keep delicate machines in order unless they were watched from minute to minute. Absolute security was therefore wanted in regard to sparking before a mining engineer would be justified in adopting electrical machinery in a fiery mine. His firm was using compressed-air, but he did not agree with Professor Lupton as to the comparative economy of the two systems. Mr. Snell's experience at a colliery in Yorkshire was important, because it supplied a comparison between two modes of doing the same work; and even if the compressed-air machinery in that case had been badly managed, and the economy mentioned by Mr. Snell were much reduced, it would still be considerable. There was often a great mistake made as to the importance of what was called the percentage of useful effect. He supposed that the Authors meant the work done as compared with the IHP. of the driving-engine. In coal-cutting the power exerted by each machine was 6 or 8 HP., and if with compressed-air 23 HP. was required to yield this amount, whereas with electricity 12 HP. might suffice, the difference in cost, with a well-arranged engine, would not exceed £30 or £40 a year, which was not worth considering in comparison with the risk of stoppages and accidents underground. In the case of compressed-air there was an almost perfect freedom from the risk of stoppage, which was a matter of great importance in a colliery. Although the useful effect might not be half so good with compressed-air as with electrical machinery, fewer repairs would be required. If a colliery manager could have the assurance of being able to carry on his electric work without an electrician, he would be much more inclined to use these machines than he was at present. The Authors had referred to one method of coal-cutting, exemplified by the radial bar on the table. According to Mr. Bainbridge's experience it was best done in an entirely different way. The most widely known

Mr. Bain-bridge. systems were those of the wheel working slowly outwards at about 30 revolutions, and the wheel working inwards and making about 200 revolutions per minute, and he ventured to say that either of those methods would accomplish more, in regard to quantity and regularity of work, than the machines described by the Author. In the one case by pressing a bar forwards against a solid mass there was a constant tearing away of the coal; whereas in the other case there was less resistance and probably more work was done with a given amount of power. Whatever might be said about the difficulties of applying electricity to coal-cutting would not apply in the same sense to pumping. As a general rule, a pump was fixed for a longer or shorter period, but a coal-cutting machine was constantly being moved about, and there was the risk of dirt and dust flying about, and damaging the machinery and the various parts of the gear which carried the electric current, especially where several hundred yards had to be traversed. In the case of pumping there could be no comparison between the cost of compressed-air and electricity. In a few days he should have a pump raising 50 gallons a minute 400 feet high at a distance of $2\frac{1}{4}$ miles from the engine; and the first cost would be less than one-half that of compressed-air. With regard to drills, he did not think that they would ever be of any service for coal. Machines were now made for drilling coal by hand which would drive a hole 3 feet deep in about two and a half or three minutes, and the speed mentioned in the Paper was but little better than that, and as the hand-drill cost about 30s. or 35s. there was not much scope for improvement in that respect. He thought that there was an excellent opening for the application of these machines to driving stone drifts and sinking shafts and that kind of work. He should be glad if the Authors in their reply would refer to some place where such machines had been in practical use. There was at present so little literature available for mining engineers as to the application of electricity underground that he felt greatly indebted to the Authors for their contribution to it.

Mr. Parker. Mr. THOMAS PARKER (of Wolverhampton) remarked that as the Authors had referred to the plant at the Trafalgar Colliery, with regard to which exact data were to hand, some few statements respecting it might be of interest. The first installation was put down in 1883 by Messrs. Siemens. It was only $1\frac{1}{2}$ HP., but the colliery manager was so favourably impressed with it that in 1885 an order was given to Messrs. Elwell-Parker to put down $2\frac{1}{2}$ HP. plant. That machine ran until 1887, at which date an order was given for a 20-HP. motor in addition. That was used for pumping,

and there was also a small plant for ventilating. The data were published in 'Industries,' December 9th, 1887. The distance was 2000 yards, and although the motor and dynamo were manufactured five years ago, the efficiency obtained was 40 per cent. of the brake HP. in water raised, and the cost per HP. in water raised was 0·2d. That was now a matter of history, and it would compare with the best compressed-air plant which could be put down for the purpose. In working the machines it was extremely advantageous to be able to know what was going on below by the instruments above ground, and the exact amount of work being done by the pumps was indicated by the voltmeter and ammeter in the engine-house. As was stated in the Paper, they used belts in that particular case, the reason being that they wished to get the motors a little further away from the pumps, which were constantly breaking the joints and scattering the water about. They were now making motors which were proof against getting wet, but he did not think it advisable to run any risk so long as it could be avoided. If the loss incurred in the leads was assumed to be 10 per cent., they could easily obtain at full load an efficiency of 75 per cent. of mechanical energy delivered at any point, however distant. With regard to a question asked by Professor Lupton implying that at varying loads they were compelled to use the same amount of energy, under ordinary circumstances the electrical motor had the power of regulating the amount of energy it received by the amount of resistance which was imposed in the way of work. As one proof that compressed-air was beginning to lose favour with mining engineers where they were satisfied with the safety of the application of electricity, he would state that he had just received orders from a colliery company in his neighbourhood, after careful trial on a smaller scale, to replace compressed-air plant with a 60-HP. installation for electrical transmission. With reference to the suggestion that there should be a competition to determine the merits of electricity and compressed-air, he could only say that he would be glad to enter into the competition at any time that might be selected. He had frequently devised machines for use in dangerous places, but he had never been able to find a colliery manager who was willing to undertake the risks, and he did not care to do so himself. It was not a question solely of sparking, but of accidents which might happen to the armature or any parts of the motors or cables; and the machines to be employed in dangerous places must be under the supervision of persons who were acquainted with their laws. If the cables were run in iron piping, in which also the switches

Mr. Parker. might be enclosed, and if that iron piping was made to carry a supply of fresh air from a safe portion of the mine into a chamber loosely covering the motor, there would be very little risk indeed if ordinary care were taken. It had been said that a high class of intelligence was needed to superintend those matters, but the same was true of compressed-air machinery when it was first made, and probably before long plenty of labour would be available to prepare and handle electrical installations. They were greatly indebted to the Authors for their Paper, and he believed that engineers were now on the eve of a very large application of electricity.

Mr. Brajn. Mr. FRANK BRAIN thought the Paper was a most valuable contribution to the subject of electricity as applied to mining. With reference to the plant that his firm had put down at the Trafalgar Colliery in the Forest of Dean, he might mention that they had increased it three times, and had had no trouble with it. With the first installation they carefully boxed up the cables, anticipating that a fall of the roof might damage them. When they put in the second and third installation they did nothing of the kind, as it was found that there was no necessity for it with a fairly insulated cable, to which proper attention was given. It was a non-gaseous mine, and the trouble from the falling of the roof, &c., was very small. He had closely followed the discussion with reference to the means taken to prevent the explosion of gas. As a practical man, he looked upon the machine as well fitted for putting into the hands of the miner. There were many mines where it could be used without danger from fire-damp, and he thought that it was one of the most practical in the market. It was so strongly made, and so closely boxed up, that it appeared almost impossible to injure it. It was much better, as the Authors had shown, to protect an armature going at a high speed, in a machine which was intended for use in a dark mine. That he regarded as a distinct advance, apart from the question of gas. The Authors stated that the construction of the machine was such that they could ensure its running in explosive gas for two hours with perfect safety. If so, that was all that colliery managers required, and so far from suggesting that a non-explosive compound should be introduced, he would say, "Stick to your text and prove it, and we shall be satisfied." The matter of efficiency had exercised his mind. In papers which he had read on the subject before the British Association and the South Wales Institute, he prominently introduced that question. He might mention that Mr. Parker had made use of some figures which were a misprint, the real figures not being quite so satisfactory.

At the meeting of the South Wales Institute there was a large Mr. Brain. number of practical men who had used compressed-air plant in their collieries, and some of the makers of it were also present, and the matter came up prominently for discussion; but he was disappointed to find that no reliable data were put before them. There were many opinions, but no practical figures were forthcoming. When the President, Mr. Colquhoun, who had a great deal to do with colliery plant, summed up, he said he had had nothing to do with electric motors, but he must confess that, so far as his experience went, the efficiency of compressed-air machinery never exceeded 25 per cent. Mr. Brain had recently spoken on the subject to an eminent engineer, who was describing a large compressed-air plant with all the latest improvements which he was putting down; and on asking him what efficiency he expected, he said that he hoped to get 40 per cent. A short time since a large colliery owner whom Mr. Brain knew asked his manager to furnish him with indicator diagrams of the compressed-air plant at all his collieries; and the efficiency was found to be 17 per cent. In the case of some modern machinery belonging to one of his friends (who had nothing to do with electricity), the average result obtained from the diagrams was 18 per cent. That was pretty strong evidence as to the present day efficiency of compressed-air plant.

Professor GEORGE FORBES differed from the Authors as to the danger of using the machinery which they suggested in fiery mines. He believed that in 1878 the largest employers of coal-cutting machinery in the country were the firm of Merry and Cuninghame. They were then using compressed-air to drive it, and were getting an efficiency of about 25 per cent. He was asked to look into the question of applying the electrical transmission of energy to the purpose. He accordingly worked out a plan, and was only deterred by a consultation with Mr. John Cuninghame, the manager of the Company, who with himself came to the conclusion that the danger of sparking was so serious that it was utterly impossible to employ electrical motors for coal-cutting machinery. And he still said, after carefully reading the Authors' Paper, that even with the precautions therein mentioned, it would be dangerous to introduce the machinery described into a fiery mine. Various theoretical reasons had been given why it was perfectly safe. First, it was said that in the ordinary way of using an electric motor the temperature of the spark was so low that it would not fire an explosive mixture. He could not believe that that statement was made with experience of what an

Prof. Forbes. electric motor would do. It was certainly true that in the ordinary way of working an electric motor under the most perfect conditions there was hardly any spark at all, and it might be that there was only the red spark which did not produce the oxidation of copper, and was therefore of a lower temperature than that required to cause the ignition of an explosive mixture of fire-damp and air. But in a large number of cases they certainly did get a spark of a higher temperature at the brushes, and he hoped that no one would believe that in a fiery mine it would be safe, from the reason suggested, to adopt a motor, or that sparking of the brushes could not possibly explode a mixture of fire-damp and air. The Authors further said that, even if an explosion could be so caused, they had enclosed the commutator in a casing by which such a result was rendered impossible. They maintained that there never could be any serious accumulation of marsh-gas in the casing, because the spark of the commutator would be continually burning it up; in other words, that the sparking was really a safeguard against an explosion. He thought they had utterly failed to recognise the fact that if the machine were left for a considerable time the gases would accumulate inside the casings, which would be a very serious matter when the machine was started again. Moreover, the Authors stated: "It is not likely that any electric motor will be placed in such a position as to be worked continuously in an explosive atmosphere for a longer period, at the outside, than two or three hours. The casings with which they are provided are tightly fitted at all the joints, many of them being packed with rubber, and it is not likely that an inflammable mixture could penetrate to a dangerous degree within that time." That was all very well, but if the machines were left unemployed for a considerable while, the gases would accumulate in the casing. Moreover, the coal-cutting machines, of which he chiefly spoke, were used in the most dangerous part of the whole mine—at the working face, where they might strike a blower at any moment and have a large outburst of explosive gases, which would be a very serious thing if they depended simply upon the protection afforded by the casing. Having originally stated that the temperature of the spark was not sufficient to ignite the gas, and having then said that if the temperature was sufficient to explode it they provided against the danger by putting the whole commutator, and perhaps the whole machine, into a casing, the Authors remarked (evidently foreseeing that it would not be accepted as sufficient precaution by engineers) that they would admit carbonic acid into the casing. He could not believe that that suggestion

was really put forward as likely to be adopted by coal-miners. Prof. Forbes. Was it conceivable that the miners would continue admitting carbonic acid into those casings for a long period when they knew that there was no fire-damp about, and would they not be perfectly certain to cease doing so? And it would be when the supply of carbon dioxide was omitted that the blower would be struck, and a large amount of fire-damp would be admitted. It was said in the Paper: "These precautions, which have been carried out successfully in practice, are, in the Authors' opinion, amply sufficient to meet all objections on the point of safety in connection with the application of electric motors to mining work." He wanted to know what those words meant. Had the machine been tried in an explosive mine, where there was known to be an explosive mixture of gases at the place where it was used, or (what was much more important) had it been worked in a chamber filled purposely with an explosive mixture of fire-damp and air? He certainly should not be willing to sit in the chamber while the experiment was being made, and he should be glad to know from the Authors whether they had made such an experiment themselves. Then there was another serious reason against the adoption of electric machinery in fiery coal-mines, namely, the danger of the fraying of the insulation, or of the actual severance of the mains by picks, &c. He could conceive no place in which it was more difficult to ensure perfect insulation than a coal-mine, in consequence of the damp which was often experienced, the dirt, the grit, and especially the darkness, which rendered the cables more liable to be trampled on and damaged. There was no place where there was greater danger of injury to the insulation, and if only for that reason, he should consider it very dangerous indeed to put down an electric plant in a fiery mine. If, however, by the adoption of extraordinary precautions, the mains could be made with a fair certainty of preserving their insulation, he should still object altogether to the use of the machines described in the Paper, owing to the danger of sparking at the commutator, and the results which might happen therefrom. He thought it might be interesting to the Institution if he mentioned some results which had been obtained from a different type of electric motor, which entirely obviated the defect to which he had referred, namely, the Tesla motor, which he believed was discovered simultaneously by Nikola Tesla and Professor Ferraris. It had no commutator, and no collecting brushes on the armature, and the armature, as an electric unit, was totally distinct from the rest of the circuit; and

Prof. Forbes. there was no possibility of sparking there. It required, however, that there should be not simply one single current, but two, and was therefore driven by means of a special dynamo, with four poles and two circuits on the armature, so arranged as to give currents differing in phase by an interval of a quarter of a period. Three wires were required for the mains, one for each current, and an intermediate return. The motor consisted of a similar arrangement—four pole-pieces, and an armature which was wound with wire and short-circuited upon itself. The result was that the current circulated round the field-magnets of the motor in such a manner as to cause the polarity of them to rotate continually in one direction round the armature, and by doing so to make the armature to revolve in the same direction. In this way without any commutator whatever they were able to get powerful mechanical effects. He thought it was worth while to mention the matter, because he supposed he was one of the few who had had an opportunity of testing these machines, which he did a year ago at Pittsburg. At that time they were not being made larger than about 5 HP.; they worked extremely well. He was only able to get a rough idea of their efficiency by the means at his disposal, but he knew that they were fairly efficient. The chief difficulty was that of getting sufficient torque, or twisting power, when the current was first put on; but by an ingenious device that difficulty had been overcome. He believed that they had been made of larger size since the time to which he referred. They had been largely used in Pennsylvania in coal mines, and he thought they were certainly the type of machine that would naturally be employed in places where there was danger from fire-damp.

Mr. Taylor. Mr. JOHN TAYLOR said he did not intend to take part in the discussion with regard to electrical machinery generally, but he was able to give some facts which would be of interest, because they were the results of working mines upon a considerable scale during a period of several months. He referred to some gold mines in California, the property of a company of which his firm had the management. They had been abandoned for some years, in consequence of the impossibility of working them to a profit by steam-power, the ores being of low grade. The matter was brought to his notice two years ago by Mr. G. Cullen Pearson, who was interested in the mines during the period of their working by steam-power. Mr. Pearson saw the future possibility of the transmission of power by electricity, and secured, in addition to the interest he then had in the mines, water-power at a

distance of about two miles. This was utilized by a Pelton wheel, Mr. Taylor. 87 inches in diameter, and capable of developing 125 HP. with 400 miners inches of water under a pressure of 110 feet. This wheel drove a Brush generator of 100 HP. The current was transmitted to the mines, which were at an elevation of 1,400 feet above the power-station, and a distance of 10,890 feet (just over 2 miles), by a No. 3 insulated copper wire less than a quarter of an inch in diameter. The wheel and the generator were capable of developing 125 HP., but they were not working up to that. The exact length of wire to complete the circuit was 22,588 feet, or 4 miles and.1 furlong. At the mines there was a Brush motor working up to 60 HP. actual. It drove a ten-stamp battery, and three Huntington mills besides, equal in all to a forty-stamp battery, and there was also a large rock-breaker. In addition, all the mills and buildings were lighted by glow lamps by the current taken direct from the transmitting-wire. The power required for running the machinery as at present used was from 41 to 43 electric HP.; there were ammeters and voltmeters placed both at the power-generating station and at the mills by the Brush Company who put up the plant, and they were guaranteed by them to be correct. The electricians present would be able to give their opinion as to whether there could be anything questionable in the results given by these instruments. Mr. Pearson had himself made numerous observations by means of a telephone from the generating-station to the mines, and Mr. Taylor had received from him particulars of one taken on the 12th of January. At the power-generator there was registered 29 amperes at 1,250 volts, equal to 48½ electrical HP. The current at the mills at the same time was 28 amperes and the pressure 1,100 volts, equal to 41½ electrical HP.; so that practically they were receiving at the mills from 83 to 85 per cent. of the HP. generated as actual working energy, at a distance of over 2 miles. They were confidently told by the electricians who put up the machinery that a wire two sizes larger would give from 2 to 5 HP. additional; they might therefore talk about 90 per cent. of the HP. at a distance of more than 2 miles. Mr. Pearson had mentioned a variation of from 1½ to 2 per cent. in the power delivered, which it appeared was dependent upon atmospheric conditions. It might be easily understood that there was a larger efficiency in cool dry weather than on a warm, damp day. The electricians of the Brush Company stated emphatically, after the work had been going on for some time, that they might safely reckon upon 70 per cent. of the HP. at a distance of

Mr. Taylor. 12 miles. The experiment was not a small one; the work had been going on since August, day and night unceasingly. They had a good deal of trouble at first, but after everything was in order they went on without a single interruption. The most remarkable thing was the small amount of wear and tear, which appeared to be confined to the copper brushes, and the copper segments of the commutators. Mr. Pearson had given the whole expense of the renewals and for oil at only \$25 per month, which was, of course, a mere trifle. He had proved, during that period of five months, that he required no skilled men. Two miners had been instructed, and they attended solely to the machinery where the Pelton wheel and the dynamo were working. Up at the mill there was no supervision whatever of the motor beyond one of the men going in to see that the oil cups did not run empty. The machinery, Mr. Pearson stated, was entirely under control, and in all his experience he had never had to do with a motive power which could compare with it for economy, cleanliness, steadiness, and the ease with which it could be handled. Between the 1st of August and the 31st of December the machinery had dealt with 19,000 tons of rock. The gold was extracted at the remarkably low average cost for mining and milling of 50 cents.—or 2s. 1d.—per ton, beating, as far as Mr. Taylor's experience went, any record even where there was water-power close to the scene of operations. It would be readily understood that there was an enormous field opened up for working mines and many other industries under similar conditions. Mr. Pearson's statement was a remarkable one, and he placed it before the Institution as the actual result of a large operation over a considerable period.

Dr. Foster. DR. LE NEVE FOSTER remarked that the point that specially concerned the mines in his district was the discovery of an electric drill, which would bore holes for blasting, and naturally, when he heard that such a machine was at work in the neighbourhood, he made an effort to go and see it. It was the one represented in Fig. 8. He was greatly disappointed on arriving at the mine to find that it had not turned out a success, and had been sent away. The reason of its failure would, he hoped, be given by the manager of the slate mine, Mr. Roberts, who saw the experiments made, and had come from North Wales to speak on the subject. The expression used by the Authors, "as hard as slate," seemed rather inappropriate, because to a miner slate was a comparatively soft rock, and it ought not to go forth to the world that it was considered by them to be one that was difficult to bore in. The

Authors had also referred to the diamond drill, stating that the Dr. Foster. expense of the diamonds was so heavy as to make the use of that machine unfitted for boring holes for blasting. It was perfectly true that the cost of diamonds was high, but it was not prohibitive. An account was given in the last *Jahrbuch fuer das Berg- und Huettewesen*, a Saxon mining annual, of a diamond drill which was in successful use in Germany for that purpose. The writer found by experience that in such rocks as the crystalline schists, gneiss, greenstone, porphyry, clay-slate, and granite, the cost per foot bored was two-fifths of a penny for diamonds alone. It was true that that was a high charge, but taking the results of actual work, it was found that, although the cost of driving tunnels had not been diminished, yet it was possible to drive them twice as fast for the same money as with hand-labour. In the case of a soft rock like slate a less expensive material than diamonds might be adopted; he believed that emery might be used with success. He should be glad if the Authors or any one else could give some information about the Edison percussive drill, which appeared from the drawings to be a handy instrument. He thought the thanks of miners generally were due to the Authors for giving so much information as to the use of electricity in mines. The Paper was one that would be read and re-read by them, and he hoped that one result of it would be the utilization of a large amount of waste water-power in the district in which he resided among the hills and valleys of North Wales.

Mr. C. WARREN ROBERTS said that a question had been asked by Mr. Roberts. Mr. Bainbridge as to where the Authors' percussive drill had been in actual use. A percussive drill had been tried at the slate-mines belonging to Messrs. J. W. Greaves and Sons, of North Wales, for whom he was Engineer. The plant put down by them was erected mainly with a view of rock-drilling either by rotary or percussive drills. They utilized a stream of water drawn from reservoirs. It averaged 300 feet per minute, and passed over wheels at various elevations, developing from 100 to 120 HP. before it arrived at the turbine, which was now used to generate the electric power. The first drill tried was of the Authors' rotary type, which was not made specially for slate, and did not work successfully in it, although it had answered well for coal. Slate, as Dr. Le Neve Foster had said, was very soft, yet it was tough. The rotary machine did not succeed perhaps for more than one reason. It did not seem to bite into the rock; and if it did there would be a difficulty in getting the dust from the pulverized slate out of the hole. Afterwards the proprietors

Mr. Roberts, of the mine tried a percussive machine, the ordinary Ingersoll drill, driven by a flexible shaft, like that in Fig. 8, Plate 4. There were various mechanical arrangements in that drill which were faulty. The principal thing was that the legs could not be fixed up with any security, there being a want of rigidity about them. The flexible shaft kicked a good deal while revolving, causing a jerk in the frame, irrespective of the concussion due to the working of the drill itself. The back leg of the tripod on which the instrument was fixed was not sufficiently rigid, and the vibration caused it to shift about. In practice he found that the length of the feed, which was only 8 inches, was much too small, necessitating the changing of the drill two or three times, and it was not easy to get the old drill out and the new one in place. Other mechanical difficulties were met with in small matters, such as pins breaking, the failure of the feed-gear, and the automatic twisting of the feed. They were now hoping to get a drill mounted on a central column fixed on a trolley, which could be screwed up to the roof, so as to ensure rigidity; while by various simple mechanical arrangements the frame of the drill could be moved into almost any required position, thus saving much time in fixing the machine for boring fresh holes. The motor also would be fixed on the same frame, thus doing away with the flexible shaft. At the present time the difficulties were mainly mechanical, and they wanted a drill to work more directly from the motor than the one they had been able to get. There was no difficulty with regard to sparking in slate mines, because there were no dangerous gases generated. There was undoubtedly a large field for the application of electric power to mining purposes, especially in the Festiniog district, where the supply of water was ample, and the mines were amongst the largest in the world. Some of the openings were from 100 to 150 feet high, 50 feet wide, and 200 feet long, and an idea of the extent of the workings might be gathered from the fact that in those with which he was connected there were over 20 miles of roadway.

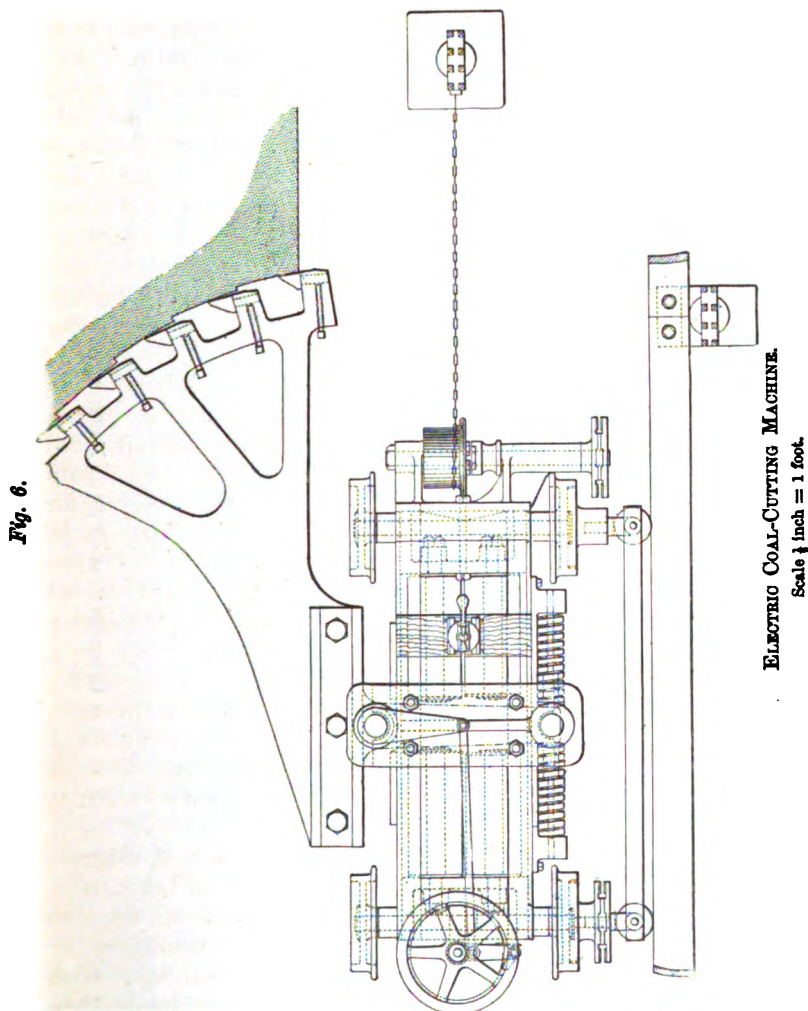
Mr. Smith. Mr. HOLROYD SMITH said the figures which had been given from America with reference to the transmission of electrical energy appeared to him to be altogether too good, and he desired, as he had done on one or two previous occasions before other societies meeting in that room, to lay stress upon the necessity of stating the particular point from which such measurements started, and the point at which they ended. When he heard of electrical energy transmitted for 2 miles with an efficiency of 85 per cent.,

it was altogether too good, at any rate for him to accept. If Mr. Smith. they took only the electricity that went out from the generating dynamo, and compared it with that received at the end of the cables by the motor, then he admitted that 85 per cent. was easily obtainable: it meant that 15 per cent. was lost in the wires themselves, and for a distance of only 2 miles such a loss, without some further justification than the saving in copper, was not to be commended. He assumed that the Authors when speaking of their percentage of efficiency, and comparing it with that of pneumatic machines, were referring to the power exerted by the steam-engine and the power given out in actual work where it was received. He had had several times to deal with statements as to the transmission of electrical energy, and when he had given his figures some of his hearers had said that they were too low, while others had stated that they could do a great deal better. His reply was that if he measured in the way that some persons did he could get the high total efficiency claimed by them. The question was one not only of scientific but of commercial importance. They ought to make it almost a matter of conscience to speak clearly, not only amongst those who were familiar with the different modes of measurement, but especially when talking to the outside world who would be the purchasers and users of the apparatus and instruments. On a question of transmission the Authors had stated that there was little difficulty in obtaining 50 per cent. of the power expended in the engine. He wished to ask whether that meant indicated HP. or the power given out by the engine. It was a little risky, if they wanted to define clearly what should be the efficiency of any system, to be dependent upon the efficiency of the engine employed, an item that seemed to be left out in some statements. His own experience had not been such as to enable him to say with certainty that he could expect an engine to lose less than 15 per cent. in itself before it began to give anything to outside work. It was necessary to know what the amount of this loss was before a proper comparison could be made between the various systems of transmission. [Mr. H. B. ATKINSON said that the horse-power referred to in the Tables was brake horse-power.] The brake horse-power given out, and the actual work done, were to his mind the points from which they ought to start and at which they ought to end in any calculations of that kind. Previous speakers had offered some criticism as to the style of dynamo employed by the Authors for their work, and he thought that any one who had had experience of coal-mining would agree with Professor Forbes in wishing, as

Mr. Smith. far as possible, to avoid sparking. What had struck him as rather paradoxical was, that Professor Forbes had started with a very strong and absolute prohibition of the employment of electricity in coal mines, and had afterwards elaborately described a particular kind of motor that had recently come under his observation in America. He thought there was no electrician present who would not much prefer an alternating-current motor if it could be economically constructed, and could be made reliable not only in working, but in the very important point of starting. Professor Forbes did mention some difficulty on that score, which he said had been overcome. He was interested to find that the Authors and several other electricians, whose knowledge and experience in these matters were much greater than his own, had, through a series of experiments, been led to a conclusion which he had himself arrived at intuitively some years ago, namely, that the Gramme type of armature was better suited for rough work than the drum type. At meetings of that kind their duty was not merely to criticise, but as far as possible to make suggestions. He would offer one with regard to the percussive drill. He did not know how far it might be practicable, but it had helped him out of a difficulty some years ago. He had been preparing for a lecture upon the action of the wings of birds and insects in flight. He wanted to illustrate a theory that he had formed upon that question, but his difficulty was how to imitate the movement of the wing of the insect without any complication of mechanism. He did so by alternately compressing and releasing air in a cylinder, the pressure being transmitted through a tube to a similar apparatus attached to the model. Possibly, in the rock-drill, the required blow might be produced by allowing the motor to force and to suck air in a similar way. Perhaps some of those who were engaged in this work might find it worth while to make the experiment.

Mr. Crompton. Mr. R. E. B. CROMPTON wished to call attention to a diagram prepared by Messrs. Smith, Beacock, and Tannett, of Leeds, who, he believed, had made the first electrical coal-cutting machine (*Figs. 6 and 7*) about three years before the date mentioned by the Authors. It consisted of an oscillating arm furnished with cutters, and mounted on a vertical spindle, so as to oscillate through a stroke of from 5 to 8 inches. The short end of the lever was worked by a pair of electro-magnets, to which the current was applied alternately by a very crude form of commutator. The result was that a vibrating motion was given to the arm and the coal was cut. The difficulty was the imperfect

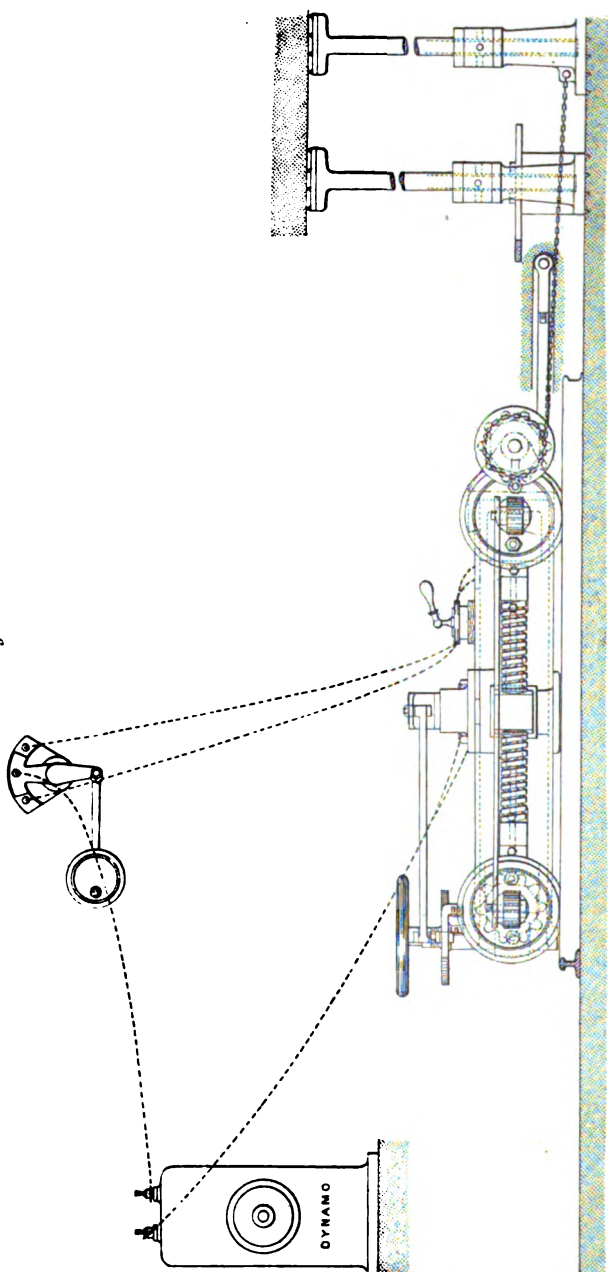
knowledge of electrical matters in those days. He did not doubt Mr. Crompton. that the Authors had acted wisely in adopting the revolving cutter-arm which they had shown. The next point to which he



wished to draw attention was the moderation of the language used by the Authors when comparing the efficiency of electrical transmission with that of compressed-air transmission. He agreed with several speakers that nothing was to be gained by over-

Mr. Crompton.

Fig. 7.



ELECTRIC COAL-CUTTING MACHINE.

Scale $\frac{1}{4}$ inch = 1 foot.

stating the case, but he thought that those who were conversant with the use of electricity would agree with him that the Authors had, if anything, erred on the side of moderation. He was surprised to hear them say that their percentages were taken on the brake horse-power. He thought that they had taken them on the indicator diagram, and even then he was prepared to substantiate them. He was quite certain, therefore, that they had allowed an ample margin, and that electrical engineers ought to be able to carry out, and more than carry out, all that had been said with regard to the transmission of power up to the distances named. Professor Lupton had thrown down a challenge to electrical engineers which he believed had been taken up by one or two gentlemen present. But it had already been taken up in a much more practical form, namely, by the supersession of air-transmission plant all over the country. This was being done to a large extent in South Wales, and he believed that in a few years the transmission of power by compressed-air would be nearly obsolete. Reference had been made to the cost of repairs for electrical-transmission plant as compared with compressed-air plant. The one complaint that the owners of the latter had made to his firm was the great expense of the up-keep. It was costly in two ways—first, on account of its being so inefficient: that portion which answered to the generating plant—the steam-engine and boilers and the air-compressing pumps—was from two and a half to three times as big as was necessary for the electrical plant, and the expenses of the up-keep were proportionately increased. Then there was also the interest on the money invested, and not only was the prime cost greater, but more space was taken up by the machinery. He had carefully gone through the figures presented by the Authors as to the comparison of the first cost of air-transmission plant with electric-transmission plant, and he unhesitatingly stated that they were correct and moderate. They had left out one important item that ought to have been put in, namely the cost of the boiler-power necessary, which, in the case of air-transmission plant, was nearly three times as much as was required for electrical transmission. He had heard with considerable interest the remarks of Professor Forbes as to the extraordinary dangers which he foresaw in the use of electrical machinery in fiery mines. Professor Forbes had apparently overlooked one important matter. It was true that, however carefully they might guard against the danger of the communication of the sparks inside the casing to the explosive gases, there was some risk. He admitted it, but it would always be so wherever

Mr. Crompton. machinery was introduced into mines. They could not work any kind of coal-cutting machinery without the possibility of the steel points coming into contact with some material harder than the coal, and so causing sparks. Explosions might be produced in that way. He thought however that the risks from such a cause were greater than they would be from sparks communicated from the commutator in carefully devised casings such as the Authors had recommended. Some of the drawings of the casings, he thought, might be improved upon. He considered far too much space for explosive gases was given, and that it might be reduced to such an extent that the danger would be extremely small. With reference to the drill question he agreed with a previous speaker, who wanted something simpler than the Ingersoll drill, driven whether by a flexible shaft as shown by the Authors, or, in a way which he himself preferred, by a simple rope on to a V pulley. He would like to have a direct-acting percussive drill, with a quick, short stroke. They should in fact imitate some beautiful drilling machinery which was shown in the Paris Exhibition two years ago, driven by compressed air, giving he did not remember how many thousand strokes per minute. The stroke was infinitesimally short, but the machine was able to cut away the surface of the hardest substance at an astonishing rate.

Mr. A. Sopwith. Mr. ARTHUR SOPWITH considered coal-cutting one of the most important subjects connected with electric mining-machinery. They had arrived at a great state of perfection in motors and had certainly got considerably beyond the experimental stage with coal-cutters. The Authors had mentioned one special type as the best, namely, the rotary cutter-bar; but so far as the application of electricity was concerned, whether the machines worked with a rotating disk, or with a band with cutters, it was practically the same. Under certain conditions they could be used to considerable advantage; but they required a fairly even floor, and a good roof, so that there might not be too much intervention of timber. They also required, in the case of the rotary cutter-bar, a band of coal or shale somewhat in a state of tension, which considerably assisted the action of the cutters. The converse of those conditions frequently existed, and would greatly militate against the working of the machine. They might often have to cut in dead tough material in which very little progress could be made. Again, the timber necessary for the roof sometimes made any continuance of working in the line of the face impossible. In America there were machines worked by

electricity which obviated some of those difficulties. Instead of Mr. A. Sopwith going along in a continuous line, a short length only was taken at a time, and a cut was made of a certain width and depth; then the machine, which could be clamped to the rails, was moved forward, and another cut was made alongside; or if anything intervened it could be placed further on, and the remaining part cut out. The principal advantage of this method was that it obviated the necessity of continuing along the face. The application of motors to work percussive or pick machines might also be easily understood. He was about to make a suggestion, which might be open to criticism, but he understood that something on the same lines had been done in America. It was practicable from a mechanical point of view; and the question he wished to ask was whether there was any real difficulty in carrying it out from an electrical point of view. Mr. Crompton had said that a machine which would give a very great number of blows, let them be ever so small, would probably be a very good type, and he agreed with that view. The point which was looked after very often in coal mining was that of having a machine which would do a great deal of work. He felt certain that a much lighter machine, although at a great sacrifice of power, would gain so much in portability and convenience, that in the long run it would do as much work as a big one. The principle of what was known in America as the Electro-Magnetic Reciprocating Machine appeared to him to be certainly applicable to drills. In it, a bar was drawn into a coil by the action of a current, and brought back again either by springs or by its own weight when the circuit was broken. The great point was the question of the make and break; but if a generator was constructed by which rising and falling currents were created in a closed circuit, the work was done without any possibility of sparking. He thought there should be no difficulty in designing a coal-cutter upon the same principle. It might be said that it would not be easy to construct a machine which would do anything like the same amount of work; but then it would have all the advantages of simplicity, and the absence of movable parts subject to wear and tear. Although in practice it might appear that the wear and tear of coal-cutting machinery worked by motors was not very great, it could be easily understood that quick rotating and heavy armatures working along an uneven floor must be a source of continual expense; but if percussive action could be employed in working coal in as simple a manner as he understood it had been in America with rock drills, he thought they

Mr. A. Sopwith. had arrived at a solution of the difficulty. A person not familiar with the subject would be struck with the large amount of power which was lost in the transmission of the electrical current. No doubt when the use of electricity became, as in all probability it would in a short time, universal throughout mines, and it had to be conveyed long distances, the question would assume greater importance. There was one thing which he thought most engineers would object to, namely, having high tensions down a mine. Although the transforming system might be carried out, it seemed to him that it would lead to great complications. But he thought there was no place so convenient for the economical carrying of a current as a coal-mine, especially if it happened to be dry. In his case he had used, although not for conveying power, a quantity of old iron and old wire-rope instead of copper, the resistance being only $\frac{1}{3}$ ohm per 1,000 yards, and the cost, including insulation, the same as that of a copper cable of $\frac{1}{12}$ of good insulation. The relative economic value of iron to copper was as 5 to 1, so that at all events there was room for allowing five times the amount of current at the same expense. He mentioned it because it had impressed itself upon his mind, especially as he had tried an experiment with laying wire-ropes side by side on the floor of a coal-mine, and found that practically there was no leakage at all, the coal-dust being a perfect insulator. Certainly great economy might be effected by the use of such conductors for conveying the current to centres of distribution in a mine.

Mr. Walker. Mr. SYDNEY F. WALKER wished to offer his hearty congratulations to the Authors, and the firm they represented, on having been the first properly to grapple with the question of the electrical transmission of power in mines. He thought that nearly all those who had studied the question had felt that, before it could be on the same footing as compressed-air, hydraulic power, and other systems now in use, they must have self-contained apparatus. If a mine-owner had some pumping to do in a place where he could get a steam-pump, he had only to connect his steam-pipe to it. Until the introduction of the present machines, they had to put down a pump with a motor and gearing separate, and he thought that these inventions would prove a marked advance in the transmission of power by electricity. As to the important question of sparking, he agreed with the Authors up to a certain point. He had repeatedly expressed the opinion, before Mining Institutes, that the sparking at the commutator was not dangerous, and would not fire gas, and he still adhered to that view, for the following

reasons. First, he had discharged ordinary coal-gas over an old series commutator ten years ago, and could not get the slightest sign of ignition. Then it should be borne in mind that in order to produce ignition, the spark must pass through the gas, and he would ask whether a revolving armature did not create something like a vacuum in the neighbourhood of the commutator, which would keep the gas out. He had another and a much stronger argument which had come to him only recently. Petroleum gas, he understood, was much more inflammable than ordinary coal-gas. The chief engineer of a petroleum steamer had told him that he had a dynamo working in their pump-room, which was always full of petroleum vapour, into which it was dangerous to go with a naked light; but there had not been the slightest sign of ignition. At the same time Mr. Walker realized with the Authors, that if there was any feeling amongst mine-owners that the danger existed, that feeling must be respected and provided for. He did not think that their cover was of the slightest value, for they could not bottle up a spark: the proper course was to get rid of it. There were two points where the spark might be—one at the switch, and the other at the commutator. It appeared to him that there was no reason why the switch need be in gas at all. It could be put in the engine-house, or at any convenient point, with an ordinary electric-bell signal between it and the motor station. With regard to the motor itself, his view was that where the gas had to be provided for, and there must be no sparks, there were three ways out of the difficulty. If the alternate-current motor proved itself a success, that was evidently the machine of the future for all work of that kind. The second way was the one which Mr. Sopwith had mentioned, and which he thought could be arranged very simply, and worked by an alternate dynamo from the engine-house or by reversing-gear in the engine-house near the dynamo. The third way was to reduce the spark at the commutators below the firing point. He thought it was clearly proved by experiments that had been made, some by himself and some by Mr. Mordey and others, that it was not a spark *per se* that ignited the gas, but a spark of a certain energy; there must be a current of about 10 amperes, and, at any rate, a pressure of 2 volts. If, therefore, they could construct a motor so as never to have a spark with a pressure of 2 volts at the brush, including self-induction and everything, it would be harmless. That was simply a question of construction and of size. Like Mr. Sopwith, he strongly advised that the tension in a mine should be kept low. He was aware

Mr. Walker. that, at the present moment, both pumping and hauling were being done with 300 and 500 volts, and no serious harm had resulted. He thought it should be remembered that those were selected cases; when they came to regular everyday work they might and probably would have accidents. It was not that a man might be killed with the shock, but that it might throw him into a position, say in front of a train of loaded trams, where he might meet with a severe accident. He might get, even from a comparatively low voltage, a very severe shock, with his wet boots, wet socks and hands, in a wet mine. He knew an instance in South Wales in which a man received an extremely severe shock from a voltage of only 160. As to the gearing, the whole thing appeared to him to lead to low voltage, which would enable them to go at a low speed. Everyone knew that the gearing was one of the difficult points that electrical engineers had to deal with, and for that reason, and also on account of the danger of shocks, he strongly advised that the motor should be made as large as possible and with a low voltage. Though the copper in the cables would be larger, the interest on the money spent on it would be more than made up by the decreased cost of maintenance.

Mr. Bolton Mr. REGINALD BOLTON said that Professor Lupton had classified the mines of this country into the fiery and the non-fiery. From a coal-miner's point of view that was all right, but Mr. Bolton ventured to divide the subject into two larger heads—soft-rock and hard-rock mining. Coal-mining came under the former head, and from the hard miner's point of view it was a comparatively simple affair. Those who had had to deal, for example, with the tin cable of Cornwall would know what he meant by hard-rock; and such materials required special consideration. He had ventured to give a few diagrams with reference to the question of percussive rock-drills in order to illustrate the particular duties required of them under the conditions which he had mentioned. He would not at that late period in the discussion enter into a detailed description of each particular machine, but the diagrams would show the main features of the rise and progress of percussive rock-drilling, from the ancient production of Samuel Miller in 1806, taken from the drawings accompanying his specification, which constituted the earliest form of percussive drill of which he could find any mention, up to those machines now in use throughout the world in all kinds of hard mining. The rock-drill referred to in the Paper was essentially what was described as a hand power-drill, and from the

point of view of mining for metals, it was nothing but a toy. Mr. Bolton. There was no possibility under such conditions as he had described of using a rotary motion in the heading of a mine or in driving hard tunnels. The Ingersoll machine, to which the motor had been shown attached, and which had been exhibited in the room, would, he imagined, bore at the utmost about 2 inches per minute, with a hole $1\frac{1}{2}$ inch diameter. The duties of a rock-drill should amount to at least 10 inches per minute, with a hole $1\frac{3}{4}$ inch in diameter, tapering to $1\frac{1}{4}$ inch at the bottom. That was an amount of work with which the machine mentioned in the Paper would not be able to cope. But there was a form of electrical rock-drill which had not been described and which possessed great merit, namely, the direct percussive electrical rock-drill, modelled upon the lines of the drills driven by steam and air of which examples had been given. There were no doubt a number of ingenious inventors at work upon the subject, particularly in the United States, and he knew at least four machines which were now being experimented with in America, only one of which had been mentioned in the discussion, that of Mr. Van Depoele. So long ago as 1880, his friend, Mr. Charles Ball, of New York, invented a percussive rock-drill, the principle of which he believed was being employed in other drills at the present time. It consisted of two solenoids, in which there was a loose soft-iron bar on a piston as it would be in the steam-drill, caused to vibrate by the action of a current which was made to pass through each solenoid alternately by a tappet arrangement outside the drill, which no doubt would cause sparking, and would be liable to considerable damage under the rough conditions in which the machine had to work. The arrangement would never, he imagined, be successful in that form. But there was a machine called the Marvin electric rock-drill, which seemed to have got over many of the difficulties. The solenoids in that case were operated by alternating pulsations of current directly produced by a dynamo, which had a special attachment upon the commutator. There was no make-and-break contact whatever upon the drill. The solenoids were enclosed in a casing of boiler-tubing, and mounted on a tripod in the ordinary way. That machine up to the present time had managed to achieve the remarkable record of boring 2 inches per minute with a hole 2 inches in diameter, which was not a serious performance for underground work. He was afraid that the principle adopted in the model of the flying insect which had been described, would not be serviceable for such a purpose, and would probably be as much a failure as would be an attempt to make a serious steam-

Mr. Bolton. engine work upon the same principle. The blow given by a drill on a hard rock was very heavy in comparison with the size of the instrument. A 3-inch drill, weighing with its tripod at the utmost 300 lbs., might possibly hit a blow of upwards of 900 lbs., taking it in a vertical direction and obtaining the full benefit of the momentum of the piston running at a speed of perhaps five hundred strokes per minute. He knew of no exhaustive experiments to determine the exact force of the blow of a rock-drill. Everything in mining went by the ultimate result, namely, the amount of speed at which they could drive a heading, which in this country was not so great as in the United States. He would only refer to one instance of rapid driving in America as showing what electrical drilling would have to compete with. There was a tunnel being made in hard red granite 8 feet high by 16 feet wide, and two Ingersoll-Sergeant 3-inch rock-drills were used. The heading was driven $98\frac{1}{2}$ feet in one week, as certified by the engineer of the railway. That was a remarkable performance, and, as far as he knew, the most rapid on record. The experience of a number of speakers had been cited in favour of electrical machinery as against the use of compressed air, and he did not hesitate to say that he was to some extent a convert. But all experience did not go in the same way, and there were cases in which electrical machinery had been put in operation in extensive mines and afterwards withdrawn. He might instance that of the Girard Coal Company in Girard, Illinois, where a complete electrical plant had been put in and afterwards pulled out. The circumstances were not actually before him, but he believed they went to show that great consideration was required before a complete plant of electrical machinery was adopted. He ventured to think that with all hard-rock mining the crux of the whole question was the use of a percussive rock-drill. When that was attained, electrical machinery would be largely used in hard mining; but it was of no use whatever to put down electrical plant for the purpose of hoisting, pumping, etc., if at the far end of the adit or heading they were obliged to use compressed air to drive the drills. There was also another point, namely, that at the end of the headings, which were in many cases extremely confined, a supply of air was absolutely necessary. One speaker had mentioned that it would still be necessary to convey air to the extreme end of the heading. That was an undoubted fact, and it would obtain equally with electrical machinery and with rock-drills operated by compressed air. He did not think that the unfortunate air-compressor had altogether had a fair chance in

the discussion. He thought he might fairly say that quite 99 per cent. of the air-compressors he had seen—and he had seen a great many—had been operated by steam-engines of the crudest and simplest character, and in many cases of very inferior workmanship. One speaker had said that anybody could put an air-compressor together. So they could, but the machines so made were brought forward as showing what compressed air could do, and they were told that no better economy could be got out of them in the end than 26 per cent. With bad engines and with faulty systems of compressing air, with restricted pipes, and with a poor motor at the far end, nothing better could be expected. With electrical machinery, on the other hand, they had the latest systems; the engine was applied to drive the dynamo directly, and they had certainly in the motor a machine of a very high efficiency. But he thought that air-compressors might possibly in future be made of a better type and have better engines supplied to them. He had laid on the table a paper which had reached him only that day from the United States, showing a large compressed-air plant put down with compound condensing Corliss engines of the finest type, and he ventured to think that the results of those engines would be very high indeed. He had also a record of an air-compressor of the direct type, in which the total loss by friction was only 5 per cent. That showed that a good deal might be done in the direction of simplifying the machine. With reference to the percussive electrical drill, he had seen a printed statement to the effect that it would cut about 8 feet per hour in granite, and it required about 5 HP. Those were items which should be borne in mind in comparing its performance with that of other drills.

Prof. HENRY ROBINSON wished to refer to the Authors' statement with regard to the advocacy of a particular system. He thought it was desirable to avoid advocating in that room. They ought as far as possible to confine themselves to facts and not push home their opinions or predilections too far. He agreed with Mr. Bolton in the main in his observations concerning compressed air, but when he stated that an electrical installation had been taken out of a coal mine it was important to know the reason why it had failed. It was impossible to judge without that information, and the bare statement might prejudice a system which was now coming into vogue. The Paper referred to the advocates of compressed air as not having recorded the results of experience in the same way as the Authors had with regard to the system which they were certainly pushing forward with a great deal of advocacy.

Professor
Robinson.

Professor Robinson. It was true that there were no good recent observations concerning compressed air, but in the absence of such data, he thought it was undesirable to bring forward the results of experiments made in 1874. He agreed with Mr. Bolton that many of the compressors in use at that time had become quite obsolete; or, if they were still at work, they ought to be broken up. He had carried out works for compressed air at Birmingham on a somewhat large scale, and some experiments were made last year with a view of ascertaining as nearly as possible the efficiency of the system. There were thirty-four motors worked by compressed air at 45 lbs. above atmospheric pressure, and it was found that the average efficiency of them was 42·66. When he said the average efficiency, he wished it to be understood that the fittings of some of the motors were very imperfect, so that the results were lower on that account. It was only right to say that in some cases the air, besides being used expansively, was heated before utilization, which was, of course, an important feature. In many instances, however, waste heat was employed, so that it did not cost the manufacturer anything. But taking the bad with the good, the average efficiency was 42·66. Within a short time after those observations were made the most defective motors were altered, and the working parts modified so as to give better results; and, as far as he had been able to ascertain, the average efficiency had been raised to 45 per cent. In another case a 40-horse engine, worked by compressed air, was experimented on very carefully, and the air was heated to 280°, and the efficiency in that case was found to be 73 per cent. Those figures might be taken as accurate, and he thought that they should be recorded. When he heard of the average efficiency of compressed air being as low as 20 or 25 per cent., he felt that those who were not familiar with the subject might receive an erroneous impression. For example, in the Birmingham works at the central station installation, in one corner of the site there was a small 200-HP. engine, which was used during the laying of the mains for testing, and in another part there were three triple-expansion high-speed engines of 1,000 HP. each. If diagrams were taken from the old type, no doubt they would show a very low efficiency, but it would not be right to take the average efficiency of the old, badly constructed 200-HP. engine, and the good modern engines as a fair representation of what compressed air would do. Nobody would now put down such an old-fashioned type of compressor. Many of the most important parts had been modified materially, so as to give much better results. It was, therefore, desirable to avoid

coming to the conclusion arrived at by the Authors, and he ^{Professor Robinson.} thought that the tables they had given were rather hard upon compressed air. He would only say one word upon the other form of energy, in which he was equally interested, for he happened to be carrying out works for the utilization of electrical energy for motive purposes, and was therefore not an advocate of either one or the other. At the present time the St. Pancras Vestry were carrying out a large installation, and next month there would be an exhibition of electrical apparatus in St. Pancras Hall on a large scale, which would probably afford a good deal of information on the subject to those who were desirous of obtaining it. He had had to do with the application of various forms of power for labour-saving appliances underground. He had examined collieries under different conditions, and was quite certain that he would never advise the introduction of a motor on a system which would increase the risks in fiery seams. Any one who had had to do with collieries, and knew the recklessness of the ordinary miner, would hesitate to increase the dangers which already existed. He desired in conclusion to express his great pleasure at seeing the Authors present, and at finding, so soon after the distinguished course they had pursued at King's College, they had made a mark in life.

In answer to Mr. Ll. B. Atkinson, Professor Robinson said the 73 per cent. meant the total efficiency from the engine to the motor, including the waste in the motor. Both the brake and the indicated HP. had to be taken into account at the same time.

Mr. T. E. CANDLER remarked that he had been brought up among ^{Mr. Candler.} fiery seams in the north, and had since had a great deal of experience in mines in various parts of the world. He was afraid the discussion had been to a great extent between the advocates of compressed air and of electricity. The Authors had chosen for the application of electricity the most difficult machine, from a miner's point of view, which they could possibly have selected, and he was inclined to agree with Mr. Bainbridge that it was not an effective one for coal-cutting. Mr. Bainbridge had brought forward one which Mr. Candler had seen doing very good work; but it was not desirable that a machine in which sparking occurred should be introduced into a mine where there was gas, whether the sparking would light it or not. Until that point had been definitely settled by experiment, neither Her Majesty's Inspectors of Mines, nor any colliery managers, would be right in allowing it to be used. The method of bottling up the spark was another thing that no mining engineer should agree to, because

Mr. Candler. there would always be a danger of something happening to it. It had been remarked that if the ventilation was not sufficiently good to make the coal mine safe, it should be made so; but the speaker had evidently no idea as to the way in which fire-damp was found in a coal mine. At one moment the workings might be perfectly safe, and at the next, through some atmospheric change, or some big fall in a goaf, large volumes of gas might be sent temporarily into them. That was one reason why the safety-lamp was so useful, because it showed when the danger existed, and they could take steps to drive the fire-damp away as quickly as possible. One great benefit derived from the use of compressed air for driving rock-drills was the assistance which it afforded to the ventilation. It had been largely employed in metalliferous mines, in driving adits or tunnels, where, if electricity had been used, they would have had to adopt some expensive mode of renewing the air. One speaker had quoted some very low figures as to air-compressors. Mr. Candler had been told by the best authorities in the United States that the efficiency was always between 40 and 50 per cent., and that it was impossible to put the average below 40 per cent. for ordinary air-compressing machines. In the north of England he had tested a good many, and during the last six or eight years they always attained from 40 to 43 per cent. The use of electricity in mining would be valuable chiefly where the water or other motive power was a long distance away. In various parts of the world there were minerals of great value, where there was no other power that could be brought to bear to work the machinery required. An illustration had been given by Mr. John Taylor, in which the mine was several hundred feet above where the water-power was. That was a case in which transmission could only be effected by electricity. In some parts of the world he had seen power taken a distance of 2 miles by wire-ropes. He should think the efficiency must have been extremely small. In other places he had seen it conveyed by water through pipes for a very long distance. He was not able to state the exact loss in friction and from the contortions of the main. Another case in which he thought electrical power might be tried, was that of a mine where there were forests a long way off, over inaccessible mountains, and no fuel was to be obtained in the neighbourhood. If the forest could be cut down cheaply plant might be laid down, and the power carried along wires as had been suggested. He had seen electricity used with great effect for pumping in old abandoned mines in order to test them. It was possible to go to places very difficult of access with a

portable electrical pump and a small quantity of wire. Those Mr. Candler. were cases in which the Authors might render great assistance to mining operations by the application of electricity; but as far as coal-cutting machinery was concerned, he was afraid that it would not at present, at any rate, be very useful.

Mr. FREDERICK HURD thought the question of danger had been Mr. Hurd. very much overrated. He spoke from practical experience. It was no uncommon thing for him to spend a sixteen-hours' shift in a mine day after day. He had seen machines at work and giving off sparks that would amaze some persons, in places where they had been most particularly requested to be careful, and he was quite sure that it was not possible for these sparks to cause explosions in the way referred to. In the north of England, in Cardiff, and all over the country such machines were used; also in France, Belgium, Austria, Hungary, America, New Zealand, India and China, in places where large volumes of gas were supposed to be constantly given off. It was impossible for the cutters to come in contact with the grit and pyrites in the coal without giving off some sparks, and there was more danger to be anticipated from the cutter than from the dynamo. It had been stated that electrical machinery for coal-cutting was entirely out of the question. He could only say that there were now scores of collieries which had been working at a loss, and had never paid a dividend until they adopted coal-cutting machinery. He had known instances in which air-compressing plant had been put down, a single machine costing £700 or £800, and after eighteen months' use £7,000 was expended upon an air-compressor. If any one wanted to get information as to what they were doing in the way of cutting coal, the reply would be: "It is an experiment. Try it for yourselves; we have nothing to say." His firm had taken contracts for 1s. 6d. a ton, finding the machinery, keeping it in order and providing the men, and they had received large royalties. They had often had notice that the mine-owners would be glad to close the contract and purchase the machinery, but they held them to their bargain, and told them, "We have contracted for three years, and if you want the machinery you must buy it," adding three years' royalty and profits. In some cases that had been done. He thought that in the appliance described by the Authors there was more than a germ of success. It had had a remarkable beginning; it was not a mere theory, for it had been put in practice for four years, and it could not be denied that the work had been successfully accomplished. It was the mining engineers who would evidently be benefited by

Mr. Hurl. it; but at present they did not seem to care to encourage it. They said, "If we give a man a pick and lamp it matters very little whether you see him or not, but if we get your machinery it means three or four nights a week going down to see what is being done." There could be no doubt that electrical plant had its advantages, if only for the handy way in which a small wire could be used to transmit power. Reference had been made to what might be accomplished with compressed air, but even if they could get cent. per cent. the advantages obtained would not compare with the facilities that would be procured by the introduction of wire. The large pipes necessary to convey compressed air were a source of great expense; and they were at the mercy of any one who wished to play them a trick. A man would be very careful before he interfered with a wire, and that was a point in favour of electricity. In a large colliery where 1,400 or 1,500 tons a day were brought up by the use of machines, it would be found that the difference occasioned by the portability of the wire was very great. Formerly there was no way of ventilating except by the old system of bratticing, which was very costly. But in driving a heading by compressed air it was found that all the bratticing was unnecessary, and that the exhaust from the machine ventilated far better and more safely than any other way. It had been said that in cases of that kind compressed air would be needed. He quite admitted it, and it was very proper that Government should step in and compel them to use it; but there was a great difference between employing it for motive power and for ventilation. He ventured to say that with a 2-inch pipe the largest colliery in Great Britain could be ventilated thoroughly, and with a better result than at the present time. Every corner of the mine could be utilized and made safe, and machinery used for hauling, pumping, driving a heading, or cutting coal, in straight work, pillar and stall work, long-wall work, or any work they liked. The weight of the machine had been objected to, and it had been said it was important that it should be portable. If they wanted good work to be done, they must have something heavy behind it. One speaker had complained that the machine shifted about, from the vibration caused by working. If the weight were greater this would be prevented. Many thousands of pounds had been wasted by colliery engineers and managers over light machinery. They had made their machines from 4 cwts. to $1\frac{1}{2}$ ton, and they found that they had greater control over them, and could move them about with as much facility as those of less weight. The

result was that they had never had any break-downs, the Mr. Hurd machines always standing to their work. They required no fixing to the sides or the roof. The wheels were all coupled together by connecting-rods, like double bogie-engines. They could easily be moved forward, but would not move backwards when cutting operations were commenced.

Mr. E. R. DOLBY remarked that various speakers had alluded to Mr. Dolby. the danger of sparking in fiery mines, and Mr. Crompton had stated that he thought the risk from the sparks produced by pick-axes was almost as great as that from the sparks on the commutator of a motor. After the disastrous explosion at St. Etienne, in France, a sub-commission was appointed consisting of three well-known gentlemen, Messrs. Mallard, Le Chatelier and Chesneau. They had prepared fire-damp, pure C_2H_4 , and let it into a wooden box from a Bunsen burner. In that way they had produced a mixture of different percentages of fire-damp and air. They then placed pieces of sandstone and porphyry near the box, and struck them with pick-axes in such a way as to cause sparks to fall into the box. The mixtures were made so that a naked light ignited them. They found that a mixture of ordinary illuminating gas and air could be ignited by sparks so produced. They then proceeded to experiment upon the fire-damp mixed with air, and they found that it could not in any case be ignited with the sparks. The pick-axes were made of mild steel with removable points, such as were used at St. Etienne, and also of iron such as were employed at the Anzin mines. Besides these they tried picks of steel with 13 per cent. of manganese, and also of aluminium bronze with 2 per cent. of silicon. The aluminium bronze picks produced no sparks, and in the whole series of experiments they never succeeded in igniting any mixture of fire-damp and air. That, he thought, was exceedingly satisfactory. It had been said that the sparks produced on the commutator never caused an explosion, and he thought it was clear from the experiments he had mentioned that sparks from pick-axes would not do so.¹

Mr. HOWARD D. PEARSALL said it had been confidently asserted Mr. Pearsall. in the discussion that the efficiency of electrical transmission was high, and that of transmission by compressed air was low. The cost of the latter had also been asserted to be much greater. Both those statements required considerable modification. With reference to the cost of an electrical installation, he would only

¹ "Le Génie Civil," vol. xvii., 1889, page 238. Also Minutes of Proceedings Inst. C.E., vol. cii., page 396.

Mr. Pearsall. remark that the Authors' estimate was based entirely on the asserted high efficiency of the transmission; so that unless that claim was maintained the estimate also fell. With regard to compressed air the Authors' estimate for pipes was only correct for a small plant with low efficiency, and was very much beyond the mark when the efficiency was as high as he should presently speak of. The best result in electrical transmission which had been laid before the Institution was that given by the Authors in Table II, but it could hardly be said to be substantiated by the "precise particulars" which according to the Authors were so amply furnished for electrical transmissions. There was nothing whatever in the Paper to indicate how those figures were arrived at; and from the way in which they were printed side by side with an estimate of air-transmission they also might be merely an estimate, and not the definite results of an actual trial. Still less was it asserted that they were the average of a long continued series of trials; indeed the Authors' own Table I threw doubt upon their Table II. There the ratio between the indicated efficiency at the pumps and the brake HP. of the prime mover was given as 67 per cent. at the highest, and 51 per cent. at the lowest, taking the three efficiencies of the dynamo, cable, and motor. But besides this, 15 per cent. had to be deducted from those figures for the difference between indicated and brake HP. of the prime mover. According to Table I, therefore, the actual efficiency of the plant never exceeded 50 per cent., and was sometimes only 36 per cent. That was for a transmission of 2 miles; at 4 miles, 32 per cent. would, according to the same table, be the maximum. This efficiency was that of the generating and transmission plant alone, without taking into account the further loss in the pumping machinery. Similarly, another statement, which was made with great emphasis by Mr. Taylor, did not, after all, show such a high result when certain other items were taken into account. Mr. Taylor had given them information only with regard to the efficiency of transmission, which he stated was 85 per cent. But that was not the efficiency of the plant, but solely that of the conductor, and meant that 15 per cent. of the power was lost in only 2 miles of cable. The loss in transmission in Paris by compressed air through 3 miles of pipe was stated, on the authority of an independent report of Professor Kennedy, to be only 2 per cent. With a loss of 15 per cent. in the cables, the total efficiency of the plant described by Mr. Taylor could not have been more than 45 per cent., and in all probability did not average 35 per cent. of the gross power of the waterfall. Besides that he believed nothing had been said about

the great falling off of efficiency, which was known to occur when- Mr. Pearsall.
 ever the dynamo ran at any other than its best speed. The unsuitability of the plant for driving some kinds of machinery had been strikingly shown by the Authors' figures for pumping by electricity, where they indicated, in one case, a net efficiency of only 10 per cent. He thought it was no exaggeration to say that the worst results with compressed air could be paralleled by similar ones with electricity. But in designing pumping plant an engineer would not assume a consumption of 10 lbs. of coal per horse-power per hour, merely because there were bad engines in existence which required that quantity. He maintained that it was just as unreasonable to assume an efficiency of 25 per cent. or 30 per cent. in contemplating an installation for distribution of power because there were faultily designed plants which gave no more than that. The Paris installation was most carefully tested by Professor Kennedy, who found an efficiency of 40 per cent., but at the same time expressly stated that the arrangements were palpably imperfect. The greatest fault was that the air was not properly cooled during compression, and the loss from that cause alone was nearly 40 per cent. Actual experience had proved again and again that sufficient cooling could be applied to the cylinder to reduce that loss to at most 25 per cent. Making this correction, the efficiency of the Paris installation would be 50 per cent., and that was the least that any competent engineer should expect to get at present. But in many places the original motive agent used was water-power. In such cases 50 per cent. was by no means the limit of what could certainly be done. There were two reasons for this, the extreme simplicity of the machinery and the fact that they had a practically unlimited cooling agent at their disposal, and that by properly applying it almost the whole of the 40 per cent. loss, which occurred when the air was not cooled, was avoided. The machinery he referred to was that in which the air was compressed directly by the water. In air-compressors driven by steam-engines it was usual to employ a quantity of water for cooling equal to about two-thirds of the weight of the air compressed, but in the machines to which he referred he had succeeded in using for cooling a quantity of water a thousand times the weight of the air, and moreover, it was employed in the most efficient manner, the cooling surface being distributed throughout the air to any desired extent. He had compressed air in that way without being able to detect any rise of temperature at all. In the Paris installation the efficiency of the prime mover was 84·5 per cent., and that of the compression was 61 per cent. The product of these was

Mr. Pearsall. 51·5 per cent., and the actual net efficiency of the whole plant was that ratio multiplied by the efficiency of transmission and that of the secondary motors. In compressing air by water-power on the principle to which he referred he had obtained an efficiency of 85 per cent., and if that was multiplied as before by the efficiency of transmission and of the secondary motors, the net efficiency to be realized at a distance of 3 miles was 67 per cent. On consideration of facts which were already well known, it would be seen that this result was in fact only what was to be expected. Those facts were (1) That 40 per cent. efficiency could be and was attained even with no cooling, as in Paris; (2) That the absence of cooling caused a loss of 40 per cent. of the gross power; (3) That a quantity of cold water, a thousand times the weight of the air, could be used so as to produce a nearly perfect cooling. Hence 40 per cent. waste was saved. If they could eliminate, in the case of the Paris installation, the loss from the heating of the air, all the other losses would amount to only 33·33 per cent., leaving 66·66 per cent. net efficiency. He had succeeded in eliminating that loss almost entirely when the motive agent was water-power, used in the way he had indicated; hence they might expect an efficiency of at least 66 per cent. in such a system, without taking into account what was due to the greater simplicity of the machinery. Even that was not the limit of what was possible. Directly the difficulty from heating was removed, they could use much higher pressures, and so obtain a great economy in the mains. The efficiency of the secondary motors could also be largely increased by making due use of the special facilities which the system he had perfected gave. He would not go into details, as it was too large a subject. It was sufficient to say that the principle had been actually carried out, and was no longer only a theory. Compression of air, with an efficiency of 85 per cent., was an accomplished fact which could be seen any day, and he thought it could not be denied that what he had ventured to call the natural and necessary consequence of that fact was a net efficiency of transmission, at any distance, superior to that attainable by any other known method.

Mr. Trotter. Mr. A. P. TROTTER remarked that his only excuse for speaking was that the first two of the machines in question were among the last which he had made before withdrawing from his manufacturing business, and he was pleased to see that the principle on which the Authors started—that of the rotary cutter geared to the motor—had been adhered to. The development of the invention had consisted in the elaboration of the details, and if the Authors had tried first one coal-cutter and then another, they would

probably not have achieved the results they had already accomplished. Many arguments had been put forward against the use of the machines in coal mines, but the only experiments which had been adduced (besides those that had just been mentioned, and which were not electrical) were those of Mr. Snell, and he did not succeed in igniting a mixture of coal-gas and air by means of sparks from a machine, until the commutator got seriously hot. With the large armatures used in the motors for the purpose of keeping them cool, it was obvious that the temperature of the commutators need never be allowed to rise to such an extent. Mr. Snell had mentioned carbon brushes. Mr. Trotter would have been glad to have more information about them, because his experience was that they heated more than any other form of brush that had been tried. But where the only reason for the ignition of a mixture of air and gas was the fact that the commutator got hot, it seemed that carbon brushes would not be suitable. Those who had spoken of fire-damp igniting at the machine appeared to have lost sight of the fact that with the carefully-protected cases used in the motors, the fire-damp could not suddenly produce an explosive mixture. It must leak in by degrees, and, as the Authors had stated—though this had evidently escaped the attention of Professor Forbes and others—before it could become an explosive mixture, the gas would burn, if it could be ignited at all by the spark, in the same way as in a miner's lamp. When the fire-damp got into the lamp it did not suddenly become an explosive mixture; it gave warning, and when the miners retired, they need not let the coal-cutting machine continue to run; the current might be cut off at the spot, or when they came back to the main switch. It was rather disappointing that the discussion which directly challenged air-compressing engineers, had not brought out a few more figures. He had hoped that at Birmingham they had attained something better than 44 per cent. It was difficult to know, with regard to the Paris installation, how to distinguish between what they were doing and what they might do. At all events, the 44 per cent. or even 50 per cent., was an enormous encouragement to electrical engineers, for there were few cases in which they need go as low as that. The loss by transmission in cables might be put at 10 per cent. or 20 per cent., leaving an ample margin for losses in dynamos and motors. Evidently air must do a great deal more than it had yet done if it was to compete with transmission by electricity in mines or elsewhere. It was remarkable that the only speaker who had really upheld the Paper, was connected with air-compressing

Mr. Trotter. machinery himself, and knew the difficulties of both systems. One interesting feature of the Paper was the application of electricity to mechanical engineering. They had all seen what terrible blunders had been made in tramway work by persons who knew something of motors and very little of tramways. The inventors of these machines had, after learning electrical engineering, studied the details of the art of coal-cutting, and adapted their motors to it. The only criticisms that had been made from a mechanical point of view, had been upon the Ingersoll drill. Not a single word had been said as to the electrical driving. It had been stated in the discussion that the wheel-cutting machine was better than the bar-cutter; but the amount bared with the bar-cutter was, if anything, rather more than with the wheel. He believed that the first machine, which used to tear both itself and the coal-face to pieces, and to throw itself off the rails, and hang on by the cutter-bar, travelled at the rate of about a yard a minute. The Authors had not mentioned one rather important point, namely, how many men would be required to do the same amount of work as one of the cutter-bars. The Authors had stated that they were going to try a reciprocating machine. That was one of the most difficult problems that an electrical engineer could have to deal with. To produce anything on the reciprocating principle larger than the electric bell, and make it work with fair economy, seemed exceedingly difficult.

Mr. Ravenshaw.

Mr. H. W. RAVENSHAW observed that series-wound motors were always used for high voltage because they required comparatively few turns on the magnets, whereas shunt-windings for high voltage required a large number of turns, and there was a great liability to failure of the insulation if the shunt-circuit was broken. The only difficulty with a series-wound motor was, that when working on a constant-potential circuit, if the load was taken off the machine was liable to run away at a very high speed. He had been working on the subject for some time, and had found that by using iron or steel having a great amount of hysteresis, i.e. retaining the magnetism induced in it, he could make a motor which would not race. Employing Dr. Hopkinson's curve for hard mild steel, he came to the conclusion that, in the case of a machine he was building, which was intended to run at 600 revolutions, if he used soft iron magnets it would make on open circuit about 2,400 revolutions per minute, which would mean the destruction of something in connection with it. With mild-steel magnets, the maximum speed would be only 1,800 revolutions, a reduction of 25 per cent. But, by employing an automatic

switch so arranged that when working at full load the two halves of the magnets would be connected in parallel circuit, and when below half load they would be connected in series, he found that with steel magnets the maximum difference would be from 600 revolutions at full load to 780 revolutions with light load. That would be an allowable variation in any case where great regularity was not required, and between full-load and quarter-load the speed would not exceed 680 revolutions per minute.

Mr. C. W. ATKINSON in reply, said that several speakers had referred to the question of the relative merits of cutter-bars and cutter-disks. Their remarks, he thought, had chiefly arisen from a misconception of the method of working the particular cutter-bar referred to in the Paper. Mr. Bainbridge had drawn attention to the fact that in the disk machine the cutter was made to revolve outwards and split the coal off along the line of least resistance, and consequently nearly the whole baring was done by splitting and not by cutting. When the Authors began coal-cutting they used the Blackburn cutter-bar (Fig. 18), with which it was intended to cut the whole of the coal. The cutters on the stars were arranged one after the other so as to bare the whole surface. They soon came to the conclusion that it was a wrong method, and that it was better to imitate as far as possible the action of the common miner's pick, and that was what they had endeavoured to do in the cutter-bars they had designed. Instead of placing six cutters on one star-shaped holder, they now placed them one after another so as to form a single-threaded screw with a pitch of 1 inch. The consequence was that each one cut a narrow groove about $\frac{1}{4}$ inch in depth, and the edge split the coal off into the next, so that nearly the whole baring was done by splitting and not by cutting. The result had been to reduce the power required by at least one-half, and to produce much less fine dust, and in every way to improve the nature of the cutting. Other questions involved the nature of the particular situation. Disk-cutters might be employed where the roof was very strong, and where there was little danger from jamming, but in most cases there was this risk, and consequently the bar-cutter was more generally useful. He thought that the greater part of the criticisms had arisen from a misunderstanding of the nature of the bar. Several speakers had stated that the wear and tear of the compressed-air machines was much less than that of electric motors. He did not think that was the case. The whole machine shown in the diagrams was completely enclosed in dirt-tight cases, the gearing itself running in oil, the only revolving part visible

Mr. Raven-
shaw.

Mr. C. W.
Atkinson.

Mr. C. W. Atkinson. being the cutter-bar, and that formed a dirt-tight joint at the gear-box cover, so that after many months' running, when the lid was taken off, the oil was perfectly clean. The consequence was that whereas in air-machinery they considered it a fairly good record if a pair of brasses wore two or three months, the wear of the brasses in the electric machines was so small that after some months it was hardly perceptible. He thought, therefore, that the mechanical wear was less in the electrical than in the compressed-air coal-cutting machine. In reference to electrical wear they had never found any difficulty. The armatures were very strongly constructed, the repair required was only on the commutator, and in their experience that had been extremely small. Several machines had been running for years without requiring anything more than an occasional turning up of the commutator.

Mr. L. B. Atkinson. Mr. L. B. ATKINSON said that exception had been taken to the Authors having used the results of figures published originally in 1874; but it would appear from the remarks of Professor Lupton, that the only improvement he was able to record since that date was one of 25 per cent., and he appeared to have fallen into the error of believing that he could add this to the 31 per cent. efficiency, making it up to 56 per cent. It was, however, only 25 per cent. of 31, or about 6 per cent. more. Professor Robinson had referred to the experiments at Birmingham, but he did not say whether he took the brake HP. of the generating-engine and of the motor, or whether he took the indicated HP. The Authors had been careful to state that they took the brake HP. of the engine and of the motor, and he hoped that Professor Robinson would make it equally clear what figures he had relied upon. It had been stated that the Paris figures might be very much improved. Possibly they might; all that the Authors had ventured to do was to deal with the figures which had been actually obtained, in working with electricity and with compressed air. They had given the figures obtained from working tests of the motors; the only remaining element being the loss in the cable, and that, in the present stage of electrical science, was a mere matter of arithmetic, and not a question involving any theory. Another important point upon which special stress had been laid was the question of the safety of electricity in fiery coal mines. Professor Lupton and Professor Forbes had contested the Authors' statement, that the arrangement of covers designed by them afforded a safe means of employing electricity in mines. The Authors had stated that all experiments went to show that

there was very little danger of ignition, but that if there was any the proposed arrangements obviated it. Professor Forbes said that the casings looked very nice in the drawings, but as a matter of fact would not exclude the gases. Mr. Brain thought if they could prove their case and keep the gas out for two hours mining engineers would be satisfied. In order to settle that point they had one of the boxed-up motors placed inside a large box filled with coal-gas, or coal-gas and air. After five hours they drew out, by means of a pipe, some of the gas inside the cover surrounding the armature. This was passed through the eudiometer, and they endeavoured to explode it with an electrical spark, but were unable to do so either when it was mixed with equal volumes of air, or with four volumes of air, or taken as it was from the interior. As a check they ascertained by experiment that they could explode a mixture as weak as 1 in 14. For the purpose of measuring the actual proportion of gas inside the covers, Mr. Pitkin had kindly lent them one of his gas-detectors, which were very sensitive. The result showed that after five hours, in an atmosphere with very much more gas than would be found in any coal mine in existence, only 0·5 per cent. of gas could be detected in the chamber. He thought that that answered both Professor Forbes' theoretical objection and also the remark of Mr. Brain. He might mention that the motor was stationary, but that was rather a disadvantage, as it was found that the chief leakage was through the bearings. When the motor was running the oil was evenly distributed on the bearings, and there was no tendency to leakage. Professor Forbes had dwelt at great length on the danger of using motors, and afterwards called their attention to the Tesla motor. They had heard of that machine for two or three years, and it had always been going to take them by storm, and do many wonderful things. The last time he made inquiries about it, nearly a year ago, he found that it was still unpurchasable even from the manufacturers in America. He thought therefore that they ought not to wait until the motors had been perfected before attempting to do mining by electricity. Professor Forbes had admitted that there was a difficulty about starting the Tesla motor, and if so that would be a fatal objection to the employment of it for coal-cutting. Sometimes, after a stoppage or a fall of the roof, the cutter-bar became jammed so tightly that a man might pull as hard as he could on a long lever placed between the bolts of the coupling and not be able to move it. By suddenly switching on a current to a motor that would take 25 amperes, with an engine with a heavy fly-wheel, they

Mr. L. B.
Atkinson

Mr. L. B. Atkinson. might get 100 or 150 amperes for a second or two, and that would pull the motor clear almost of any stoppage. The Tesla motor was difficult to get to start at all, and could not possibly move the machine in a case of that kind. The great advantage of electricity in coal-cutting was the enormous power of starting where there was a block. It was surprising to see how a machine weighing $1\frac{1}{2}$ ton would lift itself up off the rails at starting if the cutter was jammed. The rock-drill shown in Figs. 8, Plate 4, was one which the Authors had actually worked, and the difficulties connected with it were not electrical, but mechanical. The drill was not strong enough to stand the continuous wear brought upon it, and some of the cams and rods gave out. In reply to the question as to what work it had done, he had been informed that it had driven six holes, each a yard deep, in three and a half hours. That was not a great performance, but it was more than they had been doing by hand in the headings where the drill was put to work. A good deal had been said about direct-acting percussive rock-drills, and in the Paper the Authors had indicated that they were at present working upon such a drill, which they had every reason to believe would yield results better than those given. They had, however, confined themselves to what they had actually done, and had said nothing as to the results anticipated in the future. With reference to the question of the relative merits of the bar-cutter and the disk-cutter, two or three speakers had stated that they believed the latter would do the most work, but unfortunately they had given no data and no reason for the supposition. He knew that the makers of disk-cutters were very particular to choose soft materials to work in, and would not try them in hard. The Authors, on the other hand, had considered that they ought to cut in what the manager of the pit thought was stuff that he could best afford to waste, and the cutters they had designed were used in material which disk-cutters would probably not work in at all. He believed that Mr. Frederick Hurd, who had had a great deal more experience than any one present of disk-cutters, looked favourably on the form of cutter given in the Paper, after having considered the relative merits of both. Professor Lupton's argument that they ought not to attempt to use electricity in coal mines, because there was a remote possibility of an explosion, might be applied to almost every class of machinery. There were boiler explosions and railway collisions, and cables were occasionally over-wound with serious results; still they did not say that those mechanical contrivances ought not to be used because accidents might possibly

happen. The proper way of approaching the subject was to inquire if the thing was worth doing. Professor Lupton said that it was, if the Tables of efficiencies given in the Paper were correct, and he did not seriously confute them; Mr. Atkinson therefore concluded that it was worth attempting, and the Paper was the record of what they had done in that direction. Reference had been made to the firing of gas by sparks from a pick-axe or from any steel instruments striking against a hard material. Mr. Atkinson had recently read in the *Colliery Guardian* a report of the Prussian Fire-Damp Commission, in which he found the following paragraph:—"Doubts have often been raised against the supposed harmlessness of lighting by means of a spark from steel (flint and steel), because according to the experiments of Messrs. Vilaine and Griot, the sparks thus obtained inflame the lighting gas, and also because it appeared as if the steel mill of ancient use, both in England and in Belgium, had occasioned explosions of fire-damp. At first, the Prussian Commission decided to investigate this question, but afterwards renounced it on account of the experiments of Messrs. Wüllner and Lehmann at Aix-la-Chapelle, on the inflammability of mixtures of fire-damp by incandescent metallic wires and electric sparks, which proved that even violent sparks from rupture of the current accompanied with the explosion of fragments of iron in a state of combustion, had no effect on the inflammation of fire-damp."¹ The results therefore of experiments so far had been to prove that the danger had been very much over-rated, whilst the system adopted by the Authors practically excluded the gas from the point of danger.

In further reply to the discussion, the Authors intimated that they would confine themselves, as far as possible, to the ground covered by the Paper, and more particularly to maintain the various propositions contained in the summary, under the headings of A, B, and C, and to deal with the criticisms of the particular arrangements and apparatus exhibited and described. A considerable amount of additional matter had been contributed, but with this they did not propose to deal.

The view put forward by the Authors had been supported by Mr. Snell, that under normal conditions, a motor would be unlikely to ignite gas; but admitted also the advantage of arranging it, so that even under abnormal conditions no danger would arise. Mr. Snell had also upheld the opinion of the Authors, that the

¹ *Colliery Guardian*, Feb. 20, 1891

The Authors' whole armature ought to be protected, and not the commutator only. His remarks agreed with their own views as to the greatly increased efficiency obtained by utilizing electricity instead of compressed air for pumping, hauling, &c.

In the course of his remarks, Professor Lupton had severely criticised the use of electricity in mines where gas was present, on the ground that, unless certain precautions were taken, danger was to be anticipated, and therefore advised the use of compressed air, unless it could be shown that electricity offered great advantages; but Professor Lupton would lead his hearers to suppose that this advantage did not exist, and that, as the figures given by the Authors in some cases related to machinery made and tested a good many years ago, they were no longer to be relied upon, owing to the great improvements which had been made since. Professor Lupton had suggested further, that there should be a competition between electrical and compressed-air plants transmitting 10 HP. to a distance of 10,000 yards. Table V, which the Authors had calculated, showed what

TABLE V.
COMPRESSED AIR *v.* ELECTRICITY.
Transmission = 10,000 yards.

—	Size Pipes.	Engine B.H.P.	HP. given by Generator.	HP. lost in Main.	HP. put into Motor.	Motor B.H.P.	B.H.P. Motor B.H.P. Engine	Cost Complete and Erected.
Air . .	Inches. 3	62·1	38	19	19	10	0·16	£ 2,500
	4	39	23·6	4·6	19	10	0·26	3,100
	5 & 4	35·8	21·8	2·8	19	10	0·28	3,445
Electricity	1½	19·2	16	4·6	11·4	10	0·52	1,580

results might be anticipated from such a trial, taking Professor Kennedy's experiments in Paris, and well authenticated trials of dynamos and motors as the basis of the calculations. He omitted to give any tables or details of trials, to prove his contention, and in the absence of these data, and in the face of the fact, that all existing records supported the Authors' figures, Professor Lupton's suggestion ought not to be entertained. In criticising Table II, Professor Lupton referred to an installation running at the Trafalgar Collieries, in which the distance was the same, and although a cable of nineteen wires was used instead of seven, as described

in Table II, there was a loss of 20 per cent., whereas in the Table, a loss of 10 per cent. only was shown. Professor Lupton pointed out that the voltage used at the Trafalgar Collieries was one-half of that proposed to be used by the Authors, and this statement accounted for the whole difference, for by doubling the volts, and keeping the size of the conductor unaltered, the loss would be reduced to one quarter, so that the cable might be halved in size, and the loss still be one-half of that with the lower volts. This corresponded with the Table in every respect. Professor Lupton stated that a 3-inch pipe would be ample for a 10 HP. engine working with compressed air; but every maker of compressed-air machinery to whom the Authors had mentioned the point, had selected a 4-inch pipe for the work, when working at an ordinary pressure of about 50 lbs. to the square inch. Professor Lupton's alterations, therefore, to the figures and prices were incorrect. He also asked what was the price of the machine, compared with that of a compressed-air engine; these costs were given in Table II, the price of both electric and compressed-air machinery being taken at an average market price. Professor Lupton's remarks as to the apparently contradictory advice given by persons whom he had consulted as to the proper voltage to use in transmitting power were capable of an easy explanation. Small motors of $\frac{1}{2}$ HP. to 1 HP. were difficult to wind for more than 150 volts; if, therefore, it was desired to run them from mains supplying large motors, at say, 300 to 500 volts, it was better to work either two or three of them in series, or to insert resistance, and although by this means the efficiency might be reduced by 50 per cent., yet the useful work obtained was greater than would be got from a compressed-air motor of the same size, and to which power was being transmitted for an equal distance. The question as to the best voltage to use was one which an engineer in laying out a plant would carefully consider, in order to get the best results; but criticisms concerning the efficiency of motors as small as $\frac{1}{2}$ HP. running off transmission systems, involving, perhaps, 200 or 300 HP., were not very vital to the question.

Some interesting data relating to electricity in mines had been given by Mr. A. Grothe, but his remarks were rather supplementary to the Paper than in discussion of the points raised in it.

The Authors pointed out that the remarks of Mr. Bainbridge, who, whilst admitting the economy in power gained by using electricity instead of compressed air, stated that, nevertheless, he

The Authors' reply.

The Authors' reply. would prefer to employ the latter, owing to the smaller chance of stoppage or breakdown, were unsupported by results. As a matter of fact, the following statement might be given: A dynamo, driving the Authors' coal-cutting machines, was used regularly for a period of two years without any repairs or breakdown. In the earlier coal-cutting machines made by the Authors' firm, some difficulties were encountered with the failure of the armature insulation, but these had been overcome, and there was every reason to suppose that the later machines would last as long as their other motors, some of which had run daily for two and three years, without any breakdown whatever. As to the wear and tear of the coal-cutting machines themselves, whereas the brasses of compressed-air coal-cutting machines lasted usually less than one month, one of the Authors' machines, removed from a pit where it had been working for several months, was examined, and it was impossible to detect any shake in the bearings. This result was obtained by the use of simple rotary motors, and by the entire enclosing in dust-tight cases of every bearing.

Mr. Bainbridge, in describing a pump which he was putting down, had entirely corroborated the statement by the Authors, that the cost of electric plant was one-half that of compressed-air plant. Mr. Brain had quoted the opinion of Mr. Colquhoun, that in his experience the efficiency of compressed-air plant never exceeded 25 per cent., and further, gave the results of some tests of plants of modern construction which showed that 17 or 18 per cent. was all that was obtained in practice, thus showing that the Authors had erred on the side of moderation in dealing with the efficiency of compressed-air plant.

The Authors regretted that considerable bias in favour of a particular system, and apparently want of practical experience of any other, had led Professor Forbes to condemn the arrangements described by them in unmeasured terms. He appeared to be under the impression that most coal mines were normally filled with an explosive mixture, and that the working face was the most dangerous place in the mine, whilst, as a matter of fact, it was generally a part where the air was purer and more free from gas, owing to the thorough ventilation, than in almost any other. It was perfectly true that, if the Authors' motors were left for, say, a week, in an explosive mixture, it would be possible to imagine an explosion occurring from their use; at the same time, such a condition was not in any way likely to occur, and the supposition of the Authors, that an electric motor would not be worked continuously in such a mixture for a longer period than

two or three hours, was one that allowed an ample margin for every practical case. In reply to the suggestion of Professor Forbes that the words used in the Paper were intended to produce the impression that this machinery had been employed in fiery mines, although such had not been the case, the Authors might point to a pumping-plant, working with one of these enclosed motors, which had been in use in the Murton Colliery of the South Hetton Coal Company for seven or eight months, and which had been approved both by the mining inspectors and by the engineers of the colliery, and which had led to no fires or explosions. Professor Forbes had pointed out the danger of using electric cables at all; but the experience of all colliery owners and managers who had tried them had shown that, if they were properly put down in the first instance, and had reasonable supervision, difficulties of the kind suggested did not occur in practice. With regard to the "Tesla" motor—although machines of this class undoubtedly had a future before them, the Authors thought that no engineer practically acquainted with the requirements of coal-cutting machinery would recommend a motor where, with the latest improvements, the torque exerted at a standstill is considerably less than when running; and although in that motor no commutator is used, nevertheless it would be equally desirable to enclose the armatures, to prevent sparking in the event of a wire being broken.

It had been pointed out by Mr. Crompton, in the course of his remarks, which were eminently valuable, as being founded on a wide practical experience, that the Authors had, in referring to the relative efficiencies of electricity and compressed-air plants, erred on the side of moderation; and he had further referred, in answer to Mr. Bainbridge, to the fact of the decreased cost of repairs in electrical transmission.

In reply to Mr. A. Sopwith's criticisms, relating mainly to the question of the possibility of maintaining a roof along a roadway on which the coal-cutting machinery was to be worked, the Authors would point out that the fact of using machinery was in itself the best means of providing a suitable roof, for when the cutting was done by hand, the progress was so slow that the roof was weighted on the roadway, whereas, when using machinery, where the coal could be cleared within a few hours of the starting of the cutting, this weighting on the face was avoided, and much less timbering was required. The contention of the Authors as to the excessive and over-rated apprehensions which existed as to the ignition of explosive gases by electric motors had been borne

The Authors' out by the practical experiments referred to by Mr. Sydney Walker; but although Mr. Walker, in this respect, was not an alarmist, he appeared to be one on the question of volts and of shocks. The Authors' system of enclosed motors, in which every electrical part was encased in a metal cover connected with the earth, precluded all possibility of receiving a shock whilst working in the ordinary way, and therefore the dangers anticipated by Mr. Walker were overcome; and although low voltage might, in some respects, be desirable in plants transmitting, say, 100 HP., the currents to be handled became so large, that very great difficulties arose, quite apart from the extra cost of the cable.

The remarks of Professor H. Robinson called for attention, he being the only speaker who endeavoured to support the contention that compressed air was as efficient, or more efficient than electricity, by any show of figures. But the Authors could only assume that the results given as *efficiency* represented the ratio between the indicated HP. of the engine and the indicated HP. of the motor, in which case, as bearing on the present discussion, they were not comparable with those in the Paper. But if the results given by Professor Robinson could be maintained by publication of figures or records, this should certainly be done, as they were considerably in advance of what the Authors had seen.

In reply to Mr. Pearsall's criticisms, the figures in Table II were estimated or calculated, and were placed side by side for the purpose of comparison. The data on which these figures were calculated were as follows:—In the electric transmission, the loss in the cables was accurately known, while the efficiency of the electric motor had been determined by careful experiments to be 85 per cent. The brake HP. of the steam-engine was also arrived at by a knowledge of the efficiency of the dynamo, gained by careful experiments. In the case of compressed air, the efficiencies of the compressing plant and of the air motor were taken from the figures in Professor Kennedy's Paper before the British Association, on the "Popp" system in Paris, the prices in each case being those given by leading makers. The pump in Table II, which Mr. Pearsall criticised as giving a gross efficiency of only 10 per cent., was a small dip-pump, where the quantity of water, compared to the head, was large, and where, owing to the circumstances of the case, the pump was worked from a dynamo of low voltage. In order to meet this point, data were now added relating to another pumping plant (see Table VI), in which every detail, from the indicated diagrams downward, was given, showing a gross efficiency from the indicated power to the water

delivered of 49 per cent., or, taking the same data as thus used in the Paper, viz., HP. in water delivered —, an efficiency of 72 per cent. Mr. Pearsall gave a considerable number of figures, and ended by saying that compressed air, with an efficiency of 85 per cent., was an accomplished fact, which could be seen any day; the Authors only regretted that he did not indicate where it could be seen, as they were quite sure that a large number of engineers would be interested in a result which was certainly unique.

The Authors' reply.

TABLE VI.

ELECTRIC TRANSMISSION OF POWER. TESTS OF PUMPING PLANT.

		Per Cent. of I.H.P.
Size of cable	1½ S.W.G.	
Distance engine-pump	1,200 yards	
I.H.P. of engine	31.75	
Loss in engine and belt	10 HP.	31.5
" dynamo	1.92 HP.	6.05
E.H.P. of dynamo	19.8	62.5
Loss in cable	1.7 HP.	5.36
HP. put into motor	18.1	57.14
Loss in motor	1.5 HP.	4.72
B.H.P. of motor	16.6	52.4
Loss in pump and gear	1 HP.	3.15
HP. delivered by pump	15.6	49.2
Gallons per minute	118	
Pressure at pump, lbs. per square inch	190	
Efficiency of transmission—		
or $\frac{\text{B.H.P. of motor}}{\text{B.H.P. of engine}} = \frac{16.6}{21.72}$	..	76.5
Volts at dynamo	410	

Correspondence.

Mr. Fowler. Mr. GEORGE FOWLER said the Authors assumed somewhat prematurely that in the application of electricity to mining machinery they had to compete only with compressed air. It was perfectly true that of late years the use of compressed air to drive underground machinery had been allowed to occupy the field. In his opinion, steam conducted in pipes, or rope-driven gearing, would have effected the main haulages of many collieries, at far less initial and working cost. Probably no responsible mining engineer would at the present moment introduce a steam-boiler to underground workings. But the loss of power in a range of well-covered steam-piping, 300, 400 or 500 yards in length, would be immaterial in comparison with what it would be in the case of compressed air. And it might be remarked that the exhaust steam of an engine was harmless in most upcast pits. But he desired more especially to speak on the subject of high-speed endless ropes. It must be premised that the main haulages, over which by far the largest amount of power was expended, usually conveyed to the drawing shafts, and the drums or endless-rope gearing which actuated them were, in most cases, located at these points. Probably four-fifths of the haulage power required in a colliery was thus effectively expended within 500 yards of the pit bottom. He thought that this power could be most cheaply conveyed from engines on the surface to the gearing in the pit by high-speed endless ropes. Practically the belt, which in the Authors' arrangement drove the dynamo, was extended down the pit, and taken to the hauling gear where the power was utilized. The extra friction thus introduced was merely trifling, so that instead of the five losses of power arising from the use of the dynamo and motor, namely, (1) friction of the belt on the dynamo; (2) loss of power in the dynamo; (3) resistance of the cable; (4) loss in the motor; (5) friction of the belt or gearing on the motor; there was only the friction of the rope or belt round the four or five large sheaves which conducted it from the engine at the top to the machinery at the pit bottom. He had had considerable experience in this direction, and believed that in one case an effective power of 40 HP. was transmitted to the bottom of a deep pit, with the loss of not more than 10 per cent., and at a cost for ropes not exceeding £10 per annum. He was of opinion that neither compressed-air nor electrical machinery could

in first cost or working cost compete with this method when the distances from the bottom of the shaft were moderate. With regard, however, to the conveyance of power on long and circuitous routes, for small auxiliary haulages, and for coal-getting machinery, he believed that the Paper contained matter of the greatest value to the mining engineer. The form of coal-cutting machine which the Authors suggested appeared to have great promise of efficiency, although there was reason to fear that in some cases the cutter-bar might get blocked. And the irregular way in which coal seams occasionally broke off at the face, would always occasion loss with a machine which was obliged to take a straight course along a bank face. It was better to employ currents of low tension so as to avoid danger to the men. He was not quite clear whether the Authors used a double cable or returned the current on the rails. The latter course was open to the objection that they might be inadvertently touched. It was undesirable to afford the workmen any excuse for objecting to give the coal-cutting machines a fair trial.

Mr. HERBERT W. HUGHES remarked that the Authors were to be congratulated on their Paper, which could not fail to be interesting to mining men, and at the same time would remove some of the prejudices which existed in their minds against electricity. The prominent feature of the Paper was the descriptions of apparatus intended to enable electric motors to be worked in situations where an explosive atmosphere might exist. He thought that the results obtained by the Authors were very satisfactory, and would increase confidence. At the same time, it had always appeared to him that the danger of using electricity in mining had been exaggerated. In the first place, the great majority of mines did not regularly contain explosive atmospheres, and in the event of a sudden outburst of gas the motor might be immediately stopped. Sparking at known points, or in the case of short-circuiting, appeared to be preventable, as it depended on the design of the machine, the intelligence of the workmen operating it, and last, but not least, the common sense of the purchaser. In the desire to secure economy in outlay, less money was often spent on safe-guards than should be the case. Electricity appeared to be particularly applicable to the operation of coal-cutting. Machines could undoubtedly undercut coal cheaper than manual labour, under suitable circumstances; but the difficulty of driving them by compressed air or wire-ropes was so great as to nullify the advantages, even where favourable conditions existed. In the facility with which power could be carried about when

Mr. Hughes. electricity was employed, this medium stood unrivalled, and the cost of up-keep was less than with either of the other systems. Experience in this country seemed to have been confined to the type of machine described by the Authors, but in America several designs had been successfully applied and had been in daily operation for over eighteen months. The machine most in favour appeared to be the one made by the Jeffrey Manufacturing Company. It was furnished with a cutter-bar similar to that described by the Authors, except that the teeth were mounted on a shaft which had the same diameter throughout its length; this shaft was driven by chain-gearing, and was from 39 to 42 inches in length. An essential difference, however, was the direction in which the cut was made. In the Blackburn machine, the bar was at right angles to the face of coal, and the cut proceeded in that direction. In the Jeffrey machine, the bar was parallel to the face and the cut also; it really did the work in the same direction as a miner. When the cut was made to the required depth, usually about 5 feet, the bar was thrown out of gear and withdrawn, the machine moved sideways along the face over the length of cutter-bar, and the process repeated. This system got over two disadvantages: first, the inability of most coal-cutters to work in stalls which were set with timber at close intervals; because, so long as the props were wide enough apart for the machine to be got between (about 3 feet 6 inches), it could easily be placed in position, even if they were close to the face. Secondly, the irregular holeing generally produced when the floor of the seam was undulating; because this machine could follow any variation in the floor which took place within the length of the cutter-bar. From a Paper by Mr. H. C. Spaulding,¹ it appeared that twenty-three of these machines driven by electricity had been applied, and that the amount of work done by each averaged from 600 to 900 square feet of undercut in ten hours. The height of undercut was 4 inches. The distance from the power-house to the working places in the mines varied from 1,000 to upwards of 5,000 feet. The motors were wound in series for 220 volts, with a capacity of 15 HP.

Mr. Rooper. Mr. W. O. ROOPER said that the Tables and data contained in the Paper would prove of much practical value to all who were engaged in the application of electricity to mining. He had hoped

¹ Transactions of the American Institute of Mining Engineers, New York Meeting, September 1890.

to have heard from the Authors facts as to the merits and demerits Mr. Rooper. of lead-covered cable, cables run on insulators, and highly insulated cables contained in casing, with remarks as to their relative cost, durability, and damp-resisting qualities. He had obtained such good results from the use of bitumen as an insulator, that he had adopted, at Mr. T. O. Callender's suggestion, bitumen-covered cables laid in heavy wooden casing in a large mine installation for light and power. With regard to the Authors' remarks as to separate lamp and power circuits, the scheme seemed feasible for short distances, but in a large mine it would probably be found that the extra cost of laying and maintaining four cables instead of two would counterbalance any advantage which might accrue from the greater steadiness of the light. In his experience power was the primary object in a mine, and light was a secondary consideration, and the steadiness or unsteadiness of the lamps would only affect the number of hours they would last. There was one consideration in connection with the ventilation question which had been omitted by the Authors, viz., that the exhaust air from a compressed-air motor was purer than would be obtained from a fan placed in the heading itself. This was noticeable in the case of long headings, and the necessity of forcing fresh air to the workings entailed the placing of the fan as near as possible to the entrance and the use of long air-pipes in which there was considerable loss by friction. He was using a 330-watt motor, driving a small Sturtevant fan at a speed of 1,800 revolutions, and forcing air along 150 to 200 yards of 6-inch pipe so as to keep the workings clear. As to electric rock-drilling by means of the percussion drill, it seemed that the Authors had had little practical experience in this direction. The plant illustrated might be useful in proving that the work was possible, but it by no means fulfilled the most important requirements of the case. The object of rock-drilling by electricity was to supersede hand-labour. The first essential was that it should cut into the rock quickly, and the second that it should be easily adjusted, otherwise the miner working by hand would catch up the electric drill after each hole, and no practical advantage would be gained. The Authors' plant was unwieldy, and involved much labour and loss of time in setting it in position. The flexible shaft arrangement might be useful for work of an intermittent character, but it was hardly a desirable piece of machinery to introduce into a mine. These remarks were based upon actual experience. Mr. Rooper would prefer a more compact, self-contained, and easily adjustable apparatus, designed upon the lines he had indicated. The best

Mr. Rooper. work accomplished, by means of the description of plant illustrated, was the drilling of six holes 1 inch in diameter and 33 inches deep, in three hours and a half, including the time spent moving and re-setting the drill. The actual speed of drilling in slate rock was 2 to 3 inches per minute. With hand-labour the rate of progress was about $\frac{1}{4}$ -inch per minute. There was therefore reason to believe that electrical machinery might be profitably applied to this purpose.

Mr. Steavenson.

Mr. A. L. STEAVENSON observed that the subject of the transmission of power in mines had occupied his attention for nearly forty years. His present impression was that fuller tests would prove electricity to be inferior to a well-contrived rope system, in respect of useful effect, partly owing to the high speeds of the dynamos, which had to be reduced by toothed wheels or belts. Electricians seemed hardly to realise the extent of the danger if a fire should occur in the long, dark, thickly-timbered passages of a mine. The constant crushing and moving of the roof, floor and sides, must eventually affect the wires and their covering, and any fire there, with strong currents of air passing, would probably shut in for ever all the men behind it.

Mr. Stokes.

Mr. A. H. STOKES said the employment of electric motors in mines had for a long time been seriously delayed by the anticipated danger from sparking, and this especially applied to workings in which fire-damp was occasionally found, or in which locked safety-lamps were used. It was clear that managers of such mines would hesitate to adopt electric motors, if the parts liable to sparking were less perfectly secured against the danger of inflaming fire-damp than the safety-lamps. The Authors appeared to think that in the case of an inrush of fire-damp, "means should be adopted to allow the machine to be stopped working, before this explosive gas has had time to come in contact with the commutator and brushes;" but it should be pointed out that the workman's first indication of explosive gas would be from the flame of his safety-lamp, and the fire-damp would have penetrated the box cover of a motor (unless it was hermetically sealed) as quickly as the safety-lamp. It was further probable that an inrush of explosive gas would instantly place the workman in the dark, and he would flee for his life, leaving the motor running. The coal-face was the most likely place in the whole of the mine at which to find outbursts of fire-damp, and hence such machines must be absolutely safe, without dependence upon human manipulation in cases of sudden danger. The idea of boxing in the motor, or covering it with wire-gauze, had been long known to mining engineers, but such

methods had not yet obtained sufficient confidence to secure their Mr. Stokes. general use. The encasing of motors in iron covers was open to the following objections: (1) The possibility of the volume of enclosed explosive mixture being sufficient, if ignited, to burst the covering; (2) The danger of a bad joint, through which flame might pass; (3) The leaving out of a bolt, or the faulty adjustment of the cover, by a careless workman; (4) The cover might be opened whilst the machine was running, or otherwise it might be allowed to work without protection, thus exposing the brushes to the atmosphere of the mine; (5) The time taken in opening and closing such covers when the brushes and commutator required cleaning; (6) The increased weight and size of the machine. Similar remarks applied to wire-gauze coverings, with the addition that they were liable to injury. If electrical motors were to be introduced in mines they must be so constructed as to be absolutely free from the possibility of igniting inflammable gases outside them, and for this reason a motor was required in which the brushes could not be exposed to the atmosphere whilst the machine was running, nor the machine run until the brushes were securely enclosed by an absolutely flame-tight joint. The locking arrangements should not be dependent upon a workman, but should themselves govern the working or stopping of the machine.

THE AUTHORS, in reply to the Correspondence, pointed out that ^{The Authors' reply.} Mr. A. H. Stokes, while calling attention to the probable danger in fiery pits, arising from electric sparks, appeared to overlook the fact that, although sparking did occur at the commutator, it was under abnormal conditions, such as the breaking of a wire on the armature, that it was really dangerous, and these would not be provided against by the covering in of the commutator in the method he described. He was entirely mistaken in his statement that fire-damp would penetrate the covers of the motor as quickly as the safety-lamp, as their experiments showed that the gas would take probably twenty hours to produce an explosive mixture inside the covering, in which time, even should the man leave the machine, it could be turned off at the top without trouble. The answers to the objections of Mr. Stokes were as follows:—

(1) Was a possibility, not a probability.

(2 and 3) The covers were so arranged that, if they were on at all, they were properly adjusted.

(4) Could be provided against in the same way as in Mr. Stokes' suggested arrangements, either by locking the cover or by attaching the brushes to it, so that when it was off the circuit would be broken.

The Authors' reply.

(5) Was not material unless it should prove a practical objection to the working of the machines, which had not hitherto occurred.

The Authors did not know whether Mr. G. Fowler had had much experience in carrying steam in underground workings; they could only say that they had already replaced several pumps and other machines working with steam, owing to the discomfort caused by the heat and leakage of steam when carried underground. The objection to carrying ropes down the shaft of a colliery, particularly at high speeds, and the danger in the narrow roadways to men or animals in the event of a rope breaking, was sufficient to prevent any extended application of this system. In reference to the coal-cutting machines, the Authors might state that they had never yet seen one with the cutter-bar blocked. They used a double cable, and did not employ the rails to form the return circuit.

10, 17, and 24 February, 1891.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion on the Paper by Messrs. Llewelyn B. and Claude W. Atkinson, on "Electric Mining-Machinery," occupied these evenings.

LIST OF MODELS, &c.,
EXHIBITED IN ILLUSTRATION OF MESSRS. ATKINSON'S PAPER.
February, 1891.

Exhibitor.	Objects.
AQUEOUS WORKS & DIAMOND ROCK-BORING COMPANY	Boring-crown. Cores. Photographs of boring-machines.
ROBT. LIMPETT ANDERSON . . .	Gauze lamp used to examine the workings at Blantyre Colliery on the occasion of the explosion of fire-damp on the 22nd of October, 1877.
JAMES ASHWORTH	Safety-lamps (8).
REGINALD BOLTON	Working model of American ore-crushing machine.
HY. BRAMALL, M. Inst. C.E..	Rivet-moulding machine for making lead rivets for securely locking safety-lamps. Working model of Holcroft's safety-cage and detaching-hook. Working model of Owen's safety-cage.
BENNETT H. BROUGH . . .	Photographs (3) taken in the mines at Clausthal- am-Harz, Germany.
JOHN BROWN & Co. . . .	Pair of forged-steel wheels and axles.
REV. G. M. CAPELL, B.A. . .	Hand mine-ventilator. Mine friction-test tube. Working model of Capell fan.
ROBT. E. COMMANS, Assoc. M. Inst. C.E.	Grips and knot for Otto's aerial ropeways. Model of stamping-machine. Safety-lamp.
COX-WALKERS	Electric miners' bells and generators.
JOHN DAVIS & SON	Anemometers (Biram and self-timing). Clinometer (Louis Improved Davis's). Improved Hedley Dials, with Hoffman tripod heads, for instantaneous setting-up and level- ling. Safety-lamps constructed in accordance with the new Mines Act. Switches, switch-boards, and various electrical fittings. Theodolites and levels, with Hoffman tripod heads.
THOS. DOOWRA & SON . . .	Crowns with extractors. Samples of core. Working model of diamond drill machinery.
FOOTE & VON BUCH	Working model of tram-line on 'Series' electrical system.
FOWLER-WARING CABLES COM- PANY	Cables suitable for mining purposes.

Exhibitor.	Object.
GENERAL ELECTRIC POWER & TRACTION COMPANY	Portable motor for mining purposes.
W. T. GOOLDEN & Co. . . .	Bar armature (61 unit), pedestal, and spherical ohm-meter and generator for testing insulations, with sunbeam lantern and lamp for wet and dry situations. Coal-cutting bars and tools. Electric coal-cutting machines, with rotary coal-drill, grinding-jig, brush-holders, and carriers. Electrical measuring instruments, including Cardew voltmeter, and direct-reading ammeters and voltmeters (Evershed's). Electro-magnetic separator. Enclosed mining-motor. Resistance-frame for regulating current. Switches made for the Brighton Corporation.
G. J. LAMPEN & Co. . . .	Clip-pulley for rope-haulage in mines. Corf-greaser. Model of steel corf. Safety-lamps (2). Signal-bell.
LE GROS, MAYNE, LEAVER & Co.	Ingersoll rock-drills (2).
LONDON ELECTRIC WIRE COMPANY	Insulated wires and cables suitable for electrical work in mines.
EWING MATHESON, M. Inst. C.E.	Chinese translation of part of Matheson's "Aid-book to engineering enterprise."
MINING AND GENERAL ELECTRIC LAMP COMPANY	Electric miners' lamps (4) and batteries made of this company's 'lithanode.'
JAMES PITKIN	Electric miners' lamps (6). Explosive-gas detector.
C. E. RHODES, M. Inst. C.E.	Safety-lamps (31).
ROBURITE EXPLOSIVES COMPANY	Specimens of cartridges, &c.
J. R. SCHRAM, M. Inst. C.E.	Rock-boring machine on tripod.
Lieut.-Col. J. D. SHAKESPEAR, Assoc. Inst. C.E.	Safety-lamps (4).
SIEBE, GORMAN & Co. . . .	Life-size figure of miner in 'Fleuss' noxious-gas dress.
HENRY SIMON, M. Inst. C.E.	Model of 'Simon-Carvès' coke-oven.
M. THEILER & SONS	Recording water-level apparatus.
EVAN THOMAS & WILLIAMS . .	Safety-lamps (Cambrian & Bonneted fireman's).
WILLIAM THOMAS, Assoc. M. Inst. C.E.	Elliot's locked-wire rope welded by the Thomson-Houston process.
JAMES THORNE.	'Thorneburry' safety-lamp.
WELLINGTON & Co. . . .	'Gates' rock and ore-breaker.
WOODHOUSE & RAWSON UNITED	Miners' bells. Safety-lamps and lanterns. Switches and switchboards.

“Indian Bridges.”¹

ADDITIONAL CORRESPONDENCE, AND REPLIES OF THE AUTHORS.

Mr. C. O. BURGE remarked that Mr. Stoney's Paper on the New Mr. Burge. Chittravati Bridge was especially interesting to him as describing the reconstruction of one of a series of large bridges on the north-west line of the Madras Railway, of which, with one exception, he had charge when he was Resident Engineer on a maintenance division of that railway, and one of which, that over the Hugri, he partly constructed. They were the Cheyair Bridge (38 openings), the Pápaginí Bridge (20), the Chittravati Bridge (40), the Pennár Bridge (24), the Hugri Bridge (34), and the Tungabhadra Bridge (58 openings). These openings measured 70 feet from centre to centre of the piers, or about 64 feet clear between them. The original bridges were remarkable for having a great number of comparatively small spans, and for the cheapness of their construction, the cost per lineal foot being less than one-third of that of the bridge described in the Paper; the Pennár Bridge for example, only costing R.153, the Chittravati Bridge R.149, and that over the Toongabudra R.168 per lineal foot. The adoption of small spans made it possible to erect the girders at the back of the abutments, and roll them in sets of two continuous spans, over the piers to their respective places, and considerable economy was effected in this manner. The piers were of three types, viz. : (1) masonry built direct in the solid; (2) masonry on a group of small shallow brick wells; (3) screw-piles of wrought-iron. The piers of the Cheyair Bridge were undermined in a terrible flood more than twenty years ago, when the night mail train rushed into the gap with frightful loss of life, the Pápaginí Bridge had been partially or wholly reconstructed, the Chittravati Bridge failed in October 1874, as described in the Paper, and that over the Pennár was carried away on the 16th October 1889, and was now replaced by one very similar to the new Chittravati Bridge. Structures with more substantial piers and fewer of them in the first instance, would have been more durable, and it seemed, from the fact of the girders referred to in the Paper having been safely

¹ Minutes of Proceedings Inst. C.E., vol. ciii. pp. 123-200.

Mr. Burge, erected in the river bed, that little advantage was gained by the original erection on shore of the older bridges; for, as regards floods, all these rivers were of the same character. The failure of the original bridge over the Chittravati was evidently attributed to the insufficiency of the depth of the piers, and not to deficient waterway, as the new bridge was 164 feet shorter, deducting piers in both cases, a difference hardly accounted for by the fact that the old one was slightly skew to the channel. The Author was right in pleading for more latitude with regard to the dimensions of cylinder work, so as to allow for unavoidable divergence in sinking. Mr. Burge had drawn attention to a somewhat similar point in his Paper on the Hawkesbury Bridge, and in the correspondence upon that subject his opinion was supported by Messrs. Bouscaren, Collingwood, and Professor Gaudard.¹ Considering the nature of the strata passed through, the sinking of the cylinders at R.58½ per lineal foot seemed to be remarkably cheap, and reflected great credit on the Author, as it must be inferred from the fact that no contractors were mentioned, that the work was carried out departmentally. It would appear from the Paper that the piers above ground were of iron with masonry inside, and it might fairly be asked why the stonework was not exposed, the Nirgee limestone of which it was composed making very presentable masonry. Mr. Burge had not gone into the question of the quantity of metal provided for the stresses in the girder members, but it would appear from the small deflection of $\frac{3\frac{1}{8}}{3360}$ of the span with a maximum load that the erection of the structure at the maker's works and on the spot had been well carried out.

Mr. Robertson. Mr. ROBERTSON, in reply to the remarks that had been made as to the absence of information regarding the design, loads, and permissible strain, pointed out that the Paper dealt, as its title showed, solely with that part of the work with which he was connected, namely, the erection of the Lansdowne Bridge. The contract for the ironwork had been let before the Author was deputed to consider the erection. The cost of the ironwork was due partly to the fact that most of the members required some special shaping, and partly to the expense of putting it up in England, which might be considered a necessary preliminary in consideration of the locality for which it was designed. There being only a single span to the bridge enhanced the cost of erection, as special appliances, such as the central staging, were

¹ Minutes of Proceedings Inst. C.E., vol. ci., p. 2.

only available for a small tonnage. In reply to Mr. Young, con- Mr. Robertson.
sidering the position of III strut and that its length was 230 feet,
and weight 120 tons, it would have been difficult in any case to
have lifted it in one piece, and the details of construction rendered
it impossible in this particular instance. There was no difficulty
in setting the nose of III strut to exactly the right span for the
horizontal tie, when once it was completed and the distance
measured. The $1\frac{1}{2}$ -inch rope was only a guy to hold the head of
each piece after it was raised into its place, so as to prevent any
strain on the fastenings; and it was not intended to imply that
the rope lifted the piece. With reference to the suggestions that
an arch or a girder would be preferable to a cantilever, there was
no doubt that the site lent itself to an arch; but in balancing the
advantages it must be remembered that each day's work on a
cantilever was secured, while in the case of an arch the risk con-
tinued till it was closed. As for a girder, it would have been quite
impossible to erect false works in the Rori Pass, and such a proposal
was never made among the numerous schemes for bridging the
Indus. In reply to Mr. Read, the deflection under the test-load
(two of the heaviest locomotives and fully loaded wagons placed so
as to produce the maximum deflection at the nose of the cantilever)
was $2\frac{1}{2}$ inches. Deflections were observed at all the panel points
simultaneously by a water-pipe fitted with a gauge-glass at each,
the most important being checked by an observer with a level.
The oscillation was recorded by a seismograph, and only amounted
to $\frac{7}{16}$ inch at a speed of 35 miles per hour, which was the utmost
that could be attained by the test train owing to the gradients
leading up to the bridge. It was true that there was an oscillation
of $1\frac{1}{4}$ inch under a crowd, though the bridge was steady with the
train. This was due to the absence of lateral bracing on a part of
the cantilever where it only extended between the secondary
members. This deficiency having been supplied in those bays,
the oscillation was reduced to $\frac{3}{8}$ inch under a crowd marching in
step on the footways only—the arrangement which had previously
given the greatest oscillation. A larger crowd all over the floor
only produced an oscillation of $\frac{1}{8}$ inch, as did also various combi-
nations of train and men. Before this bracing had been added, an
opportunity occurred of testing the effect on the bridge of as heavy
a storm as had been experienced in those parts, while a goods train
was passing; the direction of the wind being inclined at 45° to the
bridge. No oscillation was perceptible.

In reply to Mr. Claxton Fidler, the gallowes itself had a pro-

Mr. Robertson. jecting arm to work a rope for the heel of raking-pieces as shown in Fig. 8, Plate 6, in plan and front view. A very convenient tool which was much used was a spar or tube furnished with an ordinary jack head at each end and rings to sling it by; these were provided of different lengths and used to boom out pieces. In the event of its being desired to raise a piece from a position on the floor of the bridge where it could not be reached by the overhead rope, an ordinary block and tackle hooked on the traveller on the top was used. A pair of wire-rope tackle sets were provided for this purpose. A good deal of lifting of small pieces was done with ordinary ropes working from the overhead gear. The Paper would hardly be complete without some notice of the accuracy of the work as executed by Messrs. Westwood, Baillie and Co., which enabled the most intricate joints to be brought together without difficulty.

Mr. Stoney. Mr. STONEY thought there could be no doubt that the use of small charges of dynamite facilitated cylinder sinking, and reduced the loads required by perhaps 30 per cent. The same system was used at the Pennár Bridge, having been introduced by Mr. R. E. Ellis, Assoc. M. Inst. C.E., the Author's assistant on that work. With regard to Mr. Wolfe Barry's query, there was no doubt of the fact that in one instance, after 30 feet of concrete had been put in, there was a depth of 8 feet of slurry formed over it; no analysis was made of it, but when taken out and poured on the river-bed it dried like fine mud. It was produced only in the case of one make of cement. Referring to Mr. Robinson's remarks, there was, in the absence of suitable pneumatic plant, no means of getting the large boulders out from under the cutting edge, except by blasting, as they were too large to push out or to chip, and if they were undercut and drawn into the cylinder blows of sand followed, as happened at pier No. 11. The cylinder served merely as a casing to allow of a concrete pillar being carried to the rock bottom, so that its having cracked was of no material consequence. It might be mentioned that the wrought-iron cutting-rings were not cracked by the dynamite, but their lower edges often got crushed by coming forcibly in contact with boulders or rock, when the cylinders ran down under heavy loads. With regard to Mr. Riddell's remarks, the Author had designed an annular plate to carry internal loading, Figs. 12 and 13, Plate 7, and used it very successfully in three cylinders of the north abutment, and he would have liked to adopt this plan all through, but the work had been already commenced, and there was no time to wait for castings from

Madras. The Author was fully alive to the advantages of internal Mr. Stoney. loading, and always advocated it, because, 1st. It kept the centre of gravity of the load low, and saved the great cost of stacking and unstacking rails, which moreover brought the load high above the river-bed, thus increasing the tendency of the cylinder to cant. 2nd. It made use of the permanent filling as a sinking load, and this filling could be built in above water and inspected, instead of having to be put through water by skips. In connection with Mr. Wrightson's remarks, the Author had known cylinders in the Pennár and Cheyair Bridges to sink suddenly without any apparent cause, after resisting the action of a heavy load for days, during which time they had remained untouched.

In answer to Mr. Gillott, 8 per cent. more rivets were used than were actually inserted, including all those that were lost or burned in heating. The number of loose rivets cut out was about 4 per cent. The Author would have been glad to have the furnaces and riveters described by Mr. Gillott instead of the ordinary portable forges which were used. With reference to the remarks of Mr. Macdonald and Mr. Seyrig, it should be explained that the section of the river-bed shown by the original borings was not only often quite wrong in depth, but very misleading as to strata, giving for the most part no indication of the existence of the boulder beds actually met with. For example, at pier No. 11, a depth of 6 inches only of dark boulders was shown by the borings, while 22 feet of them was actually sunk through, without reaching the rock. Piers Nos. 12 to 18 went through layers of boulders varying from 6 to 14 feet in depth over the rock, while the borings indicated none. The working section showed materials suitable for dredging throughout, and it was only when a considerable part of the cylinder-sinking had been done that the existence of the bed of boulders became known. It was then too late to procure suitable pneumatic plant from England, as including the time necessary in order to obtain Government sanction, &c., it could not have been got out in less than nine months at the least. American and English Engineers could not easily realize the peculiar difficulties of working in India, where all plant had to be ordered from England, and machine shops for repairs might be 200 miles or more distant. There was also the greatest difficulty in procuring skilled labour and trained foremen and mechanics, so that the Engineer had to see personally to everything, including minute details, as well as to direct and supervise. The pneumatic work was done with old pumps imported in 1877,

Mr. Stoney. the valves of which were worn and constantly broke down, allowing the cylinders to fill with water, which had to be again forced out; and this had to be done by native labour trained on the spot, without the supervision of a skilled foreman, so that the cost was consequently abnormally high. The Author would like to hear from Mr. Macdonald and Mr. Seyrig what the cost per lineal foot of sinking 12-foot cylinders to a depth of 50 to 60 feet below water-level should be with skilled labour and modern pneumatic plant.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2492.*)

“The von Schmidt Dredge.”

By GEORGE HIGGINS, Assoc. M. Inst. C.E.

IN a Paper on “Dredging Operations and Appliances,” by Mr. John James Webster, read before the Institution in 1887, under the head of “Sand-pump Dredgers,” mention was made of the invention of Colonel A. W. von Schmidt, of San Francisco, and a scant description, accompanying a somewhat incorrect illustration, was given of the machine.¹ It is intended now to describe the invention more fully.

“Sand-pump dredgers,” or “suction-dredgers,” or, as they are sometimes called, “hydraulic dredgers,” have been known and used for many years, and have done good work in gravel, sand and silt; but Colonel von Schmidt’s machine is the only one which will deal with clay as well as with loose materials. Nearly all hydraulic dredgers employ centrifugal, or “whirling” pumps, which have two advantages over stroke-pumps, viz., (1), that all valves are dispensed with except one foot-valve, and (2), that the action is continuous in one direction, so that the suspended material has no opportunity of settling; whereas in a stroke-pump there is a sudden stoppage and a change of direction at the end of each stroke.

The first von Schmidt dredger employed in Australia, the “Elwood,” was built by the Author for reclaiming the Elwood Swamp at St. Kilda, a suburb of Melbourne. Its first work was that of excavating a ship-canal and dock across the West Melbourne Swamp for the use of the Victorian railway department. It is still engaged there.

The “Elwood” was constructed in Melbourne. The hull, of Oregon timber, H H, Plate 6, is 100 feet long, 50 feet wide, and 9 feet deep; flat-bottomed, sides and longitudinal bulk-heads 12 inches

¹ “Dredging Operations and Appliances,” by John James Webster, M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 8.

thick; ends semicircular, 16 inches thick. The longitudinal bulk-heads divide it into three main compartments, the centre space being occupied by the boilers, main engines and pump, while those on either side are divided up into coal-bunkers, water-tanks, cabins, &c. The boilers, B B, are of the marine type, and work at a pressure of 120 lbs. per square inch. The whirling-pump, C P, stands on end, and is about 14 feet high, the runner being 10 feet in diameter. The suction-pipe is attached to the centre of the casing, the discharge-pipe leaving the pump on the top. The pump is driven by compound condensing engines, E E, of 24 inches stroke, the high- and low-pressure cylinders being 20 inches and 36 inches in diameter respectively. They are mounted upon a Δ frame, the connecting-rods of both cylinders grasping the same crank-pin. The speed varies from 120 revolutions a minute at long discharges to 100 at short ones. They indicate from 420 to 330 HP., according to the speed. The Blake surface-condenser, S C, is driven by a separate steam-engine mounted on the same frame with the air- and circulating-pumps. A donkey-boiler, D B, is used for many purposes. A Worthington pump, W P, is employed for priming the whirling-pump, and for filling the tanks with fresh water, bilging, &c. A pair of engines, S E, with cylinders 10 inches by 6 inches, give motion, by means of spur-gearing, to a shaft which has on it two chain-drums and two winch-ends. The chain-drums are used for lifting the "spuds" or piles which hold the dredge steady while at work, and the winch-ends are employed for moving it about by pulling on the mooring-ropes when the spuds are raised, and also for general hoisting-purposes.

The arrangements which distinguish the von Schmidt machine from all other suction-dredgers, and which enable it to do work that none of the others can do, are situated on deck. The suction-pipe is bent upwards a short distance from the pump, and, at this bend, a gland and stuffing-box are introduced, enabling the outer end to move horizontally in a semicircle about the gland as a centre. The movable part of the suction-pipe is placed upon a carriage or table, T, which travels to and fro on rollers around the semicircular bow of the dredge. The pipe lies horizontally upon the table, and its outer end, which is telescopic, hangs vertically over the bow, and can be raised or lowered at will. The lowest of the telescopic pipes has a bell-mouth or "hood," B M, 8 feet in diameter, placed eccentrically with regard to the suction-pipe, but concentric with an 8-inch steel shaft, K S, which, passing down outside the telescopic pipes, and through the centre of the hood, drives the horizontal wheel to which the knives, K K,

are bolted. Collars on the shaft keep the knives at a fixed distance below the hood. The upper part of the shaft is square, and slides through the bevel wheel, B W, as the telescopic pipes are lowered or raised. The traversing motion of the table, the rotation of the knife-shaft and the lifting of the telescopic pipes are all performed by means of the table engines, T E, which are mounted upon the suction-pipe. The cylinders of these engines are placed at right-angles on a Δ frame, and are each 12 inches in diameter, with 12 inches stroke. They are connected with the condenser, but may, at will, be permitted to exhaust into the atmosphere. The table traversing-gear, and that for lifting the telescopic pipes, as well as that for driving the cutting-knives, will easily be understood from the plans. Belts, friction-clutches, and some toothed gear are employed. The only valve in the suction-pipe is that shown at V, which is particularly easy of access. The portion beyond this valve, going towards the water, is primed by means of a steam ejector, or by being connected with the condenser, while the other part is filled at the same time as the main pump by means of the priming-pump, W P, already mentioned.

The discharge-pipe, D P, is of wrought-iron, and is 21 inches in diameter. On leaving the pump, it passes over the house and downwards over the vessel's side, where an elbow on a swivel connects it with a line of pipes floating on pontoons. Ball-and-socket joints of cast-iron are used to connect these floating pipes together, and between each pair of pontoons is placed a short length unsupported except at its jointed ends. This arrangement is sufficiently flexible to admit of the dredge being moved about over a large area without any stoppage to alter the pipe-line. On shore, wrought-iron pipes of a very simple description are laid on the ground so as to follow its undulations.

The area where the mud is deposited is, in the first instance, enclosed by retaining-banks, and one or more weirs provided for allowing the water to flow back after the mud has settled. Bricks, stones, bolts, pieces of iron, nail-cans, shovels, &c., are sometimes found issuing from the discharge-pipe. Lumps of iron, weighing 6 or 8 lbs., have come up along with the mud, and have been afterwards removed from the pump.

The following is a description of the method of working the machine. The dredge is floated into position, and placed so that its bow (or suction-pipe end) nearly touches the bank which is to be cut away; the two spuds are allowed to drop through their sockets, and their iron-shod ends stick into or rest upon the material in the bottom of the channel. A rope

is carried from the foremast head over the table, and made fast to some mooring placed in the direction towards which it is intended to work. Four other lines are put out from the sides and attached to moorings. The whirling-pump is primed, as before described, and the main engines, which drive it, are started. The table engines are then set in motion, causing the knives to revolve. The knives are brought into contact with the bank by moving the table sideways, and the material which they cut is carried up the pipe by the rush of water, passing through the whirling-pump and the discharge-pipe to the shore. The presence of the solid substances is at once indicated by a vacuum-gauge attached to the suction-pipe. The knives are kept at one level usually, and move with the table as far as it will go in one direction, when they, together with the telescopic pipes, are lowered a distance of from 6 inches to 36 inches, according to the hardness of the material, and are then carried back, still cutting their way, to the other side. When there another lowering of the knives and telescopic pipes takes place, and the process is repeated. At each traverse a strip of ground, 60 feet long by 10 feet wide by from 6 inches to 36 inches deep, is swept up. The to-and-fro motion of the table, with the knives and suction-pipe, is continued without moving the dredge, until the desired depth is reached. The "Elwood" has been made capable of dredging to a depth of 24 feet, but this limit could be exceeded by using longer pipes. The desired depth having been reached, the telescopic pipes are lifted up; then the spuds are raised off the bottom, the dredge pulled forward 9 or 10 feet, and the spuds again dropped, and the cutting commenced. One minute is long enough to make this change, the main pipe meanwhile discharging water. In this way the dredge cuts through a piece of ground 60 feet wide. In plan, the shape of this excavation is usually an arc of a circle, the centre of which is the ball-and-socket connection between the floating and the shore-pipes. When the excavation has been carried as far as necessary, floating-pipes are added or withdrawn, and other patches, 60 feet wide, are taken out alongside the first. It will be seen that this method ensures the bottom of the channel being left quite level, without lumps or holes.

Occasionally, an examination is made of the cutting-knives, which are brought up out of the water by letting go the chain on one side of the telescopic pipes and heaving up on the other, by which means they, together with the vertical knife-shaft and knives, are swung up to one side; a ball-and-socket joint on

the horizontal part of the suction-pipe, and two universal joints on the horizontal shaft above it, being provided in order to allow this motion to take place.

The von Schmidt dredge can work by night almost as well as by day, but daylight is generally chosen for adding or withdrawing lengths of discharge-pipes.

The machinery of the "Elwood" being quite new, there were a good many delays during the first few months, owing chiefly to defects in the main engines. More than half the working time may be taken as having been lost up to the present. The actual work done up to the 14th July, is given in the following Table:—

Date.	Number of Engine Hours.	Length of Discharge-Pipe.	Quantity.
		Feet.	Cubic Yards.
December 1889 . .	71	4,000	15,340
January 1890. . .	121	3,000	25,930
February „ . . .	199	2,500	42,830
March „ . . .	275	1,300	56,000
April „ . . .	373	1,600	70,800
May „ . . .	130	2,000	17,200
June „ . . .	292	2,000	61,000
July (1 to 14) . .	168	1,000	31,000
Totals . . .	1,629	..	320,100

A von Schmidt dredge of smaller size, with 12-inch pipes, is being built at Christchurch, New Zealand, by the Gillespie Beach Gold Mining Company, the intention being to lift wash-dirt from a river-bottom and beach. The application of the system to gold and tin-mining is one that promises to develop extensively.

Another dredge, with 9-inch pipes, is now afloat on the Albert Park lagoon, which it is proposed to deepen, while use will be made of the dredged material to raise some low-lying lands in the vicinity.

The Paper is accompanied by a photograph and two lithographed drawings, from which Plate 6 has been prepared.

(Paper No. 2500.)

**“On the Application of Governors and Fly-Wheels to
Steam-Engines.”**

By Professor VICTOR AUGUST ERNEST DWELSHAUVERS-DERY,
of Liège University.

Translated by BRYAN DONKIN, Jun., M. Inst. C.E.

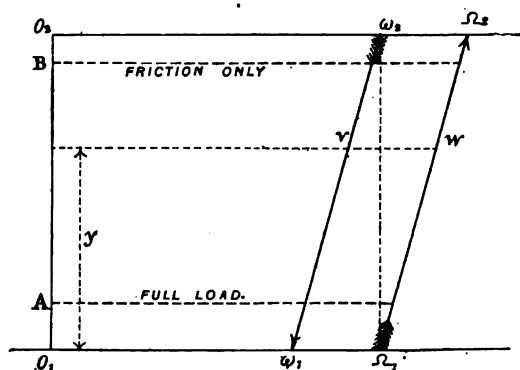
In a previous Paper,¹ the Author endeavoured to show how a governor, or tachometer, applied to a steam-engine, might be experimentally studied. He had demonstrated that no practical theory of the governor could be established unless the resistance R , which the sleeve encounters in one direction during its upward, and in the contrary during its downward tendency is taken into consideration. On account of this unavoidable resistance, he showed that the sleeve might remain without moving in a certain rigid position, while the rotatory-speed of the governor or of the engine fluctuated between the limits of—1st, the greatest speed w , corresponding to the instant when the centrifugal force of the balls establish an equilibrium with their own weight, the weight of the sleeve, and the resistance $+ R$; and 2nd, the least speed v , corresponding to the instant when the weight of the balls and of the sleeve establish an equilibrium with the resistance $- R$, and the centrifugal force, diminished by the decrease in the velocity. Thus the governor does not respond to the variations in the speed comprised between w and v , and its “coefficient of sensibility” may be defined as the proportion between the mean speed of the governor, and the difference $w - v$ of the two velocities of equilibrium $\frac{w}{w - v}$.

There are therefore two velocities of equilibrium instead of one, as maintained by the old theory, a proposition which rendered it impossible to give a rational definition of sensibility. The sensibility of a governor depends upon the resistance R , which is in

¹ Minutes of Proceedings Inst. C.E., vol. xciv. p. 210.

its turn dependent upon the kind of communication interposed between the sleeve of the governor, and the valve modifying the motive power. The sensibility depends upon the internal friction of the tachometer itself. Given a governor and the resistance R , a diagram may be traced of the two velocities of equilibrium v and w , the abscissæ of which will be in proportion to the velocity, and the ordinates to the height the sleeve reaches in its travel. In some governors the lines of these diagrams are almost straight, like those marked with thick lines in *Fig. 1*. The stops of the sleeve confine it to the two positions o_1 and o_2 . At the position o_1 we will call the values of v and w respectively ω_1 and Ω_1 . At the higher position o_2 they are marked ω_2 and Ω_2 . Thus the smallest velocity of equilibrium is ω_1 , and the greatest Ω_2 , and

Fig. 1.



the governor acts only between these limits; the space between them constitutes the allowed irregularity of the instrument.

In the "*Théorie Nouvelle des Régulateurs*," published in 1877 by Mr. Charles Beer and the Author, and in the Author's Paper before mentioned, attention was called to these definitions of sensibility and regularity, and also to a quality indispensable to all steam-engine governors, called "*astaticity*." It may be thus described. With its full load on, the engine ought to be capable of running at the mean velocity ω ; it ought also to run at the same velocity with no load but its own friction; and, lastly, it ought with an intermediate load to run at the same speed, between the maximum and minimum limits Ω_2 and ω_1 . Clearly this result will, with an astatic governor, be obtained under the following conditions:—

1. When the sleeve is in its highest position o_2 , all admission of steam will be stopped.

2. When the sleeve is in its lowest position o_1 , the maximum quantity of steam will be admitted, and will be more than that required for the maximum load of the engine. (This second condition was omitted by the Author in his former Paper.)

3. In order to make the governor practically as sensitive as possible, and at the same time to satisfy these two conditions, the two intermediate velocities Ω_1 and ω_2 are made equal to each other, and both are made equal to the mean angular velocity ω .

The Author has cited examples to show that a governor might be so constituted as to make it astatic, that is, acting under the best conditions, the diagram having the shape shown at *Fig. 1*. But although he had discussed the question in 1872,¹ he did not then touch upon the limits of speed to be chosen, and the relations to be adopted between the governor and the fly-wheel. In the engines now used for electric lighting, the whole load may be thrown suddenly on or off the engine, and it must be constructed to bear these extremes, without allowing the velocity to exceed or fall below the two limits assigned. The consideration of this question forms the subject of the present Paper. In the following remarks the resistance R to the movement of the sleeve will be placed among the data given, although it is often difficult to estimate it in practice. Usually it can be measured experimentally on an engine, and reduced by means of levers, &c., to suit any special tachometer.

It has often been said that the sensitiveness of the fly-wheel ought, under ordinary conditions, to be greater than that of the governor, otherwise the sleeve of the latter would move, although the number of revolutions did not vary, and this might affect and disturb the admission of steam at the critical moment. The Author does not attach an exaggerated importance to this consideration. To change the admission of steam, the governor has but the actual period of admission, which is very short in large expansive engines; and if during expansion the velocity of the engine has changed, all that is required is to adjust the governor, that it may regulate the admission at the next stroke. The important point is to know how the governor will act when variations occur in the velocity during expansion, because, from the very beginning of the following stroke, the sleeve ought to take up a proper position, in order to adjust the admission of steam

¹ Revue Universelle des Mines, May 1872.

to the ratio required by the modified load on the engine. The governor therefore should be regulated to act with precision in extreme cases, and its proper working under ordinary circumstances will then be placed beyond a doubt. It ought to agree with the fly-wheel, and, as long as the boiler furnishes steam to the cylinder, to prevent the speed exceeding the limits assigned.

The following are the extreme cases to be allowed for :—

1. When the engine is running with full load on at the velocity ω , the sleeve of the governor ought to remain stationary at the height A towards the lower end of its travel; but if the need arose it ought to be able to fall a little lower in order to restore the velocity, should there be a slackening of the speed through any unforeseen cause, such as a slight diminution of pressure in the boiler.

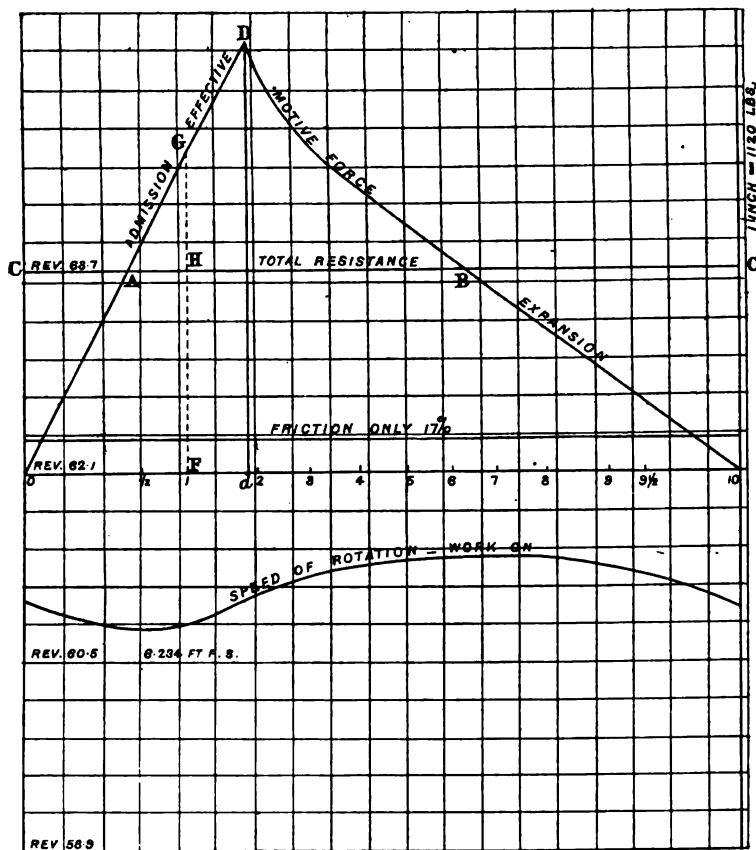
2. When the engine is running with no load but its own friction, and at the normal velocity, the governor ought to remain stationary at a height B, a little below the highest position ω_2 , because in case of need, the sleeve ought to be able to rise still higher, and cut off the admission steam, in order to restore the normal speed should the velocity be increased by an increase of boiler-pressure.

3. When the engine is running with its full load, and at its normal velocity, the whole load is suddenly thrown off, just at the beginning of expansion. In this case the governor cannot prevent an acceleration of speed, since it does not act during expansion. At the end of the stroke, if the fly-wheel is light, the velocity will be greatly increased, if it is heavy the increase will be small. It is desirable, in any case, that the governor should, during expansion, have reached the highest point in its travel, in order to suppress admission during the following stroke. Therefore from the beginning of the next stroke the velocity will diminish, until probably after slight oscillations, it becomes equal to the normal speed. On this account the maximum velocity of equilibrium, Ω_2 , in the upward stroke of the sleeve ought to be smaller than that acquired by the engine at the end of the stroke now under consideration.

4. When the engine is running with no load but its own friction, and at the normal velocity, the whole load is suddenly thrown on just at the beginning of expansion. It is impossible for the governor to prevent the speed diminishing until the next stroke; the greater or less mass of the fly-wheel alone will, for the moment, limit the decrease in the velocity. In any case it is desirable that the governor should, during expansion, fall to the

lowest point of its travel, in order to admit the maximum quantity of steam, and be able, even with the maximum load, to increase the velocity, which had fallen below the normal rate. For this reason the lower stop ought to be below the position that corresponds to the admission agreeing with the maximum useful load at the normal velocity. It is therefore necessary to make the

Fig. 2.

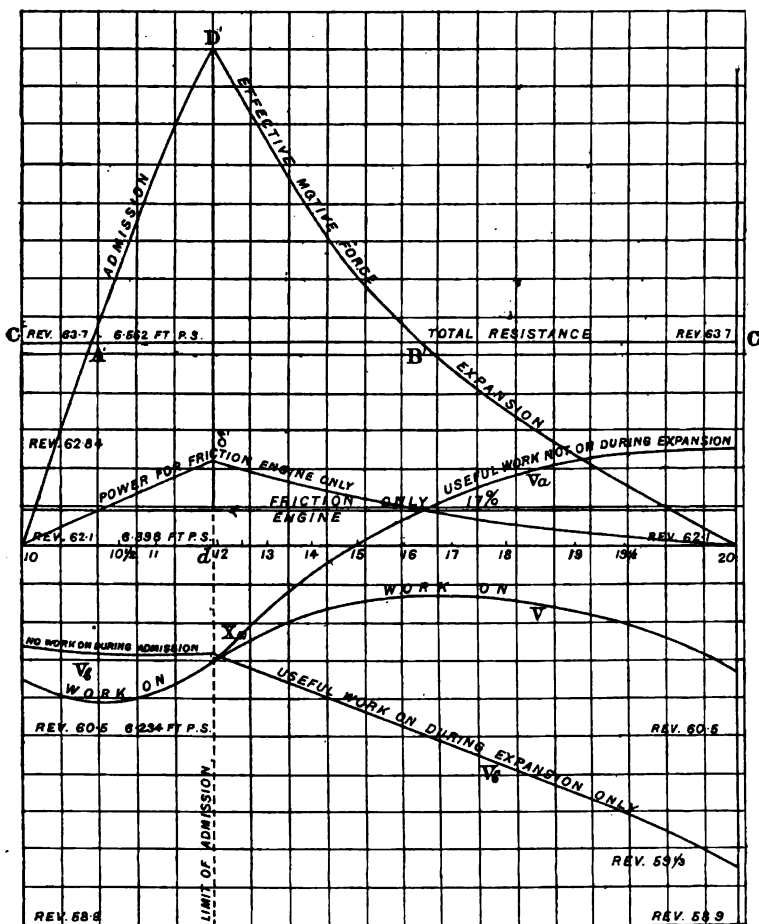


lowest limit of the governor's velocity ω_1 greater than that acquired by the engine at the end of the stroke, during which the whole load had been suddenly thrown on at the beginning of expansion.

The problem of the regulation of the governor of an engine

seems thus to be clearly defined, but does it lead to practical results? To ascertain this point the Author had recourse to experiment. He had at his disposal a steam-engine belonging to the Mechanical Laboratory of the University of Liège. Each

Fig. 2.



year he makes experiments on this engine, to determine the velocity of rotation at each instant of the stroke. Indicator-diagrams are taken, and the mean velocity, brake-power, and the distribution of the moving parts are calculated. The latter are divided into two equivalent masses; the one is rotating and

calculated as if it were concentrated at the revolving end of the connecting-rod; this mass M is = 3,621. The other, the reciprocating mass, oscillates like the other end of the connecting-rod, or like the piston; it is here called m , and is equal to 16. Both these masses have a regulating influence on the rotatory motion. With certain engines Professor Thurston found the work consumed in friction per revolution was the same, whether the engine were running light or with full load on. Wishing to verify this fact, the Author made many experiments, and though unable to draw positive conclusions, he thinks that Thurston's law may be admitted without risk of inaccuracy. The brake-power represented 83 per cent. of the indicated work in these trials. Therefore the indicated work without any useful load was probably 17 per cent. of that with full load on, and this supposition was approximately confirmed by experiment.

By the help of the indicator-diagrams taken on both sides of the piston, we can determine the power exercised by the steam upon the piston, including the back pressure, at each instant of the two successive strokes of one revolution. The pressure of the steam on the piston must be resolved into its component parts to find its equivalent, which is supposed to be applied to the centre of the crank-pin, in the direction in which this point is moving, that is, tangentially to the circumference described. This component affords a measure of the total effect of the pressure of the steam to make the shaft rotate, which is the effective motive power E . *Fig. 2* gives the diagram of the motive power in the experiment in question. The abscissæ are proportioned to the angles described by the crank, starting from the dead point; the ordinates are proportioned to the values of E , and the area of the diagram to the work performed by the motive power to turn the shaft. This is merely a graphic representation of the results, calculated from actual data, and is used as a check, on account of the laborious nature of the calculations. It was found that the motive power in the forward stroke was 6,942·4 foot-lbs., and 7,353·4 foot-lbs. in the back stroke, giving a total of 14,295·8 foot-lbs. per revolution.

Since the engine is here supposed to be running at normal speed, it follows that the work of the total resistance per revolution is exactly equal to the work of the motive power. Generally the total resistance is also reduced to a constant force, and applied to the centre of the crank-pin tangentially to the circumference described. In this case the diagram representing the resistance will, with the same base as that of the motive power, be a straight

line parallel to this base at such a height that the rectangle determined by it will have the same total area as the diagram of the motive power E. This straight line is C C' C' C, its height represents 2,311.6 lbs.

If it be wished to know the work expended in varying the velocity of the masses of the engine, from the beginning of a revolution to a given angle described by the crank, and represented by the length oF, the ordinate FHG must be drawn out, and the work T will be represented by the difference of the two areas oFGo and oCHFo. If the speed V_o of the centre of the crank-pin at the beginning of the stroke be given, and the proportion between the length of the crank and of the connecting-rod, the speed V of the crank-pin, and v of the other end of the connecting-rod, can be calculated for every position of the crank from the beginning of the stroke. The fraction $\frac{v}{V} = k$ is a function of the angle, and can easily be calculated. By virtue of the principle of *vis viva*—

$$T = \frac{M}{2} (V^2 - V_o^2) + \frac{m}{2} v^2;$$

$$\frac{2}{M} T + V_o^2 = V^2 \left(1 + \frac{m}{M} k^2 \right);$$

and

$$V = \sqrt{\frac{V_o^2 + \frac{2}{M} T}{1 + \frac{m}{M} k^2}}.$$

The Author has thus reckoned the values of V for twenty-seven different points of one revolution, a laborious but not a difficult task. The variations of velocities V are clearly marked in the diagram, Fig. 2. The axis of the abscissæ for the diagrams of velocities is supposed to be 6.07 feet below the horizontal straight line that terminates the figure at the bottom.

The minimum velocity is at the point $10\frac{1}{2}$: $V' = 6.2629$ feet, corresponding to 60.76 revolutions per minute, and the maximum at the point 17, where $V'' = 6.3534$ feet, corresponding to 61.64 revolutions, the circumference described by the point of concentration of the mass M being 6.1845 feet. The mean velocity is 6.3088 feet, corresponding to 61.21 revolutions per minute, and the coefficient of regularity is $\frac{6.3088}{6.3534 - 6.2629} = 69.7$, say 70. The mean velocity closely approximates to the arithmetical mean

between the extreme velocities. The speed at the end of the direct stroke is 6.279 feet, or 60.92 revolutions.

The axis of the abscissæ is numbered 0, 1, 2 . . . 19, 20, *Fig. 2*, corresponding to equal fractions of the stroke. The letters D, D', d, d', mark the beginning of expansion at each stroke. The work due to the motive power, the total resistance, and the friction, have been reckoned separately between two successive dividing points (including the points marked $\frac{1}{2}$, d, $9\frac{1}{2}$, $10\frac{1}{2}$, d', $19\frac{1}{2}$). The total work performed between certain points is subjoined.

—		Limits.	Effective Motive Power.	Total Resistance.	Friction only.
			Foot-lbs.	Foot-lbs.	Foot-lbs.
I. Forward Stroke.	During admission . .	From 0 to d	2425.8	2237.2	370.8
	" expansion . .	" d to 10	4517.1	4910.7	834.8
	" the whole stroke	" 0 to 10	6942.4	7147.9	1205.1
	" admission . .	" 10 to d'	2514.3	1895.2	312.1
	" expansion . .	" d' to 20	4839.1	5252.7	893.0
	" the whole stroke	" 10 to 20	7353.4	7147.9	1205.1
II. Back Stroke.					

As the engine was horizontal and the parts fairly well balanced, no count was taken in the above calculation of the weight of the moving parts. With a non-balanced engine, the weight must not be neglected.

Having obtained the speed V during the ordinary work of the engine for each point of the stroke, and traced its appropriate diagram, the Author has by the same process, based on the principle of *vis viva*, calculated and represented by a curve (*Fig. 2*), 1st, the speed V_a of the back stroke during expansion, in the case of the useful resistance being suddenly suppressed at the beginning of expansion, and 2nd, the speed V_b during the whole back stroke, assuming the engine to be running empty during admission, and the whole of the useful resistance to be suddenly thrown on at the beginning of expansion. In such a case the speed at the beginning of the stroke is supposed to be equal to the mean speed 61.21 revolutions per minute. *Fig. 2* shows clearly the variations in these speeds, V_a and V_b . The diagram of the effective motive power when the engine is running empty at the normal speed of 61.21 revolutions, has not been traced from the indicator diagram experimentally obtained, but by taking each of its ordinates as equal to 17 per cent. of the corresponding

ordinate when the engine is running with full load on. This method may be considered as practically accurate. The results are :—

In the 1st case the velocity V_a at the end of the stroke is .	Feet. 6·476
" 2nd " " V_b " " "	6·117
The first corresponds to . . .	62·84 revolutions per minute.
The second " . . .	59·34 " "

The first differs from the mean speed by 1·63 revolution per minute, the second by 1·87; the irregularity of the engine, therefore, in these two cases is 3·5 revolutions in 61·21 per minute, = $\frac{1}{17\cdot5}$, or a coefficient of 17·5.

It is the fly-wheel which permits this variation, and the governor is absolutely powerless to change it. The latter can only prevent the disturbance from going too far; it ought to set matters right, first by restoring, and afterwards by maintaining the normal speed. How it should be adjusted, in order to perform this function, the Author will endeavour to show.

Starting with the first case, when the useful resistance is suppressed at the beginning of expansion during the back stroke, the sleeve of the governor should have reached its highest position at the end of the stroke, to stop admission for the following stroke. Therefore, while the expansion lasts, some motive force must have generated the work represented by the moving of the sleeve upwards. This motive power is derived from the excess of actual centrifugal force due to the speed V_a over the ascending velocity of equilibrium w . The result is that the velocity of equilibrium of the governor (w) must, under these conditions, be smaller than that of the engine, and Ω_2 , the greatest velocity of equilibrium of the governor, must consequently be made smaller than the final speed $V_a = 62\cdot84$ revolutions. *Fig. 3* gives a clear explanation of the position.

Here the ascending and descending velocities of equilibrium of the governor are traced in thick lines, and marked with arrows. These diagrams of v and w are almost rectilinear, and are supposed to belong to a governor which has been rendered astatic by the method explained in the Author's former Paper. The mean velocity chosen is equal to the geometric mean between the extreme speeds ω_1 and Ω_2 . If we take one of these, $\Omega_2 = 62$ revolutions, and $\omega = 61\cdot21$ revolutions, the other may be found as follows :—

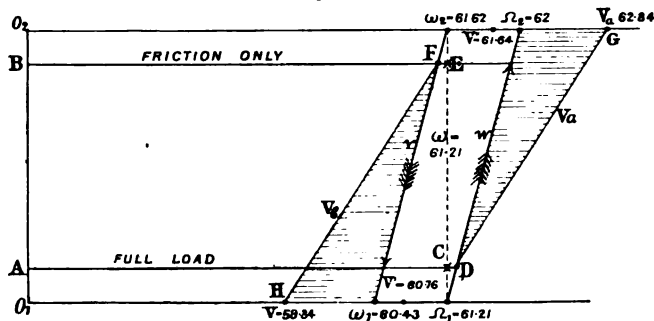
$61\cdot21 \times 61\cdot21 = 62 \times \omega_1$, from whence $\omega_1 = 60\cdot43$ revolutions.

As to the diagrams of velocities V_a and V_b , *Fig. 3*, they are

suppositions. The extreme points alone, D and G for V_a and F and H for V_s , can be determined with certainty, if the sleeve has been able to reach the end of its travel during expansion; for the law of variation of the velocity V_s is known as a function of the position of the crank, but not of the position of the sleeve. It will simplify this explanation if the accuracy of the diagrams V_s and V_s be admitted.

The sleeve of the governor being at the height A, the engine runs first at the normal speed represented by the length AC; the governor will move and ascend as soon as the velocity equals the value of $\omega_s = AD = 6.317$ feet per second, corresponding to 61.31 revolutions. It is seen by the position of the point X on the diagram of V_s in *Fig. 2*, that the governor will begin to rise

Fig. 3.



between points 12 and 13, when the crank has described a curve of 0.938 foot from the beginning of the back stroke.¹ The sleeve will then rise, and ought at latest to have reached its highest position when the piston has arrived at the end of the stroke. The time the piston takes to pass from the position X to the end of the stroke may be calculated, the mean speed of the crank-pin traversing the distance of 2.154 feet in this time being given. This mean is 6.433 feet, and the time occupied 0.335 second.

In the second case here treated, the sleeve of the governor is at the height B, *Fig. 3*, the engine is running empty at its normal speed 61.21 revolutions, and with almost perfect regularity. At

¹ It may be objected that the governor will move during the ordinary working of the engine, since the fly-wheel allows a velocity of 6.353 feet. But the same reasoning would hold good if we suppose the loaded engine to be running at a mean velocity inferior to its normal speed of 61.21 revolutions.

the beginning of expansion, during the back stroke, the load is suddenly thrown on, and the speed diminishes rapidly, as shown by V_0 in *Fig. 2*. The sleeve begins to fall as soon as the speed has become equal to BF , *Fig. 3*, which occurs towards the beginning of expansion. The mean speed of the centre of the crank-pin is 6.215 feet, and the duration of expansion 0.366 second. The speed at the end of the stroke is 6.117 feet, corresponding to 59.34 revolutions.

For reasons given above, the governor ought, therefore, to be so adjusted that, if the first case happens, the sleeve, acted upon by the excess of actual centrifugal force over that which establishes the equilibrium, should, starting from the height A , reach the highest part of its travel in less than 0.335 second. Should the second case occur, the sleeve, starting from the height B , ought to have reached the lowest end of its travel in less than 0.366 second, influenced by the lack of centrifugal force, which has decreased below that establishing the equilibrium. To choose the tachometer and calculate its mass and dimensions in accordance with these conditions is a matter of great difficulty. The Author proposes the problem, and is of opinion that the arithmetical part of it may be approximately solved by simplifying it with appropriate hypotheses. He thinks that regulators with springs alone might be sufficiently quick. It would be interesting, though laborious, to study the slow action of ordinary governors.

Finally, let it be supposed that in the first case the governor has suppressed the admission from the end of the stroke considered. Henceforth at each stroke the fly-wheel will lose 1,205.1 foot-lbs.

in power, but as it possesses an excess of $\frac{3621}{2} \{V^2_{\text{final}} - V^2_{\text{mean}}\}$
 $= 3,888$ foot-lbs. it is only after $\frac{3888}{1205.1} = 3.2$ strokes that it will be

reduced to the mean velocity, and that the sleeve will fall a little, in order to furnish 1,205.1 foot-lbs. of work per stroke. This operation will doubtless cause it to oscillate slightly. It is of course desirable that the sleeve should fall as soon as the mean velocity of 61.21 revolutions has been re-established, and therefore it is well to make the maximum descending velocity of the sleeve, or ω , equal to the average velocity. In *Figs. 1* and *3* the Author has assumed that this takes place.

Similar considerations apply to the second case and its consequences. Here, however, the increase of motive power per revolution, which is needed to restore the normal speed, starting from 59.34 revolutions, is arbitrary. If, for example, the normal

conditions are to be restored after two revolutions, an increase of work equal to $\frac{3621}{2 \times 2} \{V^2 \text{ mean} - V_i^2 \text{ final}\} = 2+62.4$ foot-lbs., must be exacted per revolution, or 15 per cent. of the work required under normal conditions, and with the maximum load.

If a governor has been so calculated that it fulfils the extreme conditions here defined, it will bring back the velocity to the normal rate whenever it deviates from it, and will keep it within the assigned limits, whatever may be the load thrown upon the engine, if this load does not exceed the fixed maximum limits. But the momentum of the fly-wheel must also be calculated, that it may powerfully assist the governor, should urgent need arise.

The communication is accompanied by a diagram and two sketches in the text, from which *Figs. 1-3* have been prepared.

(*Paper No. 2517.*)

“Investigations on the Influence of Heat on the Strength of Iron.”¹

Report of Professor Martens.

Translated and abstracted by GEORGE RUDOLPH BODMER,
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IN the year 1886 two technical societies, the “Verein zur Befoerderung des Gewerbflusses,” of Berlin, and the “Verein Deutscher Eisenhuettenleute,” of Dusseldorf, proposed to carry out experiments on the influence of heat on the strength of steel (*Flusseisen*) of various grades of hardness. A commission, representing both societies, was appointed to agree upon the plan of operations, and consisted of the following members:—

On the part of the “Verein fuer Gewerbfluess”:—Privy-councillor Dr. Wedding, president; Mr. Hoppe, machine manufacturer, of Berlin; Professor Ludewig, Berlin; Mr. Martens, engineer, Berlin.

On the part of the “Verein Deutscher Eisenhuettenleute”:—Mr. Brauns, Dortmund; Mr. Massenez, Hoerde; Mr. Minssen, Essen; and, after the death of the last-named, Mr. Asthofer, also of Essen.

In the original the Author states at length the reasons which led the “Verein fuer Befoerderung des Gewerbflusses” to act in concert with the other society for the purpose of instituting the investigations in question. It was considered that previous experiments had not been sufficiently uniform and exhaustive, especially with iron and steel up to a temperature of 600° Centigrade.

The commission decided on the following points as a basis for the conduct of the experiments:—

1. The method of producing the material shall be left to the ironworks; but the latter shall be requested to report as accurately as possible on the nature of the process adopted, as well as upon

¹ Mittheilungen aus den Koeniglichen technischen Versuchsanstalten zu Berlin, 1890, p. 159.

all details important for judging of the material, and of its particular condition.

2. The material to be tested shall be mild steel, and must be grouped according to its strength. Four groups are to be formed, corresponding to the stress-intervals 22·86, 26·67, 30·48, and 34·28 tons per square inch (in annealed condition). The first group to be of the quality of rivet-steel.

3. If at all practicable, only carbon is to be used for determining the grade of hardness; the other constituents must be as far as possible subordinate, and present, at least approximately, in equal quantities.

4. The material for each of the previously-mentioned groups is, as far as possible, to be taken from a single bloom, but in any case from a single heat. The individual pieces are to be rolled into round bars of about 1·5 inch diameter, the same proportion of stretch and the same temperature being employed for all.

5. From each of the four groups at least 229 feet 8 inches of round bars in all will be necessary, which are to be furnished in parts, the length of which must be a multiple of 3·15 inches.

6. The test-pieces are to be again annealed in the Berlin Experimental Institute by some uniform process before the commencement of the experiments.

I. THE TEST-MATERIAL.

Thirty-four bars of 1·5 inch diameter were furnished by the Hoerder Bergwerks- und Huettenverein of Hoerde, formed out of two charges, having a strength of 22·86 and 26·67 tons per square inch.

From each charge three blooms were used, and the bars so marked that it could be recognized to which bloom they belonged.

The Union-Aktien-Gesellschaft für Bergbau, Eisen- und Stahl-industrie, of Dortmund, furnished twenty-one bars of 1·5 inch, derived from two charges, but not so marked that their origin could be recognized.

As to the method of manufacture, it was agreed between the two works that the bars should be forged from 9·84 inches square blooms down to a section of 4·32 inches square, freed from the rough ends, and then rolled to a diameter of 1·5 inch in lengths of 26 feet 2·97 inches to 32 feet 9·71 inches.

In order to neutralize as far as possible the effect of inaccuracies on subsequent comparisons, the test-pieces cut from each length

were consecutively numbered and selected for testing in the corresponding order.

For the purpose of annealing, the rough test-pieces were packed in lots of seventeen or eighteen in cast-iron muffles, the covers of which were coated with clay, the muffles having been previously charged with a cake of clay furnished with strips of lead, tin, zinc, and aluminium. Each muffle held two layers of bars, one above the other, and two muffles were always placed side by side in the annealing furnace. Through the roof of the latter a graphite pyrometer was inserted in such a manner that its lower end was between the two muffles.

A detailed record of each annealing was made, and in the original an example of one of these records is given. In most cases it could be seen after annealing that the aluminium had been softened.

Test-pieces of similar quality were tested as they arrived from the manufacturers, and also after annealing. The results of these tests are stated in a tabular form in the original.

The material furnished for Group IV, which should have had a tensile strength of 34.28 tons per square inch, was found not to conform with the required standard, and was in the first instance excluded from the investigations.

II. THE EXPERIMENTS.

A. Arrangements.

The testing of the unannealed normal test-pieces was carried out in the manner usual at the Experimental Institute. For the tests at higher temperatures, however, the form of test-piece shown in *Fig. 1* was finally adopted. On the conical shoulder of

Fig. 1.



FORM OF TEST-PIECE.

the test-piece the heating furnace was supported, the arrangement being as follows:—

The test-piece was placed in a vessel, having a clear width of about 4 inches, which could be filled (up to 200°) with paraffin, or (up to 600°) with molten metal.¹ This vessel was surrounded by

¹ Either alloys of lead and tin or lead only. Previous experiments had shown that lead was not absorbed by the steel within the time required for a test.

an iron jacket into which the flames of two gas-jets could be introduced through lateral slots. The escape of the fire-gases could be controlled by means of a slide. The burners were connected to the frame of the 50,000-kilogram testing-machine, and carried through the water-main. Each flame was 4.32 inches wide.

The test-piece and furnace together were supported in the machine from the heads of the piece by means of spherical socket-bearings in the well-known way. The size of the flames could be regulated by altering the supply of gas and air to the jets. The temperature of the bath of molten metal or paraffin was determined up to 400° by the help of a mercurial thermometer filled with nitrogen, by Geissler, of Bonn, and at higher temperatures by an air-thermometer with iron air-vessel, the construction and regulation of which was at first attended with many difficulties.

The tests, in a cold condition at -20° Centigrade, were carried out in a zinc vessel with double walls, which was also secured to the cone of the test-piece. The inner, as well as the outer vessel, after several unsuccessful preliminary trials, was filled with a powdered mixture of ice and salt. In this way a temperature very near -20° Centigrade could be maintained for a considerable time. The outer vessel was surrounded with a jacket of asbestos and a layer of sawdust. The load was measured either by means of weights placed on the attachment on the right-hand side of the testing-machine, or through the automatic mechanism on the left-hand of the machine. A description will be found in the "*Zeitschrift des Vereins deutscher Ingenieure*," 1886, p. 171, and "*Mittheilungen aus den Technischen Versuchsanstalten*," 1889, Supplementary number III.

The measurement of the elastic extensions could not be carried out with the ordinary mirror apparatus; but a special arrangement had to be designed with the object of placing the mirrors beyond the influence of the stream of hot air rising from the furnace, since an accurate reading with mirrors is only possible in air of uniform density. The elastic extension of the actual test-length (a cylindrical portion 8.1 inches long, and 0.79 inch diameter) could not be directly measured. In order to protect the knife-edges for the mirrors as much as possible from the effects of the heat, both measuring rods were fixed with their knife-edges in a groove turned in the lower part of the test-piece, and wedged fast by means of a ring pushed over them. The knife-edges of the mirror-apparatus were then adjusted between the measuring-rod and the test-piece in the existing marks above the furnace.

The elongations of the test-length could also not be directly observed. Instead of this, the total motion of the piston of the machine was determined, either by means of the existing scale for the stroke, or by measuring the abscissae obtained from the automatic recorder.

The drum of the latter is actuated from the piston of the machine through a fine wire, while the pencil follows the motions of the quicksilver gauge, and thus describes a curve on the paper attached to the drum. The elongations, as well as the elastic alterations of form, had, of course, to be reduced to the test-length, as will be subsequently explained.

The previously-mentioned scale for measuring the stroke of the piston is chiefly for the purpose of controlling the velocity of flow during the experiment. In order to facilitate this, the rod connected with the piston actuates, in addition to the pointer for the scale, a roller, the indicator of which shows the stroke of the piston exaggerated fourteen-fold. It is a general rule in the Berlin Experimental Institute so to regulate the piston-speed that during the flow of the test-piece the test-length is increased by 1 per cent. of its original length in a minute.

This velocity was to be maintained as far as practicable during the experiments in question.

B. Method of conducting Tests.

In ordinary tests, with the machine employed for these experiments, no measurements are taken between the moment when the maximum load is reached and the final fracture. In the present case, however, it was thought desirable to observe more accurately the phenomena occurring between maximum load and fracture, since it was evident beforehand that at different temperatures very considerable differences in the behaviour of the metal during this period would show themselves.

For observing the decreasing tensile strength of a test-piece the automatic recorder on the left side of the testing machine was employed. The course of an experiment was generally as follows: The test-piece, after accurate measurement of all parts, was pushed from below into the furnace, and a tight joint, made by means of the conical shoulder smeared with fine clay; the test-piece and furnace were then firmly connected by a nut. The iron tube, filled with nitrogen, of the air-thermometer, was next placed inside the furnace, the measuring-rods of the mirror

apparatus were attached, and finally the stirring mechanism and cover.

After the test-piece had been fixed in the spherical bearings of the testing-machine, the mirror apparatus was connected. The adjustment of the measuring-rods and mirrors required great care, and in the original this adjustment is described in detail.

Before commencing observations it was found necessary to allow the test-piece and measuring-rods, which had become heated by contact with the hand, to cool for from ten to fifteen minutes. All the pieces to be tested at high temperatures were previously tested several times at an ordinary temperature as to their elastic extension within the limits of proportionality, so that the extension for one ton¹ could be determined with great accuracy, and from this the modulus of elasticity. After these preliminary observations, the gas-jet was lighted and the furnace gradually heated. The material for filling the inner space of the furnace was melted and poured into the latter when sufficiently hot. The temperature up to 400° Centigrade was observed with a mercurial thermometer at higher temperatures with an air-thermometer. At 450° the results obtained from the two thermometers were compared and graphically recorded. A curve of a definite form corresponded with the readings of the air-thermometer, but the curve varied on different days, so that a group of curves embraced within certain limits was obtained, the range of which can be seen from the following table:—

Mercurial Thermometer. Centigrade.	Air-Thermometer.	
	From	To
Degrees.	Millimetres.	Millimetres.
100	158	170
200	255	280
300	335	365
400	395	430
500	445	485
600	485	525

For experiments under 500° comparative readings were taken from the mercurial and air-thermometers, in order to determine the curve corresponding most closely with the records of the latter

¹ The ton used throughout this Paper is the metric "tonne," = 0.9842 ton avoirdupois.

on the day in question. In this manner it was sought to neutralize the variations of the air-thermometers.

The two mercurial thermometers used were calibrated before the experiments at 0° , 100° , and 187° (aniline vapour), and found correct. During the course of the experiments they were frequently (together with the air-thermometers) placed in boiling water, and it was found that gradually they indicated the boiling point 11° too high. The results obtained were corrected for this, but for various reasons the records cannot be considered as accurately representing the temperature actually existing in the bath. Since, however, the same instruments were employed throughout, the experiments are directly comparable with each other and relatively correct. The constancy of the mirror readings could be approximately maintained by stirring the bath.

The stirring mechanism consisted of a ring of sheet-iron, which could be moved up and down by means of a rod with curved handle. This, however, only affected the lower portion of the bath, and in future experiments some improvement on this device would be desirable.

When the metal bath was made use of in the experiments considerable oscillations occurred in the diagrams, so that frequently the readings could only be correctly taken within fifteen to twenty or sometimes even thirty ten-thousandths of a millimetre. Attempts to get rid of these oscillations were unsuccessful, and their origin could not be discovered with certainty. It is not improbable that they were due to the action of cooler currents of air on those portions of the test-pieces and measuring-rods projecting out of the bath.

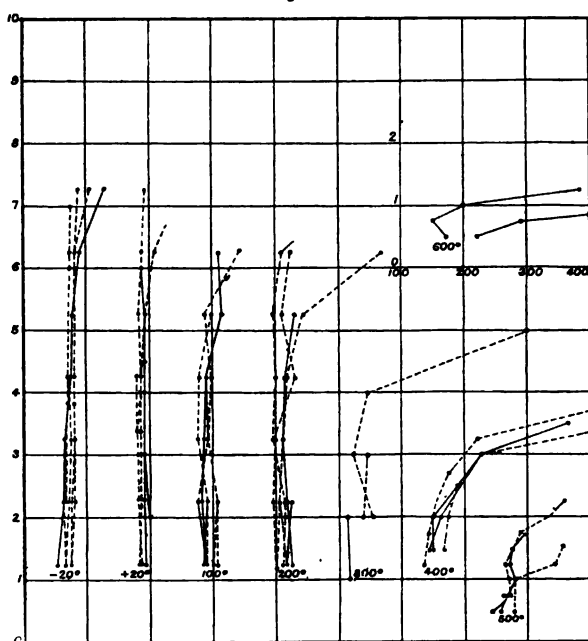
In general the mirror apparatus was employed up to the moment when flow commenced, and then the test-piece was relieved, the mirrors removed, and the experiment repeated and continued till fracture with the automatic recorder in use.

The experiments at -20° were carried out in a similar manner. In the first experiments the test-piece was surrounded with a saline solution, having its freezing-point at exactly -20° . If the outer mixture was at first too cold, it was intended that the inner solution should commence to deposit crystals, and that when towards the close of the experiment the temperature outside rose, the previously formed crystals should dissolve again; in either case the temperature would remain constant.

The mixture in the cooling vessel, with a capacity of 29.933 pints, consisted of three parts by weight of ice and one part of salt.

The temperature in the outer space of the cooling vessel was thus maintained throughout the whole experiment, which had a maximum duration of four hours, between -20° and -21° . It was, however, found impossible to reduce the temperature of the saline solution in the inner space below -17° . For this reason the inner vessel was also eventually filled with a freezing mixture, with satisfactory results. Observations taken at various points of the inner space always showed temperatures between -20° and -21° . Other observations were carried out as previously described.

Fig. 2.



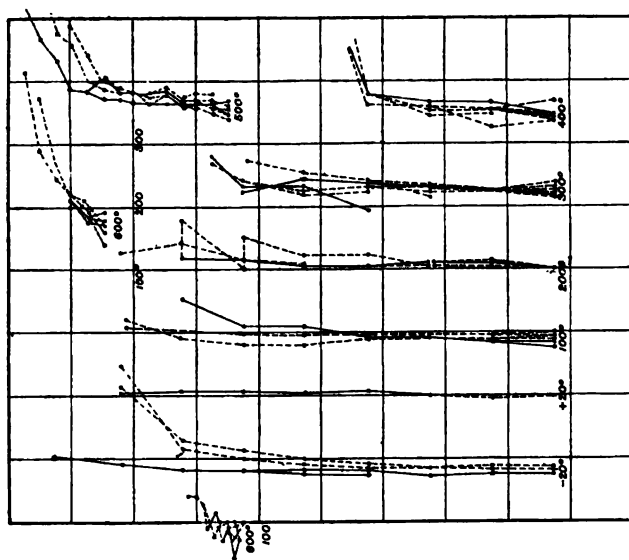
QUALITY I.—EXTENSION-DIFFERENCES FOR VARIOUS LOADS.

Scale of abscissæ, 8 millimetres = 0.001 millimetre extension-difference.

The time necessary for bringing the test-piece to the required temperature before each experiment was utilized in trying the recording instruments.

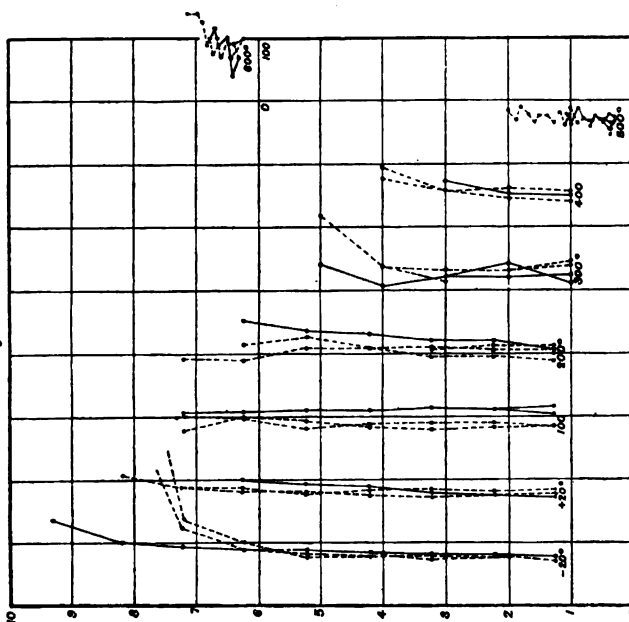
Up to the moment at which flow commenced, the hydraulic valve was only very slightly opened, in order to give the apparatus time to follow the rapidly changing stress. Subsequently the extension took place at a speed of one per cent. in the minute. The form of the diagram immediately after the commencement of flow

Fig. 2.



QUALITY II.—EXTENSION-DIFFERENCES FOR VARIOUS LOADS.
Scale of abscissæ, 8 millimetres = 0.001 millimetre extension-difference.

Fig. 2.



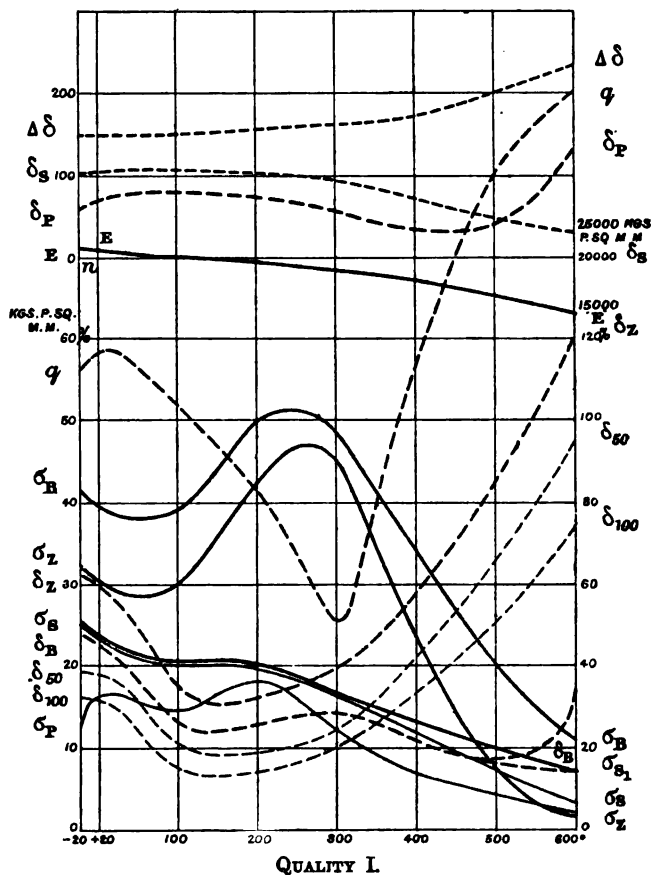
QUALITY III.—EXTENSION-DIFFERENCES FOR VARIOUS LOADS.
Scale of abscissæ, 8 millimetres = 0.001 millimetre extension-difference.

depends very materially on whether the valve is opened instantaneously and to what extent, and is therefore more or less dependent on the attention and will of the observer.

C. Calculation of Results.

Under this heading in the original the various formulas employed in determining the required quantities from observed readings and data are given.

Fig. 3.

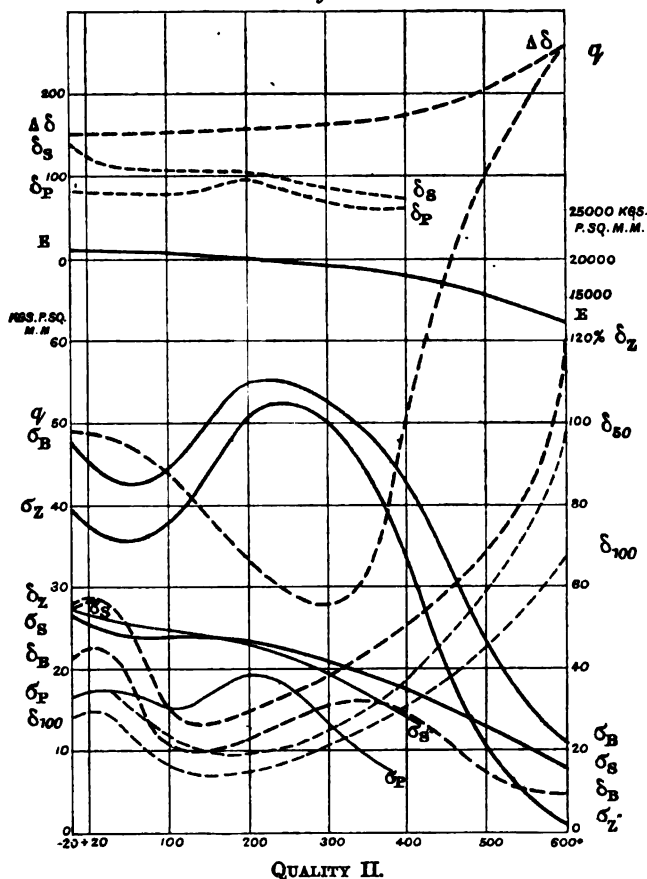


III. RESULTS OF EXPERIMENTS.

The main results are given in a tabular form in the original, but for convenient comparison are also graphically represented.

In *Figs. 2* the extension differences, corresponding to the various loads, are shown for different qualities of metal (I, II, and III) and various temperatures. These diagrams allow an opinion to be formed of the degree of accuracy obtained, and also on the question as to how far the material can be credited with a proportional extension. From the decreasing length of the parallel portions of the curve-groups with increasing temperatures, the lowering of

Fig. 4.

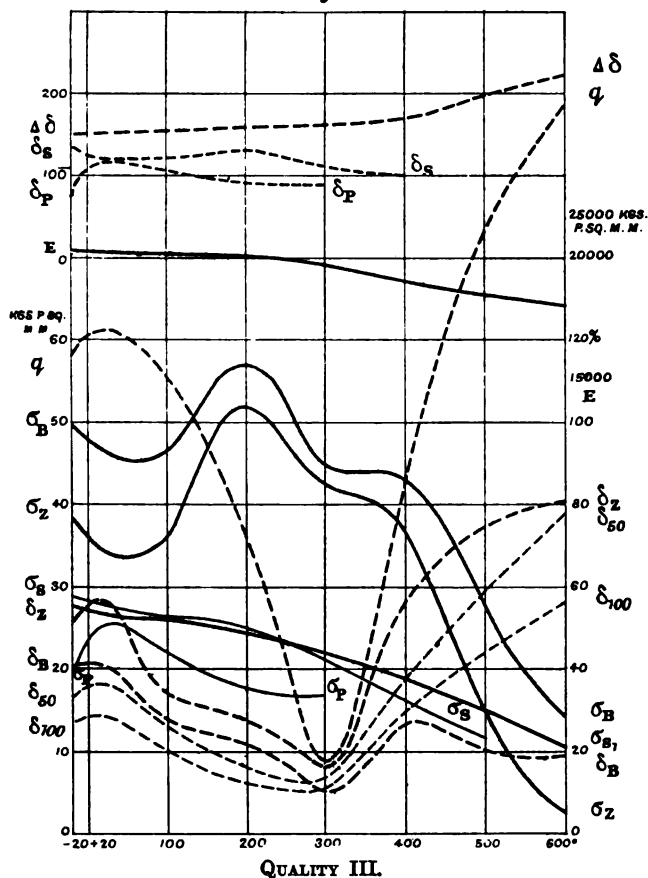


the limit of proportionality is plainly visible. Even at 300° it appears questionable whether the test-pieces can be truly said to show any proportional extension.

In *Figs. 3, 4, and 5* the chief results are delineated for the three qualities of material, respectively I, II, and III.

The quantity represented by each curve is denoted by the

Fig. 5.



letters at the commencement of each on the left hand, the meaning of the notation being as follows:—

$\Delta\delta$ Percentage of elongation per ton of load.

δ_s Percentage of elongation at the limit of stretch (*Streckgrenze*).¹

δ_p " " " proportionality (*Proportion alitactsgrenze*).²

E Modulus of elasticity.

¹ The "limit of stretch" is what is popularly termed the "limit of elasticity," and, more correctly, "yielding-point," where flow of the metal commences.

² The "limit of proportionality" is the point up to which stress and strain, accurately measured, remain proportional.

- q Contraction of area in per cent.
 σ_s Maximum stress.
 σ_b Breaking stress.
 δ_s Percentage of elongation at fracture.
 σ_s Stress at limit of stretch.
 δ_s Percentage of elongation at maximum load.
 σ_p Stress at limit of proportionality.
 δ_{100} Percentage of elongation in 200 millimetres.

the elongations, except where otherwise stated, are referred to the test-length of 206 millimetres.

Figs. 3 to 5 show very clearly how the stresses σ_s and σ_b decrease considerably from -20° up to about 50° , and after that rapidly increase until they attain a maximum at from 200° to 250° . This maximum value is for all the qualities of material tested considerably in excess of the value for $+20^\circ$, and by the following amounts:—

Quality. (Grade of Hardness.)	Excess for σ_s	Excess for σ_b
	Per Cent.	Per Cent.
I	34	62
II	27	45
III	25	50

The curves for σ_s follow a similar course. On comparing the curves for σ_s and σ_b it will be found that the maxima and minima occur at nearly the same temperatures. The following are the ratios of σ_s to σ_b in per cent. for various temperatures, as calculated from the mean values obtained:—

Quality of Material.	Ratio for							
	-20°	$+20^\circ$	100°	200°	300°	400°	500°	600°
I . .	76	75	77	86	96	66	39	12
II . .	85	82	85	92	96	76	43	7
III . .	7	74	79	91	96	84	49	16

With the exception of some of the test-pieces (of quality III), supplied by the Union Company, the material which is strongest in a cool state remains so when heated.

The diagrams, *Figs. 6 and 7*, allow a comparison of the leading results for all three qualities of material tested. Qualities