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FRENIC 5000M2 FOR MACHINE TOOL SPINDLE DRIVE

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1 FOREWORD

Fuji Electric has been selling the FRENIC5000M series as an AC spindle drive system for small machine tools since 1984. The FRENIC5000M series allows a maximum speed of 4500 to 6000rpm and is currently being used with many small NC machine tools and has gained favorable comment as an economical system with quick acceleration and deceleration performance.

Since the range of applications of this system has expanded considerable, a substantial model change has been made while maintaining economy. Besides expanding the capacity series and shortening the acceleration and deceleration times, noise, vibration, rotation irregularites, and other performances have been substantially improved by introducing a new control system.

The features and performances of the this new series FRENIC5000M2 centered about new technology are introduced.

2 SPECIFICATIONS AND FEATURES

The standard specifications of the spindle motor and drive unit are listed in *Table 1*. The main specifications, including features, are described in detail below.

(1) Continuous rated output

Models having a continuous rated output of 11kW and 15kW versus the 1.5 to 7.5kW of the old series were developed. Higher capacity machines are also under development.

(2) Speed control range

The speed of all capacity series is variable over the 150 to 6000rpm range. Standard output specifications are:

(a) 150 to 1500rpm: Constant torque
(b) 1500 to 4500rpm: Constant output
(c) 4500 to 6000rpm: Reduced output (75% at 6000rpm)

Low capacity models (7.5kW or less) having a maximum speed of 8000rpm are under development. Therefore, the maximum output frequency of the drive unit is 270Hz.

(3) Vibration and noise

Noise and vibration have been reduced considerably compared to those of the old models (FRENIC5000M series). Vibration is V5 or less and noise is 70dB(A) or less (75dB(A) or less for 11 and 15kW)

(4) Motor protection

The temperature is detected by a thermistor embedded in the motor winding and the motor is protected. Even under frequent acceleration and deceleration and other severe variation load conditions, the motor can be used up to its allowable value and burning of the motor can be prevented even if the output shaft is locked or the fan fails.

(5) Control system

Vibration, noise, and irregular rotation are reduced considerably by using a new flux control sine wave PWM system (Patent Pending).

(6) Torque boost

In the low speed range of 1/3 or less of the base speed (1500rpm), the voltage drop across the motor primary winding resistance cannot be ignored and the output torque decreases. To compensate for this, a variable resistor that adjusts the voltage to a high value is provided. The overall adjustment range is 100%. Fine adjustment while watching a digital display is possible.

(7) Acceleration and deceleration times

To accelerate and deceleration by using the torque over the motor constant torque, constant output, and reduced output range to the full, an acceleration and deceleration system by curve is used. The time required to reach the

Fig. 1 Load meter output characteristic

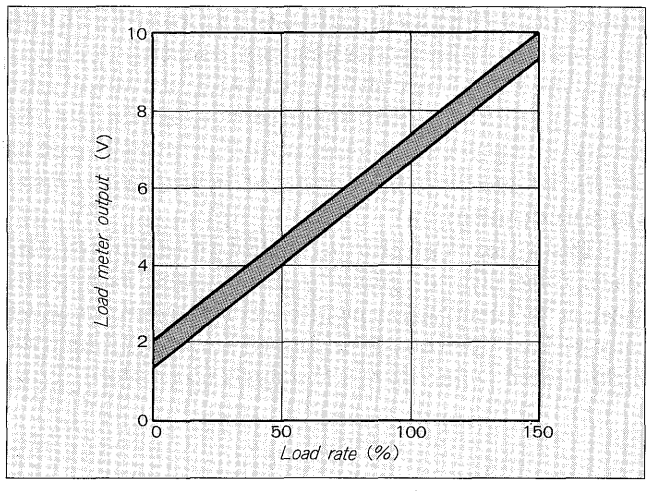


Table 1 Standard specification

Spindle motor	System name	FMD-1A	FMD-2A	FMA-3A	FMD-5A	FMD-7A	FMD-11A	FMD-15A
	Continuous rated output (kW)	1.5	2.2	3.7	5.5	7.5	· 11	15
	Model	MPF2097	MPF2107	MPF2115	MPF2133	MPF2135	MPF2165	MPF2167
	Base speed (rpm)	1500 (synchronous speed)						
	Maximum speed (rpm)	6000 (synchronous speed) *Output reduction necessary at 6000rpm (75% output).						
	Minimum speed (rpm)	150 (lowest speed at which continuous rated operation possible)						
	GD^2 (kg·m^2)	0.022	0.028	0.064	0.11	0.14	0.35	0.48
	Weight (kg)	22	26	46	60	74	127	145
	Vibration and noise	V5 or less, 70dB or less (75dB or less for 11 and 15kW)						
	Overload capacity	150% for 1 min						
	Connection to load	Belt and pulley						
	Installation system	Foot mounting: 1MB3, flange mounting: 1MV1						
	Color of finish	Munsell N5						
	Accessories	PTC thermistor, forced cooling fan *Self-cooling fan for 1.5kW and 2.2kW models with a maximum speed of 4500rpm.						
	Environment	Indoor, −10 to +40°C, 20 to 90% RH (no condensation)						
Drive unit	Drive unit	FMD-1AC-21	FMD-2AC-21	FMD-3AC-21	FMD-5AC-21	FMD-7AC-21	FMD-11AC-21	FMD-15AC-21
	Power requirement: Capacity (kVA)	3	4	7	9	13	19	26
	Power requirement: Voltage and frequency	3φ, 200/220/230V±10%, 50/60Hz±5%						
	Heat value (W)	150	200	370	480	610	960	1,300
	Weight (kg)	10	10	12	12	15	20	25
	Output: Rated current (A)	9	13	19	26	36	55	75
	Output: Rated voltage	3φ, 200V, at maximum frequency (power supply voltage proportional)						
	Output: Maximum frequency	50, 100, 120, 150, 180, 200, 240, 270Hz switching						
	Output: Minimum frequency	0.5Hz						
	Output: Frequency precision	±0.5% (25±10°C) of maximum frequency						
	Control system	Flux control sinusoidal PWM						
	Torque boost	0 to 100% adjustable						
	Overload capacity	150% for 1 min						
	Operation system	Reversible operation (by FWD and REV command)						
	Braking system	Resistance discharge regenerative system (10% ED standard resistance installed separately) and DC braking (below 0.5Hz at stopping)						
	Frequency setting voltage	0 to ±10 V/maximum frequency (+10V/100% standard)						
	Acceleration and deceleration times	1 to 10 secs (at maximum frequency 50 to 200Hz), 2 to 20 secs (at maximum frequency 240, 270Hz) curve acceleration and deceleration						
	Color of finish	Munsell N1 semi gloss (cover: Munsell 1PB5/13 half gloss)						
	Accessories	Braking resistor, external signal connector						
	Options	D/A converter, frequency meter, load meter (ammeter), simple type orientation (spindle), acceleration and deceleration time external switching						
	Environment	Indoors, −10 to +50°C, 20 to 90%RH (no condensation)						

maximum frequency can be adjusted continuously over the 1 to 10 seconds (2 to 20 seconds for 240 and 270Hz) range. The acceleration time and deceleration time can be adjusted independently. Continuous fine adjustment is possible while watching a digital display. When gear switching and other GD^2 of the load seen from the motor shaft changes considerably, the acceleration time can be switched by external signal. (Option)

(8) Braking system

A 10% ED by resistance discharge regenerative braking is standard. The braking torque is 150% and the motor is stopped positively by decelerating up to 0.5Hz and using DC braking below this.

(9) Load meter

A simple type load meter function is provided to shows the load power. Compensation by output frequency based on current detection is performed. An example of the output characteristic is shown in *Fig. 1*.

3 CIRCUIT COMPOSITION AND CONSTRUCTION

3.1 Circuit composition

Fig. 2 is a block diagram showing the composition of the drive unit main circuit and control circuit. The main circuit rectifies the input AC power by means of a power supply side diode rectifier, passes the rectified power through a resistor, charges a smoothing capacitor, and connects it to an inverter. It features a noise filter circuit at the input circuit, discharge circuit at the DC intermediate circuit, detection of both voltage and current as an AC signal, etc.

The main flow of the control circuit is the analog speed setting signal sent to the digital circuit through a V/F converter and to the PWM circuit through the acceleration and deceleration curve generator and flux controller. The mode generator manages the entire inverter based on the data of each section. The typical parts are described in detail below.

(1) Noise filter circuit

A surge absorption circuit and noise filter circuit are provided at the inverter input circuit. Besides a surge absorption circuit using zinc oxide overvoltage limiting elements, a noise filter circuit is featured. This circuit absorbs the RF noise flowing from the inverter to the power supply circuit and reduces the noise approximately 20dB at the radio frequency.

This circuit also prevents erroneous operation of the inverter by surges entering from the power line. A normal operation level of 2000V or greater was obtained at a 1μs square wave pulse noise simulation test.

(2) Discharge resistor

In the motor braking mode, the mechanical system energy is converted to electric energy and the smoothing capacitor of the DC intermediate circuit is charged. For this reason, voltage V_{dc} of the dc intermediate circuit is constantly monitored and when it exceeds a certain level, a discharge transistor is turned on automatically. This generates a 150% braking torque and quickly decelerates the motor.

(3) Flux controller

The instantaneous value of the output voltage V_{ac} and output current I_{ac} are detected and back to the flux controller and PWM control with an output waveform closely resembling a sine wave is performed. This new control system is called flux control PWM.

Generally, to reduce the electromagnetic noise of a motor, the PWM carrier frequency is made high. However, this method has such problems as (1) harmonic torque is generated by worsening of the output voltage waveform, (2) the effect of the transistor switching wasted time is large and low frequency torque pulsations are generated at a specified frequency region, etc. Flux control PWM solves these problems.

(4) Mode generator

This manages operation of the entire inverter by receiving various command input signals and the signals from sensors and commanding normal operation, stopping, intermediate control operation (operation to avoid trouble

Fig. 2 Main circuit and control circuit block diagram

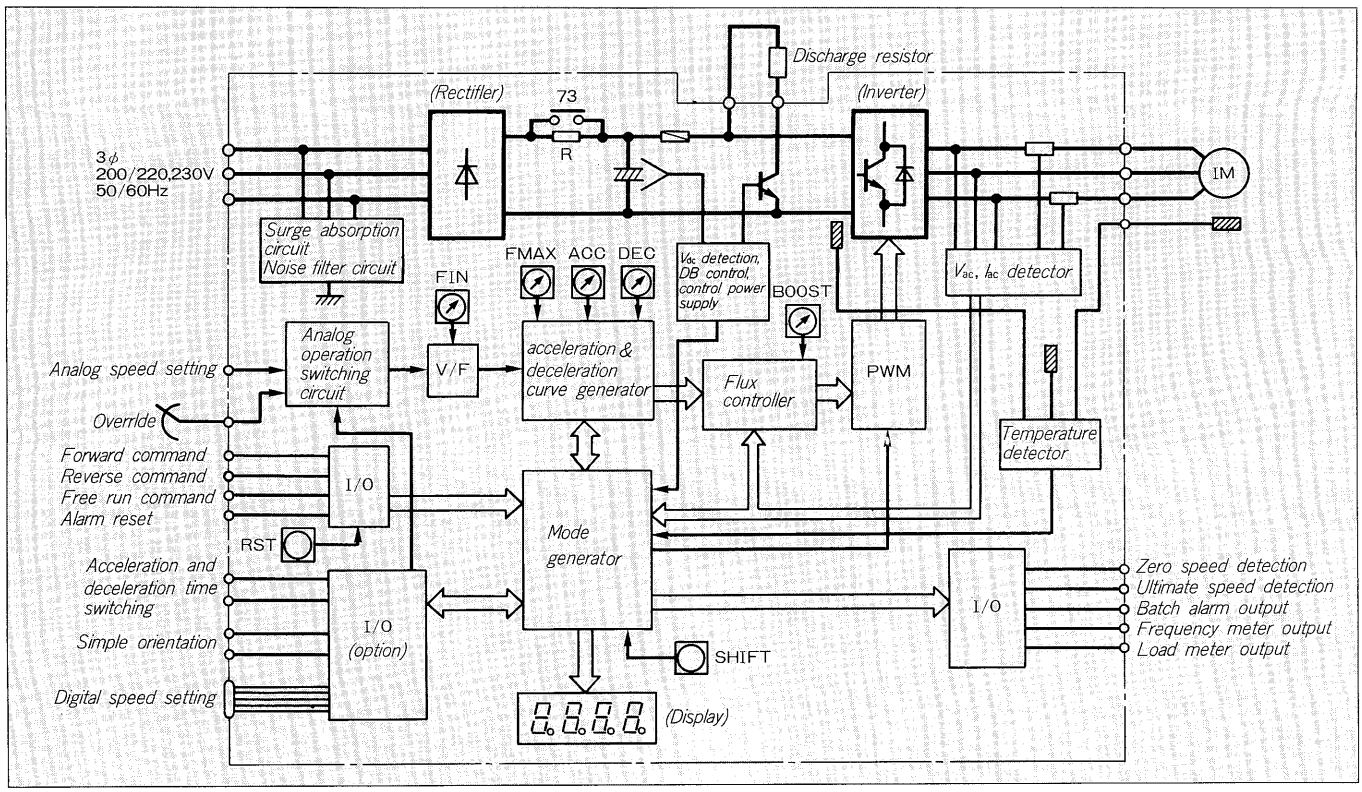


Table 2 lists the display contents in each mode

Function code	Data	
	Normal mode	Alarm mode
0	Output frequency (Hz)	The following contents are displaved in alarm generation order: OC.....Overcurrent OU.....Overvoltage OH.....Inverter overheating OL.....Inverter overload LU.....Undervoltage OP.....Motor overheating
1	Set frequency (Hz)	
2	FMAX setting (Hz)	
3	ACC setting (s)	
4	DEC setting (s)	
5	BOOST setting (%)	
6	DC braking setting (%)	Output frequency (Hz)
7	Output current (%)	Set frequency (Hz)
8	Direction of rotation (FO, rE,--)	Output current (%)
9	frequency (Hz)	Direction of rotation (FO, rE.--)
A		(CL) in overcurrent suppression mode
b		(UL) in overvoltage suppression mode
C		(UU) in instantaneous stop mode

while continuing operation for light trouble) from these, etc. It also manages the display contents of the dispaly panel, besides the output signals for conversing with NC equipment.

(5) Display

Four digit 7-segment LEDs are provided for various display during normal operation and when the inverter is stopped by a trouble. The display consists of a 1-digit (left end) display function code and 3-digit data displays. The function code uses the hexadecimal numbers 0 to F. In the normal mode and and alarm mode, the data is switched and displayed.

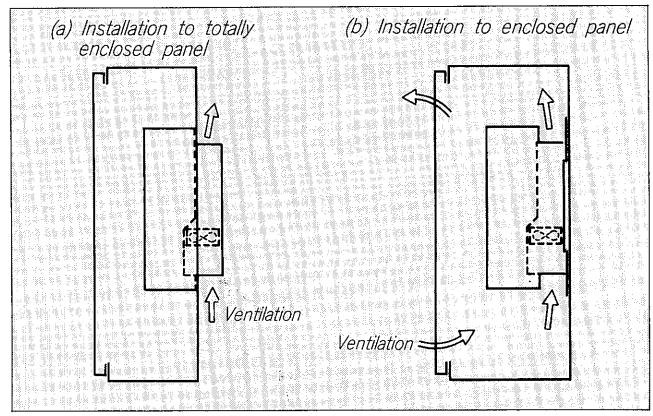
In the normal mode, function codes 0 and 7 display the operating state and the remaining codes are used to confirm the set values and command signals. Since each set value can be adjusted while watching a digital display, setting without any individual error is possible.

In the alarm mode, first the alarm generated first in time is displayed. When multiple alarms were generated, the alarm contents can be displayed sequentially by SHIFT key. Since the detailed operating state at alarm 1 generation can be called at the function code 6 to C range, positive and fast trouble diagnosis is possible.

3.2 Construction

Since there is cutting oil mist, etc. around machine tools and it is not so good environment for electronic control equipment, the trend is toward housing them in a totally enclosed panel. Since this also applies to the inverter for spindle drive, the FRENIC5000M2 series inverter are constructed so that the cooling radiator can be installed outside the panel as shown in *Fig. 3*. Since about 60% of the total heat value is dissipated directly to the outside air by this method, control panel cooling design is easy.

Fig. 3 Drive unit installation method



4 OPERATING CHARACTERISTICS

(1) Improvement of starting torque

Fig. 4 is a example of improvement of the torque characteristics. It shows the output torque characteristic when BOOST adjustment was changed 0%, 50%, and 100% at 5Hz output (synchronous speed 150rpm). Of these, the intermediate value can be adjusted continuously.

The torque increases as the BOOST adjustment % value is usually adjusted within the 50 to 90% range.

(2) Acceleration and deceleration characteristic

Fig. 5 shows the acceleration and deceleration characteristic when a 3.7kW motor is connected directly to load GD^2=0.14kg.m^2 (2.2 times the motor rotor GD^2). The curve acceleration and deceleration operation feature of the FRENIC5000M2 Series provides an almost constant output current during acceleration and deceleration. Since the maximum torque is used effectively over the entire range, acceleration and deceleration are extremely fast.

(3) Noise, vibration, and rotation irregularity characteristics

Fig. 6 shows the results of noise, vibration, and rotation irregularity measurements when the speed of a 5.5kW motor was changed over a wide range. Compared to the old FRENIC5000M series, the characteristic below the base

Fig. 4 Torque characteristic improvement example (2.2kW)

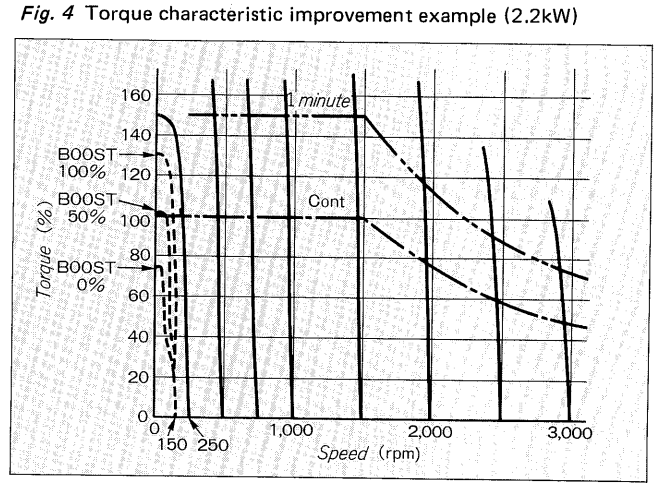


Fig. 5 Acceleration and deceleration characteristic example (3.7kW, load GD² ñ0.14kg·m²)

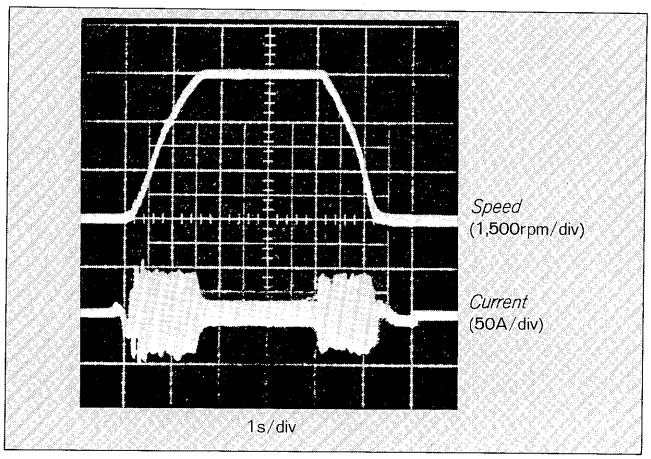
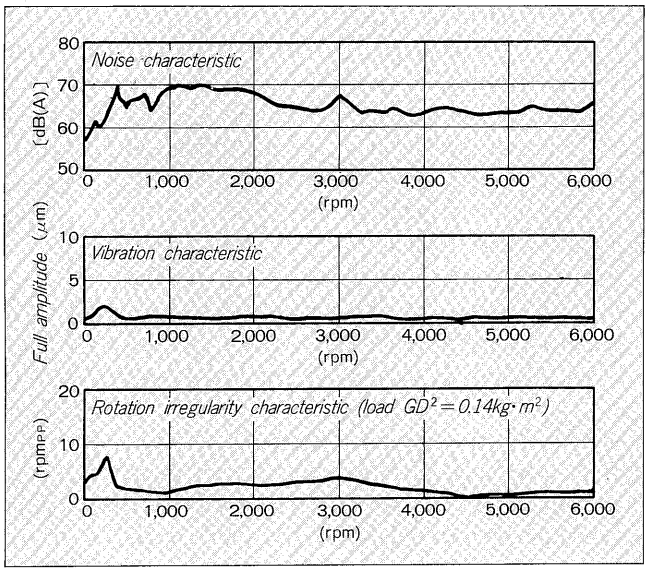


Fig. 6 Noise, vibration, and rotation irregularity characteristic example (5.5kW)



speed (1500rpm) is much better at each item.

They are almost the same as the vector control system spindle drive equipment. These were first achieved by flux control PWM.

(4) Simple orientation

Fig. 7 shows the changes in the stop position when orientation stop was performed 50 times by using simple orientation (option). At these test results, the stop positions are distributed over a range of ±2°. The stable slow speed effect of flux control PWM is also displayed here.

Moreover, a pulse encoder was installed to the spindle and a stable stopping precision of within ±1° for the target position was obtained in experiments at which compensation control was performed by angle detection signal. A

Fig. 7 Orientation stop characteristic

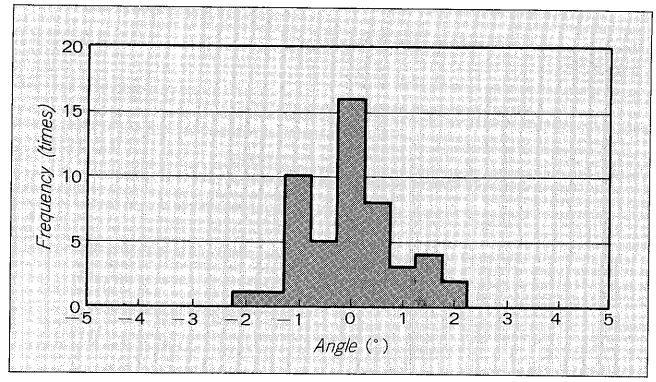
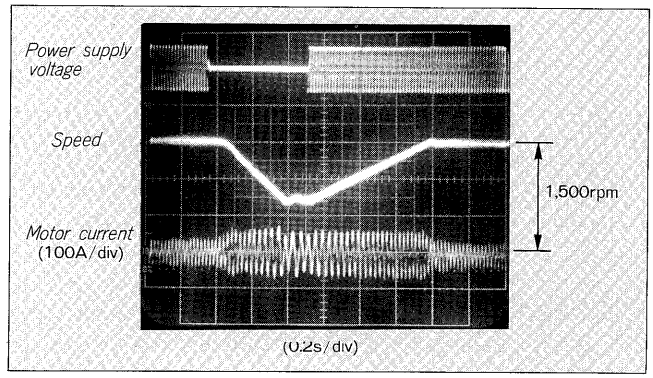


Fig. 8 Operation at momentary power interruption



multi-point indexing control option based on this system is under preparation.

(5) Operation at momentary power interruption

Fig. 8 is an operating oscillogram at a momentary power interruption. It shows the rotating speed and motor current waveforms after recovery from a 0.55 second power interruption during operation at 1500rpm. As can be clearly seen from these waveforms, the FRENIC5000M2 series can continue operating even at a momentary power interruption. *Fig. 8* is an example for a comparatively long power interruption. For a power interruption of 0.1 second or less, there is almost no drop in speed.

5 CONCLUSION

The new series, with many improved characteristics, was introduced above. The various characteristics closely approach those of vector control and we are confident that it will be used by many users as an economical spindle drive system.

Improvement of orientation performance, expansion of the rated output range, etc. are important future topics we will continue to promote development of the perfect spindle drive system while soliciting the guidance of users.