Improved Materials and Design of Pot Roll Bearings

Author: Jeremy Rydberg - Atlas Machine and Supply

October 5th 2017
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Abstract

Atlas Machine and Supply has been studying new materials and bearing designs for increasing the life of pot roll bearings. Our work includes testing several different materials including, metals, ceramics, cermet, and non-metals for corrosion and wear resistance in molten zinc with varying levels of aluminum. The study also includes testing higher performing materials in advanced bearing configurations.

The goal of the study has been to reduce the operating costs of producing galvanized, galv-alum, and aluminized steel strip by increasing the service life of bearings while also increasing roll stability leading to more consistent coating thickness and reduced maintenance costs.
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**INTRODUCTION**
In early 2017 Atlas Machine and Supply filed for a provisional patent on an invention that allows for the use of rolling element bearings on steel mill rolls that operate in molten metal baths. These types of rolls, often called pot rolls, are used in the continuous hot dip metal coating lines, Figure 1 shows a typical layout.

![Figure 1 - General Arrangement of Pot Rolls](image)
Currently metal coating lines utilize plain bearing systems that consist of a journal sleeve and bearing chock bushings. The journal sleeve rotates within the fixed bearing chock bushing and creates sliding friction at the point of contact. The sleeve, bushing, and the point of contact between the two operate submerged in the molten metal bath. The metals in the bath consist mainly of molten zinc with varying levels of aluminum and in the case of aluminizing lines, nearly pure aluminum is used. These molten metals are corrosive and bath temperatures range from 850°-1300° Fahrenheit. These extreme conditions lead to relatively short bearing life and facilitate the need to use expensive sleeve and bushing materials such has cobalt based alloys, super alloys, and ceramics. Bath chemistry, line speed, and product quality requirements are contributing factors to bearing life. In some circumstances bearings are changed as often as 4 days and some coating lines can run a set of bearings up to 12 weeks.

Plain bearings can also create some operational challenges in addition to short life. The point of contact between the sleeves and bushings creates high rotational friction forces. These high forces can lead to vibration, strip instability, and slippage between the pot roll and the strip. In the majority of metal coating lines the strip drives the pot rolls and journal friction can sometimes exceed the ability of the strip to drive the roll causing the pot roll to stop rotating, damaging the final product. To overcome this, operators reduce the journal diameter in order to decrease the rotational friction forces and increase the roughness of the roll face to improve traction between the strip and the roll. Both of these solutions have drawbacks, smaller journals are weaker and susceptible to breakage and rough roll faces are more likely to mark the sheet and experience increased dross pickup.

Rolling element bearings or roller bearings have the potential to improve or eliminate many of the challenges associated with plain bearings and also carry some additional benefits. Roller bearings inherently have much lower friction forces, longer life, and less vibration. The reduced vibration can increase strip stability and make it easier for plant operators to stay closer to the minimum coating application thickness, ultimately reducing zinc consumption costs. The lower friction forces of roller bearings will allow for engineers to rethink roll designs. The journals can be made larger to eliminate the risk of breakage and roll faces can be redesigned. Roll face roughness, materials, and groove patterns have all been designed under the requirement of driving the roll. With reduced rolling friction, roll designers can put increased focus on coating quality, line speed, and other value creating benefit.

The most significant benefit of rolling element bearings is bearing life. These bearings have the potential to run upwards of a year or more instead of days or weeks. Currently pot equipment is changed when either the bearing, or the roll face has reached the end of its life. For operators who run bearing limited the savings of a longer life bearing will be immediate. They can now operate roll face limited and run the line based on the usable life of the roll. Running longer between shut downs reduces the cost of refurbishing pot equipment, decreases
downtime, and increases annual production. Once an operator is running roll limited they can begin to look at alternative roll materials, coating, and designs to increase roll life. Many materials and coatings that may have seemed cost prohibitive in the past could become viable when considering extending pot equipment to a year instead of picking up a few extra weeks.

Rolling bearing technology that functions at operating temperatures of 850°-1300° Fahrenheit is well established, but these bearings and materials are not suited to perform in molten metal. The main reason roller bearings aren’t used in metal coating or similar applications is that seals or methods of keeping the bearings in a clean environment aren’t available on the market. Atlas’s invention has two critical components that overcome these hurdles. The first is a Rydal 12, a mechanically strong wear resistant carbon based material that has proven virtually impermeable in molten metal and a bearing enclosure and sealing system that utilizes Rydal 12 seals.

The bearing enclosure system is designed to work with slightly modified existing pot arms and rolls. It consists of a corrosion resistant bearing housing that replaces the existing bushing chocks. The significant features and functionality are detailed in Figure 2. The focus of the research performed and presented in this paper include testing the corrosion resistance of Rydal 12 and the life expectancy of the seals in service.
1. Outer seal face – Is a stationary part made from Rydal 12 and is press fit in place. The center of the sealing surface radius is centered on the self-aligning bearing (part 3).
2. Inner seal face – Is the rotating seal element made from Rydal 12 that is affixed to the bearing shaft (part 6).
3. Self-Aligning Bearing – Supplied by vendors and is allowed to slide in the housing to compensate for seal wear and is held on the shaft by the bearing nut (part 4).
4. Bearing nut – Supplied by vendors and holds the bearing on the shaft
5. Crush seal – made from Rydal 12 prevents zinc from getting between the shaft and roll journal
6. Shaft – Allows for the roll to be changed without disassembly of the bearing unit.
7. Cover plate – keeps zinc out of bearing cavity.
8. Housing – Holds the bearing assembly in a chamber pressurized by inert gas, most likely nitrogen. The air pressure creates the force necessary to keep the seal faces in constant contact. If the roll creates a momentary thrust load that exceeds the seal face force, escaping gas will prevent zinc from flooding the cavity.
METHODS — TESTING THE RESILIENCE OF RYDAL 12 IN MOLTEN ZINC.

A sample of Rydal 12 was attached to the end of a 316L piece of all thread and placed in a molten metal bath Zinc with chemistry detailed in Figure 3. The sample was left submerged for 10 days. Interaction between zinc and the Rydal 12 sample was compared to a control samples of undipped Rydal 12 and dipped and undipped samples of 316L. Experience from other experiments has shown that if a material does not begin to react in 10 days it will most likely never react and can be considered unaffected. 316L was chosen for comparison because it is a material that has an acceptable life in the zinc bath but does react within the 10 days.

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>4.86</td>
</tr>
<tr>
<td>Si</td>
<td>7.17</td>
</tr>
<tr>
<td>Cr</td>
<td>0.52</td>
</tr>
<tr>
<td>Fe</td>
<td>1.12</td>
</tr>
<tr>
<td>Zn</td>
<td>73.51</td>
</tr>
</tbody>
</table>

Figure 3 - Bath Chemistry

Figure 4 - Rydal 12 Submerged In Molten Zinc
METHODS — ESTABLISHING A LIFE RATING OF THE RYDAL 12 SEALS

The Rydal 12 seals used in the bearing system are a dry running mechanical seals. The key to understanding their life is the pressure velocity rating, or PV, of the material. PV is the operating pressure of the seal face measured in PSI multiplied by the speed measured in feet per minute. The PV rating of similar carbon materials is known to be 15,000 at room temperature. No PV data exists for Rydal 12 at high temperatures and needs to be established.

To determine the PV of Rydal 12 a test rig was built that mimics a stabilizer roll in service but has adjustable speed and pressure so these variables could be changed to establish limits and expected wear. Details of the assembly are provided in figure 5. Similar to the actual roller bearing system the bearing cavity is pressurized with 25-65 psi nitrogen. The air pressure forces the rotating seal into the stationary seal and these forces keep the system sealed and take the thrust load of the stab roll. Running higher pressures increases the wear on the seals but also allows the system to take a heavier thrust load. Understanding the PV limits of the material will allow for the design of a long life seal. Please note, cavity pressure and seal pressure are not the same thing. Seal face pressure is the push force of the rotating seal divided by the seal face contact area. Rotating seal push force is the total area of the seal multiplied by the bearing cavity air pressure. The calculations used are in Figure 6, all testing is performed at 850°F and 250 RPM.

The test rig was run for 5 days, the pressure was increased daily from 25-65 PSI in 10 PSI increments. As the seal face wears the drive shaft extended upwards out of the test rig, the distance the shaft traveled was measured and is equal to seal face wear. This number was recorded for each 24 hour period and the results were mathematically extrapolated into annual wear.

Rotating Seal Diameter = 4.25 Inches
Rotating Seal Area = \( \pi \times (\text{Diameter}/2)^2 \) = 14.18 Square Inches
Air Pressure = 25 – 65 PSI
Rotating Seal Push Force = Rotating Seal Area \( \times \) Air Pressure = 354 - 922 LBS
Seal Contact Area = 7.58 Square Inches
Seal Contact Area Pressure = Rotating Seal Push Force \( \div \) Seal Contact Area = 47 – 122 PSI
Seal Face Velocity = 232 Feet per Minute
PV Range Tested = Seal Contact Area Pressure \( \times \) Seal Face Velocity = 10849 – 28208 PV

Figure 5 - Calculations
Figure 6 - Test Rig Cross Section
RESULTS – RESILIENCE OF RYDAL 12 IN MOLTEN ZINC

Micrograph examination of Rydal 12 dipped in a zinc bath for 10 days shows no interaction with the zinc. The micrographs of the dipped Rydal 12 sample where compared to undipped samples and no change could be detected. The Rydal 12 samples where compared to dipped and undipped 316L samples. The 316L had clear interaction with the zinc, zinc adhered to the sample and there is fusion line where the zinc and base metal reacted to form unknown compounds. Only visual observation of these compounds is required for comparison, no testing was done on the 316L to determine what compounds formed.

RESULTS – LIFE RATING OF THE RYDAL 12 SEALS

<table>
<thead>
<tr>
<th>Day</th>
<th>PSI</th>
<th>PV</th>
<th>Wear</th>
<th>Hours</th>
<th>Annual Wear (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>day 1</td>
<td>25</td>
<td>10864</td>
<td>0.001</td>
<td>18.0</td>
<td>0.49</td>
</tr>
<tr>
<td>day 2</td>
<td>35</td>
<td>15209</td>
<td>0.003</td>
<td>22.5</td>
<td>1.17</td>
</tr>
<tr>
<td>day 3</td>
<td>45</td>
<td>19554</td>
<td>0.003</td>
<td>23.3</td>
<td>1.13</td>
</tr>
<tr>
<td>day 4</td>
<td>55</td>
<td>23900</td>
<td>0.002</td>
<td>23.8</td>
<td>0.74</td>
</tr>
<tr>
<td>day 5</td>
<td>65</td>
<td>28245</td>
<td>0.003</td>
<td>16.6</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Figure 9 - Wear Data of Rydal 12 Seals

Figure 9 details the wear the seals experienced at different PV levels. The results were fairly consistent with a jump in wear between 55 PSI and 65 PSI. Wear of the seals ranged from .49 inches through 1.17 inches within the PV range of 10,864 to 23,900.
CONCLUSION

Rydal 12 had no detectable interaction with the zinc bath in 10 days which indicates that it will most likely never react. Seal life should be unaffected by chemical reaction and the only factor to consider will be mechanical wear. Mechanical wear testing of Rydal 12 in a configuration similar to the final seals ranged from .49 inches to 1.17 inches within a PV range of 10,864 to 23,900. These are acceptable wear parameters that will allow for an effective seal design that can be used in service for over 1 year.

DISCUSSION

The invention of this roller bearing system utilizing Rydal 12 materials has shown sufficient results to warrant in service testing. The next step for this project is to adapt the roller bearing system to an actual coating line and perform in service trials. The system can be applied to a single roll without effecting the other pot rolls. It is recommended that testing be performed on a front stabilizer roll for easier monitoring and change out if required. Please contact the author, Jeremy Rydberg, for further information and to request a trial.

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