Solution for Continuous Caster DC Motor / Encoder Failures

Fernando Ardines[1], Bernardo Sainz[2], Hector Ortiz[3]

[1]EVRAZ Rocky Mountain Steel
1612 East Abriendo Av. Pueblo, Colorado, United States, 81004
Phone: +1-719-561-6000
Email: fernando.ardines@evrazna.com

[2]AMI Automation
Boulevard Gustavo Diaz Ordaz 402, Nuevo Leon, Mexico, 64650
Phone: +52-81-1001-4050
Email: bernardo.sainz@amiautomation.com

[3]AMI Automation
Boulevard Gustavo Diaz Ordaz 402, Nuevo Leon, Mexico, 64650
Phone: +52-81-1001-4050
Email: hector.ortiz@amiautomation.com

Keywords: revamp, enclosed, AC, DC, shield, motor, temperature, cooled, encoder, resolver

INTRODUCTION

The six-strands continuous caster at EVRAZ Rocky Mountain Steel in Pueblo, CO, experienced reliability problems with the withdrawal/straightener (w/s) DC motors, encoders and drives. The location of the motors exposes them to extreme heat conditions, resulting in high motor and encoder failure rates. In order to mitigate the problem, the EVRAZ maintenance team fabricated a water-cooled jacket for the motors and the use of water-cooled encoders, but the actions were not sufficient to fix or considerably reduce the failure rates.

EVRAZ decided to upgrade the caster withdrawal/straightener control system, including the replacement of the old DC motors and drives. The solution proposed by AMI Automation included new standard AC motors with RTD probes for temperature monitoring, and standard encoders inside a water cooled enclosure and new drives as a part of the upgrade. The first three w/s motors of strand 1 were replaced in November 2013 as an initial trial. Motor winding temperature readings showed a maximum temperature rise of 85 °C, well below the motor insulation ratings.

The six w/s motors from strands 2 and 3 were replaced in May 2014 and the remaining nine for strands 4, 5 and 6 were changed in October 2014. Since that time, not a single motor or encoder failure has been reported.

DISCUSSION

The caster has been in operation since the 1980's. The straightener/extraction portion of the caster is composed of three stands per strand, each with an independent motor for a total of 18 motors. See figure (1) for a general view of the caster. The main straightener motors for the caster extractor stands were TENV (totally enclosed not ventilated) shunt type DC motors, controlled independently with drives, both armature and field. They use encoders for speed regulation and tracking wheels for the cast length measurement.

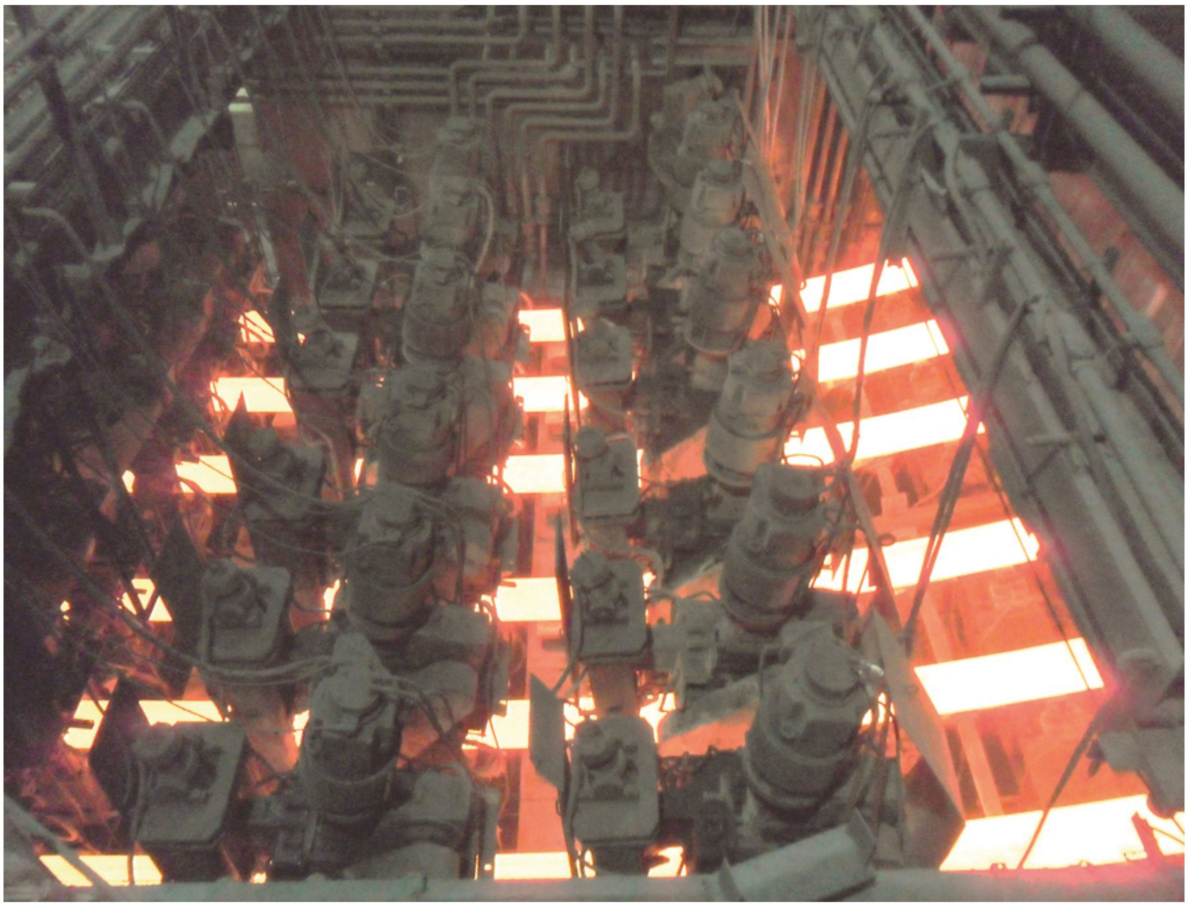


Figure (1). Six-Strand Caster Configuration. Shown with the original motors and encoders.

The stands often had to be removed from operation for predictive maintenance or due to failures during production, impacting overall caster productivity, yield goals and scheduling challenges. The most common motor and encoder failures were due to electrical heat fatigue. Damage to winding insulation and encoder circuits was typically attributed to high temperature exposure. With surrounding structures reported to be at 300°F during the summer, the provision of process cooling water around the motors and encoders was typically not sufficient to prevent the damage. Figure (2) shows an original DC motor with a water-cooling coil.

The caster problem previously discussed was subjected to an analysis and breakdown into several focused problems. Once the root cause is defined, a feasible solution will be provided for each one.

Figure (2). Original DC Motor with water-cooled coil in the center.

ANALYSIS

Overall problem definition

The main driver is to achieve caster operation without disruptions from motor/encoder failures. In Figure (3) is a diagram with the problem map.

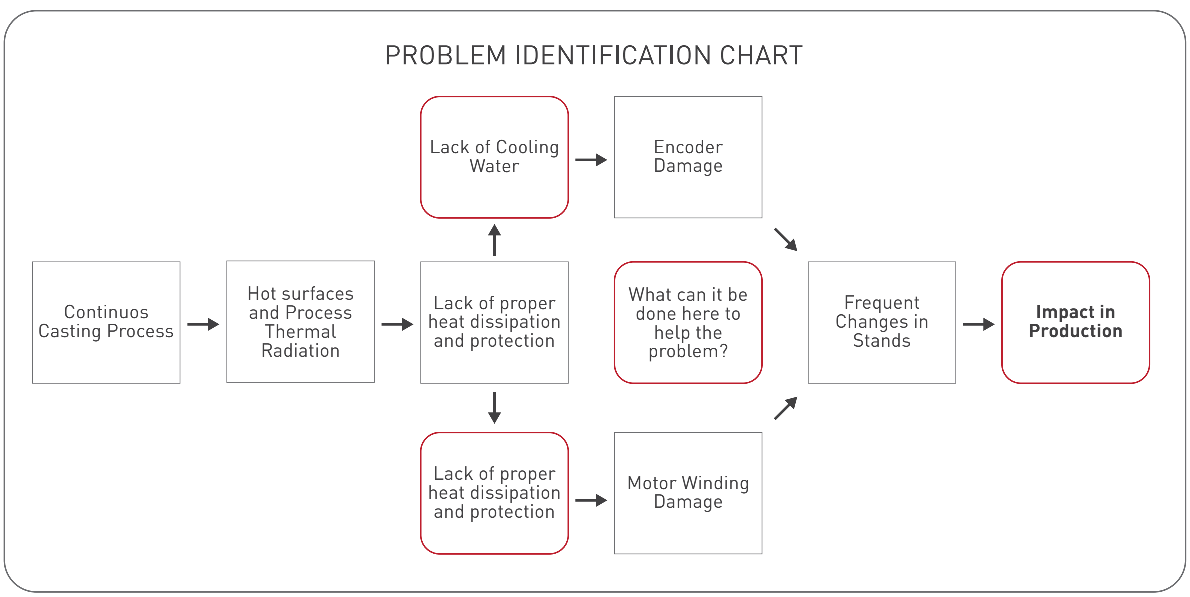


Figure (3). Relational diagram for problem identification.

As the problem map in Figure (3) shows, the following problems were defined:

- Excessive heating of the main motor/encoder unit.
- Excessive heat of main motor assembly structure.
- Encoder dependency for the process.
- Change of stands wiring methods.
- Dependency of cooling water.

Heating problem analysis

A heat flux diagram shown in Figure (4) gives a better understanding of how the motor–encoder assemblies are situated in relation to the caster flows. As shown in Figure (4), the motors are directly next to the pathway of the blooms, which are at a temperature of approximately 1750°F. At the first stand the irradiated energy is absorbed by the nearby structures, including the stands.

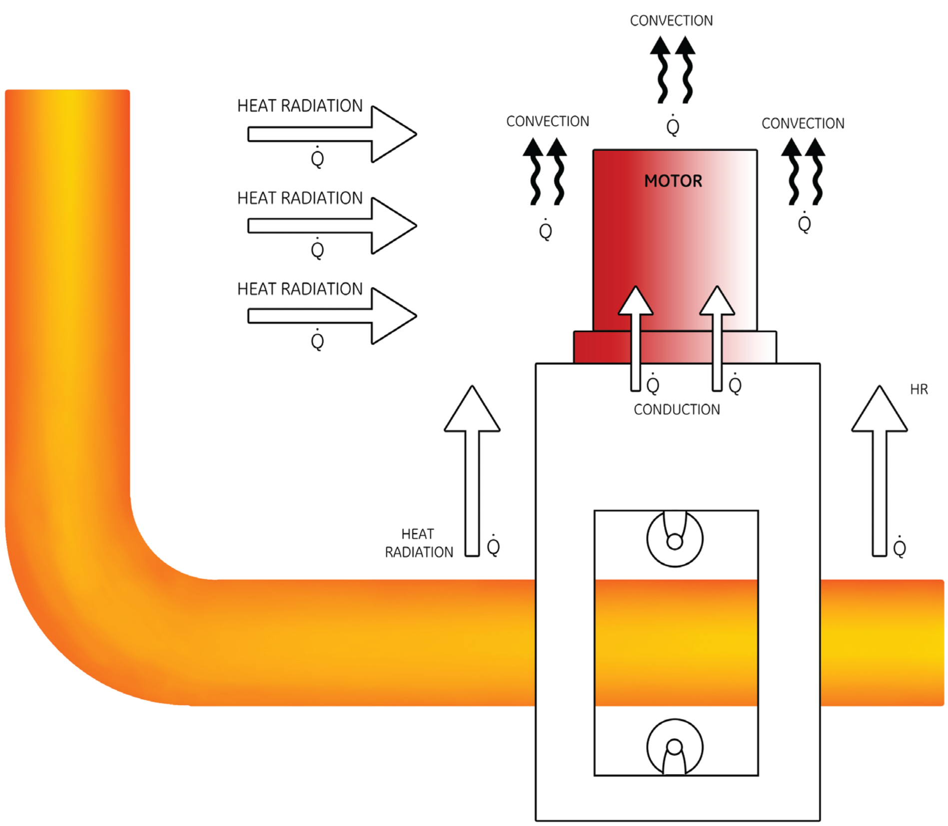


Figure (4). Produced heat diagram.

The produced heat of the motor can only be dissipated by air (convection). This is complicated by the wide range of climate conditions in Pueblo, CO, with temperatures ranging up to 103°F during the summer and down to -17°F during the winter (2014 ref (1)). Hot summer days would affect the motor dissipation by air. It was not possible to measure the mean temperature of the caster environment at the stands due to lack of instruments present and the cost/complexity of adding infrastructure to achieve it.

As figure (2) shows, the water-cooled coil surrounds a small portion of the motor. This can extract a portion of heat from the motor; nevertheless, it does not prevent radiant heat from reaching the motor. In addition, the DC motor heat is not easily dissipated by the exterior cooling coil since the main current flows through the rotating armature, while the stationary part only contains the field winding.

From the previous analysis of heat flow around the motor, it can be deduced that the motor field armature windings are being degraded by excessive heat stress to the chemical coating of the conductors. The heat resistance capacity of the winding insulation material has a known limitation in the industry, so there is a temperature range at which any given motor-construction will ultimately fail, no matter what the insulation rating is (even the available class H rating).

Encoder failure

The encoder's thermal behavior is similar to that of the motor subject to direct radiant heat exposure. The only difference is that the encoder's adapted water-cooled coil covers a larger area.

The encoder is installed in the ODE side of the motor shaft. As in the previous problem, radiant heat can reach the encoder, its coil and its mounting portion of the motor.

Even though the encoder has a water-cooled coil to protect it from radiant heat, the encoder is still connected to the motor shaft by a large and continuous cross section, which conducts a considerable amount of heat to the encoder. In addition, most of the DC motor's heat production is in the rotating armature. If not ventilated, the heat has to be dissipated by its mechanical parts, including the encoder. Further, maintenance personnel reports indicate that pipe clogs are commonly found in the water-cooled coils of failed encoders, eliminating only heat dissipation capability of the encoder other than ambiant air.

Stand maintenance connect-disconnect needs

Since the stands are commonly mounted and un-mounted for mechanical maintenance, motors and encoders require a fast disconnect method. The encoders commonly have an exterior socket connection but that is not the case for the motors. Instead, they have an exposed connection point that provides a direct point of entry to the motor interior for particles, humidity and other contaminants. This may lead to non-temperature related problems, but there is no information available to support that motor failures were related to internal contamination.

SOLUTIONS PROPOSED

Analysis of the root causes and determination that the failures are related to heat helped determine the optimal solution. First the initial requirements driven by production and maintenance goals are compared. There is a need to weight the goals in order to direct the solutions. To achieve this, a typical benchmark and voice of client technique –QFD tool– is used. Figure (5) is the house representation of QFD.

The tool is useful when multiple objectives are requested and helps to connect the initial problem statement to the actual possible objectives for the solution.

The main functional requirements that the solution will aim to address are as follow:

- Use of heat removal auxiliary equipment. This is defined as the use of any equipment that may be able to remove heat from the motor and the encoder.
- Increase in capacity of heat removal. This is defined as the means of the actual system to conduct the heat away from the motor and encoder.
- Increase in encoder heads. This is defined as the amount of units that are able to monitor the rotation speed of the motor shaft.
- Increase in temperature sensors. This is defined as the amount of monitoring devices capable of sensing the temperature of motor and encoder.
- Selection of AC motors over DC motors. It is found that the relative weight shows more relationship between the aimed functional requests than the DC motor. This is purely arbitrary.

Motor change to AC

A change from DC to AC motors was selected. This has an alternate implication in that the approach requires migration to AC drives as well. Features are as follows:

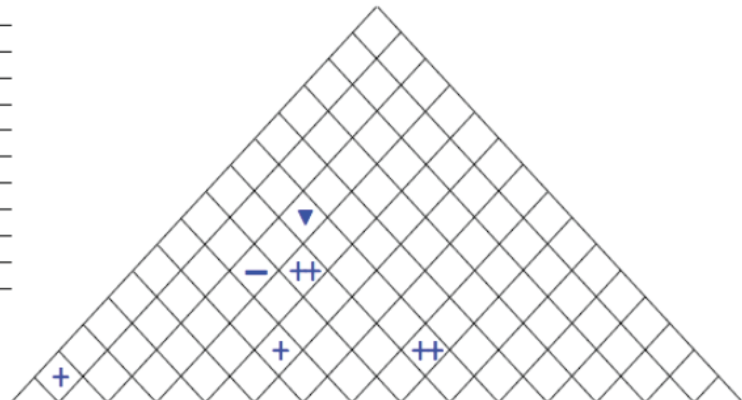
- Class H insulation rating, which allows the motor to run up to 165°C (329°F).
- Motor is totally enclosed and not ventilated (TENV). This will prevent outside contamination from reaching the winding construction. Nevertheless, it will affect the overall motor heat dissipation.
- 10 hp motor, six pole, 1190 rpm to increase stand power and motor current capacity.

The torque had to be similar or higher than the replaced DC motor. Comparison was calculated using Equation (1) for torque in lb-ft. The different values are shown in Table (1). The general AC motor information is shown in Table (2). The 10 hp 1200 rpm six pole AC motor is chosen for this application, which will be able to supply 159% more torque than the existing motor. The motor is selected to be able to run at a 150% nominal speed, to fulfill the DC motor speed range.

$$\text{Torque} = \frac{(\text{hp})\times 5252}{\text{rpm}}$$

Equation (1). Calculation of torque in lb-ft based on motor power (hp) and speed (rpm).

Title: EVRAZ Solution Comparison
Author: Hector Ortiz
Date: November 2012
Notes:



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	x	▼	x	▼	▲	▲	▲	▲					
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Encoder Heads	Use of Resolvers	Increase power of the 7.5 hp motor	DC Motors	Quick power connectors	Use of additional water flow sensor	Use of additional temperature sensor	Use of heat removal auxiliary equipment	AC Motors	Capacity of heat removal					
1	9	21.3	10.0	High temperature resistance	○	⊖	▲	○	▲	▲	▲	⊖	○	⊖					
2	9	4.3	2.0	Easy to change motor	○	▲	▲	▲	⊖	⊖	⊖	⊖	⊖	○					
3	9	17.0	8.0	Temperature can be monitored	▲	▲	▲	▲	▲	▲	⊖	▲	▲	▲					
4	9	21.3	10.0	Have reliability in encoder	⊖	○	▲	▲	○	○	○	⊖	▲	○					
5	9	4.3	2.0	Motor protected from environment	▲	▲	▲	▲	▲	○	○	⊖	▲	⊖					
6	9	10.6	5.0	To replace system easyly	⊖	○	▲	⊖	⊖	○	○	⊖	⊖	⊖					
7	9	21.3	10.0	To reduce heat absortion by radiation	▲	▲	▲	▲	▲	▲	▲	⊖	▲	⊖					
8																			
9																			
10																			
				Target or Limit Value															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)															
				Max Relationship Value in Column	9	9	1	9	9	9	9	9	9	9					
				Weight / Importance	406.4	334.0	100.0	227.7	261.7	206.4	342.6	763.8	261.7	610.6					
				Relative Weight	11.6	9.5	2.8	6.5	7.4	5.9	9.7	21.7	7.4	17.4					

Figure (5). QFD Diagram to understand function relationships.

MOTOR	Torque (lb-ft)
DC motor 7.5 hp and 1450 rpm	27 lb-ft
AC motor 10 hp and 1800 rpm (four poles)	29 lb-ft
AC motor 10 hp and 1200 rpm (six poles)	43 lb-ft

Table (1). Comparison of motor nominal torque.

AC Motor Information	
Voltage	460 volts
Phases	3
Poles	6
Power	10 hp
FLA Current	14.4 amps
Speed	1190 rpms
Insulation Class / Rise	H / F

Table (2). Selected AC Motor Information.

Motor-Encoder assembly heat protection

Based on the QFD diagram shown in Figure (5) there is a strong negative relationship between "Capacity of heat removal" and "Increase power of the 7.5 hp motor". Arbitrarily, this relationship is redirected to integrate the surroundings. Now the negative correlation is stated as "how to increase capacity of heat removal and increase power at the same time". By heuristics, it understood that if power increases, losses increase and dissipation will be more difficult.

The strong negative relationship is supported by TRIZ principles of design. To prevent overheating generated by the cast blooms from reaching the motor assembly, a shield was installed shown in Figure (6). The shield is constructed by an upward coil made of tube, which circulates water in an upwards direction from the process cooling water.

The motor shield has the following operative functions:

- Blocks the heat transfer from the blooms from reaching the motor and encoder.
- Removes the incidental bloom heat by means of the circulating water.
- Exposes a cooler face to the interior of the shield.
- Prevents dust and particles from free falling into the encoder.

As shown in Figure (4), heat to the motor was primarily from two sources: 1) bloom radiation heat and 2) stand structure heat by conduction. To reduce heating from the stand structure, a cooling base was attached. Now rather than mounting the motor directly to the stand, the motor is mounted onto the cooling base. The base is cooled by process water in the same circuit as the upper coil. Hence the motor shield comprises: a cooling base, an upper wall water coil and a cover plate (without water flow).

To speed up stand change

Compared to the original solution, the new motors are installed with fast connectors. These connectors are IP6X class, so they can withstand the environment and humidity. At the cable side liquid tight cable glands are installed. It is expected that these connection terminals will decrease overall motor connection and disconnection time from the electrical system to one minute.

Encoder Reliability and Availability

Encoders are left mounted in the motors. Nevertheless, the encoders remain inside the shield as well. In contrast with the original design, in which a small water-cooled coil covered a portion of the motor and a portion of the encoder, the new scheme protects the encoder from thermal radiation, which is estimated to improve the encoder's life. Encoders rated for operation under 220°F were selected.

Another issue with encoders is availability. Unlike motors, encoders are difficult to monitor for maintenance goals. The encoder electrical breakdown is difficult to estimate and often fails under operation conditions. To improve the availability, a two head encoder was selected. Both pick up heads were connected to AC drives for speed regulation and to PLC for cast length purposes.

Figure (6). Motor heat shield assembly.

IMPLEMENTATION

The new system was implemented in three stages, to test performance and reliability. The implementation stages were as follows:

- Strand 1 – October 2013
- Strand 2 and 3 – May 2014
- Strand 4, 5 and 6 – October 2014.

Programming for commissioning was designed so at stage 1 the system architecture and motor shield design could be tested. From this approach the thermal solution provided by the motor shield was proven to be correct. The motor did not show a temperature above 185°F.

Even though stage 1 was successful, strands three and four are the stands with more demanding heating conditions. These stands are located just in the middle of the caster, where temperatures are expected to rise. In this zone the air temperature is high and the area receives much more radiation than the edge strands one and six. In Figure (7) strands one through three are shown with the motor shields and the new motors, while four through six still have the original motors.

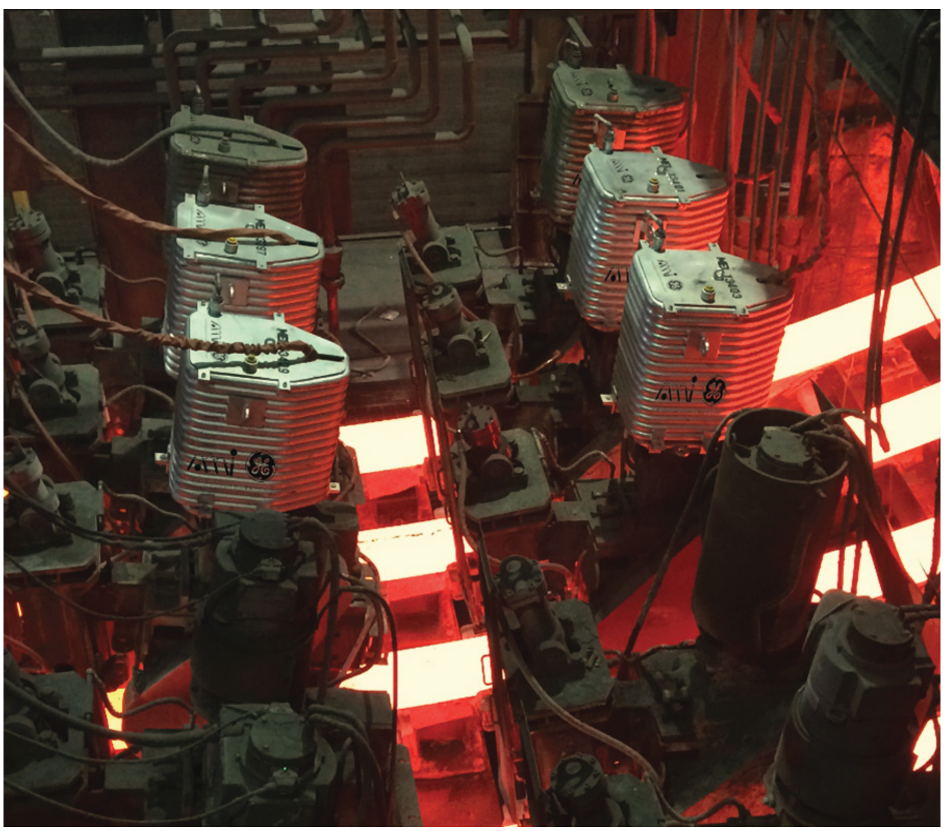


Figure (7). Motor heat shield construction.

Overall system performance

The system outperformed the expected temperature. In May 2014, after two days of caster production the hottest motor showed a temperature of 165°F. As expected, the hottest motor is in strand three, the stand closest to the withdrawal section of the caster. The coldest motor at that time was the output stand of strand one (edge strand) with a temperature of 122°F. Working temperatures are well below the motor limits of 329°F.

During the switchover from DC to AC drives, a load sharing logic was implemented among the stands of every strand. Different than a droop the load balance, a master reference and slave compensations were used. With the selected 10 hp AC motor and over torque the motor load was around 5-20% depending on the cast product cross section. For large cross-section blooms the system went into regeneration quadrant. To achieve this a line regeneration AC unit was installed. The energy required to slow down the bloom was returned to the line by the AC drives and the regeneration.

Further tests and monitoring is taking place at this time by EVRAZ to measure the success of the revamp and savings in down-time compared to previous motor failures. A comparison of caster temperature performance during the upcoming summer (second summer since the initial installation) will also be conducted.

CONCLUSIONS

The revamp of the original DC motors with the new AC motors and motor shields outperformed expected behavior. The motor running temperature has been below the 300°F and active temperature monitoring is done, for preventive maintenance purposes. The motor load is very low, mainly due to the extra torque available. For future implementations, a more standard AC motor with insulation class F and an ambient temperature of 40°C (104°F) is being considered. Due to the reduction in temperature of the working motor-encoder space, a standard encoder can be utilized.

The system revamp demonstrates the benefits of topology changes in casters and can be considered successful. Introducing AC motors that run cooler and the use of motor thermal shields helps and improves maintenance periods, reducing failures and improving caster production levels.

REFERENCES

1. Kevin Otto, Product Design, Prentice-Hall, Upper Saddle River, NJ, 2001, pp 289.
2. Pyrhönen, Design of Rotating Electrical Machines, Prentice-Hall, Upper Saddle River, NJ, 2001, pp 432.