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PREHEATING COLLECTOR BARS AND CATHODE BLOCKS PRIOR TO RODDING WITH CAST IRON BY PASSING AN AC CURRENT THROUGH THE COLLECTOR BARS

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Abstract

Three basic methods for heating collector bars and cathode blocks, prior to pouring cast iron, are in use today: gas burners directly impinging on the collector bars, ovens for heating bars and blocks separately, and third, passing an alternating electrical current through the collector bars to heat bars and blocks simultaneously. This paper examines electrical heating using the collector bar as the heating element. Passing an alternating current through the collector bar produces an easily regulated and uniform temperature throughout the bar. Radiant energy from the bar heats the slot area of the cathode block. Temperature levels are adjusted by time and voltage selection. Electrically heating collector bar/cathode block assemblies uses less than 15% of the energy required for propane gas burner heating. The method is quiet, requires little or no supervision, has no products of combustion to exhaust, and temperatures are highly repeatable.

Introduction

The voltage drop between collector bars and carbon cathode blocks depends on the contact pressure between them. If the pressure is too low, the voltage drop will be high. If the pressure is too high, the block may develop a longitudinal wing crack, eventually allowing metal pad penetration to the collector bar and ultimately cathode failure.

Cast iron rodding or sealing of collector bars to cathode blocks is the most common method of connecting the two components in use today. When done properly, the method provides a good mechanical and electrical joint between bars and blocks. When done improperly, longitudinal wing cracks and transverse cracks may develop.

Cracks, created by improper preheating and casting procedures, may appear after iron pouring and then seem to disappear as the block/bar/iron assembly cools. These cracks are still there, even though they are not visible [1] and may be the cause for premature cathode failure.

The purpose of heating collector bars and cathode blocks, prior to sealing with molten iron, is to minimize potential cracking due to thermal shock, differential thermal expansion [1], and rapid expansion of water vapor in the blocks [2]. Another purpose of heating bars and blocks is to prevent steam blow-back of molten iron.

Cathodes experience a complex set of stresses during their lifetime, starting with the molten iron sealing of steel collector bars in prebaked cathode blocks. Blocks are susceptible to wing cracks (WC) that start at the slot corners, and transverse cracks (TC) located at or near the mid-points of the bar length. Improper procedures used during rodding (sealing) with cast iron may be the cause of these types of cracks.

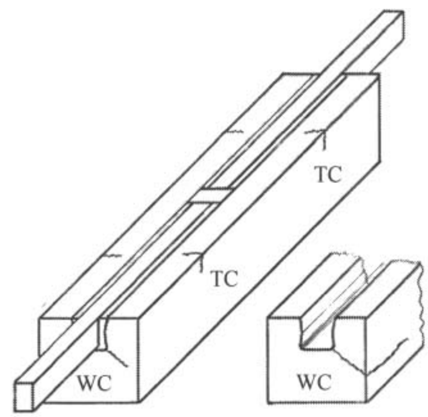

Figure 1. Types of potential cathode block cracks from casting (WC = wing crack, TC = transverse crack) (redrawn from reference [2]).

When molten iron at 1,300°C – 1,400°C is poured into the gap between collector bars and cathode blocks, the carbon experiences a thermal shock. Collector bars initially have a higher temperature at the surface closest to the slot bottom, due to the freezing iron. The temperature differential between bar top and bottom causes the bars to bend with ends higher than the middle. Because the bar slot is keyed and the iron freezes rapidly, this initial curvature of the bar creates bending stresses in the block wings. The stresses, thus created in the slot corners, may be near or exceed the elastic limit of the cathode block and create wing cracks (WC in Figure 1). As the temperature in the bar equalizes, the bar straightens, and the forces on the block wings diminish [3].

As the iron cools and solidifies, the block develops a higher temperature in the slot than at the bottom of the block, causing the block to bend. The portion near the middle of the bar becomes higher compared to the block end or portion near the bar ends. This bending, created by block differential expansion, may create transverse cracks in the tops of the block wings, if block tensile strength is exceeded (TC in Figure 1) [3].

Proper preheating of bars and blocks and other procedures help reduce the thermal shock and stresses generated by the hot iron.

Most of the current between collector bar and cathode block flows through the sides of the cathode block slot [4]. The electrical resistance of this connection goes down with increasing contact pressure between the cast iron and carbon. However, too much pressure can exceed the bending (tensile) and shear stress limits of the block, resulting in wing cracks [5]. Small wing cracks that appear immediately after pouring iron, and then disappear, may result later in separation of the wing during pot operations. If wing separation occurs, electrical resistance between bar and block increases and the block integrity is compromised.

An increased potential for wing separation may occur during operation, if bars are not preheated prior to pouring cast iron.

Table I lists bar and block temperatures prior to pouring cast iron specified by different block suppliers and users. Recommendations for block temperatures vary from 200 °C to 350 °C. Recommendations for bar temperatures are in the range of 500 °C to 700 °C. Heating time for cathode blocks should be sufficiently long to minimize moisture, especially in the slot area. In practice, these temperature ranges may be wider depending on the individual cathode sealing operators.

Table I. Collector Bar and Cathode Block Preheating Requirements Prior to Pouring Iron.

	Units	Cathode Block Mfg. A	Cathode Block Mfg. B	Plant 1	Plant 2	Plant 3
Collector Bars						
Bar Temperature	°C	650-700[A]	600-700[B]	650-670	500	500
Time bars heated	Minutes			120	180	180
Cathode blocks						
Block Temperature	°C		200-300	320-340	300	300
Minimum temperature at cast iron pouring	°C			300	300	300
Time blocks heated	Minutes			120	180	180
Iron temperature at pouring	°C	1300-1370		1430-1460	1450	

[A] Assumes bars and blocks are heated together by gas flame on collector bars. Cathode block slot edges protected by steel angles.
[B] Recommended minimum of 550°C at bar ends.

Discussion

There are three primary methods for preheating bars and blocks:

1. Gas or oil burners with flames impinging directly on collector bars mounted in the slots of cathode blocks. This method heats the top of the collector bar and the slotted surface of the block.
2. Furnace heating of the bars and blocks separately. Bars are placed into the block slots hot, prior to pouring cast iron.
3. Electrically heating the bars using the bars as the heating element. In this method the bars are mounted in the blocks and provide radiant and convective heating to the block. This method is the subject of this paper.

The third method consists of passing an alternating current (AC) through the collector bars at a controlled power load and duration, to generate the heat necessary to raise the bars and blocks to their specified temperatures. The collector bars are placed in the slots of the cathode block and then connected in a series circuit with the alternating current (AC) electrical supply.

The concept was initiated by ALMEQ together with the Norwegian inventor, Asbjørn Moen. The concept was tested at The Electrical Research Institute of the Norwegian SINTEF Group of the University of Trondheim. The initial tests used a two slot cathode block and two collector bars. The test results became the foundation for the development of the first commercial installation of the conductive cathode bar and block heater. The system has been further refined to heat collector bars and cathode blocks in a variety of sizes, and the heating time has been shortened. A schematic diagram of the method is shown in Figure 2.

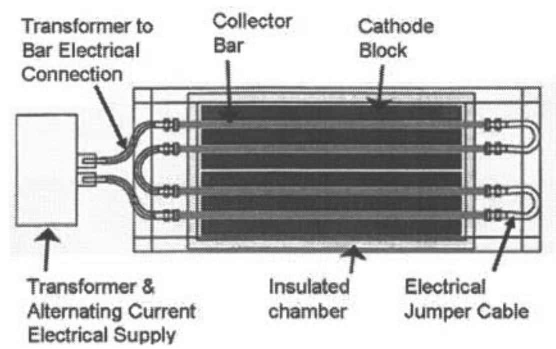

Figure 2. Schematic diagram of collector bar heating method. Note the jumpers that connect the collector bars into a series electrical circuit.

Electrical contact is made to the collector bars by conductive shoes clamped to the bars by pneumatically operated cylinders.

The two drawings shown in Figures 3 and 4 demonstrate how this works.

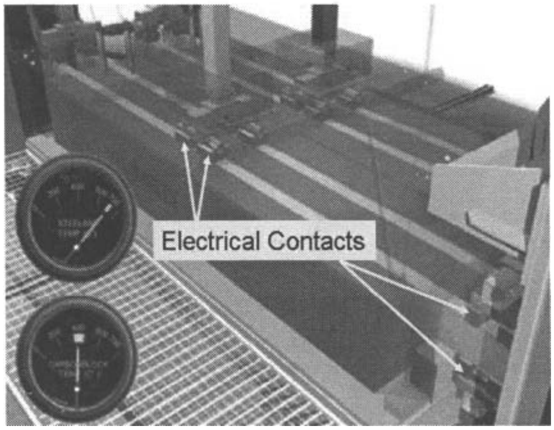

Figure 3. Split bar jumpers.

The collector bar ends are clamped between contacts in a series arrangement (creating a series electrical circuit as shown in Figure 2). For block/bar assemblies with split bars, contact blocks in the middle of the unit bridge the current from one bar to the next as shown in Figure 3.

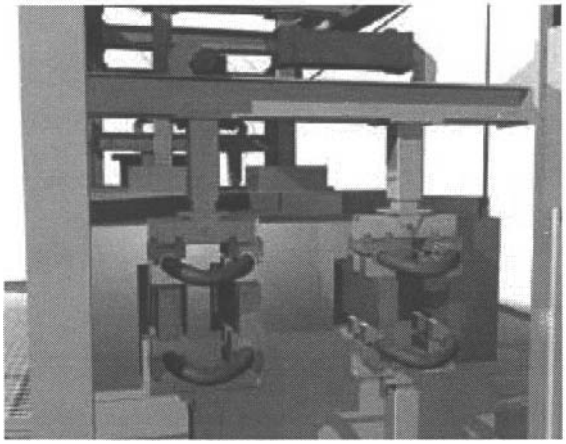

Figure 4. Contact shoes and bar to bar jumpers at non-transformer end of the assembly.

The heating elements of this system are the collector bars. They in turn heat the cathode blocks. An insulated cover is lowered over the assembled bars and blocks, prior to heating, creating an insulated electric oven with collector bar heating elements.

A programmable logic controller (PLC) records the temperatures and amperage during the heating cycle. When the set-point temperatures are reached, the system maintains the temperatures and alerts the operator.

Block and bar temperatures are measured by thermocouples and continuously recorded by the system controller.

The controller also has the capability to accept the input of individual cathode block serial numbers and to match these to their respective temperature curves for eventual use as pot lining historical data.

The heat generated by the bars is radiated to the bottom and sides of the slot, and to the inside of the insulated chamber, where it adds heat to the block by convection.

The latest system is equipped with a multi-winding transformer with a tap changer to optimize the heating cycle and to allow the system to accommodate different types and sizes of cathode blocks and bars that may be in use at the same plant.

The transformer primary is wound to accommodate the plant distribution voltage. The secondary windings are designed to produce less than 40 volts.

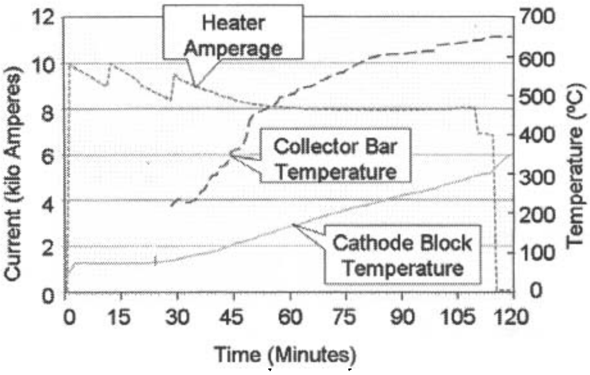

Figure 5. Bar and block temperature and amperage development over time at Plant 1.

A typical graph of current, collector bar temperature and cathode block temperature is shown in Figure 5. The steps in the current curve represent transformer tap changes to compensate for the increased resistance of the circuit, caused by rising collector bar temperature.

Comparison of Bar/Block Heating Methods

Direct flame heating of bars in blocks usually involves a series of burners mounted in a line above the collector bars with flames directed to the top of the collector bars. The corners of the slots are usually protected by steel angles to prevent excessive air burn of the slot corners. Control is sometimes based only on length of time under the burners. The uniformity and repeatability of temperature from bar to bar, or within a single bar, are not assured. The uniformity and repeatability of temperatures from batch to batch are also not assured. The process is frequently noisy and creates products of combustion.

Oven heating bars and blocks provides controlled temperatures to bars and blocks separately, but requires assembling hot bars to hot blocks prior to pouring cast iron. One would expect temperatures in each of the two furnaces to be highly repeatable. Energy consumption is relatively high, because heating requires either burners or electrical heating elements in each of the two furnaces (one for bars and one for blocks).

Collector bar resistance heating by alternating current is efficient, quiet and produces no products of combustion. The bars are mounted in the blocks cold, prior to heating. After reaching the required temperature, the powered trolley holding the bar/block assemblies brings them to the pouring position for immediate sealing with cast iron. The system is efficient, because the electrical resistance of the collector bar is used to heat itself and the hot bar then heats the cathode block. Little or no oxidation of the slot edges has been detected. Therefore, steel angles are not needed to protect the slot edges from airburn. The process is very quiet.

Energy Consumption

During a recent expansion, Plant 2 converted from propane heating of cathode bar/block assemblies to alternating current heating of the collector bars. Plant 2 reported that the average propane energy needed was 946 kwh/cathode bar-block assembly. The energy consumption using the AC electrical heating system is 101 kwh/assembly. This is more than an 89% energy savings over the previously used propane heater.

Another plant, heating with oil burners, required 1,335 kwh/cathode bar-block assembly. The AC collector bar heating system now in use consumes 142 kwh/assembly. This is also more than an 89% energy savings from the previous oil burner energy consumption.

Temperature Studies

A temperature study using infra-red (IR) instruments was conducted at Plant 2 in 2009. Unfortunately, there is no corresponding temperature study of the propane burner heater used previously at this plant for heating collector bars and cathode blocks, prior to sealing with cast iron.

Six cathode blocks, each with one slot and split collector bars, were heated for 180 minutes. Infra-red (IR) temperature measurements were taken at the twelve points shown in Figure 6.

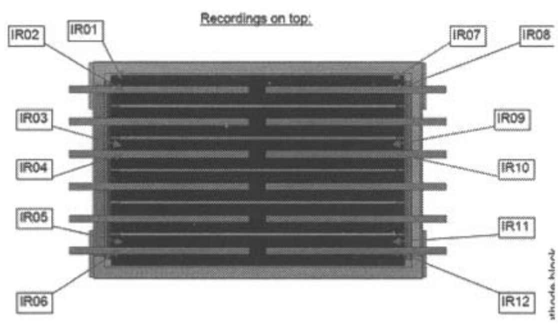

Figure 6. Locations of infra-red temperature measuring points.

Measurements were taken when power was off and with the cover open. The cycle was interrupted several times to move the cathode bar/block assemblies out from under the heater for IR photographs. Table II lists the temperatures measured by the infra-red devices and Figure 7 is an infra-red photograph illustrating the relative uniformity of temperatures.

The maximum temperature difference of steel collector bars was 24°C. The maximum temperature difference of cathode block measuring points was 14° C.

Table II. Block and Bar Temperatures after 180 minutes.

Recording Time: 180 Minutes		
Measuring Point	Cathode Block Temperature °C	Steel Collector Bar Temperature °C
IR01	216	
IR02		478
IR03	230	
IR04		462
IR05	218	
IR06		486
IR07	222	
IR08		474
IR09	230	
IR10		462
IR11	223	
IR12		484

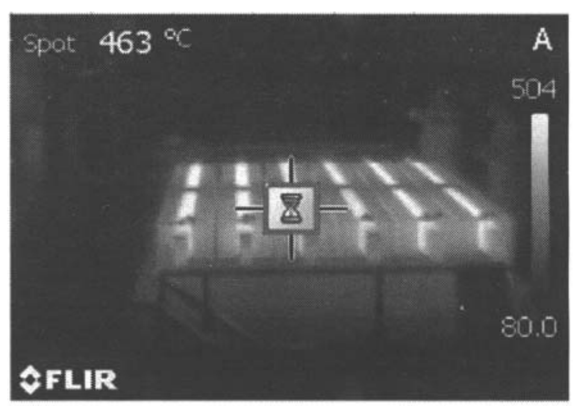

Figure 7. Infra-red photograph of bars and blocks at Plant 2.

Another indication of temperature distribution is the start-up data recorded at Plant 1. Bar and block thermocouple temperature readings were recorded for twelve batches of blocks and bars. Each batch consisted of 6 blocks, 3,250 mm long and each block had one collector bar.

The cathode block temperatures for the start-up batches are shown in Figure 8. There were three temperature measuring points for each batch and 12 batches are presented. The maximum cathode block temperature differential batch to batch was 50° C, and the maximum temperature differential within a batch was 16°C.

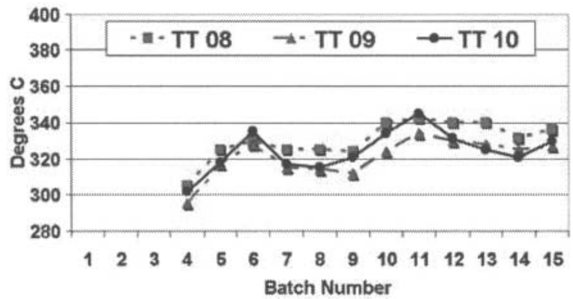

Figure 8. Cathode block temperatures for 12 batches of blocks.

Figure 9 shows the collector bar temperatures for the 12 batches. There were three bar temperature measurements per batch. The maximum collector bar temperature differential, batch to batch, was 24° C, and the maximum temperature differential within a batch was 16° C.

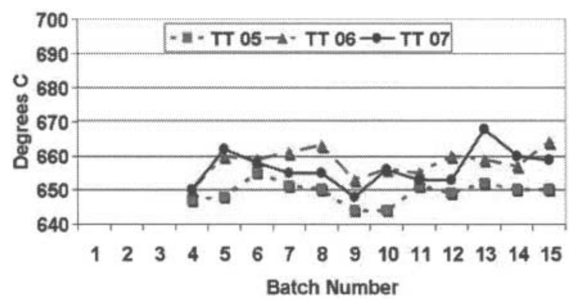

Figure 9. Collector bar temperatures for 12 batches of bar/block assemblies at Plant 1.

Equipment Arrangement and Operation

The equipment layout for Plant 1 is shown in Figure 10. A single heater serves two trolleys. With this arrangement, one batch of bars and blocks can be heated, while another batch is either sealed with cast iron, or bars and blocks are assembled prior to heating. Figure 11 is a photograph of this arrangement.

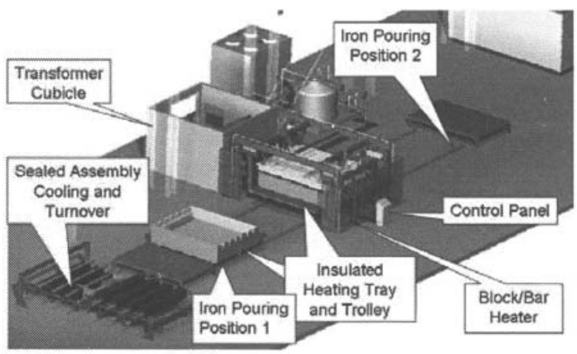

Figure 10. Layout of Heating and Rodding (Sealing) System for Collector Bars and Cathode Blocks at Plant 1.

Once activated, the system automatically positions the trolley containing the bar/block assemblies in the heating position, then applies pneumatically activated electrical contact shoes and switches on the alternating current electrical power. The system is designed to accommodate blocks and bars of different lengths at the same plant, by entering the appropriate lengths in the control panel.

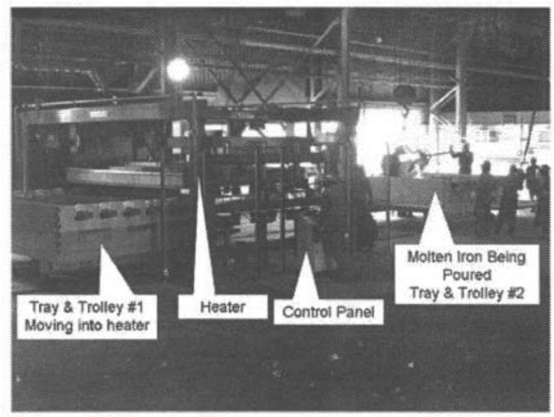

Figure 11. Heating System at Plant 1. Note: one tray of block/bar assemblies is entering the heater and one tray of assemblies is being sealed with molten iron.

When the required bar and block temperatures are reached, the power is shut off, the contact shoes are released, and the trolley is moved out to the pouring position. However, bars and blocks can remain in the heater with the cover on, to retain heat until the iron crucible is ready. Movement of the block trolley from release of the conductor clamps, until it is located in the pouring position, takes about 90 seconds. Pouring iron from a single crucible for six, 3,225 mm long blocks, each with one bar, takes about 10 to 12 minutes.

There appears to be no impediment in using the AC resistance heating method to heat composite collector bars (a copper rod inserted in a longitudinal hole in the steel bar).

Summary:

- Collector Bars and cathode blocks can be preheated successfully by connecting the bars to an appropriate alternating current electrical supply.
- The block bar assemblies are heated inside a covered and insulated box, effectively forming a furnace with collector bars acting as the heating elements.
- No products of combustion are emitted from the process.
- Steel angles are not required to protect the top corners of the collector bar slots. No, or extremely small, evidence of block oxidation has been observed in this area.
- The process makes efficient use of energy to heat the bars and blocks. Two users of the electrical heating system have reported energy savings of 89%, compared to their previously used propane and oil fueled heaters.

- Block and bar temperatures are measured by thermo-couples and controlled and recorded by the system PLC.
- Noise levels of the process are very low.
- The heater can accommodate bars and blocks of different sizes and lengths at the same plant.
- The system works with either continuous or split collector bars.

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