Advanced Pouring Technology and Temperature Control for Casting Iron

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Introduction

From the perspective of the casual observer, it may appear that the Foundry Industry has not seen the same amount of technological change as other industries. In fact, many still refer to Foundry as "Low Tech" industry.

Nothing could be further from the truth.

Since man learned how to melt and form iron, continuous improvements have been made to increase the production and improve the quality of this metal. Until the 20:th century, change was slow and new discoveries and methods often spread only through word of mouth.

The Foundry Industry entered into the "Modern Times" in 1903, when ASEA of Sweden introduced the first induction furnace for melting iron. At approximately the same time, mass production of automobiles created an unprecidented need for quality castings produced in high volumes.

Today, the extreme quality demands on automobiles have forced the top foundries around the world to become fully automated, computerized production units, producing high quality castings at very high volumes.

Traditionally, most of the attention has been given to improving the molding and melting processes. As a result, we have seen great advances in mold and core making, resulting in increasingly higher mold rates. We have also enjoyed improved melting methods for higher melt rates and melt efficiencies. Better melting (and conversion) controls have provided the ability to produce the stronger, lighter castings demanded by the automotive industries.

It was not until the mid 1980's that serious attention started to be given to the pouring station. The LaserPour System, developed in 1984, was the first closed-loop system for pouring control.

The goal of this paper is to review the pouring systems available today and to present innovations and philosophies at and around the pouring station, including the latest technologies in automated iron pouring and temperature control.

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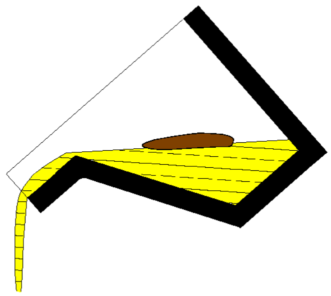
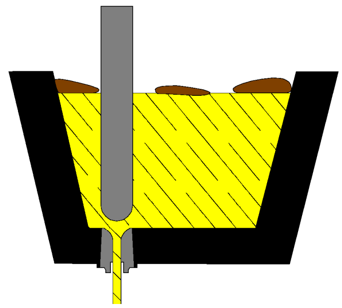
Pouring Methods

There are two basic methods for pouring iron. Tilt Pouring (pouring over lip) and Bottom Pouring (pouring with stopper rod and nozzle). There are several variations of both systems and both methods have their own advantages and disadvantages.





Tilt Pouring

Tilt pouring offers some advantages over bottom pouring:

- The initial investment for a manual system is low.
- Thanks to the small size of the pouring ladles, it is possible to change the metal quality frequently, a great benefit for jobbing shops that produce short runs.
- It is possible to "bring the metal to the mold" and pour molds in batches, allowing a number of molds to be produced before a new melt is prepared and poured, an important benefit for foundries producing low volume specialty castings.

There is also some "back sides" to tilt pouring:

- The method is labor intensive.
- Due to the nature of tilt pouring, it is difficult to pour repeatably - which causes frequent over-, short- and interrupted pours.
- Excess waste. When the ladle is close to empty, the pourer must decide if there is enough metal to fill one more mold. If he starts to pour and does not have enough metal, a short poured scrap casting will be produced. If he decides not to pour the mold, the remaining metal must be emptied and re-melted.
- Low production rates. The constant filling or changing of the pouring ladles causes frequent production interruptions.
- Limited metal buffer. If the mold line stops, and there is still metal in the ladle, it will loose temperature very fast, forcing it to be dumped after only a few minutes of delay.

Manual pouring with tilt (hand) ladles is the most fundamental type of pouring. Hand ladles are typically suspended from an overhead rail system, and the metal is dispensed manually into the mold by way of tilting the ladle.

Metal is brought to the pouring station in transfer ladles, which fills the hand ladle with enough metal to fill a limited number of molds – typically only a few hundred kg of metal.

Tilt pouring systems can be automated. By placing the ladle in a cradle, the tilting can be semi-automated. With the addition of a sensor, such as a laser, the ladle can be tilted to a "ready position", where the metal is just below the edge of the ladle.

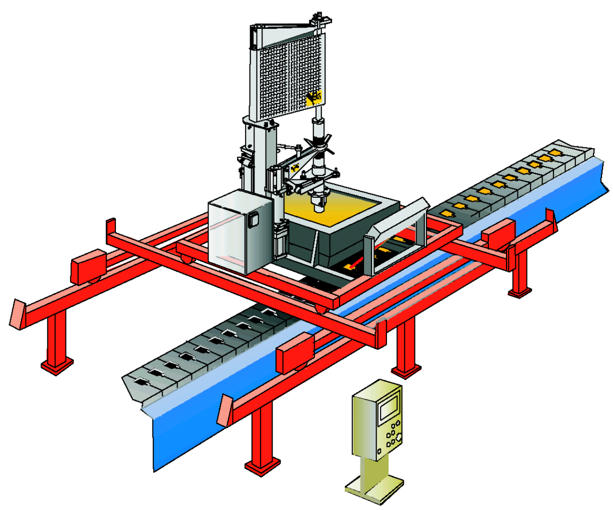
From this point, a pre-programmed automated pouring sequence can be run. By designing the ladle so that it delivers the same amount of metal per each degree of tilt, a pre-determined amount of metal can be poured. However, due to the constant slag build-up in the ladle, it is not possible to eliminate the operator, who must also ensure that the ladle is lined up with the mold.

During the pour, the iron stream will move "in-and-out" relative to the ladle. The stream will be far from the ladle when the flow is high and move towards the ladle when it is reduced. In order to accommodate this variation, the pour cup must be made very large, decreasing the casting yield.
Fully automated systems become very complex, requiring a multitude of sensors, but can be made to pour virtually operator free. They do however require extremely large pour cups (at times holding up to 50 kg of iron) to accommodate the "walking" iron stream and slow control, resulting in very poor yield.

Automated tilt pouring is not feasible for high-speed production, such as on a DISAMATIC® line. For both semi- and fully automated systems, the constant changing of pouring ladles causes production interruptions with production losses of as much as 10%.

Bottom Pouring with Ladles

In the 1950's, the concept of increasing the size of the ladle gained popularity. This required a larger, stationary ladle, holding a few tons of metal. The molds had to be brought to the ladle and the pouring was done with "bottom pouring" using a stopper rod and nozzle combination.



Bottom pouring provides several benefits over tilt pouring:

- Metal can be added to the ladle without interrupting the pour, thus eliminating the production interruptions associated with tilt pouring.
- Floating slag will not enter into the pouring stream, provided the ladle is not allowed to run empty.
- More refractory provides better heat retention.
- Changing from one metal quality to another is relatively fast.
- The iron stream stays vertical, regardless of flow rate, making it possible to use smaller pour cups.
- Less labor intensive. The operator does not have to manually handle a ladle.
- Safety. The operator can be removed a few meters from the pouring. In many cases, the operator in placed in an operator's booth or behind a protective screen.

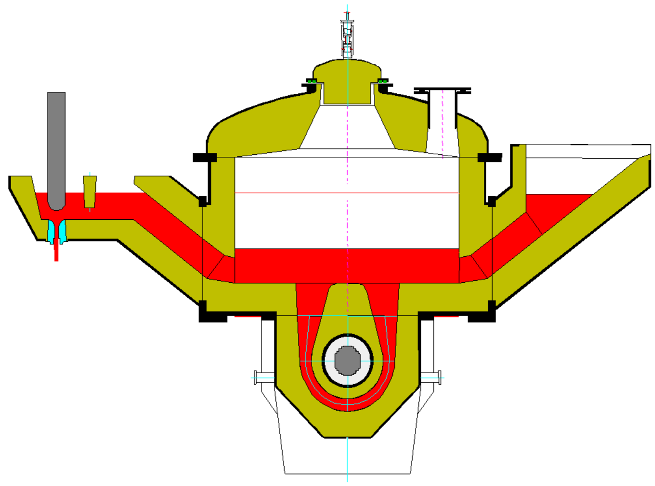
The increased metal volume in the ladle, in combination with increased refractory thickness, makes it possible to hold the temperature for several minutes. This makes it possible to continue pouring after short production interruptions, without the need to first pig and replace the metal. However, if the line is stopped for a longer period of time, the metal in the ladle must either be "reheated" by adding a new batch of hot metal, or it will have to be dumped (pigged).

There are some negative sides to bottom pouring as well:

- The ferrostatic head will change as the level in the ladle changes, which changes the flow rate. This makes it more difficult to automate with "predictive" systems, such as timers and teach-in systems.
- Since the metal in the ladle is exposed to the air, Nodular Iron will fade rapidly. If the metal is not poured within approx. 10 minutes, it must be pigged and new metal must be added to the ladle.

Bottom Pouring with Heated Pouring Furnaces

In the 1960's, pressurized pouring furnaces were introduced to the foundry industry.



Pouring Furnace with Channel Inductor

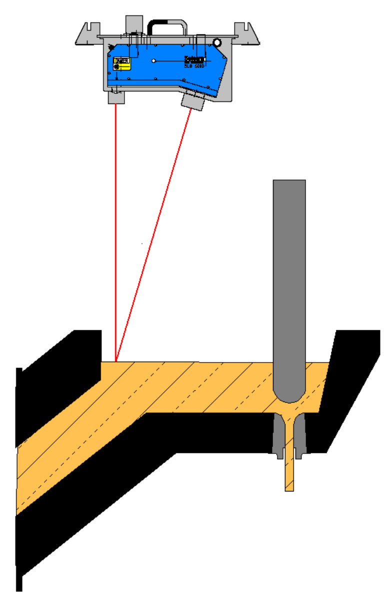
In addition to the normal bottom pouring benefits, the pouring units provides a number of additional benefits to the pouring station:

- Large metal buffer. The pouring furnace can – to some degree – double as a holder.
- Induction heating – allowing active metal temperature control, eliminating the need to "pig" cold iron.
- Pressurization. By "pushing" the metal up into the pour siphon (spout), the ferrostatic pressure is maintained at a constant level.
- Covered vessel – allowing the use of an inert gas to reduce Magnesium fade in Nodular Iron.

The pressurized pouring unit is equipped with a sensor to provide level feedback in the pour spout. The most basic of these sensors are Contact Rods that can only sense at one level. For every pour, the pressure in the furnace is increased slightly, until the metal touches the rod, closing an electric circuit. Once it is touched, the pressure drops until the circuit is broken, and the procedure starts over again. This sensing method is the least precise, and creates large level variations in the spout.

The more precise way to control the level is to provide real-time, analog level feedback. By constantly comparing the level in the spout with the desired level, as set by the operator, the pressure system will make small changes to the pressure inside the furnace to "push" more or less metal up to the spout. This improved control makes it possible to keep the steady state level variations in the pour spout to within +/- 25 mm.

The first available type of feedback device was the "Float". By tying a piece of refractory to a linear transducer, an analog level output could be created. Although being a much better solution than the contact rod, the float has two distinct disadvantages. First, due to the weight of the float, its inertia makes the response slow and second, because it is partially submerged into the molten metal, slag can build up between the float and the sidewall of the spout, "freezing" the float.



In the late 1970's, Laser Sensors were introduced for this measurement. The Laser provides a non-contact measurement that measures over the entire level range (full to empty), and can be set up to measure down into the furnace spout. Being a non-contact sensor, it does not have any inertia or risk of freezing, and reacts instantaneously with high precision.

These sensors collects level data at 16,000 times per second and provides a linear, analog (4-20mA) output that represent the real-time level in the pour box.

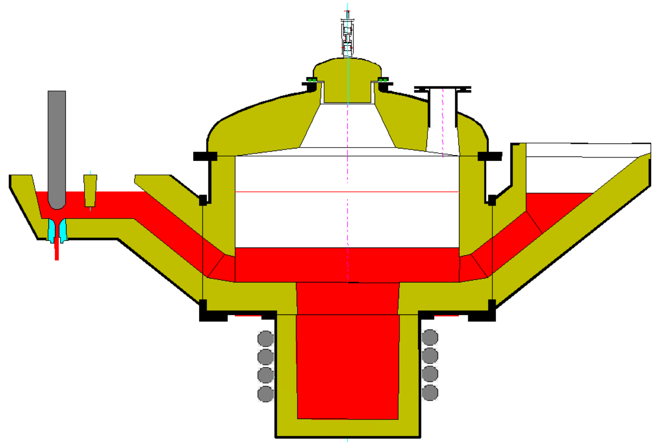
Disadvantages with pouring furnaces:

- High initial investment.
- Large metal buffer. Makes the pouring furnace less suitable for production with frequent metal quality changes.
- High maintenance requirement – especially during Nodular Iron production.
- Power consumption.

There are two basic types of pouring furnaces. One features a channel inductor (see above) while the other features a coreless inductor. From an operational standpoint, the channel inductor cannot be emptied without replacing the inductor, and must therefore always be under power.

The coreless inductor is approx. 30 % less efficient than the channel inductor, but has a better power control much more sophisticate than the original channel inductor being possible to increase the power without steps.

The other advantage is to not have the channel loop, as exists on the channel inductor, being easy to change alloys.

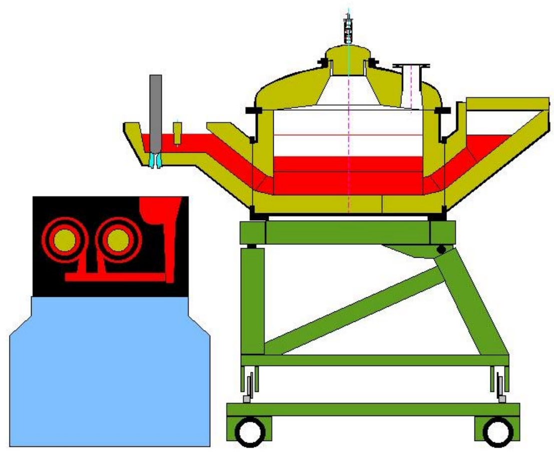


Pouring Furnace with Coreless Inductor

Bottom Pouring with Unheated, Pressurized Vessels

In the 1990's, ABB introduced a pouring unit that provides most of the benefits of the pouring furnace without adding the expense of an induction heating system. The Pouromat® is an unheated pressurized vessel that provides the following benefits:

- Low temperature losses (0.5-1.0 [illegible]
- Low fade rate (0.010-0.015 %, per hr)
- Constant pour box level – constant ferrostatic head
- Metal buffer
- Low initial investment (no pit requirement)



As this unit does not have an inductor, it is designed to have a very small heel. This means that the vessel can be almost completely emptied during normal operation, leaving only a small amount of metal to pig at the end of the production run.

During a production interruption, the Pouromat® can be de-pressurized and back-tilted slightly, emptying the pour box. This reduces the amount of metal exposed to the air (the fill spout is equipped with a cover), which further reduces both the temperature losses and fade rate.

Automatic Tilt- or Bottom Pouring?

Automating tilt pouring is a difficult task. The pouring systems must rely on a great number of sensors to control the tilt angle of the ladle, ready level in the ladle, pour stream size, etc. Any flow rate adjustment must be made slowly to avoid waves to develop in the pouring ladle. Once waves develop, it is very hard to predict the flow rate.
It is also difficult to aim the pour stream directly into the pour cup. During the pour, the stream will migrate towards the ladle as the flow rate is decreased. In order to accommodate for this variation and the ladle's slow response, the pour cups must be made very large to avoid overpouring of the mold. This reduces the casting yield, at times by as much as 10%.

One of the main arguments for tilt pouring is the possibility that leaks will develop between a stopper rod and nozzle. In the case of automatic bottom pouring, this argument does not hold true. The concern is that iron will drip into the next mold, causing a "cold shot". This problem can be eliminated in an automated system. By starting the pour as soon as, or before the mold is in position (see SpeedPour below) the problem is eliminated by not giving a drop enough time to cool inside the mold before the mold is flooded with hot metal.

Tilt pouring does have its place, but for most high speed, high volume production lines, bottom pouring is preferred.

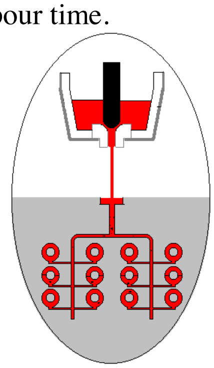
Automatic Bottom Pouring Systems

There are two basic approaches to automatic pouring.

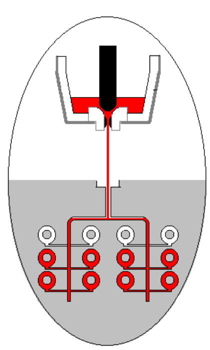
- Predictive Pouring, such as timer or teach-in systems
- Closed loop systems, such as Vision and Laser systems

Predictive pouring

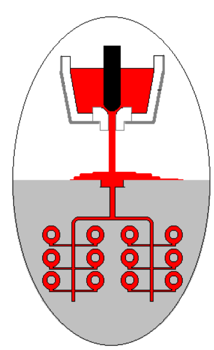
The first type of automated pouring systems came in the form of time based pouring. By opening the stopper rod to a specific opening for a pre-determined time, a specific amount of metal will be poured. This method assumes (predicts) that the next pour will behave the same way as the previous. However, it does not take into consideration any flow rate changes due to slagging or wear of the nozzle, or changing level in the pouring vessel (ferrostatic head). Typically, this type of system is only semi-automated and requires an operator to constantly adjust the stopper rod opening or the pour time.



Normal metal level - pour time and stopper opening is set



Metal level drops - causing a short pour



Metal level increases – causing an overpour

In addition, this approach does not take into consideration any variation in the flow rate into the mold (typically high in the beginning of the pour and less as the mold fills), as it pours with the same flow rate throughout the pour.
Some slightly more advanced systems divide the pour into two or more segments with different flow rates, giving the operator a means to try to accommodate for this variation.

Together with the introduction of the pressurized pouring vessel, teach-in systems were developed. As these pouring vessels do not display the large level variations of the open ladle, it is possible for the operator to pour molds with joystick control, and record and repeat the joystick signal. Once the operator was satisfied with a pour, the joystick signal would be repeated for the molds to follow. Again, this type of pouring assumes (predicts) that the flow rate for a certain stopper rod opening stays the same, and does not take into consideration slagging or wear of the nozzle. And although the level variation in the pour box is low, it still exists and will affect the final level in the mold.

Closed loop pouring

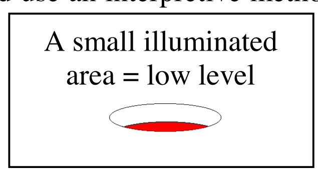
During the 1980's, closed loop pouring systems were introduced. These systems feature sensors that provide real-time feedback of the metal level in the pour cup, making it possible to control the opening of the stopper rod to maintain a certain level in the cup throughout the pour. These systems are flow control systems that match the flow rate from the nozzle with the mold's intake rate, using the metal level in the cup to provide feedback.

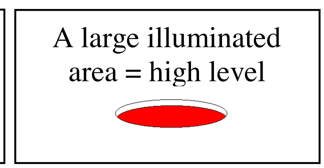
Basically, if the sensor detects that the level in the pour cup is increasing, the system closes the stopper rod slightly. If the level decreases, the stopper rod is opened slightly. A steady level indicates that the flows are perfectly matched.

Closed loop systems are defined by their sensors. There are three basic types available on the market today.

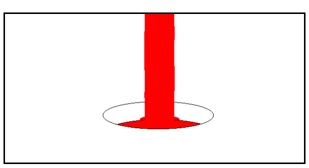
- Vision Systems – Using CCD based cameras
- Point Laser Systems – The traditional laser systems
- Line Laser Systems – The new generation laser systems

Vision systems collect data at 50 – 120 images per second, and use an interpretive method to determine the level in the pour cup. By counting the number of pixels illuminated by the metal in the cup, a level is estimated. A low number of pixels represent a low cup level, while a high number represents a high level.

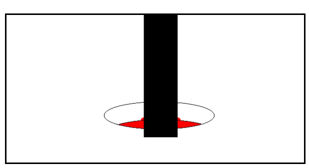




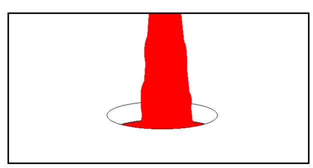
There are a number of complications associated with this type of interpretive measurement. First, the iron stream itself will produce illuminated pixels, although they don't represent level. In order to "ignore" the iron stream, the control system must apply a "black out mask" to hide the stream. As the iron stream deteriorates, due to slag build up or nozzle wear, the width of the stream will increase, forcing the "mask" to be increased with it. This reduces the area available for the actual level measurement and the systems must often be switched to manual mode.



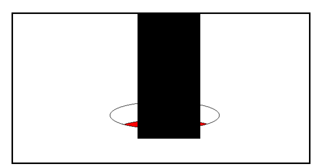
Normal stream



Normal stream – Blocked out



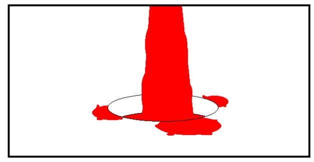
Deteriorated stream

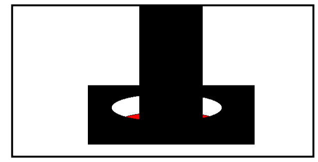


Deteriorated stream – Blocked out

Due to the likelihood of stream deterioration, vision systems are primarily recommended for pouring with large pour cups, in order to keep the uptime high.

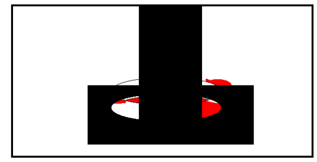
The vision system must also be able to ignore any overpour, as this also increases the number of illuminated camera pixels. This increases the size of the "mask" even further.





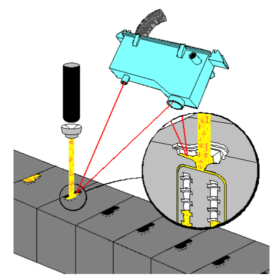
When pouring on a DISAMATIC® type molding line, it is critical for the pouring result that the nozzle is aligned correctly over the pour cup. The vision camera is not well suited to find the cup, since it would be looking for "a black hole in black sand".

It is not able to identify the boundaries of the cup until it already has been filled – at which time it is too late for any position corrections. If the correct mold position is not detected, the "mask" will be applied incorrectly, further deteriorating the measurement signal. Additional position sensors must therefore be added to the system.



The advantage of the vision systems can be found in the low sensor cost, and vision systems show their strength when used on flask lines featuring large pour cups and no requirement to constantly re-position the pouring vessel.

Point Laser Systems were introduced by the LaserPour division of LMI Technologies in the mid 1980's. The sensor consists of a triangulation laser that is aimed into the pour cup, taking 16,000 direct level measurements per second. The laser sensor is housed in a water-cooled and air purged jacket, allowing it to operate in the extreme environment close to the mold.

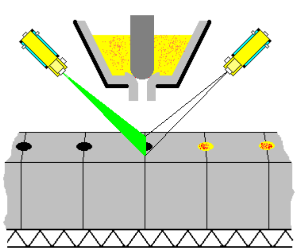


The pour cups used with this type of sensor are typically modified to feature a "laser tail". The purpose of the tail is to provide a well-defined surface for the laser to find during the positioning phase and to separate the measurement point from the iron stream during the pouring control phase. This allows the point laser to operate with very small pour cups.

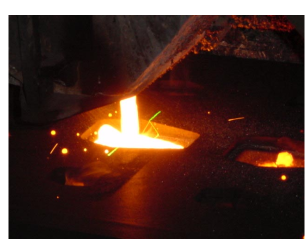
Thanks to the speed and accuracy of the laser, it is possible to use the same sensor for both the positioning and the pouring control task. This is particularly important for high speed, vertically parted molding lines.

The point laser is used for pouring from both pressurized and non-pressurized systems. In the case of the open ladle, the laser sensor works in combination with ladle load cells to reduce the effect of the varying metal level.

The **Line Laser System** is the latest LaserPour System to hit the market. It consists of a laser line generator and a line sensor, both housed in water-cooled, air-purged jackets. Each device is mounted on opposing sides of the pouring vessel, making it possible to make triangulation measurements across multiple points (the line) across the pour cup.



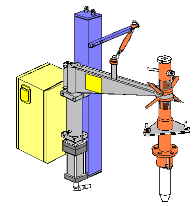
By projecting a line across the pour cup, the sensor becomes less sensitive to deteriorating streams. As long as the sensor sees a portion of the line, a level measurement can be made - thus eliminating the need for the "laser tail".



Stopper Rod Actuators

There are two basic types of stopper rod actuators:

- A basic unit for pouring Gray Iron
- An advanced unit for pouring Nodular Iron, featuring automatic rod twist and nozzle cleaning systems.

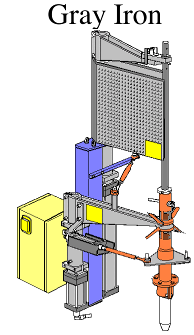


Gray Iron

The twist function makes it possible to make a small rotating motion, a "jog", of the stopper rod when it is seated in the nozzle, preventing leaks. The nozzle cleaning function sends a cleaning rod down through the stopper rod and nozzle, knocking out any slag that has accumulated there, keeping the nozzle from slagging up and reducing the flow.

From a drive standpoint, there are three drive types:

- Electric Servo and Ball Screw
- Hydraulic Servo
- Pneumatic Servo



Ductile Iron

Of the three drives, the Electric servo has the fastest and most precise response, but is the most expensive and requires the highest level of maintenance budget.
Second in performance is the hydraulic drive, although the initial investment in hydraulic pumping equipment is high and the thought of bringing any kind of liquid to the pouring area is not accepted by all foundries.
The least precise drive is the pneumatic servo drive system, although its performance is still sufficient for pouring control. The greatest benefit of this drive is its simplicity and low maintenance cost.

The pouring sequence

In order to benefit fully from automation, the pouring system must be able to fill the mold's runner system up quickly, bringing metal up into the pouring cup. This assures that sand and slag stays floating on top of the metal and does not enter the casting. By keeping the pour cup full, the highest possible ferrostatic pressure is achieved, and the mold fills as fast as possible.

However, as the pour comes to he end, and the flow rate is reduced, it is sometimes possible to reduce the final level in the cup, reducing the amount of metal that has to be sent back for remelt. The level can typically be lowered if the casting or feeder system does not come too close to the top of the mold.

SpeedPour®

The LaserPour System offers a patented solution for increasing productivity when pouring on a vertically parted molding line. The SpeedPour System monitors the mold sized of the molds between the molding machine and the pouring station and is able to predict where the next pour cup will end up, once the index completes. This calculation is done at the same time the index begins, so that the pouring vessel can be repositioned (if needed to), and be ready for the new pour cup to arrive. Then, before the cup has reached its final position, the LaserPour System starts the pour, and as the metal is about to hit the top of the mold, the cup arrives.

This anticipated pouring start reduces the machine cycle time, resulting in a net productivity increase of up to 15%.

Inoculation systems

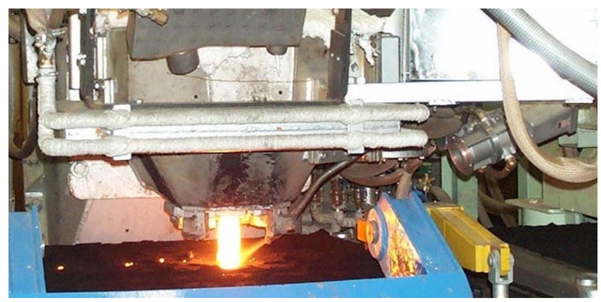
An automated pouring system must be able to interface with in-stream inoculation systems. By starting the inoculation system before the pouring starts will ensure that even the first metal that enters the mold is inoculated. The pouring system should also be tied into the alarm outputs, making it possible to abort the pour if the inoculation system faults.

One feature of the LaserPour System is the ability to control the feed rate of some inoculation systems. This allows the system to provide individual feed rates for each pattern, optimizing the inoculation use.

Automatic Temperature Control

Second to metal chemistry, the metal temperature is the most important pouring criteria and must constantly be verified. Most foundries use manual thermocouples that are dipped into the metal to record the temperature. These dip sensors are very accurate, but relies on an operator to do the measurement.

An alternative to measuring the temperature in the metal bath is to measure the temperature of the metal as it is poured through the nozzle, using non-contact optical sensors. Several infrared systems are available.



By taking temperature readings for every pour, it is possible to stop the molding line if the temperature is outside the accepted limits. By recording the data, it is also possible to add the pouring temperature to the quality sheet for each produced casting. This information can then, together with the chemistry report, become part of the quality report that follows the castings to the customer.

The drawback with the in-stream measurement is that the temperature is not measured until the pouring has started. If the temperature is incorrect, it will be necessary to either abort the pour, and waste a mold or finish the pour, risking the production of a bad casting.

A few years ago, semi-permanent systems were introduced on the market. These sensors are designed for submersion into the iron bath and left there, continuously measuring the temperature. This allows the temperature to be verified before the pour is started and if incorrect, it can be corrected and the pouring can be resumed.

From a cold state, once the sensor comes in contact with the molten iron, it takes approximately 15-20 minute before the temperature readings are stable and accurate, but once the steady state level have been reached, the sensors are very accurate and follow the iron temperature well.

Continuous temperature measurements in a heated pouring vessel can close the loop and make it possible to control the inductor power to maintain a very constant metal temperature in the pour box. European foundries are currently using this feedback in their power control and are able to hold the pouring temperature to within +/- 5

Why Automated Pouring ?

The installation of an automated pouring system requires an investment, so the question must be asked if there is payback for these systems. In order to evaluate the feasibility of automation, all benefits must be analyzed.

- **Increased productivity**
    - Charge on the fly eliminates production interruptions (bottom pouring only)
    - Better pouring control reduces the overpouring and the associated mold line down time
    - SpeedPour – cycle time reduction
    - Less time is wasted while scrap is produced

- **Improved yield**
    - Reduced over-, short- and interrupted pouring
    - Reduced pour cup size
    - Reduced final level in the pour cup

- **Increased quality**
    - Less sand and slag inclusions
    - Better temperature control
    - Elimination of short- and interrupted pours
    - Integration with inoculation systems

- **Reduced labor**
    - Automated system requires only one (or less) operator
    - Less labor is required to handle the lower amount of tramp iron produced
    - Productivity increases are achieved without adding staff

Summary

For today's leading foundries, automation is key to reducing operational costs, allowing them to keep their competitive leads.

The traditional way of tilt pouring iron is loosing ground to bottom pouring in high-speed production applications where yield and productivity is of essence. Bottom pouring systems have proved to be a solid base for automation, providing good control capabilities, and allowing the pouring to continue while metal is added to the pouring vessel, eliminating the changeover delays common with tilt pouring systems.

There are a number of different pouring control systems available, and each system displays disadvantages that must be weighed against their benefits. However, there is always a solution that provides the best payback for each application.

The future belongs to those who automate.