Batch Induction Melting
The Science and Technology

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A compilation and update of Mr. Mortimer’s papers and articles prepared for the American Foundry Society, The Centre Français de l'Electricité the Australasian Foundry Institute, Foundry Management & Technology magazine and Modern Casting magazine

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Introduction
The last quarter of the past century saw the development of high reliability, solid state power supplies for coreless induction melters, with inverters capable of developing and maintaining maximum power throughout the melt cycle. The efficiency of these units increased from the 85 percent level of the 1970s to 97 percent today. Now, medium frequency power supplies of up to 16500 kW at 200 Hz are in operation.

The development of flexible, constant power tracking, medium frequency induction power supplies has resulted in the widespread use of the batch melting method in modern foundries. Research has shown that this method substantially increases overall melting efficiency and furnace production at lower operating and fixed costs.

Batch melting
First, batch melting is defined as a process where the furnace volume is poured empty after the melt has reached the proper temperature and successive melts are started using ordinary unheated or preheated solid charge materials.

Although this type of operation was typical of the small to medium-sized systems, either their inherent design characteristics or the lack of reliable power components prohibited their manufacture at high power levels until recent years. As a result, virtually all of the large production requirements were handled by the low frequency 50 or 60 Hz heel melting units.

Heel melting is a process where molten metal is held in the furnace after tapping. Typically, this heel of metal is between 60-80 percent of the furnace capacity.

Although the best choice of equipment available at the time of their manufacture, these low frequency systems imposed several significant operating limitations on the foundry, such as:

- The necessity of keeping a molten heel in the furnace between taps which meant that, in most cases, charge drying or preheating equipment had to be employed to reduce the risk of wet materials becoming submerged below the melt line.
- The need to accept a larger-than-necessary furnace melt volume just to reduce the turbulent, low frequency molten metal stirring activity rather than selecting the melt volume best suited for the foundry requirement.
- The extra cost for electric energy needed to not only keep the molten heel at liquidous temperatures during the off-shift time, but also to compensate for the greater heat losses of the larger furnace area.
- The higher maintenance and component costs associated with and required for the larger furnace.
- The extra cost to cast starter blocks to help reduce the long, cold lining melting time which is characteristic of the heel melting design.
The first technological advance necessary to make high-volume batch melting a practical reality was the development of powerful, reliable, solid state inverters for coreless induction furnaces. Line frequency (60 Hz) induction power systems that required a molten heel for melting could not be used for the batch melting process. The early spark gap and motor generator units, first used to achieve frequencies above 60 Hz, were less than 75 percent efficient and could not achieve the high power levels needed for high-volume batch melting. Later systems, which multiplied line voltage magnetically, and the first solid state power supplies, were much more efficient, but were still too small to make high-volume batch melting practical.

Early coreless induction batch melting equipment was best suited to small steel and investment casting foundries. Furnace size wasn't the obstacle to greater production, applying power to the furnace was. In early solid state induction power supplies, power densities approaching 400 kW per metric ton were available in units able to track furnace loads and supply full power throughout the melting process. Power supplies of 500 kW were considered quite large. The subsequent development of powerful, reliable, solid state inverters incorporating "hockey puck" design SCR devices made high-volume batch melting not only practical, but the most efficient way for many foundries to produce metal. (Fig. 2) Now, medium frequency power supplies providing 700 kW per metric ton are common. Units able to apply 1000 kW per metric ton are achievable with existing technology. For Inductotherm alone there are well in excess of 500 induction batch melting installations worldwide boasting power units of 2000 kW or larger. There is even a solid state unit providing 42000 kW of induction power. It is used at Geneva Steel in Utah for heating massive steel slabs.

Modern induction power units achieve electrical efficiency levels exceeding 97 percent. It is not likely that tomorrow's equipment will show further significant increases in electrical efficiency. What will prove meaningful to foundrymen, however, will be new levels of equipment reliability.

**New power supplies shrug off faults**

While the reliability of even early solid state power supplies was high, particularly in units engineered with a substantial safety margin in component ratings, abnormally large voltage spikes on the incoming power lines, shorts caused by accidental shorting of the bus bars or furnace problems could cause components to fail. This interrupted production and often required costly repairs.

Now envision a highly advanced induction power supply with the ability to absorb faults and keep on running. Such units are available now from Inductotherm. These new units use special energy absorbing technology to protect an induction power unit's electronic components. These extremely reliable units simply shut down in response to electrical faults, without damage to any component parts. Restarting these units is as simple as resetting the system (in the absence of the condition that caused the fault in the first place, of course). With power fully restored, production can resume immediately. (Fig. 3)

**FIGURE 2. Silicon controlled rectifier (SCR)**

**FIGURE 3. Before leaving the factory, Inductotherm tests every power supply by creating a dead short across the bus bars while running the unit at full power. To pass this rigorous test, the unit has to absorb this short without damage and be able to resume full operation when reset.**
Stirring

In the early thinking about the viability of high volume batch melting, concerns about furnace stirring led many to believe that the high power densities required would produce too much stirring in the furnace.

Furnace stirring was one of the least understood areas in the coreless induction furnace. In the mid-1970s research was undertaken at Inductotherm regarding coreless furnace stirring. Up until that time it had been thought that inductive stirring in an induction furnace was related linearly to the meniscus height in the furnace. This relationship is described in the following formula and illustration (Fig. 4).

\[
MH = \frac{7050 \times kW}{D \times H \times SG \times \sqrt{(\rho \times f)}}
\]

Where
- \( MH \) = meniscus height (inches)
- \( D \) = diameter of the melt (inches)
- \( H \) = furnace metal height (inches)
- \( SG \) = specific gravity of metal
- \( \rho \) = metal resistivity (microhms-cm)
- \( f \) = frequency in hertz

Meniscus height varies directly with kilowatts and inversely with the square root of frequency. However, it became apparent from actual melting operations that this simplistic approach was not an accurate measure of stirring. Furnaces containing the same amount of the same metal, but running at different frequencies, did not stir the same, even though the meniscus heights were identical. It was found that meniscus height is caused by the interaction of the magnetic field from the induction coil and the current that is flowing in the molten metal. This force is equal to the vector product of the magnetic flux density multiplied by the current density of the melt \((B \times J)\). Current flows in the surface of the melt to a depth determined by the frequency of the current flowing in the induction coil and the metal type. This is called the “depth of penetration” and is described by the following equation:

\[
d = 2 \sqrt{\frac{\rho \times f}{\mu}} \text{ inches}
\]

Where
- \( d \) = depth of current penetration (inches)
- \( \rho \) = metal resistivity (microhms-cm)
- \( f \) = frequency in hertz
- \( \mu \) = permeability (magnetic property)

This force acting on the surface of the metal at the top of the melt opposes gravity and causes the formation of the meniscus. As both \( B \) and \( J \) are proportional to the current flowing through the coil, the meniscus height is proportional to the current flowing through the coil squared. As \( kW = \Gamma R \) where \( R \) is the resistance of the coil and the melt, the meniscus height is proportional to the kilowatts applied to the furnace and inversely proportional to the resistance of the furnace coil and the melt. Meniscus height \((MH)\) represents the potential energy of the melt in the same way as the height of water in a reservoir \((WH)\) represents the potential water energy pressure in that reservoir. (Fig. 5)
In the furnace, the flow of metal is accelerated only when current is flowing in the melt. Thus, the accelerated flow only occurs in the region defined as the depth of current penetration. This depth of penetration is equated to the size of a pipe connected to a reservoir. A large depth of current penetration would be a large pipe and a very small depth of current penetration, a very small pipe. (Fig. 6)

Obviously, for the same meniscus height (pressure of water available), the larger the depth of current penetration (the larger the diameter of pipe), the greater the flow (of water).

To carry this analogy further, if you considered these pipes as hoses feeding into a swimming pool, the size of the swimming pool would be related to the size of the furnace. (Fig. 7) Thus, a very small hose being placed in the swimming pool, like a small depth of penetration with a given size furnace, would result in very light stirring. However, a large fire hose being placed inside a swimming pool, like a large depth of penetration for a given meniscus and furnace size, would obviously result in very high stirring.

When you do the math on this process, you find that stirring is not linearly proportional to the meniscus height, but is much more dependent on the frequency itself. The following formula predicts the level of stirring in a given system using factors that include power.
STIRRING INDEX CHART

Stirring Index = 80 to 120  Heavy to violent stirring
Stirring Index = 55 to 80  Heavy stirring
Stirring Index = 40 to 55  Medium stirring
Stirring Index = 20 to 40  Light stirring
Stirring Index = 0 to 20  Very light stirring

A stirring index of 40 to 55 is ideal for iron (gray, ductile iron and borings). A stirring index of 55 to 80 is preferred for aluminum (UBC, scalpings and chips).

A stirring index of 40 to 55 is ideal for iron (gray, ductile iron and borings). A stirring index of 55 to 80 is preferred for aluminum (UBC, scalpings and chips).

FIGURE 7a. The Stirring Index number provides a good indication of the degree of stirring that can be expected in a given system.

frequency, furnace size and the alloy being melted:

\[
SI = \frac{60,000 \times \sqrt{\frac{kW \times D}{SG \times p \times f}}}{A}
\]

Where
- \( SI \) = stirring index (see Fig. 7a)
- \( kW \) = kilowatts
- \( D \) = furnace diameter in inches
- \( SG \) = specific gravity of the bath
- \( p \) = metal resistivity (microhms-cm)
- \( A = (\pi D^2) / 4 \)
- \( f \) = frequency

Stirring examples

Iron
Iron foundries normally want a medium amount of bath stirring to properly mix in additives and provide a homogeneous alloy.

One foundry melting ductile base iron achieved its desired level of stirring with a 9000 kW induction melter powering a 12.5 metric ton furnace. This system operated at 210 Hz with a medium stirring index of 42.3.

A larger foundry melting gray iron ran its 16500 kW, 20 metric ton induction melting system at 180 Hz to achieve a medium stirring index of 47.9.

Aluminum (stirrers and melters)
Aluminum melting demands a higher level of stirring.

One aluminum alloy producer achieved its required stirring with a 300 kW induction power supply running a .8 metric ton furnace. Operating at 60 Hz, it produced a very heavy stirring index of 117.27.

An aluminum alloy producer melting UBCs ran its 1500 kW, 7 metric ton aluminum melting system at 60 Hz to achieve a heavy stirring index of 75.7.

Steel
Steel foundries typically run their alloys at high temperatures and want a low level of stirring to maximize lining life. A steel abrasive plant operated a 1500 kW induction power supply and 2.2 metric ton furnace at 590 Hz to achieve a light stirring index of 22.6.

A steel investment plant melting various steel alloys ran its 175 kW, 75 Kg induction melting system at 2800 Hz to achieve a light stirring index of 25.7.
FIGURE 8. Frequency selection chart.

Of course, an easier way to determine stirring is to use the chart shown in Fig. 8. The research on stirring showed that much higher power densities could be placed on induction melting furnaces as the frequency was increased than had otherwise been thought. For instance, the stirring in a 6 ton furnace powered by 1500 kW at 60 Hz would have been thought to have the same stirring as it would at 3000 kW at 250 Hz. In fact, the equivalent stirring occurs at 6000 kW at 250 Hz. This means a power density of 1000 kW per ton at 250 Hz provides the same stirring as 250 kW per ton at 60 Hz. The knowledge of stirring gained by the 1975 studies was pivotal in the development of batch melting as it allowed for the high power densities required for this process.

Furnace efficiency

In 1980 batch melting was common in small furnaces with low kilowatt power supplies. Earlier, in 1976, Inductotherm had developed a line of equipment with constant power draw characteristics throughout the melt. It had been determined that these particular units were melting at about a 10% higher melt rate for iron and steel than had been calculated, even allowing for the unit’s full power from start to finish operation.

A research project was started in 1980 to determine why this was so. The initial thought had been concern over accuracies in the metering system. Furnace efficiency studies over a wide variety of metals and furnace sizes found that the reason for this was not faulty metering, but was the result of change in the resistance of the melt related to the magnetic properties of iron and most steels.

In its simplest form, and ignoring many significant engineering considerations, the electric efficiency of a coreless furnace can be represented by the formula:

\[
\text{Efficiency} = \frac{\text{Melt Resistance}}{\text{Melt Resistance} + \text{Induction Coil Resistance}}
\]

If we will assume a resistance of 80 microhms* for a furnace having a molten heel and an effective resistance of 20 microhms for the coil, the efficiency would be:

\[
\text{Efficiency} = \frac{80}{80 + 20} = \frac{80}{100} = 80\%
\]

When batch melting, however, the furnace is charged with materials which could easily increase the contact resistance between the charge pieces to about 200 microhms*, raising the batch efficiency as shown in the above formula to:

\[
\text{Efficiency} = \frac{200}{200 + 20} = \frac{200}{220} = 90\% \text{ (A 10% increase.)}
\]

If magnetic materials are melted, the coil efficiency at the beginning of the cycle could be as high as 95 per-

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*The values for resistance used in the formulas were selected to illustrate the comparative efficiencies and do not represent actual values.
cent because of the shallower depth of current penetration, the increased magnetic coupling, as well as the addition of hysteresis losses which are induced in the charge pieces. As melt temperatures rise above the Curie point, the magnetic effect disappears but the contact resistance still keeps the efficiency in the 90 percent range until molten conditions are reached.

Whereas a furnace with a fully molten charge may have an efficiency of around 80 percent, the same furnace with a magnetic charge of solid material may have an efficiency of 95 percent or more at the start of the melt. Since batch melting always starts with solid charge material, this results in an overall furnace efficiency of 88 percent for the batch melter through a melt vs. 80 percent for a heel melter using an 80 percent heel. However, only the system with a constant power draw could take advantage of these higher efficiencies since it alone could deliver full power into the charge from the start of the melt, when the furnace was at its highest efficiency level. This work was finally published in 1985 and 1987.

### Production increases

The increased production possible from a batch melting system is shown in Fig. 10. These early systems demonstrated the practicality of the theoretical work.

![Graph showing efficiency comparison between batch and heel melters.](image)

**FIGURE 9.** A comparison of the batch melter versus heel melter shows that efficiencies for the batch melter are much higher until molten conditions are reached. After that time, efficiencies are essentially the same.

**FIGURE 10.** Comparison of 1987 systems.

<table>
<thead>
<tr>
<th>Power Supply</th>
<th>Furnace Size</th>
<th>Melting Process</th>
<th>Initial Heat</th>
<th>Following Heats</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 kW</td>
<td>60 Hz 3.6 MT</td>
<td>Heel Melter</td>
<td>4 Hrs. 45 Min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>500 Hz 1.4 MT</td>
<td>Batch Melter</td>
<td>1 Hrs. 15 Min.</td>
<td></td>
</tr>
</tbody>
</table>

**STARTUP TIMES**

<table>
<thead>
<tr>
<th>COLD LINING / HOT LINING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Supply</strong></td>
</tr>
<tr>
<td>1000 kW</td>
</tr>
<tr>
<td>200 Hz 1.8 MT</td>
</tr>
</tbody>
</table>

| **Furnace Size**         |
| 60 Hz 3.6 MT             |
| 500 Hz 1.4 MT            |

<table>
<thead>
<tr>
<th><strong>Melting Process</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel Melter</td>
</tr>
<tr>
<td>Batch Melter</td>
</tr>
</tbody>
</table>

| **Initial Heat**          |
| 4 Hrs. 45 Min.            |
| 1 Hrs. 15 Min.            |

| **Following Heats**       |
| (905 Kg/Hr)               |
| (1450 Kg/Hr)              |

| **Following Heats**       |
| (2085 Kg/Hr)              |

| **With Cold Lining**      |
|                          |
|                          |

| **With Hot Lining**       |
|                          |
|                          |

**FIGURE 10.** Comparison of 1987 systems.
## A COMPARISON OF 2500 kW FURNACES MELTING GRAY IRON (Pour Temp. = 1500°C)

<table>
<thead>
<tr>
<th>Tap Size</th>
<th>Charge Method</th>
<th>Charge Size</th>
<th>Melt Time</th>
<th>Idle Time</th>
<th>Production Rate</th>
<th>Utilization</th>
<th>Comparison* (kW/Hr/MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500 kW</td>
<td>60 Hz 9 MT Heel Melter</td>
<td>3400 Kg.</td>
<td>47 Min.</td>
<td>8 Min.</td>
<td>585</td>
<td>85%</td>
<td>3700 Kg/Hr</td>
</tr>
<tr>
<td>2500 kW</td>
<td>200 Hz 6 MT Heel Melter</td>
<td>4 x 850 Kg. Bucket</td>
<td>43 Min.</td>
<td>10 Min.</td>
<td>540</td>
<td>81%</td>
<td>3850 Kg/Hr</td>
</tr>
<tr>
<td>2500 kW</td>
<td>500 Hz 3.4 MT Batch Melter</td>
<td>3400 Kg. Feeder</td>
<td>39 Min.</td>
<td>7 Min.</td>
<td>500</td>
<td>85%</td>
<td>4430 Kg/Hr</td>
</tr>
</tbody>
</table>

*Assumes 3-shift operation and does not account for auxiliaries such as hydraulic and water cooling/recirculating systems, etc.

Two heel melting systems – 1000 kW, 60 Hz 3.6 metric ton and 1000 kW, 200 Hz 1.8 metric ton – are compared with a 1000 kW, 500 Hz, 1.4 metric ton batch melting furnace. The major advantages of the 500 Hz batch equipment include substantially faster melt times and improved production.

Systems of 2500 kW are also compared. (Fig. 11) The 50/60 Hz system is a heel melter with a 9 metric ton furnace. The tap size is 3400 Kg and there are two bucket charges of 1700 Kg producing 3700 Kg/Hr with a pouring temperature of 1500 degrees C. The medium frequency heel melter with a 5 metric ton furnace also is bucket charged but, because of the smaller furnace, smaller buckets and more charges are required. The resultant production rate of iron is 3850 Kg/Hr.

The batch melter is continuously charged using a feeder with the charge being preheated by the previous charge before melting. The production rate has increased to 4430 Kg/Hr. The energy usage has been reduced by nearly 15 percent due to the increased efficiency and reduced thermal losses of this method.

All three systems described require a large tap size for good utilization and perfect timing of the ladle. In addition, the heel melters require that the charge bucket always be ready as there is no charge storage on the melt deck as with the batch method.

Further production increases can be obtained by adding another furnace to the same power supply. After the first furnace is charged, but still melting, a second charge is prepared on the feeder. When the first furnace is at temperature, the melting process starts on the second furnace by switching over the power supply and continuously charging. The first furnace may now be emptied into smaller ladles over a 15-minute period. This process is now repeated by charging and melting in the first furnace while the second is poured.
First large application

The first high-powered batch melter had a target production of 3200 metric tons per month of gray iron, which corresponds to a 10 metric ton per hour pour rate. In the past, this would have been handled exclusively by a low frequency system, but Fig. 12 shows the many advantages of the 300 Hz batch melter.

The 5000 kW Inductotherm batch melting system was selected and put into operation in April 1987. Included were many features that would be standard in melters to come.

<table>
<thead>
<tr>
<th></th>
<th>60 Hz Heel Melter</th>
<th>200 Hz Heel Melter</th>
<th>300 Hz Batch Melter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Coreless</td>
<td>Coreless</td>
<td>Coreless</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>60 Hz, Fixed</td>
<td>200 Hz, Variable</td>
<td>300 Hz, Variable</td>
</tr>
<tr>
<td><strong>Power Rating</strong></td>
<td>3500 kW x 2</td>
<td>3500 kW x 2</td>
<td>5000 kW x 1</td>
</tr>
<tr>
<td><strong>Power Control</strong></td>
<td>Off-Load, 10 Taps</td>
<td>Stepless</td>
<td>Stepless</td>
</tr>
<tr>
<td><strong>Furnace Capacity</strong></td>
<td>12,700 Kg x 2</td>
<td>12,700 Kg x 2</td>
<td>5500 Kg x 2</td>
</tr>
<tr>
<td><strong>Tap Size</strong></td>
<td>1800 Kg</td>
<td>1800 Kg</td>
<td>Up to 5500 Kg</td>
</tr>
<tr>
<td><strong>Charge Method</strong></td>
<td>Bucket</td>
<td>Bucket</td>
<td>Conveyor/Feeder</td>
</tr>
<tr>
<td><strong>Quantity</strong></td>
<td>1800 Kg</td>
<td>2 x 900 Kg</td>
<td>5500 Kg</td>
</tr>
<tr>
<td><strong>Melt Rate</strong></td>
<td>6350 Kg/HR x 2</td>
<td>6680 Kg/HR x 2</td>
<td>10,500 Kg/HR x 2</td>
</tr>
<tr>
<td><strong>Melt Time</strong></td>
<td>17.0 Minutes</td>
<td>16.2 Minutes</td>
<td>31.0 Minutes</td>
</tr>
<tr>
<td><strong>Cycle Time</strong></td>
<td>22.0 Minutes</td>
<td>22.0 Minutes</td>
<td>32.0 Minutes</td>
</tr>
<tr>
<td><strong>Utilization</strong></td>
<td>77%</td>
<td>74%</td>
<td>97%</td>
</tr>
<tr>
<td><strong>Production Rate</strong></td>
<td>9.8 MT/HR</td>
<td>9.8 MT/HR</td>
<td>10.3 MT/HR</td>
</tr>
<tr>
<td><strong>Hold Overnight</strong></td>
<td>Yes</td>
<td>Optional</td>
<td>No</td>
</tr>
<tr>
<td><strong>Start Up (Cold)</strong></td>
<td>4:45 Hrs.</td>
<td>1:45 Hrs.</td>
<td>1:00 Hrs.</td>
</tr>
<tr>
<td><strong>Starter Blocks Required</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Electrical Demand</strong></td>
<td>7400 kW</td>
<td>7500 kW</td>
<td>5200 kW</td>
</tr>
<tr>
<td><strong>Energy Used to 1510 C (Two-shift operation)</strong></td>
<td>610 kWh/MT</td>
<td>580 kWh/MT</td>
<td>510 kWh/MT</td>
</tr>
<tr>
<td><strong>Natural Gas for Dryer</strong></td>
<td>975,000 CF</td>
<td>975,000 CF</td>
<td>32' by 21'</td>
</tr>
<tr>
<td><strong>Floor Space, Two Units</strong></td>
<td>40' by 24'</td>
<td>34' by 32'</td>
<td>73 MT</td>
</tr>
<tr>
<td><strong>Shipping Weight</strong></td>
<td>106 MT</td>
<td>87 MT</td>
<td>$895,000</td>
</tr>
<tr>
<td><strong>Budgetary Pricing (Comparative)</strong></td>
<td>$1,000,000</td>
<td>$965,000</td>
<td>$895,000</td>
</tr>
</tbody>
</table>

FIGURE 12: A major advantage of the smaller furnace-higher frequency concept is that much faster melt times for both cold and hot lining conditions are achieved with the batch melter as shown on this 1987 table.
FIGURE 13 (left). In 1987, this foundry in Canada was the first to melt with a high-powered batch melting system.

FIGURE 13a (above). Europe’s first high-powered batch melting system was this foundry in the Netherlands. It operated with a 7000 kW power supply. It began operations in 1989.

A weighing system was used to prepare the charge that was discharged from a conveyor onto a swivel vibrating chute that fed either of two furnaces. (Fig. 13) The movement of the charge material from the weigh feeder to the furnaces was under the control of the melt control computer.

The following year, Inductotherm installed a similar 7000 kW system in Europe. (Fig. 13a)

The furnaces were equipped with back slaggng. (Fig. 14) This was done at the end of each melt with power on the other furnace at the start of its melt cycle.

Silica lining material with a backup of alumina brick against the coil was used. Expected lining life was...
Setup of the system was accomplished easily by foundry supervision using a setup screen. Initial cold melts were made at the start of each operating shift on both furnaces using the Meltminder® computer control system. Both furnaces were preheated ready for use at the start of each operating shift. Lining life was further enhanced by the sinter controls on the melt computer. The computer controlled the furnace power to follow a preset temperature time curve, always giving the ideal sinter.

1400 metric tons per furnace. A push-out lining removal system was used for safe, quick lining turnaround.

Another feature of this advanced melting system was computer control. A plasma screen (Fig. 15) was used for operation information so that the controls could be placed on the melt deck. A series of menu driven screens was available for operation of the system. The melt control screen showed control of the melting process during normal operation. The computer read weigh cells on each furnace to determine the charge in the furnace.

An initial charge of 1500 Kg was added by the feeder under computer control. At the start of the melt sequence, maximum power was applied to the furnace (5000 kW) and the melt condition estimated from the energy (kWH) and weight readings. When the computer determined that melting was taking place, it automatically added charge from the weigh feeder to maintain furnace conditions. This ensured that cold charge was not added directly to molten metal and increased operator safety.

As the temperature approached the set level, the operator was alerted to take a test dip temperature reading which was read by the computer. If accepted by the operator, the reading was used as true temperature and the melt was completed to the desired temperature automatically. Diagnostics for faults and indications of system parameters also were included.

Batch melting schemes

The understanding of batch melting efficiency and furnace stirring, coupled with the development of large solid-state power supplies, led to the rapid development of high production batch melting. Various operational approaches to batch melting have been developed over time. These use a variety of equipment types and operating cycles.

Single power supply on a single furnace

This system works extremely well where the complete furnace can be rapidly emptied. This type of system is one with a very small, up to say a 3 ton furnace, and a power supply no larger than 2500 kW. (Fig. 16) However, when the furnace size becomes much larger than 3 tons, there may be too much metal to be taken out all at once. Therefore, the furnace must either be emptied into a holding furnace or the power supply must be turned to holding power while the furnace is emptied progressively with resulting loss of utilization.

FIGURE 15. This pioneering computer system was used for operator information and provided control of the entire melting process during normal operations.
**Butterfly batch melter**

To overcome the need for a holding furnace and allow small taps to be taken to the pouring line, butterfly batch melting has been used. In a typical butterfly batch melting operation, a pair of induction furnaces is used to produce a continuous supply of metal.

**Figure 17.**

One furnace melts while the other pours, with the furnaces alternating in their melting and pouring roles. In standard butterfly systems, the two furnaces share a single power unit that supplies current to one furnace at a time for melting or reheating. This involves the mechanical switching of power between the furnaces. (Fig. 17) Typically, a swivel pivot conveyor or some other mechanism charges each furnace. When the charge in one furnace is fully melted, the power supply switches to the other furnace that starts its melt cycle. The first furnace is then emptied. This system is well described in the BCIRA International Conference report on a 7 MW power supply with a 7.5 metric ton furnace. This system works well as described in the article with the only reported problem being maintaining temperature during the 30-minute tap cycle. (Fig. 18)

**Melter and holder**

To overcome the temperature loss as a furnace is being poured over time, a holding power supply is provided. (Fig. 19) This provides the power needed to
I hold the temperature of the pouring furnace while the other power supply provides melting power. A weakness in this system is that sometimes superheating is needed and the holding power unit may not be suitably rated for this. Therefore, it may still be occasionally necessary for the melting power supply to be switched back to the pouring furnace. Also, mechanical switches are still involved. The holding unit must operate at a similar or higher frequency than the melting furnace to match the same coil. This power supply, therefore, produces inadequate stirring for any late alloy additions, necessitating switching the main power supply back and forth.

**Half and half**

In this scheme there are two equal power supplies and two equal furnaces. A switching setup is utilized so that both power supplies can be connected together to one of the furnaces. In a system with two 3000 kW power supplies and two 6 ton furnaces, for example, the two 3000 kW power supplies would be connected to one of the furnaces for its melting cycle. Once that furnace charge was molten, the two units would be re-configured to start melting on the other furnace. When additional heating was required on the first furnace, one of the 3000 kW units would be switched back to that furnace so that holding power could be supplied and some melting power would still be maintained on the melting furnace. (Fig. 20) This system proved to be unsuccessful due to the amount of switching back and forth, the variability of electrical demand and the fact that the frequency of the two power supplies together was inherently lower than the frequency of each power supply when connected to a single furnace, resulting in incorrect stirring patterns.

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**Dual-output power via switches**

The first attempt to design a power unit engineered specifically for butterfly batch melting was in 1986 when Inductotherm developed a single power supply which was connected to two furnaces with the coils tapped in such a way that most of the power was applied to the furnace during the melting and a small part of the power was tapped off to the pouring furnace to hold at temperature. Thus, a single 750 kW unit was able to apply about 650 kW for melting and 100 kW for holding to each of two furnaces. This worked extremely well in the low kilowatt levels, but was severely limited by switch ratings and switch reliability from going to any higher levels.

**Solid-state dual-output power to maximize a batch system’s pouring rate**

In early 1991, Inductotherm introduced an induction power supply engineered specifically to maximize the efficiencies of butterfly batch melting. Named “Dual-Trak®,” it was a unique single power unit with two outputs.10 With its two outputs, a Dual-Trak unit is able to feed continuous and completely controllable power to two furnaces at the same time. (Fig. 21) This allows the furnace operator to melt in one furnace and simultaneously apply the power needed to maintain temperature in a pouring furnace. As a result, it is no longer necessary to interrupt melting in order to reheat the metal in the pouring furnace, a common but inefficient practice with single-output power supplies. Consequently, with dual-output power, the overall time needed to complete a melt cycle is reduced. This can increase metal production by up to 20 percent, depending on the
number of times a furnace operator had to reheat the pouring furnace during a batch cycle with a standard power unit. (Fig. 22)

Also, because holding power is applied continuously to the pouring furnace, precise metal temperature is maintained, an important factor in many applications.

A dual-output power unit gives the furnace operator complete control of both furnaces. With separate controls, he can allocate power in any way between them, up to the unit's total power rating, just by turning the power knobs. For example, one furnace could be run at full power, with no power being sent to the second furnace, or both furnaces could be run at holding power levels - or even superheat when required. The holding furnace power setting always dominates so that the lesser power going there is exactly set by the operator and the remaining power is then available to go to the melter. Unlike single-output power units, there is no need for mechanical switching or a second power unit with a dual-output system.

Another significant advantage of this technology is its ability to sinter or cold-start two furnaces at the same time or to sinter one furnace while melting in the other. This reduces production downtime and increases system output. It also features the ability to direct full rated power to one furnace while fully isolating the other during maintenance or lining changes.

While a single dual-output power unit provides the batch production capacity of two separate power supplies, it offers a number of advantages over two-unit systems. First, there is just one set of power and water connections and the line KVA of a single unit, a significant savings in installation and maintenance costs. Second, it takes up less room in the melt shop than two separate units. Third, it offers a level of equipment utilization approaching 100 percent because it is designed to use its full power capacity throughout the batch melting cycle. Finally, it offers a minimum investment per ton of metal poured.

*FIGURE 22. This chart shows how a 1650 kW Dual-Trak unit with a pair of 3000 Kg furnaces maintains the same pouring rate as a 2200 kW single output power unit with an 4000 Kg heel melting furnace.*
**Balancing variable metal demands**

Before the advent of Dual-Trak power units, batch-melting foundries with highly variable metal demands during the operating day relied on separate holding furnaces to provide the metal reserve they required. But with a dual-output system’s ability to provide steady and reliable holding power during melting operations, it is practical to configure a two-furnace batch system able to meet even the most variable demand for molten metal.

The key to this system is to size the dual-output power unit to meet the overall daily demand for metal and to match it with furnaces sized to hold enough metal to meet the day’s greatest demand. Take, for example, a foundry requiring 480 metric tons of metal in a 16-hour period. That’s an average demand of 30 metric tons of metal per hour. However, its actual hourly demand varies greatly, ranging from 15 metric tons in an hour to 45 metric tons in an hour. (Fig. 23) This foundry would be able to operate efficiently with a Dual-Trak unit able to melt 30 metric tons per hour using a pair of 60 metric ton furnaces. No additional holding furnaces would be required.

With this arrangement, metal is always ready in the amount needed and at the temperature required. Balancing the varying power needs for melting and holding are what Dual-Trak does best.

**Dual-output and multiple-output induction melting**

In the early part of the last decade, an induction power supply engineered specifically to maximize the production output of batch melting was introduced. It was a unique single power unit with dual outputs able to allocate continuous and completely controllable power to two furnaces at the same time up to the unit’s total power rating. Now multiple-output power units with three or more outputs are in operation in foundries where they are achieving the high levels of metal production previously the preserve of cupolas.

![FIGURE 23. Variable metal demand](image-url)
Dual-output power units allowed foundries to simultaneously melt in one furnace and hold with power in a second pouring furnace. This could increase metal production by up to 40 percent, compared to a single furnace/single power unit system and by up to 20 percent compared to a butterfly batch melting system with two furnaces and a single power supply. At Benton Foundry in Pennsylvania, a 7000 kW dual-output power supply runs two 10 metric ton furnaces in a typical batch melting operation. (Fig. 24) Charge is delivered, via bucket, from the scrap dryer to a vibratory conveyor that serves both furnaces. While holding power is directed to the furnace being tapped, melting power is applied to the furnace being charged. (Fig. 25)

**FIGURE 24.** A vibratory conveyor mounted on the melt deck loads charge materials into an induction furnace.

**FIGURE 25.** Ten metric ton induction furnace pours into a ladle.
Small foundries also can take full advantage of dual-output systems. At a foundry in Washington, two 1 metric ton furnaces operate with a 750 kW dual-output induction power supply. (Fig. 26)

The first use of a triple-output induction power system was in Ohio. Installed in 1997, this was a 5000 kW induction power unit able to direct full power to any of three furnaces or to allocate that power in any way among the furnaces. (Fig. 27)

At a more recent installation in Georgia, three 12.5 metric ton furnaces are powered by a single 20000 kW triple-output power supply able to direct up to 10000 kW each to any two furnaces. (Fig. 28)

A company in Tennessee is using a 9000 kW triple-output unit to power three 10 metric ton wide-bodied furnaces. This unit allows the foundry to melt in one furnace and hold at the desired...
FIGURE 28. Schematic of a 20000 kW triple-output induction melting system.

Inductotherm’s development of capacitive isolation allows each furnace to be protected by its own ground leak detector system, a crucial safety requirement, and provides the ability to fully isolate a furnace during maintenance or lining changes. It also allows temperature in one or both of the other furnaces, providing maximum alloy flexibility to meet varying requirements for gray and ductile iron.

The production advantages of triple-output systems are not diminished when these systems are scaled up in size. For example, a 35500 kW triple-output batch melting system with three 20 ton furnaces with a 36 minute melt and 18 minute pour will produce 65 metric tons of metal per hour. And the power utilization continues at 100 percent. (Fig. 29)

Other significant advantages of multiple-output induction power supply technology include:

- The ability to sinter or cold-start multiple furnaces at the same time or to sinter one furnace while melting in others.
- The unit’s single set of power and water connections and the line kVA of a single unit, a significant savings in installation and maintenance costs.
- Less space required in the melt shop than separate units.
- Equipment utilization approaching 100 percent.
- Minimum investment per ton of metal poured.

FIGURE 29. Graph showing a 65 T/hour production cycle for a 32000 kW triple-output system.
Dual-output power supply with capacitively isolated furnaces

FIGURE 30. Capacitive furnace isolation supports multiple-output induction power systems.

multiple-output power systems to operate any number of furnaces connected to a common DC bus. (Fig. 30)

Fig. 31 shows a 100 ton per hour furnaces powered by a 50 MW system able to direct up to 20 MW to any furnace. With this system, for example, two furnaces could be melting at 20 MW each with the remaining power allocated to one or both of the other furnaces for melting, holding or sintering.

More than 500 Inductotherm dual and multiple-output induction power systems are operating today worldwide.

Powerful induction systems spur computer controls

Industrial designers used to focus on the man-machine interface when it came to control technology. Today the focus is on the man-computer interface and the computers control the machines. In airplanes this type of control system is called “fly by wire” and many advanced planes, such as the stealth fighter, could not stay in the air without it.

The world of the computer is a digital one and control systems are becoming increasingly digital. Digital controls offer advantages which simply were not easily obtained with their analog predecessors. These include:

- Direct connection to a computer.
- The ability to link multiple devices and have them communicate with each other locally or at any distance.
- Maximum accuracy and repeatability of instructions and information.

For the foundry worker, these properties of digital control systems translate into valuable operational benefits:

FIGURE 31. Schematic of 100 ton/hour induction melting system.
FIGURE 32.

Computer Control — Because today’s high power density batch melting systems melt the charge so rapidly, they have driven the development of computerized melting operation control systems designed both to provide precise control of the melting process for enhanced quality and to reduce the risk of accidental superheating. Some of these systems operate on special computers, some are built into the melting equipment itself and some are PC based, including the latest system running under Windows NT®. This Windows-based system offers the full advantages of the Windows operating system for the customizing of reports and interfacing to other applications. (Fig 32)

Batch melting is an ideal process for computerized control. A typical control system uses the weight of the furnace charge, either from load cells or as entered by the operator; the melt rate; and the desired pouring temperature to automatically calculate the kilowatt hours needed to complete the melt. It then turns off the system or drops to holding power when the melt is complete. Thermocouple readings can be transmitted to the computer to further enhance accuracy. (Fig. 33) This precise melting control optimizes power usage by minimizing temperature overshooting, saves time by reducing frequent temperature checks and enhances safety by reducing the chance of accidental superheating of the bath, something which can happen very quickly in a high power density system and which can cause lining failure.

FIGURE 33.
The most advanced foundry melting automation systems also provide fully programmable control of sintering and the ability to schedule and control furnace cold-start procedures. In addition to operational control, computerized melting systems can offer real-time information about system diagnostics and operation. (Fig. 34)

**System Diagnostics** — Diagnostic checks are an important part of this information. Some technologically advanced systems are able to identify specific problems before any power is applied, protecting equipment from damage.

Maintenance information can help the furnace operator keep track of key maintenance requirements such as lining replacement, an impor-
tant safety consideration. (Fig. 35)

**Digital Control Networks** — Because information in a digital format can be easily communicated and shared by a variety of systems, digital control systems in a foundry can link and control many pieces of equipment. Typically, this can be done with just a simple cable containing a pair of control wires plus power and shielding. This is in contrast to complex cabling required for non-digital control systems. Link your induction power supply to several remote control stations. Store important operational information on your melt shop computer as well as on your company’s mainframe computer at corporate headquarters. Coordinate charge makeup with melting operations and even with production much further down the line. (Fig. 36)

**Harmonics**

"Harmonics" is a general term often used to describe many of the effects a piece of electrical equipment may feed back into its power source. Now, with the foundry industry operating solid state power converters of up to 50000 kW, power utility companies have begun to study what effect such high power may have on utility lines. Power interface problems are often difficult to resolve and may include:

- **Low Power Factor** causing current to flow from the induction power supply back into the power line due to reactive loading.
- **High Frequency Current Harmonics** generating excessive heating and other adverse effects on power utility facilities.
- **Line Voltage Notching** caused by semiconductor or contacts switching, producing severe voltage on the line. These spikes are short in duration, but may carry significant energy. They also generate radio frequency noise that may jam communication equipment in the area and sometimes cause arcing and coronas, damaging line utilities.
- **Inter-Harmonic Distortions** occur when static power converters inject currents into the power line at frequencies that are not a multiple of line frequency but a multiple of the inverter operating frequency. These harmonics, when superimposed on the AC line, may induce fluctuation in line voltage, causing flickering of lights in the neighborhood of the induction power supply.

Induction power converters may produce some or all types of line distortions.

Line distortions represent a series of problems that must be addressed by designers and users of induction melting equipment. Failure to consider the effect of static converters in early planning may become very costly, if not impossible, to correct later, when the equipment is commissioned. The higher the generated power, the more acute is the problem.

**FIGURE 36 - A melt shop control network.**
Two types inverters are available on the market: current-fed inverters and voltage-fed (Fig. 37). Analysis of equipment and techniques of static power conversion shows that a voltage-fed inverter with multiple full-wave rectifiers is the best technology today for large megawatt level induction melting systems. Voltage-fed inverters provide:

- Minimal line voltage notching. Notching is often the source of power spikes and radio frequency noise.
- High load matching which minimizes high frequency harmonics on power lines.
- High efficiency with a power factor of 95% or better.
- Minimal inter-harmonic distortion due to the capacitive energy storage devices.

Therefore, full-wave, voltage-fed systems generate the minimum possible distortion back to the power lines that feed them.¹² (Fig. 38)

![Current-fed power supply driving a parallel-resonant furnace circuit.](image1)

![Voltage-fed power supply driving a series-resonant furnace circuit.](image2)

**FIGURE 37. Current-fed and voltage-fed induction power supplies.**

**Power Quality Comparisons (Single-Rectifier-Bridge Configuration)**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Current-Fed Inverter</th>
<th>Voltage-Fed Inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-Voltage Notching</td>
<td>Yes (Caused by Phase Control)</td>
<td>No</td>
</tr>
<tr>
<td>Harmonic Generation</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>System Power Factor</td>
<td>0.7-0.95 (Depends on Phase Control)</td>
<td>0.95</td>
</tr>
<tr>
<td>Generates Inter-Harmonics</td>
<td>Yes (Depends on Furnace Frequency)</td>
<td>No</td>
</tr>
</tbody>
</table>

*Source: Electric Power Research Institute (EPRI), Inc., Telecommentary (TC -114625) 1999*

**FIGURE 38. Current-fed and voltage-fed induction power supplies.**
Powerful induction systems now challenge arc furnaces

With their continually increasing size, high power density induction melting systems today present a direct challenge to the original electric batch melter, the arc furnace. Induction furnaces offer a number of advantages over arc furnaces in most foundry operations. These include:

- **Better control of bath metallurgy.** Induction heats the metal from within so there is little or no metal loss. Electric arc furnaces heat by temperature differential, heating the surface with the arc and burning off appreciable amounts of metallic elements, making it difficult to maintain precise metal specifications.

- **Better control of carbon.** With induction furnaces there are no carbon arcs and no carbon gets into the metal as a result of the melting process.

- **Better metal homogeneity.** Inductive stirring mixes the elements in the metal bath.

- **Cleaner melting.** Induction furnaces melt cleanly, producing little or no smoke or fumes. Arc furnaces generate heavy metal fumes, carbon dust and other pollutants.

- **Quiet operation.** Compared to arc furnaces, induction furnaces are quiet in operation.

- **Lower cost of refractory and other consumables.** Induction furnaces use less refractory in their linings and do not require the purchase of carbon electrodes.

Illustrative of this challenge to the arc furnace by modern high powered induction systems is the new installation at the Foundry Division of John Deere Waterloo Works, Waterloo, Iowa. John Deere, a leading manufacturer of farming machinery, has replaced its six 16 ton arc furnaces with three 16500 kW solid state, medium frequency induction units powering three 20 metric ton steel shell coreless furnaces. (Fig. 39) Completed in the summer of 2000, it is the largest, solid state, medium frequency induction melting installation in the world.

Overall melt shop control is provided by a dedicated computer system in a central, elevated control room with line-of-sight monitoring of each furnace. Local operation is via a full remote control station adjacent
FIGURE 40. Vibratory conveyor at the John Deere Waterloo Works adds charge to a 20 metric ton furnace.

The new installation also includes integrated and automated alloy makeup and charge delivery equipment. (Fig. 40) The alloy makeup system operates from preset recipes to achieve the desired consistent bath chemistries and temperatures. Each of three furnaces is served by its own conveyor. As each charge car is loaded, a weigh frame built into the melt deck indicates when a full 20 metric ton charge is on board. At that point, the car moves on rails to the furnace for unloading.

John Deere’s new, high power density induction furnaces include back tilting for easy slag removal, integral fume collection covers and lining removal mechanisms. These new furnaces generate minimal effluences and produce substantially less noise than the six existing arc furnaces they replaced, providing John Deere employees with a cleaner and quieter working environment.

High power density furnace design for batch melting

There is a wide range of engineering and manufacturing challenges involved in building a high power density induction batch melting system. It’s not sufficient simply to build a higher output power supply and attach it to a standard induction furnace. The entire system, from charging equipment to the design of the furnace, must be engineered as a high power density system.

The coil

The first consideration in engineering a high power density induction furnace for batch melting is the coil design.

Calculating the amount of copper needed to carry the current needed for a high power density induction coil is only a small part of the coil design challenge. The coil also requires more cooling ca-
and rigid structural support elements to limit the coil expansion and flexing often responsible for short refractory life. These elements include nonmetallic coil supports, which lock each coil turn solidly into place, and adjustable tie rods that control vertical movement. The furnace's magnetic shunts also play a vital structural role by keeping the coil and furnace lining under compression without yielding. High power density furnaces require extensive shunt coverage to redirect the strong inductive field into the charge material and molten bath. By making these shunts an integral part of the overall structure of the furnace, the coil's rigidity is greatly enhanced. (Fig. 42)

**Advanced coil insulation**

Another important consideration in the design of modern furnaces for batch melting is the careful and effective insulation of the coil. Proper coil insulation has always been crucial in vacuum furnaces, but many of today's high power density air melting furnaces also need an insulated coil to help prevent arcing.

FIGURE 41.

Opacity due to the higher power levels, greater mechanical strength and a more complex configuration program to determine the optimum coil turns and dimensions.

To meet the power transmission requirements, water-cooling needs and structural strength necessary for a high power density coil, the coil must have a high section modulus.

This provides enough copper to carry the current, a large open area within the tubing for water flow, and inherent structural stability. A rectangular cross-section with rigid walls of uniform thickness provides the maximum ability to withstand the stresses imposed by the thermal expansion of the refractory and the weight of the molten metal in the furnace as well as the supporting forces from the furnace structure. (Fig. 41)

In addition to heavy copper tubing, high power density furnace coils require strong...
The heavy steel shell furnace

In high power density batch melting furnaces based on the advanced steel shell design, the inherent hoop strength of the heavy steel shell provides an extremely strong and rigid all-around structure that minimizes distortion during tilting and pouring operations. This shell forms a firm base into which the other key furnace structural elements are tied.

EMF emissions

While extensive shunt or yoke coverage provides substantial structural strength to the furnace, the most important job of the shunts is to capture the magnetic field which is not going into the metal charge and redirect it back into the charge. But with anything less than 100 percent shunt coverage, some of the magnetic field is missed. However, in a steel shell furnace, the shell itself prevents emissions from escaping. (Fig. 43) That is why heavy steel shell furnaces easily comply with today’s most rigorous international EMF standards.

Noise reduction

A variety of traditional coil insulation materials and techniques continues to be available, but today’s most advanced materials are monolithic coatings. The best of these materials offer a dielectric or insulating value surpassing conventional coil insulation as well as strong mechanical properties, such as resistance to heat and abrasion. They also remain highly flexible to move with the coil as it expands and contracts.

Foundries can be noisy places, but noise can be controlled. This can be accomplished first by the careful selection of inherently quiet equipment. Induction furnaces, as noted earlier, are much quieter than arc furnaces.

Second, choosing equipment with built-in acoustic suppression will reduce unnecessary noise. (Fig. 44)
Steel shell furnaces, by design, keep noise inside the furnace shell. And they can be constructed with supplementary sound insulation within the shell. Similarly, charge conveyors can be built with beds lined with sound absorbing materials.

Finally, acoustic enclosures can be incorporated in equipment and installation designs. Acoustic enclosures can either be in fixed locations to contain individual pieces of equipment or they can be attached to a piece of equipment and move with it. Enclosures also can isolate complete areas of the foundry. Such enclosures are extremely effective.

Noise reduction will increasingly become important in equipment and foundry design.

**Metal splash protection and fume reduction systems**

Among other benefits of steel shell furnace construction are the effective protection from metal splash it provides the coil and its compatibility with fume capturing systems.

Fume collection — Unlike cupolas and arc furnaces, induction furnaces themselves produce no smoke or fumes. However, the charge materials being melted can generate undesirable emissions. These can be as simple as smoke or dust from oily or dirty scrap. Or the emissions can be the inevitable by-products of melting certain metals. To capture smoke and other fumes associated with melting, induction furnaces can be equipped with highly effective fume collection covers with integral furnace lids.

These covers can be designed to operate effectively both when closed and when open for charging. (Fig. 45) They also can be engineered to be compatible with a wide variety of automated charging systems.

**Fast and complete slag removal**

As induction furnaces grow larger and faster, efficient removal of slag becomes more difficult. To be effective, the furnace crucible must allow enough reverse tilt so that sufficient surface area of the bath is exposed and at the proper height in relation to the rear slag spout.
Because of varying metal levels in any operation, a back-slagging furnace that is equipped with separate cylinders and an additional furnace frame allows as much as a 33 degree reverse tilt for slagging. (Fig. 46) This allows the furnace operator, regardless of metal height, to remove all of the slag from the furnace directly into the slag cart in a quick and efficient manner. The additional furnace frame permits a high furnace hearth to allow a slag cart to be positioned under the rear slag spout. (Fig. 47)

This dedicated back-slagging system is more effective than furnace back-tilting which uses only the forward tilting cylinders in a single furnace frame and has a lower furnace hearth in relation to the melt deck. With such arrangements, the amount of back-tilt will be restricted to 10 or 12 degrees.
This may mean that it is more difficult to reach the metal bath or utilize a slag cart under the rear spout, resulting in dragging the slag on the melt deck before lifting into a slag hopper. (Fig. 48)

For most applications, furnaces of 6 tons and larger should include back-slagging.

Mechanized slag removal

Large furnaces that do not have rear slagging spouts should use a mechanized slagging device to speed up slag removal.

Push-out linings

Large coreless induction furnaces also benefit from lining push-out systems. These systems generally consist of a moveable block in the bottom of the furnace and a hydraulic cylinder. (Fig. 49) When a lining is ready to be replaced, the furnace is tilted to a 90-degree angle and the cylinder is attached to push the block toward the front of the furnace, pushing the old lining ahead of it. (Fig. 50) When the old lining drops away into the waste bin, the pusher block is returned to the bottom of the furnace, which is then restored to an upright position for relining. The advantages offered by these systems include the speed of lining removal, fewer man-hours and reduced silica dust exposure.
Wide-bodied furnaces

The typical coreless induction furnace is taller than it is wide. This is an appropriate shape for most melting applications and the vast majority of furnaces are built to this model. But for some applications, this is not the ideal shape. Rather, the ideal shape called for might be a wide-bodied furnace. (Fig. 51) A wide-bodied furnace is wider than it is tall and features a significantly larger crucible opening than a standard furnace of comparable capacity. (Fig. 52) The advantages offered by this design relate to the applications for which it was engineered.

Generally speaking, a wide-bodied furnace’s larger crucible opening and proportionally shallower furnace depth provide:

- The ability to load larger, bulkier (and consequently cheaper) scrap.
- Better access for removal of slag or dross buildup on furnace walls.
- Greater overhead clearance (or a reduced requirement for overhead clearance)
- Minimal depth of pit.

**FIGURE 51.** "Wide-Body" Steel Shell Furnace (53 1/2" Diameter) vs. Standard Steel Shell Furnace (41" Diameter). Both have 10 Metric Ton Capacity.

**FIGURE 52.** A 10 metric ton wide-bodied furnace.
FIGURE 53. The wide furnace opening accommodates the counter-gravity casting device.

The first wide-bodied furnace was developed in the late 1980s to support an innovative counter-gravity casting process. (Fig. 53)

A company in Tennessee recently installed three 10 metric ton wide-bodied induction furnaces to allow it to use long raisers as part of its normal furnace charge. These internally generated raisers required a larger than normal furnace opening to avoid tangling during charging. The wide-bodied furnace offered an opening that was almost 20 percent larger than a standard furnace of the same capacity.

Automated charging systems

The growth of batch melting has spurred the development of remotely controlled, mechanized charging. Batch melting systems typically use advanced induction furnaces that provide high power densities and are able to run at full power throughout the charging process. These furnaces require rapid charging to keep pace with the melting power of the system. Manual charging simply cannot support a large induction furnace able to melt a full charge in less than 30 minutes. Mechanized charging systems are engineered to deliver charge materials to the furnace quickly and efficiently, allowing maximum utilization of the melting system. They also permit manpower to be used more efficiently.

In batch melting, the vehicle emptying the charge into the furnace ideally should hold a full furnace load. This allows additional charge materials to be continually added as melting drops the level of cold charge in the furnace. This takes maximum advantage of the higher efficiency of cold charge melting, prevents wasteful delays in charge delivery during the melting process and enhances safety by introducing cold charge materials on top of solid material already in the furnace rather than directly into the molten bath.

The enhancement of worker safety is an important reason for the growth in automated charging systems associated with induction furnaces. Many serious foundry accidents have occurred during manual furnace charging, when foundrymen were close to the
molten bath. Splashes caused by dropping large pieces of scrap and by water/metal explosions caused by wet or damp scrap have proven to be an ever-present danger. But these dangers can be reduced through the use of charge drying and preheating systems to reduce moisture and remotely controlled charging systems to keep the furnace operator away from the molten metal during hazardous charging operations.

In general, in-foundry charge transportation systems can be divided into four categories: electromagnet cranes, belt conveyors, buckets and vibrating conveyors (Fig. 54). These in turn are available in a wide variety of configurations and modes of motion. For example, vibrating conveyors, the most versatile and rugged of all furnace charging devices, may be in fixed positions for holding, consolidating, weighing and transferring charge materials. They also may be extremely mobile. They may move along tracks in any direction, may pivot and/or may index forward and backward. In fact, vibrating conveyors have been built to traverse, pivot and index, all in the same unit (Fig. 55). This mobility enables a vibrating conveyor to be built to service a single furnace or any number of furnaces. Largely unaffected by heat, vibrating conveyors are ideal for feeding charge materials directly into the furnace. Vibrating conveyors also can be fitted with integral fume collection covers over the discharge chute to enhance fume removal during charging.

Ultimately, whether you use belts or buckets or vibrators or cranes, the final configuration of any charging system depends largely on the physical layout of the melting facility. Ceiling height will determine if your facility can handle buckets, floor space and elevations will largely dictate the types of...
FIGURE 56. A reducing flame provides optimum temperature with minimal oxidation of charge material. A dryer/preheater raises the charge to the desired temperature to remove moisture from the scrap and will reduce furnace melt time and overall energy costs.

FIGURE 57. A scrap dryer in operation.
conveyors required for the job. Key considerations remain safety and the ability to keep pace with the melting furnaces’ need for charge materials. There is a charging system that’s right for every foundry.14

Dry scrap is essential to safety
Wet or damp scrap exposes melt deck workers to the very real and life-threatening danger of furnace eruption or explosion. The best way to ensure that there is no water or moisture on your scrap is to dry it in a gas or oil fired charge dryer or preheater. Charge preheating may also significantly increase productivity in melting operations.

Drying and preheating systems pass scrap through an oil or gas fueled flame tunnel, heating the scrap and minimizing moisture that could cause a water/metal explosion. (Fig. 56) These systems also burn off much of the dirt, producing a cleaner charge and reducing the energy required in the furnace to melt the scrap. These systems, however, cannot remove trapped liquid, such as oil in cans and cylinders. Such materials must be shredded before they are used.

The use of drying and preheating systems and remotely operated charging systems can significantly reduce accidents related to furnace charging operations. (Fig. 57)

Scrap weight
Accurately measuring the weight of the furnace charge has always been important to avoid accidental overheating and to determine the proper amount of additives needed to maintain the desired metallurgical properties. The advent of high power density batch melting and advanced computer control systems, however, has made accurate charge weight absolutely crucial. Computers can only function as designed when provided accurate data.

Accurate charge weight can be obtained through furnace load cells and/or via weighing hoppers located on the charge conveyor or at the charge makeup location. (Fig. 58)
Batch melting continues to evolve into the 21st century

Much has been written in recent years about the significant and compelling advantages of induction batch melting. These include reduced furnace capacity requirements (compared to comparable heel melters), easier alloy changes, safer charging and energy-related efficiencies in units able to deliver full power into the charge from the start of the melt.

As is true of any viable operational process, batch melting will continue to change as new and more advanced techniques and technologies are developed and as those running the systems gain knowledge and experience.

The following looks at some of the more recent operational advantages being discovered by batch melting practitioners.

Batch melting's operational advantages

**1. Reduced charge oxidation**

The most significant advantage of batch melting is the ability to maintain full power throughout the melt, especially in the early stages, and its importance in the reduction of oxidation in ferrous metals.

Ferrous charge materials oxidize rapidly once the charge reaches Curie, the point at which a solid charge becomes non-magnetic. This is stage 2 in the melting cycle illustrated in Fig. 59. The power supply must have sufficient flexibility to quickly take the charge through this stage. Power units unable to achieve full power until the charge is largely molten lengthen the duration of stage 2 and may create oxidation problems in the bath. Reducing oxidation also may play a role in increasing lining life, according to a phenomenon observed in the field. One report, for example, indicates that melting a layer of oily borings in the bottom of the
Furnace may play roles both in reducing free oxygen and increasing lining life by 30 percent to 50 percent, depending on the amount of borings used in the initial charge. The hypothesis is that when the oil on the chips ignites at the beginning of the melt, oxygen in the furnace is depleted, creating a nonoxidizing environment, much as melting in nitrogen gas or other replacement atmosphere would. This phenomenon requires further study.

2. Greater lining life

Increased lining life is also a significant batch melting advantage.

With greater kilowatts being placed on a medium frequency furnace, it is important for foundries to maximize lining life so that refines may be scheduled during a nonproduction period of time, such as a weekend. Batch melting operations, where a complete batch is melted and poured with little holding time, typically allow much longer lining campaigns than comparable heel melting operations. That's because batch melting minimizes the amount of time the lining is in contact with molten metal. For example, where a complete batch can be duplexed into a holder or ladle the same size as the furnace, foundries can double the lining life of the equivalent medium frequency heel melter.

The average lining life in a 10 metric ton furnace is between 300 and 400 batch heats or 3000 and 4000 tons. The maximum lining life that has been reported on a 10 ton furnace running gray iron is 8000 tons.

As with everything, there can be trade-offs depending on application.

Lining life in dual-output or multiple-output systems with more than one furnace will not realize the same lining life as a single batch melting furnace connected to a single power supply. While these systems allow you to achieve 100 percent utilization of the connected power, they are designed to operate with one or more furnaces acting as a holder during part of the batch melting cycle. For example, a Dual-Trak® dual-output system with two furnaces cannot have an effective load factor of more than 50 percent. Therefore, lining life will be determined by how long a particular user is holding iron and at what temperature.
Average lining life would be equivalent to a medium frequency heel melter and would be expected to range between 250 and 350 heats for a 10 ton furnace. All efforts should be made to maximize the furnace load factor to achieve maximum lining life. Operations that have low furnace load factors will have poor lining life.

Basic lining considerations
With high power density batch melting, it is particularly important to closely control the factors which determine lining life. Special care must be taken during lining installation and sintering, during daily melting operations and in the performance of lining maintenance tasks. (Fig. 61)

There are some basic fundamentals in installing the lining:
• Lining forms must be held down mechanically by either cross-bracing over the top of the furnace or some welded tabs to keep the form from moving up when vibrating. It should be noted that the lining forms will move up very easily. In fact, if not held down, simple forking of the material on the first layer will cause the form to move up. The form moving up will cause an air gap between the melt-out form and refractories and it doesn’t take very much air gap to make an excellent insulator. A 1/16" gap will prevent the bottom refractory from properly being sintered.

**FIGURE 61.**

Furnace Load Factor
Erosion is caused by two basic factors, mechanical and chemical. Few linings fail because of mechanical abuse. When mechanical damage occurs, it tends to be noticed. Chemical damage, however, is much more subtle. It is important to pay close attention to chemical erosion, especially on the first heat. The first heat is the most important because if we were to start a furnace up with low silica charge, steel and some high carbon pig, we would have some initial erosion as the charge would attempt to take silicon from the refractory, as all elements will try to go to their neutral state. (Fig. 62) One solution is to have at least a 2% or higher silicon formula at least halfway up the furnace.

Silicon will also help reduce the oxygen within the metal, reducing the chances of oxidation. Elements like manganese reduce at low temperatures and can be very detrimental to a new lining. The addition of such elements should always be late in the charge when the temperatures are elevated.

Experience with channel furnaces has shown that holding at low temperatures for long periods of time will develop manganese oxide and cause excessive erosion at low temperatures. The addition of carbon should not be early in the first melt, as it will reduce the silicon oxide and cause early erosion and spalling. Carbon gas can penetrate a new lining and condense toward the coil as carbon. This also can happen when torching the furnace with a rich flame developing CO gas, causing the carbon to deposit as far back as the steel shell.

The better care we take of the initial charge, the better the overall lining will run. This type of problem can be seen easier with ductile iron where there is a low silica content in the batch at an elevated temperature. A simple detail of when to add carbon and silicon to a new batch can give good life or unsatisfactory life.17 (Fig. 63)

**FIGURE 62.**
Elephant's Foot Lining Erosion

**FIGURE 63.**
Isotherms of Equilibrium between Silica ($\text{SiO}_2$) Of the Lining and Carbon (C) of the Iron Charge.
Bottom refractory problems

It has been noted that some iron melting furnaces have had premature bottom wear equal to half or less of sidewall wear during a lining campaign. This has been attributed to insufficient initial sinter of the bottom of the lining form. This can occur because of two reasons:

1. Bottom of form not in contact with bottom refractory.
2. Bottom of form not attaining sufficient temperature to achieve hot face sinter.

Present sinter instructions do not allow for monitoring the temperature of the bottom of the steel meltout form. If the initial sinter charge does not have sufficient density to allow a minimum of one hour at 1900°F temperature, premature failure will occur. To eliminate this problem, heavy charge pieces such as a solid sinter block should be set on the bottom of the form to attain a mass heating source. A thermocouple should be placed at the bottom of the form to verify temperatures. The initial sinter cycle should be held for whatever time is necessary to achieve a 1900°F bottom temperature to eliminate premature bottom failures.

Top refractory problems

It is not uncommon to have top cap or top refractory finning problems until the necessary refractory installation and maintenance procedures are established. Close capture furnace hoods that continuously pull cool air across the top hot refractory surfaces further complicate this problem.

In establishing the proper written procedures for each application, it is very important to know what you have done and where you are going. Some important steps in solving top finning problems include:

1. Shut off or turn down fume collection systems during sintering procedures.
2. Ensure that sufficient temperature is attained (1600°F to 1900°F) and held for one hour at the top of the lining form during sintering. If the lining form has a tendency to drop in the furnace before the top sinter is complete, tack weld tabs on the top to hold the form in place.
3. Use a gas torch as an induction assist to evenly heat the top of the form.
4. Bring the metal level to two to three inches below the spout when increasing to final maximum sintering temperature.
5. Make sure the bath is clean and slag off, if necessary, to ensure molten metal and not slag is at the preferred height.
6. If possible, eliminate or reduce the amount of wet material used for the top cap, spout, etc.
7. Patch and washcoat the spout and top cap often to eliminate metal penetration through any refractory cracks.
8. Reduce fume extraction flow when holding or otherwise not actively melting.

Contact your refractory supplier representative for information on all of the above to ensure you are working with the correct materials.

3. Lower raw material costs

With diminishing ideal charge materials for heel melting applications, the batch melter again excels in reducing purchased raw material cost by allowing the foundryman to melt less than desired scrap. This includes loose and bundled bushelings, shavings, borings or oily ferrous chips.

It is important that this material be automatically and continuously fed into the furnace from a charge system capable of feeding the entire furnace contents on demand. The most common charge system utilized is a dedicated charge car for each furnace. One documented case was to add 7-1/2 to 15% oily borings to a 10 ton charge.

The savings amounted to more than $80.00 per charge. In a 6000 ton per month operation, the savings would be $48,000.00 a month. Of great importance to the user was that no special equipment had to be added to handle the chips and no adverse effects were created metallurgically. In fact, lining life actually increased as reported above under reduced charge oxidation.

4. Reduced electrical power costs

Power cost is a very important consideration not only for new foundries, but also vintage induction melt shops utilizing older line frequency melt systems. In study after study, batch melting systems have consistently proven to have the lowest electrical cost per ton produced compared to even medium frequency heel melting systems.
Because of the ever increasing electrical cost, Inductotherm has developed batch melting melt systems that effectively run 100% of the production period. As a result, total overall kilowatts are reduced, resulting in a much smaller induction system.

The early systems that provided this ability were the Dual-Trak batch melters which have now evolved into the Tri-Trak® batch melter. While older line frequency systems may be retrofitted with modern solid state medium frequency power supplies, the overall improvement may be limited because of the existing charge scheme or ladle transfer size.

A detailed study of the operating impact of any improvement under consideration should be performed and understood by everyone involved.

**SUMMARY**

In summary, where many melt systems may meet your production requirements, batch melting will do so at the lowest cost. Operating cost becomes a fixed cost whether it’s your monthly power bill, or the type scrap you must melt, or the cost of relines you have per year. Batch melting systems have proven to provide the foundryman with the lowest cost system in all operating areas. Batch melting systems have also proven to be more economical to purchase and least costly to install.

**References**

2. J.H. Mortimer; Research (1976)
3. J.H. Mortimer, Research (1975)
6. R.Q. Sharpless; Foundry Management & Technology (Feb. 1985)
11. O.S. Fishman; “AC Line Distortion for Static Power Converters Used In Induction Melting,” Inductotherm (May 2000)
12. Electric Power Research Institute (EPRI); “Power Quality for Induction Melting of Metals Production,” Telecommentary (TC-114625, 1999)
13. R.C. Turner, J.J. McKelvie; “Molten Metal Splash,” Foundry Management & Technology (July 1997)
16. T. Kretz, Melt Manager, Auburn Foundry, Plant 2

**Acknowledgments**

The author gratefully acknowledges the assistance of the following individuals in the preparation of this paper: (Listed alphabetically)

Joseph T. Belsh
Paul B. Cervellero
Mark. T. Eckert
Oleg S. Fishman
John J. McKelvie

John C. Thorpe
Francesco Tirillo
Robert C. Turner
Victoria Xiang