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Zoran Tesic
Managing Director of TCT Tesic GmbH

Induction – Furnace - Handbook

by
Herbert H. Netzel

This handbook is intended as a reference aid for foundry workers, process workers, master craftsmen, technicians and engineers employed in metal shops, foundries and maintenance.

The technical terms are arranged alphabetically, and are therefore easy to find.

3rd edition, extended by approximately 130 key terms and now containing approximately 310 key terms,

March 2004

Published by

I E S
Induktion Experience Service
Harkortring 6

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Foreword

The author Herbert H. Netzel has had 35 years of experience with crucible induction furnaces. Before joining BBC in 1970, he made his initial contacts whilst studying electrical technology with an operator of a 1-t mains frequency furnace. After starting work for the major furnace manufacturer in Dortmund, he was involved in the customer service area in the design, construction, installation and commissioning of mains frequency and medium frequency furnaces, including 20 years as the manager of the Customer Service Department. In addition to melting furnaces, holding furnaces and casting equipment in general, he also provided consultation on subsidiary equipment such as transformers, recooling systems and charging equipments. His area of responsibility also included auxiliary equipment such as crucible cleaning devices, slag-tapping equipment, crucible ejection machinery and extraction systems. His particular area of interest always remained the specific operating procedures used within the different foundries.

Due to the demand for information by many employees in the foundries, the author subsequently decided to compile this handbook.

The 1st edition of May 2003 was sold out within 2 months, and the 2nd edition was published to meet the lively demand.

The supplier industry came up with the suggestion of printing the Induction Furnace Handbook in English, and including in it advertisements for the products of interested firms. This provided the impetus for the 3rd edition and the increase in the number of technical terms by approximately 90 %. Depending on the demand, the English edition will be published at the beginning of 2004.

Chapter 1 – Manual for safe Induction Furnace Operation

Chapter 2 – Induction Furnace Handbook

Witten, March 2004

Chapter 1

Manual for safe induction furnace operation

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1. Foreword

With the aid of this Manual on the safe operation of induction furnaces, we would like to provide all interested parties and operators of such systems with helpful information for their employees.
A known or recognised danger can be prevented by taking suitable measures, before accidents or damage are caused. Lack of awareness of dangers and their consequences is the greatest omission in casting foundries. Avoiding accidents costs a lot less than rectifying the consequences of accidents. Every works should therefore carry out relevant training for their employees at least once per year. New employees can thereby learn from experienced employees, and at the same time be familiarised with them about the latest state of the technology.

2. System components

An induction furnace system consists of:

a) Energy supply with performance switch in front of the furnace transformer

b) NF switching system with control devices for the performance unit and an operating cabinet with switching and display devices for the operation of the furnace system

c) MF converter system with control devices for the performance unit and an operating cabinet with switching and display devices and, if necessary to, a processor for the operation of the furnace system

d) Cooling water supply system including return cooling system

e) Hydraulic system for the operation of the hydraulic components from a control panel

f) Ventilation system for the system areas

g) Charging system for charging the crucible furnaces

h) Scrap pre-heating system for drying out preheating charging materials

i) Induction crucible furnace for holding the melting crucible

j) Channel induction furnaces and casting equipment

3. Functional description of the system components

a) Energy supply

The energy supply with performance switch in front of the transformer serves to connect the furnace transformer to the medium voltage power supply network of the power supply company. The transformer converts the medium voltage to the voltage required for the operation of the furnace, e.g. from 20 kV three-phase current to 770 V for MF systems or 2000 V for NF systems. In the case of MF systems, a secondary fixed voltage is used, and no multiple contact switch is required. 10 or 12-stage multiple contact switches are used for NF systems. The transformers are equipped with the following built-in monitoring devices: Thermometers, oil filling level monitoring, Buchholz relays and air de-humidifiers.

b) Power supply line frequency switching system

A power supply frequency switching system consists of a main contactor combination for operating the main power circuit, a switchable resistor for reducing the surge current when switching on, which can be up to six times the nominal current, the balancing system with the balancing reactor, capacitors and switching devices to control the system in line with operating requirements, compensating capacitors with switching devices for controlled compensation to cos phi = 1 and the connecting leads to the furnace connection. The system is controlled using the devices in the operating cabinet.

c) Medium frequency converter system

For an MF induction furnace, a converter is required to produce the necessary to medium frequency from the 50 Hz power supply. In order to do this, a direct voltage is produced in a rectifier, and fed to the inverter via a smoothing choke, and a medium frequency voltage is produced in the inverter with the aid of compensating capacitors and the inductivity of the furnace coil. The regulation of the converter is carried out by the built-in control electronics. The control of the furnace is carried out using the devices in the operating cabinet and if necessary with the aid of the processor.

d) Cooling water supply system

The operation of an induction furnace system requires a cooling water system, including return cooling of the heated water. In the converter, including the capacitors and the smoothing choke, the water circulating in the circuit is heated up from approx. 34 °C to 38 °C, and must be cooled down again to 34 °C by a cooling system activator to. Approximately 215 l/h must be pumped through the electrical equipment per kW of performance loss. In the furnace coil, the water is heated up from approx. 35 °C to 62 °C, and must be cooled back down to 35 °C by a separate cooling system. Approximately 32 l/h have to be pumped through the system per kW of performance loss. In the event of a power failure or other interruption, an emergency water supply must be installed for the furnace circuit. For operation in winter, when the furnace is switched off, heating must be provided.

e) Hydraulic system

A hydraulic station was high-pressure pumps is required for operation of the tilting, cover and hood cylinders. The cylinders are actuated from the control panel with the aid of lever-type switches for the electric valves. Formerly, purely mechanical, hand-operated block control valves were used. In the case of channel furnaces, emergency return valves are sometimes fitted, which are actuated by hand and can be installed at various points in the system.

f) Ventilation system

Since a certain amount of dust and dirt is inevitable in smelting operations, the system components in the various areas have to be protected. The heated air in these areas also has to be replaced with fresh air for cooling purposes. In order to fulfil both these requirements, filtered air is fed into the system rooms at a slight over-pressure. These rooms are therefore almost completely dust-free to do this over-pressure. At an air heating performance for the cooling air of 10 K, approx. 310 m^3/h per kW of performance loss are needed.

g) Charging systems

Charging systems are required for the charging of the crucible furnaces. Smaller furnaces up to approx. 500 kg are as a rule charged by hand. Furnaces of up to approx. 3,000 kg are filled with the aid of hydraulically operated delivery chutes without a vibration drive. In the case of furnaces from approx. 5000 kg and crucible diameter is of greater than 800 mm, vibration chutes are used. From approx. 1,200 mm diameter, charging buckets with opening bottoms are also used for mains frequency induction furnaces. The most commonly used system is the vibration chute with various additional devices such as: impact protection for the crucible, a connection for an extraction hood, a complete housing for the purposes of noise protection and lateral swivel equipment for the operation of two furnaces from one rail system in a Y-arrangement. The charging troughs must be so designed that the available scrap can also be made up and conveyed in sufficient quantities. In the case of a high proportion of small particles, a separating device may have to be installed in the area 500 mm in front of the edge of the crucible.

h) Pre-heating of scrap

In the operation of crucible furnaces, care must be taken to ensure that no damp or wet materials and can be immersed in the liquid bath. Scrap-drying systems are used to avoid the water vapour explosions that can then occur. Here the scrap or other material is heated up to over 100 °C before being charged into the crucible furnace.

i) Induction crucible furnace

The most commonly used smelting system is the induction crucible furnace. The induction crucible furnace has a crucible which heated by an induction furnace coil surrounding the crucible. This arrangement makes use of the transformer principle of induction, i.e. if an electrical conductor is placed in a fluctuating magnetic field, a voltage will be induced in the conductor. In crucible furnaces, this voltage causes strong eddy currents, which due to the resistance of the material, cause it to be heated and ultimately to melt. The water is fed by means of cooling water hoses, and ducted away by the water-cooled cables used for the energy supply. The individual cooling water lines are monitored with regard to volume and temperature.

j) Channel furnaces and casting equipment

In the case of channel furnaces and casting equipment heated by inductors, channel inductors are used as the heating equipment. A channel inductor is designed in a similar way to a transformer, and consists of a closed yoke, on which one or two coils are mounted. The channels of the inductors run around these coils. The water is fed by means of cooling water hoses, and ducted away by the water-cooled cables used for the energy supply. The individual cooling water circuits are monitored with regard to volume and temperature.

4. The melting process

The melting process is the procedure from the first charging to the tapping of the finished melt batch.
When cold-starting mains frequency furnaces, starter blocks, starter rings or compressed scrap are required, that have been made up into starter blocks.
Mains frequency furnaces are used as sump melting furnaces. At a liquid metal filling level of approx. 60%, a suitable quantity of scrap is filled into the liquid bath at a temperature of approx. 1,450 °C. The charged scrap is now melted by super-heating the melt. After the first set has settled and started to melt, the second set is added. This process is continued until the filling level for taking a sample is reached. In accordance with the analysis, the final analysis is now set and the remaining materials with the alloy elements are added and melted. The melt temperature should be 80 - 100 K below the tapping temperature. By agreement with the foundry, the furnace is skimmed for tapping and brought up to the target temperature. In the case of NF furnaces, approx. 8 minutes are needed for this purpose, depending on the specific performance, e.g. 12 t – 3,240 kW at 432 kWh per 100 K.
MF furnaces are operated without a sump as charge melting furnaces. The material is charged into the empty furnace up to the upper edge of the furnace coil. When the electrical power supply is switched on, a voltage is induced in the scrap, which causes strong eddy currents. Due to the high electric current and the resistance of the material, the material is heated up to the point of melting.
The melting material settles together, and the furnace can be recharged with more material. In MF furnaces, the material is not charged into the liquid bath, but onto the still solid material. When the liquid filling level has about reached the upper edge of the coil, the sample is taken and the material for the final analysis added to the furnace. This material is now melted, and the melt brought up to a temperature of 80 - 100 K below the tapping temperature. By agreement with the foundry, the furnace is now skimmed and brought up to the tapping temperature. In the case of MF furnaces, 2 – 5 minutes are needed for this purpose, depending on the specific performance. At 5 t and 3,600 kW performance, 3 minutes are required for 100 K, after which the 1^{st} tapping is carried out.

5. Safety instructions

The smelting process is always associated with dangers due to molten material which cannot always be accurately estimated in advance. It is said that known dangers are no dangers, or at least dangers that can be anticipated and counteracted. Most foundry accidents are caused by the ejection of molten metal in the form of splashes, small and large drops, heat radiation from the melting bath and water vapour explosions. The causes of these occurrences are explained below:
Metal splashes with a relatively low volume of melt are created when very small metal parts come into contact with the melting bath and are ejected from the melt. If these parts are also wet or damp, this leads to the ejection of small and large drops.
In the case of hood extraction systems, which are tilted forward for skimming and radiate heat back toward the operator, the operator is exposed to a great deal of heat. If the operator is not wearing adequate protective clothing and face protection, this can lead to burns on the skin and damage to the eyes.
Water vapour explosions always occur when liquids get under the surface of the bath. In extreme cases, 1 cc of water penetrating deep below the surface can expand in a moment to 1,600 times its original volume.
Water can get into the melting bath not only during the melting process from the materials charged: water vapour explosions can also be caused by damp or wet tools.
When operating a crucible furnace, it can happen that the ramming mix has suffered damage, and the melt has been moved forward up to the coil. If this condition leads to a blockage of the windings and the release of water, water can also penetrate under the melt, resulting in a sudden upward ejection of the melt. These water vapour explosions have been known to be so powerful that the cover supporting arm with the furnace cover has been pushed to the side, and the melt thrown out onto the furnace platform. Operators who were in this area, and not wearing adequate protective clothing, suffered severe burns.
In every foundry, personnel should receive regular training on such dangers and the need to observe all applicable safety regulations. The most important safety instructions are given below:

a) Neatness and tidiness at the workplace means that the furnace platform should be tidy at all times, with the necessary tools ready to hand in their proper places. Any other materials or objects lying around should be removed immediately.
b) Adequate lighting at the workplace ensures that irregularities or problems on the furnace platform can be recognised and rectified immediately.

c) Damage to equipment, operating switches, electrical and hydraulic lines must be noted in a fault book and reported to maintenance, who should carry out repairs immediately. Indicating lights are safety devices, and should be tested once every week.
d) The condition of the crucible should be inspected visually after every emptying or every tapping. Possible cracks in the crucible wall are indicated by dark traces, which can then be inspected more closely.
e) The material to be charged should be inspected when being made up. Pipes, tubes or hollow components should be sorted out by hand, and checked to ensure that they do not hold any water. In winter, scrap should be checked to ensure it does not contain any snow or ice, which can also lead to water vapour explosions.
f) Visitors or personnel from other areas must always be made aware of the dangers and told to remain in a safe place, e.g. the operating station.
g) The minimum level of safety is the equipment of persons on the furnace platform with safety shoes, or at least closed shoes covering the whole foot, long trousers extending over the tops of the shoes, overalls or fabric jacket, protective goggles with side protection and safety helmet. The shift foreman is responsible for ensuring that safety regulations are observed, and should if necessary report to the works manager. A protective overcoat and face protection should be worn during the tapping process.
h) The emergency outlet channel must be kept dry and clean at all times.
i) The furnace body should be inspected once every week, and cleaned every month of dust, small particles of scrap and other impurities using a vacuum cleaner.
j) Any oil that has leaked out must be picked up and the spot covered with sand. The leak must be located and repaired.
k) There must always be two emergency escape routes from the furnace platform in the event of accidents. These routes must be kept clear at all times, and may not be blocked even for short periods.
l) Personnel must be notified of the need for safe working practices, and must also be held responsible for observing these regulations.
m) When working with metal tools in the melting bath, and with the furnace switched on, the tools must be earthed, or the operator must at least wear dry leather gloves. Such work should only be carried out with the furnace switched off. The tools should be warmed up over the bath before immersion, in order to remove any damp or humidity.
n) The formation of bridges must be avoided in order to prevent the unforeseen breakthrough of molten material to the outside. If a bridge has formed, the furnace must be switched off and tilted, so that contact with the melt can be made using a thin handspike. In some cases, the

bridge can be melted with the furnace at low power and in the tilted position, and the furnace then recharged with more material through this opening in the basic position, and then fully melted. After tapping, the crucible must be inspected thoroughly, replaced if necessary and the furnace relined.

o) In the event of a power failure when the furnace contains a full melt, and it is not known how long it will take to correct the problem, the further procedure must be established. There are two options - either to allow the melt to solidify, or to empty the crucible. Depending on the bath temperature, a crucible furnace loses 30 – 50 K/h with the cover closed. For example, at a bath temperature of 1,500 °C, the furnace can be left for up to 4 h without power, and with the cooling switched on, and then slowly be brought back up to temperature. If the shut-down time cannot be estimated after 2 h, the furnace can still be emptied. In the case of a channel furnace, the channel has a somewhat higher temperature loss due to the water-cooled jacket. At 70 K/h, the inductor can be left for up to 2 h without power and with the cooling switched on, and then be started up again at low power. In case of longer interruptions, an inductor should be protected against solidifying with 15 % of its nominal performance. The vessel iron loses a maximum of 30 K/h due to its good insulation.

p) The electrical insulation of the live components against earth is measured with the aid of an earthing relay. If the melt at earth potential approaches the coil, the resistance will fall, and the system may have to be switched off.

q) The Saveway system continually measures the distance between the Saveway electrodes and the melt by means of a special resistance measurement. Depending on the filling level and the indicator sector, the point of damage can be localised to within approx. 600 mm.

r) If work has to be carried out with the furnace in the tilted position, the furnace must be secured against tipping. The furnace must also be secured when pushing out the crucible.

s) Aluminium in pellet form must be available to stop cooking processes.

t) Electrical systems may only be opened and repaired by suitably trained personnel.

u) Induction furnaces may only be operated by trained personnel who are aware of the possible dangers.

The condition of the crucible must be inspected visually, and the remaining wall thickness determined with the aid of measuring devices. An assessment of the average remaining wall thickness can be made from the performance measurement for NF furnaces, or from the frequency display in the case of MF furnaces.

6. Sanitary instructions

Sanitary instructions must conform to the applicable regulations.
In every foundry, the basic safety equipment must be accessible to all employees at all times.

The basic safety equipment consists of:

a) Fire-extinguishing blankets

b) First aid box

c) Eye rinsing / washing equipment

d) Fire-extinguishing beater

e) Dry powder fire extinguishers

f) Wooden ladders, 3 m and 6 m or longer for channel furnaces and large crucible furnaces.

g) Emergency telephone numbers

h) Instruction board for first aid at the workplace in foundries.

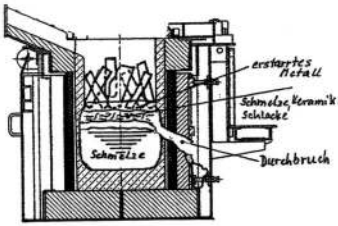
7. Conclusion

In conclusion, we would like to point out that it is impossible to list all the conceivable features of safety training. There is a wide range of different situations, which all require the appropriate action. The above information is provided to the best of our knowledge and belief for the benefit of operating personnel in foundries.

MF melting at 1000 Hz in crucibles with 300 and 1000 kg capacity

The higher the working frequency of crucible furnaces, the closer the process must be monitored and the charging adapted to the melting process. At a frequency of 1000 Hz, the penetration depth of the magnetic field is approx. 17.5 mm, meaning that a thickness of 35 mm could be regarded as ideal for the charge material. Taking the melting process into account however, parts of up to 70 mm in thickness can be used without any problems. Care should be taken on the 1st charging however to ensure that the lengths of these parts do not exceed 40 % of the crucible diameter. When the 1st charging has come up to temperature and settled together, more cold material can be added, depending on the furnace performance. Theoretically, a furnace can melt approx. 2.7 kg per 100 kW of performance in one minute.

2 practical examples are given below:



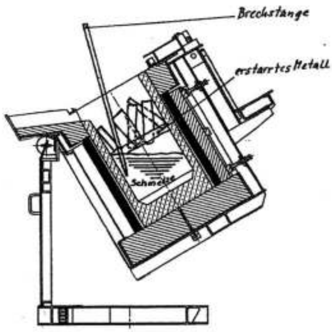
A With breakthrough

300 kg	**Capacity**
300 kW	**Nominal performance**
1000 Hz	**Nominal frequency**
45 dm^3	**Volume of the crucible**
340 mm	**Nominal diameter of the crucible**

With compact scrap with a thickness of 70 mm and a length of 140 mm, the 1st filling has a maximum weight of 80 kg.
After about 4 minutes melting time, the charge settles together, and more cold material can be added. Since the melting performance at 300 kW is approx. 8 kg / min, 8 kg can therefore be recharged every minute. It is not practical to increase the quantity to 25 kg every 3 minutes. If an open melting bath has been formed due to uneven charging, the furnace should under no circumstances be charged with a large piece of compact scrap. Due to the low bath excess height, bath movement and the penetration depth of the 1000 Hz, the bath will solidify at the surface, and the recharged material will not have any heat-conducting contact with the melt.
Since the melting bath at 1000 Hz is significantly better coupled than the solid charge above, the transmission of heat will take place more thermally through contact with the melt than directly buy means of the magnetic field. As a result, the already molten material will be superheated and the crucible wall brought to the point of melting. The resulting mixture of melt, ceramic and slag then leads to formation of a bridge, which allows no heat transmission to the material above the bridge. Continued operation will lead to a breakthrough below the bridge.

The avoidance of a breakthrough is described in the following example.

B With bridge melting



1000 kg	**Capacity**
1000 kW	**Nominal performance**
1000 Hz	**Nominal frequency**
150 dm^3	**Volume of the crucible**
510 mm	**Nominal diameter of the crucible**

With compact scrap with a thickness of 70 mm and a length of 210 mm, the 1st filling has a maximum weight of 240 kg.
Here too the charge settles together after about 4 minutes melting time, and more cold material can be added. At 1,000 kW, the melting rate is approx. 27 kg / min, which can now be recharged. The furnace should only be recharged with enough material so that the operator can still see parts of the molten bath (wet melting). By this means, the formation of a bridge can either be prevented, or at least spotted as soon as it starts to occur. If a bridge is formed, i.e. no melt can be seen, suitable corrective measures can then be taken.

1. **Ensure that there are no personnel in the area in front of the furnace and have a ladle ready.**
2. **Switch off the crucible furnace and tilt the furnace, in order to melt a possible bridge with the surrounding melt.**

If this process proves unsuccessful, an attempt can be made, with the furnace tilted, to break up the bridge or to establish contact with the melt bath using a thin handspike. If this proves impossible, contrary to expectations, the emergency switch for the furnace must be activated with the furnace in the tilted position.
The melting of the bridge is started at approx. 30 % of the nominal performance, in this case 300 kW. In such a case as described above, this is as a rule quite practicable. After a visible melt bath has again been achieved, the furnace is returned to its basic position and the melt bath charged. By this means, the bridge can be melted, and the furnace brought up to its nominal filling level.
Once the nominal filling level has been achieved, the slag produced must be checked for its rough composition and quantity. If there are any variances from the normal slag and slag quantity, the crucible must be measured using a T-measuring device. If the crucible diameter has increased to over 560 mm, the crucible must be cleared and replaced. The new crucible must be prepared and sintered in accordance with the manufacturer's instructions. If molten metal is available, liquid sintering can also be recommended. During normal operation, the crucible should be refilled with cold material and switched on again immediately after tapping. If the furnace is shut down after this charge, various measures must be carried out, depending on the lining materials.

In the case of acidic lining materials, the crucible can be left to cool off with the cover closed, or filled with compact scrap and heated at high performance until the charge starts to settle together. The furnace is then switched off, the cover closed and the furnace left to cool down. The cooling water remains switched on.
In the case of alkaline lining materials, the crucible must be maintained at temperatures above 800 °C. This can be done inductively or using a gas burner. With inductive temperature maintenance, the crucible is filled and maintained at a temperature of 800 °C by means of a thermo-element. When maintaining the temperature, the cooling water supply to the coil must be switched on even during gas operation.
In the case of neutral lining materials, the crucible may, as for acidic lining materials, be left to cool off empty, or filled with scrap, heated up and then be left to cool.
From a cold start with acidic or neutral liming materials, the crucible must always first be heated up to a temperature above 800 °C, and then maintained without liquid metal for at least 30 minutes at a temperature of 1,000 °C at the crucible wall.
Empty crucibles can be pre-heated using gas. When charging scrap into the cold crucible, care must be taken to ensure that no chips or fine pieces of scrap get into the cracks that will still be found in the crucible. To maintain the condition of the cold crucible, it should be charged manually with compact scrap, and then heated up using a suitable performance to over 800 °C over a period of 90 minutes. Manual charging prevents damage to the crucible walls, which due to fine cracks are sensitive to shocks and impacts. This prevents the lining flaking off, dripping and the formation of further cracks. The furnace should then be maintained, without liquid metal, for at least 30 minutes at a temperature of approx. 1,000 °C at the crucible wall. The melting process can then be continued.
The penetration depths of induction and materials thicknesses for iron materials at the most common frequencies are given below for information.

Frequency in Hertz	**Penetration depth in mm**	**Optimum thickness in mm**	**Advisable thickness in mm**	**Max. thickness in mm**
50	78.0	160	320	600
150	45.0	90	180	360
250	38.1	76	152	300
500	24.4	48	96	150
1000	17.5	35	70	100
2000	12.3	24	48	60

For copper, copper alloys and aluminium approx. 50 % of the above thicknesses have been found to be advisable in practice.

The diameter of the crucible furnace should be at least 5 x greater than the optimum thickness of the charge materials.

Witten, date 07. 09. 2003
Herbert H. Netzel

Chapter 2

Accident prevention grills

provide safety for operators against the furnace pit which is revealed when the furnace is tipped. There are 3-sided accident prevention grills which raise themselves automatically to a height of approx. 1 m behind the furnace and inclined toward the front at each side by means of counterbalance weights. A later construction works without counterbalance weights, and instead uses pre-loaded springs, which allow a maximum movement of 1.2 m.

Accumulator

is any device for the storage of energy, such as an electric battery, a pressure vessel in the case of air or a pressure accumulator for hydraulic systems.

Additive

is the term for slag-forming, solid materials which are added when melting metals or for the treatment of melts.

Alitisation

is a surface protection process for steel and certain types of iron for the improvement of the scaling resistance by means of the infusion of aluminium. The aluminium is applied by means of spraying or immersion, and then diffuses into the material by annealing. Material treated in this way becomes resistant to scaling up to approx. 950 °C.

Alloy

is a metallic material consisting of at least 2 elements, produced by alloying during the molten state.

Alloying

is the introduction of alloy components into a molten mass, in order to produce an alloy or to correct or adjust an existing alloy.

Alpaca

is the trade name for the compound also known as German silver or argentan, consisting of 47-60% Cu, 12-25% Ni, up to 2% Pb, and the rest zinc.

Annealed cast iron

is a chill casting made from iron containing 2.4 to 3% carbon, which is annealed (tempered) for up to several days at temperatures above 900 °C. This comes in the form of white and black annealed cast iron. White annealed cast iron is decarburised annealed cast iron with the following composition:
3 to 3.2% C
0.75 to 0.55% Si
max. 0.20% S
max. 0.10% P
Mn=1.7x% S

Black annealed cast iron is non-decarburised annealed cast iron with the following composition:
2.40 to 2.60% C
1.40 to 1.20% Si
max. 0.15% S
max. 0.10% P
Mn= 1.7x% S

Arc furnace

are available with indirect arc heating, as in the graphite rod furnace, and direct arc heating, as in the 3-phase and direct current arc furnace.

Automotive castings

is the designation used for castings for the automotive industry.

Balancing

is required when connecting a 1-phase crucible induction furnace to a 3-phase power supply. Through the use of Steinmetz switching, the 1-phase load is converted into 3-phase of the same size. The power suppliers allow an imbalance of 10% of the highest phase current, depending on the stability of the network. In case of the failure of a balancing choke, a crucible induction furnace can also be operated without balancing devices. It may be necessary to obtain the permission of the power supply company for this imbalanced load at 60% of the nominal current with 2 phases.
The important factor in this method of operation is that the nominal current of the transformer is not exceeded. an example is given below for a 12.5-t furnace with 2,000 V and 2,600 kW nominal output.

1. the balanced phase must be disconnected from the network.
2. the choke must be completely removed.
3. the maximum phase current is determined from the rating plate of the transformer.

4. by slowly increasing the output at 70% of the crucible filling level, the maximum voltage in practice can be determined. If for example at 1,700 V the phase current is over 1,000 A, the next lower step at 1,400 V must be defined as the maximum voltage step, in order not to overload the transformer. The output will then be 1,275 kW and 49% of the nominal output.
   This current is given for the lowest melting stage for constant output. As a rule, the top 5 steps are designed for this purpose, which in this case means at 1,700 V and Step 6 with 930 A.
5. at 1,700 V and 930 A, this gives an output of 1,580 kW, or 60% of the nominal output.

Back-filling

of moulds and crucibles is essential for stability. Crucibles made of SiO_2 compounds or graphite clay are back-filled with quartz sand. Patching compound is applied to the upper edge in order to prevent the back-fill trickling out.

Baled scrap

should be free of water, oils and greases, and without hollow components or organic inclusions. Baled scrap is used in induction and cupola furnaces. The dimensions must be suitable for the furnace dimensions, i.e. the maximum length/diagonal should be no more than 60% of the furnace diameter.

Bath earthing

for safety reasons, the melting bath in a crucible induction furnace should be continually earthed. This earthing is as a rule provided by bottom electrodes. In the case of ceramically lined furnaces, this is no problem. When using crucibles of graphite clay or silicon carbide, a spiral of St 4828 in graphite is embedded beneath the crucible and connected to earth potential outside the furnace housing. Another method is earthing by means of the casting spout, in which is a shackle which is welded on one side to the steel construction. With the 1st casting from a crucible, the molten metal flows over the shackle, and the bath is then earthed via the conducting crucible. Lost tamping forms have as a rule no connection with the bottom electrodes during the sintering charge, since the crucible bottom is tamped 5-10 mm higher than the bottom electrodes. In order to ensure earthing in this case, the earthing between the form and earth can be created with the aid of an earth cable with 2 contact magnets, in the same way as for arc welding.

Bath excess height

occurs in crucible induction furnaces as a result of the potential forces in the melt. According to the law of induction, a conductor with a current flowing through it is subject to a movement force, which in a crucible induction furnace acts vertically to the wall, and thus pushes the melt away from the crucible wall. The melt can only compensate for this force in an upward direction, and this creates the bath cone, which is higher or lower depending on the output and frequency.

Blast furnace

is a shaft furnace for the production of raw iron, a preliminary product of steel.

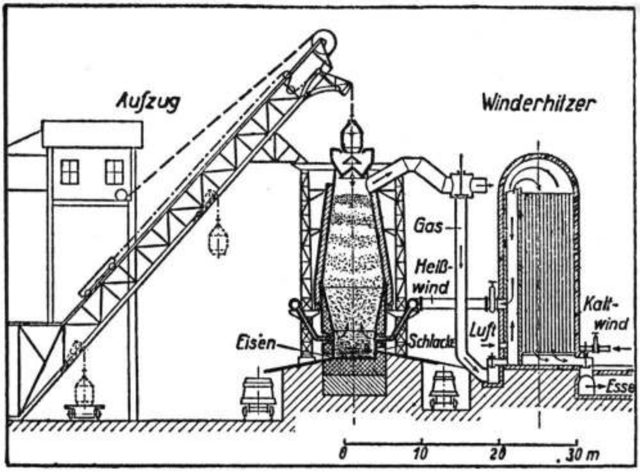


Bild 1. Schematische Darstellung einer Hochofenanlage
Blast furnace

Blasting materials

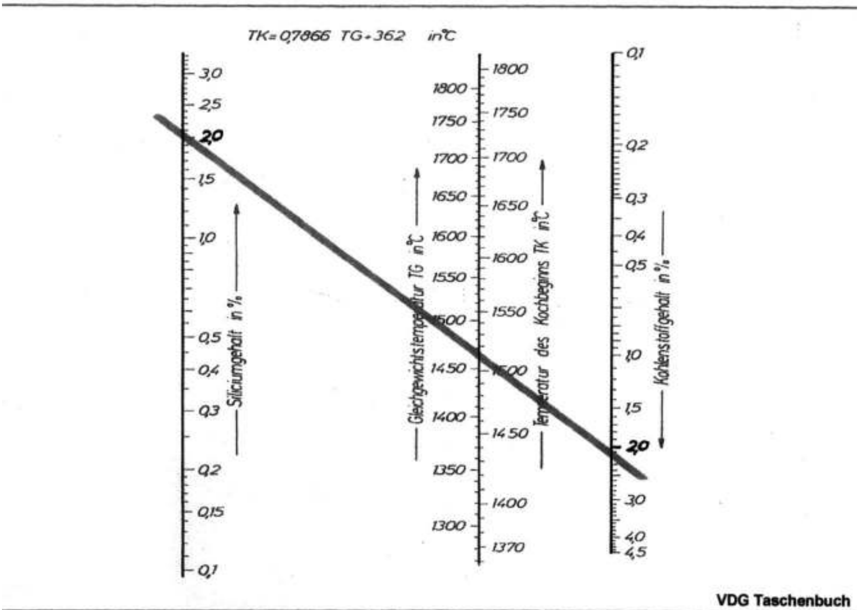
are used for cleaning with granular materials, which are either blown or flung onto the castings or work pieces to be cleaned. These can take the form of metallic blasting materials, non-ferrous blasting materials, or non-metallic blasting materials such as mineral and organic blasting materials consisting of nutshells, fruit kernels or plastics.

Boiling

or retardation of boiling occurs at a certain ratio of silicon to carbon and working temperature. The VDG has carried out and published several investigations on this subject. According to the VDG manual, the start of the boiling process or retardation of boiling will be initiated at a ratio of Si to C of approx. 0.91 or 2% Si and 2.2% C and 1,510 °C. This condition should be avoided if possible, or gone through quickly, since boiling cannot be interrupted or stopped without negative effects on the melt. The addition of aluminium is the worst, yet most efficient solution, if delay can be expected to lead to serious damage. A sudden temperature reduction brought about by the addition of cooling scrap can also be sued successfully without negative effects on the composition of the melt.

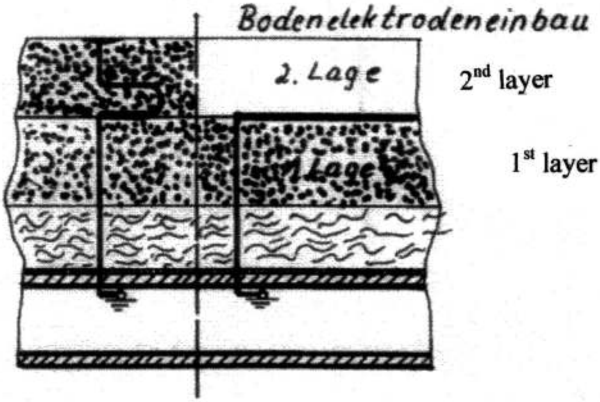
Boiling point

is the temperature at which a material is converted from the fluid state into the gaseous or vapour state.



Leitertafel zur Bestimmung der Gleichgewichtstemperatur

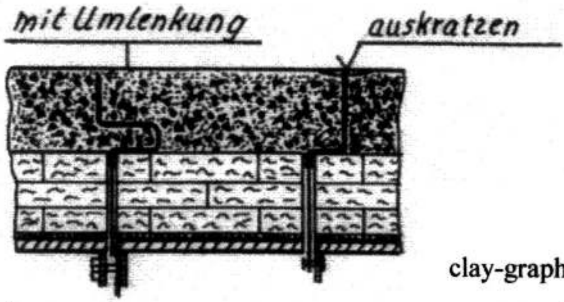
Bottom electrode installation



2nd layer

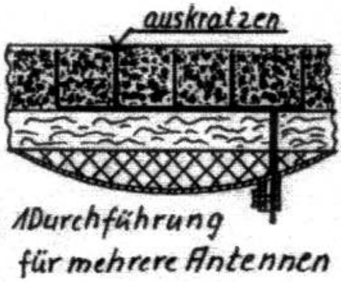
1st layer

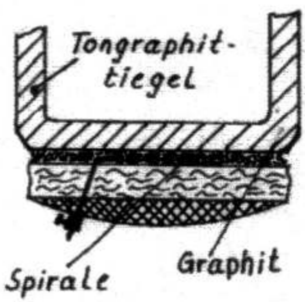
with bend   scratch out



clay-graphite crucible

scratch out





hole for several antennae   spirals   graphite

Bottom Electrode Installation

Bottom electrode installationis carried out in different ways depending on the bottom construction. As a rule, heat-resistant wires from 2 up to a maximum of 5 mm are used. Below the furnace body are 1 – 4 earthing clamps, depending on the size of the furnace.
To allow the crucible to be pushed out, individual wires are usually fed through the concreted furnace body and attached to a ring
below the furnace bottom. 1 pipe 10 mm in diameter and 50 mm in length can be welded to the furnace bottom. An M8 screw is fitted at the side to create an earth contact with the wire. The wire can thus be fed further as it wears away. The bottom electrode wires, which are also referred to as bottom antennae, must be installed in such a way that when the bottom vibrates, there must be no contact between the vibration plate and the wire ends. In the case of 2-layer bottom vibration, the wire can be vibrated in via a guide with a 100 mm offset and a height of approx. 50 mm. In the case of 2-layer bottom vibration, the wires can be bent at the height of the 1st layer with a remaining length of at least the layer height plus 250 mm for the bend parallel to the bottom. The mix for the 1st layer is filled in, ventilated and then compacted with the vibration plate. Before the mix for the 2nd layer is filled in, the 1st layer must be properly keyed in order to ensure good contact with the 1st layer. The antennae wires are now set at the right installation height by means of a bend, and the required mix for the 2nd layer filled in and compacted. Since the wires should always end 5 - 10 mm within the crucible bottom, there is still no "earth contact" in the sinter charge. In order to ensure that an earth contact is created in the sinter charge, the mix must be scratched away at one electrode wire. The position can be established with a magnet or by markings on the coil wall.
In clay-graphite and silicium carbide crucibles, a spiral of heat-resistant steel is placed on the furnace bottom before insertion of the crucible. One end is fed downward through the furnace bottom and then attached to the bottom from the outside. A layer of graphite shale or powder approx. 30 mm thick is now applied to the bottom. The crucible can now be used with turnings. The back-fill mix is now filled in as usual and compacted. By means of this bottom electrode installation, the crucible has a relatively reliable earth connection.

Breakthrough

is the escape of molten metal through the crucible as far as the furnace coil or through the furnace coil into the outer furnace area.

Bridge formation

is a phenomenon that cannot entirely be avoided in induction furnaces. If there is no proper heat-conducting contact between the liquid melt and the material above, the crucible is said to have a bridge. This phenomenon can occur for example due to material becoming jammed above the melt or a ceramic cover over the melt due to superheating and break-up of the ramming mix. To avoid this happening, the furnace should only be recharged with so much material so that a smooth surface can still be seen in the crucible. If a bridge has nevertheless formed, the furnace should be tilted, and the bridge broken up with extreme care. In MF furnaces, the bridge can sometimes be melted at low power. Serious damage and injury to personnel has in the past been caused by the uncontrolled melting and breaking up of the bridge in the basic position.

Bunkers

are supply containers for the storage of bulk materials. In foundries, bunkers are used for holding mould materials, fuels and materials for making up the charge.

Buttons

is the designation for the remaining metal that solidifies in the ladle or the furnace. This is also referred to as ladle or furnace buttons.

Cables

are water-cooled in induction furnaces and used as cooling water return lines. In the case of low performances, cables can also be used as water feed lines. The copper conductors have 35 or 50 mm^2 copper cross-sections. For medium frequency the individual conductors have a paint insulation, although this offers no benefits for mains frequency. The electrical connections can take the form of flat connections or clamp-ring connections.

Calorie

a formerly common unit of measure for heat, with the abbreviation ‘cal’. 1 cal is the amount of heat required, at normal pressure, to increase the temperature of 1 kg of water from 14.5 °C to 15.5 °C. 1,000 cal = 1 kcal. In the international system of weights and measures, the calorie has been replaced by the Joule. 1 cal = 4.1868 J (old conversion ratio, 1kWh = 860 kcal/h for cooling system calculations).

Carbonisation

is essential in the production of cast iron from steel scrap and carbon, since the exact carbon content is very rarely achieved with the metallurgical sample. As a rule, the carbon content must be increased by up to 0.3%.
The induction crucible furnace is very well suited for the carbonisation process. The bath movement, agitating effect and the simultaneous temperature increase produce the optimum results, provided that the following conditions are also

observed. For 0.3% carbonisation, these are 5 minutes agitation time, a temperature increase of 100 K and a bath filling level above the active induction coil of approx. 25% of the coil height for mains frequency (50/60 Hz), and about 5% of the coil height for medium frequency (500 Hz) with the same specific performance. The specific performance for equal bath movement is 300 kW/t for mains frequency, 545 kW/t at 250 Hz and 750 kW/t at 500 Hz.
If in certain cases carbonisation by approx. 0.5% is required, an agitation time of approx. 7 minutes must be provided, in addition to increasing the temperature differential from 100 K to 130 K, in order to achieve reliable dissolution of the carbon in the melt.

For the 3 frequencies specified above, the following furnace sizes and performances can be regarded as ideal:

NF - 50 / 60 Hz	12.5 t - 3,000 kW	9 minutes	for 100 K – 25% over-filling
MF - 250 Hz	5.5 t - 3,000 kW	4 minutes	for 100 K – 25% over-filling
	with 2,400 kW	5 minutes	for 100 K – 20% over-filling
	with 3,000 kW	5 minutes	for 125 K – 25% over-filling
MF - 500 Hz	4.0 t - 3,000 kW	3 minutes	for 100 K – 25% over-filling
	with 1,800 kW	5 minutes	for 100 K – 15% over-filling
	with 3,000 kW	5 minutes	for 166 K – 25% over-filling

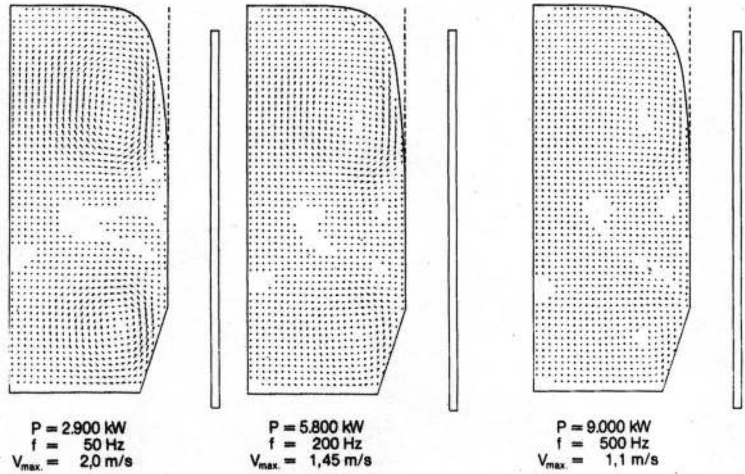


Fig. 13: Amount and direction of the melt flow in a 6 t coreless furnace

2. Correction of chemical composition, carburisation

As described in the section „Batch operation", where the chemical analysis of the charge materials is not known, the melt analysis may have to be corrected by adding alloyants after melt-down; to obviate additional non-productive times, this should be done during the superheating period while the furnace is still full. As is generally known, the addition of ferro-alloys does not give rise to problems, whilst melt carburisation requires that the bath movement regularities described above be taken into account because of the low specific gravity of carbon.

To establish boundary conditions in larger MF melting installations, carburisation tests were run in the IMTK 5 of Messrs. DOVRE, Weelde, Belgium. The furnace has 6 t capacity, 3600 kW rating and 250 Hz rated frequency; it is supported on load cells and connected to the melt processor PRODAPT®-M. Oil coke with 99 % carbon content was used as a carburising agent. The initial melt analysis was: 3.13 to 3.15 % C; 1.81 to 1.97 % Si; 0.49 to 0.52 % Mn; 0.053 to 0.06 % P; 0.056 to 0.06 % S.

Fig. 14 shows the carburising speeds for various bath levels. The object was to verify that the melt can be carburised by 0.3 % in 5 minutes at a minimum bath level corresponding to the coil top edge, when the bath temperature may rise by max. 100 K.

It can be seen from Fig. 14 and **Table 5** that, with a crucible content of about 4 t, namely a bath level about 185 mm below the coil top edge, the carburising speed is significantly higher than the target and, with a crucible content of about 5 t, namely a bath level around the coil top edge, the carburising speed corresponds to the target magnitude. Carbon yield was 90 to 95 %.

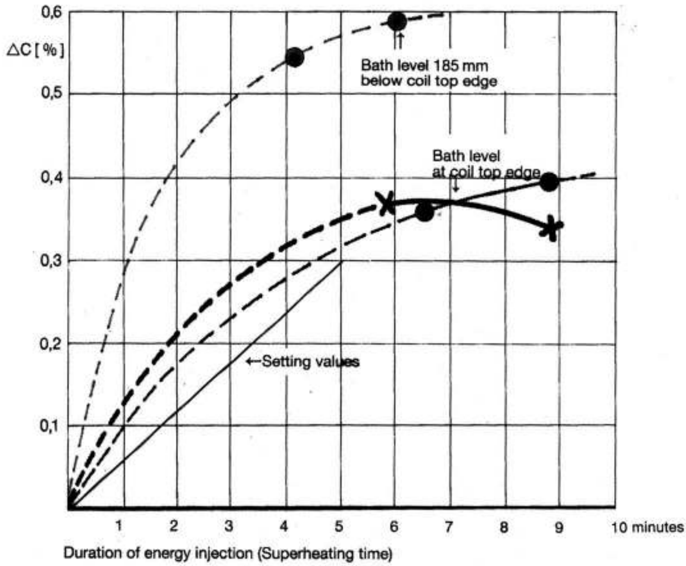


Fig. 14: Carburization velocities in a 6 t induction furnace of 2600 kW and 230 Hz

Test No.	Furnace content kg	Initial temp. °C	Initial C-content %	Carbon added kg	Power/ Frequency kW/Hz	Superh. time min, s	Final temp. °C	Final C-content %	Yield %
1	4.055	1.377	3,14	25	2.550/230	5'40"	1.510	3,72	95
2	4.945	1.395	3,15	20	2.740/230	6'30"	1.500	3,51	90
3	5.035	1.386	3,13	20	2.760/230	5'40"	1.500	3,49	91

Table 5: Test data for establishing the carburising speed

Test result which is confirmed in practical operation [4]: In the MF furnace, the carbon is absorbed at high yield and within „acceptable“ time by the bath even if (see **Fig. 15.**)

- the melt at the bath surface flows from the centre towards the wall,
- there is a visible bath displacement (remainder of a crest) at the crucible wall where the carbon is absorbed in annular intercalations.

Capacity 6,0t/Frequency 250 Hz/Power 2.9 MW

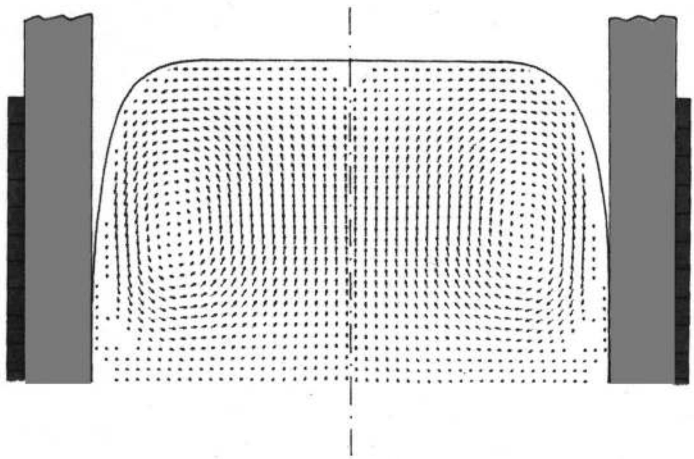


Fig. 15: Melt flow in a coreless induction furnace ITMK 6

From these figures, it can be seen that a mains frequency furnace can be overfilled by approx. 300 mm, a 250 Hz furnace by approx. 220 mm and a 500 Hz furnace with suitable performance by approx. 150 mm.
If a significantly higher specific performance is installed, due to the melting performance per hour required for operation, the metallurgical melting control must be properly set, and when reaching the upper edge of the coil, the required quantity of carbon for the final filling level must be added.
For example, a 5.5 t furnace operating at 4,800 kW has a superheating capacity of 40 K/minute, and thus an agitating time of approx. 2.5 minutes for 100 K. In order to maintain the agitating time of 5 minutes, the temperature difference would have to be 200 K. This value is not realistic in practice. This furnace should be operated at approx. 3,000 kW for about 5 minutes with a temperature difference of 125 K.
movement force, which in an induction crucible furnace acts vertically to the wall, and thus pushes the melt away from the crucible wall. The melt can only compensate for this force in an upward direction, and this creates the bath cone, which is higher or lower depending on the performance and frequency.

Caster

is the general designation for the foundry specialist, and the professional term for foundry workers who perform the casting into the moulds.

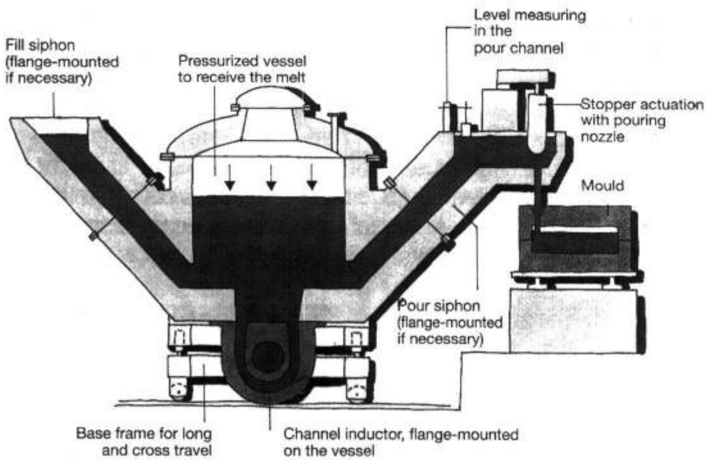


Fig. 1: Pressurized ABB pouring furnace PRESSPOUR®

Possibilities for automatic pouring

Fig.3 shows the commonest solutions used in automatic pouring.

Fig. 3: Tilting ladle, stopper ladle, pressurized pouring system

The tilting ladle represents a pouring process that can also be completed manually. Here, the ladle movement is motorized and integrated into a control system. The problem of melt sloshing when pouring is too fast and a migrating pouring stream remain virtually unchanged with the automated system. The amount that can be supplied is very limited. The ladle has to be constantly changed very rapidly to maintain a continuous pouring process. Batch operation results in the fluctuation of the alloy composition and temperature of the melt, and this has a direct influence on the divergence of the quality of the castings produced.

The same applies to the stopper ladle. The advantages of this pouring system over the tilting ladle is the bottom-pouring principle. The pouring stream does not migrate and it can be conducted into the sprue cup without sloshing, and all pouring points can be reached. Rapid pouring is not a problem. The slag floating on the surface of the melt cannot enter the pouring stream as long as the melt level does not come under a minimum above the nozzle.

The pressurized pouring system unites these advantages, with the levelling of the fluctuations in the alloy composition and temperature. It is characterized by the following features:

- A sufficiently large holding capacity is always available at the pouring line to ensure continuous mould filling.
- Effective insulation and the ability to heat ensures that the temperature can be kept within defined limits during standstills of the mould installation.
- Quantity portioning is reproducible as the unchanging metallostatic pressure does not cause any variation in the flow speed.
- The pouring stream to the mould is short and without severe turbulence.
- Little maintenance and a high availability rate reduce costs.
- The siphon ingate and discharge gate ensure slag separation and provide a closed atmosphere over the melt. This permits the use of inert gas which is particularly advantageous when pouring Mg-treated melts.

Types of pressurized pouring systems

A distinction is made between unheated and heated systems (fig. 4).

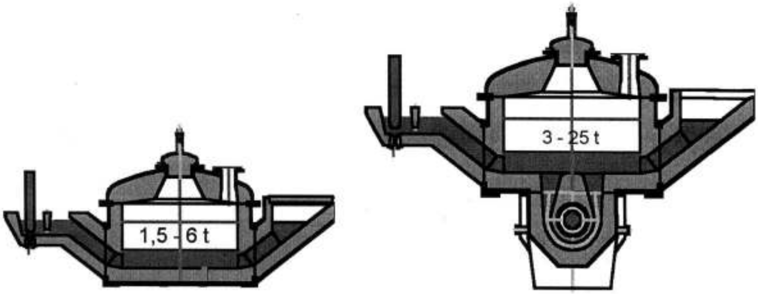
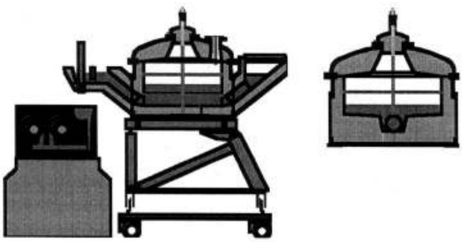


Fig. 4: The unheated Pouromat® System and the heated Presspour® System

The unheated Pouromat® system (Fig. 5) is designed for smaller quantities and rapid alloy changing. A runner in the bottom of the vessel ensures that the residual amount that has to be drained out is minimal because very little heel remains in the vessel.
The flat design means that the system can be set up on a foundry floor without a pit. The frame construction ensures rapid changing of the pressure vessel. The stopper mechanism, pouring level control, inoculating system, etc., are connected to the frame. The time for vessel changing is approx. 1-2 h.



The temperature drop of the melt in the unheated Pouromat® system is limited to max. 1.5 K/min. This is enhanced by the shape of the pouring basin with a very small surface and the pneumatically actuated lid over the filling funnel.

Fig. 5: The unheated Pouromat® pouring system

The heated system PRESSPOUR® is deeper in his design as an inductor is incorporated in the bottom. An channel inductor is standard in this context, but it is also possible to attach a crucible inductor. Filled pouring furnaces with a channel inductor are kept hot during standstills on account of the susceptibility of the inductor refractory lining to cracking. Pouring furnaces fitted with a crucible inductor can stand without melt over the weekend, and they only require a gas burner for preheating.

The pressure gas forces the melt out of the induction heated furnace vessel into the outlet runner, the discharge opening of which can be closed with a stopper. The melt level in the runner is kept constant even if the vessel fill varies. The stopper stroke and the outlet diameter govern the pouring rate, namely the amount of melt flowing out per unit of time.

The furnace can be travelled longitudinally and transversely to the moulding line to suit different pouring positions. A hydraulic tilting mechanism enables the vessel to be emptied completely (**Fig. 2.**).

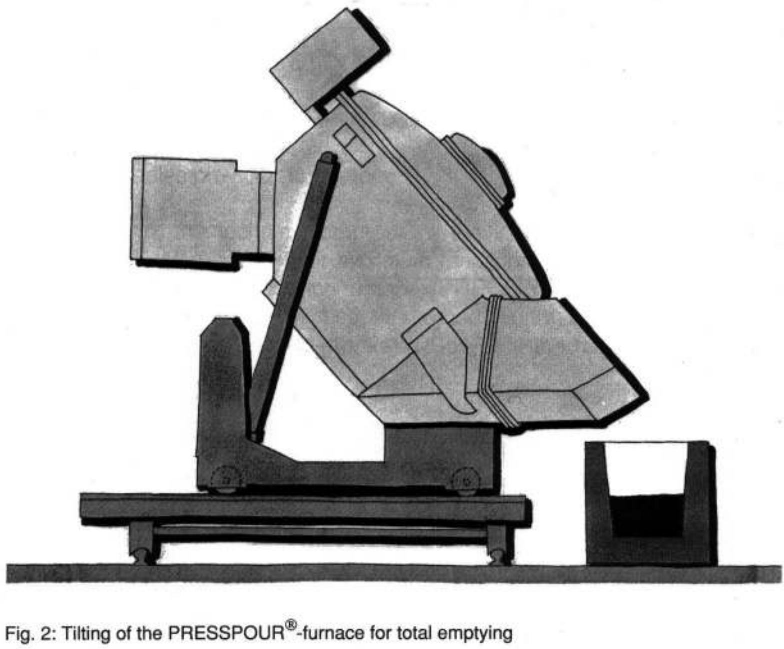


Fig. 2: Tilting of the PRESSPOUR®-furnace for total emptying

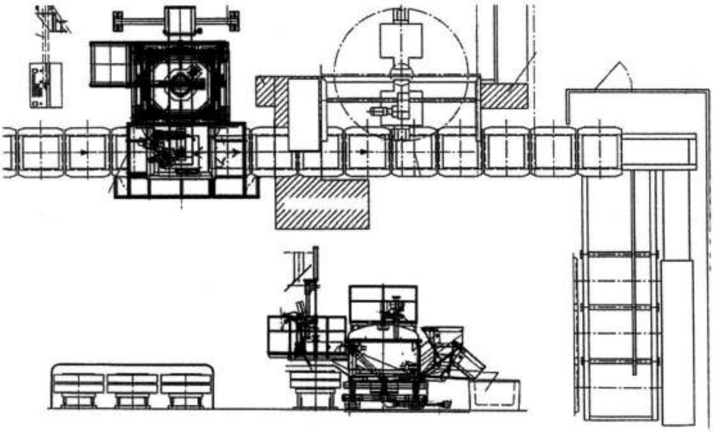


Fig. 1: POUROMAT configuration of the casting line

Increasing casting output

Fig. 2 shows the pouring field with the most frequently adopted casting positions.
As can be seen, positions have to be reached both in the box centre and at the box edge. With the old installation the box centre could not be reached by transverse travel (y-axis travel). This would have required an intermediate ladle with all the resulting additional handling disadvantages and loss of temperature.
To overcome this deficiency a pouring basin with a connecting runner to the actual pouring gate had to be cut, thereby giving rise to all the associated disadvantages such as increased returns and the possibility of flushing in sand and slag. As a result of the two travelling axes of the POUROMAT®, the entire pouring field can be covered with a positioning accuracy of +/- 1.5 mm.

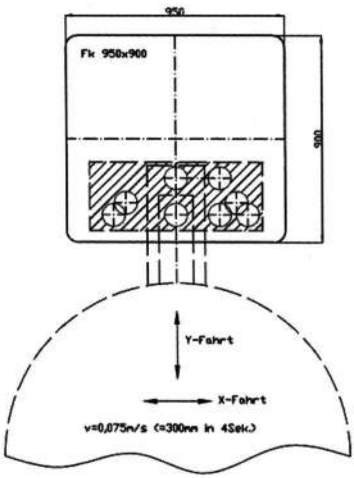


Fig. 2: Pouring field with the most frequently adopted casting positions.

Although travelling to different pouring positions in the mould sequence A/B within a very small time window is difficult, the problem can still be resolved.
As a result of the given model and program structure, position changing and pouring in both the longitudinal (x-axis travel) and transverse (y-axis travel) direction had to be completed in any sequence within the given cycle time.

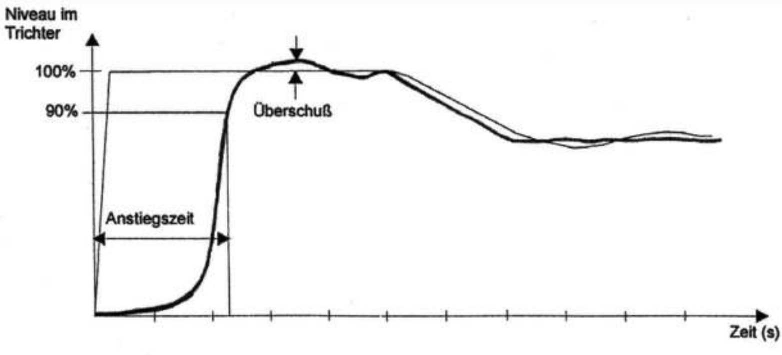


Fig.3. Ideal pouring curve

Within approx. two seconds the height of the base area of the laser measuring channel should be reached. Thereafter the laser takes over level control in the sprue cup. The laser not only detects height changes in the pouring sprue cup but also locates the cup position.

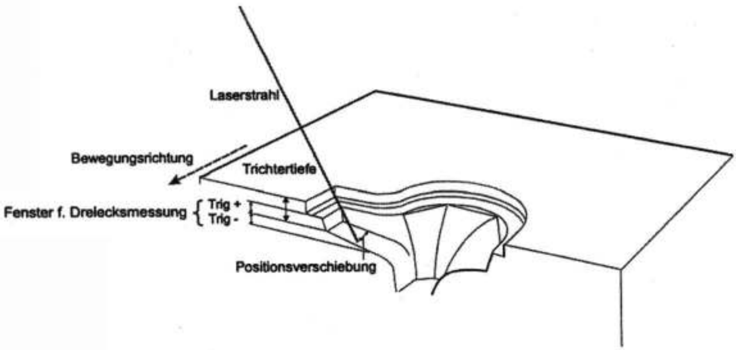


Fig. 4: Design of the Selcom suggested

Fig. 4 shows the basic design of a sprue cup as suggested by Selcom. It is clear that the design of the sprue cup is of fundamental importance for optimized pouring. A narrow flat run promotes output, but this may overtax the capability of the moulding plant to position the moulding boxes, and it may diminish the reactivity of the stopper mechanism.

A deeper run means greater controlling accuracy and thus a lower sprue cup. However, this advantage is lost as a result of the larger opening angle (higher cup weight) for the reflected laser beam.

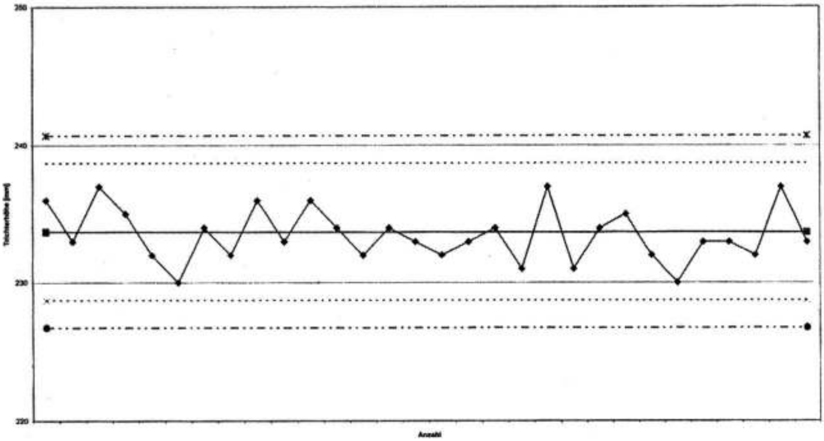


Fig: 7: Measured spone cup hights of 30 pouring sequences (B)

It should be pointed out that the control system can only operate as accurately as is possible with the given framework conditions. Two of these framework conditions, namely the pouring gate and the running and feeding system, have already been mentioned.
Other conditions include the cleanliness and proper functioning of the stopper and brick and contact pins as these are exposed to constant wear and slag incrustation.
These processes are gradual and influence the system in small steps. Early detection of these changes and the implementation of the corresponding corrections depend primarily on the attentiveness and skill of the personnel working at the moulding plant. Regular corrective measures include the cleaning and readjustment of the contact pins and the removal of the incrustations on the stopper and brick.

Temperature consistency

An important point that influenced the decision to operate the POUROMAT® was the conviction that a closed system with the appropriate insulation would guarantee good temperature consistency. The program structure required a temperature window of 1340 to 1380°C.

Figure 8 (lower curve) shows the temperature course during the early shift plotted over the consecutive ladle number of the charging ladle. The runner temperature of the holding furnace is shown (upper curve) for comparison.

Summary

The expectations placed in the POUROMAT® and LASERPOUR® have been fulfilled. Casting output has been significantly increased through level-controlled pouring with precision positioning. System conditioned waiting times and the associated cycle time losses at the moulding plant were almost totally eliminated. The necessary running and gating adaptations as a result of the conversion were quickly implemented by simple means. After almost two years of operation we have found that the POUROMAT® may not have fulfilled all foundryman dreams, but only few remain unfulfilled!

Casting

is the moulding of a material, which is filled into a mould corresponding to the shape of the finished product in the molten state under the force of gravity, centrifugal force or under pressure, where it then solidifies. In general, casting refers to the pouring of the molten casting material into the mould.

Casting compounds

are usually produced on the basis of Al_2O_3 or MgO. Depending on the application, approx. 5 – 11% water is also added. The compaction is carried out in vibration vessels, which are available in the trade with diameters of approx. 15 to 60 mm. The lower the water content during processing, the denser the compound becomes. The drying of the compounds must take place very carefully and very slowly. The recommended temperature increase should be 30 °C/h, followed by a standing time of 30 minutes on reaching 500 °C, which is repeated at every further 100 K while increasing the temperature again by 50 °C/h. The compounds must be heated up to at least 1,000 °C, followed by a standing time of 2 hours. High-performance burners using oxygen reach temperatures of approx. 1,200 °C, in which case a standing time of 1 hour is sufficient.

Casting drum

is a drum ladle with a fireproof cladding, which also has lower temperature losses than with a normal casting ladle due to the lower heat radiation properties.

Casting finishing

refers to the separation of the rough castings from the ingates and feeders, the removal of casting burrs and mould material residues and the cleaning of the castings by treatment with blasting materials.

Cast iron

is an iron-carbon alloy containing at least 2% C and other alloy components, notable silicon. The main types include “grey cast iron” (cast iron with laminar graphite) and cast iron with nodular graphite (nodular cast iron), as well as grey cast iron with vermicular graphite, which all have a grey break surface. Tempered cast iron and hard cast iron solidify with a white appearance, and usually have a white break surface.

Casting materials

that can be efficiently melted in crucible furnaces are listed below, although not in any order of priority:
Grey cast iron, steel, copper, brass, aluminium, zinc, magnesium, gold, platinum, tin and bronze, nickel and silver.

Casting spout

is the term for the outlet of a crucible furnace. The quality of the casting from the crucible furnace is largely influenced by the design, i.e. the shape, length and angle to the crucible.

Casting units

are usually heated, but can more rarely come in unheated versions. Today, casting is less frequently carried out via a stopper direct from the vessel. Instead, the process of casting via a siphon outlet with a stopper has become more popular. Casting equipment is available with capacities ranging from 0.8 t to approx. 20 t. The heating equipment consists of the conventional channel inductor and for special applications also a crucible inductor with a capacity of up to 300 kg. The vessel or boiler has an inlet and outlet siphon, which can be fitted by means of a flange. By increasing the gas pressure above the bath level, the bath level within the vessel is lowered, and it rises in the outlet siphon to the specified casting height, which is also maintained throughout the casting process. The casting process is controlled and regulated with the aid of laser or camera equipment. The ‘teach-in’ principle stores up to 99 predefined and manually initiated casting programmes, which can then be run off box by box.
The total emptying of the vessel is carried out with the aid of hydraulic cylinders through the inlet. Casting units are coupled to the mould system, and in this way are always brought into the correct casting position.

Cavitation

is created by fluids flowing through pipes at high speeds, and containing gas or vapour bubbles, causing wear or erosion to the surface.

Channel furnace

is the term for an induction furnace that is operated with 1 to 4 channel inductors. Channel furnaces are generally used as holding or storage furnaces.

Due to their high efficiency, channel furnaces are also used for the melting of non-ferrous metals and zinc. This principle and design have not however proven popular for grey cast iron. In non-ferrous metal foundries, the double-chamber channel furnace has come into common use. This consists essentially of a channel inductor with 2 flanges, to which are flanged an inlet chamber and a casting chamber. These furnaces have only a low output, which is not suitable for the melting of solid charge materials. For aluminium, higher-performance furnaces are available, which can also melt solid pigs.

Charge

is the material placed in the furnace in order to be melted.

Charge material

is the general term for the material to be melted. An induction furnace is basically suitable for the melting of all electrically conductive materials. The limits are defined by the behaviour and properties of the molten material within the crucible material.

Charging

usually refers to the filling of a casting furnace with the materials to be melted. For small furnaces with a capacity of up to 1 t, charging can be carried out by hand. For larger furnaces, mechanical lifting equipment is used.

Checklist

is the new German expression for the checklist compiled for the performance of specified checking points. In the case of induction furnaces, a distinction is made between the electrical and mechanical components of the furnace. All leading furnace manufacturers have worked out the checklists for the system components separately, or provide the relevant information in the operating instructions.
Fundamentally, cleaning should be carried out every 4 weeks, together with a visual inspection. Special attention must be paid to ensure that there are no leaks in the water or hydraulic systems of the furnace. Repairs must be carried out immediately, in order to avoid unforeseen breakdowns.

Chip melting a

is associated with various difficulties due to the relatively low weight of the chips. Most customers have developed their own processes, which in combination with the available equipment are used quite successfully.The use of “chip briquettes” has not proven popular. The specific density or filling weight is too low for them to be immersed properly in the melt. The briquettes fall apart shortly after contact with the melt, and the chips spread out over the surface of the bath. In the case of channel melting furnaces, some success has been achieved with the use of mechanic stirring systems. Brass melting furnaces with channel inductors are for example equipped with concrete blocks, which cover approx. 80% of the surface, and which are installed by cranes for lowering onto the charged scrap.In crucible induction furnaces, the filling level in the coil should generally be 40%. With dry chips and high specific outputs, the chips can be charged in up to the upper edge of the coil.

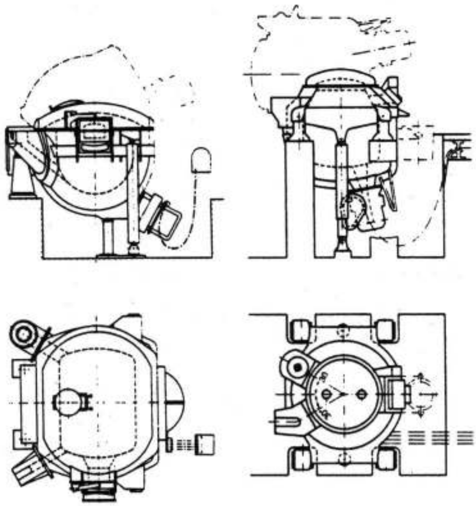


Figure 2: Design of vat-shaped (IRV) and crucible-shaped (IRT) channel-type furnaces

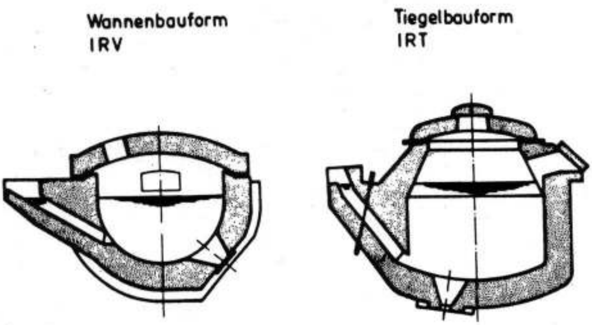
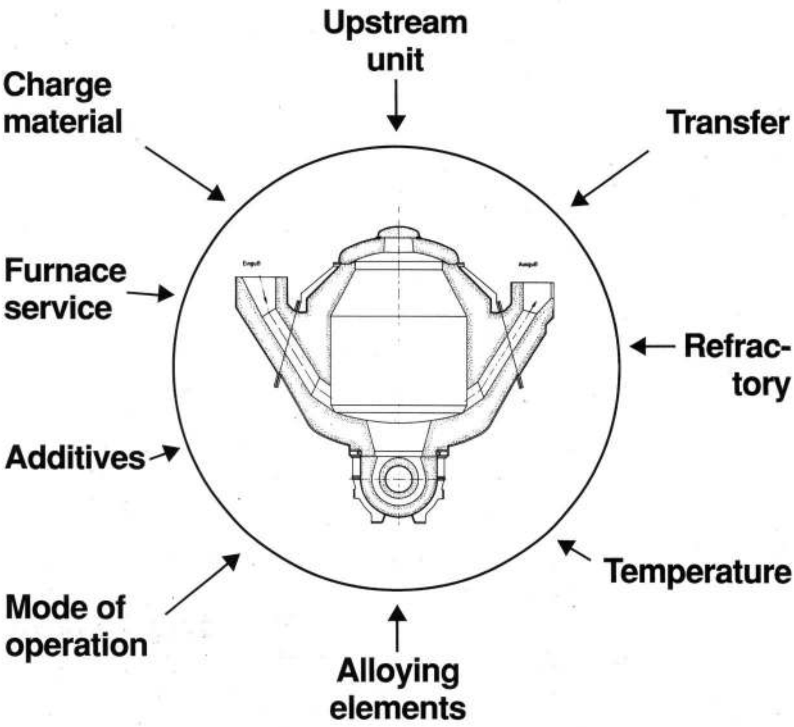


Figure 3: Cross-section through the vessel of a tub-shaped (left) and crucible-shaped channel-type furnace tub shape (IRV) - crucible shape (IRT)

Influences
on the channel furnace



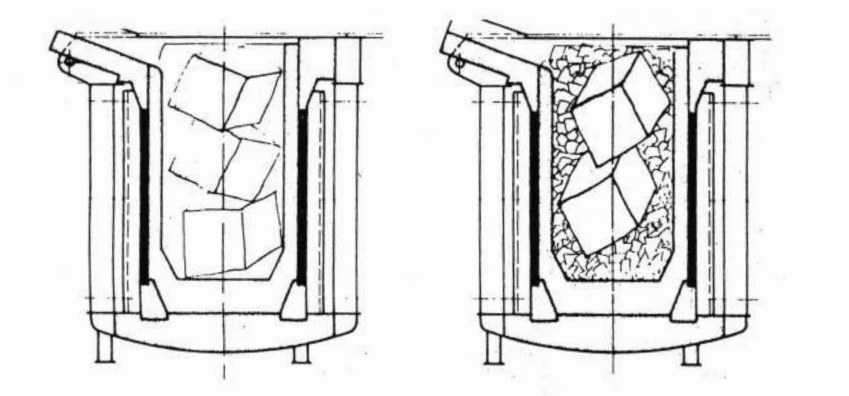


Figure 16: Charging of medium-frequency melting furnaces in charging/melting mode with large sized and bulky charge material

Legend Fig. 16

Cross-sectional diagram a
Cross-sectional diagram b

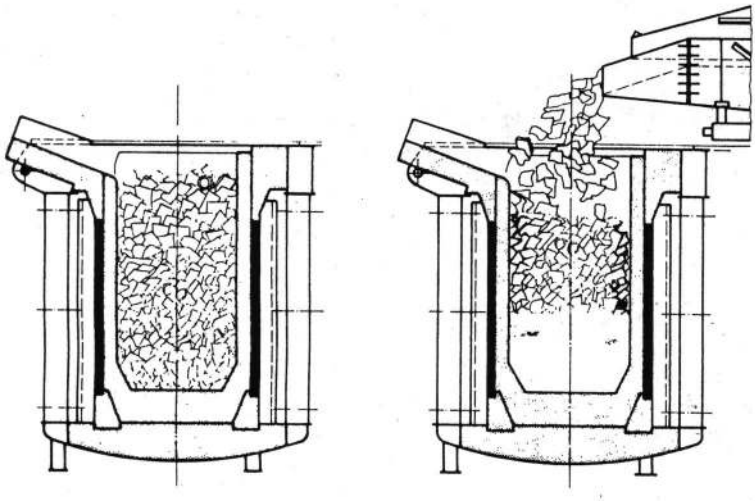


Figure 15: Charging of medium-frequency melting furnaces in charging/melting mode with normal sized and small charge material

Chip melting b

In mains frequency furnaces, melting usually continues until a smooth bath surface appears before recharging. In foundries with medium-frequency furnaces, recharging usually takes place earlier. With this procedure, melting can be continued up to the upper edge of the furnace coil, before bringing the furnace up to the maximum melt level using compact scrap or pigs. With modified outputs and frequencies (240 kW/t for low frequency, 540 kW at 250 Hz and 760 kW at 500 Hz), continually charged chips charged in on top of the molten bath can be melted from approx. 30 to 70% of the filling level. For brass or red cast, and using this process at approx. 330 kW/t and 960 kW furnace output with mains frequency in a 4-t furnace, approx. 1.6 t of chips can be melted in approx. 33 min. An important factor here is that the chips must be fed evenly over the centre of the bath at a rate of approx. 45 to 50 kg/min.
Trials with an 18-t brass-furnace at 3,500 kW have shown that this method of melting works very well up to a rate of approx. 175 kg/min. From approx. 200 kg/min of continuous charging, a ring formed around the crucible wall which could no longer be melted, but had to be brought into the melt manually.

Circuit

is a designation for cast recycling materials from the foundry's own production. These may be sprues, risers or connectors. In some businesses, rejects are incorrectly counted as part of the circuit, although this is not advisable from a commercial standpoint. In the case of rejects, a distinction must be made between direct casting rejects from the mould, casting faults following cleaning, faults following mechanical processing and faults following annealing. With the aid of suitable measures, these individual faults can be minimised, and costs reduced significantly.

Clamping ring screw connection

is best known from the field of high-pressure hydraulics. Use has also been made of this technology in high-tension electrical technology. For current and water connections, copper pipes are used, ranging in size from DN 18 to DN 60. At a size of DN 40, the current to be transmitted is in the order of size of up to 9,000 A. The construction elements consist of Ms 58 and the sealing ring is made of electrolytic copper, which is soft-annealed according to the application. In the case of frequently changed elements for replaceable furnace inserts, the ends of the pipes are made of brass, or sometimes even high-strength special alloys.

Cleaning

is the general term for all work carried out on the rough casting as this comes from the casting mould after cooling.

Cogemikanit

is a trade name for a plate coating material, which is used in induction furnace construction as an electrical insulation and separating agent on the crucible between the wear crucible and the coil plastering.
Plate thicknesses of 0.5 to 2.5 mm can be treated. Above 2.5 mm, the plates are no longer mobile enough, and their application possibilities are therefore limited. There are thicknesses of 0.4; 0.5; 0.6; 0.8; and 1.0 mm on rolls with a width of 1,000 mm and lengths of 10 to 25 m, depending on the thickness.
A special version is Cogemikanit with internal "fly screening" and an outer layer of 0.5 mm micanite for the connection of monitoring systems in crucible furnaces.
Iron piles are insulated against the coil outer jacket with 2 mm of Isoplan and depending on the operating voltage, with 2x 0.5 to 6x 0.5 mm of Cogemikanit at 3,000 volts.

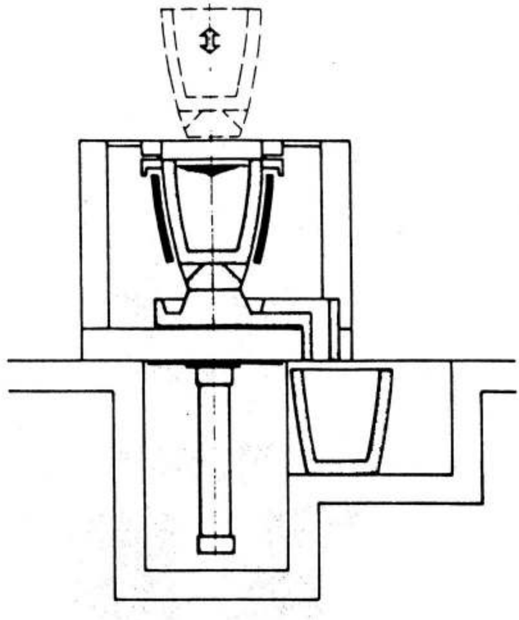


Figure 2: Cross-section through lifting crucible furnace for or 200 kg capacity.

Coil Repair

in the installed condition is only possible in the case of a few furnace manufacturers. This must be an open cage construction, in which the iron piles can if necessary be detached from the outside and moved to the side. The coil jacket is then cut open at the damaged point of the coil. The coil can then be exposed from the inside by removing the coil plastering or smooth coil coating. The damaged intermediate layer insulation is removed, and the defective coil copper cleaned and repaired. After the water pressure test, the intermediate layer insulation is installed, the coil copper painted and the repair spot dried with hot air for approx. 15 min. The plastering can then be applied again. Before lining the crucible, the repair spot should be allowed to dry for 4 to 12 hours, depending on the thickness and density of the coil plastering. The coil jacket is glued back on again from outside, and the cut areas sealed off with glass fibre material. The iron pile or piles are replaced in position and attached using the press-screws.

Coil jacket

is the term for the outer protective cladding of induction furnace coils, consisting of flexible ceramic-organic panels of glass fibre materials. This serves to protect the coil against metallic dusts and spray iron during operation. For safety reasons, no materials or paint coatings may be used that are impermeable to moisture. These would then act as a damp course, which can lead to winding shorts with leakage of water out of the coil. If this water penetrates into the area of the smelt, this can easily cause water vapour explosions, which usually result in the uncontrolled ejection of melt from the furnace and the breakthrough of molten mass through the coil. This can also lead to serious injury to personnel.

Coil short-circuit

is a short-circuit between 2 parallel windings, which can occur due to an insulation fault. If for example there is too much damp or moisture in the area of the intermediate layers due to inadequate drying, the voltage must be reduced to a low level, so that no leak currents can flow. As a rule, such leak currents are only very low, and this will not lead immediately to short-circuits. In the long term however, a dangerous point will be created, which can be further damaged with every new lining. If now in the course of the coil's life, e.g. after 18 months operating time, and under moist weather conditions and formation of condensation on the coil copper, the coil is activated at too high a voltage (> 1,000 V), this can lead to a short-circuit/winding short. The copper of the coil is eroded as in the case of electrode welding, and water can leak out. If the leaking water cannot escape through the intermediate spaces of the coil, the water will penetrate further and further toward the melt, and this will inevitably lead to a water vapour explosion. In order to prevent this, most furnace manufacturers have chosen an open coil construction with water-permeable construction elements. The "packing of the furnace coil" with glass fibre materials and waterproof coatings has in the past often been proven to be an error.
Winding shorts can also occur due to localised over-heating at the inner edges of the intermediate insulation layers. The lightly carburised intermediate layers can retain the moisture very well, thus providing the ideal conditions for a winding short. Accumulations of scrap always occur in the rear area of the furnace coil. This material cannot fall down when the furnace is tipped. Under the effects of the magnetic field, scrap can also collect in the area of the induction coil in the coil jacket, subsequently leading to a winding or earth short. To avoid this, the lower area of the furnace should be cleaned every 4 weeks or vacuumed out with an industrial vacuum cleaner. Under no circumstances should compressed air be used, since this could blow metal parts behind the "core insulation". This will result in an earth short, which can only be located laboriously by checking every iron pile.
If dark areas can be seen on the inner surface of the furnace coil after removing the crucible, this area should be carefully cleaned of plaster and the condition of the intermediate layers checked. This check and any subsequent repair may well avoid unexpected failure with devastating consequences.

Coil grout

is applied in crucible induction furnaces direct to the coil, which is insulated with intermediate layers. This ceramic “coil insulation” is also referred to as the smooth coil plastering. This serves to even out any uneven areas of the coil at the inner coil wall, and as a sliding bearing for the crucible, which is gradually increasing in size. Between the coil plastering and the wear crucible, a separating material of micanite, Isoplan or similar materials is applied as an “insulating layer”. The crucible can slide down the wall as the wall gets colder and upwards as it heats up. If a crucible is operated continuously without any “extended interruptions”, this sliding or separating layer can be dispensed with. In the case of a 3-t furnace and 10 crucible changes per year, this can provide a saving of approx. 1,500 €, or for 20-t furnaces of approx. 5,000 €.

Cold start

is the starting of a crucible following a shut-down. In an NF furnace, starter blocks are required reaching up to 2/3 of the coil height. These blocks are heated inductively and then settle together. At this point, small quantities of scrap can be recharged. After reaching the 2/3 filling level, larger quantities of scrap can be added (5% of the total capacity) and melted. The furnace is brought up to the maximum filling level at approx. 70% of nominal performance. The melt should now be brought up to about 100 K below the normal tapping temperature, and maintained at this temperature for 1 hour. The furnace is then brought up to tapping temperature and the 1^{st} tapping carried out.

Compound alloy

consists of at least three alloy elements.

Compressed air

is air compressed by a compressor, which is used for driving machinery and tools, as well as the energy transmitter for certain pneumatic conveyor systems or for spraying and blowing equipment.

Compressors

are machines for the transport and compression of gases. In pipelines, compressors are used to absorb linear expansion.

Concrete rings

are ceramic construction elements which on installation of the induction coil serve as buttresses and “fixing elements” below and above the induction coil.

The lower concrete ring bears the thermal/mechanical forces of the crucible below the furnace coil. The upper concrete ring serves to hold down the furnace coil, which is "pushed" upward by the thrust forces of the ramming mix. These are made of fire-proof concretes which are resistant up to approx. 1,450 °C.

Condensation

is the transition from the vapour state into the liquid state.

Condensers

are used to compensate for the idling output which occurs with an inductive consumer such as an induction furnace. At 50 Hz, approx. 4.5x the level of the effective output is needed as the condenser output, if the system is being operated at 250 Hz, approx. 7.5x the level needs to be taken into account, and for systems operating at 500 Hz, the figure is approx. 11x the effective output.
500 Hz – 1,000 kW – 11,000 kVar
250 Hz – 1,000 kW – 7,500 kVar
50 Hz – 1,000 kW – 4,500 kVar

Mains frequency condensers are as a rule air-cooled, while medium-frequency condensers from approx. 100 Hz are produced as water-cooled units.

Continuous casting

is used for the production of symmetrical and non-symmetrical solid and hollow castings by means of continuous die-casting. Depending on the direction of withdrawal, these are referred to either as vertical or horizontal die-castings.

Control

refers in general to the checking and monitoring of certain processes. Some of the main types of control include quantity, cost and quality control.

Conversion from low to medium frequency

can be advisable for commercial reasons and reasons of energy policy. Some of the advantages of medium-frequency systems are listed below:
– starter blocks and laborious starting procedures are not required
– no laborious scrap drying or dry storage required
– increased electrical efficiency through charge operation
– melting with higher output and shorter melting times
– improvement of thermal efficiency due to the smaller furnace size
– lowest possible energy consumption with optimum flexibility
– saving of maintenance and repair costs

– increased operating safety
– reduction of the fireproofing costs for the same throughput
– increase in overall economy
– old energy consumption with 13-t furnace with mains frequency, 750 kWh/t (2,800 kW)
– new energy consumption with the same furnace, 640 kWh/t (4,800 kW – 250 Hz)

Converters

are motor generators which produce the required operating frequency via the combination of motor drive with mains frequency and generator. Up until approx. 1970, converters were supplied in horizontal or vertical versions of approx. 30 kW to 3,000 kW. Due to the relatively low efficiency level, the complicated regulation and the repair requirements, converters have been increasingly replaced by static frequency converters.

Cooling towers

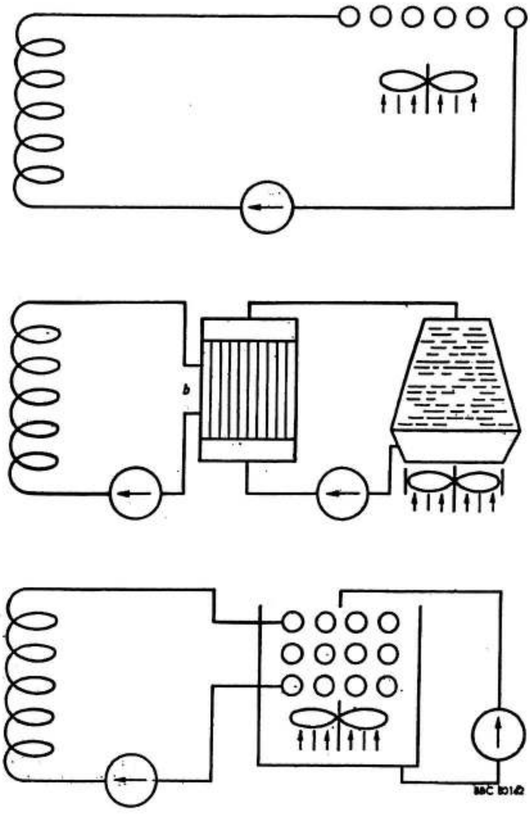


Figure 4-18

Principle of water-air return cooling
a = water-air heat-exchanger
b = trickle-evaporation cooler
c = trickle-evaporation cooler with return cooling

Cooling

is the temperature loss of the crucible when the open is switched off, and when the crucible is usually empty. Acidic crucibles are left to cool off during interruptions in operations. Neutral and alkaline crucibles are as a rule maintained at temperatures above 800 °C.

Coolingdown speed

is specified in Kelvin/sec or Kelvin/min.

Converter for Mg-Iron

are manufactered from some companys. The most known is the G+F-Converter.

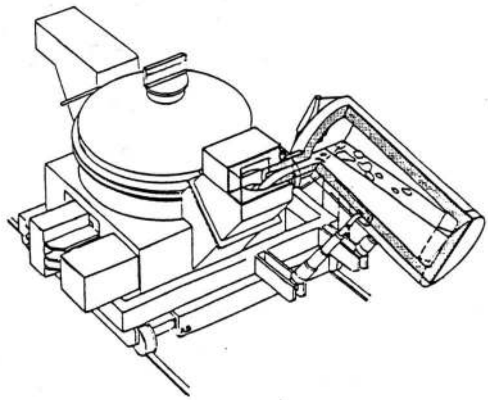


Figure 3: Converter (=transport ladle) in transfer position to casting furnace

Cooling towers

are necessary for the recooling of cooling water heated up by frequency converters and induction furnaces. There are 3 types of cooling towers used in direct combination with induction furnace systems (look pages before).

a) Dry cooling towers, which work like vehicle radiators with cooling vanes and high air volumes, can be used in central and northern Europe. Relevant heating equipment and ventilator covers must be provided for extremely low temperatures. In order to ensure the maximum supply temperature for frequency converters of 34 °C, supplementary coolers are used which operate from the municipal water supply.

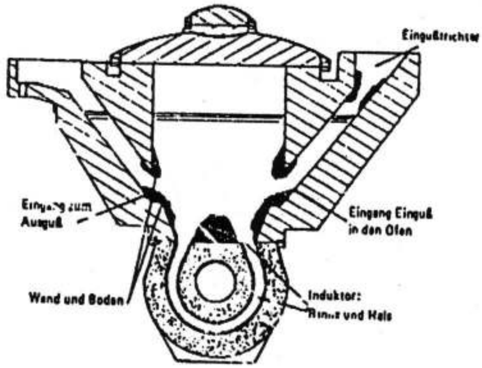


Figure 1: Slag deposit areas in a pressure casting furnace for Mg-treated spheroidal graphite cast iron

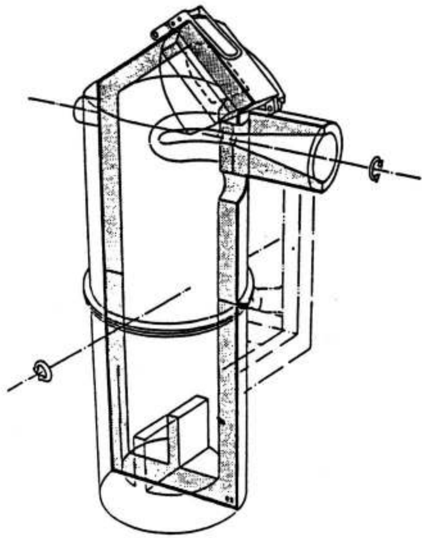


Figure 2: Converter for production of spheroidal graphite cast iron

b) Closed cooling towers, which work like dry cooling towers, but which at air temperatures above the maximum supply temperature also use spray water to provide the required cooling performance.
   These two types of cooling towers are connected directly to the system components to be cooled, for recooling without water/water-exchangers. No water consumption occurs with "a". For "b" however, the water that evaporates must be replaced.
c) Open cooling towers, in which a water/water-exchanger must necessarily be used, have spray nozzles, which atomise all the cooling water and then cool it down by means of the air flow through the tower. This water then cools the system water down to the required supply temperature in the water/water-exchanger. These systems are very efficient, although they do have the disadvantage of "water consumption", which may be up to 5% of the hourly throughflow over a 24-hour period. (look 4 pages before)

Cooling water

is needed to dissipate the heat losses of the furnace coil, caused by the high current and the resistance of the furnace coil, the losses in the iron piles, the short-circuit ring and the thermal losses from the crucible wall. The water is usually obtained from the municipal supply system. Only in the case of very hard water with a very high limescale content is it necessary to resort to boiler water or treated water. The water runs within a closed circuit, and only the "lost water" has to be replaced.

Cooling water hoses

for induction furnace systems are produced using low-carbon rubber compounds with fabric inserts. The firm of Lippmann sells one type under the trade name Protector. ABB has also had a hose developed which is sold under the name ABB INDUCTION FURNACE.

Cooling water monitoring

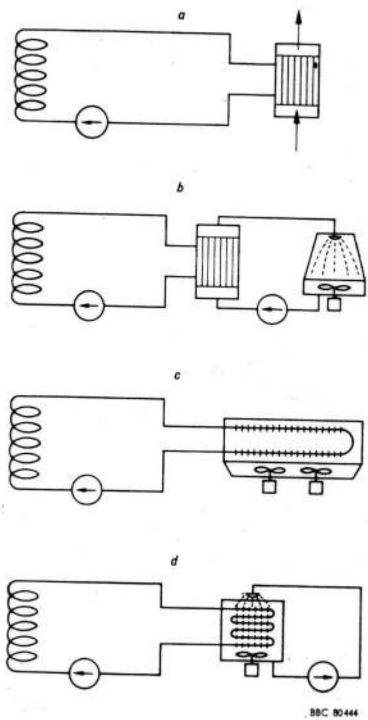
is used in the energy supply systems of induction furnaces and on the induction furnaces themselves. The cooling water volumes and cooling water temperatures in the return limes are monitored. In frequency converter systems, the maximum supply temperature must not exceed 34 °C, and the return temperature should be a maximum of 40 °C. Due to the precipitation of limescale, the maximum return temperature of induction furnaces should not exceed 72 °C.
Formerly, mechanical flow controls were used, which worked by means of counterbalance weights. Since the introduction of electronics however, more and more electronic devices are being used, which have also proven themselves in principle. However, it often happens that these devices indicate a throughflow, but the calculated volume does not correspond to the actual throughflow. The

1. Treated water can be used in the furnace circuit, thereby preventing corrosion damage and deposits of limescale and dirt. There are however no great requirements on the untreated water, which can therefore be cheap.

2. In the intermediate cooling circuit, the temperature level can be set so that it does not fall below that of the surrounding air. This prevents the formation of any condensation throughout the whole piping system, and particularly at all water-cooled components, such as the furnace coil.

   The layout of a cooling circuit with the different methods of water recooling by untreated water and/or air, is shown in Figure 7-14.

Figure 7-14
Layout of cooling circuits; the heat is dissipated by the following methods:
a = untreated water
b = air via the cooling tower
c = air via recooler
d = air via recooling plant



If cheap untreated water is also available, recooling of the furnace water by untreated water may be the most cost-effective solution.

If untreated water is not available, or if the water costs are very high, the cooling of the furnace water will have to be carried out in a water/air-recooler.

display may shut down after a short time, especially in cooling water circuits with high electrical currents.

Cooling water volume

is determined mainly by the electrical output. One can say roughly that approx. 27% of the furnace output and the heat losses from the crucible wall will have to be dissipated. In rough terms, one can reckon on approx. 35% of the furnace output as the total loss performance that must be dissipated.
In the case of a 5-t furnace with 250 Hz and 3,000kW, this gives 1,050 kW or 903,000 kcal/h, that must be dissipated at a temperature difference of 27 K. This gives a cooling water volume of 33.5 m^3/h (33.444 l/h). (kcal/h divided by the temperature difference gives the volume in litres/h).

Cores

are as a rule used for the creation of cavities in casting moulds for the casting to be produced.

Corundum

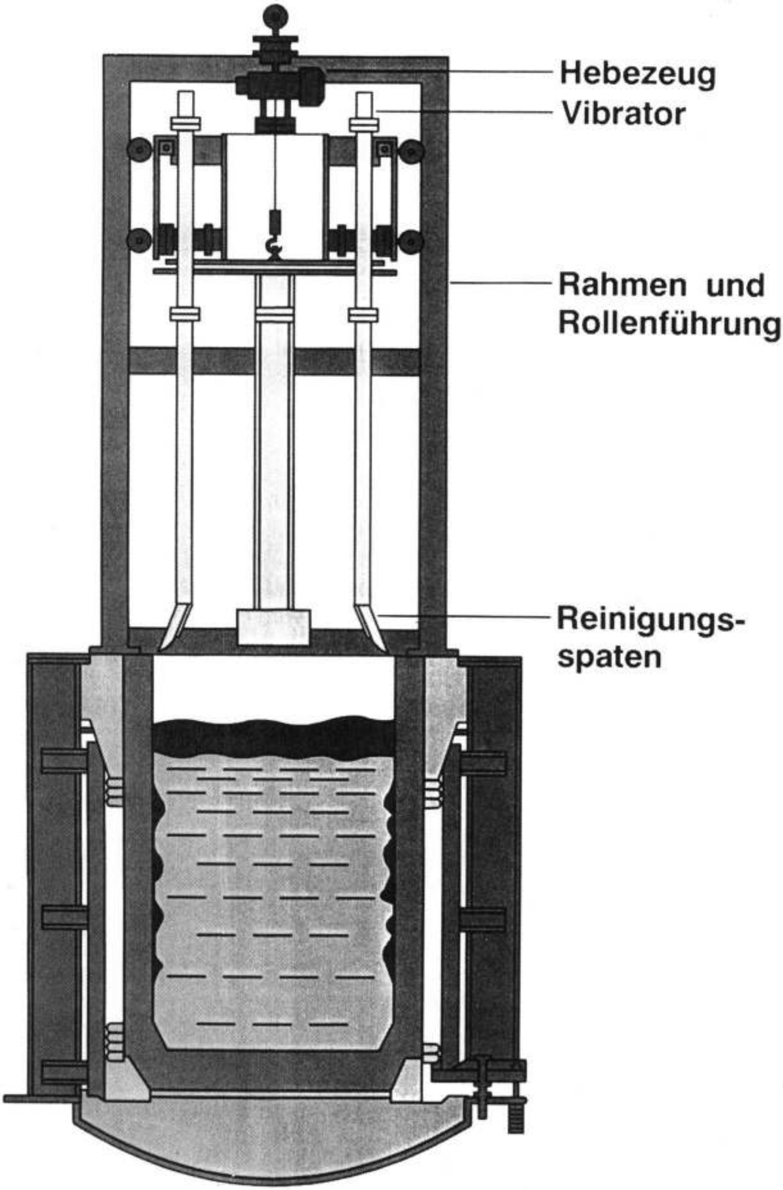
is obtained from bauxite, and has the chemical formula Al_2O_3; this is a crystallised aluminium oxide, which is used as an abrasive agent and fireproof lining material.

Cover drives

for crucible induction furnaces are available in a wide range of versions. Flap covers or sliding covers are normally operated by means of differential cylinders and chains. If cover hoods are being used, the drive takes the form of 2 differential cylinders.
Swivel covers are driven via a curved roller and guide cylinder by means of a vertically acting plunger cylinder. The lowering takes place under the own weight of the cover and the piston rod. In case of certain special requirements, a small differential cylinder can also be used.

Cover extraction hood

is a combination of an internal cover, fitted with an extraction hood enclosing the cover. This type of extraction has proven itself well in practice, and is used almost exclusively for high-output furnaces. The hood can be adapted to meet the corresponding requirements by means of set opening angles, and can for example remove all the smoke during charging. Another option is the fitting of this extraction system with automatically opening slots in the frontal area for smoke extraction directly in front of the crucible furnace during the production of nodular graphite iron.



Tiegelreinigungsgerät

Crucible cleaning equipment

Cover extraction rings

are mostly used only for smaller furnaces. This type of extraction uses a conical ring with extraction slots, which is ceramically cladded on the crucible side. The attachment to the furnace cover takes the form of wedges. Adequate extraction performance is provided when the cover is closed or raised by approx. 200 mm. The emission of smoke cannot however be avoided when the cover is opened for charging.

Crucibles

up to approx. 1.5-t capacity are made of graphite clay or silicon carbide, and in the case of metal crucibles, of cast iron, cast steel, steel plate and plated steel plate. These crucibles are used in metal foundries for non-ferrous metals. Acidic crucibles with capacities of up to 13 t are made from SiO_2 material. The crucibles are rapped in in special moulds with the addition of binding agents, and after being allowed to cool in air are dried in drying furnaces, or even pre-sintered so that they can be transported by road or rail. These crucibles are “fixed” with back-fill compound after being installed in the furnace, patched at the upper edge, and then sintered in the same way as a normally lined crucible. The working life of such crucibles is comparable to that of conventionally lined crucibles.

Crucible cleaning equipment

is used for scraping off and cleaning of ceramic crucibles in aluminium crucible melting furnaces. This consists of a device with 3 or 4 shovels, which if necessary can be operated individually under pneumatic power like a compressed air hammer. After the 1st downward stroke, the shovels are moved upward, rotated through the specified angle and then lowered 2 – 5 times to clean the crucible. About 300 mm of aluminium are left in the crucible, so that the residue can then be removed from the furnace with the aid of a modified “slag excavator”. This work must be carried out with the crucible still in the warm, operating condition, since if the crucible is too cold, not only will the dross be removed, but the crucible wall can also be severely damaged. Mechanical milling devices have not proven effective in this application.
(look 1 page before)

Crucible induction furnace

is the term for a furnace containing a crucible, which is heated by an induction furnace coil surrounding the crucible. There are crucible induction melting furnaces and crucible induction holding furnaces, which differ mainly in their nominal output. The same design of furnace can be operated at different voltages as a melting, storage and holding furnace. In the case of furnaces of the same design, the furnace connection voltage is the definitive factor in determining the nominal output.

Crucible inductor

is a relatively small crucible furnace, which has a flange above the upper concrete ring for attachment to the actual furnace. When used as holding equipment, these crucible inductors have a crucible diameter of approx. 500 mm and a crucible height of approx. 750 mm. The capacity is thus approx. 1,000 kg with an output of 300 to 500 kW. The largest crucible inductor furnace constructed has a total capacity of approx. 100 tonnes including the crucible inductor with 6.6 tonnes for grey cast iron, and approx. 38 tonnes of aluminium in total. The diameter of the crucible is 950 mm and the height 1,400 mm. The installed output is 2,300 kW.

Crucible furnaces

have crucibles heated from the outside, and can be designed for heating by induction, fuels or resistance. The best known type of crucible furnace is the crucible induction furnace.

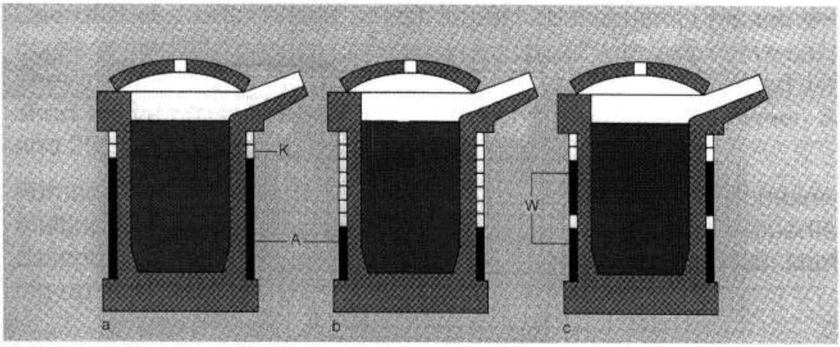
Crucible edge extraction

is arranged in a similar way to cover ring extraction with a conical ring, although this is set at a greater distance from the cover than the ring of the crucible edge extraction system. This functions well when the cover is closed. However, when the cover is swung to the side, the extraction effect is largely cancelled out, and the smoke is not extracted adequately.

Crucible measurement

is a laborious procedure, which requires much preparation and preliminary work, even when installing the coil. The centre of the crucible must be able to be determined accurately by means of 3 or 4 fixed points on the furnace platform. When installing the furnace coil, the coil must be installed exactly at this central point. Markings must be applied to the vertical plumb fitted in the centre of the coil at vertical spacing of 100 or 150 mm. The distance between the centre and the coil wall is now determined and documented in four directions. When installing and aligning the lining template, the exact centre, i.e. the distance from the plumb and the tamping template, must also be maintained and documented if necessary. After furnace operation, and the first cooling down of the tamping compound to approx. 40 °C, the crucible can then be measured accurately. This method also allows the identification of any lateral, excentric erosion of the tamping compound .A simpler method, which however does not allow the identification of excentric erosion, is the use of an excentric T-beam. The shorter T-beam is welded to a holding rod at a distance of 1/3 : 2/3. The short T-beam is the measuring beam, which can be produced in 4 different lengths, or adjusted to different lengths by means of screw bolts. This gives firstly the nominal dimension and then the enlarged diameters in steps of 10-15 mm. With this measurement method, the crucible diameter can be checked immediately after total emptying.

Nominal dimensions for 12.5-t furnace
Coil diameter 1,470 mm
Crucible diameter 1,190 mm
Total wall 140 mm
min. remaining wall 95 mm
i.e. max. crucible diameter 1,280 mm
Measuring beam max. 1,260 mm
Holding rod = furnace depth + 1 m



K Cooling coil
A Active coul
W Active/cooling coil

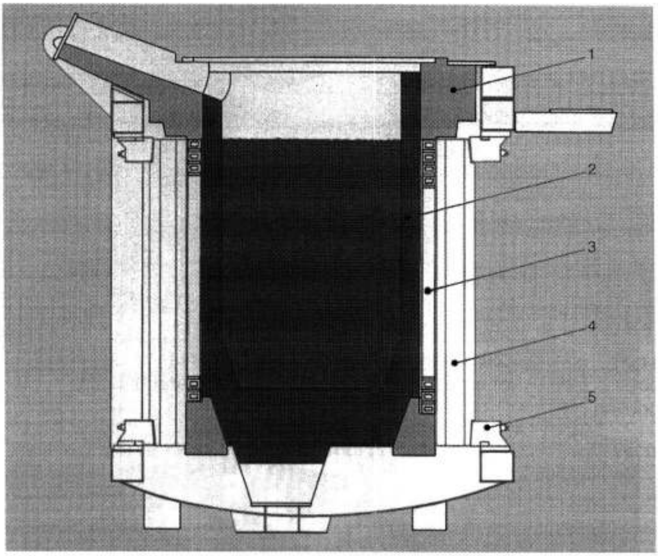
Coil arrangement for coreless furnaces for melting ()a), holding (b), and melt-and-hold (c)

Fig. 8: Various types of a coreless holding furnace with different coil arrangements

Crucible lining

The refractory lining of a coreless holding furnace normally comprises a dry SiO_2 mass, as in the case of coreless melting furnaces. This material is highly resistant to temperature fluctuations, so that even large coreless furnaces can be cooled to ambient temperature when empty and then restarted without causing any significant damage to the refractory lining.

In the case of a continuous coil, such as that shown in Fig. 9 for a modern MF coreless holding furnace, the fact that the crucible is cooled over its full height has a favourable effect on the service life of the refractory lining and thus permits a very much longer service life than in the case of conventional short-coil coreless furnaces.



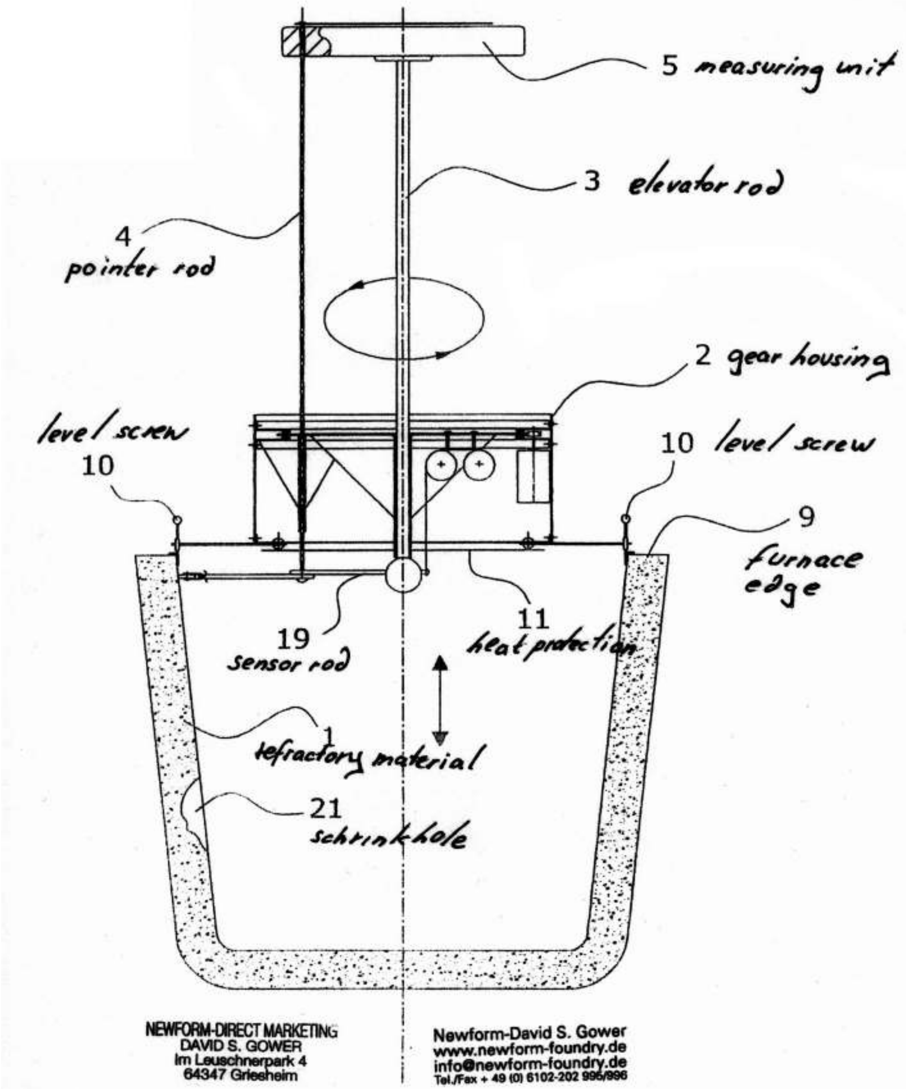
1 Top and bottom concrete ring
2 Refractory crucible
3 Induction coil
4 Laminated cores
5 Top and bottom core support

Fig. 9: Medium-frequency coreless furnace of type IFM as holding unit

Modern power supply with frequency converter technology

The criteria to be considered when selecting the operating frequency of a coreless holding furnace are the same as for a coreless melting furnace, namely improving the power absorption through the variable frequency on the one hand, and the bath movement generated by inductive power transmission on the other.

One of the advantages of supplying an induction furnace with power via a static frequency converter is that the frequency adjusts to the load circuit automatically. In the case of a partly filled coil, the frequency of the load-switched anti-resonant converter drops to around 55% of the nominal frequency and the induced power increases accordingly. In this way, the full power is transmitted to the bath by a continuous active coil even at a low bath level.



crucible measuring

Furnace Design

Out of necessity a rather unique design evolved which has a large vessel or upper case without a power coil, similar to a channel furnace.
The actual powered part is a relatively small coreless furnace mounted underneath. **Fig. 1.** shows this so called coreless inductor furnace.

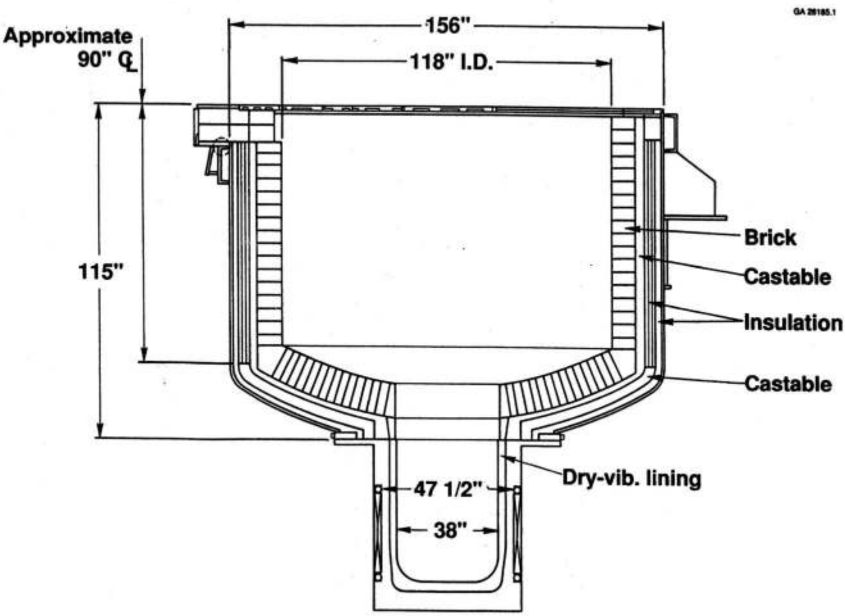


Fig. 1: Coreless inductor furnace

Fig. 3 shows the calculated metal flow in the furnace as caused by the inductive energy transfer. In indicates the typical double „Figure 8“ pattern in the coreless inductor and its extension into the upper case with an additional vortex just below the bath surface.

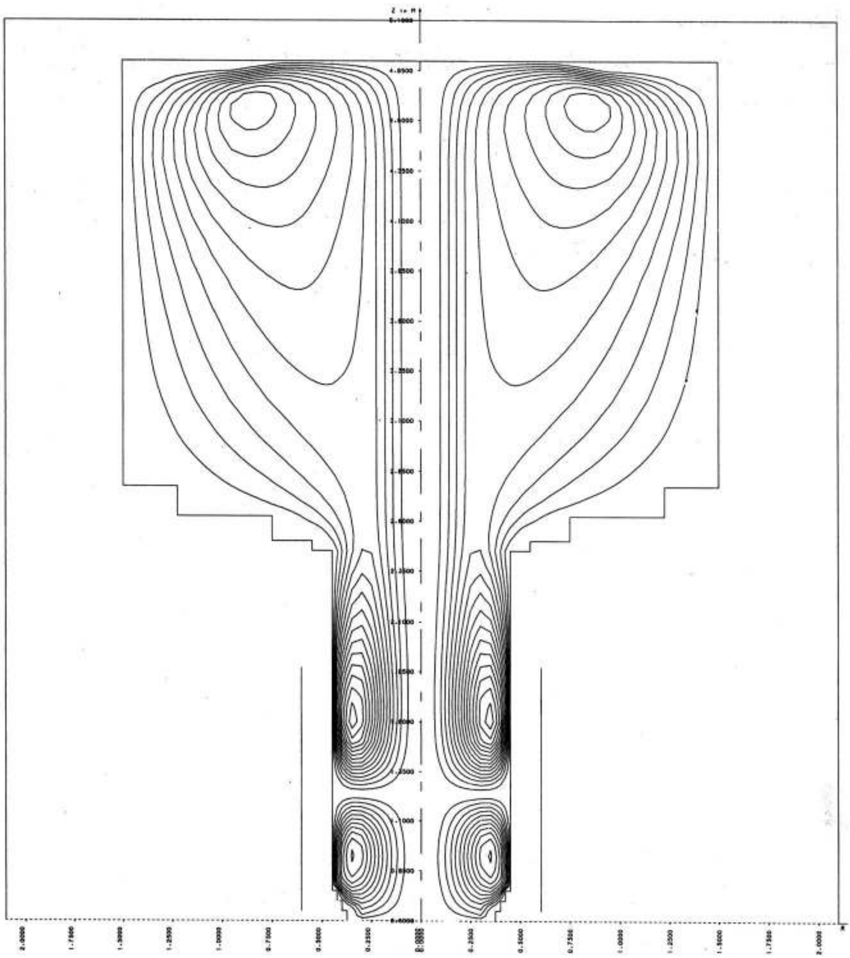


Fig. 3: Calculated metal flow

Crucible monitoring

is a crucial task of the insulation monitor. This device measures the insulation resistance between parts carrying voltage and other components connected to the earth potential. The measurement is made possible by direct voltage. The firm of Saveway has developed a system for continual crucible monitoring without measuring the insulation of the system. Here, the "thermally" influenced resistance of the compounds is measured between measuring anodes on the "outer wall" of the wear crucible, see Saveway.

Crucible push – out – device

is a device for removing the wear crucible from the crucible furnace. Due to the contraction of the crucible in the cold condition and the conicity of approx. 0.8%, this can be done with hydraulic cylinders with different pressure surfaces and strokes. In order to prevent possible difficulties, the crucible should be "loosened by hand" in the area of the casting spout. If the crucible cannot be removed due to too little contraction, the crucible must be slit from bottom to top to a width of about 100 mm. Slitting from bottom to top has 2 advantages over working from top to bottom: 1. when starting in the lower cone area, the work is not carried out directly against the coil, and 2. during further caulking toward the top the work is carried out against the existing hole and later against the slit. This minimises the risk of damage to the coil. The position is opposite to the casting spout. The crucible is started out at a force of up to 200 kp/cm^2 and the further removal at 30 – 60 kp/cm^2, depending on the crucible size, without damage to the coil.

Crucible storage furnaces

are in principle designed in the same way as crucible melting furnaces. Depending on their particular application however, they are equipped with significantly better heat insulation and sometimes also an induction coil, split into sections. In the case of a 50% division, both coils will for example have an output of 3,000 kW. When both coils are switched in series, the total output is only 1,500 kW. Crucible storage furnaces have the advantage that in the event of problems, stoppages or other interruptions, they can be completely emptied. Due to the low specific output, it is advisable to sinter crucible storage furnaces with molten iron.

Crucible wear

occurs due to the enormous temperature stress on the fireproof lining and the mechanical abrasion during charging. As a rule, crucible furnaces are designed so that they can stand wear to the wall of approx. 30% of the total nominal wall thickness. However, since this wear does not usually occur evenly over the wall surface, measurements of the crucible must be carried out from time to time. In the case of premature wear, this is referred to as an “elephant’s foot”, which can occur more frequently with mains frequency systems than with medium-frequency systems. This wear can be continually monitored with the aid of the “Saveway” system described above.

A three-dimensional framework of the furnace inner surface is created with, typically, 100000 points being scanned within 10 s. The built-in industrial PC evaluates the residual refractory thickness by comparing it with a previous reference measurement.

Manipulator. At EBW the laser manipulator, **figure 2,** is installed on the off-gas extractor, it essentially comprises an arm with two guides and a cooled box to accommodate the laser scanner. An electrical motor enables the manipulator to traverse at high speed, so as to minimise the overall time taken for the measuring procedure. Additional cooling systems permit unlimited measurement, even at extremely high furnace temperatures.

Application equipment. The Minscan system installed at Buderus in 1996 proved unable to meet the new requirement of gunning fully automatically on the basis of the LaCam measurements. A much faster equipment with very smooth movements was required. Furthermore a co-ordinating system was needed in the gunning head for finding the correct position in the furnace. The new equipment makes it possible to apply gunning and fettling material in a precise, efficient, safe and rapid manner using the new Ar speedometer system.

The head can perform a continuous 360° rotational movement and a simultaneous vertical movement from the centre to the upper edge of the furnace panels. Inside the head is a special new eccentric jet mixing nozzle to moisten the material completely at high speed (420 kg/min). The new cooling technique ensures that the maintenance operation remains continuous without any temperature restriction, **figure 3.**

Refractory products. The new system is capable of applying gunning and dry bottom material at very high rates (420 kg/min) under both hot and cold conditions. These materials are specially engineered for improved flowability, wettability and plasticity. The unique particle sizing and binder package allows outstanding adhesion to the furnace substrate, thus improving on-wall density and minimising rebound. As a result, material durability is increased which, in turn, reduces maintenance operations and increases furnace availability.

The chemical composition of the MgO bottom construction material M-Frit KK, and the repair material M-Frit has been developed in such a way that there is an exact balance between fusion behaviour and adhesive strength.

Quantum gunning material is used to maintain and repair the slag zone. It has been successfully redesigned for fully automatic shot gunning using the Ar speedometer system. The result is a much higher application rate allowing up to 150 mm thickness per layer. The use of pure MgO sources and the synthetic additives guarantees resistance against hot erosion and slag attack and leads to extremely high material durability. The binder system does not contain any phosphate, such that the phosphorus content in the steel is not affected.

Interface between laser and manipulator. The Scantrol interface module transforms the measurement data from the laser scanner in such a way that this information is evaluated, and then a maintenance strategy is derived to control the robot maintenance unit.

Evaluation. Figure 4 shows a flowchart for the process. The operator at the EAF initiates the measuring procedure.

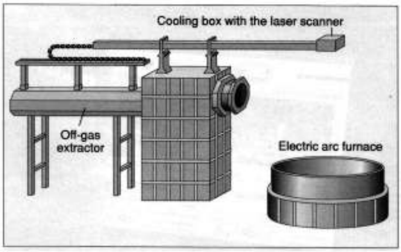


Fig. 2. Schematic diagram of the LaCam manipulator unit
Bild 2. Schematische Darstellung des Laser-Manipulators

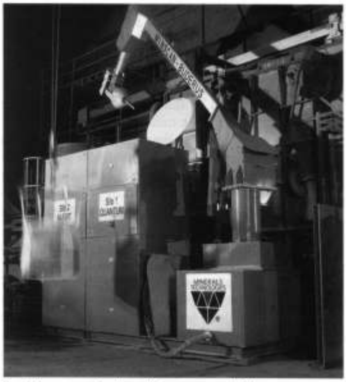


Fig. 3. The new robotic maintenance unit Minscan
Bild 3. Die neue Minscan-Einheit

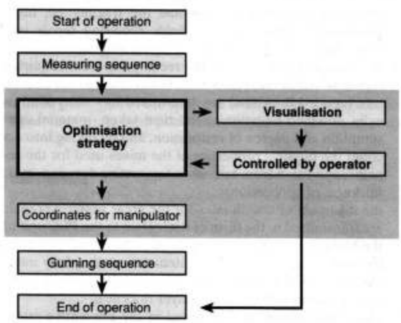


Fig. 4. Scantrol process (schematic)
Bild 4. Der Scantrol-Prozess

Crucible withdrawal device

were developed in order to circumvent the patent for the crucible removal device. In this case an approx 20 mm thick steel plate with a 30 – 50 mm hole is inserted centrally below the crucible. To withdraw the crucible, a hole is then drilled in the crucible bottom, a rod fed through the hole from inside the crucible, and the rod fixed in place below the withdrawal plate by means of a nut or wedge. The crucible is then withdrawn with the aid of a crane, although the crab must not be in the centre of the jib when lifting, since this method of working is not without risk. When applying a lifting force of approx. 10 t, the crucible is released suddenly, and the weight of the crucible now hanging from the crane hook is in this example only 3 t. This procedure with the sudden change of load can cause the crane to "buck".

Crucible working life

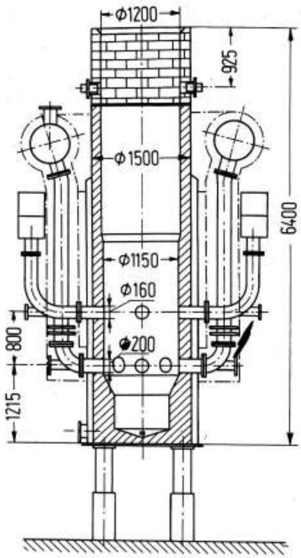
is usually specified in terms of throughput, number of charges or working days. Depending on the working methods used, e.g. 1-, 2- or 3-shift operation, the crucible working life will vary greatly. Very high casting temperatures above 1,600 °C reduce the working life by approx. 30% in comparison to the same furnace operated at 1,540 °C.

Cupola furnace

is a foundry shaft furnace for the melting of cast iron. The metal charge (raw iron, scrap and recycled materials) is melted with the addition of slag-forming additives, limestone and coke as energy transmitters. The combustion air (known as wind) is compressed by a blower, and blown into the furnace shaft through nozzles. These are categorised into cold wind or hot wind cupola furnaces, depending on whether the combustion air is cold or heated.

Cokeless cupola furnace

The Flaven furnace can be regarded as a forerunner of the cokeless cupola furnace, and consisted of a combination of shaft and hearth furnace. Figure 39 shows the design of the system. It can be seen that the charging column, which is normally supported by the coke bed, rests on a water-cooled grill. The bars of the grill are fitted above the burner level, so that the molten iron dripping down falls through the grill into the collector basin. The combustion takes place in a burner sleeve outside the furnace, so that the hot gases give off their heat to the charge on their way through the furnace shaft. Since there is no glowing coke bed to take care of the over-heating zone, an over-heating bed of nodular fireproof material must be built up on the water-cooled grill.
According to W. Sachs, the consumption of fireproof nodules comes to 30 to 50 kg/t of charge materials, which must continually be added with the charge to maintain a height of about 500 to 700 mm as the over-heating zone. No adhesion must occur in the fireproof bed or on the grill.



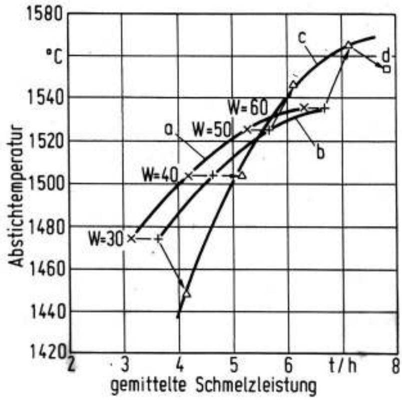


Figure 33. Furnace with secondary row of nozzles

Figure 34. Iron temperature in relation to wind volume and added oil, coke percentage = 10% a without oil, b 50-60 l oil / h, c 90 l oil / h, d 120 l oil / h

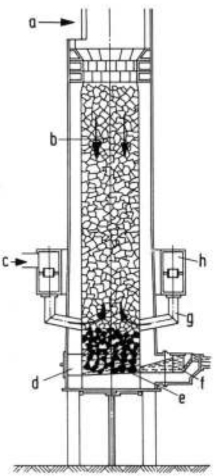
Supplementary oil firing

Attempts have also been made to apply the favourable experiences obtained with blast furnaces with supplementary oil firing to the cupola furnace. The oil must be burnt before entry into the oven shaft, i.e. while still outside the cupola furnace. The useful effect also depends on the arrangement of the burners. If the nozzle level is selected, the effect is usually weaker in comparison to feeding in at a higher level. The known trials do not allow any concrete conclusions in this respect, such as for supplementary natural gas firing; however, one can certainly work on comparable assumptions.
In further investigations, the burners were fitted at the nozzle level

Figure 34 shows that at an oil consumption of 90 l / h, corresponding to 13 l / t, a temperature maximum is reached; if the oil supply is increased further, the temperature starts to decline again. The temperature gain in comparison with 0% addition of oil was 30 °C with 10% coke.
90 l of heating oil (74 kg of oil) with a calorific value of 35,169 kJ/l corresponds to a calorific value of 3,181,968 kJ.
106 kg of coke with a calorific value of 30,124 kJ/kg also corresponds to a calorific value of 3,161,968 kJ.
In relation to a melting performance of 6.5 t/h, this gives an equivalent coke quantity of 1.6%.
It thus follows that 74 kg of oil corresponds to 106 kg of coke. 1 kg ……….

In the case of an unlined cupola furnace, the shaft is not cladded with fireproof lining, and the jacket is cooled from the outside by flowing water.
The firm of Dücker has developed a cokeless cupola furnace, in which the carbonisation is carried out in a preliminary heater inductively heated by a channel inductor. This preliminary heater is known as a "flow heater".

A cupola furnace shown in operating condition, showing the quantity of the descending charge. This consists essentially of the fuel component (coke) and the metal charge, which is melted drop by drop by the energy released from the combustion of the coke, and then rolls down over the glowing coke to collect in the bottom of the furnace. The energy required for melting is only generated in the cupola furnace itself. The melting is therefore subject to all the fluctuations of the combustion processes, which are caused for example by different coke quantities and properties, wind volume and temperature, and air humidity.



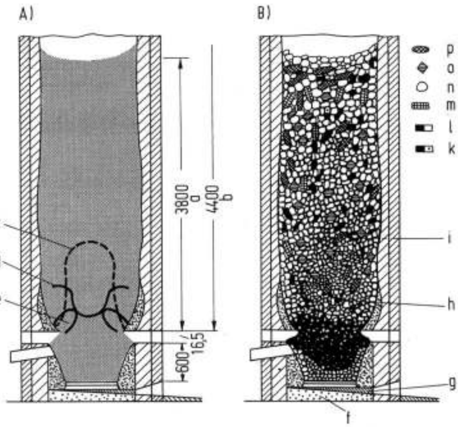


Bild 5.

Bild 4.

Figure 4. Shaft furnace principle
a Feeding of the charge, b Charge (iron, coke and limestone), c Blower, d Inlet opening, e Coke bed, f Siphon, g Nozzles, h Wind ring

Figure 5. Section through a water-quenched cupola furnace; diameter at nozzle level 1,200 mm

A) Combustion and melting zones
B) Position of the metallic charge components
a Filling height, b Distance to lower edge of throat opening, c Limit line of coke combustion, d Penetration depth on non-molten iron, e Zones of strong coke combustion, f Sand floor, g Metal, h Slag and metal, i Original filling height, k Steel (inner), l Steel (outer), m Rail pieces, n Coke, o Cast iron scrap, p Raw iron

The coke used as the energy transmitter also serves simultaneously as the supporting column for the charge. The lower part of the shaft is filled with white-hot coke, which on contact with the drops of molten iron gives off carbon and sulphur to the iron, and has a reducing effect on contact with the slag oxides. As a ballast material, the coke has an ash content of 9 to 10%, which because of its high proportion of SiO_2 (40-50%) is referred to as acidic working. The remaining components are 27 to 40% Al_2O_3, 8 to 14% Fe_2O_3, 4% CaO and 2.5% MgO. Acidic working, which is caused not just by the coke ash, but mainly by the burn-out of the lining and the silicon loss, is .....

..... which was also apparent in the increase of FeO and MnO in the slag. The reduced dust production brought about by natural gas substitution falls within the already explained relationship of the dust production to the coke component (Figure 35).

In the same way, a reduction occurs in the sulphur absorption, together with lower sulphur release via the waste gas (Figure 38).

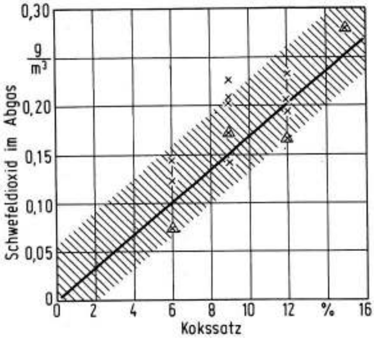


Bild 38.

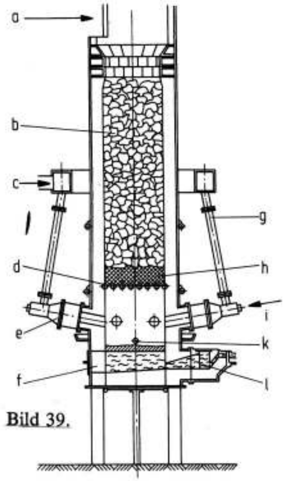


Bild 39.

Figure 38. Sulphur dioxide content of the waste gas in relation to the coke proportion
x Mean daily values, Δ Mean daily value for optimum melting

Figure 39. Cokeless cupola furnace
a Feeding of the charge, b Charge (iron and limestone), c Blower, d Water-cooled grill, e Burner, f Inlet opening, g Wind pipe, h Ceramic nodules, i Fuel, k Carbonisation, l Siphon

Curie point

is the temperature at which the metallic material is converted from the ferromagnetic state into the non-magnetic state.
Some examples are: Iron, 769 °C and Nickel, 320 °C.

Current

in electrical technology is measured in Amperes, or A for short. As defined by Ohm's law, 1 Ampere is the current which is caused to flow through an Ohm resistance of 1 Ohm by a voltage of 1 Volt.

Current density

is the physical value for current divided by the cross-sectional surface area. The unit of measure is A/mm^2. With mains frequency, air-cooled current rails have a maximum of 2 A/mm^2, and with medium frequency up to 500 Hz approx. 1 A/mm^2. If the electrical conductor is surrounded by flowing water, as in water-cooled cables, a maximum of 16 A/mm^2 will be available in this application. Because of the line losses, the length must also be taken into account in addition to the cross-section. double the length with the same cross-section also means double the losses. A 5 m long cable with 600 mm^2 copper cross-section has losses of 13.7 kW at 9,600 A of transmitted current, so the losses in a 10 m cable will be 27.4 kW. If the furnace has 2 cables, the losses will therefore be 27.4 kW at a length of 5 m and 54.8 kW with a 10 m cable length. This application example applies to a furnace with an output of 2,150 kW at 1,000 V. The reduction of the current density, in this case from 16 A/mm^2 to 10.67 A/mm^2 thus produces losses of 18.2 kW and 36.4 kW.

Current distribution

via parallel conductors requires "bridges" at separating distances or phases of 2 – 3 m in order to reduce the line losses. If the rail length between the condenser bank and the wall-side furnace connection is 3 m, such a phase bridge should be used here in the area of the transition point. Bridging should also be used for longer rail lengths and also current pipes. In the area of switches for switching off or over, the rail guide must run without any branching for at least 1 m in front of and behind the switch. Lateral outlets should be avoided at high-tension switches, since the current takes the path of least resistance. If for example both outlets are to the same side, the poles on the other side will be subjected to less load than those in the area of the current supply and off-take.

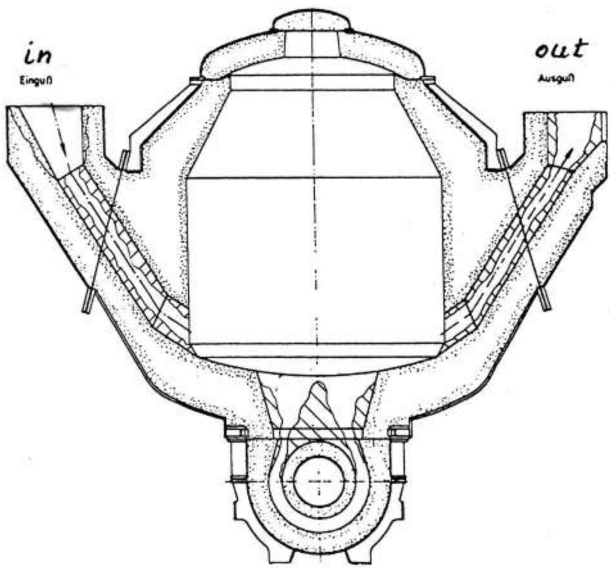
Cyclone

is a centrifugal force separator used in dust extraction systems.

Decay

refers to the loss of alloy elements. The loss of magnesium content during storage and casting of nodular cast iron in larger containers is the most frequent application of the term decay.

Oxides in deposits	Origin of oxides
Al_2O_3	Refractory, steel scrap
MgO	e. g. GGG-foundry returns
Sio_2	Refractories, alloyants, charge material, moulding sand residues
CaO	Alloyants; limestone for cupolas
FeO, Fe_2O_3	Rust, charge material
Rare earths	Alloyants



Deoxidisation

is the removal of oxygen from the melt, i.e. the reduction of the oxides present in the melt.

Desulphurisation

partial or more thorough removal of sulphur from metal melts, e.g. with the aid of calcium carbide, lime or soda for cast iron. Good desulphurisation is a primary requirement in the production of cast iron from nodular graphite.

Differential cylinders

are "dual-acting" cylinders, i.e. both ends can be subjected to pressure in order to carry out movements. These cylinders can also be installed in the horizontal position.

Diluting

is the reduction of the carbon content of an iron melt from a cupola furnace, a raw iron melt or a melt removed from a holding furnace by approx. 30% of the original carbon content by means of the addition of low-carbon content steel scrap.

Diodes

are non-controllable semi-conductor components, which are used in frequency converters in the area of the rectifiers with low and high outputs, i.e. flowing currents.

Drill conductors

See Roebel (transposed) conductor.

Dualtrak

is the designation for 2-furnace operation from an electrical energy supply of the firm of Inductotherm, Simmerath.

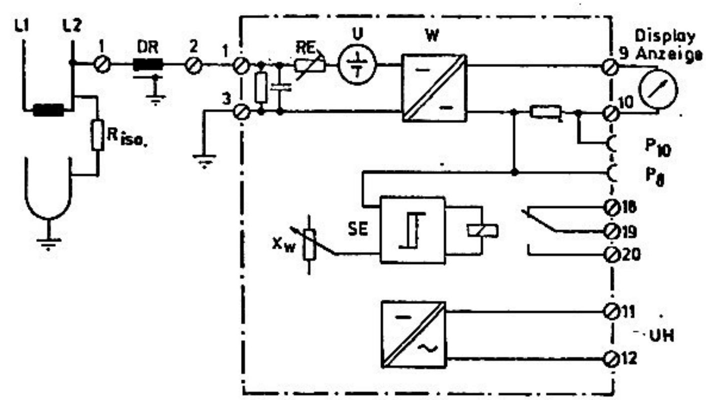
Duomelt

is the designation of the firm of Junker, Lammersdorf, for a 2-furnace operation from an electrical energy supply with electronic switches (look next page).

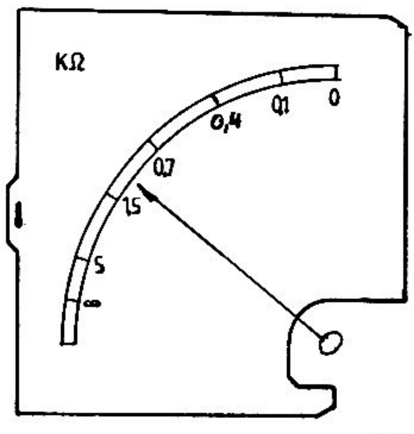
Duplex operation

refers to melting in a furnace with the additional of already molten material, e.g. from a cupola furnace, or the mixing of cupola furnace or blast furnace iron.

Anschluß-Schaltbild



earth resistance measurement



R_{iso}	0	0,1	0,7	1,5	5	10	20	100	∞
I_m	20	17,43	10,30	7,14	3,93	3,02	2,52	2,1	2,0
α	90°	78,44	46,35	32,13	17,69	13,59	11,31	9,45	9°

Dust extraction

is the cleaning of the exhaust air, the dust-laden extraction filters and the hot gases in industrial operations and foundries.

Earth shorting

is an insulation fault between construction elements carrying voltage and those connected to earth or the melting bath earthed by means of the bottom electrodes.

Earth shorting insulation test

is restricted as a rule to the area of the furnace and there mainly to the immediate area of the furnace coil. The first thing to do is check the function of the earth shorting indicator with a 500 Ohm resistance, which is installed in the measurement line. In order to establish whether the earth short lies between the melt and the coil, a significantly higher resistance value must be displayed after disconnecting the bottom electrodes. If the earth short is still present with the same value, the short must lie outside the furnace coil. In a dark furnace area, the short may even be visible to the naked eye. If the short lies in the area of the supply lines or the power supply, this might also be visible in dark working areas. In mains frequency systems, earth shorts often occur in the area of the starter resistors. One “rough method” is a check using a bridged insulation detector, the earthed neutral point of the transformer using a 25 or 35 A fuse. This method can even be used over a longer period to arrive at an audible diagnosis, e.g. in the balancing choke or between an iron pile and the coil.

Efficiency

describes the relationship between the net and gross output. For 1 t of grey cast iron, approx. 370 kWh of energy are required. In a crucible furnace, between 470 and 540 kWh/t are required, depending on the construction features and capacity of the furnace. This corresponds to an efficiency level of between 0.79 and 0.69. Due to the optimum design of a furnace with regard to its heat losses and economical dimensions, this gives a ratio of 1.13:1 between active induction coil length and coil diameter. The purely electrical efficiency level depends on the coil length or height. With the same crucible capacity and same electrical output, this can be explained by means of 3 versions of a 13-t crucible furnace. The crucible wall thickness is in this case 140 mm. If one considers the magnetic field and the lines of flux in a completely molten furnace, there is a transverse field at the upper and lower end of the coil, and a longitudinal field in the centre of the coil. At the same electrical output, the sectors of the transverse fields are of equal length, i.e. with a coil length of approx. 1,300 mm there are transverse fields each of approx. 300 mm at top and bottom, and a 700 mm longitudinal field in the centre. These assumptions give an efficiency level of approx. 75%. If the coil length, for the same crucible capacity within the coil of 10 t, is changed, this gives, in the case of a reduction to approx. 1100 mm coil length, a transverse field at top and bottom of 300 mm each and a longitudinal field of 500 mm, resulting in a theoretical electrical efficiency level of approx. 69%. In case of the extension of the coil to a height of 1,700 mm, this would give a longitudinal field of approx. 1,100 mm and an electrical efficiency level of approx. 81%.

Effective output

is the product of the coil voltage multiplied by the effective current flowing through the furnace coil, given in kW.
At 1,000 kW effective output and 250 Hz operating frequency, this gives a condenser output of approx. 7,500 kVar as the idle output. The rail output in this case comes to approx. 7,570 kVA.

Emission

refers to the expulsion of jets, gases or materials, e.g. dust emission from a cupola furnace.

Energy / Energy consumption

is the designation for the product of performance (output) x time, and is specified in kWh. In melting, the concept of "energy consumption" per tonne of melted material is usually of interest. Here however, a distinction must be made between theory and practice. In the case of high-output casting furnaces, the theoretical consumption is between 510 to 540 kWh per tonne of molten iron. Practical experience however shows that a more accurate figure is 585 to 640 kWh/tonne. If a crucible furnace is operated as a "melting machine" with optimum charging, extraction and process control, energy consumptions of 560 kWh/tonne and tapping temperatures of 1,550 °C can be achieved.

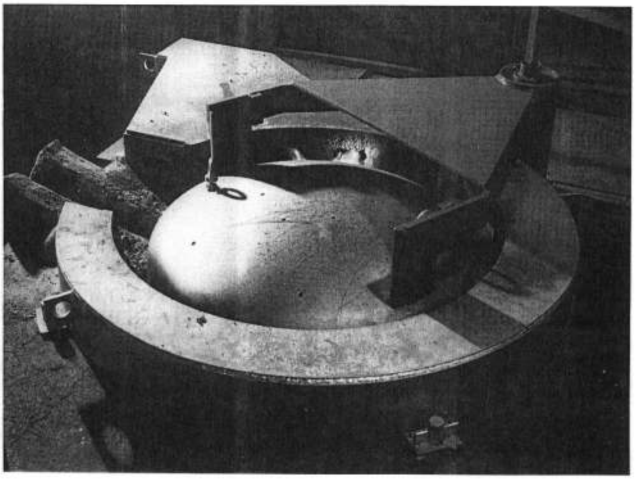


Bild 7: MF-Ind.-Tiegelofen mit Tiegelrandabsaugung

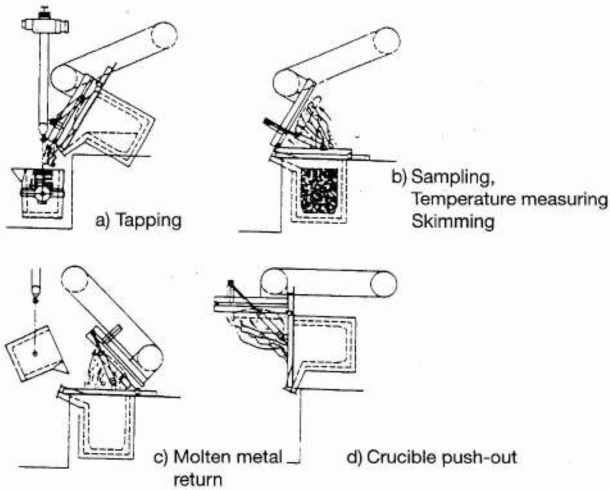


Fig. 2 a): Function of flue gas exhaust hood for various operating conditions

The IFM-furnace is usually equipped with an exhaust hood with integrated furnace cover. The furnace hood can be designed such that it only tilts in one direction (e.g. forward) or in two directions (forward and backward).

The flue gas extraction hood is tilted forward for charging and skimming and backward for returning liquid iron and for pushing out the crucible.

Erosion

is the carrying away of material from the surface of components, due to the action of liquids, vapours or gases flowing past them.

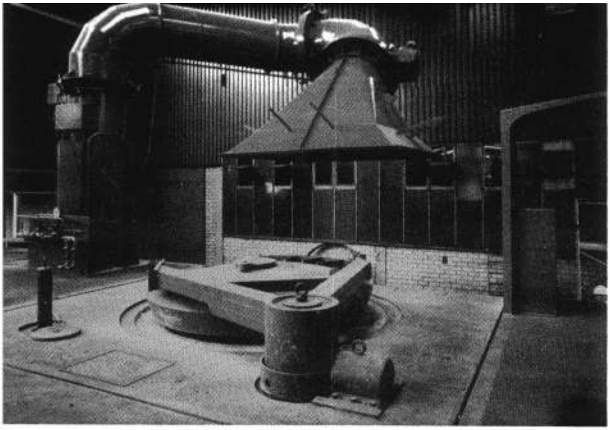


Figure 4: Furnace platform and extractor hood

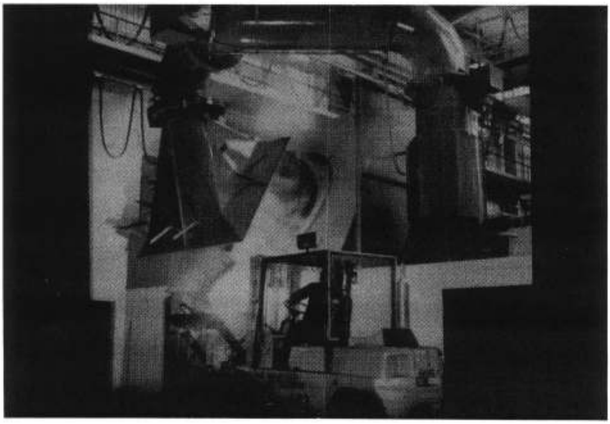


Figure 5: Magnesium treatment during tapping from the 40 t crucible-type furnace

Extraction systems

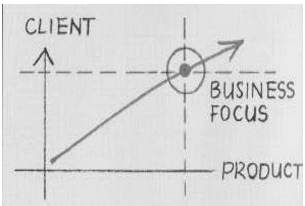
are generally specified for the operation of induction furnaces. In the case of crucible furnaces, so much smoke and dust is created directly in front of the furnace when charging and producing nodular cast iron that extraction systems are essential. For a 5-tone furnace, an integral hood extraction system with cover is required with an extraction capacity of approx. 10,000 Nm3/h. In the case of a separate hood, which is swung over the furnace, approx. 15,000 Nm3/h and corresponding flow speed measures must be taken.

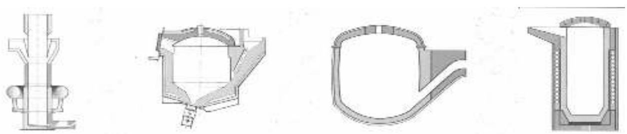
Filter

contained in foundries most out of clothes for holding back solid sustances (look pages later).

Fireproof

is dealt with under the term “Lining”.





Flaking

refers to surface faults in cast products, which are caused by gas or air inclusions below the casting surface. These usually flake off during the heat treatment of the castings. Flaking can also occur to fireproof brickwork and to crucible linings due to incorrect heating, sudden temperature changes or chemical effects.

Flushing

of cooling water circuits depends on the level of contamination of the pipes and the operating temperatures of the cooling water.

The hardness of the water in the system also pays a role. Some firms have specialised in the flushing of water-cooled power circuits. These firms work in co-operation with furnace manufacturers, and know the special features of the individual system components. The systems are usually flushed out with descaling agents in order to remove deposits, and then flushed through again to neutralise them with water from the municipal supply. These agents are environmentally friendly, and are also used in the foodstuffs industry.

Flushing block

is the normal term for a porous bottom block, through which gas can be introduced into the melt in furnaces or a ladle. The melt is usually flushed with argon. The gas is fed into the melt at low pressure, and removed from the melt by the partial pressure reduction of other gases. The blowing in of flushing gas (including nitrogen) can also be used to stir or mix the melt with added reaction materials, e.g. carburisation and desulphurisation agents.
When melting chrome-nickel alloys in the crucible induction furnace, flushing with argon can significantly reduce the melting and alloying times.
In the case of light metals and zinc, a higher melting performance can be achieved with the aid of a nitrogen flushing lance due to the intensive movement of the bath.

Flow speed

in lines carrying water, as in cables, pipes and hoses, should not exceed 2.5 m/sec. In the crucible induction furnace coils the flow speed should be approx. 2 m/sec. In connection areas and necessary restrictions in pipes caused by the design, flow speeds of up to 4 m/sec. can sometimes occur. The lengths of line where this occurs should be kept within a maximum range of 100 mm.
In extraction systems, speeds of up to approx. 40 m/sec. can be achieved in the pipelines. In a hood extraction system of a 13-t furnace, the flow speed at the extraction slot in the crucible cover should be approx. 6 m/sec., in order to create an adequate under-pressure.

Forklift trucks

are wheeled vehicles used for the lifting, transport and stacking of transport goods. See also 'Industrial trucks'.

Foundries

are industrial operations engaged in the moulding of materials by casting, in order to produce cast metal products.

Foundry coke

is produced specially for use in the cupola furnace, the size of the pieces being greater than 80 mm. In the case of special foundry coke, the pieces are over 100 mm in size.

Foundrymen

are employed in foundries for the operation of the foundry systems.

Frequency

is the number of vibrations occurring in the time unit of one second. The formula symbol is 'f' and the unit of measure Hertz (Hz). The mains frequency in Europe is 50 Hz, while some power supply networks overseas operate at a frequency of 60 Hz. Frequencies above 60 Hz are referred to as medium frequencies.
Normal operating frequencies for induction furnaces are:
70 Hz, 95 Hz, 150 Hz, 250 Hz, 500 Hz, 750 Hz, 1,000 Hz, 2,000 Hz and more rarely higher frequencies such as 3 kHz, 4 kHz, 5 kHz and 10 kHz for very small furnaces and inductive heating for forging or hardening.

Frequency converters

are frequency converters which create an oscillating circuit without rotating parts via a combination of a condenser and a choke. In the case of so-called triductors, 3-fold mains frequency, and quinductors, 5-fold mains frequency, the 3-fold or 5-fold mains frequency is generated as the operating frequency direct from the mains frequency with a converter efficiency level of approx. 0.94.
Modern converters have an efficiency level of 96%, and generate the required operating frequency of approx. 70 – 10,000 Hz via a rectifier.
These converters are equipped with a rectifier, which generates a 1-phase direct current from the 3-phase rotary current by means of thyristors or diodes. A direct current smoothing is incorporated between the rectifier and the inverter as an intermediate circuit. After the choke comes the adjustable inverter, which automatically generates the corresponding operating frequency in relation to the inductivity of the furnace, the capacity of the condenser bank and the power consumption. These are referred to as load-controlled converters, which are known as "A" parallel or "B" series oscillating circuit converters, depending on the condenser switching.

A: high current between furnace and condensers only

B: high current in the complete furnace circuit

(look 4 pages later)

Thyristor converter with anti-resonant circuit

Power approx. 100-16000 kW
Frequency approx. 60-10000 Hz

Application

The "thyristor converter" (also referred to as a static frequency converter, resonant-circuit converter of simply converter) is used as a power supply installation for:

Induction melting furnaces/holding furnaces

Induction heating systems in forges, rolling mills and metal works

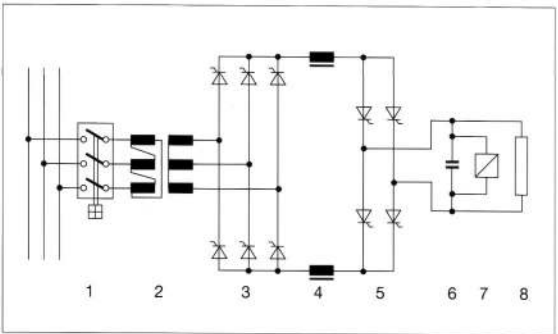


Figure 1: Block diagram of a thyristor (6-pulse)

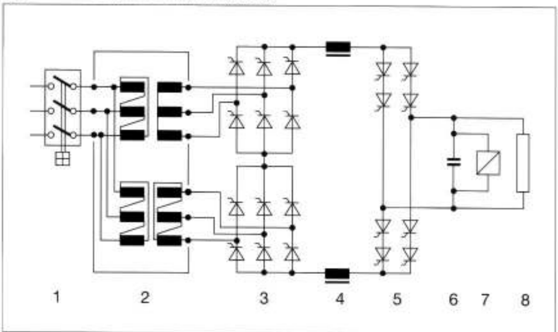


Figure 2: Block diagram of a thyristor converter (12-pulse)

1 Power switch
2 Rectifier transformer
3 Rectifier
4 DC link with symmetrically split smoothing reactor
5 Inverter
6 Parallel capacitor bank
7 Starting device
8 Induction coil

Design and mode of operation

The frequency of the three-phase supply system is converted to the appropriate frequency by way of a DC link.

Of the various circuit configurations for a converter with parallel compensation, Figure 1 shows the version with a 6-pulse rectifier and Figure 2 the version with a 12-pulse rectifier. Converters with a 24-pulse rectifier are also available. A maximum degree of line compatibility is achieved with these options.

All the power components in these converters are watercooled.

Compact overall size yet good accessibility is achieved by using disk-type thyristors – up to 4" disks depending on the power – with bilateral cooling.

Table 1 provides an overview of the number of power semiconductors in ABB converters for frequencies of 60 – 500 Hz.

	Rectifiers (GR)			Inverters
Converter power	6-pulse	12-pulse	24-pulse	(WR)
≤ 2,5 MW	6	12	–	8
≤ 8 MW	–	12	24	12

Table 1: Converters with the number of power semiconductors for frequencies of 60-500 Hz

The load circuit

The converter's load circuit consists essentially of the consumer (induction coil) and the capacitor battery, which is configured parallel to the consumer. The load circuit is connected up directly to the converter output (in special cases also via a transformer).

The consumer's reactive-power demand is covered by the load capacitors; the converter supplies only the active power.

Post-compensation of any change in the consumer condition takes place automatically via the change of frequency in the load circuit. Switching of the load circuit capacitors during operation is therefore unnecessary.

The converter is switched on and off by enabling and disabling of the rectifier. Since no mechanical switches are actuated and the converter is immediately ready for operation, it can also be switched off during short interruptions to production.

When the converter is switched on, a starting device in the load circuit generates the first wave and checks it for any faulty conditions.

At the same time steps are taken to ensure that the rectifier is supplied instantaneously with sufficient power in order to maintain the triggered wave. The commutation power is drawn from the load circuit.

Figure 5 shows the basic characteristic of a converter's output voltage and output current.

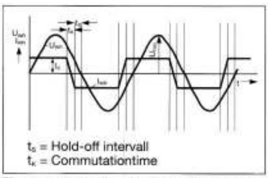


Figure 5: Time characteristic of the converter voltage U_{WR} and the converter current I_{WR}

Constant-power control

Particularly converters for medium-frequency melting plant are equipped with a constant-power control system. The following two characteristics result from appropriate dimensioning of the inverter and control of the converter:

- The inverter always supplies the consumer with the nominal power over a wide range of output voltage (e.g. between 70 and 100%). This is essential for the operation of melting furnaces in batch mode because the furnace resistance changes during a charge (level of fill, temperature).
- The rectifier is always fully controlled within the above mentioned range of inverter output voltage, i.e. the line-side power factor (cos. phi) remains at the optimum value.

ABB

The TWIN POWER circuit

With the TWIN POWER circuit it is possible to divide the power drawn from the system (1 transformer, 1 rectifier) among two consumers in any ratio by infinite adjustment, e.g. among two melting furnaces in tandem operation or among the two coils of a heater. Each consumer is assigned to its own load circuit capacitor bank and its own inverter.

Figure 7 shows the front view of a converter for 4.8 MW/250 Hz, 24-pulse, with TWIN POWER circuit.

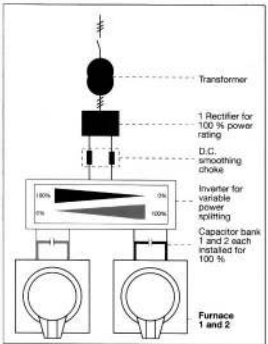
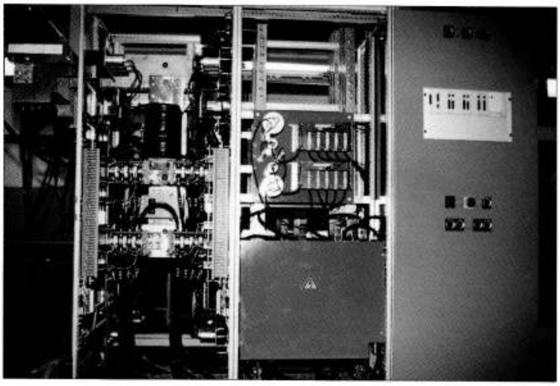


Figure 6: TWIN POWER circuit

Figure 7: A TWIN POWER for 4.8 MW / 24-pulse



Characteristic features of inductive melting with converter equipment

1. Basic design

The basic design of a medium frequency melting installation is schematically illustrated in **Fig. 1.** The induction coil encircling the crucible is fed via an oscillating circuit with parallel capacitors by a medium frequency converter which is load-commutated both in the rectifier and in the inverter part. This installation is connected to the high-voltage network by means of a three-phase current rectifier transformer.

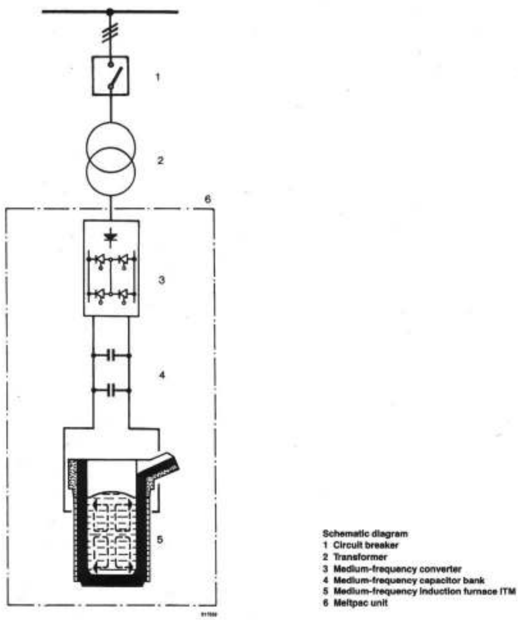


Fig. 1: Schematic set-up of an MF melting system (ABB Design)

This power density was assumed as the limit rating [1]. **Table 1.** shows the conditions for a typical medium-size MF furnace with 250 Hz (4 to 8-t furnaces).

Frequency	Max. power density
at NF (50/60 Hz)	300 - 350 kW/t
at 250 Hz as per $\sqrt{f}$-law	670 - 715 kW/t
at 250 Hz built until 1986	up to 600 kW/t
at 250 Hz operated since 1989	up to 1000 kW/t

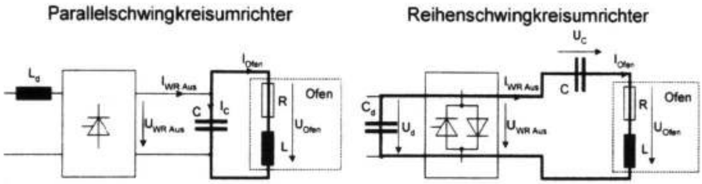
Table 1: Maximum power density for mains frequency and 250 Hz

Hence the simple conversion of the maximum power density according to the f$\sqrt{\ }$law which related chiefly to bath movement is no longer valid. A new simple function p[kW/t] = $\sqrt{f}$ (frequency) cannot be given at this stage. The limits are not yet discernible.

Over the past few years, simultaneously with power density, the absolute rating of MF furnaces was increased from max. 5000 kW in 1986 via 6000 and 7000 kW (1987/88) to now 9300 kW. We are now able to build converters with 12 to 16 MW, say for a 16 to 20-t furnace.

To achieve this technological level, significant technical effort was required for the development of the furnaces themselves and their electric energy converters.

Grundlagen der Umrichtertechnik



Parallelschwingkreisumrichter:

$P = 3000kW$

$U_{Ofen} = 3000V$

$Q = 8$

$f = 250\,Hz$

$U_{WR\,Aus} = U_C = U_{Ofen} = 3000V$

$I_{WR\,Aus} = \frac{P}{U_{WR\,Aus}} = \frac{P}{U_{Ofen}} = \frac{3000kW}{3000V} = 1000A$

$I_C \approx I_{Ofen} \approx Q \cdot I_{WR\,Aus} = 8000A$

Reihenschwingkreisumrichter:

$P = 3000kW$

$U_{Ofen} = 3000V$

$Q = 8$

$f = 250\,Hz$

$U_{WR\,Aus} \approx \frac{U_{Ofen}}{Q} \approx \frac{U_C}{Q} = \frac{3000V}{8} = 375V$

$I_{WR\,Aus} = \frac{P}{U_{WR\,Aus}} = \frac{3000kW}{375V} = 8000A$

$I_{WR\,Aus} = I_C = I_{Ofen} = 8000A$

Furan resin binders

are cold- or warm-hardening mould material binders, which are usually used for the production of the core.

Fuel – heated crucible furnaces

are heated with gas or oil, and are used as metal smelting furnaces for bright metal such as copper alloys, aluminium, magnesium, lead etc.

Furnace bottom construction

varies in design according to the furnace size and the application in question. Although the heat losses can be reduced by the installation of heat insulation blocks, this also reduces the strength and rigidity. Cast concrete elements have greater strengths and somewhat higher heat conduction properties. This trend has lead to longer working life, thanks to the use of high-quality concretes. In most cases, the masonry underpinning of induction coils has been replaced by concreting for cost reasons. With furnace sizes of up to approx. 5 t, the crucible removal device can be installed in a central position. Above 5 t capacity, the installation is displaced excentrically in the direction of the casting spout.

Furnace control

is the operation of a furnace, particularly a melting furnace, in order to fulfil certain metallurgical conditions. This is also referred to as process control.

Furnace covers

serve essentially to avoid heat losses, and as safety devices for the operating personnel, to screen them against the heat radiation and prevent the danger of falling. Furnace covers are made of steel plate with a ceramic cladding, which is as a rule cast. An imaginary furnace cover is et in place under processor operation of a crucible furnace at he end of the melting process, and all stored values of the melt are processed, and displayed on the screen or printed out for the information of the operator (ready for further measures).
Larger furnaces with cover diameters of over approx. 1,200 mm have an additional small cover that can be swung open by hand. Through this opening, additives can be added to the melt or the temperature measured.

Furnace lining

fireproof cladding of a furnace for the melting of metals.

Furnace scales

are used for the continuous registration of the overall weight of a furnace. By means of tareing of the empty furnace, the exact filling quantity, or after tapping the quantity removed and the remaining contents, can be accurately determined and recorded. As a rule, this is carried out with the aid of pressure measuring units with wire strain gauges. There are both round measuring cells, and for heavy loads measuring beams, which offer the advantage of 100% fixing of the furnace. In the case of round measuring cells, the furnace has a mobile mounting, and is only secured against tipping by means of a lifting lock. The scale graduations are 2 kg for small furnaces, and 5 or 10 kg for larger furnaces. The use of furnace scales is essential for processor-controlled systems.

Furnace size

is usually given in terms of the content or capacity of the different furnaces. Older specifications, for example in the case of crucible furnaces, referred to the contents within the furnace coil and the nominal capacity e.g. 4/5.2 t or 10/13 t. For channel furnaces for example, the size might be stated as 45/60 t, or for casting units 5/6.2 t.

2. Switchable installations

Whilst a furnace with a modern straight energy feed unit loads the mains constantly during melt processing and thus achieves the lowest possible power maximum, the non-productive times for skimming, sampling, pouring, etc. cause „power gaps“ which necessitate increasing the power level required to achieve the specified production level. Solutions with switchable furnaces present themselves for this application; moreover, there is a number of variants available which can be tailored to suit special operational requirements **(Fig. 10.):**

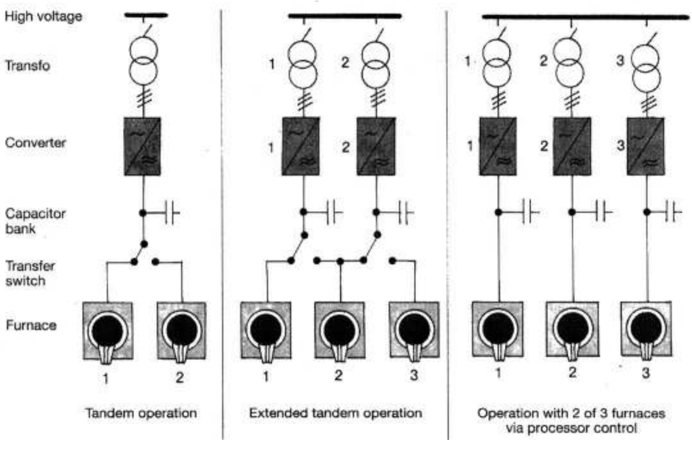


Fig. 10: Schematics of melting systems and associated power supply

Another means of utilising the available power at optimum and according to operational requirements is illustrated in **Fig. 11.** This melting installation can be operated in the following modes:

- Two converters feed one furnace: 6 to 6.5 MW
- One each converter separately feeds one each furnace at max. 4.25 MW. The total of the two converter outputs is then limited to 7400 kW in line with the mains capacity. The individual converter outputs may vary.

This system is described in more detail in another paper [4].

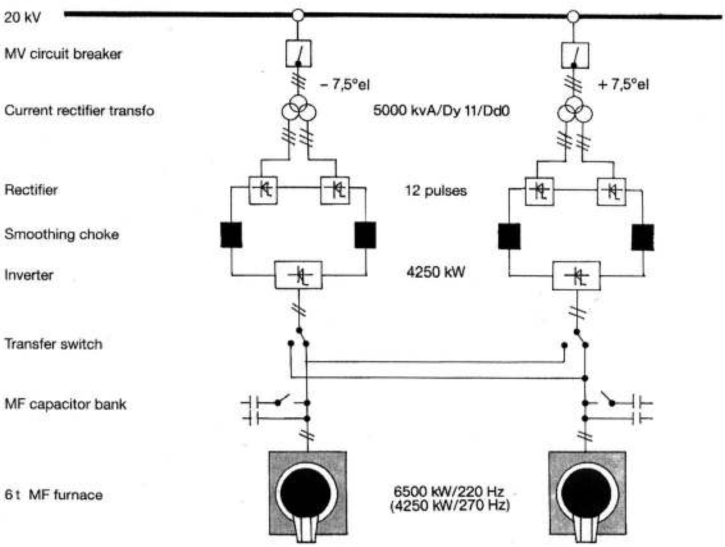


Fig. 11: MF power supply system 6,5/4,25 MW for 2 MF furnaces of 6 t each

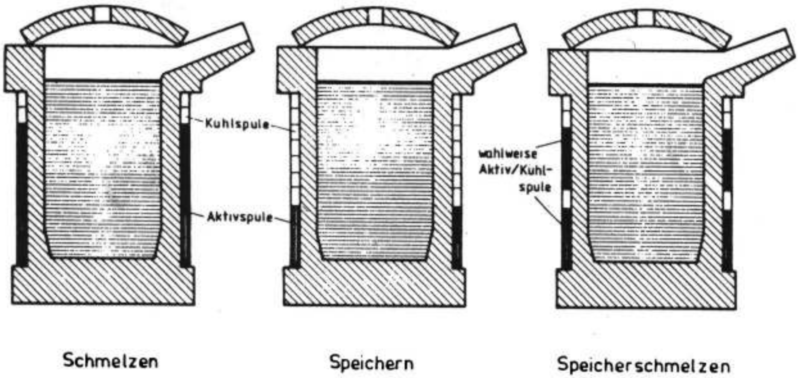


Figure 8: Schematic diagrams of crucible-type melting furnace (left) and crucible-type storage furnace with single coil (centre) and with reversible coil (right)

Legend Fig. 8

Cooling coil
Active coil
Alternate active/cooling coil
Melting
Storage
Storage melting

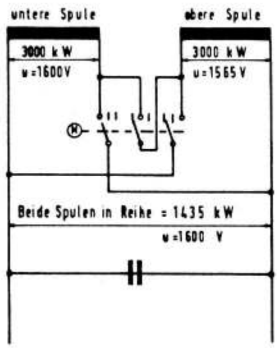


Figure 9: Circuit diagram of crucible-type storage furnac with reversible coil (Figure 8, right)

Legend Fig 9

Lower coil
Upper coil
Both coils in series

Furnace switching systems

are always required when several furnaces are to be supplied from one or more energy supply systems. The simplest form of switching is furnace current switching from one switching system to 2 following furnaces. An alternative here would be effective current switching, with a condenser bank for each furnace. The furnace switching system with the optimum “reserve” for the furnaces and the energy supply is the so-called busbar distributor. With this system, every furnace can be switched to every power supply. This requires the same number of furnaces as energy supply systems, together with the corresponding number of effective current switches for each furnace. In the case of more than 3 furnaces, these systems require too large and complex a busbar system, so that from 4 furnaces, a 2 x 2 furnace system is used.
In mains frequency systems, the current to the furnace is approx. 4.5x higher than the effective current. 250 Hz systems have a current to the furnace approx. 7.5x higher than the effective current, while for 500 Hz systems, the current is approx. 11x higher than the effective current.
As an alternative to these switching systems, other systems have been developed with unstepped distribution of the output to 2 or more furnaces. These systems also have the advantage that 2 furnaces can be supplied with energy simultaneously.
Electronic switching has not come into such common use, since in this case only 1 furnace can be supplied with energy at any one time. The switching off and on time is approx. 1 second.

Furnace transformers

except in the case of medium-frequency systems, are designed as step transformers. As a rule, 10- or 12-step secondary windings are used for mains frequency systems. The switching takes place in the no-load condition on the secondary side. The top 5 or 6 steps are designed for nominal output, while at the lower steps, the output falls by the square of the reducing voltage. The lowest step is set so that the relevant furnace can still be kept hot at 60% of its capacity, without the temperature rising significantly. In the case of a 12.5-t furnace, the output used by the furnace should be about 140 kW. If the maximum voltage is 2,000 V for 2,600 kW, the lowest voltage step must operate at 465 Volt.

Gas burners

are operated as normal burners with air, or as high-performance burners using oxygen. Depending on the size of the crucible, holding, storage or channel furnace, outputs of from 100 to 500 kW are used, and more rarely 750 kW. The application temperatures to the ceramics range from 800 °C to 1,200 °C. The flame temperatures are considerably higher, and can reach levels of up to approx. 2,400 °C.

Gas flow agitation

is the treatment of the melt in a ladle with a gas flushing block in the bottom of the ladle. Depending on the pressure and the volume of gas, an agitation effect can be achieved in the ladle. Metallurgic work can be carried out by the specific use of deslagging and carbonising agents.

Graphit

is a black substance (a form of carbon) used in lubrication, as a moderator in atomic piles, and in making lead pencils. In different types of iron, You will find the folowing types.
The four basic types of iron are: Gray Iron, Ductile Iron, Mallable Iron and White Iron.

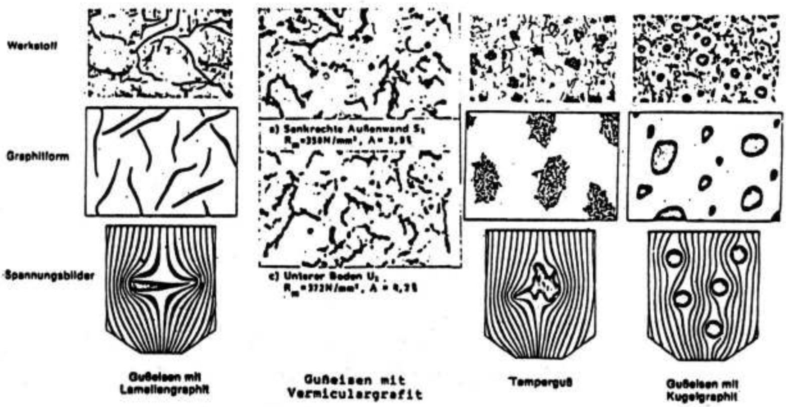


Figure 1: Structure, graphite form and tension patterns of various cast iron materials

<u>Legend Fig. 1</u>

material
graphite form
tension patterns
cast iron with lamellar graphite
a) vertical outer wall
c) lower bottom
cast iron with vermicular graphite
malleable cast iron
cast iron with spheroidal graphite

Graphite clay crucibles

must be prepared for optimum earthing at the crucible bottom. Earthing in the casting spout is only effective after the 1st casting. In order to earth the crucible, a spiral with at least 5 windings of 3 mm wire is installed in the furnace bottom. This spiral is then covered with fine-grain graphite powder to a level such that the graphite clay crucible reaches its installation height after a few rotations. The back-fill compound is then filled in and compacted. Finally, the upper edge of the back-fill compound is sealed off with a patch, so that the back-fill compound cannot trickle out when the crucible is tipped. Prior to the 1st charging with scrap or molten material, the crucible should be heated up inductively at an output of approx. 40 kW/250 kg of crucible weight. The crucible should have a light red colour approx.100mm below the crucible edge. Fine material (preferably chips) should now be placed in the bottom and normal scrap filled in on top. The 1st charge can now be melted.

High-alumina cement

is a cement which sets very quickly and becomes very hard with water binding. As a 25% additive with normal cement, this leads to setting within 30 minutes.

Hardening

is the heat treatment of metallic materials in order to increase their hardness.

Hard casting

is the term for an iron-carbon alloy with a low graphitising factor, so that the material solidifies white.

Heat recovery

can only be practiced successfully with crucible furnaces to a limited extent, and only with great effort, depending on the system configuration.
As a rule, the temperature range of the cooling water lies between 30 and 65 °C, with a temperature difference of 27 K. Heating pumps work efficiently at approx. 80 °C. Above 72 °C, the limescale precipitates out of the cooling water, the water lines become clogged, and the water has to be treated accordingly. Practical applications include:
Treatment of washing water and heating of rooms in winter. With a 5-t furnace with 3,000 kW, a maximum of 900 kW of heat energy will be absorbed by the cooling water, which can only be used economically to a very small extent. There is a large number of engineering companies involved in the field of heat recovery.

Heat losses

occur in all vessels containing melts at high temperatures. In the case of channel holding furnaces, the losses are determined by the melt contact surface, the bath surface and the inductor idle losses. For a 120 kW inductor the inductor losses amount to approx. 25 kW and for a 2,000 kW inductor approx. 100 kW. With optimum vessel design, the melt diameter also corresponds to the height of the melting bath, thus achieving the lowest possible contact/bath surface with the largest possible capacity. Holding furnaces can act like a "thermos flask" depending on the heat insulation and the lining. With a 13-t crucible furnace, the following losses must be expected: 120 kW thermal wall loss, 20 kW bottom loss, 35 kW surface loss with closed cover, totalling 175 kW idling losses.

Holding

is the expression for the temperature control to casting temperature. Depending on the furnace construction and the heat insulation, the heat losses in kW/t of capacity can amount to between approx. 6 for channel holding furnaces with 130 t capacity and 28 for crucible furnaces with approx. 3 t capacity. Holding costs money, and should be kept to a minimum as far as the process controls allow.

Hood extraction systems

were installed above furnaces in the same way as forge hearth extraction systems. Very high air transport capacities are required due to the large separating distance from the furnace platform. In order to increase the air speed at the end of the hood, flow nozzles were installed in the funnel. Since these hoods have to be swung to the side for charging and casting, a complicated swivelling system is also necessary. In order to reduce the high separating distance during melting, raising and lowering systems can also be fitted. One could say that this system can be optimised, but for the same result, the costs are significantly higher than with other extraction systems.

Hydraulic systems

are complete systems for the hydraulic operation of machinery, consisting of a pump assembly, hydraulic working cylinders or hydraulic motors, pipe systems and control devices. The energy is transmitted by a hydraulic fluid, such as oil or emulsion, which is supplied by the pump assembly at pressures of up to 200 kp/cm^2.

Idle output

is the product of the coil voltage multiplied by the idle current flowing between the furnace coil and the condenser battery, given in kVar.

Immission

is the generation of jets, gases or solid materials of outside origin, e.g. dust immission from cupola furnace operation on a neighbouring property.

Induction

is based on magnetism in conjunction with electrical voltages and currents. The following rules apply, as used in the design and construction of motors and for transformers: when an electrical conductor is placed in an alternating magnetic field, an electrical voltage is induced in the conductor. When a current flows through the conductor, a thrust is imparted to the conductor, which acts at an angle of 90° to the direction of the current. This property is used in the construction of motors.
In the generator, a voltage is generated in the rotor or stator winding of a conductor.
In the transformer, a core holds 2 separate coils, each with a different number of windings. The voltage is transformed to a higher or lower level, depending on the number of windings, i.e. the transmission ratio. Because the actual output remains the same, the current changes in the inverse proportion.
e.g.

Primary:	10 kV	200 windings	50 A	500 kVA
Secondary:	1 kV	20 windings	500 A	500 kVA

The crucible induction furnace is based on the induction principle of transformers, which is explained below by means of an example.

A medium-frequency furnace with a 5 t capacity has an output of 3,000kW at 3,000 Volt, 11 windings and a crucible wall thickness of 140 mm. An effective current of 1,000 A flows in the coil.
If the melt or scrap charge is now applied as a secondary winding, this gives a theoretical voltage in the crucible of 273 Volt and a total current as a product in the melt of approx. 11,000 A. This high current acts as an eddy current, which heats and melts the charge.
A connection between the coil and bath (lining leak) can also be identified with an earth short or imbalance monitoring device. In this way, a warning signal can be generated if the melt penetrates into the vicinity of the coil.
There is also the danger that a winding short caused by this metal will damage the conductor to such an extent that cooling water escapes.
It is essential at all times to avoid water getting into the melt. The voltage must therefore be switched off automatically if the bath gets dangerously close to the coil. This danger can also be significantly reduced by the appropriate design of the coil.
The furnace itself also includes the additional electrical devices shown in Figure 114 for a medium-frequency furnace; the only difference in a mains frequency furnace is the absence of the frequency converters.

Inductor

this is the heating assembly for channel furnaces and casting units. A channel inductor is constructed in a very similar way to a transformer, and comprises a closed iron core/yoke on which are mounted 1 or 2 coils. The channel is arranged as a secondary winding at 90° through the yoke opening. An inductor has a relatively high area output in the channel, in relation to the cross-section and the inner jacket surface of the channel. An 800 kW inductor has a coupling surface of approx. 2.1 m^2. The inductor coil for example – at 660 V/50 Hz – has 34 windings with an effective current of approx. 1212 A and this 41,208 ampere windings. The channel consequently has a current level of 41,208 A, since the number of windings is 1. This corresponds to a current density of 1.84 A/mm^2. The area outputs are: approx. 890 kW/m^2 for the inductor and approx. 380 kW/m^2 for a comparable crucible furnace with 3 t capacity and 800 kW output.

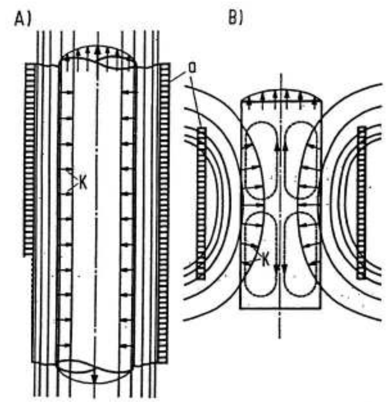


Figure 76. Principle of the induction crucible furnace [73]
A) parallel magnetic field lines with infinitely extended coil and the resulting direction of forces.
B) bent magnetic field lines with a finite coil and the resulting force components
a - coil, K - force components

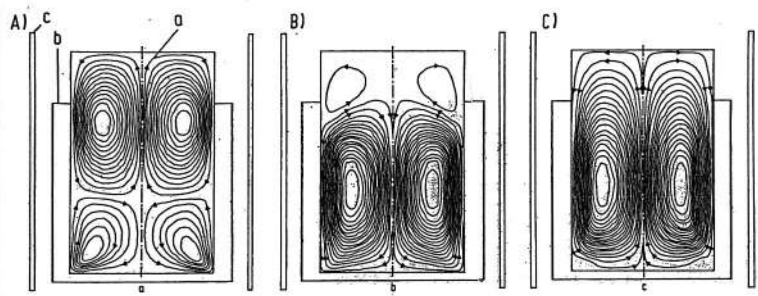
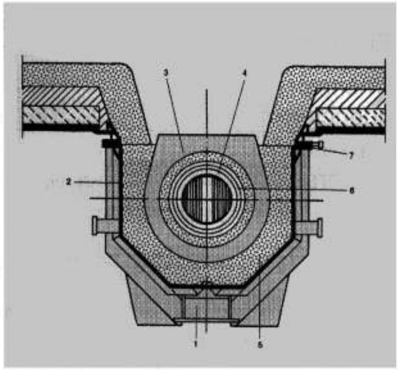


Figure 78. Flow field of a melt with single- and multiple-phase (travelling field) coil [73]
A) single-phase coil, B) three-phase coil with travelling field direction from bottom to top, C) three-phase coil with travelling field direction from top to bottom.
a - melt, b - coil, c - yoke

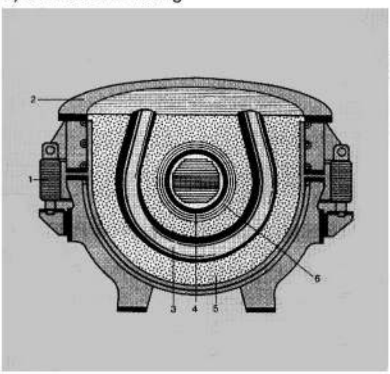
The mechanical design of the inductors up to 700 kW (Fig. 2a) permits low weight and compact dimensions. Yoke, coil and cooling jacket are easily removed so that the lining can be replaced more easily. The inductors rated at more than 800 kW (Fig. 2b) have a particularly robust, two-part housing ensuring optimum refractory life at high inductor power levels.

1 Magnetic core
2 Inductor housing
3 Channel pattern
4 Inductor coil
5 Refractory lining
6 Cooling jacket
7 Cooling frame



a) up to a rating of 700 kW,

b) over 800 kW rating



1 Magnetic core
2 Inductor housing
3 Channel pattern
4 Inductor coil
5 Refractory lining
6 Cooling jacket

Fig. 2: Elementary diagram of channel-type inductors

Even today, many procedures in foundries still continue to be performed manually. Past attempts at automation often either failed completely, or at least failed to provide the required performance. The main reasons for this was automation equipment that was not suitable for foundries and a lack of higher-level process knowledge about foundries on the part of automation specialists.

Suitable robotic equipment

Figure 1: Angular-arm robot IRB 7600 with 500 kg load capacity.

The harsh environment of the foundry demands machinery that is both designed and constructed to the relevant protection class, and is also easy to operate.

Modern angular-arm robots built to protection class IP 67 (Figure 1) are tightly sealed against the ingress of dust and moisture (Figure 2) and can even be washed down using a high-pressure cleaner. These are available from ABB with load capacities from 5 - 500 kg and with reaches of up to 3 m. Portal robots are also available for applications requiring heavier loads or longer reaches. The robot consists basically of the manipulator (angular arm or portal) and the controls, which can be easily operated from a control panel after some basic training and instruction. Additional, PC-based software simplifies the programming and maintenance requirement by means of the capability of remote maintenance and simulation/offline programming.

In addition to the mechanical demands, foundry work also requires particular durability with respect to temperature. The high-precision mechanics of such robots must be capable of reliable operation over a wide temperature range.

Figure 2: Example of a dirt-caked robot in an aluminium foundry

Planning and project management of robotic applications

In order to take the best advantage of the capabilities of industrial robots and utilise them to their limits, a thorough and accurate assessment of the process in question is essential. This can only be guaranteed by extensive experience in the foundry environment. While robots themselves and the relevant software are becoming increasingly simplified as standard products, the delivery and installation in the foundry of a properly functioning system still remains a complex procedure. Thorough and comprehensive planning is essential if the robot is to be able to carry out the intended function from the very beginning.

The construction components are cladded on all sides. The height arrangement of the coil and thus of the crucible is selected to allow ease of operation. There are no special requirements on the design of the foundations. The furnace can be set up in any operating area with light anchoring, and is ready for operation after connection of electricity and water.

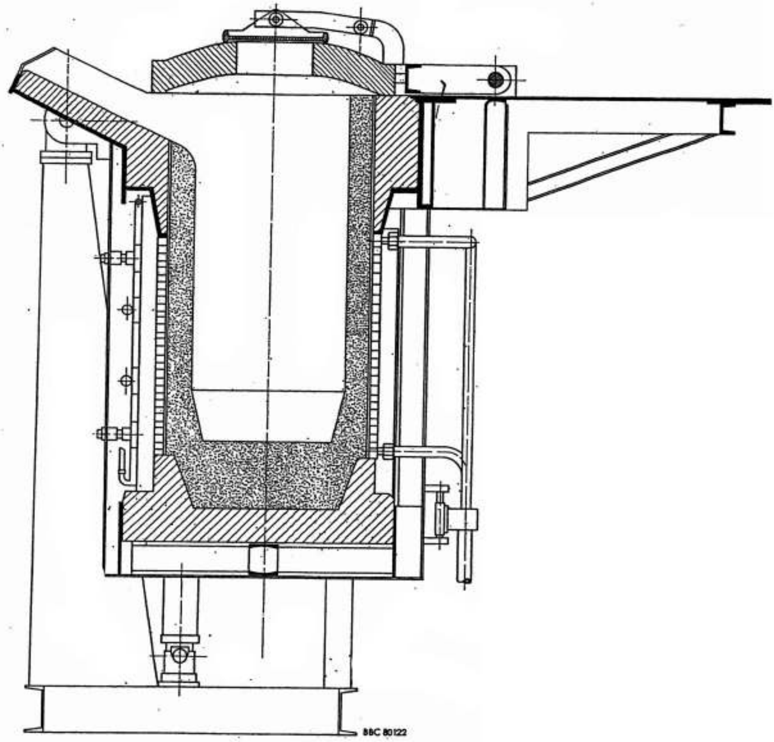


Figure 3-69
Furnace equipped with cylindrical, water-cooled coil, capacity 12.5 to 90 dm^3.

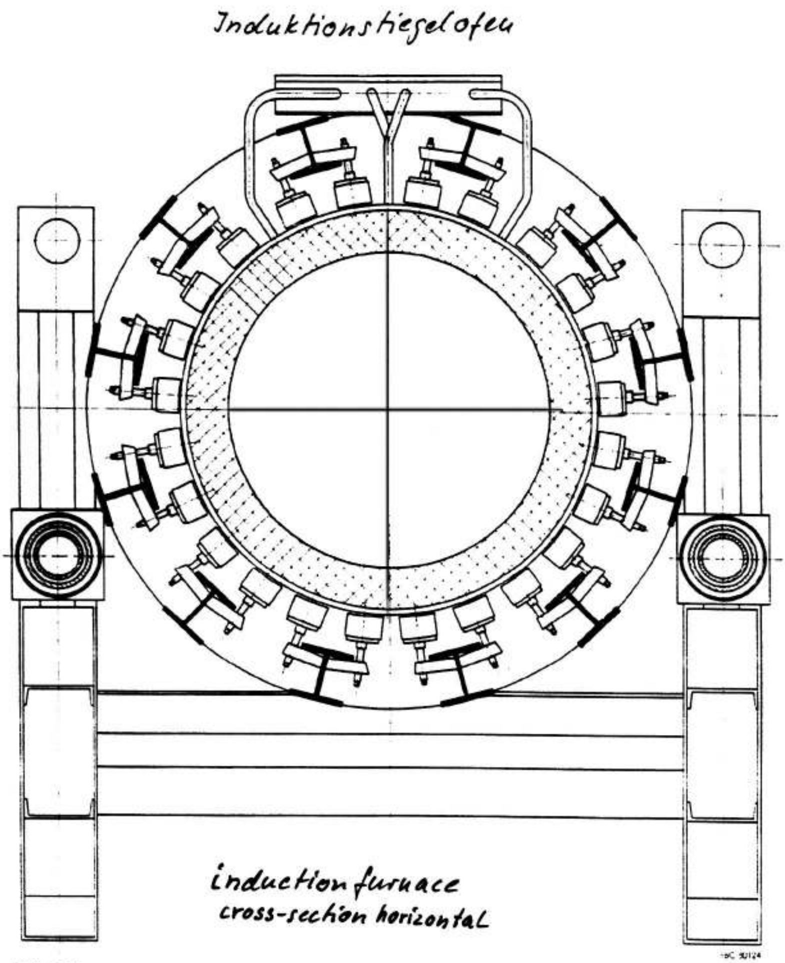


Bild 3-71
Ofenquerschnitt in waagerechter Richtung. Ofen mit zylindrischer, wassergekühlter Spule ausgerüstet. Fassungsvermögen 140 bis 3600 dm^3

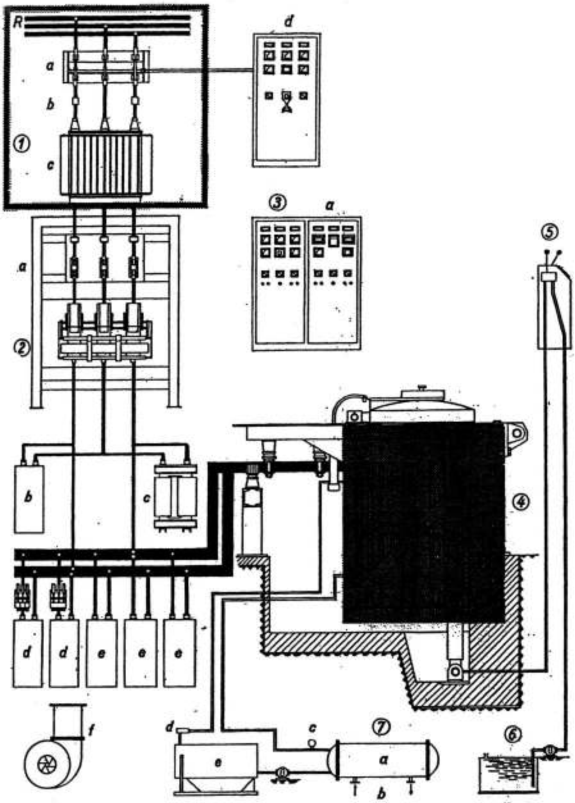


Figure 4-10
basic layout of the switching system of a crucible furnace smelting system for mains frequency
f = 50 Hz

1. High-voltage cell
   a = circuit-breaker switch
   b = current converter
   c - transformer
   d = measuring cell
2. Low-voltage switching system
   a = protective frame with fuses, cut-outs and measurement converters
   b = balancing capacitor
   c = balancing reactor - coil
   d = fixed capacitors
   e = switchable capacitors
   f = ventilation
3. Switch cabinet
   a = automatic compensation
4. Mains frequency crucible furnace
5. Control panel
6. Hydraulic tilting
7. Return cooling system
   a = heat-exchanger
   b = water
   c = pressure gauge
   d = temperature gauge
   e = collecting container

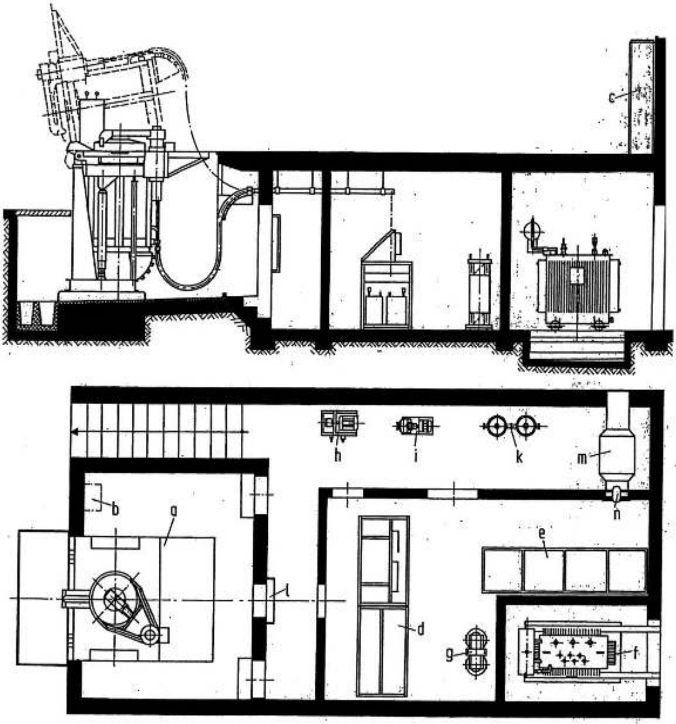


Figure 114. Layout of a complete system and installation plan for medium-frequency crucible furnaces [82].
a - MF crucible furnace, b - Control panel, c - Switch cabinet, d - Capacitor rack, e - Thyristor converter, f - Transformer, g - Reactance coil, h - Hydraulic assembly, i - Water pump, k - Water return cooler, l - Cooling water gauge, m - Air filter, n - Fan

The layout of an induction crucible furnace is shown in Figure 112. The windings of the coil are insulated all round or separated by insulation distance pieces, and in some cases covered with insulating material. An asbestos or glass fabric jacket is laid over the inside of the coil, before the actual crucible material is fitted.

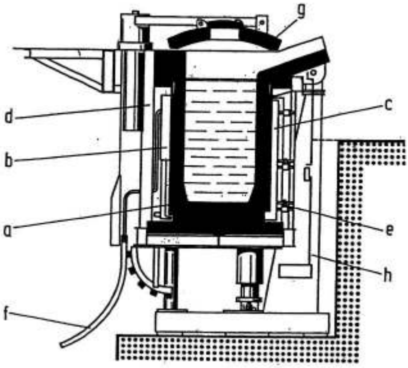


Figure 112. Layout of an induction crucible furnace [82]
a - ceramic crucible, b - copper coil, c - yoke, d - frame (profile steel), e - tensioning device, f - water-cooled cable, g - cover, h - protective cladding

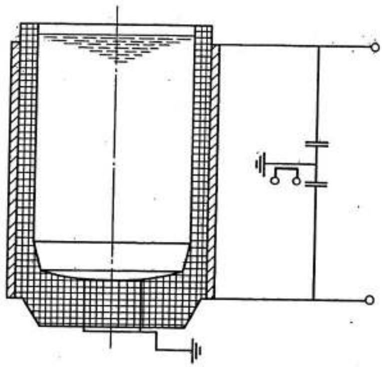


Figure 113. Crucible monitoring by means of bottom electrodes and soft central earthing of the coil [99].

The danger of the bath carrying a voltage dangerous to the operator is generally counteracted by earthing the bath, in the case of furnaces for cast iron or steel by means of bottom electrodes (Figure 113). One requirement however is that the potential of the furnace coil is not fixed.

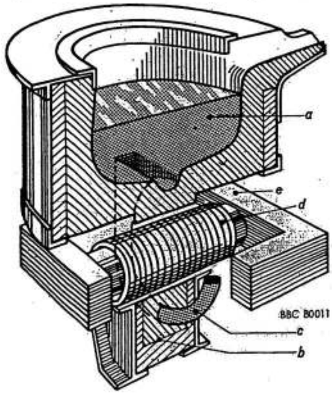


Figure 3-44
Schematic section of an induction furnace with vertically arranged channel

a = crucible, containing the liquid metal
b = stamping
c = channel
d = coil
e - iron core

Industrial robots

are computer-controlled, freely programmable automatic machines that can be equipped with various grippers, tools etc. On production lines, they can also carry out complicated working procedures without human intervention. They are programmed by one-time manual performance of the task in question by the operator. Robots are available that can handle useful weights of up to approx. 300 kg, and can therefore also be used in foundries (look 7 pages before).

Industrial trucks

is a common term for forklift trucks used in production areas and warehouses.

Ingot moulds

are permanent moulds for the production of die-cast products. Ingot moulds are usually water-cooled, and are made of graphite or metallic materials.

Injection (Inoculation)

is the introduction of easily soluble alloy elements in order to achieve the optimum material properties. The injection materials are usually introduced into the casting stream in powder form during casting. If a very large quantity of injection materials is needed because of special requirements, the use of wire injection devices is recommended. Injection prior to the filling of the iron into a heated casting unit can lead to increased formation of deposits in the channel inductor or the inductor neck.

Inlet funnel

is the upper, conical section of the inlet for sand and ingot casting.

Inmould process

is a process developed by the International Meehanite Metal Co. Ltd., Reigate (England). The magnesium treatment of cast iron melts forming the nodular graphite is carried out not before the casting in a ladle, but directly in the casting mould. The process uses a granular powder, which in addition to magnesium also contains calcium and silicon, and therefore acts as an injection agent in the sense of mould injection.

Insulation

in induction furnace construction refers either to electrical or heat insulation. The insulation materials are 100% asbestos-free. For electrical applications, epoxy glass hard fibres (Diverrit E), micanite and ceramic-organic pressed materials are used, while thermal applications make use of ceramic fibre materials and pressed materials such as Isoplan, Nevalit and similar materials. Silica-glass materials are used for both applications.

Inoculating and alloying systems

Because inoculant efficiency fades in the pouring furnace, melt inoculation must be performed downstream of the pouring furnace just before pouring into the mould. When pouring directly from the furnace, the inoculant is added to the metal stream as a function of time and quantity either by means of a carrier gas or in the form of a wire. The operation is controlled by the stopper mechanism actuator. Where intermediate ladles are used, the inoculant is added to the melt in the weight dosing mode while the ladle is being filled. In the same manner, alloyants can be added after they have been drawn from various hoppers as required for the next pour by means of a weighing system similar to that in the HONDA foundry as described in the previous section. **Fig. 17.** shows the pouring area of a 6-t PRESSPOUR™ furnace in a Buderus foundry. The camera of the OPTIPOUR® control system can be seen in the foreground and the inoculant storage hopper with dosing device for pouring stream inoculation with carrier gas at the left edge of the picture.

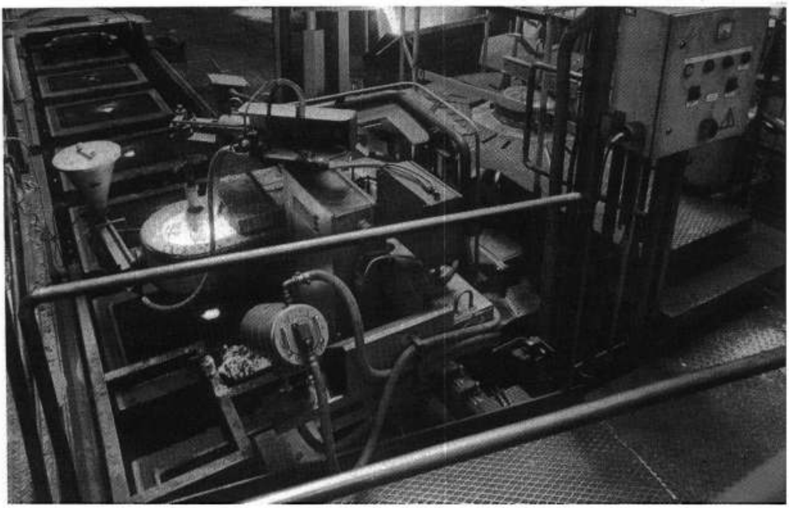


Fig. 17: 6-t PRESSPOUR® pouring furnace with OPTIPOUR® metal level control and inoculation system in operation at a Buderus moulding line.

Integrated inoculation

Another advantage of the pouring system is reliable inoculation just before mould filling. The method described here ensures that the timed sequence between inoculation and solidification is reproducible for each casting, while the fluctuations caused by fading and segregation can be ignored. The inoculation control is integrated in the control system of the pouring device.

The most used form of inoculation in conjunction with an automatic pouring system is pouring stream inoculation. The powdery inoculator is blown into the pouring stream during mould filling. It is important for the foundryman that the complete inoculation process can be entirely documented. Figure 8 shows an example of a complete monitoring system.

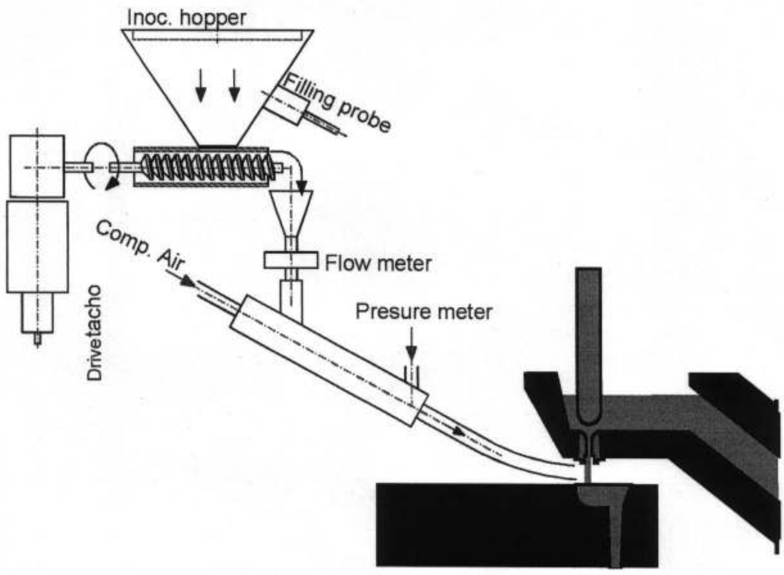


Fig. 8: Diagram of pouring stream inoculation with the necessary monitoring system.

Wire inoculation can be used as an alternative or in addition to stream inoculation. For that, the wire filled with the inoculator is fed into the pouring basin by a spooling device just during pouring (see figure 9). The variable parameters (speed, length, moment in time) and the type of filler wire (diameter, composition) can be influenced in the control.

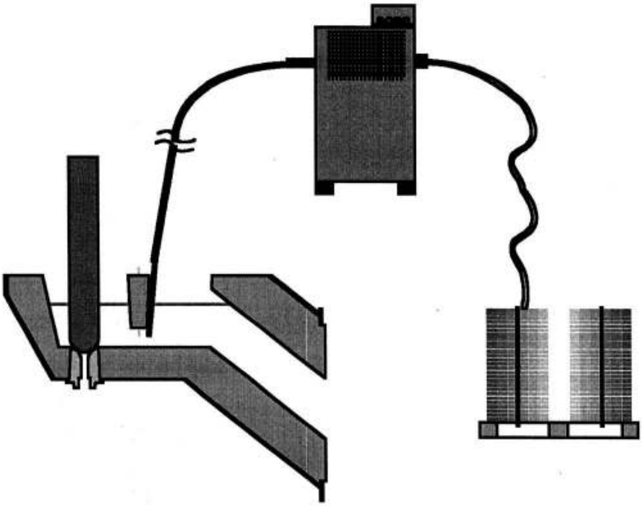


Fig. 9: Wire inoculation in the pouring spout

Even higher standards of accuracy are achieved by the Isopour® process (fig. 10). The inoculator is added in a closed chamber so that only the defined quantity that is to be poured is treated. However, this system requires more mechanical maintenance work which is to evaluate in comparison to the metallurgical advantages.

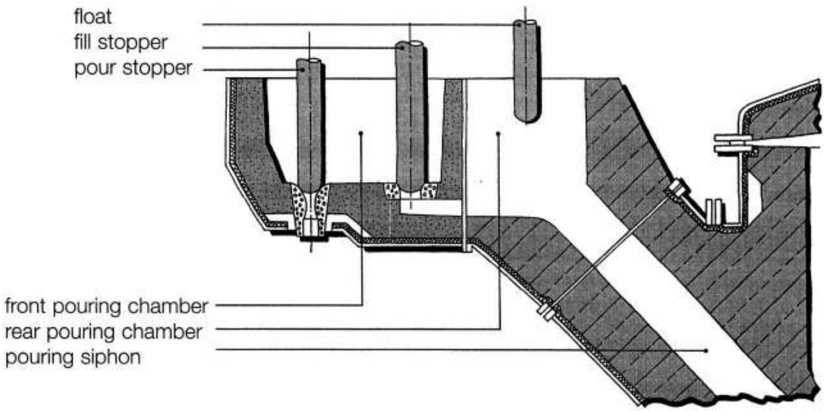


Fig. 10: Isopour® process

Insulation blocks

placed in moulds, delay the solidification of the casting at certain points in the mould. The heat conductivity of these blocks is substantially lower than the remainder of the mould material.

Insulation monitoring

by means of a melting bath earthed by bottom electrodes offers great safety for operating personnel, and can sometimes also give an indication of the condition of the crucible. In this system, the insulation value between the voltage-carrying furnace coil and the earth potential is determined by means of direct current measurement. In the case of proper electrical insulation between the coil and the iron piles, and the high-current system, the power supply and the earth potential, a low insulation value can be attributed to the resistance between the coil and the earthed melting bath, and thus also the condition of the crucible (page 98).
In the case of a newly concreted coil installation with coil plastering, the poor resistance value is usually due to the high moisture content. At resistance values below 400 Ohms, a crucible induction furnace should therefore not be operated at above 1,000 Volt operating voltage. From 400 – 700 Ohms, a level of 1,500 Volt should not be exceeded, since in addition to the measured "earth short" due to moisture between the coil and earth, the winding voltage can also lead to winding shorts. At approx. 60 Volt winding voltage and mains frequency, there is a winding insulation of 3 mm. In the moist condition, the winding voltage should be no more than 10 V/mm, or in other words 30 Volt. In the case of medium-frequency furnaces, one has winding voltages of up to 270 Volt and 15 mm of intermediate layer insulation, so that consequently a winding voltage of 150 V should not be exceeded.

Iron piles / yokes

are used for the return and direction of the magnetic flux outside the furnace coil. The iron piles are physically hold the furnace coil. The construction of large crucible induction furnaces would be impossible without these iron piles. Iron piles are used with operating frequencies of up to approx. 2,000 Hz. The loss performance is between 0.35 W/kg and 1.5 W/kg of iron. The iron piles are used with a minimum projection over the coil length/height of 100 mm or the distance between the melt and the coil diameter. The iron piles are very important in the design, and the dimensions depend on the magnetic load and the mechanical requirements with regard to stability. In the case of high electrical outputs and medium frequency, the iron piles are water-cooled. Iron piles of crucible furnaces are made of ungrained plate.

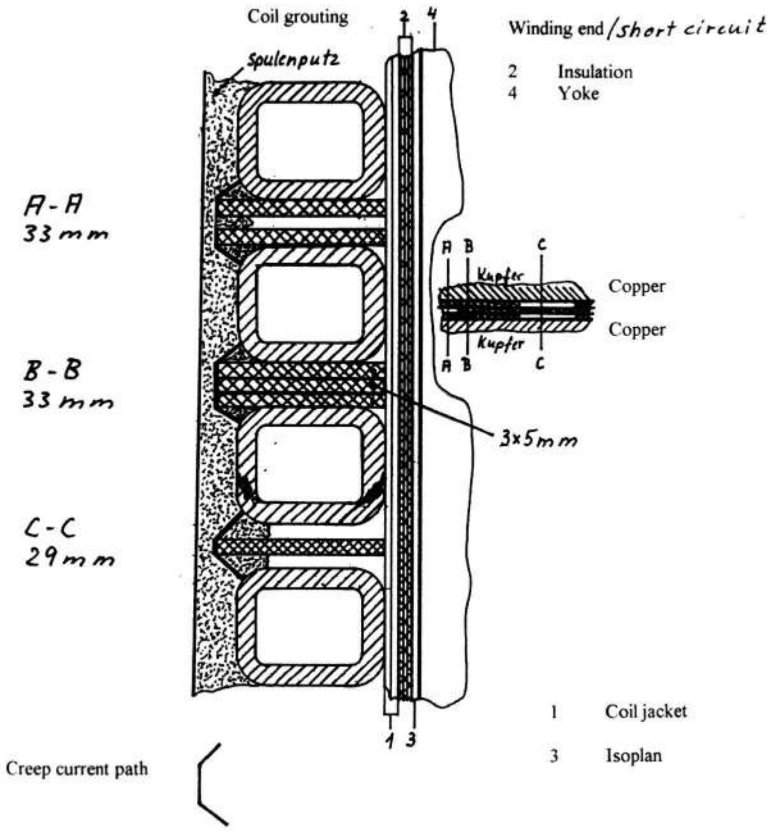
Iron pile projection

is required for constructional and electro-magnetic reasons. The iron piles serve to guide and direct the magnetic flux outside the induction furnace coil. A trans-

verse field is created at both ends of the induction coil, which must be "trapped" by the iron piles, so that the scatter field that would otherwise be created cannot inductively heat the steel constriction of the furnace body.
The iron pile projection at the top should be about the same as the distance between the nominal crucible diameter and the coil internal diameter. In the lower area, approx. 30% more projection is used. More accurate values can be obtained from the electrical data of the relevant furnace. In the case of a 5-t furnace with 3,000 kW, these dimensions are approx. 120 mm at the top and approx. 160 mm at the bottom. If the furnace is operated at 4,800 kW, dimensions of 150 and 200 mm may be required.

Intermediate layers

are used as winding insulation between electrical conductors and winding conductors. The HGW material is cut to the external coil diameter. For small furnaces l - 100 mm, for furnaces from 1 - 30 t l = 150 mm, for furnaces over 30 t l = 200/250 mm.
The intermediate layers are glued in offset by 1/3 of their length, in order to allow an open design of the coil for the expulsion of humidity. Ground intermediate layers are of very accurate dimensions and have optimum adhesion properties. Unground material is in general 15/100 mm over size, thus changing the coil length, and the adhesion properties are very poor.



Ladle

is a vessel equipped with fireproof cladding used for holding the melt from a furnace for the purposes of transport or casting. These come in the different forms of transport and casting ladles.

Laser

is a focus light, generated from a device for amplifrying and concentrating light waves into an intense highly directional beam. In foundries laser operated for measuring of distances and pouring levels in the mould.

Lining

is the term for the fireproof cladding of furnaces and ladles.

Lining

is also the designation for the melting crucible or wear crucible without the concrete rings or fixed ceramic components. Nowadays dry tamping compounds are generally used. Damp compounds are sometimes still used in aluminium and zinc furnaces. There are 3 different types of material: acidic, basic and neutral compounds. Mixtures of the 3 above types of material are also used for certain applications.
Acidic compounds contain approx. 98.5% SiO_2
Neutral compounds contain approx. 84.5% Al_2O_3 and up to 13% MgO
Basic magnetic compounds contain approx. 88.0% MgO, up to 10% Al_2O_3 and approx. 2% SiO_2. The application temperatures of acidic compounds are normally in the area of 1,600 °C and can reach up to a maximum of 1,700 °C for short periods.
For neutral compounds, the normal application temperatures are in the area of 1,650 °C and can reach up to a maximum of 1,750 °C for short periods.
Basic magnetic compounds have a normal application temperature of 1,650 °C and a maximum of 1,800 °C for short periods.
In a 1-t crucible furnace with 1,000 kW for example, the maximum temperature can be reached within 2 minutes, after which the furnace must be emptied immediately and re-charged with scrap. The furnace is now brought up to temperature for approx. 3 minutes at high output, so that the crucible is not cooled down too much from the extremely high temperature required. With this procedure, charge numbers of from 40 to 70 can be achieved, depending on the method of operation, compound and charge materials.
Dry compounds are usually supplied in 25 kg sacks or disposable containers weighing up to 1,600 kg. The compounds are supplied ready for use with sintering agents, and do not need to be mixed. Acidic compounds containing boric anhydride contain no crystalline water, so that these can be used with tempera-

ture increases of up to 150 K/h. High-alumina and magnesitic compounds are specially mixed and supplied by manufacturers for individual applications.

Lining work and sintering

The inner surface of the induction furnace coil and the ceramic upper construction (upper concrete ring) must form a smooth surface, without any deposits, which tapers gradually to form a cone at the top. If a crucible removal device is used, the conicity should be 0.8%. When working with an outer lining with approx. 40 mm overlap at the bottom, the coil plastering should not be applied conically. In this case, the conicity of the outer lining is sufficient. The coil plastering and the outer lining are applied with a water content of 5 – 8%. This moisture leads to a long drying time, and thus also to extended starting times. In order to remove this moisture from the coil plastering and the outer lining quickly, these can be dried out with a gas burner and the tamping form. The coil plastering can be dried out at a maximum of 150 °C and the outer lining at a maximum of 350 °C in the lower area.

The drying time in both cases should be at least 24 hours, if the outer lining has been cast immediately after application of the coil plastering, the drying time should be at least 36 hours. The temperature increase should be between 30 to 50 K/h.

If no burner is available, the drying can also be carried out inductively for medium-frequency furnaces.

If neither gas nor inductive heating are to be used, the coil plastering and the outer lining should be allowed to dry out normally in air for approx. 12 hours, and then dried out for a further 24 hours with a 3 kW or 6 kW fan heater placed on the bottom of the furnace, depending on the furnace size. Some customers use resistance-heated “baskets”, which are supplied with a line through the furnace bottom. In the case of electrical heating, the heating should be carried out with the furnace cover closed.

Before applying the tamping compound, the inner surface of the coil is “papered” with 0.5 mm of Cogemikanit or similar material up to the edge of the furnace. Micanites with added flow materials are expensive, and provide hardly any heating benefits.

The furnace bottom with the bottom electrodes is now prepared for the application of the bottom compound. The tamping compound is filled in to such a level that the bottom electrodes can be tamped over to a depth of approx. 10 mm. This is usually carried out after manual ventilation using a bottom agitator, which is powered electrically or pneumatically. Agitation continues for 5 – 10 minutes depending on the furnace size. For bottom thicknesses of over 350 mm the work should be carried out in 2 layers, paying special attention to the bottom electrodes. After the bottom agitator has been removed, the bottom height from the furnace edge must be checked and recorded. Now an outer ring is well keyed around the furnace bottom up to the cone of the tamping form (at least 15 mm),

in order to provide a good connection to the crucible wall. The tamping form is installed, centred and fixed in place at the crucible edge using wooden wedges. The crucible wall is filled up to the edge of the furnace in layers of 300 to 400 mm. After every layer, "Neptune zinc" ventilation is carried out to ensure better final compaction. Compaction must now be carried out very carefully in the area of the bottom cone. For the crucible wall, the self-rotating wall agitator is used. This must be installed in the lowest possible position using a crane, and agitation applied in this area for approx. 5 minutes. Agitation then continues for 2, 3 or 4 minutes for furnaces with up to 800 mm diameter and 100 mm height difference, up to 1,200 mm diameter and 125 mm height difference and over 1,200 mm diameter and 150 mm height difference respectively. Since the crucible wall will be subjected to high mechanical stresses in the upper area, the greatest care must be exercised here. The upper 200 mm are compacted by hand after removal of the wooden wedges. Die tamping compound should finish approx. 50 – 70 mm below the furnace edge. Tamping compound should be added continually during agitation to avoid the formation of layers between the compacted compound and the added compound. A thin patch layer is then applied to the ring of the crucible wall to prevent the tamping compound trickling out at the 1st tapping. The compound is not scraped out of the casting spout. In the case of disposable and permanent templates, the casting spout should also be filled with compound in order to achieve a higher filling level during sintering. In the case of a disposable template, the compound is removed from the casting spout following completion of the sintering process, and the area dried with a welding burner. After approx. 10 minutes, this part of the tamping form becomes so soft that a "breakthrough" can be made to the casting spout using a crowbar. The iron now flows into the casting spout and the furnace can be tipped for the 1st time.
When using a permanent template, this must be provided with a supporting film of micanite or with a separating agent prior to installation. There are conical complete templates available, as well as folding templates.
In the case of the conical complete template, this is heated up to approx. 450 °C after agitation at a rate of approx. 150 K/h, and then cooled down after 1 hour to 200 °C with compressed air or cooling fans. To remove it, the template must be pulled directly upward in a single movement. The folding permanent template is not heated, and is removed by folding in one of the 120° segments. Following removal of the templates, an "impact protection" layer of recycled material is applied to the furnace bottom. The height of this layer should be 200 – 300 mm, depending on the furnace size. The crucible must now be filled up to the casting spout as quickly as possible. No power should be switched to the furnace during this time. Once the maximum filling level has been reached, power is switched to the furnace, providing a temperature increase of approx. 100 K/h, i.e. about 40 kW/t, or 200 kW for a 5-t furnace. At this output, the melt is brought up to sintering temperature and maintained at this level for approx. 2 hours. The 1st tapping is then carried out, and a total of 3 charges should be processed.

Liquid Sintering

is a good practice to save sinteringtime in the meltshop (look the pages later).

Loam

is a type of clay containing sand, and usually interspersed with iron oxides.

Long-term trials

refer to series of tests or trials lasting at least 1,000 operating hours.

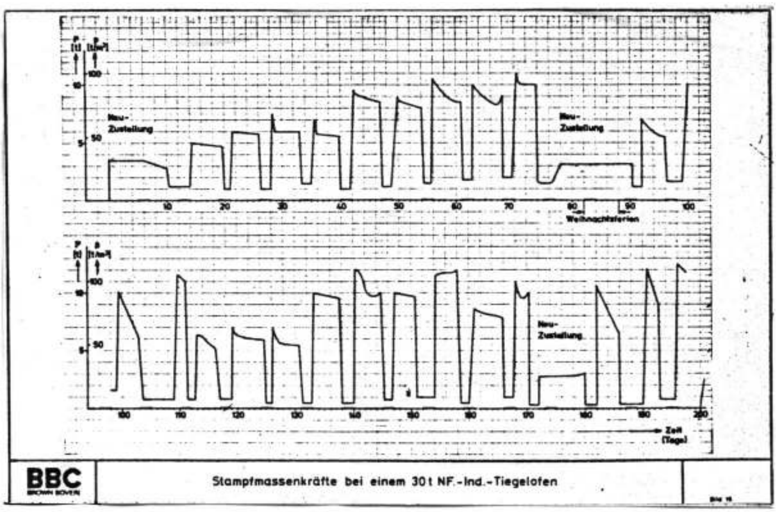
Loss performance

is the overall term for the difference in performance between the performance provided via the cable from the transformer to the furnace and the performance actually induced in the melt. The main types of loss performance are listed below: Switch system losses, condenser losses, performance and cable losses, coil losses, thermal furnace losses and cover losses.
These overall losses can total up to 40% of the nominal system output. Depending on the method of operation of a furnace system, these losses can be reduced to approx. 32%.

Machine casting

refers to the production of castings for the engineering industry.

lining power



Magnesium melt

is produced in steel crucibles. The main application is found in pressure die-casting foundries. The furnaces can be heated by induction resistance or by fuels. In recycling operations with annual throughputs of > approx. 3,000 t/p.a. and scrap dimensions of approx. 500x200x50, the inductively-heated steel crucible furnace manufactured by ABB is used successfully. These furnaces are available with capacities of approx.800 kg with 400 kW and 1,500 kg with 560 kW. Ceramically-lined magnesium furnaces have not proven popular for recycling purposes due to the high level of dross. Ceramically-lined magnesium furnaces of 7 and 10 t capacity are operated in the USA, although these are operated with 1/3 sump and charged pigs. The pigs come from Russian and Chinese production, and contain impurities which are then cleaned out in these furnaces. The furnaces have to remain in operation continuously, since the tamping compound must not be allowed to cool off.

Magnetic crane

is an aid for the transport of magnetic melting materials from one point to another, and for the sorting and making up of the charge. Great care must be exercised when operating such equipment, so that other magnetic aids such as spoons or rods are not picked up, creating the risk of accidents. The maximum "attraction weights" must be strictly observed, so as not to create dangers during operation. Figure 5 shows the making up of the charge in the conveyor channel using a high-performance magnet and a suspended crane, which is also equipped with scales for weighing the materials accurately.

Magnetic separators

are used for sorting and separating magnetic materials out from other materials. These devices are sometimes also constructed as belt separators.

Bild 5: MF-Ind.-Schmelzanlage, 35 t/Tag Gesamtproduktion - Gattierung

Maintenance / Preventive maintenance

of production plant leads to the improved availability of such systems. On the one hand there is pure repair maintenance, i.e. which is only carried out when the system has broken down or when minor faults provide indications of possible failure. For some components, this can still be the best solution. On the other hand, it is becoming increasingly necessary to undertake repair measures before damage actually occurs. In the case of cars, inspections are carried out and certain parts replaced on the basis of mileage or the time interval between servicing. The same procedure should also be considered for induction furnace systems and the relevant system components, in order to avoid unpleasant surprises. For this reason, some companies have introduced preventive maintenance. Depending on the level of utilisation of systems, maintenance work and checks are carried out with a view toward maintaining availability of the system. Certain parts are replaced as a preventive measure, irrespective of their actual condition, so that unforeseeable or unavoidable breakdowns cannot occur. This can include for example the replacement of an induction furnace coil after 5, or even after 3 years of operation. Depending on the condition of cooling water hose surfaces, it may prove necessary to replace such hoses prematurely even after very short operating times. The firm of ABB introduced a system of preventive maintenance by means of checklists as early as the mid-1970's. In this process, as for a car undergoing a road test, the whole system and all its components are inspected, from the furnace transformer to the casting spout, and the further procedure or necessary repairs established. Some foundries have these checks carriedout every year in the period up to April, so that the necessary measures can be taken during or even before the company holidays.

Making up the charge

is the filling of the charging device with the material to be melted. This work is usually carried out with the aid of a magnetic crane.

Material condition

specifies the condition of a material – solid, liquid or gaseous.

Mechanisation

is the use of mechanical aids and systems instead of manual working methods.

Meehanite cast iron

is a proprietary trademark of the Meehanite Metal Corporation for a cast iron material that has been extensively developed with regard to melting, casting, moulding and heat treatment. This is based on a patent originally awarded to A. F. Meehan in the USA in 1922, which essentially covered a special injection process on a CaSi basis to create very fine graphite in the structure.

Melt

is the fluid state of a material. Metals are generally converted to the fluid state in a furnace. Mercury is the only metal to exist in a fluid state at room temperature.

Melting time

and specific throughput/h are determined essentially by the specific output in kW/t, the melting process and the operation of the system. The heat losses are proportional to the melting time and are correspondingly lower at high furnace output than at low outputs. With a 5-t furnace and a furnace output of 3,100 kW, one can reckon on a tap-to-tap time of approx. 60 min for GG at 1,450 °C tapping temperature. At a tapping temperature of 1,550 °C, this gives an increased tap-to-tap time of approx. 64 min. These times also include the additional time for the required handling. The pure melting times for the above examples are approx. 52 min. and 55 min. respectively.

Melting loss

refers to metal losses which occur during melting mainly as a result of oxidation or vaporisation. The oxides form part of the slag, and are then removed with them from the melting bath. The melting loss is therefore defined as the weight difference between the cold metal charge and the finished melt available in the furnace. In case of charges made up of small pieces, such as chippings and fine stamping waste, the melting loss is higher than for compact scrap. For the same overall weight of the charge, the surface area of the charge material (chippings) is many times that of compact scrap.

Metal spraying

is the spraying of a molten metal onto a work piece.

Micanite

is the trade name for plate and formed parts for the electrical insulation of induction furnaces and heating equipment operating by induction resistance, e.g. toasters in the household or core insulation in induction furnaces.

MIG welding

is the abbreviation for Metal-Inert gas Welding. This is a method of arc welding using an additional wire in an atmosphere of inert gas such as argon or helium.

Model

is the moulding equipment for the direct forming of the cavity of the casting mould for the production of an accurately dimensioned casting.

Model plates

hold the model halves for the production of the casting mould. The model plates are fixed to the mould machine table.

Monorail

is a suspended conveyor device for handling and transport of materials by means of a crane or shackle/cable system.

Moulding

refers to the manufacture of casting moulds, and especially sand moulds. These are roughly divided into machine moulds and manual moulds.

Mould boxes

are rigid frames very resistant to warping and bending, used to position and hold the mould materials that are compressed inside them.

Mould gases

are released when casting the molten metal into the mould, and due to the oxygen in the air within the mould, are usually combustible and are seen as a gas flame.

Mould injection

is a very effective and efficient process, since the time interval between injection and solidification is very short.

Mould machines

are devices for the production of sand moulds. They are divided into the following groups, according to the type of sand compression: (look next page)

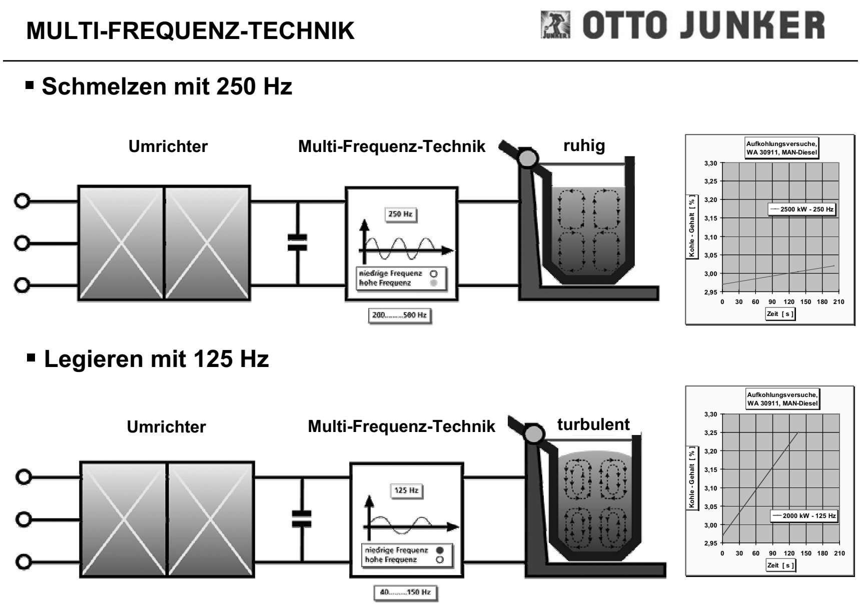
a) Manual mould machines
b) Vibrating mould machines
c) Press mould machines
d) Stamp mould machines
e) Blast mould machines
f) Injection mould machines
g) Slinger mould machines

Mould weights

are weights of cast iron, which are placed on top of sand moulds ready for casting, in order to counteract the upward pressure of the casting mould.

Multi-frequency

is a designation of the firm of Junker referring to frequency switching during melting and carburisation.



Ni hard cast iron

is a martensitic, white cast iron alloyed with nickel and chromium for heavy-duty pump housings, pump pulleys, grinding components, rollers etc.

Nodular graphite iron

is the registered trade name of the International Nickel Ltd. London for cast iron containing nodular graphite.

Oil burner

a burner fuelled by heating oil for the heating of furnaces and firing systems.

Optipour system

is the optical casting system of the firm ABB, which measures the surface of a casting sump in the inlet funnel of a mould to be cast with an electronic camera, and then regulates the casting process in relation to the molten metal surface as determined by the camera. The casting process is stopped on reaching the specified filling level. (look over next page)

Oscillating conveyors

are continuous conveyors in channel form for the transport of bulk materials, and are used in foundries for the charging of crucible furnaces. They can also be used for the separation of old sand. Depending on their cladding, they can also be used for the transport of pre-warned scrap or still hot castings.

Outer linings

are fitted in crucible furnaces with wall thicknesses of over approx. 150 mm. As a rule, these consist of casting compounds with a high clay content, which are cast with the aid of a form which is conical toward the top. The conicity is approx. 0.8%, as for crucible removal devices. For technical casting reasons, the thickness at the upper edge should not exceed 25 mm.
For a 30-t furnace, the thickness at the top is 30 mm, and therefore 46 mm at the bottom. These compounds are prepared with approx. 6% water. Although larger quantities of water produce better casting characteristics, this has the disadvantage of greater porosity, and consequently significantly lower strength. The water also has to be removed by means of various, laborious heating methods. Drying can be carried out with gas- or oil-fired burners, or inductively. The maximum temperature at the lower edge of the outer lining should not exceed 400 °C, in order to prevent any damage to the water-cooled induction furnace coil. Otherwise the drying process should be carried out in the same way as for casting compounds. An outer lining that has been dried

slowly will not tend to form cracks as quickly as an outer lining that has been dried too rapidly.

Outlet block

is the term used for the block holding or supporting the outlet.

Output

is the term used in electrical technology for the product of voltage in V multiplied by the current in A, and is measured in units of Watts or Kilowatts, in short kW. P = U x I.

Output increase

of existing systems using medium frequency or mains frequency are possible in the range up to 10%, although a basic requirement is a water recooling system of adequate size. Changing the voltage at the coil by 5% while maintaining the same frequency produces an output increase of approx. 10%. Most transformers have +/- taps. Condensers are voltage-stable to approx. + 5%. A reduction of the frequency by approx. 8% at the same voltage will give an output increase of approx. 10%. At the same frequencies and coil voltages, output increases can also be obtained by altering the number of windings.
In the case of a mains frequency for example, the induction coil has 25 windings and a length/height of approx. 1000 mm. If the number of windings is now reduced by 1 winding to 24 windings while maintaining the same coil length/height, the electrical output will be increased by approx. 8%. If the length of the coil is also reduced, the output will be increased by approx. 4%.
The total wall thickness from the new lining to the coil diameter at the copper winding determines the coupling. If the wall thickness of an induction furnace is reduced by 1 mm, this will give an output increase of approx. 0.8%, for the same frequency and voltage. An increase in diameter of 10 mm will therefore give an output increase of approx. 4%.
In mains frequency systems, an output increase of up to 10% may also be possible by means of over-compensation by the condenser bank and the associated capacitive voltage transformation.

Overcasting process

is the alloying of a molten metal with another solid metal by means of placing the added metal on the bottom of the alloying ladle, and then pouring the molten metal over it. This procedure is also used for the production of nodular graphite castings.

Oxidation

the addition of oxygen for the purpose of oxidation.

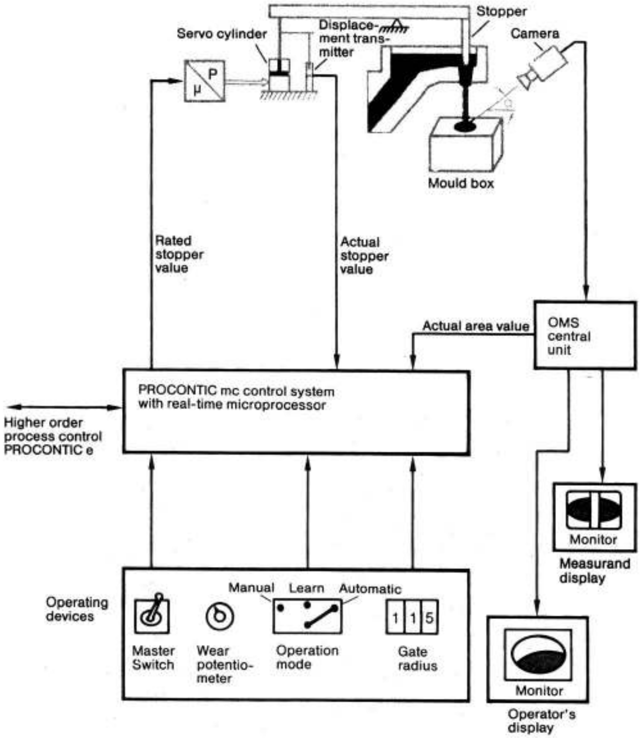


Figure 8: Schematic diagram of casting level control system **Optipour**

Particle Size limit

is the maximum size limit of a crystal particle, as determined from a sectional view.

Patching compounds

refers as a rule to the drying of the charge material prior to charging into induction furnaces. The advisable temperature range has proven to be 150 – 180 °C. At higher temperatures the efficiency level is too low.
The pre-heating of the crucible is carried out with the aid of gas or oil burners, or inductively with a sintering cylinder.

Pellet

is a pressed briquette made of fine-grained materials using bonding agents with a maximum length of 100 mm. Briquettes can be up to 250 mm in length.

Pigs

are cast into sand or ingot moulds. For non-ferrous metals, finished alloys are cast in weights of 1-50 kg. For ferrous metals, square or rectangular moulds of up to 500 kg are used.

Pinching

is the expression for the breaking of the stream in the channel and thus also the secondary inductor current due to too high an output, in relation to the static pressure of the melt from the vessel above the inductor. Pinching can also occur at static pressures adequate for normal operation due to the accumulation of deposits and the associated restriction of the channel. In order to avoid damage to the inductor, the output must be reduced when pinching occurs.

Plunger cylinders

are "single-acting" cylinders, which are arranged vertically, and are operated by hydraulic, or more rarely pneumatic power. Lowering takes place under the weight of the lifted load. The piston rod is simultaneously the piston itself. The maximum stroke is limited by means of a turned ring at the lower end of the piston rod and a stop bush in the upper area of the cylinder sleeve. The sealing elements are installed in the cylinder sleeve.

Pore

is the term for an open or closed cavity in the structure of a material.

Positive mixers

are always used when compounds need to be mixed and prepared in small quantities and in a relatively short time (up to approx. 3 min). For larger quantities, mixing times of approx. 5 min. will be required.

Pouring / Automated Pouring

is an other term for Casting and the most needed word in the foundries for this operation. The demand for tighter, more stringent requirements has brought on the development of automated pouring systems as a quality control and productivity enhancing process step. Manual systems suffer from difficulty of reproducibility in pouring and inoculating practices, variable productivity, cosistency of temperature and chemical analysis, and safty conditions.
Automated systems provide the melter and pouring operator the control and consisttency required. The prime purpose of this type of furnace is to deliver liquid iron at the proper temperature for the best possible casting to the mold. The automatic sys-

tems provide metal at that temperature and at the proper flow rate to either a ladle or automated line whether in-ladle, in-tundish, or in-mold inoculated. (it goes later on) The pouring furnace can be outfitted with either a conventional channel inductor or a crucible inductor. The primary advantage of a channel inductor is that it is energy efficient, more than ten precentage points better than a crucible inductor. Its primary disadvantage is that it has to be kept hot at all times to avoid cracking of the refractory. In practice, this usually means leaving hot metal in it as a minimum heel at all times. It also has a tendency to clog, particulary when using ductile iron.

Flexible solutions for automated pouring. Using ABB pouring systems always brings you advantages

Timely provision of pouring material

- Holding of molten metals, also of magnesium-treated cast iron, a minimum of servicing expenditure

Automated pouring

- Great reproducible pouring accuracy through programmed control and mould level control
- Automatic operation in corelation with automatic casting systems

Constant pouring temperature

- Constant pouring temperature for pouring furnaces, minimal temperature loss for unheated systems

Inoculation

- Addition of inoculant and possibly other alloy materials at the right time and in the exact quantity.

High degree of reliability, availability and operational safety

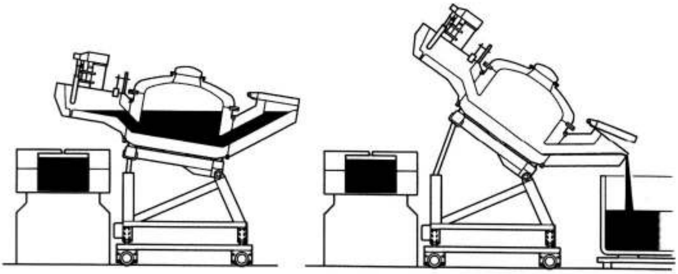
- Continuous automatic monitoring of the pouring system
- High operational safety through replaceable vessel and inductor

Easy handling

- Very little space required and easy installation
- Slag-free pouring
- Easy positioning of the furnace
- Quick and easy refractory lining

Longevity

- ABB pouring systems have stood the test for many years under the most critical operating conditions.
- Operational experience with pouring systems gained in foundries from all over the world.



Minimal heat losses

Heat losses are kept to a minimum by:

- The refractory lining of the furnace vessel and the highly insulating furnace cover
- The pneumatically actuated cover on the tundish
- The short narrow tundish with its small surface area for the stopper and the bath level monitoring electrodes.

The maximum temperature drop of the melt in the POUROMAT is 1.5 K/min.

Furnace tilting in case of standstill

If the unit comes to an accidental standstill, the POUROMAT can, at the push of a button, be tilted to completely discharge the contents of the tundish. The stopper should then be opened so that it does not freeze solid. For a long time, the heat content of the melt is sufficient to maintain the furnace vessel close to operating temperature. Depending on the length of the downtime, pouring operations are either continued immediately or the furnace vessel is tilted further to fully discharge the contents and later recharged with fresh melt ready for restarting operations.

Monitoring and operational safety

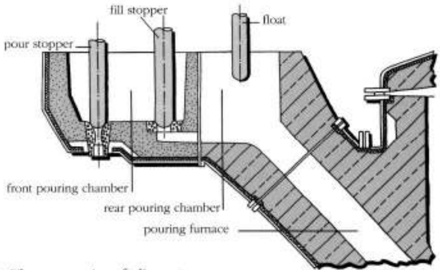
The continuous and automatic monitoring of the pouring furnace system guarantees safe operation at all times, The entire pouring process can be controlled in the same way as it is in the case of PRESSPOUR® furnaces.

Simple operation, maintenance and assembly

At the designing stage, the main emphasis was placed on simple operation and maintenance of the system. Detailed instructions make possible an efficient and quick training of technical personnel for assembly, operation and trouble-shooting.

Cost-effective pouring using Isopour® for integrated melt treatment

As an alternative to the ladle system, ABB has developed the pouring system Isopour®, involving the integration of a second chamber to the pouring vessel. This way, an exact, controllable melt treatment immediately prior to pouring can take place. Isopour® is used for inoculating and alloying the cast iron.



Pouring of magnesium-treated cast iron

The ABB PRESSPOUR® furnaces and POUROMAT pouring systems have a proven record of success in many foundries, especially for the processing of magnesium-treated cast iron. In addition to the cost-effective criteria for using a pouring furnace, the holding and pouring of spheroidal graphite casts has the following special advantages:

- The magnesium fading rate after forming of the furnace is so low that the melt remains ready for pouring even after extended holding times.
- The magnesium content is homogenized in the pouring furnace so that the casting quality is optimized.
- The rated magnesium content in the individual charge can thus be reduced by about 10%.

The processing of magnesium-treated melts does, however, impose special maintenance requirements, especially on how to cope with the increased formation of slag and deposits in the pouring furnace. In close cooperation with the operators of pouring furnaces for pouring magnesium-treated cast iron, ABB has designed solutions, like flange mounted siphons and deposit cleaning mechanisms, which ensure cost-effective operation of the foundry with high availability of the pouring system.

Worldwide service

ABB guarantees you a qualified, fast service – anytime and everywhere. Our specialists for specialized maintenance and repairs are available for you around the clock. In addition, with our customized consulting services, we optimize your processes and enhance your profitability, ensuring that you make the best-possible capital investments and add more value to your systems and processes. This is because competent and expert service form the basis of our successful cooperation.

Service hotline
+49 (0) 231 997-11 11

The primary advantage of a crucible inductor is that it can be emptied and allowed to cool down without too much penalty on refractory life. It also has less tendency to clog in the first place and can be more easily cleaned with mechanical means. The nature of the foundry operation will determine if the flexibility and high up-time of the crucible inductor will outweigh the disadvantage of its lower electrical efficiency.

Pouromat

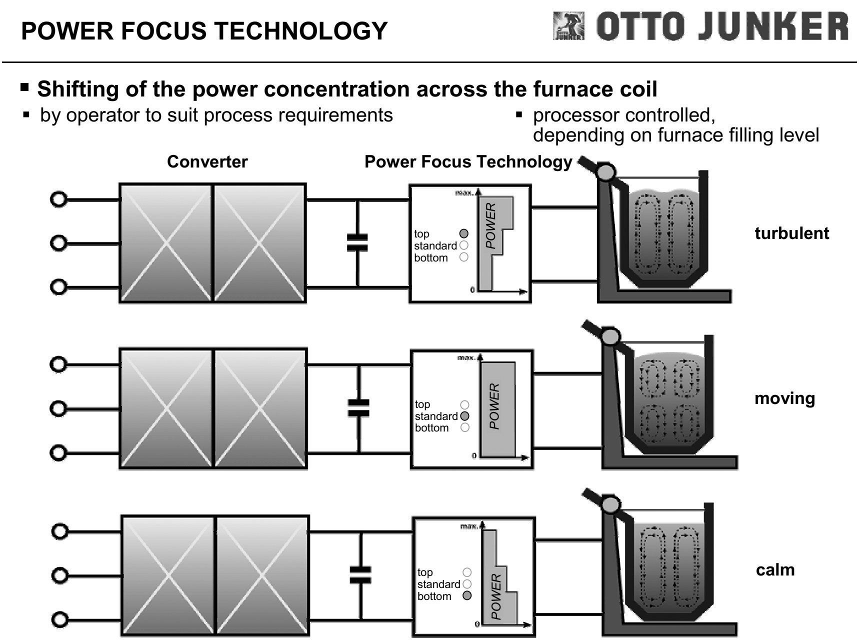
is the registered trademark of the firm of ABB for all casting units with and without heating manufactured by ABB.

Power-Focus

is the name used by the firm of Junker or the displacement of the output concentration over the height of the furnace coil.

Precision casting

should only be used as a general term for waste-wax casting.



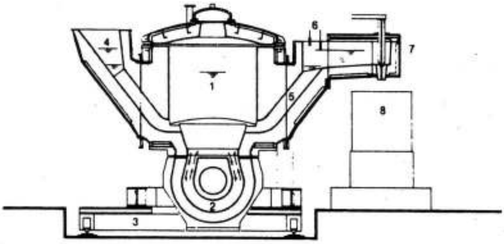


Figure 1: Schematic drawing of the pressurized gas-operated Pouromat OCC pouring system

Leg Fig 1

1 = pressurized vessel with molten iron
2 = channel inductor (heating system)
3 = base frame with long and cross travel mechanis
4 = fill siphon
5 = pour siphon
6 = contact pins for level regulation in the pour siphon
7 = stopper actuation with pouring nozzle
8 = casting mould

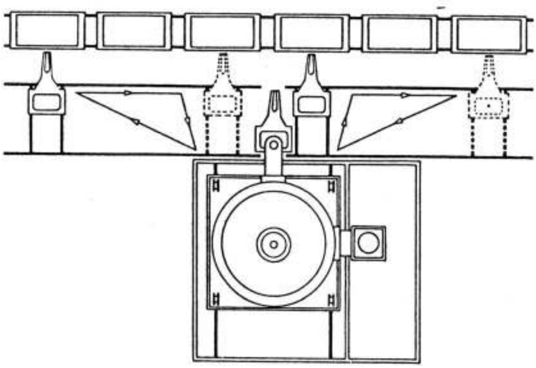
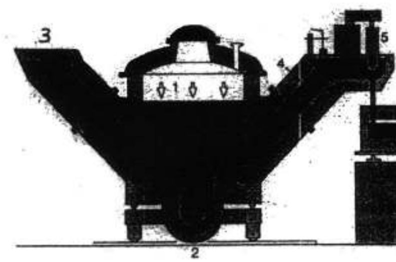


Figure 2: Pouring ladle carousel with 8 tonne casting furnace for automatic casting of continuously moving moulds



1 Pressure vessel with melt
2 Inductor
3 Filler pipe
4 Pouring siphon
5 Level control and stopper mechanism

Principle of the **PRESSPOUR®** channel furnace, whose melt content is under gas pressure, so that the metal level can remain constant at the outlet

Some special cases require intermediate ladle systems between the outlet of the casting spout and the mould (see Figure 16). Distribution ladles are suitable for this purpose, such as tilting or stopper ladles in a single or double arrangement, with the special feature that they can follow the movement of the mould during casting. The ladles are mainly required on continual mould systems, where they follow the mould line under automatic control during casting, returning to the filling position under the furnace spout after casting.

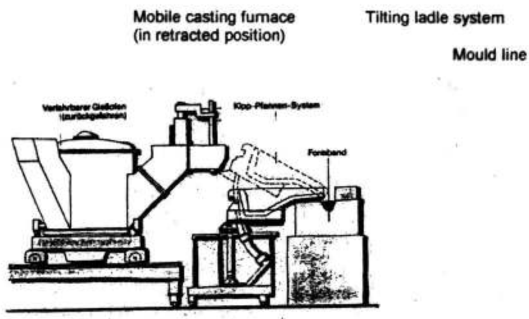
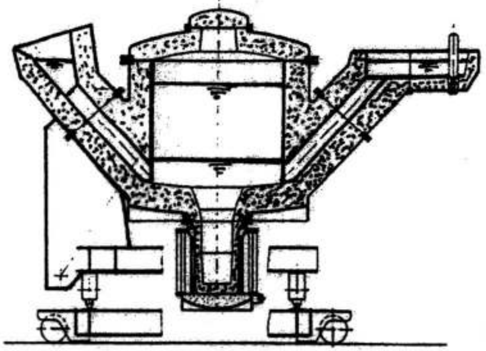
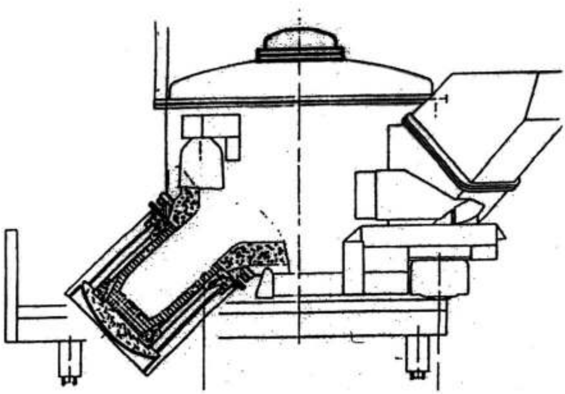


Figure 16: Tilting ladle system with the **PRESSPOUR®** casting furnace

Ladle systems are also required if large quantities of alloys are to be added during casting, or if the geometry of the barrel or box or mould weight do not allow direct casting from the outlet of the furnace nozzle.



PRESSPOUR® casting furnace with flanged crucible inductor, usable capacity 5 t, converter performance for crucible inductor 350 kW at 260 Hz.



PRESSPOUR® casting furnace with crucible inductor flanged at 45°.

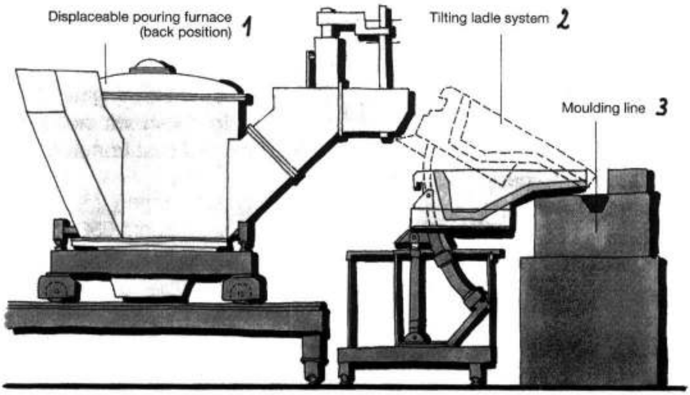


Fig. 13: Tilting ladle system with the PRESSPOUR® pouring furnace
1 travelling pouring furnace in retracted position
2 tilting ladle system
3 mould chain

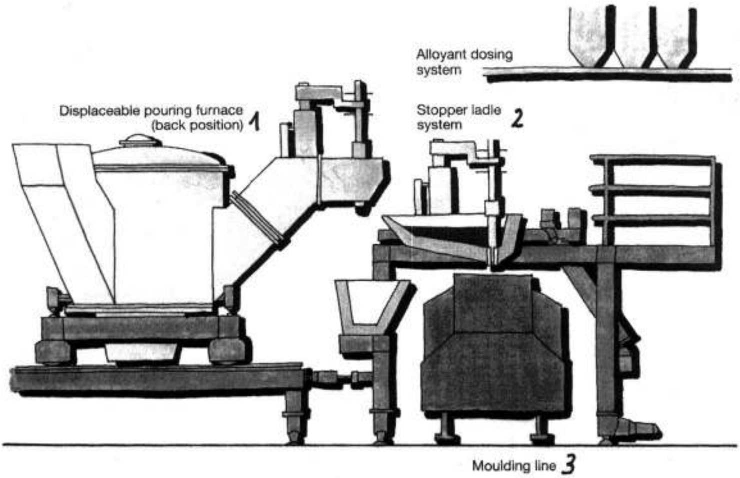


Fig. 15: Stopper ladle pouring system with pouring furnace and ladles arranged on a car
1 Pouring furnace in retracted position
2 Stopper ladle system
3 Moulding chain

Summary

The significant advantage afforded by automated pouring, such as increased production, lower material and personnel costs at the pouring station, higher quality of castings and improved conditions at the work place, are mainly achieved with induction heated pressurised gas operated pouring furnaces featuring stopper mechanisms for exact melt dosing and an intermediate ladle system added as required.

Pouring furnaces available are of the PRESSPOUR® type which are designed as small channel furnaces and can assume certain buffer and holding functions at useful capacities of 20 t and over. For higher demands respecting flexibility and the changing between lamellar and spheroidal graphite iron, MINIPOUR® furnaces are particularly suitable for small to medium production rates.

Normally, pouring as such is effected directly from the furnace into the mould. For this application, an efficient stopper mechanism which can be operated either pneumatically, electromechanically or hydraulically has meanwhile become available; an important feature of the mechanism is a patented nozzle brick cleaning device. Pouring is performed under a teach-in generated program or with a regulation system based on measurement of the metal level in the feeder head.

Intermediate ladle systems are chiefly used in automated pouring of continuously moved moulds or if the pouring times are longer than the cycle times. The ladles are designed as tilting or stopper ladles. An application of special interest is the utilisation of a stopper ladle system for adjusting the chemical composition of the melt downstream of the pouring furnace, enabling different iron grades to be poured in sequence without having to change the basic melt in the pouring furnace.

Pre-heating of Scrap

are usually used only at the edge of the crucible and in the spout area. One also refers to patch compounds, which are applied in accordance with the usage instructions. Since these compounds contain at least 5% water, they can also be sprayed on with the aid of suitable equipment. After an air-drying period, they must also be dried with a gas flame, in order to prevent such compounds flaking off on contact with the molten mass.

Preliminary alloy

is the designation for alloys used exclusively as alloy materials.

Pyrometers

are used for the measurement of high temperatures, and come in the form of thermo-electric and radiation pyrometers. Pyrometers are used for measurements between 1,000 °C up to a maximum of 1,600 °C (or for brief periods 1,800 °C).

Processors

are available for crucible, channel and holding furnaces and for casting units. The melting processor fulfils the widest possible range of tasks. In the case of crucible melting furnaces, the processor consists of a computer with colour monitor for the information of the operating personnel, a function keyboard for the operation of the system and a printer for recording and printing out the operating data.

The following devices are connected via the relevant interfaces:
– the weighing system of the crucible furnace, which is mounted on pressure measurement units/weighing beams
– the immersion temperature measurement system
– the memory-programmable controls required for locking the system
– the analysis spectrometer a modem for remote diagnosis or service purposes a higher-level process control system
– The processor regulates and controls the furnace output and energy supply in relation to the signals it receives from the connected devices. The melt processor calculates the average temperature of the charge on the basis of the furnace contents and the amount of energy already supplied. The following information is displayed on the monitor during the running of the melting programme:
– the weight of the melt
– calculated average temperature of the melt
– total energy consumption in relation to the charge
– specific energy consumption in relation to the charge
– remaining energy available
(look pages later)

JOKS

JUNKER Furnace Control System

Data logging

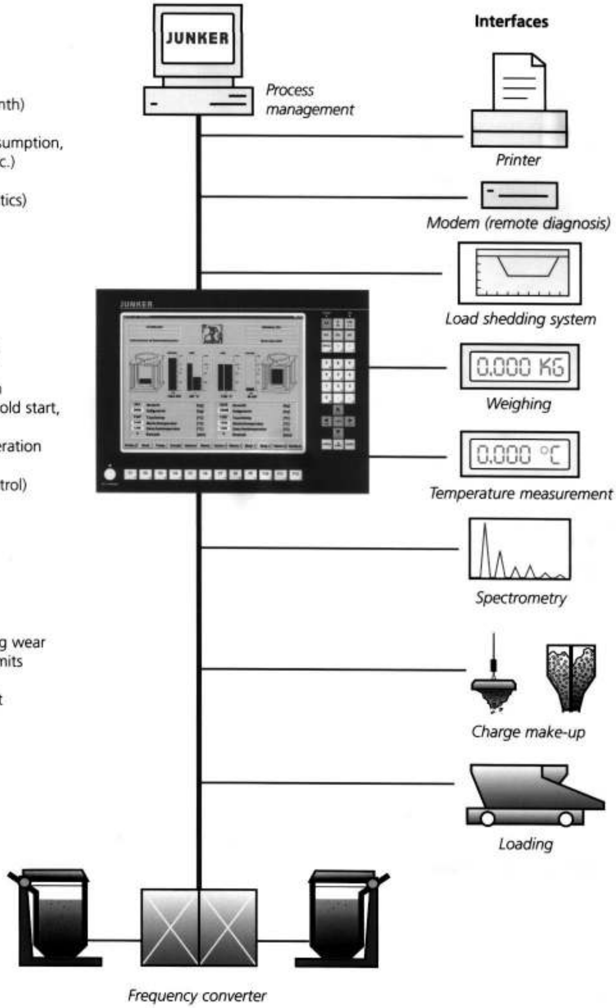
- Report generator (per load, shift, month)
- Charts (trends, power consumption, refractory status, etc.)
- Alarms (errors, faults, statistics)

Automation

- Charge make-up
- Loading (Charging)
- Power input
- Modes of operation (melting, holding, cold start, sintering, etc.)
- Parallel furnace operation
- Data exchange (PLC, converter control)

Monitoring

- Analysis correction
- Cooling water, lining wear
- Operating status, limits
- Process data
- Power management
- Quality assurance



Tele-Service

The melting processor Tele-Service module enables the ABB service team to perform diagnostics, maintenance and customer service by telephone on a world-wide basis. It connects the plants and the experts with each other throughout the world.

Tele-Service enables the service personnel in the ABB departments to operate the melting processor in the customer's plant as if they were on site.

The fault can be diagnosed and the parameter can be changed from Dortmund via Tele-Service.

Tele-Service for the melting processor is the fastest communication of our specialists with the plants installed all over the world; it is a novel economic service from continent to continent.

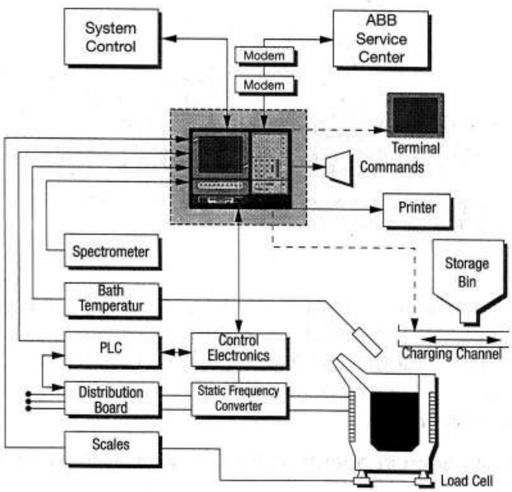


Fig. 6: Tele-Service

The cooling water temperatures in the individual water circuits and the supply temperature can be displayed and monitored via further connections. On completion of the melting process, an imaginary cover is placed on the system, and all the values registered so far are processed and displayed on the screen. The correction quantity of the individual materials is calculated from the temperature measurement and the analysis of the melt. Following the addition of these correction materials, they are blended in, and the melt simultaneously brought up to the preset

casting temperature and target composition. The melt processor then switches the furnace to the holding mode, and instructs the operator to start the casting. After casting of the maximum quantity available, taking into account the sump quantity remaining, the next melting process can be started. Besides the control of the actual melting process, the melt processor also has several other programmes that can be called up. The processor has a programme for the starting of a cold crucible after extended shut-down, e.g. following the weekend or longer shut-down periods. The programme enables the safe inductive heating of the charged crucible, so that normal melting operations can be resumed at the start of the shift.
A further programme is available for the sintering of a newly relined crucible. After relining, the processor controls the sintering process by means of time-related temperature profiles. The wear to the crucible is also monitored by means of the changing parameters for effective and idle output, frequency and crucible capacity caused by the gradual reduction of the wall thickness. It calculates the washing-out of the furnace crucible from the electrical data of the furnace. The time progression of the wall thickness during the life of the crucible, and the current condition of the crucible during operation are then displayed on the screen. All similar events signalled by the relevant interfaces, including any faults or problems occurring, are registered, recorded and printed out at the appropriate time. All relevant operating data are provided regularly via the charge report, and automatically printed out for the last charge whenever required, or when starting the next charge. In the case of inductively heated channel furnaces or casting furnaces, the processor stores the following data:inductor voltage and current effective and idle output insulation resistance between the inductor cooling jacket and the metal in the inductor channel, other parts carrying voltage and earthcooling water temperatures of the supply and individual circuits temperatures at 5 points in the boiler the processor for this application stores all the values measured. It can display one or more of the values on the monitor, in relation to time, and print them out on the printer as required. The operator can select between several periods between the start of the inductor and the last 4 hours.In order to guarantee reliability against faults, the inputs and outputs of the computer must be connected to the furnace by memory-programmable controls. All registered and stored data can be transmitted and processed for remote maintenance by means of a modem. With the aid of the recorded values, the inductor diagram can be calculated and displayed. If critical situations occur during operation, the processor generates the relevant alarm.
The integral statement regarding the relationship of effective and idle output can be assisted by the display of the losses in the water-cooled components of the housing. This also tells the operator whether the inductor is being washed out, e.g. in the area of the lower section and accumulating deposits in the upper section.

Process Solution for Sand

is an importand point for the modern foundry. On the next 2 pages You will find some interesting information from a competent company GUT

Quartz

is a fireproof material, which consists largely of silicon dioxide (SiO_2). At 870 °C a conversion takes place, which on cooling leads to contraction cracks. These cracks close up again on heating up to over approx. 1,000 °C.

Quality symbols

are used to designate certain products. The best-known quality symbol for foundries using nodular graphite is the “4G”.

Quenching

is the general term for a temperature reduction at a high cooling speed. Mould materials with high heat conductivity lead to the quenching effect, which is all the greater, the thinner the wall of the casting is.

Raw iron

is the first smelt produced in the blast furnace, and consists of the untreated iron obtained from iron ore. Raw iron is used as the charge material for the production of cast iron and for steel production. Hematite raw iron is used exclusively for foundry production. The standard material has the following chemical analysis:
2.50 to 3.00% Si, 0.70 to 1.00% Mn, max. 0.12% P, max. 0.04% S, 3.70 to 4.1% C. Foundry raw iron is also used in foundries, and differs from hematite manly with regard to the phosphorous content, which at 0.50 to 0.70% is 4 to 6 times higher. Specular pig-iron is a special raw iron with a significantly higher manganese content of from 6 to 30%. The normal analysis is: 4.00 to 5.00% C, 6.00 to 30.00% Mn, 0.10 to 0.15% P, up to 1.00% Si, up to 0.04% S.
Further types of raw iron include:
Low-carbon or high-carbon raw iron, Siegerland special raw irons, special raw iron for the production of cast iron with nodular graphite and charcoal raw iron. Raw iron is generally used in the form of pigs or ingots of approx. 20 kg in weight, or more rarely as 60 kg joined ingots consisting of 3 20 kg pigs.

Racking off

is the removal of slag from the surface of the bath. Racking off is also used to refer to the removal of auxiliary casting materials from bunkers with the aid of mechanical devices.

Reactive power

is the product of the coil voltage multiplied by the reactive current flowing between the furnace coil and the capacitor battery, given in k Var.

Resistance

in electrical technology is the product of the voltage present at the two ends of an electrical conductor and the current flowing through it (current strength). R=U: I. This resistance is also referred to as the Ohm resistance. In addition to the Ohm resistance, electrical technology also uses the terms "inductive resistance in coils" and "capacitive resistance of condensers". The unit of measure is the Ohm. This relationship was discovered by the physicist Ohm, and the formula is referred to as "Ohm's law".
U=RxI (voltage=resistance x current strength / Volt=Ohm x Ampere).

Robot

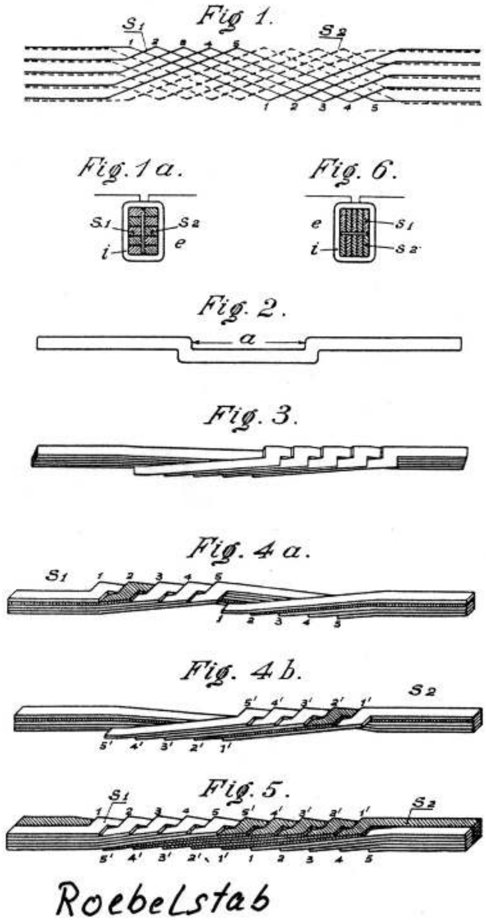
is a designation for a human-like mechanical device or machine, which comes from the Czech language. Modern industrial robots are highly mechanised, and are now indispensable in the foundry industry. In die-casting foundries in particular, and in view of the low piece weights involved, robots started to be used as soon as they had been developed. Today, robots with handling weights of up to 500 kg are used successfully.

Roebel (transposed) conductor or drill conductor

was a special conductor guide used in generator technology. The BBC engineer Ludwig Roebel was awarded a patent for these interwoven or drilled copper strips on 19th March 1912. The special feature of this conductor is the fact that every individual conductor within a specified length range is present in every layer of all the individual conductors. The individual conductors are insulated from one another, and therefore reduce the considerable eddy currents that cause losses. In induction furnace technology, advantage has been taken of this knowledge in the design and construction of air-cooled inductors of up to approx. 500 kW per inductor coil. This form of conductor cannot be used for crucible induction furnaces. Due to the dimensions of the channel, the iron core, the diameter of the coil, the number of windings, the length and the cooling air ducts necessary for the construction of inductors, the use of air-cooled inductors is necessarily restricted. From the physical and energy-technology point of view, their use can be highly recommended, since the losses are lower than with normal conductors formed in parallel and water-cooled hollow copper conductors. For comparison, the copper loss figures for the 3 most common conductor types at 500 kW nominal output are:

water-cooled hollow copper conductors	approx. 90 kW
12-way flat individual conductors, undrilled	approx. 75 kW
12-way flat individual conductors, drilled	approx. 64 kW

However, since it is comparatively expensive to provide the relatively clean cooling air required, the water-cooled inductor has become the type more commonly used in practice. Air-cooled inductors are constructed with an output of up to approx. 150 kW and generally have 1-way flat conductors, or from approx. 120 kW also 2-way flat undrilled conductors.



Rotary drum furnaces

are heated by means of gas or oil, and are used for the production of non-ferrous metals and grey cast iron. With the aid of high-performance burners, temperatures of up to 1,500 °C can be reached in the melt. Despite the relatively low investment costs, this type of furnace has not become very widely used, due to the very restricted alloying possibilities.

Sample ladles

are casting ladles used for taking a sample of the melt and for the casting of test pieces.

Sand preparation

is he general term for the production of finished moulding sand used for sand moulding, shell moulding and for core production. Sand preparation is divided into new and old sands.

Saveway

is a system that works as follows: it is based on the highly non-linear change in the electrical resistance of the fireproof material. As the crucible wall thickness is reduced, the melt penetrates further forward in the direction of the installed electrode plates. This causes the temperature of the fireproof material in front to rise, while its electrical resistance falls. For the measurement current, this means that it flows from one electrode to the melt, and from there back to the other electrode. A certain proportion of the measurement current flows directly from electrode to electrode. This proportion tends toward zero with reducing wall thickness, while the measurement current through the melt increases sharply. This alteration in the condition of the fireproof lining is assessed by the complex measurement system, and the wear to each electrode plate is calculated and displayed (page 222).

Scrap drying

is essential for induction furnaces if the charge material is stored in the open instead of indoors. When operating induction furnaces, care must be taken to ensure that no fluids get into the melt. 1 cm^3 of fluid getting into the bath will expand suddenly in volume to 500-600 cm^3. This is referred to as a water vapour explosion. With medium-frequency furnaces, scrap drying can be dispensed with provided that the scrap is handled accordingly. The operator must at all times ensure that material is not charged into the sump, but that there is always enough solid material on top of the melt so that it will be dried before coming into contact with the melt.
The former practice of heating scrap up to temperatures of approx. 200 °C is no longer viable nowadays because of increased energy costs. The material made up 60% and the container the remaining 40%. The achievable melting performance increase is significantly lower than that indicated by the theoretical calculations.

Scrap pre-drying

For all materials used in induction furnaces, care must be taken to ensure that no damp material is immersed in the molten bath, since this can cause explosive eruptions. Usually only a small proportion of the materials are damp to any

extent. If this part of the charge is charged in last, the damp can dry off before the material is immersed in the bath.
In critical cases, and for reasons of operating safety, the charge materials must be dried out in advance. The heating needed for this purpose is usually provided by oil, natural gas or electrical energy.
Earlier systems were usually designed for pre-heating temperatures of up to 600 °C, so that in addition to drying, pre-heating was also carried out, which equated to a heat content of the iron of around 100 kWh/t. This meant that about 25% of the required heat was provided by means of the pre-heating. The electrical output could consequently be reduced, or the throughput increased accordingly. High oil and gas costs have meant that this process is now restricted to drying of the charge material. This also allows some technical simplifications, since the process can be carried out at lower furnace temperatures.
The stationary system works with single-bucket heating. The filled bucket is brought into the heating station, the burner device is fitted, and the gas forced or sucked through the charge. For better utilisation, it can also be redirected and ducted away via the dust extraction system.

Yoke scrap is accordingly, and especially in larger systems, better dried in a push-through furnace (Figure 110). The heating is provided by oil or gas combustion, with the furnace temperature being set to 500 °C. In older systems of this type, a temperature of 800 °C was used; due to the more intensive convection created, the temperature could be reduced to 500 °C, which represents a better use of energy.

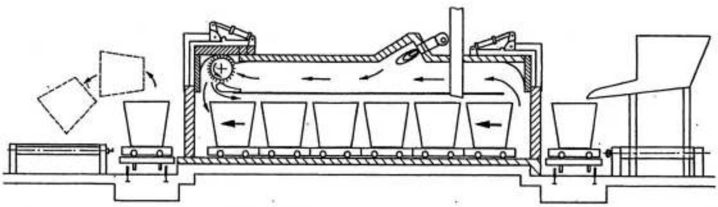


Figure 110. Pre-heating and drying of the charge for induction crucible furnaces; System: gas-fired push-through furnace system (500 °C) with high gas circulation, especially for the pre-heating of magnetic yokes. Furnace time about 60 min., core temperature of the magnetic yokes 200 °C, charge weight of the furnace 2 t, throughput 2 x 2 t/20 min. = 12 t/h.

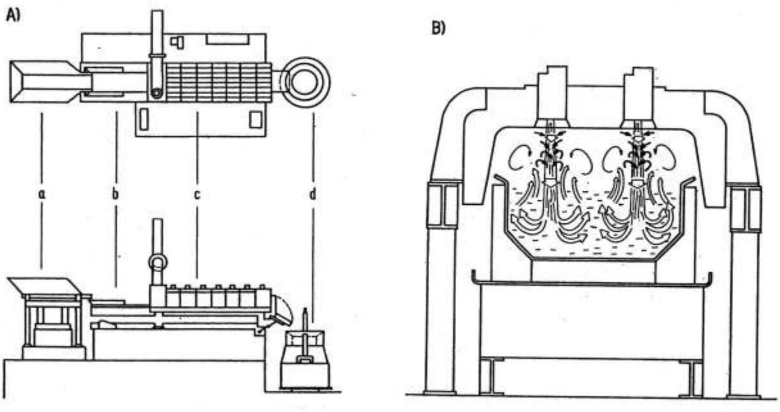


Figure 111. Pre-heating and drying of the charge for induction crucible furnaces; System: conveyor pre-heater [121]
A) Principle, B) Flue gas flow
a - feeding, b - pre-heater conveyor belt, c - pre-heating hood, d - charging basket

Semi-finished products

are metallic products in the form of pressed or drawn rods, wires, tubes and profiles, or rolled plates and strips.

Setting

is the hardening of mortar and concrete.

Shaking ladle

are used as treatment ladle for molten metals. The shaking movement is produced y means of an excentric drive. Shaking pans are often used for the desulphurisation of blast furnace and cupola furnace iron. The weights range from 0.8 t to a maximum of approx. 10 t.

Shell moulds

consists of least 2 mould halves or shells, which are stabilised with filling sand and used in mould boxes. The shell moulds are machine-manufactered, and are used for casting materials that tend to penetration.

Short-circuit rings

are used in magnetic applications in order to keep the scatter fields away from certain components. In crucible induction furnace design, short-circuit rings are required for furnaces with a high specific output, so that the components mainly in the upper furnace area are not heated excessively by the scatter field. In the bottom area, the electrically conductive parts are further away from the coil than those in the upper area. The short-circuit ring is made of coil copper in a water-cooled design. The ring is usually fitted above and behind the iron piles, in order to generate an opposing field to the scatter field. By reason of the induction law, the magnetic field generated is arranged in opposition to the generating magnetic field.

In furnaces with high specific outputs, the loss performance in the short-circuit ring can amount to approx.10 kW. The amount of water required to dissipate this energy is approx. 35 l/h and kW, and therefore approx. 350 l/h at 10 kW. The short-circuit ring must be installed electrically insulated from the supporting construction. Casting into the upper concrete ring without any possibility of escape for loss water is not recommended.

Shrinkage dimension

is expressed as a percentage shrinkage between the model and the casting. This is the linear contraction of a casting when cooling down from the solidification temperature to room temperature.

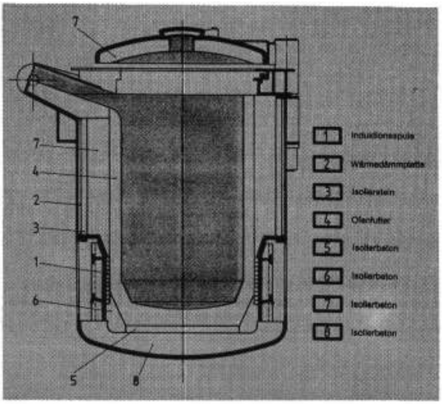


Figure 12: Crucible-type storage furnace with short coil

<u>Legend Fig. 12</u>

1 induction coil
2 heating insulation plate
3 insulation brick
4 furnace lining
5 insulating concrete
6 insulating concrete
7 insulating concrete
8 insulating concrete

Shrinkage cavities

are created when a melt solidifies due to volume contraction. With suitable mould design, the shrinkage should occur in the ingate or riser, and not in the casting itself. Exothermal supply heating can be provided with the aid of shrinkage powder.

Shellac

is used in the foundry in an alcohol solution with methylated spirits as a coating for plaster models. Shellac is a natural resin.

Short-coil furnaces

come in 2 quite different versions. In version A, a "lower furnace with an integrated low induction coil" is flange-fitted below a "cylindrical upper furnace" without cooling equipment. The iron piles are fitted only in the area of the furnace coil. Version B consists of a crucible furnace with a low induction coil and a cooling coil made of V2A material installed directly in the coil extension. The iron piles are fitted with electro-plate in the area of the coil, and in the area of the cooling coil, only the extended side plates with their welded bridges serve to support the cooling coil against the furnace body. Die losses with Type B are approx. 15% lower than with Type A, due to the higher induction coil (look page before).

Silicosis

is a lung disease caused by breathing in dust with a high proportion of very small particles. A respirator mask with nose filter should be worn whenever working with SiO_2 materials.

Simplex operation

refers to the melting of solid materials in a furnace without the addition of any molten charge.

Sintering

is the compaction of crystalline, granular or powdered materials by means of accretion of the crystallite under corresponding heating, without any of the components being melted. With the use of sintering agents, the reaction temperature can sometimes be reduced by up to 200 °C. For example, boracic acid or boric anhydride are used in the case of acidic tamping compounds. With the addition of 0.8%, the sintering point of pure quartzite is lowered from 1,700 °C to 1,550 °C.

Siphon outlet

a siphon outlet enables slag-free casting from foundry ladles. In channel furnaces, the inlet and outlet are arranged according to the siphon principle. In this way, the molten metal is always fed in and removed below the bath surface. When emptying below the minimum sump level, the function of the siphon must not be interrupted for filling, i.e. the furnace may only be tipped back slowly, in relation to the filling level. If the furnace is tipped back into the basic position while still under-filled, the ingress of air, and thus also oxygen, is unavoidable. The furnace atmosphere is therefore enriched with oxygen, leading to increased slag formation on the melt sump. The ceramics in the transitional area between the siphon and the furnace vessel can also be damaged.

Skimming

is generally carried out after reaching the tapping filling level. In most cases, a slag forming agent is applied to the bath, and then removed with manual equipment or pneumatic slag removers.
The tools used must be treated in advance with blackening to facilitate subsequent removal of the slag. Tools must be heated and dried over the bath before immersion in the liquid melt.

Slag

consists of oxidic materials which are largely insoluble in molten metals, and instead separate from them to form a separate layer on top of the molten metal. A distinction is made between basic and acidic slag.

Slag control agents

are added to the melting furnace as slag additives in order to alter their composition, or to bind the slag being formed, so that this can then be removed with suitable tools, i.e. tapping the slag. Such agents are also used to remove heavy slag deposits from the furnace walls. Normal soda is also often used for this purpose. When using soda however, care must be taken to ensure that the crucible wall itself is not damaged.

Soldering

is the term for the joining of 2 metallic materials by means of a soldering material with a lower melting temperature. The metal components to be joined must be metallically clean. This cleaning is carried out with the aid of soldering fluid or soldering grease. The heat source can be provided by soldering irons, soldering lamps or burner flames. In industrial applications, induction heat and electrically heated through-type furnaces are used.

Solidification

is the transition from the molten to the solid state. Contraction occurs during solidification, and the resulting volume reduction on the mould has to be compensated for by the addition of more molten metal.

Solidification temperature

is the temperature at which a material changes from the liquid into the solid state, or at which solidification starts. Solidification is completed when the solid temperature is reached.

Soot

is produced in special furnaces by means of the incomplete combustion of gases, liquids or solids containing carbon. Soot is a carbon product with a particularly small particle size.

Spectral analysis devices

are used for the rapid chemical analysis of a material by means of the spectrum of its components. The sample is exposed to an electric arc. The light emitted by the arc is refracted into its different spectrums, showing the spectral lines of all the elements contained in the material. The qualitative analysis of the individual elements contained in the sample is carried out by identifying these lines. As a rule 8-10 elements are identified.

Spin casting

is a casting process in rotating moulds using the effects of centrifugal force. This process is used for the production of tubes and cylinder sleeves.

Spinel

is an aluminous mineral with the chemical formula MgO Al_2O_3 for genuine spinel. Consist of at least 2 mould halves or shells, which are stabilised with filling sand and used in mould boxes. The shell moulds are machine-manufactured, and are used for casting materials that tend to penetration.

Starter blocks

are needed for starting up induction crucible furnaces of up to approx. 150 Hz operating frequency,so that the furnace can start with an acceptable power consumption and electrical efficiency. The diameter should be approx. 100 mm less than the crucible diameter on relining.
Conicality is required for rapid emptying from the mould. Some customers have made themselves separable moulds, and can therefore work with a very low conicality of below 1%. When casting the starting blocks, the lifting eyes of construction steel are cast directly into the block. In order to prevent damage to the lifting eyes during stacking in the crucible or during storage, it is advisable to create corresponding recesses in the lower area of the starting blocks. With the corresponding design of the mould with 2 lateral grooves, the prefabricated lifting eyes are inserted into these grooves and thus adequately held in place. Operators of medium-frequency systems should also keep a number of starter blocks in stock, since these are very helpful for pushing in light scrap or lowering the melt temperature for sump smelting.

Starter rings

can be used as a substitute for starter blocks. The outer diameter is approx. 100 mm less than the crucible diameter, and the inner diameter of the rings is approx. 200 mm less than the outer diameter. The use of such rings was recommended in the 1970’s for mains frequency furnaces with crucible diameters > 1,000 mm for sinter charging. The first ring was placed on the crucible cone; distance pieces 50 mm thick and about 100 mm long and wide were then placed at three places around the circumference of the ring. The next ring was then placed on top of these parts. This procedure was repeated up to the upper edge of the induction coil. Compact scrap can also be filled in inside the rings right up to the top. Due to the good coupling, this ensures very even heating of the rings, and thus also of the ramming template and ramming mix. Dry mixes were heated at approx. 100 °K/h. When semi-plastic mixes with up to 4% moisture were used, the temperature increase was reduced to 50 °K/h. This allowed even drying by means of the ramming template on the crucible wall. This process was however discontinued at the end of the 1970's for cost reasons. The starter rings were made from approx. 80/100 mm thick steel plates. One customer in Finland cast the rings from scrap iron.

Starting

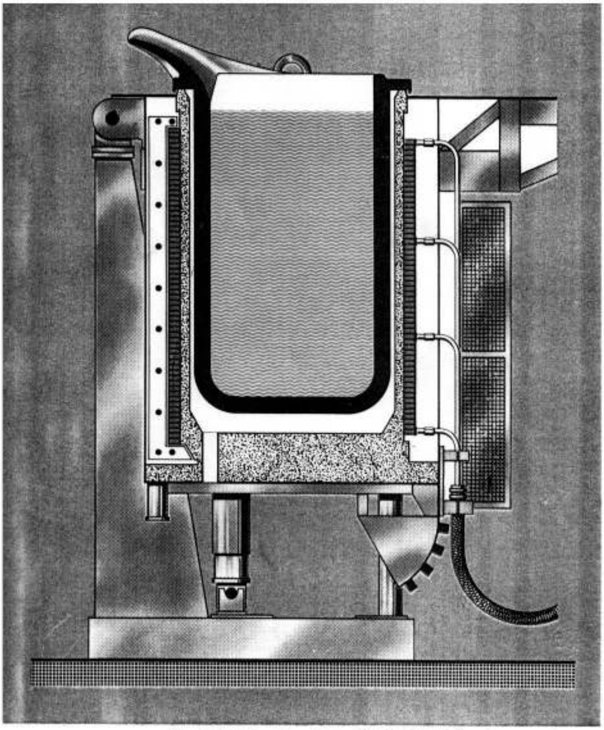
of induction crucible furnaces varies greatly, depending on the working frequency. There is the starting of a new crucible, and a crucible that has already been in operation, also known as cold starting.
Starting of a new crucible is also referred to as sintering; this may be liquid sintering following removal of a permanent template, or with a lost template, which remains in the furnace and is also melted. After reaching the maximum filling level, the melt is brought up to approx. 50 – 100 K above the normal tapping temperature, and maintained at this temperature for up to 2 hours for acidic crucibles and for up to 4 hours for neutral and alkaline crucibles. The 1^{st} tapping is then carried out.
When starting damp lined crucibles, the manufacturer's instructions must be strictly observed, in order to ensure that the damp is driven out. These crucibles cannot be charged with molten metal.
Mains frequency furnaces without liquid filling must be started using starter blocks. The diameter should be approx. 100 mm less than the crucible diameter. The filling height should be about 2/3 of the coil height.
Medium-frequency furnaces without liquid filling can be started using normal steel scrap, although this should not contain any chips, any dimensions greater that 50% of the crucible diameter or any magnetic yokes.

Steel

is an alloy of iron which can be forged without any further treatment. The limit of forgeability or malleability lies at approximately 2% C (as a rule at 1.7% C). In the binary iron-carbon system, all alloys with contents of up to about 2% C are considered as steels, whereas cast iron, tempered cast iron, hard cast iron and raw iron are not. There are a large number of trade and manufacturing designations for steel, some of the better-known types of which are given below:
Austenitic steel, machine steel, strip steel, construction steel, stainless steel, case-hardened steel, cast steel, spring steel, profile steel, cold-rolled steel, LD steel, alloyed steel, magnetic steel, non-rust steel, tempered steel, heat-resistant steel and tooling steel.

Steel crucible furnaces

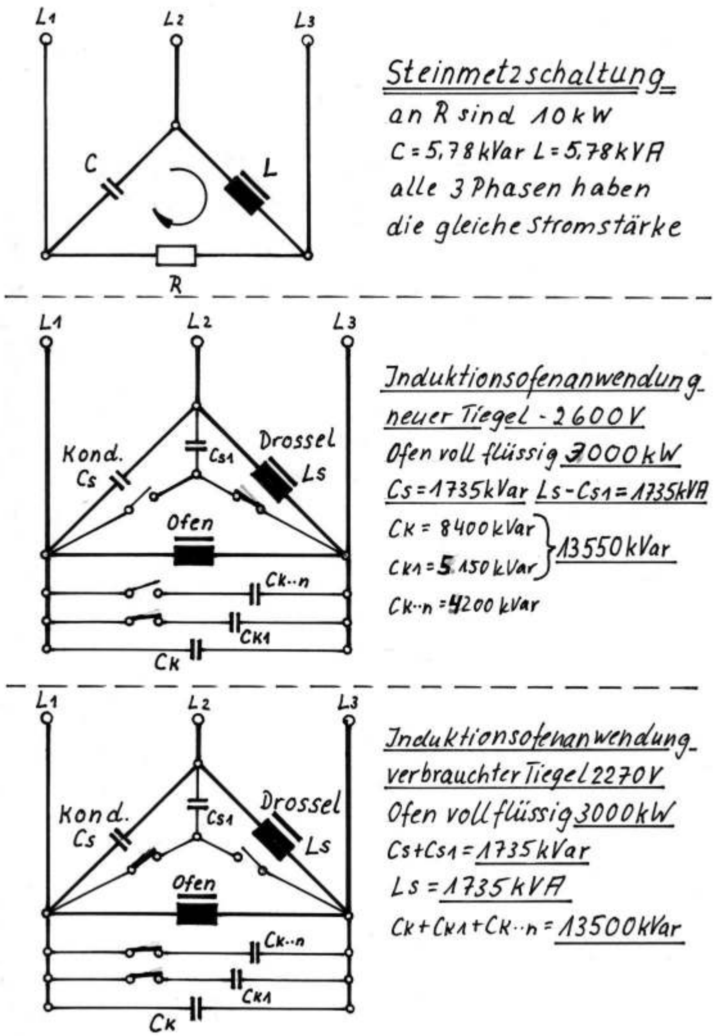
are crucible furnaces that work with a crucible made of welded or cast steel. Steel crucibles are used for non-ferrous metals and as a rule for special applications. The most common application is the melting of recycled magnesium.

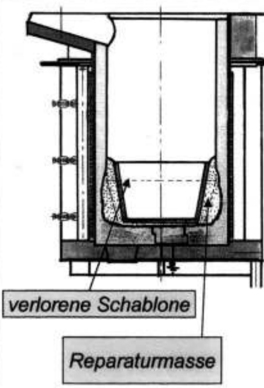


Stahltiegelofen f. Magnesium

Steinmetz switching

is the balance switching for the operation of 1-phase induction furnaces from 3-phase rotary current networks. In the case of Steinmetz switching, it is assumed that the compensation of the 1-phase furnace is set to 1. By means of balance control, the capacitive part of the balancing is switched in sequence with the inductive part, i.e. the capacity of the balancing condensers equals the output of the choke. By means of corresponding condenser stage switching, condensers are switched in parallel to the choke or the balancing condensers. The level of the balancing performance depends on the output being absorbed by the induction furnace. The ideal figure is the furnace output divided by 1.73. Since a crucible induction furnace is designed so that it can still be operated at nominal load even with approx. 25% washing-out, the transformer steps must be designed in the same way. The balancing must thus have a sufficient capacity even at correspondingly low furnace voltage. With a 12.5-t furnace with 3,000 kW output at 2,600 V, the voltage steps for the same output would be arranged as follows: 2,600V, 2,490V, 2,380V, 2,270V. The balancing must be designed to cater for this lowest voltage, so that at this voltage, the condenser output still has the required 1,735 kVar and the choke the required 1,735 kVA. At 2,600 V, the balancing condensers thus have 2,275 kVar and the choke 2,275 kVA as the nominal output.





Beim Entleeren des Ofens in kleinen Mengen bei konstanter Abgießtemperatur kommt es zu Vorverschleiß im Konusbereich (Elefantenfuß)

Reparatur:

- Feuerfestfutter von Schlacke reinigen
- Teilschablone einbauen (verlorene Schablone)
- Quarzitstampfmasse hinterfüllen und verdichten
- Ofen auheizen wie bereits beschrieben

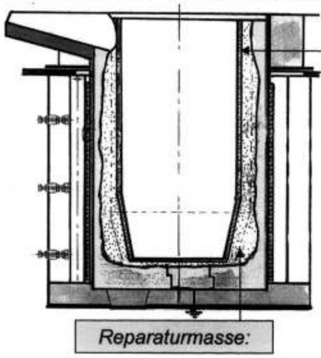
W.Clören/R.Wesser

EKW Feuerfest und Service im System

Konusreparatur des Induktionstiegelofens

RWesser

22.43



Normaler Verschleiß im Induktionstiegelofen

Reparatur :

- Boden und Ofenwand von Schlacke reinigen (schälen)
- Boden stampfen
- verloren Schablone einbauen
- Trockenstampfmasse einfüllen
- Vibrieren mit Wandrüttler
- Aufheizen wie bereits beschrieben

W.Clören/R.Wesser

EKW Feuerfest und Service im System

Ofenwandreparatur des Induktionstiegelofens

RWesser

22.45

Stripping

is rarely carried out nowadays in view of the relatively low costs of acidic tamping compounds. In stripping, the crucible wall, which is infiltrated with iron, is removed with the aid of compressed air hammers. The thickness of this layer ranges from 30 to 50 mm. After the removal of the waste, the “crucible wall” is cleaned of loose particles. A lost tamping form is now put in place and the dry compound filled in. After vibration and compacting, the crucible furnace is started up again as for a normal relining. This process saves the costs of the insulation behind the wear lining and the proportion of the compound remaining in the furnace of approx. 30%.
If the crucible is pressed out with the aid of a crucible removal device, the costs of stripping are only worthwhile in rare cases. For mains frequency furnaces <over approx. 12 t, more economical repair can often be effected by means of partial stripping of the lower section. Stripping is carried out over about the lower third of the crucible height, and an approx. 60 mm smaller repair template then positioned. A nominal diameter of 1,190 mm thus gives approx. 1,130 mm. This is pre-heated with a gas burner and then liquid-sintered (look page before).

1. Direct pouring into the mould

As long as there are no additional requirements (see below), the melt is poured directly from the furnace into the mould as schematically illustrated in Figs. 1 and 8. In this case **the stopper mechanism must be particularly efficient** to meet the specified task. **Fig. 10.** shows the current ABB stopper mechanism with cleaning system.

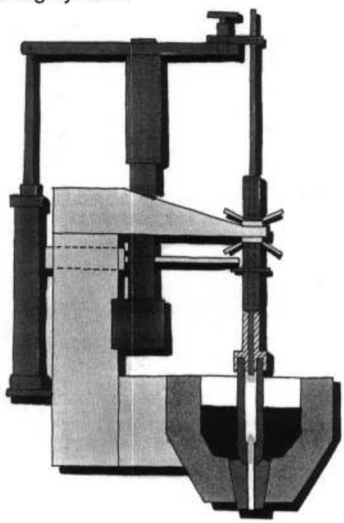


Fig. 10: ABB stopper mechanism with patented pouring nozzle cleaning device

The advantage of pouring furnaces over unheated systems lies in the fact that, after an unexpected stillstand of the moulding plant, production can be resumed as the pouring furnace is ready for pouring without any time delay.

Both heated and unheated systems feature the same practice-proven substructure with longitudinal and transverse axles so that they can be readily adapted to differing pouring positions.

The stopper design mechanism is associated with both systems. Figure 6 shows the design of a pneumatically actuated stopper mechanism consisting of a pneumatic drive with torsionally rigid arm, a rapid-change stopper holder, a stopper turning device and a patented cleaning device for the nozzle. The latter has proved to be particularly valuable in connection with automatic pouring of Mg-treated melts.

The pressing force of the drive has been purposely limited to 750 N to minimize stopper wear. This pressure still produces a tight closing seal, yet the surface pressure exerted on the edge of the nozzle still remains well within the limits of the materials. A pneumatic cylinder adequately dimensioned for this purpose and fitted with a proportional valve operates faster (by the factor 2.5) than a hydraulic cylinder designed for the same limit values. Moreover, the pneumatic system eliminates the use of hydraulic fluid within the hot zone of a pouring installation [2].

The stopper rotating device prevents leakage. The stopper is turned by approx. 60° during the closing operation before the maximum closing pressure is applied. The number of pouring cycles between the individual turning operations can be adjusted in the control system for adaptation to individual requirements.

The outlet cleaning rod conducted through the hollow stopper can be used whenever required. At the end of a selected pouring cycle the cleaning rod passes through the nozzle and scrapes off the incrustation which falls onto the mould box. The resulting clean cross-section of the nozzle guarantees a reproducible volume stream.

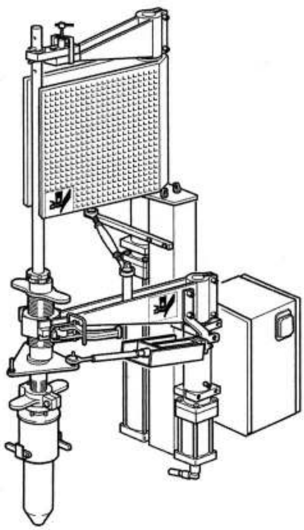


Fig. 6: Design of the ABB stopper system for automatic pouring.

Stoppers

are used for sealing off the tapping hole of cupola furnaces. The material used is graphite clay. For sealing off a stopper ladle, a stopper is screwed to the stopper rod that seals off the outlet hole.

Stopper actuators

come in hydraulic and pneumatic versions. Through the use of optimised components, both types are fast enough, and also very reliable. The casting of nodular graphite iron is usually carried out with the aid of hollow stoppers, through which the outlet block can be cleaned at regular intervals or after every casting by means of a suitable cleaning stopper.

Stopper ladle

is a casting ladle with bottom emptying, which can be emptied by raising the stopper rod. Alternatively, a swivelling stopper can also be used.

Storage

is the term for the “storage” of a melt in a storage or holding furnace, which can take the form of a channel or crucible storage furnace. When storing GGG, special attention must be paid to the magnesium melting loss, so that the cooling of the magnesium content does not get out of control.

Stored heat

is the heat content of the crucible and the mass in the cover. If a furnace cools down completely over the weekend, this energy has to be re-supplied to the crucible again at the beginning of the next week. A 5-t furnace has approx. 900 kWh as stored heat in the crucible and the cover.

Sump

is the technical term for molten metal in a melting furnace or a ladle which is not emptied, but is reused.

Sump melting

is as a rule practiced in mains frequency induction furnaces, The optimum sump height corresponds to approx. 2/3 of the filling level, since in this case the whole coil is filled with molten metal, and the maximum electrical / inductive coupling is available. Medium-frequency furnaces are operated with a sump of approx. 15% of the total capacity. After tapping a medium-frequency furnace, the sump is still at a relatively high temperature. When switching on the output again after charging, the remaining sump would be very well coupled, and would be over-heated for a short time. This produces an "elephant's foot" as is normal in mains frequency furnace operation. To avoid this, approx. 30% of the sump weight charged into the sump should consist of compact cooling scrap (risers, sprues and approx. 100 mm large pieces). In larger furnaces (from approx. 5 t), a "starter block" with a weight of approx. 30% of the sump weight can also be charged in. This simultaneously lowers the temperature, raises the bath level and reduces the wear to the crucible wall.

Switching on

of crucible induction furnaces is carried out as a rule by hand, or automatically with the use of processor controls. Mains frequency systems are usually connected in 3-phase to the 3-phase power supply system. By means of Steinmetz switching, the 3-phase system is also loaded equally over all 3 phases in the event of 1-phase connection of the induction furnace. Depending on the load on the system, the out-of-balance load of the 3 phases amongst each other may also be up to 10% of the maximum phase current. At phase currents above approx. 500 A, the balanced phase is switched on in advance of the field, and a furnace current is switched via a switch-on resistance with reduced switch-on current. A short time after this switch-on process, the bypass contactor is switched in to short-circuit this switch-on resistance. By this means, the high switch-on current of approx. 1,500 A can be reduced to about one third of this level. The starting of a mains frequency furnace via the individual transformer steps offers no benefits, since every individual step is ultimately switched on at full load. The main disadvantage is the multiplication of the hysteresis at the main and bypass contactors.
In the case of medium-frequency systems, the current is brought up, in accordance with the specifications, from 0 to the maximal value of the required current by means of a so-called start-up ramp. For example, some customers have this process set so that in the 1st switch-on phase, the output is brought up to 1,000 kW and then after approx. 10 seconds to the maximum output of 3,200 kW. As soon as the electrical power is switched on, the energy is available in the form of heat, in the same way as a flow heater. For this reason, and before switching on an induction furnace, the water supply to the furnace coil with sufficient volume of water at the right temperature must be ensured.

Synthetic iron

is a term for cast iron produced from steel scrap with the addition of carbon and silicon.

Tapping

is the removal of the molten metal from the furnace. Tapping refers in particular to the opening of the tapping hole of a blast furnace or cupola furnace, so that the metal can flow out into the channel.

Tapping temperature

is the temperature at which the molten metal is removed from the furnace.

Temperature

is the heat level of a material, measured in Kelvin (K) or degrees Celsius (°C). K is the SI unit of measure. The Kelvin scale begins at absolute zero, which corresponds to –273.15 °C. Conversion between k and °C:

K = °C + 273.15
°C = K – 273.15

Temperature differences are expressed in Kelvin, although they can also be specified in degrees Celsius.
In some countries, Fahrenheit is still commonly used as a unit. In this case, the conversion is as follows:

°C = (°F-32) x 5/9
°F = °C x 9/5 + 32

Temperature increase

is as a rule the temperature difference in °C or K per hour. Observation of the specified temperature increases is important when heating ceramic compounds. When over-heating melts, the values are given in K/min.

Temperature gradient

Temperature difference in relation to the distance between 2 points. The unit of measure of the temperature gradient is K/m or K/cm.

Temperature loss

is given in K/h for a completely filled crucible and with the electrical output switched off. Smaller furnaces have higher temperature losses than large furnaces. In a 1-t furnace at 1,450 °C, this will produce a figure of approx. 50 K/h and for 12 t approx. 30 K/h. These figures apply for a fully heated crucible and completely closed furnace cover, with the exhaust gas extraction switched off.

Temperature change

or temperature change resistance refer as a rule in induction furnaces to the properties of the ceramic materials at different temperatures. An acidic lining is less temperature-sensitive, and thus more resistant to temperature change than basic or neutral compounds.

Temperature Conversion

°C		°F	°C		°F	°C		°F
538	**1000**	1832	732	**1350**	2462	927	**1700**	3092
543	**1010**	1850	738	**1360**	2480	932	**1710**	3110
549	**1020**	1868	743	**1370**	2498	938	**1720**	3128
554	**1030**	1886	749	**1380**	2516	943	**1730**	3146
560	**1040**	1904	754	**1390**	2534	949	**1740**	3164
566	**1050**	1922	760	**1400**	2552	954	**1750**	3182
571	**1060**	1940	766	**1410**	2570	960	**1760**	3200
577	**1070**	1958	771	**1420**	2588	966	**1770**	3218
582	**1080**	1976	777	**1430**	2606	971	**1780**	3236
588	**1090**	1994	782	**1440**	2624	977	**1790**	3254
593	**1100**	2012	788	**1450**	2642	982	**1800**	3272
599	**1110**	2030	793	**1460**	2660	988	**1810**	3290
604	**1120**	2048	799	**1470**	2678	993	**1820**	3308
610	**1130**	2066	804	**1480**	2696	999	**1830**	3326
616	**1140**	2084	810	**1490**	2714	1004	**1840**	3344
621	**1150**	2102	816	**1500**	2732	1010	**1850**	3362
627	**1160**	2120	821	**1510**	2750	1016	**1860**	3380
632	**1170**	2138	827	**1520**	2768	1021	**1870**	3398
638	**1180**	2156	832	**1530**	2786	1027	**1880**	3416
643	**1190**	2174	838	**1540**	2804	1032	**1890**	3434
649	**1200**	2192	843	**1550**	2822	1038	**1900**	3452
654	**1210**	2210	849	**1560**	2840	1043	**1910**	3470
660	**1220**	2228	854	**1570**	2858	1049	**1920**	3488
666	**1230**	2246	860	**1580**	2876	1054	**1930**	3506
671	**1240**	2264	866	**1590**	2894	1060	**1940**	3524
677	**1250**	2282	871	**1600**	2912	1066	**1950**	3542
682	**1260**	2300	877	**1610**	2930	1071	**1960**	3560
688	**1270**	2318	882	**1620**	2948	1077	**1970**	3578
693	**1280**	2336	888	**1630**	2966	1082	**1980**	3596
699	**1290**	2354	893	**1640**	2984	1088	**1990**	3614
704	**1300**	2372	899	**1650**	3002	1093	**2000**	3632
710	**1310**	2390	904	**1660**	3020			
716	**1320**	2408	910	**1670**	3038			
721	**1330**	2426	916	**1680**	3056			
727	**1340**	2444	921	**1690**	3074			

°C		°F	°C		°F	°C		°F
1093	2000	3632	1288	2350	4262	1482	2700	4892
1099	2010	3650	1293	2360	4280	1488	2710	4910
1104	2020	3668	1299	2370	4298	1493	2720	4928
1110	2030	3686	1304	2380	4316	1499	2730	4946
1116	2040	3704	1310	2390	4334	1504	2740	4964
1121	2050	3722	1316	2400	4352	1510	2750	4982
1127	2060	3740	1321	2410	4370	1516	2760	5000
1132	2070	3758	1327	2420	4388	1521	2770	5018
1138	2080	3776	1332	2430	4406	1527	2780	5036
1143	2090	3794	1338	2440	4424	1532	2790	5054
1149	2100	3812	1343	2450	4442	1538	2800	5072
1154	2110	3830	1349	2460	4460	1543	2810	5090
1160	2120	3848	1354	2470	4478	1549	2820	5108
1166	2130	3866	1360	2480	4496	1554	2830	5126
1171	2140	3884	1366	2490	4514	1560	2840	5144
1177	2150	3902	1371	2500	4532	1566	2850	5162
1182	2160	3920	1377	2510	4550	1571	2860	5180
1188	2170	3938	1382	2520	4568	1577	2870	5198
1193	2180	3956	1388	2530	4586	1582	2880	5216
1199	2190	3974	1393	2540	4604	1588	2890	5234
1204	2200	3992	1399	2550	4622	1593	2900	5252
1210	2210	4010	1404	2560	4640	1599	2910	5270
1216	2220	4028	1410	2570	4658	1604	2920	5288
1221	2230	4046	1416	2580	4676	1610	2930	5306
1227	2240	4064	1421	2590	4694	1616	2940	5378
1232	2250	4082	1427	2600	4712	1621	2950	5324
1238	2260	4100	1432	2610	4730	1627	2960	5360
1243	2270	4118	1438	2620	4748	1632	2970	5378
1249	2280	4136	1443	2630	4766	1638	2980	5396
1254	2290	4154	1449	2640	4784	1643	2990	5414
1260	2300	4172	1454	2650	4802	1649	3000	5432
1266	2310	4190	1460	2660	4820			
1271	2320	4208	1466	2670	4838			
1277	2330	4226	1471	2680	4856			
1282	2340	4244	1477	2690	4874			

Relationship of Carbon Equivalent (CE[12]) to Liquidus Arrest Temperature for Low Phosphorus Hypoeutectic Gray Cast Irons

CE	Liquidus °F	Temp. °C	CE	Liquidus °F	Temp. °C
3.60	2250	1232	3.86	2198	1203
3.61	2248	1231	3.87	2196	1202
3.62	2246	1230	3.88	2194	1201
3.63	2244	1229	3.89	2192	1200
3.64	2242	1228	3.90	2190	1199
3.65	2240	1227	3.91	2188	1198
3.66	2238	1226	3.92	2186	1197
3.67	2236	1224	3.93	2184	1196
3.68	2234	1223	3.94	2182	1194
3.69	2232	1222	3.95	2180	1193
3.70	2230	1221	3.96	2178	1192
3.71	2228	1220	3.97	2176	1191
3.72	2226	1219	3.98	2174	1190
3.73	2224	1218	3.99	2172	1189
3.74	2222	1217	4.00	2170	1188
3.75	2220	1216	4.01	2168	1187
3.76	2218	1214	4.02	2166	1186
3.77	2216	1213	4.03	2164	1184
3.78	2214	1212	4.04	2162	1183
3.79	2212	1211	4.05	2160	1182
3.80	2210	1210	4.06	2158	1181
3.81	2208	1209	4.07	2156	1180
3.82	2206	1208	4.08	2154	1179
3.83	2204	1207	4.09	2152	1178
3.84	2202	1206	4.10	2150	1177
3.85	2200	1204			

Densities, Melting Points, and Heats

Substance	Density[13] g/cm³	Melting point °F	Melting point °C	ΔH_f, kcal
Aluminum	2.70	1218	659	2.55
Barium	3.75	1310	710	1.83
Calcium	1.54	1562	850	2.07
Carbon *(gr)*	2.22			
Cerium	6.75	1479	804	2.20
Chromium	7.10	3448	1898	5.00
Cobalt	8.71	2718	1492	3.64
Copper	8.96	1980	1083	3.12
Gold	19.32	1945	1063	2.955
Iron	7.87	2797	1536	3.70
Lead	11.34	622	328	1.14
Magnesium	1.74	1202	650	2.14
Manganese	7.43	2269	1243	3.50
Molybdenum	10.30	4700	2607	6.60
Nickel	8.90	2650	1453	4.21
Palladium	11.90	2826	1552	4.00
Platinum	21.45	3215	1769	4.70
Silicon	2.34	2575	1413	12.11
Silver	10.49	1762	961	2.70
Tin	7.30	450	232	1.72
Titanium	4.54	3033	1667	3.70
Tungsten	19.30	6152	3400	8.42
Vanadium	6.00	3474	1912	(4.20)
Zinc	7.14	788	420	1.765
Zirconium	6.50	3362	1850	(4.00)

Densities, Melting Points, and Heats

Substance	Density[13] g/cm^3	Melting point °F	Melting point °C	ΔH_f, kcal
Al_2O_3	4.00	3686	2030	26.0
B_2O_3	1.85	842	450	5.5
BeO	3.00	4586	2530	17.0
CaF_2	3.18	2584	1418	7.1
CaO	3.40	4712	2600	19.0
CaS	2.80			
CaC_2	2.22	4172	2300	
$CaSiO_3$	2.89	2804	1540	
Ca_2SiO_4 (α)	3.27	3866	2130	
Cr_2O_3	5.21	4109	2265	
$Fe_{0.95}O$		2498	1370	7.2
Fe_3O_4	5.20	2906	1597	33.0
Fe_2O_3	5.10			
FeS	4.80	2183	1195	7.73
Fe_2SiO_4		2223	1217	22.03
MgO	3.65	5072	2800	18.5
MnO	5.18	3245	1785	13.0
MnS	4.00	2786	1530	6.24
NiO	7.45	3540	1950	
SiO_2 (crist)	2.32	3115	1713	3.1
TiO		3668	2020	14.0
Ti_2O_3	4.60	3866	2130	
TiO_2	4.26	3344	1840	15.5
ZrO_2	5.6	4892	2700	

Templating

refers to the production of sand moulds of larger sizes for the production of rotationally symmetrical castings, using rotating templates in place of models, for example for the casting of bells.

Thermal storage heating furnaces

are used as holding and storage vessels in continuous and non-continuous foundry operations. Unforeseeable problems can also occur in continuous casting operations, which can then be rectified with the aid of storage furnaces. Storage furnaces are designed as channel furnaces or crucible furnaces with good heat insulation. A crucible storage furnace has the advantage of total emptying over a channel furnace, which must always be operated with a sump. The heat losses are as follows for 40-t furnaces:

a) normal crucible melting furnace	approx. 400 kW
b) crucible storage furnace	approx. 300 kW
c) channel furnace 40 t usable capacity/12 t sump	approx. 250 kW

Thermoelement

is an electrical element which generates a voltage when heated. It consists of 2 different wires, which due to the voltage, cause a current to flow. These are used up to a maximum of 1,600 °C. The voltage generated is in the mV-range.

Throat

is the term for the upper section of a shaft furnace, such as a cupola furnace. The furnace is charged through the throat, and the furnace exhaust gases are also drawn off through the throat.

Throat platform

is the platform or working stage for charging the furnace with the material or charge to be melted.

Thyristor

in electrical technology is a controllable semi-conductor element, as opposed to a diode, which cannot be controlled. Thyristors are used in frequency converter technology for rectifiers and current inverters for the operation of induction furnaces. High-performance thyristors are water-cooled, and can therefore be very small in size. Thyristors have also been developed in air-cooled versions, although these require relatively clean cooling air at a maximum of 33 °C.

Tipping cylinders

are as a rule designed in the form of "plunger cylinders", i.e. the piston rod, without its own sealing elements, acts simultaneously as the "piston". Lowering takes place due to the counter-pressure of the furnace being raised. In most cases, the 2 tipping cylinders are arranged laterally in the front area of the furnaces. The lever arm has a length of 250 mm for small furnaces and a length of up to approx. 1,000 mm for a 70-t furnace. Wherever possible, the arrangement should be such that in the basic position, the tipping cylinders are standing either vertically, or inclined up to 3° to the rear. In the end position, the tipping cylinders should be either vertical, or inclined a maximum of 3° toward the front or rear. For furnaces from approx. 10 t, the tipping cylinders are equipped with "end-position damping", which is achieved due to the piston rod design at the bottom. This is done to avoid sudden, jerky lowering into the basic position and any associated shocks when positioning the crucible.. In order to prevent any unforeseen "tipping errors", the cylinders should be bled every 6 months.

Tipping point

of a crucible furnace refers to the pivot point of the crucible furnace, around which the furnace is tipped. The casting spout length and the relevant tipping point must be optimised, depending on the use of the furnace and the device employed to accept the melt. An optimum pivot point for all applications is the "lower lip" of the casting spout with a relatively long casting spout, in order to provide clearance for ladles in front of the furnace. This arrangement means that the casting stream can be directed accurately, and produces the lowest possible height differences between casting and total emptying.

Tipping points

Tipping point at the end of the casting spout, no fluctuating casting stream, optimum design

Tipping point 100 mm below the end of the casting spout, casting stream fluctuates normally, normal design

Tipping point 200 mm below the end of the casting spout, casting stream fluctuates severely, uncommon design

Tipping angles

are important for total emptying. In the case of duplex furnaces, a tipping angle of 100° often has to be used because of the shoulders of the crucible. Most crucible furnaces work with a tipping angle of 95°. For casting units, an angle of between 60° and 95° has to be catered for in order to take into account the inductor installation angle and the vessel dimensions.

Transformer

in electrical technology is a device for increasing or reducing an alternating voltage without significant energy losses. A 1-phase transformer has the primary and secondary coils arranged at either end of a closed, O-shaped core. The alternating current flowing in the primary coil generates, by means of induction, a voltage in the secondary coil, which is proportional to the number of windings. In order to achieve the strongest possible common magnetic field of the two windings, these also sit on one arm of the O-shaped core.
In rotary current transformers, the primary and secondary windings of each phase are arranged on the three vertical arms of pillars. The primary coils consist of relatively thin wires or flat profiles. For the secondary coils, at high currents, conductor strips are used with widths of up to 1 m.

Twin Power

is the registered trademark of the firm of ABB for the operation of 2 induction furnaces from a single electrical power supply with optional power distribution of approx. 5% to 95% in order to make 100% use of the total output.

Ultrasonic testing

is used for the detection of material faults by ultrasound, i.e. with sound vibrations of over 20,000 Hz. The frequencies used lie between 0.05 MHz and 25 MHz. In practice, the average level is around 12 MHz.

Ventilation

is required primarily to dissipate the heat loss to the system components. In induction furnace systems for smelting operations, the system is designed in such a way that the air outlets produce an over-pressure in the power supply room, meaning that hardly any dust can enter from outside. In the case of air-cooled converter cabinets, the fresh air must be kept clean with the aid of corresponding filters.

Vermicular graphite

is a vermicular graphite, a form of graphite between laminar graphite and nodular graphite. This is not desirable in the production of nodular graphite. This occurs as a result of inadequate magnesium treatment, or due to excessive dead-melting of the treated iron.

Visualisation

is the pictorial or graphic representation of switch conditions or processes on monitor screens.

The load circuit

The converter's load circuit consists essentially of the consumer (induction coil) and the capacitor battery, which is configured parallel to the consumer. The load circuit is connected up directly to the converter output (in special cases also via a transformer).

The consumer's reactive-power demand is covered by the load capacitors; the converter supplies only the active power.

Post-compensation of any change in the consumer condition takes place automatically via the change of frequency in the load circuit. Switching of the load circuit capacitors during operation is therefore unnecessary.

The converter is switched on and off by enabling and disabling of the rectifier. Since no mechanical switches are actuated and the converter is immediately ready for operation, it can also be switched off during short interruptions to production.

When the converter is switched on, a starting device in the load circuit generates the first wave and checks it for any faulty conditions.

At the same time steps are taken to ensure that the rectifier is supplied instantaneously with sufficient power in order to maintain the triggered wave. The commutation power is drawn from the load circuit.

Figure 5 shows the basic characteristic of a converter's output voltage and output current.

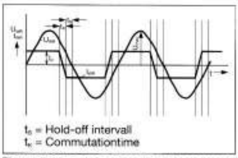


Figure 5: Time characteristic of the converter voltage U_{wr} and the converter current I_{wr}

Constant-power control

Particularly converters for medium-frequency melting plant are equipped with a constant-power control system. The following two characteristics result from appropriate dimensioning of the inverter and control of the converter:

- The inverter always supplies the consumer with the nominal power over a wide range of output voltage (e.g. between 70 and 100%). This is essential for the operation of melting furnaces in batch mode because the furnace resistance changes during a charge (level of fill, temperature).
- The rectifier is always fully controlled within the above mentioned range of inverter output voltage, i.e. the line-side power factor (cos. phi) remains at the optimum value.

ABB

The TWIN POWER circuit

With the TWIN POWER circuit it is possible to divide the power drawn from the system (1 transformer, 1 rectifier) among two consumers in any ratio by infinite adjustment, e.g. among two melting furnaces in tandem operation or among the two coils of a heater. Each consumer is assigned to its own load circuit capacitor bank and its own inverter.

Figure 7 shows the front view of a converter for 4.8 MW/250 Hz, 24-pulse, with TWIN POWER circuit.

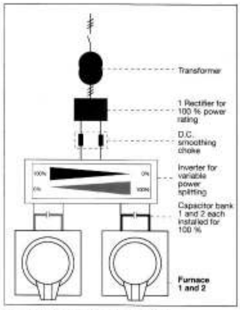
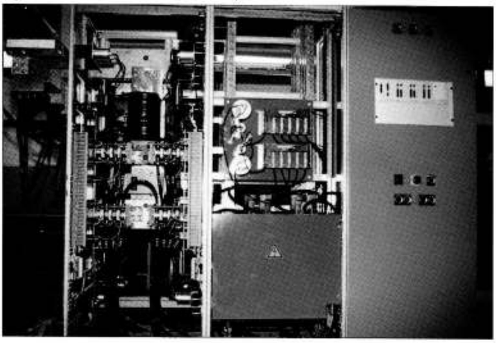


Figure 6: TWIN POWER circuit

Figure 7: A TWIN POWER for 4.8 MW / 24-pulse



Volt

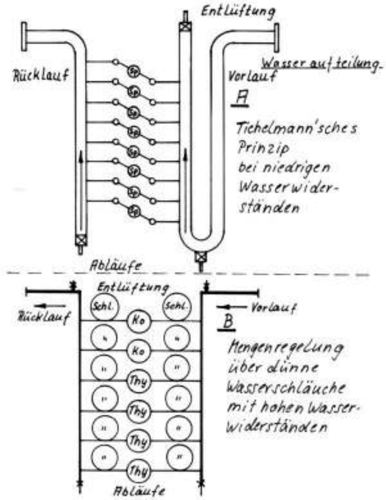
is the unit of measure of electrical voltage. The definition is that 1 Volt is the voltage that causes an electrical current of 1 Ampere to flow through a resistance of 1 Ohm. Ohm's law: U=R x I.

Voltage

is the term for the electrical voltage. This is the measure of the potential between 2 electrical phases at 3-phase or 2 poles under direct current. The voltage is measured in Volts. 1 Volt is the voltage that causes an electrical current of 1 Ampere to flow through an electrical resistance of 1 Ohm.

Water distribution

via collector pipes on the supply and return side requires the observation of "Tichelmann's principle", if the collector pipes are connected relatively close to each other with short cooling water paths. In older induction furnaces, the supply and return lines on both sides were installed directly next to the coil connections. In this case, the flow direction had to be the same in both pipes, i.e. on the right side the water flows in total from the top and in order to the coil sections. On the left side, the water flows in order from the top down and in total away at the bottom.
Tichelmann's principle refers to the optimum distribution of collective flows between individual flows and the return of individual flows to collective flows. Expressed more simply, the flow direction must be the same in both systems. With water, this can be solved for volumes of over 10 l/min. as shown in Diagram A. With volume regulation by means of narrow pipes (DN 5 – 8 mm) and lengths of 3 -6 m, this principle can be dispensed with, see Diagram B.



Water / Water exchangers

are used for higher outputs and an available operating water system. In regions with high air temperatures these are used in conjunction with evaporation coolers to maintain the minimum cooling water supply temperature of 34 °C for frequency converters and 45 °C for induction furnaces.
Exchangers function like an electrical transformer. If for example 34.5 m^3/h flow through the furnace circuit, which must be cooled down from 65 °C to 38 °C, 103.5 m^3/h must flow on the cooling tower side or operating water side, which in turn will be heated up from 21 °C to 30 °C.
The product of volume x temperature difference must be the same on both sides.
103.5 m^3/h x 9 K=34.5 m^3/h x 27 K ➜ 931.5 mm^3 K/h=931.5 m^3 K/h

Water vapour explosions

occur when water or damp gets under the bath surface of molten melts. In the operation of medium-frequency furnaces with total emptying, the danger is somewhat less, since the charging process can be controlled so that any wet or damp charge material can dry out above the melting bath. If water penetrates below the melt, it will expand suddenly and quickly to about 600x its original volume.

Wear lining

Is the part of the fireproof cladding that is subject to wear, and which must therefore be replaced from time to time. The outer lining is not exposed to wear, and has a longer workinglife.

Welding

is the term for the joining of 2 metallic materials with a welding material that melts at approximately the same temperature. Welding rods are used for flame welding, and electrodes for arc welding. In the process of inert gas welding, a special wire is fed in continuously from a roll. These processes include MIG (metal/inert gas) and TIG (tungsten/inert gas) welding.

Wood's metal

melts at 70 to 72 °C. This alloy of bismuth has the following composition: 25% Pb, 12.5% Cd, 12.5% Sn, and the rest Wi.

Yoke

is an alternative term for iron piles. As a rule, one uses the term yoke when referring to a channel furnace, since these use closed iron cores in a U- or E-shape. For crucible furnaces, the terms iron piles, and more rarely iron beams, are used. Yokes are produced from grained electro-plate.

Zinc vapour

is an accompanying phenomenon of melting which is unavoidable when melting plate materials containing zinc. The zinc vapour emitted from the melt must be extracted and filtered out by suitable extraction devices. The negative effects on the durability of acidic crucibles can be reduced to a reasonable level by suitable measures. Using the following procedure, the working life of a crucible should not be significantly lower than when working with zinc-free plate: The sintering charge and the complete 2nd and 3rd charges are melted with zinc-free scrap. From the 4th charge, scrap contaminated with zinc can be used. After interruptions in operations, the 1st charge is again melted with zinc-free scrap.