The Use of Channel-type Inductors and Coreless Inductors in the Non-Ferrous Metal Industry

Christian Eckenbach, Wilfried Spitz

This article gives an overview of the different types of induction heating units for melting, holding and casting furnaces. The presentation focuses on coreless inductors and their advantages over channel type inductors when it comes to holding/casting of special copper alloys. At the example of a holding/casting furnace in an aluminium semi-fabrication plant in Europe the modification from a channel-type furnace into a furnace with coreless inductor technology is illustrated and explained. The paper gives technical information comparing the new detailing benefits, such as an increased service life of the furnace of up to three years with the crucible inductor. Photographs and diagrams show advantages as well as results from the testing and measurement of residue build up in the inductor. Especially the revamp and upgrade of a 28 ton holding and casting furnace with a power of 200 kW to 40 tons and 450 kW will be demonstrated by construction and field results.

Keywords:
Channel inductor – Coreless inductor – Induction furnace – Channel furnace – Crucible furnace – Melting furnace – Holding furnace – Casting furnace – Induction – IGBT converter – Special alloys – Copper and copper alloys – Aluminum and aluminum alloys

1 Applications of channel and coreless inductors

Basically two different kinds of induction furnaces are used for melting, holding and casting of metals, the channel-type induction furnace and the coreless type induction furnace.

The channel-type induction furnace consists of a refractory lined furnace body made of steel to which one or several channel-type inductors are flanged for heating the metal.

Due to reasons like thermal conductance and buoyancy of the hot melt in most cases the channel-type inductor is flanged at the bottom of the channel type furnace body resulting in the typical design of a small to medium-sized channel-type melting furnace as shown in Figure 1.

Depending on the function of the furnace in the production line other positions of the channel inductor and furnace body designs can be appropriate. Figure 2 is one of the rare examples where the inductor, by special reason, is flanged horizontally to the upper furnace body.
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Fig. 1: Typical design of a channel-type furnace

Fig. 2: Channel-type furnace with horizontally flanged channel inductor

Fig. 3: Forehearth casting furnace

Fig. 4: Forehearth casting furnace
Channel-type induction furnaces are used for copper and copper alloy melting, as the copper is sensitive to oxygen pick-up and channel-type furnaces offer a smooth bath surface but a sufficient bath turbulence inside the melt so that homogenous melts in regards to chemical analysis and temperature can be achieved. Channel-type furnaces are the preferred choice for holding and casting of copper and copper alloys, too (Figures 3 and 4).

But they are used also for melting aluminium and its alloys as well as holding/casting furnaces for aluminium and its alloys (Figure 5).

Another application for the channel inductor is the holding of iron melts in huge storage furnaces or holding/casting furnaces with flanged forehearth being used at automatic high-speed sand mould casting lines (Figure 6).

Channel-type furnaces have a much higher electrical efficiency than coreless furnaces but when it comes to iron and steel melting (high power density required) and frequent alloy change or the demand for emptying the furnace on a regular basis, the coreless furnace is the preferred choice as melting or holding/casting furnace (Figure 7).

In the copper casting industry coreless furnaces are used for melting of special copper alloys, which are known to clog the inductor channels. From the furnace the melt is poured into a tundish and from there straight into the discontinuous vertical casting machine. Such alloys could be CuFe, CuNi, Al bronze etc. A further application is melting aluminium bronze for producing ship propellers (up to 80 t holding capacity of the coreless furnace) or when frequent alloy change is requested in smaller multi-alloy producing foundries, e.g. the master alloy producers.

Holding alloys like CuNi or CuFe for feeding them into a continuous casting machine prove to be uneconomical as those special copper alloys reduce the lifetime of the channel inductor significantly by washing out the refractory (channel cross section increases) or clogging the channels (channel cross section decreases). A better and more economical solution was requested and found in the use of coreless inductors (Figure 8) which similar to channel inductors can be flanged to any position of the holding furnace body allowing for flexibility in designing such furnace bodies tailor-made to the production and casting process. Such coreless inductors already beginning of the 1980s were used for heating holding furnaces in the aluminium
and copper casting industry. Typically holding furnaces in continuous casting lines were equipped with such inductors which consume more energy than a channel-type inductor but offer much higher lifetime and allow for empting the holding furnace on a regular basis. Figure 9 reflects the development in design of coreless inductors. The 250 kW inductor on the left side was put into operation in the end of the 1990s heating a three-chamber holding/casting furnace for copper alloys. It has no inductor case in contrary to the 340 kW inductor on the right side which has been used at several holding furnaces in the aluminium semi-fabricating and casting industry for many years now.

In a previous meeting of the GDMB’s Copper Committee results of using coreless inductors with oval design at copper alloy holding/casting furnaces were reported. The Marx Group in Germany has gained a good experience in modifying existing holding furnaces being heated by channel-type inductors into furnaces being heated by coreless inductors. Such a refurbishment and modification offers the possibility to increase holding capacity and to change the old conventional tap switch power cabinet against a more economical IGBT transistor converter cabinet allowing for achieving a precise holding/casting temperature of the melt.

2 Modification of a channel-type furnace into a furnace heated by coreless inductor

Such a furnace refurbishment will be illustrated and explained at the example of a 28 t holding furnace at a prominent semi-fabricator plant in the European aluminium slab casting industry. This customer has been operating eleven 20-30 t holding furnaces being fed with liquid metal by gas heated melting furnaces and supplying the metal by tilting into a semi-continuous vertical casting line (Figure 10). The holding furnaces had been equipped with 200 kW channel-type inductors which required a cleaning on a weekly basis due to clogging of the channels, resulting in significant production downtimes and difficult and time consuming maintenance. 5 to 6 inductor changes per year at one holding furnace were necessary, resulting in additional maintenance costs and production downtimes.

Converting an existing furnace requires to collect the furnace’s structural data. It is of use and recommendable to visualise them in a 3D-image representation. Then the question must be answered whether the furnace volume shall remain unchanged or whether the furnace casing is to be extended. For this purpose, the unit needs to be subjected to static and dynamic functional testing, the complete movement (tilting, driving) devices and power input has to be checked and calculations have to answer the question whether these units have to be exchanged against more powerful ones.

Design and construction of a new furnace substructure which, after the old furnace substructure has been severed off, is being attached completely new to the furnace vessel situated in the furnace stand (Figure 11).

For this purpose it is necessary to find suitable cutting sites for severing the furnace bottom, to create the new size of the furnace vessel bottom in accordance to the FEM calculations and to prepare for installation onto the furnace itself (Figure 12).

These pre-fabricated sub-structural elements (Figures 13, 14) are normally produced turnkey ready, checked and transported to the construction site in weldable condition.
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Fig. 12: FEM calculation of the new furnace substructure

Fig. 13: Drawing of the new furnace substructure

Fig. 14: New furnace substructure

Fig. 15: Disassembly of the old furnace substructure – connecting the new furnace substructure
On the construction site itself, the disconnection of the old lower furnace body structure is prepared and carried out. The welding area is being mechanically and technically prepared and the new substructure is positioned on the contact surface and then welded onto the furnace (Figure 15). The new furnace substructure supports the receiving structure for the crucible inductor that is installed later on (Figure 16). After successful welding and structural support, the furnace is ready to undergo welding analysis and, after approval, needs to be prepared for a new lining. Constructional conditions, such as the furnace pit, are also checked in terms of spatial geometry. The necessary clearance spaces for more expansive tilting movements may require structural changes; this however is normally not the case (Figure 17).

In terms of cost saving and production increase such conversion is refinanced in less than one year. For operating personnel, handling becomes much easier.

In the meantime, approximately 30 of such furnace plants have been refitted or have been prepared for refitting. It is usually always possible to use the existing furnace vessels, to shorten them at the bottom and to fix a new substructure, thereby completing the refit within the shortest of times, with good preparation in approximately four weeks.

### 3 Benefits of the modification

Due to the technical solution to dock a coreless inductor onto the lower furnace body and to arrest it by key fastenings, a worn-out inductor, from pouring the furnace vessel empty to its restart, can be changed within a time frame of 24 to 30 hours maximum. The cost–benefit equation in relation to channel furnace vs. crucible furnace is surprisingly clear in favouring the crucible furnace (Table 1).

In order to change the coreless inductor, it is cooled down at the emptied furnace in a warm condition by its own water cooling over approx. eight hours until it reaches a medium temperature of 50 °C maximum. Thereafter, the coreless inductor can be separated from the furnace and placed on a new receptacle, which is also designed for it. This is not possible in the case of channel inductors.

![New furnace substructure with mounted coreless inductor](image1)

![Modified furnace back in operation](image2)

<table>
<thead>
<tr>
<th>Table 1: Comparison of maintenance costs</th>
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<tbody>
<tr>
<td><strong>Furnace with channel inductor</strong></td>
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<tr>
<td>Cleaning cycles</td>
</tr>
<tr>
<td>52 cleaning cycles</td>
</tr>
<tr>
<td>3 man-days each (1248 h)</td>
</tr>
<tr>
<td>52 production downtimes due to cleaning</td>
</tr>
<tr>
<td>2 × 24 h each (2496 h)</td>
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<tr>
<td>Inductor change</td>
</tr>
<tr>
<td>At least 5 inductor changes/shutdowns for repair</td>
</tr>
<tr>
<td>10 man-days each (80 h)</td>
</tr>
<tr>
<td>5 production downtimes</td>
</tr>
<tr>
<td>5 × 24 h each (120 h)</td>
</tr>
<tr>
<td>At least 5 repair deployments</td>
</tr>
<tr>
<td>10,000 €/piece each → 50,000 €</td>
</tr>
<tr>
<td>Ceramics work</td>
</tr>
<tr>
<td>5 levelling processes and conditioning work on rectangular flange</td>
</tr>
<tr>
<td>5 × 3 h (15 h)</td>
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![Fig. 16: New furnace substructure with mounted coreless inductor](image1)

![Fig. 17: Modified furnace back in operation](image2)
and can be prepared for re-use. For this purpose, the pre-fabricated crucible inside the inductor is lifted out of its bedding by a hoisting device and can be disposed of as a single compact piece (Figure 18). Full extraction of the crucible in one lump provides a very good possibility to control what defects the crucible may have suffered and what ceramic and temperature related conditions are found. Afterwards, the crucible inductor can be relined, the mounting flange of the furnace shell can be reworked (facing).

Parallel to this process, an already pre-heated crucible vessel is brought to the furnace and is to be attached to the furnace itself (Figures 19, 20). Process time for flange-mounting the pre-heated crucible amounts to six hours maximum, most of the time even less. After the crucible inductor has been fully mounted it is heated via the furnace burner at a cycle of 50 °C/h from pre-heating temperature to nominal temperature and is cast on again. This process requires altogether approximately 24 hours and is therefore extremely maintenance-friendly.

The dismounted overhauled coreless inductor remains in stand-by (Figure 21).

Over a period of two to four years, the crucibles will clog. The slag-forming constituents are usually aluminium-magnesium spinels that can normally be removed mechanically but, in terms of the chemical compounds, are not soluble in the melting bath and therefore remain inside the furnace chamber, clogging it over time (Figures 22, 23).

The clogging process in the crucible is accompanied by a frequency change at the converter and, because of this, reduced performance. The shown performance reduction...
at the crucible allows to draw clear inferences in respect
to the crucible’s slag contents and, from 75 % of content
onwards, the converter’s performance is so low that proper
operation of the furnace is no longer ensured since the
remaining holding power is no longer sufficient to hold
the furnace vessel warm with enough flexibility and to
superheat.

After phase 3 of the crucible’s condition has been reached,
the coreless inductor can again be removed from the fur-
nace and be replaced by a suitably prepared new one and
restart within 24 hours.

In Figure 24 a number of informative pictures show the in-
crustation status and formation of aluminium-magnesium
spinel. Here, we still can ascertain a still impressively good
condition of the crucible after clogging and therefore can
infer a high degree of operational reliability.

4 New IGBT transistor converter power supply

As already mentioned the modification period can be used
to change the old conventional style power supply against
a more efficient new converter power supply. Application of an infinitely variable power supply via tran-
sistor converter in IGBT technology (Figure 25) provides
for automated and visualised control of the holding and

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Fig. 22: Sectional view of a coreless inductor

Fig. 23: Clogging of the coreless inductor

Fig. 24: Incrustations in the coreless inductor
casting process and, at the same time, allows for monitoring the condition of the crucible inductor itself. It is clearly worthwhile to look on one’s old existing plants and to refit them with modern technology and to keep melting and heating technology one step ahead of the market.
Dipl.-Wirt. Ing (FH) Christian Eckenbach studied Business Administration and Engineering at the South Westphalian University of Applied Sciences in Hagen from 1997 to 2002, where he finally got his graduate degree. He started his career in 2002 at Marx Elektrowärme GmbH in Hennigsdorf. In 2003 he became managing director. In 2005 he changed to the company Marx GmbH & Co. KG in Iserlohn. With the change of generations in 2007 he assumed the management of the Marx group in Iserlohn, Donauwörth and Hennigsdorf together with his brother Guido Eckenbach. In 2008 he established the fourth company, Marx LLC in Youngstown (Ohio), USA together with his brother.

Dipl.-Ing. Wilfried Spitz studied metallurgy at the Technical University of Aachen from 1984 to 1990. End of 1990 he got his diploma degree. From 1991 till 1994 he worked as project engineer and vice foundry manager in an aluminium foundry of the Mahle group. In 1995 Wilfried Spitz changed to the company Hoesch Metallurgie GmbH, where he worked as sales engineer. He cared about key customers in iron, steel and aluminium foundries and non-ferrous re-smelters. End of 1999 he started at Induga GmbH & Co.KG (nowadays belonging to Otto Junker Group) as sales engineer for induction furnaces for the ferrous and non-ferrous metal industries worldwide. Since beginning of 2011 Dipl.-Ing. Spitz has been employed at Marx GmbH & Co. KG, Iserlohn. He is head of sales of the induction furnace department for new induction furnace plants.