Medium frequency induction crucible furnace when tapping an aluminum master alloy (Photos and graphics: Otto Junker)

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20 Years of Otto Junker Melting Technology Centre – state-of-the-art induction technology

For 20 years, Otto Junker, Simmerath, Germany, has been operating a Technology Centre for carrying out melting and casting trials in cooperation with customers and for internal development projects. The heart of this facility always has been a coreless medium-frequency induction furnace of close-to industrial size. In 2015 the originally used 750 kg furnace (related to iron) was replaced by a new furnace with a capacity of 1,700 kg which incorporates all the latest developments and innovations and is thus from unmatched flexibility. The article summarizes the work carried out in the Technology Centre over the years. Also, there is a detailed explanation of the technical innovations implemented in the new furnace plant.
**Introduction and retrospective**

For 20 years, Otto Junker GmbH has been operating a Technology Centre in Lammersdorf, Germany, to carry out R&D projects in the fields of melting, holding and pouring equipment. In all, the facility comprises a surface area of approx. 450 m². The relevant building features a crane with max. payload capacity of 3.2 tonnes, an array of indispensable machine tools, a welding station, several annealing furnaces, a dedicated forklift truck and other miscellaneous equipment. In addition, an extensive array of advanced measuring equipment is available. The core of the Technology Centre, however, is a medium-frequency coreless induction furnace, originally with a capacity of 750 kg (related to iron alloys), a power rating of 400 kW and an operating frequency switchable between 250 and 500 Hz (Multi-Frequency Technology). The Multi-Frequency Technology will be explained in detail later in this paper. One crucial benefit is that the Technology Centre holds an operating permit for melting all common wrought, cast and special alloys.

This pilot system has been employed in diverse customer projects aimed at investigating metallurgical and process engineering issues. A number of specific applications are listed by way of example:

- Determination of melting behaviour and collection of melting data for small-sized silicon for the solar cell industry (numerous trial series for multiple customers)
- Recycling of silicon dust from wafer slicing processes
- Trials investigating the smelting reduction of filter dusts from high-grade steelmaking processes
- Trials on the smelt reduction of electric arc furnace (EAF) dusts
- Recycling of aluminium chips
- Testing of crucible materials for silicon melting
- Determination of melting behaviour and collection of melting data for ferrosilicon
- Pouring trials relating to a copper anode casting process

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**Figure 1: Bath movement and meniscus**

**Figure 2: Multi-Frequency Technology - carburization behaviour of cast iron melts at different operating frequencies and power input levels**

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- Trial series relating to melt refining of silicon melts
- Determination of melting behaviour and collection of melting data for ferrochrome
- Investigation of the carburization characteristics of cast iron melts
- Sponge iron meltdown experiments
- Melting of copper-zinc alloys for low pressure die casting
- Furnace engineering for the Vacural die casting process

Of course, this pilot system has also been used extensively for in-house development tasks, such as testing of temperature and melt level sensors, development of crucible monitoring systems, refractory testing, and the like. It is worth mentioning here that numerous trial series conducted as part of customer projects have ultimately led to orders for corresponding furnace systems.

When conducting extensive melting trials, the melting process is of course the first step, but then invariably comes the problem of providing a sufficient number of suitable containers to receive the molten metal. Metal molds are a perfectly good solution for individual trials, but trial series stretching over several days or even weeks would necessitate a high number of these costly molds, as the cooling times need to be taken into account. This is where another advantage comes into play, namely that Otto Junker also operates a sand casting foundry for high-grade steel at its Lammersdorf site, so that the required number of sand molds can be turned out without much trouble. In this case, the molten metal is cast into formats that can easily be recharged into the furnace.

In all, experience has shown that a furnace of the size mentioned above constitutes the minimum size required for extrapolating the results of melting trials to our customer’s larger industrial installations. Mere laboratory-scale coreless induction furnaces of the type commonly found in research institutions and universities can only yield findings of very restricted information value in this regard. The reasons will be explained below.
Meanwhile, the state of the art in medium-frequency coreless induction furnaces, especially in the field of converter technology, had evolved so much that the decision was taken in 2012 to replace the old well-tried system by a new furnace which was to be outfitted with everything Otto Junker has to offer in this segment. This system was commissioned on October 21, 2015. But before presenting this system, let us first look more closely at one of the key technical aspects of induction melting, i.e., the melt bath agitation caused by electromagnetic forces.

**The medium-frequency coreless induction furnace – cause and importance of bath movement**

One key property of the coreless induction furnace which distinguishes it fundamentally from other melting resources is the melt bath agitation caused by the electromagnetic forces. This is illustrated in some detail in **Figure 1**, which depicts the current-carrying water-cooled induction coil and symbolically indicates the direction of the current flow. It also shows the refractory crucible which contains the melt and is placed inside the coil. The inductor current produces a magnetic field which in turn induces ring currents in the molten metal. It should be noted here that the current density is highest, due to the skin effect, in the rim zone of the melt directly adjoining the crucible wall. Because the currents are short-circuited, Joulean heat is generated in the melt, mainly in the boundary layer close to the crucible wall. In addition, these currents – extending in a direction opposed to that of the inductor current – produce a secondary magnetic field. Due to this effect, the coil exerts repelling forces on the melt. With a coil of infinite length, the magnitude of these forces would be the same at all places over the coil height. In a finite coil as encountered in practice, the electromagnetic force density is variable over the height of the coil (Fig. 1). Hence, melt volumes situated at the centre of the coil encounter a more intense repelling force and hence, are accelerated more strongly in the direction of the coil axis than melt regions located near the edge of the coil.

![Figure 5: IGBT frequency converter](image1)

**Figure 6: Furnace visualisation and automation system JOKS 4.0**

The intensity of this bath movement firstly depends on the furnace power; the higher the power input, the more vigorous the bath movement will be. In addition, the melt flow intensity varies with the frequency of the alternating current (a.c.) feeding the coil: the lower this frequency, the more vigorous the bath movement. It follows, first of all, that for a given fixed frequency the heat input into the melt and the intensity of the bath movement are always correlated. Furthermore, bath movement intensity can be selectively controlled at a given required furnace out-
put by selecting the proper operating frequency.

Finally, at a given power and frequency, the intensity of the bath movement depends on the furnace filling level; and this is particularly true for the melt flow in the bath surface region. The higher the filling level at a given power and frequency, the less vigorous will be the bath movement.

In the above considerations we have assumed laminar flow conditions for reasons of descriptive simplicity. In reality, however, a substantial turbulent flow portion will be superimposed over the laminar flow. This will be the more pronounced the lower the furnace’s operating frequency.

Bath movement is very important from a technological viewpoint since it facilitates optimum melt homogenization and stir-down of constituents and thus ensures a uniform melt composition and temperature at the same time. Also, without this forced convection, the coreless induction furnace simply wouldn’t work because most of the heat input takes place via a boundary layer situated close to the crucible, as explained earlier. If there were no bath movement to distribute this heat to the entire charge, strong overheating of the melt close to the furnace wall would inevitably occur within a very short time, causing a failure of the refractory lining.

Finally, it is important to remember that for induction furnaces which are operated at a fixed nominal frequency, which is the majority of furnaces so far, heat input into the melt and the intensity of bath movement are always correlated.

Special circuit techniques

From a metallurgical point of view, the ideal induction melting process is one in which both the input of thermal power and the melt flow can be controlled to match given technological needs. Therefore it is desirable to decouple heat power input and bath movement from each other, i.e., the desired melt movement in the furnace should be adjustable independently of the respective heat input. While controlling electrical power – and hence, the input of thermal energy into the melt – poses no major problem to the furnace engineer, it takes very special circuit technology to control the melt movement independently of the power input.

To achieve this objective, Otto Junker had initially developed the special circuit variants known as Power Focus Technology and Multi-Frequency Technology, both of which have been successfully deployed in a large number of furnace systems.

Power Focus Technology permits an automatic or freely selectable concentration of power in the coil region where it is most needed (i.e., the upper or lower section of the coil). Thus, on a half-filled furnace, the power input can
be focused in the lower crucible area to make more energy available there. On the other hand, when the furnace is filled to capacity, the operator can raise the power input in the upper coil section to agitate the bath more intensely and thus improve stir-down, e.g., of metal chips.

Multi-Frequency Technology provides a means of changing the operating frequency either manually or automatically during the melting process. With cast iron, for instance, a suitable frequency of 250 Hz is used for melting down the charge materials. A lower frequency – e.g., 125 Hz – is then selected for introduction of the carburizing agents and alloying additives. Practical experience shows that this changeover to a lower frequency greatly accelerates the carburization process performed to adjust the melt composition (Figure 2). At the same time, burn-off of carburizing agent is reduced.

It should be noted here that these two circuit technologies can also be combined for even greater effect. This approach has proven its merits, e.g., in melting furnaces used for the recycling of aluminium chips, which are always molten with a liquid heel. Here, on the one hand, the filling-level-related surface movement must be reduced as far as possible in order to minimize oxidation and melting loss, while on the other hand it must always remain sufficient to ensure a rapid stir-down of the chip material. This is achieved via an automatic use of the Power Focus and Multi-Frequency Technology functions [1].

These options are substantially expanded by the newest developments relying on the special technical advantages of IGBT converter technology:

Apart from proven thyristor-based frequency converters, the successful development of special IGBT converters has gained increasing importance in electrothermal processes. These systems involve the use of Insulated Gate Bipolar Transistors (IGBTs) instead of thyristors in the inverter.

A special design of the IGBT converter with two separate inverters and a system providing phase-shifted power supply to two furnace coil sections creates the technical prerequisites for an even broader control of the bath movement. In the charge melt-down phase the furnace can thus be operated at an appropriate nominal frequency of, e.g., 250 Hz and to increase the bath agitation at low power the frequency can be controlled steplessly below 100 Hz. The amount of phase offset between the two coil sections is likewise adjustable to provide a more selective control of the flow pattern (i.e., direction of rotation and velocity), as illustrated in Figure 3. In this example, illustrating a 0° offset vs. a +60° offset, the second offset section permits the region of maximum flow velocity to be moved to the centre of the molten metal bath to obtain more effective intermixing of the entire melt.

In addition, the turbulent portion of the melt flow is increased substantially with this circuit technology, especially at low frequencies, so that the mixing effect can be maximized with minimum heat input.

The technical options available for influencing bath movement in a coreless induction furnace can be implemented and combined in manifold ways to address specific metallurgical tasks. The decisive factor is that the development of said circuit technologies (stepless frequency variation, phase shift) has made it possible for the first time to largely decouple heat input from the intensity and pattern of bath movement.

One typical application for this technology is for example the production
of master alloys presenting high concentrations of alloying elements. In this application, production rate is determined mostly by the dissolution kinetics of the respective alloying agent. This is why this process calls for a strong stirring action along with very low heat input, so that the melt temperature remains constant and does not rise excessively. Such alloys are also often prone to separation or gravitational segregation, so that a certain amount of bath movement is necessary during the pouring process, which takes some time also. During this time the melt temperature, in turn, is not allowed to rise. Said circuit technologies are also used to improve the reaction kinetics in vacuum induction furnaces for melt distillation, as well as in other special applications [2, 3, 4].

The new melting system in Otto Junker GmbH’s Melting Technology Centre

The new system (Figure 4) is equipped with all three of the circuit variants described above and thus offers unique flexibility when it comes to selective control of the melt bath movement. Here are some key specifications:

- Power rating, related to iron materials: 600 kW
- Nominal melting frequency in melting mode (switchable): 200/100 Hz
- Operating frequency during stirring at reduced power, steplessly variable: 30-100 Hz
- Two coil sections (top/bottom) with independent inverters, providing different power input into the respective sections.
- Phase-shifted operation of the coil sections within the range of: -90° to +90°
- JOKS furnace control system with touch screen.
- Furnace weighing system
- Optical Coil Protection (OCP) system
- Radio remote control of power input and furnace tilting operation
- Full cooling circuit instrumentation for calorimetric measurements
- Ring-type exhaust system and filter system
- Diverse charging equipment
- Operation under protective gas atmosphere

Figure 5 shows the converter cabinet, Figure 6 the graphic user interface implemented on a touch screen. Care is taken that always the latest version of Otto Junker’s furnace control system for visualisation and automation is installed, which is currently JOKS 4.0. Figure 7 shows the control cabinet for manual furnace operation installed on the furnace platform. A complete view of the furnace platform is provided in Figure 8. Figure 9 shows the filtration system and Figure 10 the existing vibratory feeder for charging of fine materials such as chips, for example.

The capabilities of the furnace system in terms of influencing the melt flow via power, frequency and phase-shift control are demonstrated in a video (see QR-Code).

The video shows the bath surface (molten aluminium) and bath surface movements at following conditions (power and frequency, as indicated): 400 kW/200 Hz; 200 kW/100 Hz, 100 kW, 35 Hz. The objective is to demonstrate that the apparent bath movement has nearly the same intensity in each of the three cases, even though heat input is halved from case to case. The fourth example illustrates the influence of a 90° phase shift at a frequency of 35 Hz and an even lower power setting (60 kW). It is clearly visible that bath agitation is somewhat more intensive than in the previous examples. Especially, it is apparent that the turbulent portion of the melt flow emerges here. In the Otto Junker Academy courses held twice annually, this trial series is demonstrated “live” – i.e., using actual molten metal – to the participants.

Needless to say, the system has also been used for numerous trials carried out as part of customer projects. Examples include the following:

- Implementation of copper melt refining trials using selective oxidation
- Melting trials with introduction of silicon flakes into an aluminium melt
- Melting trials aimed at producing aluminium-titanium-boron grain refinement alloys
- Melting down of aluminium returns contaminated with ceramic filter residue
- Production of complex aluminium alloys for plain bearings
- Recycling of zinc-containing dross
- Melting and foaming trials with special glass
- Melting experiments related to the production of ultra-pure aluminium

In those examples, the pilot system was used to determine optimum design parameters for the respective coreless induction furnace. Also, customer objectives were addressed in trials requiring the full range of capabilities (e.g., phase shift) in the context of sophisticated industrial process sequences. In the meantime, eleven furnaces so equipped have been sold, nine of which featuring steplessly variable frequency adjustment. At this point, it is important to reiterate that in the systematic elaboration of solutions for metallurgical tasks, a supplier-customer relationship built on communication and trust is the most important key to success, just as much as the actual equipment. In this context, it is standard practice to sign a Non-Disclosure Agreement up front.

Of course, the system has also been routinely employed for in-house trials, e.g., in refining pouring technology and designing new equipment. These activities are related mainly to aspects of pressurized pouring and automatic tilt-pouring of cast iron. As for the latter method, extensive trial campaigns were conducted at the Melting Technology Centre in the past two years using a PUMA-type automatic ladle pouring system developed by Induga GmbH, Simmerath, Germany (Figure 11). Here, the medium-frequency furnace served as a melt source and buffer vessel. The aim of the trials was to optimize pouring parameters as well as the underlying mathematical models [5].

To come back to what was said earlier: A system of the dimensions and capabilities discussed here is indispensable if the results are to be extrapolated to a large furnace, having a capacity of 10 t for example. This implies in particular that power density and intensity of bath movement must be transferable. This brings us directly to the aforementioned problem with small lab furnaces (with capacities between 1 and 50 kg) as used in research institutions and universities. They are mostly operated at high frequencies in the kHz range and offer comparably high power densities, so that the relation between heat input and bath movement is far removed from the real-world conditions in actual industrial furnaces. For example, 250 Hz is a typical nominal operating frequency of standard coreless induction furnaces used to melt cast iron.

On the other hand, melting experiments with the above-mentioned furnace (which, after all, has a capacity of 1.7 tonnes) take a not inconsiderable effort with regard to refractory materials, charge material logistics and pouring operations. In 2017, therefore, the Melting Technology Centre's equipment pool was completed with the addition of a smaller furnace and frequency converter that allows reduced-scale trials to be realized more flexibly and with less cost and effort. The unit has a capacity of 100 kg (related to iron materials) and a power rating of 60 kW. Its operating frequency can be selected in steps between 350 Hz and 1,000 Hz, i.e., close to the range encountered in industrial practice.

**Heat treatment research and development systems**

Although the present paper deals mainly with the company's Melting Technology Centre, it should be mentioned here that Otto Junker GmbH also maintains an extensively equipped Thermoprocessing Technology Centre.

In addition to a series of test set-ups, several of which were built to custom order with a view to investigating special application issues, a hot dip tinning line and a strip flotation furnace with cooling section deserve special mention.

These last two units serve primarily for systematic development and improvement. In this regard the use of simulation techniques has proven its worth: Firstly, they make it possible to select a number of particularly suitable test variants beforehand. Secondly, empirical data obtained through experiments permit continuous improvements to the simulation models. The HiPreQ mist quench (Figure 12), already established in the marketplace, and the proprietary blow-off system for
hot dip tinning lines are examples of whole new equipment components developed from the combination of simulation and measurements, which create major advantages for our customers, such as the planarity of strips, which are cooled down only as fast as is necessary from a metallurgical viewpoint, or the unmatched visual and dimensional uniformity of tin-coated strips. As a useful side effect, numerous parameter variations in the empirically proven simulations also permit complex interactions to be coordinated such that the mathematical models used in the thermoprocessing equipment offer sufficient accuracy and real-time capability. All these possibilities are also benefits for our customers to the extent that heating or cooling processes can be verified and, where necessary, optimized already during the planning stage. This not only ensures that the potential investment into new equipment will ultimately yield products with the required metallurgical properties. The findings also contribute to achieving maximum economic efficiency as expressed by productivity and energy efficiency. And in cases where a problem cannot be solved with ‘forced convection’, e.g., due to requirements for very short heat-up times or locally limited heating, it is always possible to use the synergy with the Melting Technology Centre and fall back on inductive heating processes [6].

Conclusion

The new melting system in Otto Junker GmbH’s Melting Technology Centre provides an ideal basis for addressing metallurgical and process engineering tasks via melting trials performed jointly with the customer to define the optimum parameters and equipment level of any future melting system. In addition, a multitude of circuit configuration options form a perfect toolset for exploring complex metallurgical processes involving different operating sequences. Finally, it should be noted that Otto Junker offers the use of this melting system, complete with peripheral equipment and operating personnel, not only in melting furnace projects but also as a contract service on attractive terms.

References:
www.cpt-international.com
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