Control of an induction melting plant on a virtual machine

by **Erwin Dötsch, Jean-Pierre Hacquin, Dietmar Mitschulat**

The Kempten iron foundry Adam Hönig AG has introduced a data management system on its way to Industry 4.0, with which the manufacturing processes of the diverse production program are made transparent via app and smartphone. In this context, high demands are made on the control of the two induction furnace tandem systems, which are fully met by the ABP melt processor Prodapt-Enterprise in combination with virtual systems and an in-house server. The consistent acquisition and evaluation of the process data brings savings in the use of energy and materials.

The Kempten iron foundry Adam Hönig AG (KE, **Fig. 1**) is a family-owned company that has been in existence for more than 60 years. As a job shop foundry with mold construction and design consultancy, it manufactures cast iron parts primarily for mechanical engineering. Castings in gray and nodular cast iron are cast in a hand-molding shop and in an automated machine shop with part weights of a few kilograms up to 8.5 t in one-off production as well as in small and medium production runs (**Fig. 2**). The variety of products is in the range of 6,000 to 7,000 different models. **Fig. 3** shows some examples of average casting weight. 170 employees produce about 1,000 t of good castings per month. KE is certified according to DIN EN ISO 9001: 2019 and maintains a high quality and environmental standard.

The variety and quantity diversity of the liquid iron requirement requires a flexible melting plant. This requirement is met by two ABP induction furnace tandem systems. Tandem 1 consists of two 3 t crucible furnaces, type ITMK 6000, which are powered by an 1,800 kW / 250 Hz inverter. Two 6 t crucible furnaces, type FS 60 (**Fig. 4**), form the second tandem powered by a 3,500 kW / 250 Hz inverter. Both furnaces are equipped with the TwinPower system, so that their power can be distributed electronically to the two associated furnaces in any ratio [1].

The melting plant is operated in a single-shift process. In each case after the last tapping the melt is charged for the start of the first batch of the next production layer in the hot crucible. The furnaces then cool to near room temperature and then re-melt at 6:00 in the morning. For this purpose, the 6 t furnaces are automatically ramped up from 3:00 o'clock with the cold start program to 1,000 °C, while the 3 t furnaces are only supplied with the cold start program from 4:00 o'clock, also at 1,000 °C melt temperature by 6:00 o'clock and are ready for full power.

Fig. 1: Iron Foundry Adam Hönig AG in Kempten, Allgäu (Germany)

Fig. 2: Pouring of an 8,5 t-machine-base

Fig. 3: Beams of EN-GJS-400-15, each 484 kg

KE DEVELOPMENTS ON THE WAY TO INDUSTRIE 4.0

With the support of Kempten University of Applied Sciences and funding from the German Environmental Foundation (DBU), KE has introduced a data management system with the aim of making the production process transparent and optimising it so that energy and material use can be saved [2]. For this purpose, the process data from the gating and the mold production to the unpacking of the cast blanks are recorded and evaluated. The digital monitoring is carried out by app on smartphones, where barcodes are used on the pans and boxes, which the employee scans and transmits to a database (**Fig. 5**). That way it is possible to track which box was filled with which melt at which time. This, for example, gives you the opportunity to process important components faster without increasing your production capacity. Another advantage is the potential increase in energy and resource efficiency by optimising the ratio of foundry sand to melt and accurately melting only the amount of metal that is actually needed for the particular casting.

Fig. 4: 6 t / 3,500 kW – Induction-furnace-tandem, type ABP FS 60

Fig. 5: Scanning of a flask barcode

The specific energy consumption of the melting furnaces averaging 611 kWh/t of melt is an indication of the benefits of data management. This value should be seen in the context of the single-shift operation and the production program: Firstly, in the daily cold start, the heat of storage of the refractory lining must be applied each time and, secondly, the provision of melt amounts above the capacity of a single furnace inevitably results in high holding times. Under these conditions, the energy expenditure of just over 600 kWh/t is a favourable value, which can be attributed to transparent production logistics.

In this context, the control of the melting plant is of central importance. The demanding conditions for the implementation of the described data management system on the part of the smelting operation were created by the installation of the ABP control system Prodapt-Enterprise in conjunction with an in-house server based on virtual systems.

CONTROL USING VIRTUAL SYSTEMS

The PC systems used in foundries are often only partially utilised to capacity. As a result, resources remain unused which leads to higher operating costs. One way out of this unsatisfactory situation is the use of virtual systems at KE. It

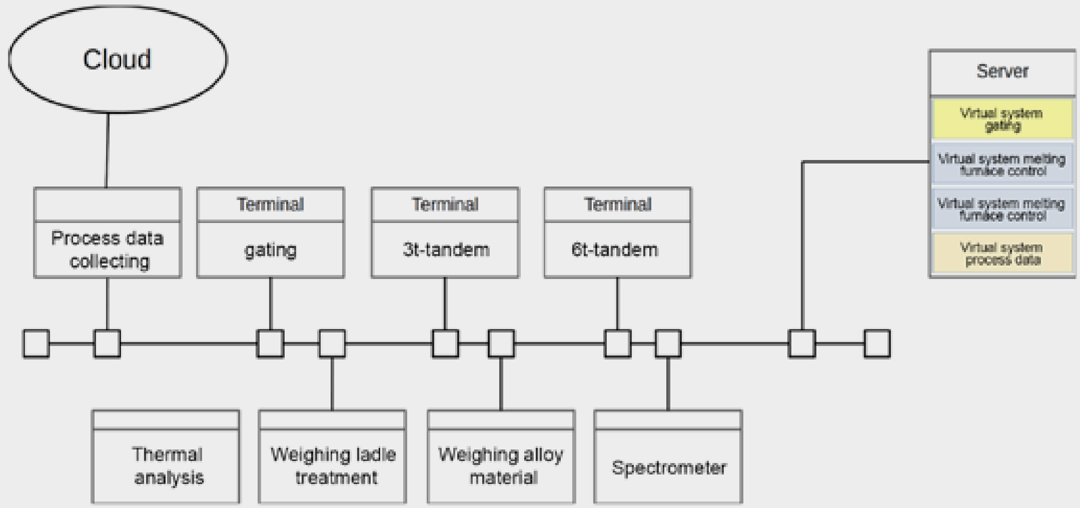

Fig. 6: Hardware concept for the melting operation

uses special software to simulate hardware functions and create virtual machines. This allows multiple computers with different operating systems to run on one server. In addition to better utilisation of the server, this leads to higher availability of the applications as the susceptibility to hardware failures decreases. The hardware concept for the KE melting operation is shown in **Fig. 6**.

On the central server, the virtual machines are installed with the control systems for the different parts of the melting operation. The data exchange between the applications on the virtual machines and the components in the field is based on TCP / IP based protocols. If field components are not network-capable, they are expanded by corresponding devices and via a software known as connectors are integrated into the data exchange.

This makes it possible to record a large part of all process-relevant data of the individual subsystems and to store them for cross-departmental analysis in a process database so that the manufacturing process becomes comprehensible for each casting. The monitoring of this production data opens up the possibility of early detection of errors and the initiation of corresponding countermeasures.

Modern systems monitor themselves and inform the operator when the unit leaves the normal operating range. In this context, the system performs extended monitoring of the cooling systems for the furnace and converter circuit as well as the cooling station. These data can be exchanged between the operator and the furnace system manufacturer and form a first step in the direction of a rule-based plant monitoring.

To control the melting process, the subsequently described melt processor Prodapt-Enterprise is used. With the charging system the batch composition is determined according to the program prescribed by the work preparation and transferred to the automatic charging crane. This then loads the calculated amounts of materials into the charging trolley, from where they are charged according to the requirements into the crucible and melted. At the same time, the additives also specified by the charging system computer are charged by hand from the furnace platform into the crucible. The sample drawn at the end of the melting process is analysed in the spectrometer and the result in the charge calculator compared with the target analysis. This is followed by the information for the correction materials to be provided on the furnace

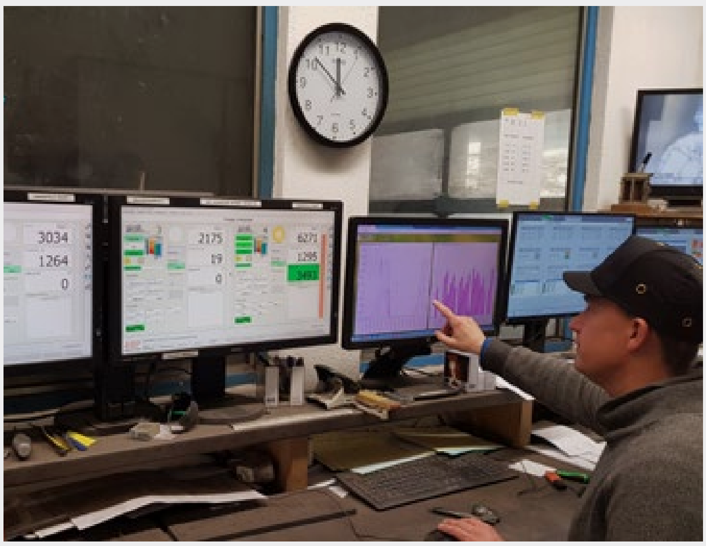

Fig. 7: Monitoring of the melting operation in the control room

Fig. 8: Overview screen of the 6 t-tandem

platform. The additional additives specified by the charge computer are taken into account, prepared on the foundry floor, and added to the ladle during tapping.

In addition to the spectrometer, a thermal analysis for the control of the melt quality is randomly applied. There, the C and Si contents are determined and a so-called K factor as a measure of the nucleation state of the melt.

MELT PROCESSOR PRODAPT-ENTERPRISE

The ABP Prodapt-Enterprise processor provides a complete melting process control solution. It supports the operator in guiding the furnace in sintering, melting and cold start modes. The process screens on the monitor inform the operator quickly and comprehensively about the situation of the melting process, pending faults and the measured parameter values (**Fig. 7**). In addition to economical operation, high availability and operational reliability of the melting system is achieved.

The process screens are designed so that the user can access the trend of the measured values in addition to the current data with a mouse click. In addition, in the fault message system the individual messages can be assigned instructions in the form of pictures and texts.

As an example, **Fig. 8** shows the overview screen of the 6 t tandem with the furnaces 3 and 4. During the normal melting process, this image is displayed on the monitor above the control panel and provides the operator with clear information about the current events in the furnaces. The large numbers indicate from top to bottom: crucible contents in kg, melt temperature in °C, power in kW. The horizontal green bar (under the furnace image) is a measure of the lining wear, which will be discussed in more detail later. Below this are the batch and material numbers along with an index number for the operator. The

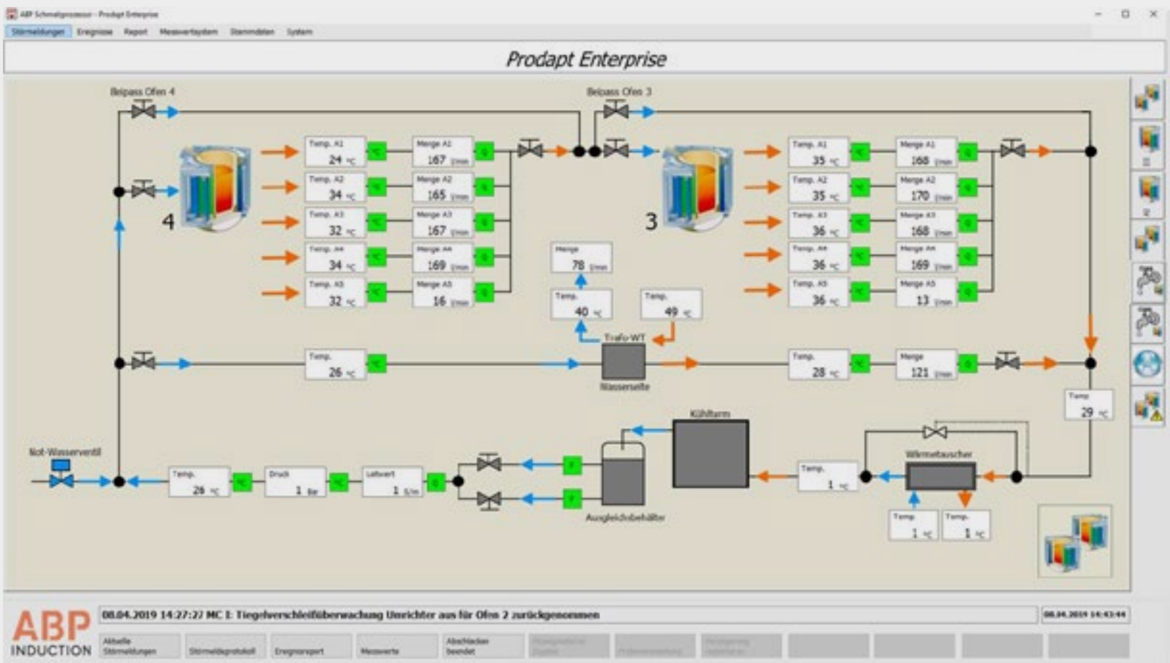

Fig.9: Supervision screen of the furnace cooling system

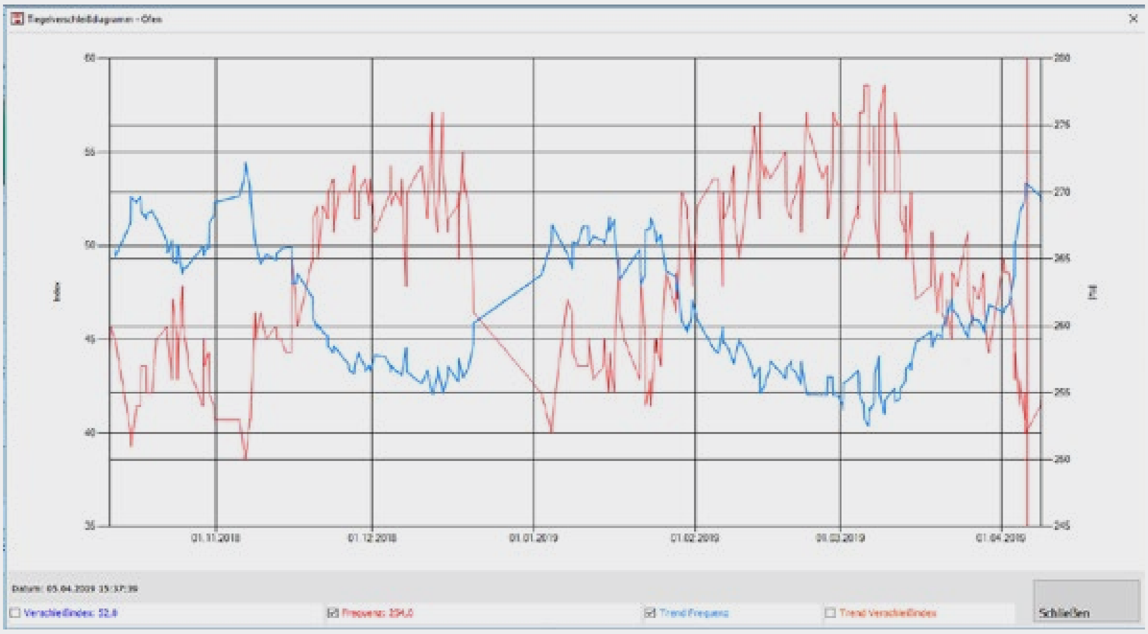

Fig. 10: Graph of the crucible wear figures over several campaigns. Blue: Frequency; Red: Wear factor

vertical orange bar indicates the amount of furnace power.

The required traceability of the melting process is taken into account by the Prodapt-Enterprise by linking the order number and the melt number to insure correlation. In addition, the work carried out on the furnace is logged. In addition to the general data of the melt, this logging stores the course of treatment with one-minute resolution. The course of treatment includes the heating process as well as the process events such as scale taring, temperature measurement and tapping. For each event, the time, duration, furnace contents and temperature of the melt are recorded. In addition, the characteristics of the selected material and the measured analyses are archived in the process database.

In addition to process control, the visualisation of the Prodapt-Enterprise captures the current status of the cooling system, hydraulics and energy supply. Limits that are exceeded or disturbances are represented by colour changes in the measuring fields and symbol fields. The furnace cooling system supervision screen shown in **Fig. 9** is representative of these screens.

The collected data is shown in a schematic representation of the system. The measurement fields show not only the values but also limit violations by colour change, and by clicking the trend of the value over the last 8 h can be viewed. The symbols are animated, and the status is indicated by colour changes. The system also records the water temperatures and volumes of the individual furnace cooling circuits. In case of trend violations, warnings are generated and forwarded to the maintenance department.

The fast and targeted reaction in case of failure is an essential factor for the availability of the melting plant. For this purpose, there is a plain text message when a fault occurs in the header of the process pictures. According to their classification, the displayed message is highlighted. This information is supplemented by the detail screen "Shutdowns". This detail image lists the malfunctions that cause the entire system or the relevant furnace to be switched off. The operator receives the fault information per SMS additionally which is helpful during down times, for example in case of cold start during the night.

MONITORING THE CRUCIBLE WEAR

The crucible monitoring has a special significance for the trouble-free operation of the melting plant. In addition to the regular visual inspection after tapping while the crucible wall has a dark red surface, monitoring is done by:

- Checking the resistance between the melt and coil (ground fault indication)
- Measurement and evaluation of active power and frequency using the Prodapt-Enterprise.

The ground fault indication system is described in detail elsewhere [3]; Here, the second method, namely the use of the Prodapt data will be discussed in more detail. Their significance in terms of crucible wear is due to the change in inductance of the coil as its distance from the melt changes. Accordingly, active power and frequency increase with decreasing wall thickness. In melting operation, once per batch with a full furnace and defined temperature, always at the same measuring conditions, the frequency and an index number for wear are determined. The latter is calculated from the specified power and the ratio of the resulting voltage to the rated voltage.

The values determined for the frequency and the wear index number are plotted over time and displayed in a process graph over the course during a lining campaign. **Fig. 10** shows an example of the graph of the measured values over several campaigns. At the end of a crucible campaign, the graphs are compared and correlated with the current condition of the worn crucible. In this way, it is possible to deduce from the course of the next campaign the expected crucible life and the time of re-lining.

A simplified and clear depiction of the wear process is shown in the overview process images (Fig. 8). There the measured values of frequency and power are converted to the length of a bar. At the beginning of a lining campaign, the horizontal green bar has the full length; it then decreases with progressively thinner crucible wall until complete disappearance when reaching the predetermined minimum wall thickness.

The term INTEGRAL is a characteristic statement for the evaluation of this signal. It follows from the physical contexts that the described determination of the measured values characterising the wall thickness always relates to the entire crucible in the area of the active coil. A local refractory wear in the form of an annular wear or a so-called elephant's foot is averaged over the entire crucible and accordingly not identified in its extent. As mentioned at the beginning of this section, therefore, the Prodapt signals must always be interpreted in the context of expert visual inspection. In this way, INTEGRAL offers reliable and clear help with crucible evaluation.

OUTLOOK

The benefits of end-to-end data management, beyond the goals already achieved, can be further expanded on as plant builders and operators work together. For example, it is conceivable that the results of the thermal analysis will be more closely integrated into the improvement of the melt quality or algorithms will be developed on the basis of the available data, which will further improve the coordination between the melting and casting shops. Furthermore, the improvement of quality in the process chain is conceivable. With the aid of process data acquisition and evaluation of tolerances, errors can be derived from deviations. For this purpose, automatically generated algorithms can be used which are specially designed for the foundry process.

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AUTHORS

Dr.-Ing. **Erwin Dötsch**
ABP Induction Systems GmbH
Dortmund, Germany
+49 (0)231 / 997-2451
erwin.doetsch@abpinduction.com

Jean-Pierre Hacquin
Kemptener Eisengießerei Adam Hönig AG
Kempten (Allgäu), Germany
+49 (0)831 / 58110-34
EDV@ke-ag.de

Dietmar Mitschulat
ABP Induction Systems GmbH
Dortmund, Germany
+49 (0)231 / 997-2526
dietmar.mitschulat@abpinduction.com