Overhauled electric arc furnace during tapping (Photos: SHB)

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Modernization of tree-phase electric arc furnaces in steel foundries

The article presents a major furnace overhaul and modernization project by way of the example of an 8 t electric arc furnace commissioned in 1984. The described project comprised the electrical, hydraulic and mechanical equipment of the furnace. Special emphasis was placed on a user-friendly design, safety aspects and improved measuring and control systems. Measurements during heat processing were performed before and after the project. The operating and maintenance personnel were provided all necessary training. A comparison of the results for the parameters measured before and after the project reveals the effectiveness of the measures. This is certainly of interest also for other foundries

The task

Advancing wear, deteriorating performance and failures of the 8 t electric arc furnace (**Figure 1**) as well as problems associated with the procurement of spare parts led to the placement of an order covering the complete overhaul and modernization of the furnace plants, excluding the circuit of the furnace, the furnace transformer with reactor, the high-current line with the current-conducting cables all the way to the electrode arms. The disassembly, overhauling, installation and commissioning of the equipment as well as the training of the operating and control staff had to be performed according to a specified schedule. The scope of the project encompassed the installation of a new furnace control system including the renewal of the complete hydraulic plant and the required valves for regulating the electrodes. All hydraulic cylinders were to be reconditioned and reinstalled. The complete control systems for all main, back-up and ancillary plant units had to be renewed. These included the following components:

» furnace circuit breaker with transformer,
» furnace transformer with transformer protection equipment,
» the hydraulic plant,
» the furnace cooling system,
» the main control pulpit for the control room and the local control pulpits,
» all furnace sensor and signal equipment, and
» the systems for an emergency shutdown.

The project activities including the commissioning procedures and hot testing were scheduled to take six weeks.

Figure 1: Electric arc furnace 1 before the overhaul.

Electrical equipment

Switchboard

The existing switchboard for the closed- and open-loop controls of the furnace plant was completely dismantled. **Figure 2** shows the old control pulpit. The newly designed switchboard (**Figure 3**) includes the low-voltage input and all necessary outputs for the back-up systems, the valve actuation as well as all control components for signal processing. For the supply of the control voltage a multi-partitioned design was chosen in order to be able to move the furnace in an emergency mode in the event of cable damage. Signal processing is by means of a Siemens Simatic-S7 PLC system. Depending on the requirements, integration of the process signals can be digital, analogue or via field bus. To guarantee maximum electromagnetic compatibility, the coupling with the field bus is fibre-optic-based, even for short distances.

Operating pulpits

The operating pulpits were designed and positioned in such a way that, while providing the operators a great deal of flexibility, also very high safety standards are guaranteed. This resulted in a much wider range of control possibilities integrated into the main control console (figure 4) and the local control consoles at the furnace. The central external control console was installed near the electric arc furnace (EAF). From this pulpit, the following hydraulic cylinders are actuated:

» lifting/lowering of electrodes 1 to 3,
» joint lifting of all electrodes,
» lifting/lowering of the furnace roof,
» swivelling of the furnace roof and
» tilting of the furnace (forwards/ backwards).

For example, it is possible to tilt the furnace from four different operating positions via analogue joysticks. Operating errors or overlapping commands are precluded as the operation of the plant is structured into several interlocked enabling circuits. Further local pulpits were provided for tapping, deslagging and lifting of the furnace door. All local pulpits are protected against mechanical damage by sturdy protection hoods. An operator protection switch was installed at each operating unit, . The switches are secured by padlocks. As a protection against short circuits during electrodes changes, a separate protective system was provided.

Human machine interface

The HMI of the furnace plant via Siemens touch panel and WinCC is highly flexible (**Figure 4**). The type and contents of the displays and operating screens were designed according to the customer's specifications. The information shown is thus perfectly tailored to the plant operator's needs.

Control concept and electrode regulation

Furnace control and electrode regulation is via discrete operation from the pulpits and data entries via the HMI. The completely overhauled hydraulic plant can now be started in a state-of-the-art fashion by a single operation and is automatically monitored. The electrode regulation concept was specifically tailored to the requirements of electric arc furnaces of this relatively small size and was accordingly implemented in PLC-S7. By adapting the regulating parameters, the regulating behaviour changes according to the progress of the melting process [1]. The setpoint values for the regulation can be separately and independently selected for each electrode. This provides the operator the possibility of setting asymmetric secondary currents as required and depending on the scrap quality. The furnace plant is protected against excess currents by means of redundantly actuating protection devices. Redundancy was consistently implemented throughout the entire system and is guaranteed by the implementation of separate signal routes for the current measurement, by separate evaluation systems and finally by separate electrode lifting actuators. The modernization measures also included the implementation of a state-of-the-art electrode breakage protection system working on the basis of pressure measurements in the electrode cylinders and the installation of an advanced tilting angle measurement and display system.

Others

Autonomously operating ancillary systems are generally integrated into the plant control system upon customer request. In this example, the customer had specified that the control and display of the off-gas regulation system was to be integrated into the plant HMI.

Figure 2: Operating control console – old design.

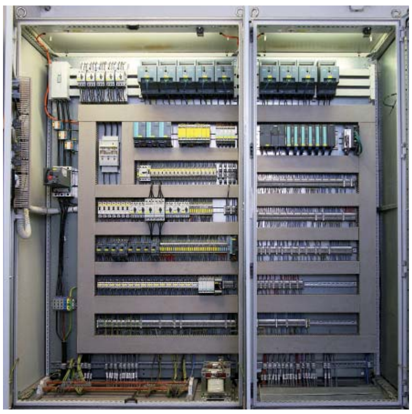

Figure 3: The new control cabinet.

Figure 4: The new main control console.

Hydraulic plant

Concept

The overhaul concept for the hydraulic plant provided for the heavily worn water-hydraulic plant to be completely renewed. However, the existing hydraulic cylinders were to be reconditioned and reused. The working pressure of max. 30 bar was retained, achieving the required electrode adjustment speeds for a stable furnace operation. The manually operated hydraulic valves were replaced by electrically actuated magnetic valves. HLP-46 D is used as hydraulic fluid. This fluid is a high-grade mineral oil featuring excellent viscous and thermal properties. The renovation started with the complete dismantling of the existing hydraulic plant. The plant components and pipe lines were disassembled and scrapped. The hydraulic cylinders were taken to the workshop for reconditioning. After the disassembly, the pits and ducts of the EAF were thoroughly cleaned, immediately followed by the installation of new pipe lines for the complete plant and by the assembly of the new hydraulic equipment.

Hydraulic room

The hydraulic room was cleaned after removal of the old equipment. The walls were repainted and the new tank, with a capacity of 2,400 l hydraulic fluid, was set up. **Figure 5** shows the hydraulic room with the new equipment. The two axial piston pumps, installed directly on the tank, ensure redundant EAF operation. The accumulator was set up next to the tank. Via a bypass system, a third pump supplies a heater, a cooler and a filter to provide uniformly optimal conditions for the oil. All functions are monitored and transmitted to the programme control system for logging and evaluation.

Electric arc furnace

The control blocks with the corresponding valves are installed next to the EAF. Pilot-control proportional valves are used for regulating the electrodes. **Figure 6** shows the proportional valves. Digital power amplifiers ensure that the volumetric flows are precisely and reproducibly adjusted. The main piston in the valve is position-controlled. For rapid electrode lifting, a rapid feed control (bypass – valve) was established for each electrode. A second accumulator unit for emergency operation was mounted close to the control valves. It was designed such that an ongoing tapping process can be completed or that, in the event that the control system fails, the electrodes can be lifted out of the steel bath via manually operated valves.

Design features

Furnace tilting is actuated by a proportional valve which allows smooth tapping of the EAF. Electrode locking at the electrode arms is activated by manually operated valves. Load cells installed in the pressure lines to the three electrode cylinders actuate the "electrode breakage protection system". This system prevents the graphite electrodes from breaking in case they hit non-conducting particles in the scrap charge. The installed valves with hand levers make it possible to move the electrodes and tilt the furnace during operation in the emergency mode. A pneumatically actuated emergency safety valve, which operates independently of the control voltage, was installed to disconnect the hydraulic line of the accumulator station. All hydraulic lines were completely replaced.

Cooling water supply

Also the cooling water supply system of the EAF was completely replaced. The new equipment (manifold, water collecting tank, piping) is made of CrNi steel.

Mechanical equipment

The mechanical components of the furnace plant were completely disassembled and overhauled. The current-conducting cables were only demounted, not overhauled, because they had been completely newly installed about three years ago. The then installed insulated type cables were still in good condition.

The following disassembled components were overhauled in the workshop:

» three electrode arms,

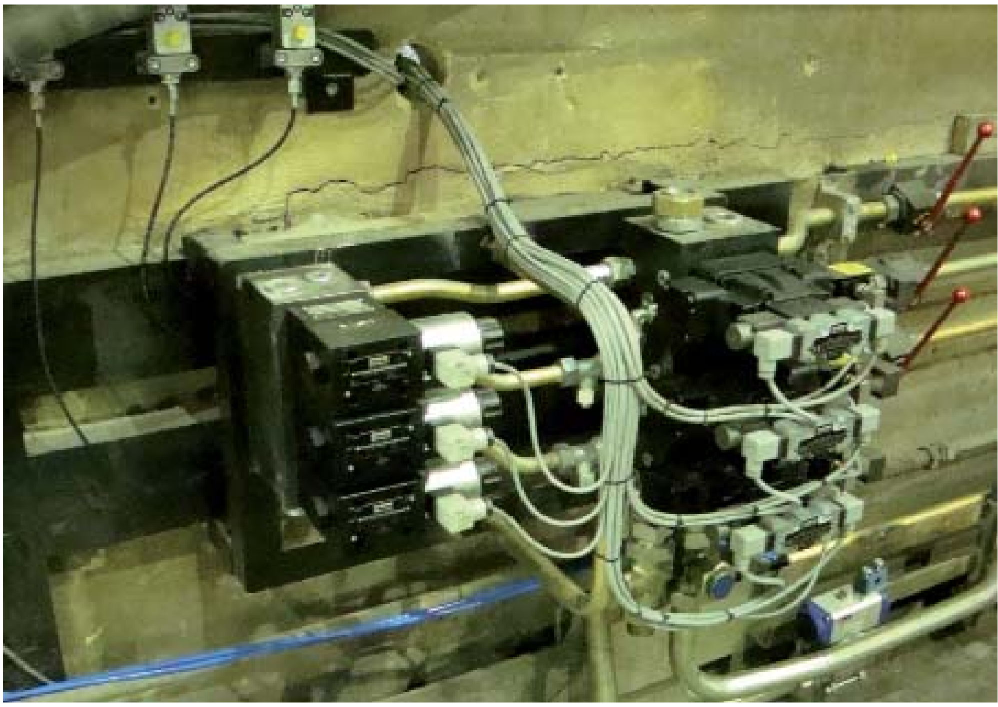

Figure 5: The hydraulic room with the new equipment.

» three electrode columns,
» the complete electrode guiding system,
» the roof lifting and swivelling equipment with drive, and
» all hydraulic cylinders.

Basically, these components were overhauled by installing the provided spare parts. At the electrode arms, the electrode clamping device, the contact jaws, the water-cooled power lines and the operational insulation were inspected. Identified damage was repaired. The heavily worn guides of the electrode arms turned out to require the most intensive mechanical overhaul. The guide rails had been deeply rutted, requiring complete reworking. Therefore, all guide rollers had to be manufactured anew with a larger diameter in order to make up for the resulting reworking tolerance. The drive for the roof lifting and swivelling mechanism had also been heavily worn and had to be completely overhauled. The bearings were replaced. Also the two hydraulic drives were overhauled. Additionally needed spare parts were promptly made available. All mechanical plant components were subjected to a colour

Figure 6: The new proportional valves.

treatment. The furnace vessel and the furnace cradle were placed in an on-site repair area, cleaned and inspected. After repairing the damage, both the vessel and the cradle were subjected to a colour treatment. The assembly of the overhauled mechanical furnace plant took place according to a specified schedule. The photo on page XXX shows the furnace after the overhaul.

Results

Measurements

To be able to compare the conditions before and after the overhaul, measurements were made during the

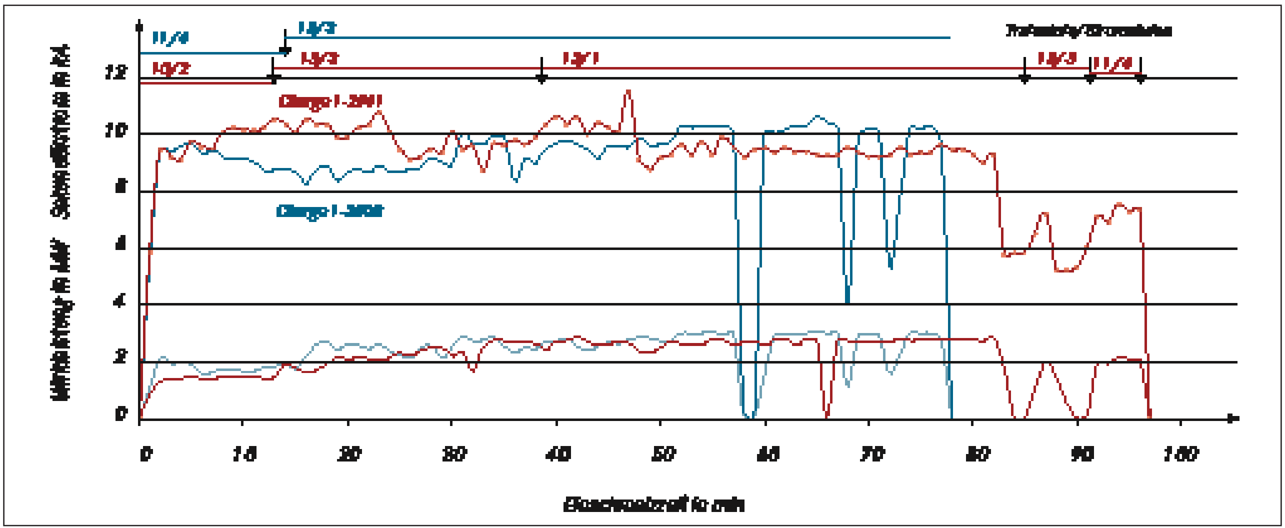

Figure 7: Real power and secondary current before and after the upgrade (source: ATS Sachse).

processing of selected heats. The measurements were made in line with the applicable test standard IEC 60676 using an AC Power Analyser D5155 (measuring intervals 60 s). The measurement log included:

» electrode assignment to channel a, b or c and the time of the measurement,
» secondary current/phase and mean value,
» voltage at point of measurement/phase and mean value,
» active power/phase and mean value,
» power factor cos φ/phase and mean value,
» resistance/phase and impedance/phase,
» energy consumption/phase and Σ energy consumption (cumulative).

Each measurement starts with the assignment of each electrode to channel a, b or c. Additionally, values like the charge weight, charge number, kWh meter reading of the furnace, switching of voltage and current steps as well as the primary voltage are captured. It is useful to install modular terminal blocks for connecting the measuring equipment. In order to determine the conditions prevailing prior to the project (hot-running furnace state), it is necessary to make measurements during a maximum of three charges. The measurements provide the basis for the assessment of the present state of the electrical, electrothermal and mechanical properties. The measurements must be performed approximately three weeks prior to the start of the project. Additionally, the following data are captured: circuit breaker position, transformer, inductor, high-current line, temperatures of plant components, electrode arm guiding, etc. Subsequent evaluations based on the characteristic furnace curves for selected transformer taps provide information as to the wear situation and as to which areas should be predominantly tackled. It is possible to include additional observations as to the melt-down times (in min), heating rates (in °C/min), radiation index (in MWV/m²), operation characteristics depending on charge type, specific electric energy consumption (in kWh/t) and graphite electrode consumption rates (in kg/t) [2]. During commissioning, around five heats were necessary to achieve a favourable operating behaviour with the corresponding settings. During the following two heats, fine adjustments and minimal corrections were made to the input values. This guarantees that the plant works optimally under the prevailing preconditions. **Figure 7** shows the measured and set values during melt-down before and after the overhaul. The internal quality management personnel evaluate the consumption data on a monthly basis against the values captured after commissioning of the overhauled plant. This makes it easier for the personnel to keep track of any changes and take appropriate action if necessary. It is recommended that the furnace plant should be checked every two years by means of appropriate measuring equipment. Through this, it is possible to recognize and remedy any irregularities in the operation of the EAF.

Comparison

The order for the complete overhaul and upgrading of the furnace did not specify any performance indicators. However, according to the contract, prior and after the overhaul/upgrading of the EAF, measurements were to be conducted during heat processing. The results of projects of this complexity are of interest not only for the customer. Therefore, selected comparable charges were analyzed with respect to the following values and melting parameters:

» melt-down rate,
» effective power for melt-down,
» electric energy consumption,
» graphite electrode consumption,
» mean electrode current (rms values),
» other electrothermal values.

The comparative values given in **table 1** take account of differences in the charge weights and the tolerance of the electric energy reading. The furnace transformer and the inductor re-

	Before modernization		After modernization	Results
	Heat I-2941 Date: 2.2.12	Heat I-3008 Date: 28.3.12		
Charged weight (cold charge) in t	**8.200**	7.900	**8.200**	**8.200**
Melt-down time (1,545/1,537 °C) in min	94	77.00	79.8	
Power-on time in min	91.2	73.9	76.7	**-14**
Mean melt-down rate (power-on time) in t scrap/h	5.397	6.414	6.356	**0.959**
Mean melt-down rate (gross) in t scrap/h	**5.234**	**6.156**	**6.104**	**0.870**
Electric energy consumption in kWh	3655	3220	3342	
Mean energy input (power-on time) in kWh/min	40.1	43.6	43.6	
Specific electric energy consumption in kWh/t	445.7	407.6	407.6	**-35**
Specific power in kW/t	293	331		
Bath temperature at end of melt-down in °C	1550	1545		
Mean current (rms) in kA	**9.428**	**9.381**	**9.381**	
Resistance in mV	9.020	9.902		
Loss resistance (reactor + transformer + line) in mΩ	0.987	0.887 -0.1		
Electric arc resistance in mΩ	8.033	9.015		
Electric arc voltage in V	75.7	84.6		
Electric arc length in mm	55	65		
Real power in kWh/h	2405	2614	209	
Electric power loss in kWh/h	263	234		
Heat loss in kWh/h	268	260		-8
Electric arc power in kWh/h	2142	2380	2120	
Useful power in kWh/h	1874	2120		**246**
Electrothermal efficiency	0.779	0.811		0.033
Electric efficiency	0.891	0.910		
Radiation factor (w/o cover) in MWV/m²	89	110		22
Graphite electrode consumption (calculated) in kg GE/t	3.047	2.557	2.565	**-0.48**

Notes:
Melting on the basis of 1,545 °C;
all measured values provided by ATS Sachse GmbH;
active power primary/secondary factor 1.034;
the primary energy was measured at the start and end of melting;
for an adjusted comparison, the energy consumption values "before overhaul" have been corrected with the factor 0.9933 of the new energy measurement;
from experience, good-quality contact jaws reduce resistance loss by at least 0.1 mΩ (-26.5 kWh/h at 9.4 kA);
the coating of the furnace vessel reduces heat losses through the furnace vessel by approx. 3 % (-7.8 kWh/h during melting, approx. 15.6 kWh/h during blowing and refining).

Table 1: Comparison of parameters and measured values before and after the overhaul/modernization.

mained unchanged. The decrease in specific electrode consumption was determined by way of a theoretical calculation [3]. With identical mean electrode currents, the savings result from the shorter melt-down time and the enhanced features and adjustment capabilities of the electrode regulation system. This leads to fewer short circuits (less tip burn-off) and less frequent electrode breakages (breakage protection). **Table 2** includes corrective factors which can be used to take into account the thermal condition of the furnace (stored heat). They can be used, for example, to correct the following parameters or, in case of a defined number of heats/day, to calculate the means of the melting time, the melt-down rate, electric energy consumption, electrode consumption and the heating rate. **Table 3** gives reference power values for holding at temperature. The set values for the above described electrode regulation system also take into account the prevention of excessively high arcing zone temperatures. For holding and in case of a low heating rate, the arc voltage was set slightly higher and the arc currents somewhat lower. This avoids local overheating of the arcing zone, a situation to be prevented for metallurgical reasons.[4].

	Heat				
	1	2	3	4	5
Factor Kth	1.20	1.10	1.05	1.02	1.00
Furnace state	cold				hot

Table 2: Corrective factors for the thermal state (kth) of the EAF

Temperature in °C	Mean power in kWh/h	in kWh/min
1,500	520	8.7
1,600	592	9.9
1,650	629	10.5
1,700	668	11.1

Table 3: Reference values for holding, mean power, flue gas flap shut ("0"), hot-running furnace.

Conclusions

The objective of the comprehensive overhaul and modernization of EAF 1, type IHF 31 (manufactured by KGYV, Hungary), in operation at SHB Stahl- und Hartgusswerk Bösdorf GmbH, Knautnaundorf near Leipzig, Germany, for 28 years, was to fully restore the functionality of the plant. Measures like the integration of a PLC 7-based electrode regulation system, user-friendly measuring, control and regulation systems and improvements to the protection and safety equipment have revamped the EAF into a high-performance and reliable melting unit.

Measurements before and after the overhaul allow a comparison of selected heats and prove the achieved improvements. Especially for steel foundries, the above described solution is an economic alternative to the investment in a new electric arc furnace.

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References:

www.giesserei-verlag.de/cpt/references