MODERNIZATION OF THE ELECTRIC ARC FURNACE OF CELL 1 AT VILLARES METALS[1]

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Abstract

In May 2005 Villares Metals initiated the modernization project for the EAF 1 and awarded SIEMENS-VAI a contract for the modernization of the electric arc furnace. The main goal of the project was to introduce water cooled panels and roof in order to utilize the available transformer power and a door lance for carbon and oxygen injection for creation of foaming slag at engineering steels as well as at high chromium tool- and stainless steel grades. A new hydraulic system and automation system were implemented, together with the new electrode control system and a dynamic process model.Besides more comfortable operation and maintenance, major productivity and cost reductions were achieved. The operation with foaming slag could be implemented successfully for various steel grades, also with high Chromium content. The measurement of the foaming slag index reflects well the observed presence of foaming slag.The paper describes main features of the equipment and summarizes the results of the operation with the modernized furnace.

Key words: Electric arc furnace.

MODERNIZAÇÃO DO FORNO ELÉTRICO A ARCO - VILLARES METALS

Resumo

Em Maio de 2005, a Villares Metals iniciou um projeto de modernização do Forno Elétrico 1 e concedeu à Siemens VAI o seu contrato execução. O objetivo principal do Projeto foi utilizar paineis e abóbada refrigerados a água de forma a utilizar toda a potência disponível do transformador, e, além disso, instalar uma lança de injeção de carbono e oxigênio pela porta de escória para a produção de escória espumante na produção de aços de engenharia, aços ferramenta de alto cromo e inoxidáveis. Dois novos sistemas, hidráulico e de automação foram implementados, juntamente a um novo sistema de controle de eletrodo e um modelo de processo dinâmico. Além de operação e manutenção mais confortáveis, produtividade superior e redução de custos foram alcançados. A operação com escória espumante pôde ser implementada com sucesso para vários tipos de aço, inclusive com aço de alto cromo. A medição do índice de escória espumante reflete bem a sua presença observada. Este trabalho descreve as principais características do equipamento e aponta os resultados da operação com o forno modernizado.

Palavras-chave: Forno elétrico.

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INTRODUCTION

The electric arc furnace of Cell 1 of Villares Metals is a spout furnace for the production of special and stainless steels. The furnace was designed in the late 1970'ies by BBC and had an original design capacity of 18 t. During the years the refractory design was modified, and in 2005, before the modernization the furnace operated at a maximum capacity of 27 t tapping weight. The furnace did not possess any water cooled wall or roof panels. During 2005, the furnace transformer was rebuilt and upgraded to a nominal capacity of 20 MVA.
In order to operate the furnace at full power, a major furnace revamp was initiated by Villares Metals, by introducing water cooled panels and a water cooled roof, a new electrode control and automation system, and a door lance manipulator for oxygen and solids injection for decarburization as well as for foaming slag creation. With these optimizations of the design and the resulting process improvements, a maximum steel capacity of 33 t and a remarkable increase of chromium and iron yield could be reached, furthermore the furnace could be operated at the maximum transformer tap with 20 MVA total power.

New Furnace Mechanical and Process Equipment

The goal of the modernization project was to maximize the productivity considering reuse of existing foundation, furnace gantry and electrode arms. The modernization project included a new split shell, the upper shell equipped with water cooled panels, a new water cooled roof and new hydraulic unit with proportional valve control. The operating pulpit was replaced by a new fully enclosed control room, and the hard wired control and electrode control with the technology from the 1960'ies was replaced by a new PLC control and a modern ArCOS electrode control with proportional valves.
The practice for quick exchange of the lower shell was adapted to allow off-line refractory work on the furnace. In order to fit the new furnace on the same foundation and reuse the furnace gantry, the furnace rocker track is attached directly to the furnace shell, and the design does not use a tilt frame. This significantly reduces the investment cost for the revamp.
A new door lance manipulator with remote control was installed with a capacity of 1600 Nm3/h for oxygen blowing, and 20-60 kg/min of carbon or silicon injection. The lance manipulator is water cooled, with a lifetime of the tip and lance body of typically 3 months. The design of the furnace was made in 3d which enables checking of interference of the new equipment with existing installations.

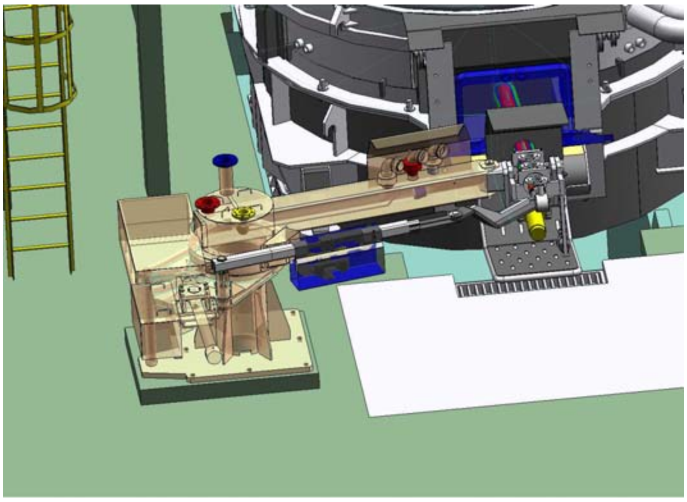

Figure 1: 3-Dimensional Model of the Lance Manipulator

The predefined shut down period of 3 weeks at the end of 2005 and beginning of 2006 made the project schedule very challenging. With the start of the project in May 2005, the time schedule allowed only 8 months for engineering, manufacturing, erection and commissioning of the new furnace. The tasks also included construction of a new control room, and a reinforcement of the foundation and exchange of rocker tracks, which had all to be accomplished in the 3 week shut down period.

Automation Solutions

The modernization project also included a new PLC control of the main furnace functions such as furnace movements, interlocks, control of hydraulic unit, carbon and silicon injection through the door lance, and the ArCOS electrode control system. The level 1 automation concept includes all functions such as main furnace controls, injection system control, control of the lance manipulator via remote control, and the hydraulic unit.

ArCOS is a standalone system receiving current, voltage as well as electrode position directly and controls the proportional valves of the electrode columns in order to stabilize the electric arc. The controller supports different control algorithms like current-, impedance-, arc-resistance- and arc voltage regulation. An additional loop is provided for Automatic Set-point Optimization (= ASO). The ASO unit is able to adapt set-points accordingly to the stability of the melt down process. By harmonics analysis (Fast Fourier Transformation) of the current the arc stability is calculated. A special developed algorithm modifies the regulation Set-points to achieve optimum arc stability.

Additional control loops, such as short circuit protection for fast electrode raise in case of scrap cave in or an anti resonance circuit for avoiding horizontal or vertical electrode vibrations are further improving the process stability.

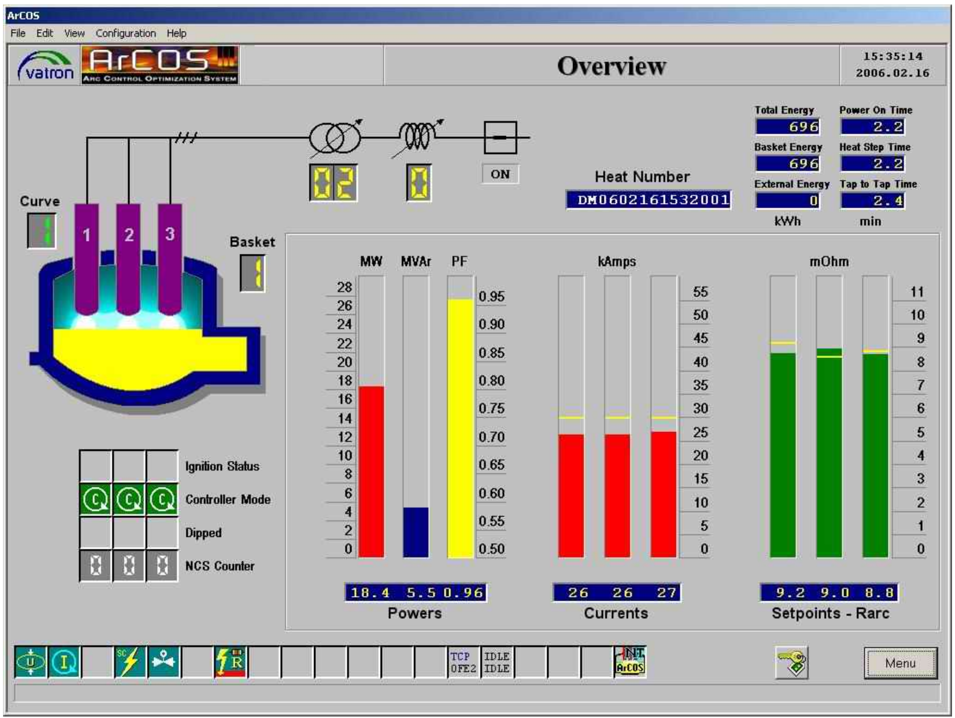

Figure 2 : ArCOS main screen

ArCOS's integrated visualization system gives an excellent support for start-up, optimization and maintenance. Several screens make the system total transparent to the user. One can watch the different control modules, the I/O signals or can display every variable stored in the internal database by a six channel Composition.Additionally all relevant process data can be logged on the systems Hard Disk for offline data analysis.

ArCOS uses a smart measuring transducer for signal pick up. This kind of transducer collects the true root mean square values (TRMS) of currents and voltages as well as the active power in considering the shape of the signals. Additional information as reactive power, apparent power, power factor, arc stability, THD (Total harmonic distortion) for example can be determined by further calculations.

The DynArCOS system, installed in a second phase, allowed the definition of melting profiles for a variety of steel grades, similar to a level 2 system.

Supplemental DynArCOS includes a temperature model for thermal furnace balancing.

This fuzzy controller based temperature model considers the cooling water temperatures of the side wall panels and shifts the arc radiation by means of arc length correction of the individual electrode in order to avoid high radiation exposures of panels and roof. Thus the switching back to a lower transformer voltage can be delayed or even avoided, which results in higher power input.

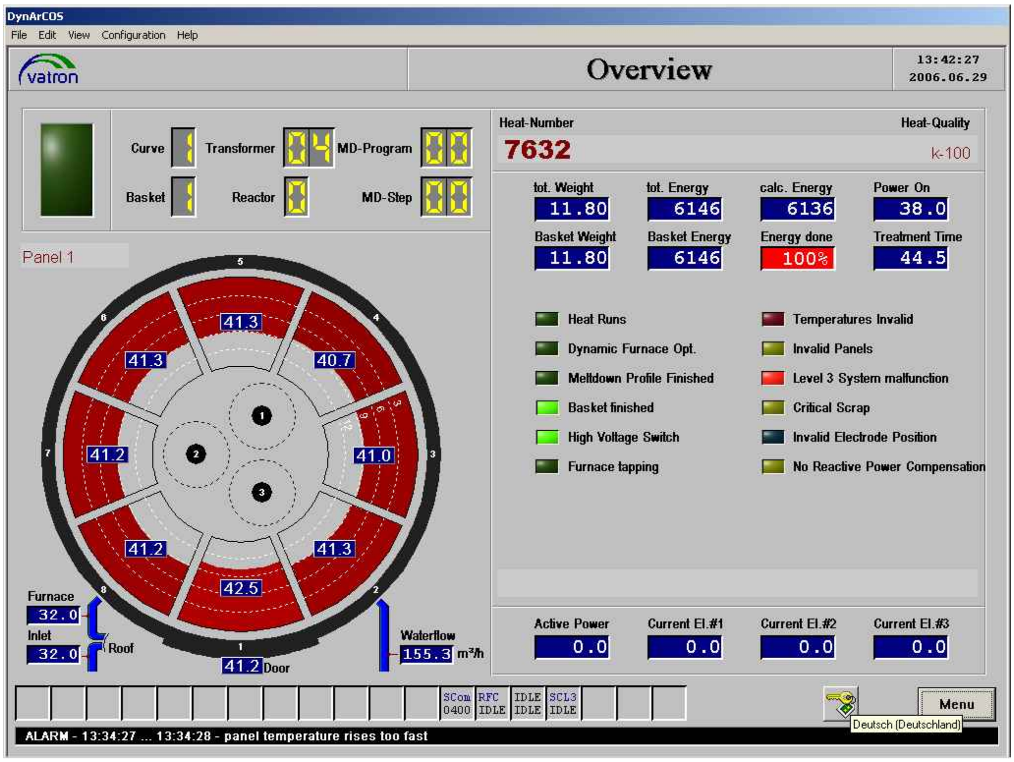

Figure 3: The DynArCOS Main Screen

DynArCOS includes a dynamical meltdown system, which selects the optimal transformer and reactor tap out of a multitude of furnace magnitudes and peripheral influences. This system is based on an extremely flexible and free programmable meltdown program which can handle up to 80 different programs.
Each program is subdivided into a – theoretically infinite – number of steps. The desired transformer tap, reactor tap and involvement of peripheral units can be assigned to each step. Using these logics every heat step can be perfectly adjusted to the process requirements. Interrupt sequences e.g. for soft restart after a heat interruption can also be defined.

Foaming slag process at high chromium stainless and tool steels

With the lance manipulator and the ArCOS regulation system Villares metals got the preconditions to develop and introduce a foaming slag process even for the production of steel grades with Chromium contents up to18%
ArCOS is able to give an actual quantitative information on the slag foaming situation by calculating a Foaming Slag Index (FSI). This FSI is evaluated by analyzing the distortion of the arc current of the furnace. For this reason the ratio of the amplitude of the fundamental frequency to that of the sum of the harmonics 10 to 20 is calculated according to the following equation:

$$FSI = \frac{H_1}{K_1 \cdot \sqrt{\sum_{i=10}^{20} H_i^2} + K_2}$$

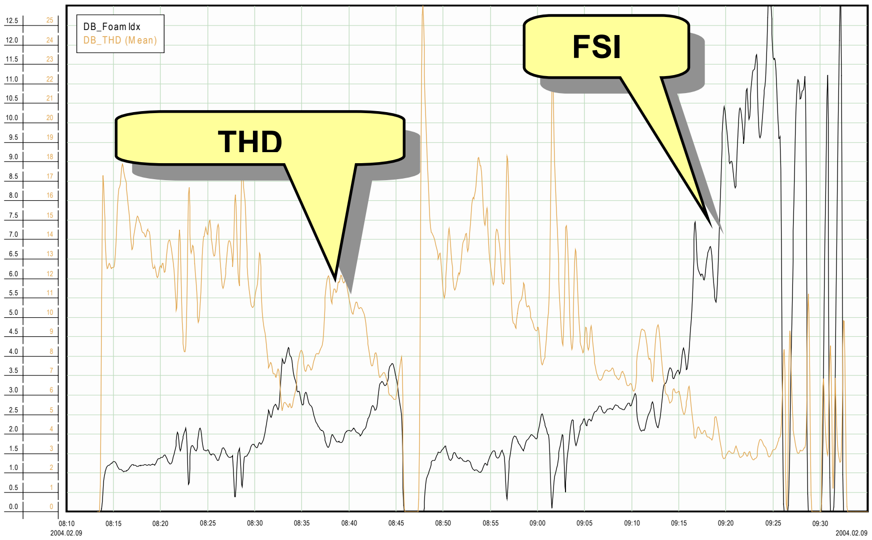

Figure 4: Foaming Slag Index (FSI) and Total Harmonic Distortion (THD)

The FSI is an inverse function of the THD as can be seen from Figure 4 . Increasing FSI is indicating increasing slag heights. The detection of the FSI proved to be an excellent tool for the development and the control of the foaming slag process at high chromium containing steels .

To explain this the basic considerations of the foaming slag process applied at Villares Metal shall be discussed shortly , a detailed discussion was published recently.(1)

In general the foamy slag process is based on of a steady generation of sufficient gas and physical properties of the slag favoring foam formation. These conditions have to be kept stable over the whole process.

In chromium steels the process applied at Villares Metals is based on the oxidation of chromium to Cr_2O_3 and its subsequent reduction by carbon, forming CO as gaseous agent for the foam formation. The formed Cr_2O_3 is a powerful refractory and makes the slag stiff and less reactive if its content exceeds 5-10%. The interdependence between the injection parameters and the resulting slag properties as a precondition for a stable process is therefore very sensitive.

The preconditions for a successful foaming slag process for high chromium stainless steels can be described as follows:

Formation of sufficient gas

Gas generation is performed, as described above, by Cr_2O_3 formation by oxygen blowing in the steel bath and simultaneous CO formation by reduction of Cr_2O_3 by means of carbon injection in the slag according to the reaction:

$$Cr_2O_3 + 3C = 3CO + 2\,Cr$$

Thermodynamically the CO formation is favored by a high activity of Cr_2O_3 and C and a low CO partial pressure. Therefore the activity coefficient of Cr_2O_3 in the slag system applied, should be as high as possible, which is favored by a high basicity of the slag.(2,3) The activity of C and can be influenced by the steel composition. Because of the equilibrium between CO and Cr_2O_3 rather high temperatures depending on the chromium and carbon content have to be maintained.(1) Lowering of CO partial pressure is not applicable in the arc furnace until now.

Physical properties of the slag

To avoid undesired CrO formation and support the reduction of Cr_2O_3 basic slags are favored. The reported slag compositions for successful foaming are within the following limits.[1,4-6]

CaO ~40-55%; SiO2 ~20-40%; MgO ~ 6-15 % ; FeO ~ 2-10%

Cr_2O_3 > 5% forms stiff slag creating poor reaction kinetics. (Figure 6)
Figure 5 shows the system CaO (+MgO)-SiO2- Cr_2O_3. In this system according to M. Görnerup[4] three areas are marked;
the red area marks slag compositions which provide good reduction as well as good foaming properties
the green with poor foam ability and reduction
the blue with good foam ability and bad gas generation

The red area is in accordance with (5). Own results are indicating a smaller area (mey). There is now a overlapping of the red with the green area indicating the range, which only allows good results if FeO injection is performed.[7] The blue area will be discussed below.

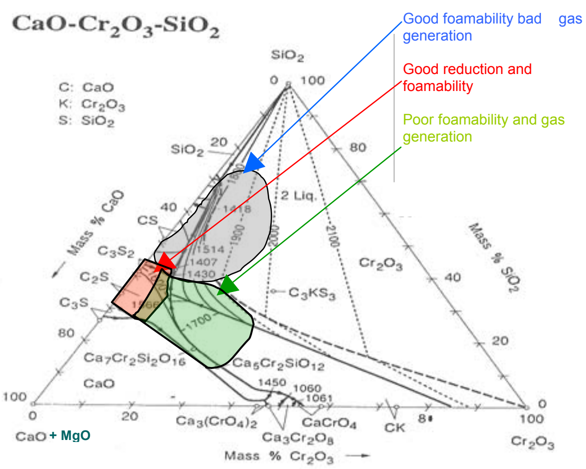

Figure 5: Phase diagram showing the areas of different foaming and reduction properties

Summarizing the preferred way should aim at a stationary process consisting of a simultaneous oxidation and reduction by carbon from the beginning of the foaming period. This keeps SiO_2 in the slag stable and keeps the system within the area with favorable slag properties for sustainable foam formation and of sufficient high a_{Cr2O3}. (Figure 5)
Several authors stated that the intensity of foaming is directly related to the reduction (4), (6), (7) a good foaming process results in a low Cr_2O_3 content in the slag, which is also in accordance with own results, as can be seen from Figure 6. Therefore a quantitative determination of the status of the foaming situation of the slag is very useful and can help to operate the process in a stable way.
With the determination of the FSI ArCOS is offering a tool for continuous recording of the foaming situation. Thus providing the necessary information a to operate the process with the right parameters in a stationary way.

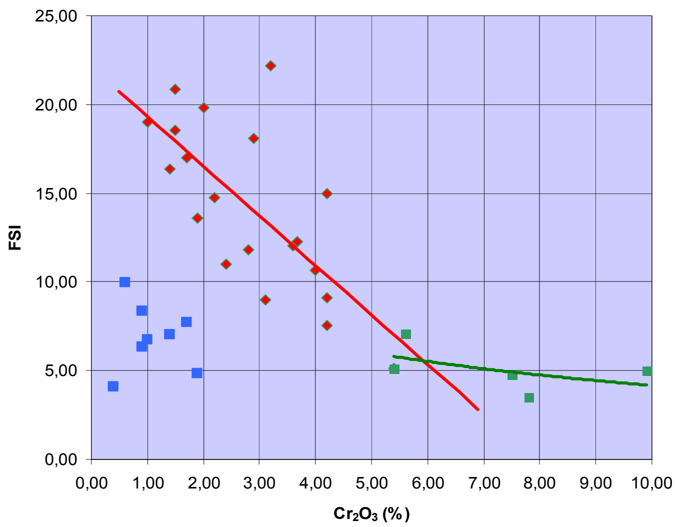

Figure 6: FSI versus Cr_2O_3 contents of heats with different slag composition

Figure 6 shows the dependency of the Cr_2O_3 content of the slag samples on the FSI value. The different colors of the points representing the different areas of slag composition in Figure 5. It can be seen, that in red area there is a direct dependency of the resulting Cr_2O_3 content with the FSI. A good reduction by carbon results in low Cr_2O_3 contents and a very good chromium yield.

Slags with a composition according to the overlapping region between red and green have already too high Cr_2O_3 contents for a good reduction (green points). Therefore a low gas generation and worse foaming behavior. The figure shows furthermore, that about 5% Cr_2O_3 are the limit for a successful reduction by carbon. This is of importance for the initial phase of the foaming process

The blue dots are results from steels with very high silicon and medium chromium content. In this case during the oxygen injection a high amount of SiO_2 was produced and the reduction was performed by the silicon. This is indicated by the fact that these heats show no relation between reduction and FSI. Only a small amount of Cr_2O_3 was reduced by carbon, therefore only a poor gas generation took place. The final slag composition was due to the high amount of SiO_2 already according to the blue area in Figure 5

Results

The New Furnace with lance manipulator and new automation system presented a new challenge for the operators. However, the operation of the new furnace and lance was dominated quickly and the benefits and improved results could be realized immediately.

Foaming slag practice was implemented from the beginning for steels where this practice is possible.

The savings offered by the introduction of the foaming slag practice are remarkable, and there is still potential for further improvement. Nevertheless an average chromium oxide content of 3% in the slag is realistic and already regularly achieved at some steel grades, compared to 15 -20% which is a common value in most of the plants today. Better heat transfer and an increased arc voltage are causing time savings up to 15%. The amount of refractory savings can be seen from the below table.

Table 1 : Comparison of main features and results before and after the revamp

	Before	After
Liquid Steel Capacity	27 t	33 t
Furnace Diameter (inner diameter of upper shell)	2900 mm	3686 mm
Transformer Power	16 MVA	20 MVA
Average Tap to tap	146 min	118 min
Productivity	11,0 t/h	15,2 t/h
Refractory consumption	13,0 kg/t	9,2 kg/t

Figure 7 : New Furnace

Acknowledgements

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