A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 53 2008 Issue 2

CH. SEDIVY*, R. KRUMP*

TOOLS FOR FOAMING SLAG OPERATION AT EAF STEELMAKING

NARZĘDZIA DO TECHNOLOGII PIENIENIA ŻUŻLA PRZY WYTWARZANIU STALI W EAF

Foaming slag operation at the EAF process is state of the art. A stationary foam operation can be maintained only by adjustment of the blowing parameters according to the real situation in the furnace.

The best results can be achieved by using an automatic slag management system which is able to detect the actual situation quantitatively and control the carbon addition in order to achieve perfect foaming condition.

From operations aspect it is essential to have simple and robust devices for slag determination, since this requires a minimum of installation cost and a minimum of failure risk.

The automatic foaming slag based on harmonics analysis of the current is a meanwhile proven technology is meanwhile implemented in numerous installations worldwide.

Keywords: Foaming Slag Management, EAF, Electrode Control System

Technologia pienienia żużla w procesie EAF jest stale rozwijana. Utrzymywanie stabilnego pienienia żużla może być realizowane poprzez dopasowaniu parametrów dmuchu, odpowiednio do rzeczywistej sytuacji w piecu.

Najlepsze wyniki mogą być osiągnięte przez użycie automatycznego systemu regulowania poziomu żużla, który jest zdolny ilościowo określić aktualną sytuacje oraz sterować dodawaniem węgla, aby uzyskać najlepsze warunki pienienia.

Aspekty technologii wskazują na możliwość zainstalowania prostych i solidnych przyrządów do oznaczania poziomu żużli, dodatkowo cechujące się niskimi kosztami instalacji i niską awaryjnością.

Automatyzacja pienienia żużla oparta o analizę harmonicznych obwodu jest potwierdzona i aktualnie wprowadzana w wielu światowych instalacjach technologicznych.

1. Introduction

Steel melting with foaming slag is common practice meanwhile and has been explored and investigated intensively.

Some of the advantages of this operating in an EAF are:

- increased productivity
- decreased refractory consumption
- decreased energy consumption
- decreased electrode consumption
- better arc stability

A main point for achieving good results is the electrical power input for the EAF. It must be quickly and flexible adapted to the actual process situation and the foaming-behaviour of the slag.

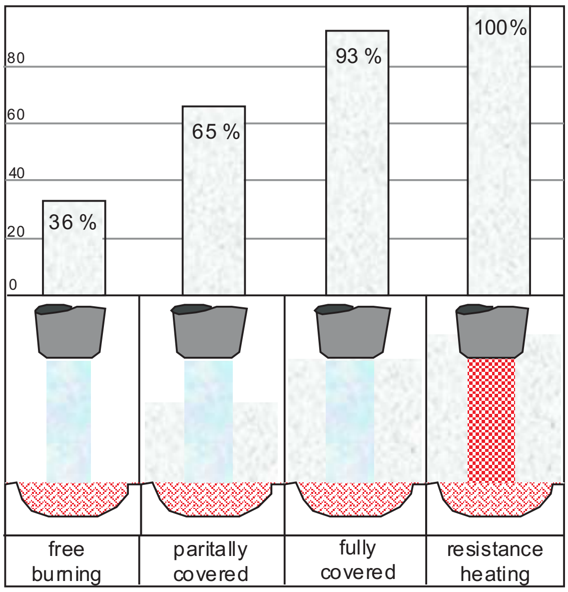

Fig. 1. Influence of foaming slag to the efficiency of power input (after Ameling & Petry; 1986)

* VATRON GMBH, VOESTALPINE STR. 3, 4031 LINZ, AUSTRIA

The foaming of the slag is done by direct injection of carbon granulate into the slag zone by means of water cooled injection lances.

$$FeO + CvCO + Fe \qquad (1)$$

The volume of the slag is multiplied by the generation of CO gas and consequently the electric arc is covered by the slag. This changes the characteristics of the arc and the efficiency of power input is heavily increased.

2. JUDGING CRITERIA AND SLAG-INDEX

Simple and robust measuring devices for determining the slag height are necessary for automatic control of foaming slag quality.

When investigating an arc furnace, the extremely high noise generation is noticed. This noise emission is heavily reduced as soon as the furnace operates under foaming slag conditions. Especially the high frequencies disappear with growing slag height.

A measurement of sound emission however, has some practical problems, as background noise influences the measurement. Also the maintenance of a sound measurement system is not negligible, as the environment is very bad (dust).

As a consequence the electrode current – the origin of the sound emissions – can be used. As every electric arc furnace is equipped with an accurate current measurement to regulate the arcs (electrode control system), this information can be used for further investigations.

The following diagram shows a typical current/voltage scan of an EAF in the first minutes of the first basket (cold scrap).

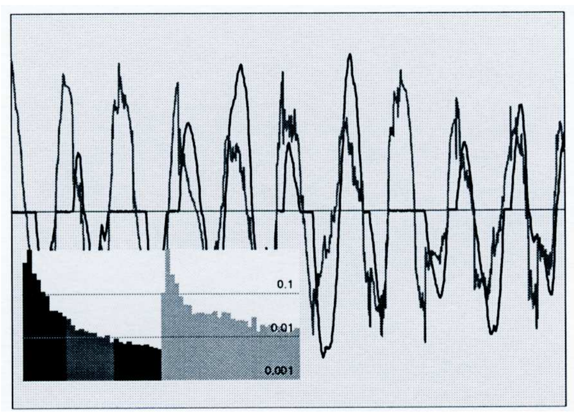

Fig. 2. Current/voltage scans in the first minutes of the first basket. The spectra (left…current, right…voltage) are calculated over one period (20ms) and then averaged

The strong distorted waveform of current and voltage is in evidence. The current shows typical drop-outs in the beginning of a heat. The frequency distribution is evaluated for one period (20ms) and then averaged over 10 periods and shows a high content of harmonics.

Fig.3 shows the current/voltage scans of the same heat at the end of heat (foaming slag conditions).

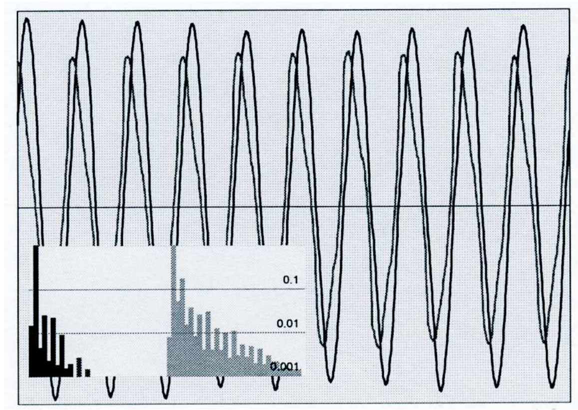

Fig. 3. Current/voltage scans at the end of the heat with good foaming slag

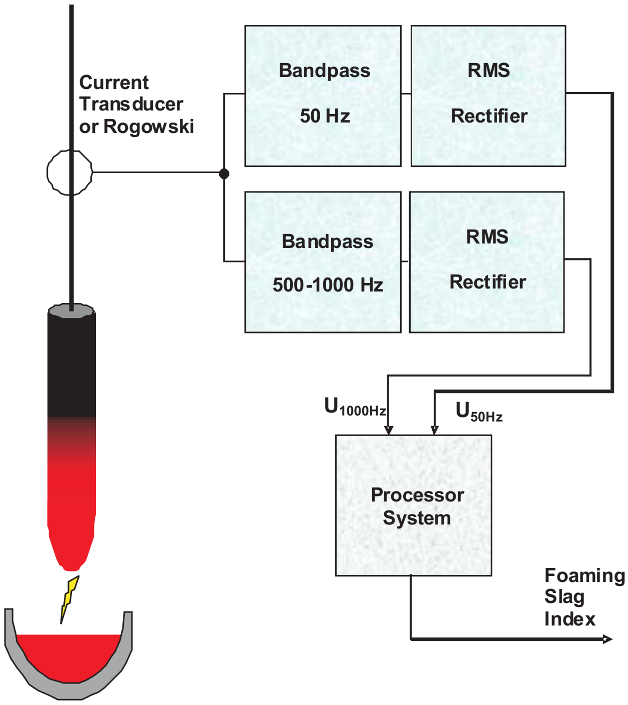

Fig. 4. Schematic setup for measuring the foaming slag index

The waveforms are almost sinusoidal, the content of harmonics is already very low (3^{rd} and 5^{th} harmonic is generated by the transformer). The ratio between even and odd numbered harmonics has decreased. Furthermore it is noticed, that the harmonics of current are much less than those of voltage. For a technical analysis of the harmonics the frequency range between 500Hz and 1000Hz is interesting, since smaller frequencies are already influenced by the furnace transformer and higher frequencies are more difficult and expensive to measure.

Therefore the relative intensity of harmonics is used to determine the foaming slag index.

Fig. 4 shows a schematic setup for such a measuring device.

To adapt the foaming slag index for different furnaces, two parameters are introduced:

$$FSI = \frac{U_{50Hz}}{K_1.U_{1000Hz} + K_2} \quad (2)$$

3. TECHNICAL REALISATION

As the electrode control system of an electric arc furnace needs all three electrode current signals for operation, it is equipped with appropriate current measurement devices. Hence it is easy to implement the evaluation of the foaming slag index into the electrode control. Since nowadays electrode control systems are digital ones, also the whole foaming slag control can be implemented easily.

The electrode control system ArCOS uses an intelligent data acquisition adapter for measuring the current signals. This card samples three current and three voltage signals 128 times per period (16 / 20ms) and generates a TRMS value for all these signals every 16 / 20ms. Furthermore it generates a frequency spectrum (via FFT) for all three electrode currents at the same time.

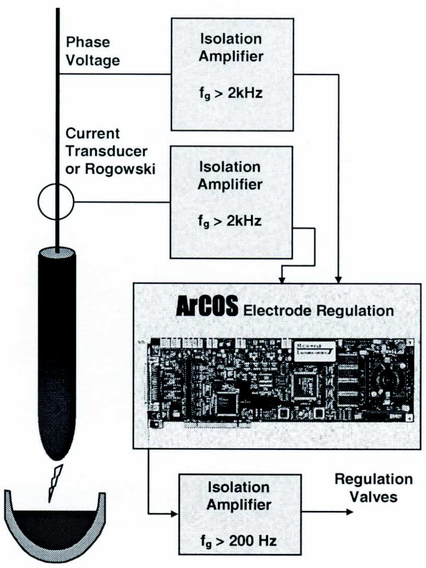

Fig. 5. Schematic diagram of current/voltage measurement at the ArCOS electrode control system (vatron gmbh)

First, ArCOS determines the frequency distribution of the current

$$H_k = FFT(I_t)$$

Then the foaming slag index and the THD (Total Harmonic Distortion) are calculated:

$$FSI = \frac{H_1}{K_1.\sqrt{\sum_{i=10}^{20} H_i^2 + K_2}} \qquad THD = \frac{\sqrt{\sum_{i=2}^{20} H_i^2}}{I_{RMS}} \quad (3)$$

THD versus FSI

Starting with the definition of the foaming slag index (ArCOS measurement)

$$FSI = \frac{H_1}{K_1.\sqrt{\sum_{i=10}^{20} H_i^2 + K_2}} \quad (4)$$

Then splitting up the expression for the total harmonic distortion:

$$THD = \frac{\sqrt{\sum_{i=2}^{20} H_i^2}}{I_{RMS}} = \frac{\sqrt{\sum_{i=2}^{10} H_i^2}}{I_{RMS}} + \frac{\sqrt{\sum_{i=10}^{20} H_i^2}}{I_{RMS}} \quad (5)$$

The left expression holds only low frequency harmonics and is mainly caused by the transformer and therefore is proportional to the total transformer current.

The harmonics are assumed to be small compared to the transformer current (H1 ~ IRMS).

Considering all these facts, we end up in following expression:

$$THD \approx K + \frac{1}{FSI}$$

4. DYNAMIC SETPOINT CONTROL

At the beginning of a heat, the current distortion is very high, thus the harmonics generate a increased voltage drop at the high-current-busbar-system which results in a decreased power input. To avoid this effect the system is able to correct the originally chosen set-point to lower impedance values, to achieve the desired power input. Besides this a shorter arc leads to higher stability as well.

The technical solution is to use the THD value for selecting a correction factor to the defined set-points. For this reason the range of values of the THD is divided into 6 areas. For each of these areas a separate set-point correction factor can be chosen. With this tool it is possible to operate at the beginning of the heat with a smaller impedance set-point and for instance in the fining phase under good foam with shorter arcs and high currents (stirring effect) without changing the "official" set-point for the respective process phase.

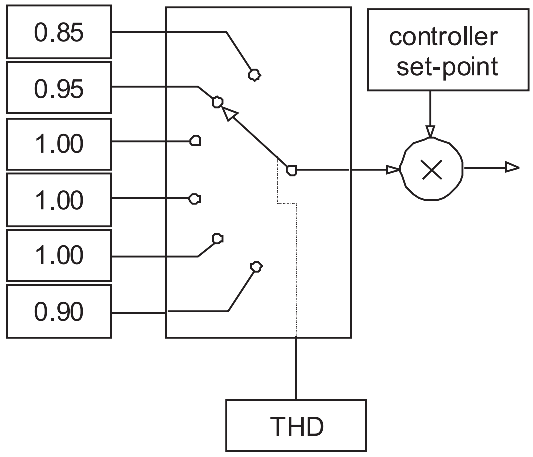

Fig. 6. Principle of the dynamic set point control of the ArCOS electrode control system

5. FOAMING SLAG MANAGER

The automatic carbon injection is the main application of foaming slag detection.

Therefore ArCOS calculates the foaming slag index (after equation 3) and determines the difference between new and old FSI value every 15 seconds.

With these two values a fuzzy controller is fed. The use of a fuzzy controller has the advantage to work with terms like "little Slag", "much Slag", "Slag growing", "Slag shrinking" instead of numerical values of FSI and ΔFSI.

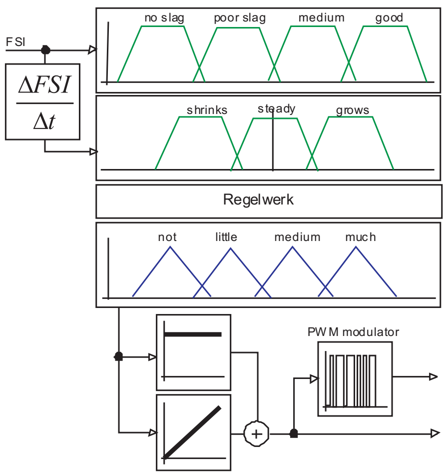

Fig. 7. Schematic diagram of the foaming slag manager used in the ArCOS electrode control system

Also the output is subdivided in terms like "low injection", "high injection"… which makes it easy to configure the controller.

Finally the output signal of the fuzzy controller is fed into a PI-controller which generates the analogue output signal for the carbon injector.

An additional pulse width modulator (PWM) generates a digital signal with an adjustable cycle time of approximately 20 seconds to be able to work with simple ON/OFF valves as well.

6. STAND-ALONE SLAG MANAGER

The technical efforts for stand alone systems have to be kept rather small, as a high price would not sell these systems. Therefore the use of PCs or PLCs with expensive data acquisition cards must be avoided.

A good solution is the "Foaming Slag Xpert" system (vatron gmbh), which uses standard analogue circuits for current measurement and filtering and a micro-controller for the control tasks.

Fig. 8. Foaming Slag Xpert – FOX 300 (vatron)

This tool combines the necessary isolation transducers, filter circuits and data acquisition in a compact unit. The regulation algorithms are quite simple, in order being able for easy implementation into the existing automation environment.

7. FOAMING SLAG DETECTION AT DC FURNACES

Comparing frequency spectra of two different melting stages one can notice a technical useable difference in within the frequency range between 20 and 80 Hz. A strong peak caused by the rectifier system can be further noticed at a frequency of 300 Hz.

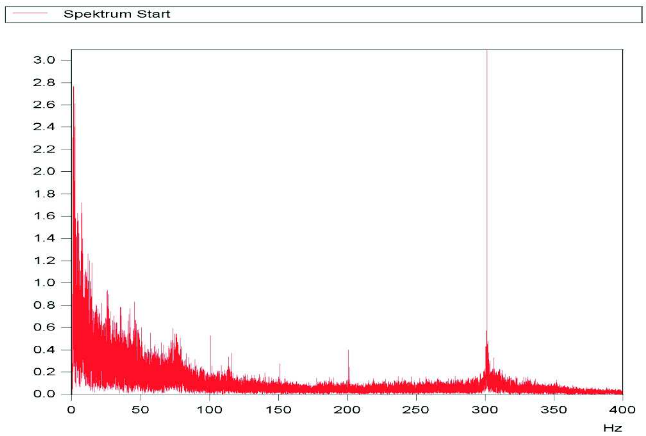

Fig. 9. Spectrum of the current of a DC furnace – beginning of melting phase (Thürstahl / Germany)

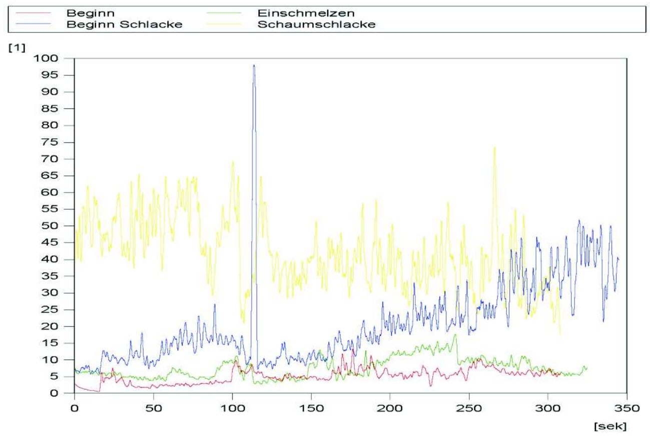

Fig. 11. DC Foaming Slag index at test measurements at Thürstahl / Germany

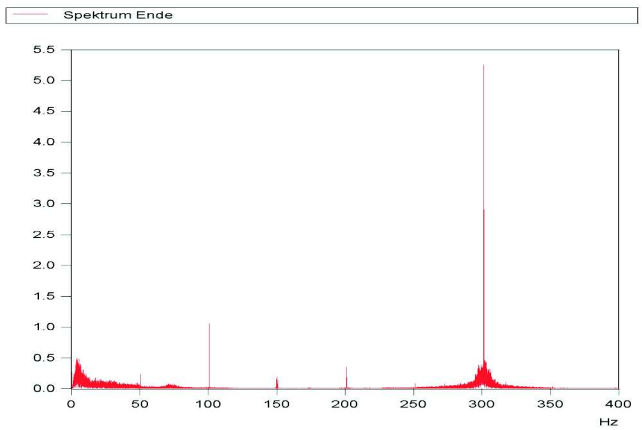

Fig. 10. Spectrum of the current of a DC furnace – end of melting phase (Thürstahl / Germany)

Based on this information a foaming slag detection system analog to AC furnaces can be realised. Also here the harmonics are put in relation to the fundamental for determining the FSI.

Tests with this system have been carried out at Thürstahl / Germany and lead to useful results.

Figure 13 shows four measuring campaigns where the slag index was compared at different melting stages. Each record was taken for six minutes log. One can see very good the correlation of the DC-Slag index and the actual slag height.

8. SUMMARY AND CONCLUSION

A stationary foam operation can be maintained only by adjustment of the blowing parameters according to the real situation in the furnace.

The best results can be achieved by using an automatic slag management system which is able to detect the actual situation quantitatively and control the carbon addition in order to achieve perfect foaming condition.

From operations aspect it is essential to have simple and robust devices for slag determination, since this requires a minimum of installation cost and a minimum of failure risk.

The main advantages of an automatic slag control are:

- reproducible results
- Possibility of fine tuning due to reproducible results.
- Decrease of carbon consumption

The carbon consumption is decreased because an automatic system recognizes the shrinking of slag much earlier than with manual control. Consequently countermeasures (carbon injection) are taken much earlier and less carbon is necessary to build up the slag instead of a total new build up of the slag.

The automatic foaming slag based on harmonics analysis of the current is a meanwhile proven technology is meanwhile implemented in numerous installations worldwide.

Received: 3 April 2008.