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

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FOAMING SLAG AND SCRAP MELTING BEHAVIOR IN ELECTRIC ARC FURNACE – A NEW AND VERY PRECISE DETECTION METHOD WITH AUTOMATIC CARBON CONTROL

PIENIENIE ŻUŻLA I PROCES TOPIENIA ZŁOMU W ELEKTRYCZNYCH PIECACH ŁUKOWYCH – NOWA I BARDZO DOKŁADNA METODA DETEKCJI Z AUTOMATYCZNYM STEROWANIEM WDMUCHIWANIEM WĘGLA

Foaming slag in electric arc furnaces is one of the topics that engage many steelwork operators around the world. Since the 80's a variety of methods, such as FFT analysis of the electric current or also directional microphone investigations, have not led to successful detection of the foaming slag height and nor, therefore, to complete automation of the electric arc furnace process. Therefore Siemens Industry Sector, Metals Technologies Division developed a new possibility to detect the level or at least the quality of foaming slag in the furnace. In different publications [1, 2, 3, 4] the topic of this special development was reported. In February 2005 research and development was launched to investigate detectability by means of structure-borne sound. Second step was to develop a control algorithm for the injection of carbon. The successful commissioning of the carbon control at the arc furnace No.1 of Lechstahlwerke GmbH led to further steps: The first results, details are explained later in the paper, are extremely good, so that an entirely full automated arc furnace operation seems to be possible in mid time range from the authors side of view. Siemens is setting up a research and development program for the next 3 years.

Keywords: Foaming Slag Detection, Carbon Control, Electric Arc Furnace, SIMELT electrode control, structure-borne sound, vibration sensor, foaming slag manager

Pienienie się żużla w elektrycznym piecu łukowym jest jednym z tematów, który angażuje wielu stalowników na całym świecie. Od lat osiemdziesiątych różnorodność metod, takich jak analiza FFT prądu elektrycznego, czy badania mikrofonem kierunkowym, nie doprowadziły do poprawnej detekcji wysokości pieniącego się żużla, ani udoskonalenia automatyzacji procesu elektrometalurgicznego.

Dlatego Siemens Industry Sector, Metals Technologies Division opracował nową możliwość detekcji poziomu przy najmniejszej jakości pieniącego się żużla w piecu.

W lutym 2005 roku rozpoczęto badania i rozwój wykrywalności z użyciem dźwięku structure-borne. Drugim krokiem było opracowanie algorytmu sterowania wdmuchiwaniem węgla. Sterowanie wdmuchiwaniem węgla z sukcesem zostało przeprowadzone w stalowni Lechstahlwerke GmbH. Pierwsze wyniki są niezwykle dobre, więc w pełni automatyczne sterowanie piecem łukowym w trakcie procesu wydaje się możliwe. Siemens powołał program badań i rozwoju na najbliższe trzy lata.

1. Introduction

Foaming slag in electric arc furnaces is one of the topics that engage many steelwork operators around the world. Since the 80's a variety of methods, such as FFT analysis of the electric current or also directional microphone investigations, have not led to successful detection of the foaming slag height and nor, therefore, to complete automation of the electric arc furnace process.

Therefore Siemens Industry Sector, Metals Technologies Division developed a new possibility to detect the level or at least the quality of foaming slag in the furnace. In different publications [1, 2, 3, 4] the topic of this special development was reported.

In February 2005 research and development was launched to investigate detectability by means of structure-borne sound.

Objectives:

Examination of the feasibility of the specified vibration sensors

Comparison with other methods
(FFT current analysis and directional microphone)

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Second step was to develop a control algorithm for the injection of carbon.

Objectives:

Carbon – control algorithm for different valve types

Optimization function with fuzzy logic

Independent carbon input over 3 valves

The successful commissioning of the carbon control at the arc furnace No.1 of Lechstahlwerke GmbH led to further steps:

Objectives:

Diagnosis of scrap type in the furnace

Diagnosis of melting down behavior

Determination of singular effects (e.g. scrap cave in)

The first results, details are explained later in the paper, are extremely good, so that an entirely full automated arc furnace operation seems to be possible in mid time range from the authors side of view. Siemens is setting up a research and development program for the next 3 years.

2. Technical partner Lechstahlwerke GmbH

The technical partner in the program, as mentioned in chapter 1, is Lechstahlwerke GmbH in the south of Germany near Munich. Lechstahl operates 2 arc furnaces with a tapping weight of 100 mt, 2 ladle furnaces, one VD plant, two 4 strand billet caster, and beside the melt shop also a rolling mill.

The foaming slag detection and carbon control unit is installed at arc furnace No. 1

Description of the characteristic data:

⇒ Product mix: 80% reinforcing bars, 20% SBQ grades
⇒ Average 73 min. tap to tap time
⇒ Tapping weight 100 mt
⇒ 3 bucket operation
⇒ Capacity of arc furnace transformer: 75 MVA
⇒ Dynamic compensation plant (SVC)
⇒ Burner system with multi-point carbon injection
⇒ Siemens SIMETAL^{CIS} SIMELT electrode control system.

3. Foaming Slag Manager installation at arc furnace No. 1

The installation of the foaming slag detection and carbon control unit looks like this:

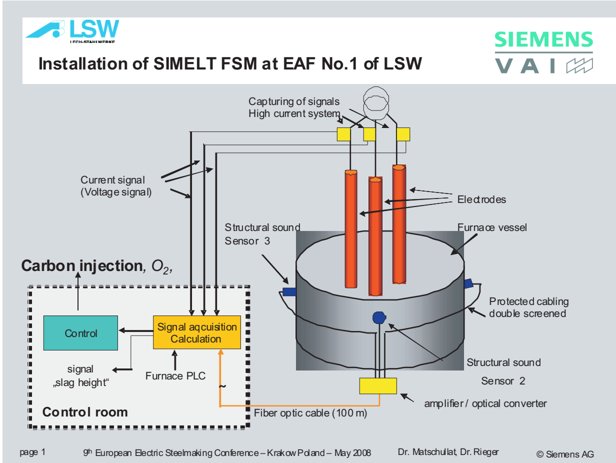


Fig. 1. Installation of SIMELT FSM at arc furnace No.1 of Lechstahl

It can be seen that a total of 3 sensors is used. Vibration sensors were attached to the furnace panel opposite to the three electrodes, with an adapter plate having been welded to the panel. On the next figure one can see an example for the actual installation of a single sensor.

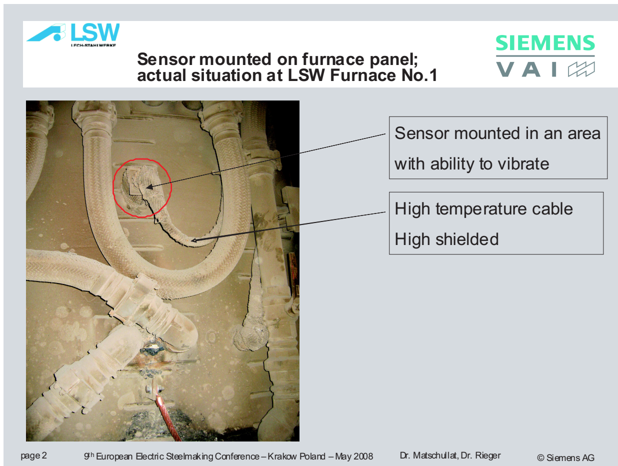


Fig. 2. Example for sensor mounting on furnace panel

In addition to the measuring instruments shown on the previous slide, the current signal of the SIMETAL^{CIS} SIMELT AC closed-loop electrode control system was also picked up in order to be able to investigate the FFT method as well, which is the usual method on the market at present.

The electric arc serves as the acoustic source for determining the height of the foaming slag. As the generation of the sound cannot be measured at its source itself, the current signal is used as a reference signal for the subsequent evaluations. The signal at the furnace wall is then nothing other than the weakening of the generated signal, which ultimately is equivalent to attenuation. The attenuation depends on the foaming slag height, as the vibration transmission path mainly passes through the steel phase and only to a minor extent via the gas phase.

4. Control concept and development results

The sole detection of foaming slag level in the arc furnace is o.k. for the means of process diagnosis, but not satisfying for the control of the carbon injection phase. Siemens developed a control system with two different algorithms. One as I-Controller with flexible adjustment, the other for simple injection carbon valves as fuzzy controller. The last led to a pulsed width method for carbon control.

Each carbon valve is controlled individually from the related level of slag in the referring region of the furnace.

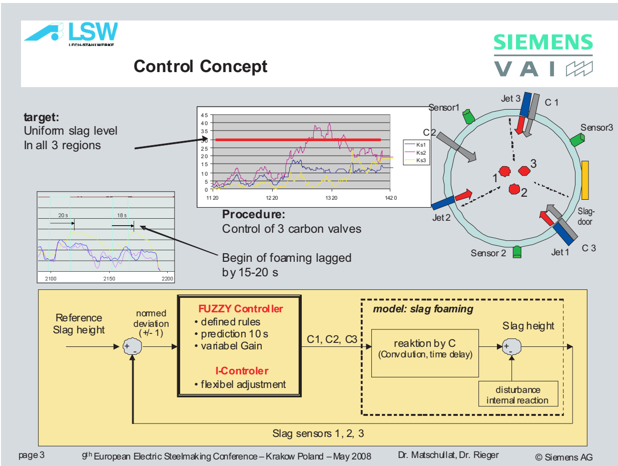


Fig. 3. Control concept for injection carbon

The next figure shows the possibilities of different phases in the process of blowing carbon into the furnace

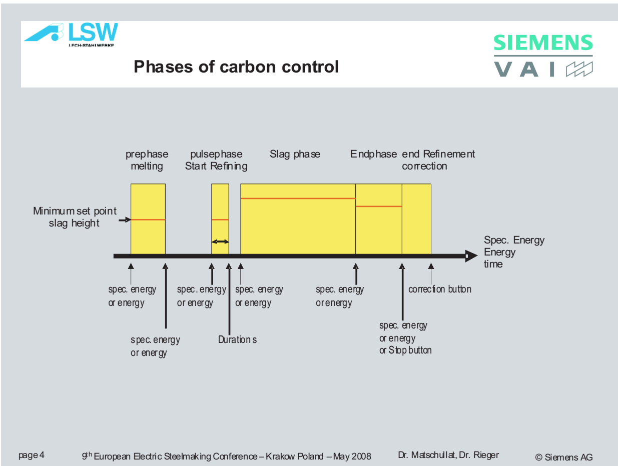


Fig. 4. Phases of carbon control

The system is independent from the number of scrap buckets charged into the furnace. If necessary the system can be used for each bucket phase. Also it is possible to divide the process of carbon blowing in different steps as shown in figure 4. Furthermore standard starting and operating points for slag levels can be stored in the system, which is very important for different steel grades and for different furnace situations like cold furnace, new lining etc.

As starting point for the full automatic start of the carbon control the related value of entire electrical energy to the entire charged material can be used, as specific value in case of Level 2 system is in use or as total energy value if only Level 1 is available. In the figure 5 one can see the behavior of slag signal versus electrical energy. In nearly each case all 3 signals start to increase at the same energy level, which is described as energy threshold in figure 6.

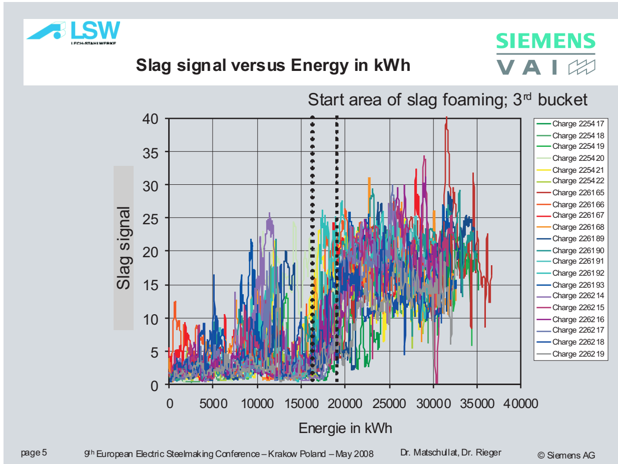


Fig. 5. Slag signals versus electrical energy in kWh for different heats

If a certain value of electrical energy (in the range of 250 kWh/t) is reached the carbon control will be activated full automatically.

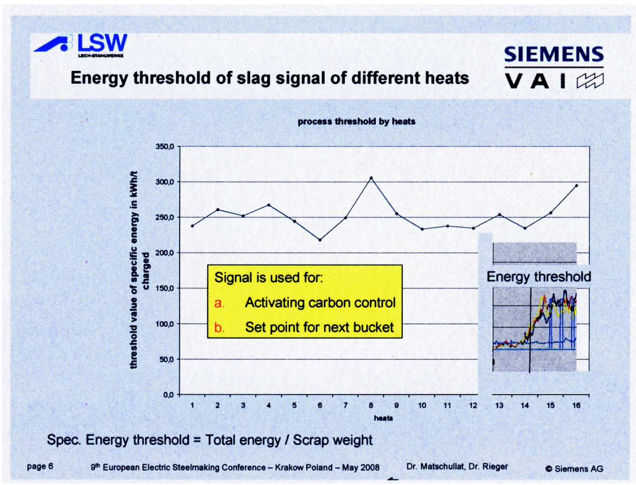


Fig. 6. Energy threshold of slag signal of different heats

5. Results with carbon control and benefits

The commissioning of carbon control started in February 2007. From this time the control is switched on and the operators were very familiar with from the first moment.

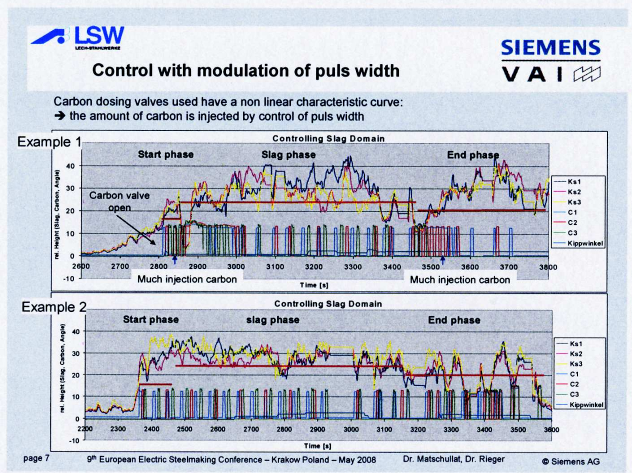
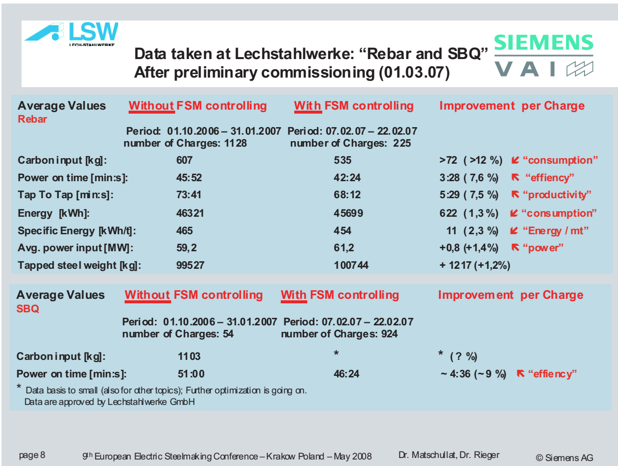


Fig. 7. Carbon control with SIMELT FSM in the commissioning phase

In figure 7 one can see for example two graphs of the foaming slag signals, one from the first day and the second from the third day of the commissioning. All in all after a very short period the behavior of the slag in the furnace was stabilized and at least the operation led to very good performance, which can be taken from the figure 8.


Data taken at Lechstahlwerke: "Rebar and SBQ"
After preliminary commissioning (01.03.07)

Average Values Rebar	Without FSM controlling	With FSM controlling	Improvement per Charge
	Period: 01.10.2006 – 31.01.2007 number of Charges: 1128	Period: 07.02.07 – 22.02.07 number of Charges: 225	
Carbon input [kg]:	607	535	>72 (>12 %) ↙ "consumption"
Power on time [min:s]:	45:52	42:24	3:28 (7,6 %) ↖ "effiency"
Tap To Tap [min:s]:	73:41	68:12	5:29 (7,5 %) ↖ "productivity"
Energy [kWh]:	46321	45699	622 (1,3 %) ↙ "consumption"
Specific Energy [kWh/t]:	465	454	11 (2,3 %) ↙ "Energy / mt"
Avg. power input [MW]:	59,2	61,2	+0,8 (+1,4%) ↖ "power"
Tapped steel weight [kg]:	99527	100744	+ 1217 (+1,2%)

Average Values SBQ	Without FSM controlling	With FSM controlling	Improvement per Charge
	Period: 01.10.2006 – 31.01.2007 number of Charges: 54	Period: 07.02.07 – 22.02.07 number of Charges: 924	
Carbon input [kg]:	1103	*	* (? %)
Power on time [min:s]:	51:00	46:24	~ 4:36 (~9 %) ↖ "effiency"

* Data basis to small (also for other topics); Further optimization is going on.
Data are approved by Lechstahlwerke GmbH

page 8 9th European Electric Steelmaking Conference – Krakow Poland – May 2008 Dr. Matschullat, Dr. Rieger © Siemens AG

Fig. 8. Performance and Benefits; Data taken at Lechstahlwerke GmbH

After only some weeks with the Control algorithm in operation one can make a summary with improved results in:

- Reduction of Power on time
- Optimization of the injected carbon
- Stable furnace operation due to arc stabilization
- Operator acceptance
- Reduction of power off time

Assumption of further potential:

- Further reduction in power on time seems to be possible (~ 1 min)
- Reduction of injected carbon (rebar grades)
- Reduction of power off time due to more stable furnace operation
- Scrap condition in the furnace, see also chapter 6

6. Investigation of melt down phase

After the successful development of the carbon control the idea was very near to investigate with the same installed equipment the type of scrap and the melting down behavior of the charged scrap. The melting down period has – as everybody knows – a bigger lever (figure 9) to process time than the superheating and foaming slag time.

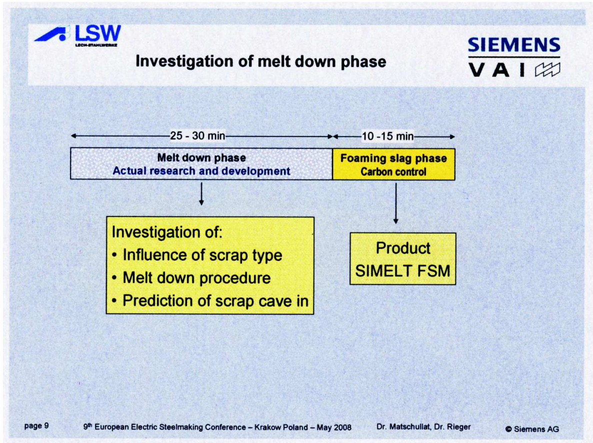


Fig. 9. Investigation of melt down phase

For the last mentioned time a product is available. The other time was investigated in 2007 and the first results led to an investment in an extended research and development program, which started in the beginning of 2008 and will be finished approx. in the year 2010.

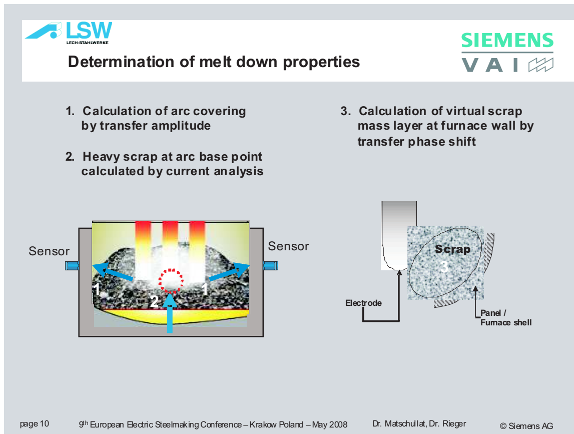


Fig. 10. Determination of melt down properties

In the first investigations defined scrap charges were melted down. After evaluation of the measured signal from vibration sensors and the current three different, but consecutive calculation methods (figure 10) describe the procedure of scrap melt down very well.

These methods describe 3 different situations:

Method 1: The charged scrap covers the electrical arc and influences the vibration transmission to the sensor at the furnace panel. The calculation is done by the transfer amplitude.

Method 2: The "heavy scrap" at arc base point is calculated by the current analysis. "Heavy scrap" at arc base point means nothing else than an agglomeration of partially melted and caved scrap.

Method 3: Calculation of virtual scrap mass layer at the furnace wall by transfer phase shift.

In figure 11 one can see an example for the arc covering. The signals were translated to an arc covering factor, what can be compared to the inverse covering of foaming slag. On phase No. 1 a free burning arc was detected.

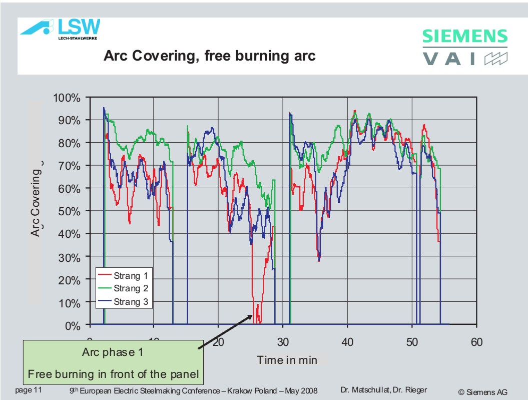


Fig. 11. Basic record with qualitatively slag height and actual distribution of slag in the furnace

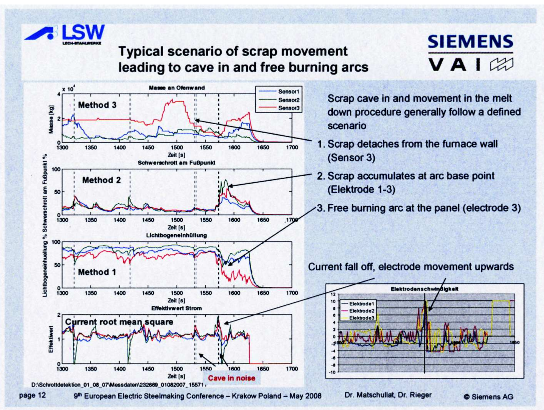


Fig. 12. Typical scenario of scrap movement leading to scrap cave in and free burning arcs

All in all the combination of these 3 methods including the current root square method is able to describe a typical scenario of scrap movement and melting down, which is shown in figure 12.

As can be seen from this figure, scrap detaches from the furnace panel (sensor 3) (method 3), scrap accumulates at the arc base point (method 2; phases 1-3) and the arc is burning free at the panel (method 1; phase 1)

7. Summary

The benefits of the foaming slag manager show encouraging results. The SIMELT FSM (Foaming Slag Manager) is either available as module of the SIMELT electrode control system or as stand alone product, which also fits to other controllers or furnace automation systems than Siemens. 3.5 min reduction in power on time and 2 min in power off time show the encouraging results of the system.

The development of the scrap melt down mechanism model is just at a beginning. It shows new possibilities for diagnosis. But in the future not only diagnosis is the target; also the creation of measures to the process itself will be developed. More and more it seems to be possible to operate the furnace in an entire automatic mode.

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Received: 3 April 2008.