

DIAGNOSIS OF FOAMING SLAG AND SCRAP MELTING BEHAVIOR IN ELECTRIC ARC FURNACES: A NEW DETECTION METHOD WITH CARBON CONTROL¹

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Abstract

In 1998, a serious rail accident (ICE high-speed train) occurred in northern Germany near Eschede. Over a hundred people died, underlining the horror of the event. The cause was disintegration of a wheel tire brought about by cracks in the material. A set of measuring methods and sensor technology were developed on the basis of structure-borne sound, with the aid of which changes in the wheel tire microstructure or the formation of cracks can be detected (“heard”) in online train operation. At the Industrial Solutions & Services Group, in the Iron & Steel business area, the idea emerged that this sensor technology could be used to detect the foaming slag height in an electric arc furnace. In February 2005 research and development was launched to investigate detectability by means of structure-borne sound. The trials with carbon control started on the 12 th. of February 2007. From this time the control is switched on continuously with encouraging results such as reduced power on time and stable furnace operation

Keywords: Electric arc furnace; Foaming slag.

DIAGNÓSTICO DE ESCÓRIA ESPUMANTE E COMPORTAMENTO DA ESCÓRIA EM FORNOS ELÉTRICOS A ARCO: NOVO MÉTODO DE DETECÇÃO COM CONTROLE DE CARBONO

Resumo

Em 1998, um grave acidente de Trem-bala (trem de alta velocidade ICE) aconteceu no nordeste da Alemanha, perto de Eschede. Mais de cem pessoas morreram. A causa do acidente foi a desintegração de uma das rodas do trem, originada por fissuras no material. Um conjunto de métodos de medição e tecnologia de sensores foi desenvolvido baseado na propagação sonora em meios sólidos, com a ajuda de que mudanças na microestrutura das rodas ou formação de fissuras poderão ser detectadas (“ouvidas”) na operação *online* do trem. No Grupo Soluções & Serviços Industriais, na área de negócios Ferro & Aço, surgiu uma idéia de que esta tecnologia de sensor pudesse detectar a espessura da escória espumante em um forno elétrico. Em fevereiro de 2005 foi lançada uma pesquisa de desenvolvimento para investigar a detectabilidade por meios de propagação sonora em sólidos. As tentativas com o controle de carbono começaram no dia 12 de Fevereiro de 2007. A partir desta data o controle é desenvolvido continuamente com resultados encorajadores, como a operação estável do forno.

Palavras-chave: Forno elétrico a arco; Escória espumante

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1 INTRODUCTION

Foaming slag in electric arc furnaces is one of the topics that occupies many steelworks operators around the world. 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 the automation of the electric arc furnace process.

Therefore Siemens Industrial Solutions and Services developed a new possibility to detect the level or at least the quality of foaming slag in the furnace. In different publications⁽¹⁻⁴⁾ 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)

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

Objectives:

- C- 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 step:

Objectives:

- Diagnosis of scrap type in the furnace
- Diagnosis of melting down behaviour
- 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 set 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 an 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 transformer: 75 MVA
- ⇒ Dynamic compensation plant
- ⇒ Burner system with multi-point carbon injection
- ⇒ Siemens 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:

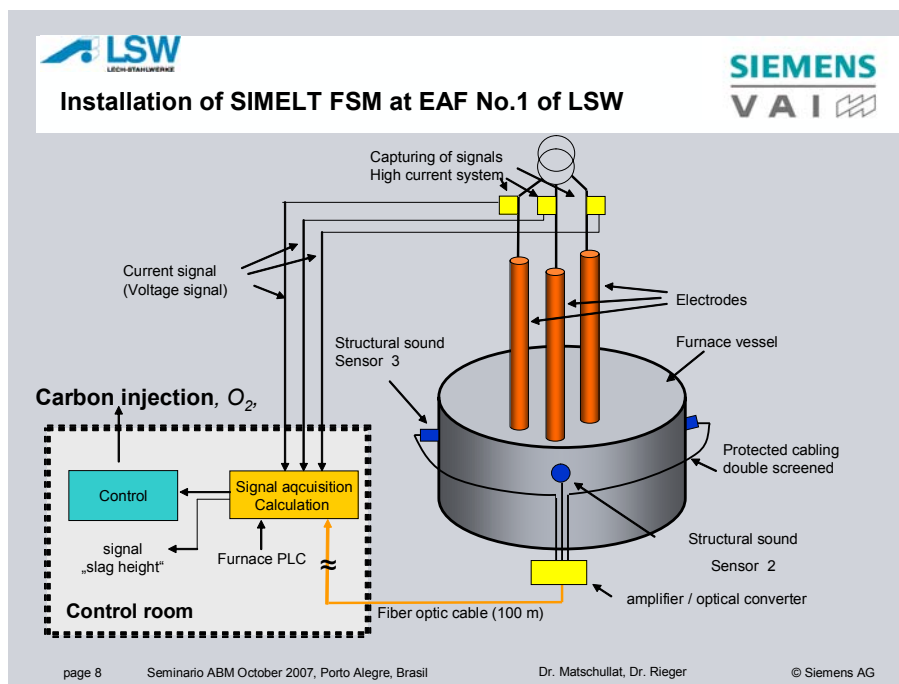


Figure 1: Installation of SIMELT FSM at arc furnace No.1 of Lechstuhl

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

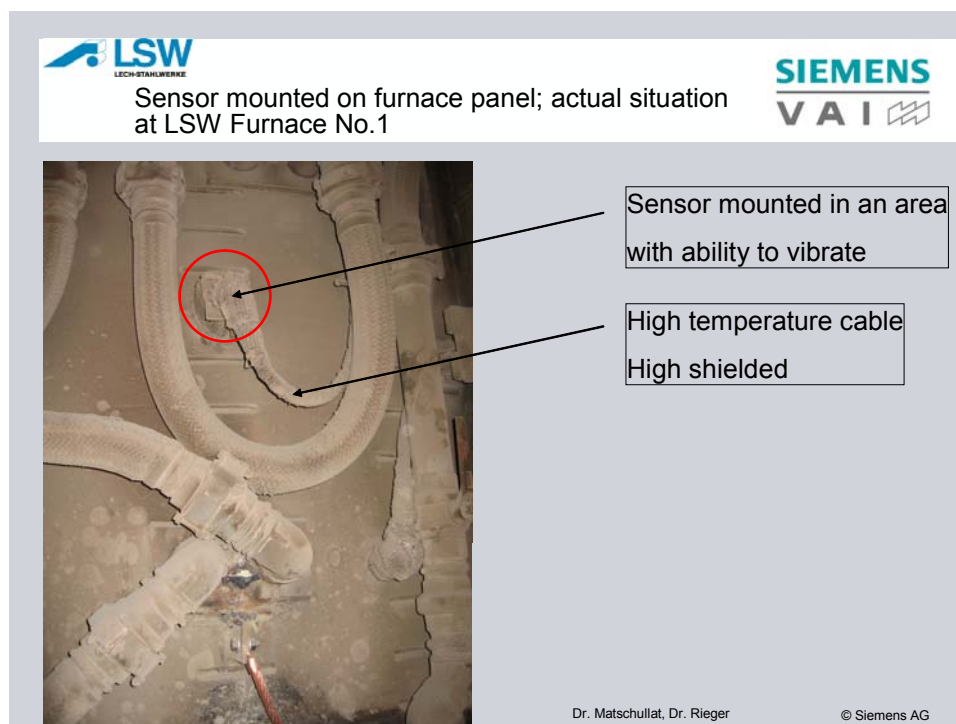


Figure 2: Example for sensor mounting on furnace panel

In addition to the measuring instruments shown on the previous slide, the current signal of the SIMELT^{CIS} 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 enough for the control of the injection carbon 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 with method for carbon control. Each carbon valve is controlled individually from the related situation of slag in the referring region of the furnace

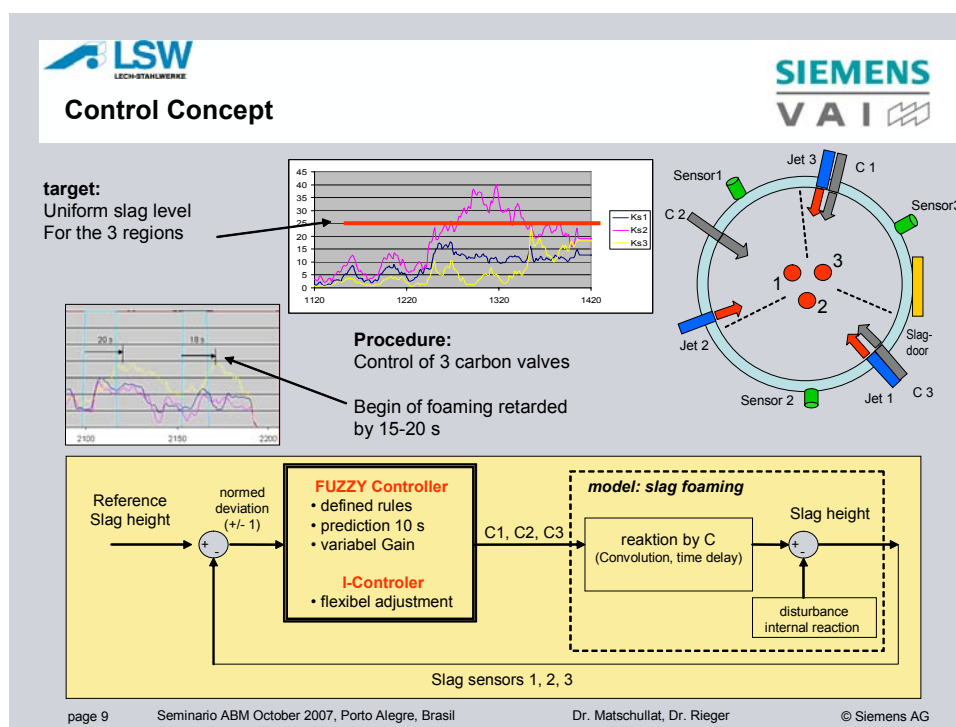


Figure 3: Control concept for injection carbon

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

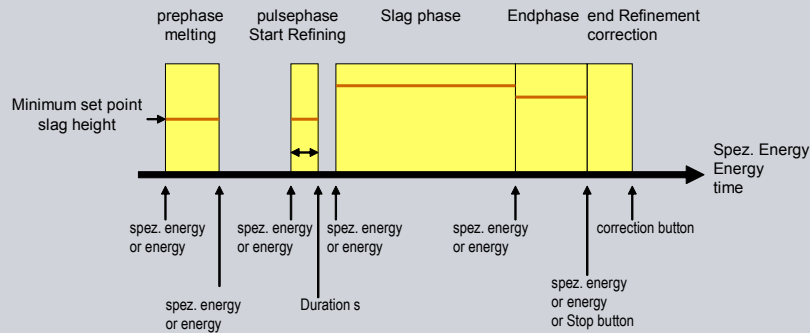


Figure 4: Phases of carbon control

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, what 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 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.

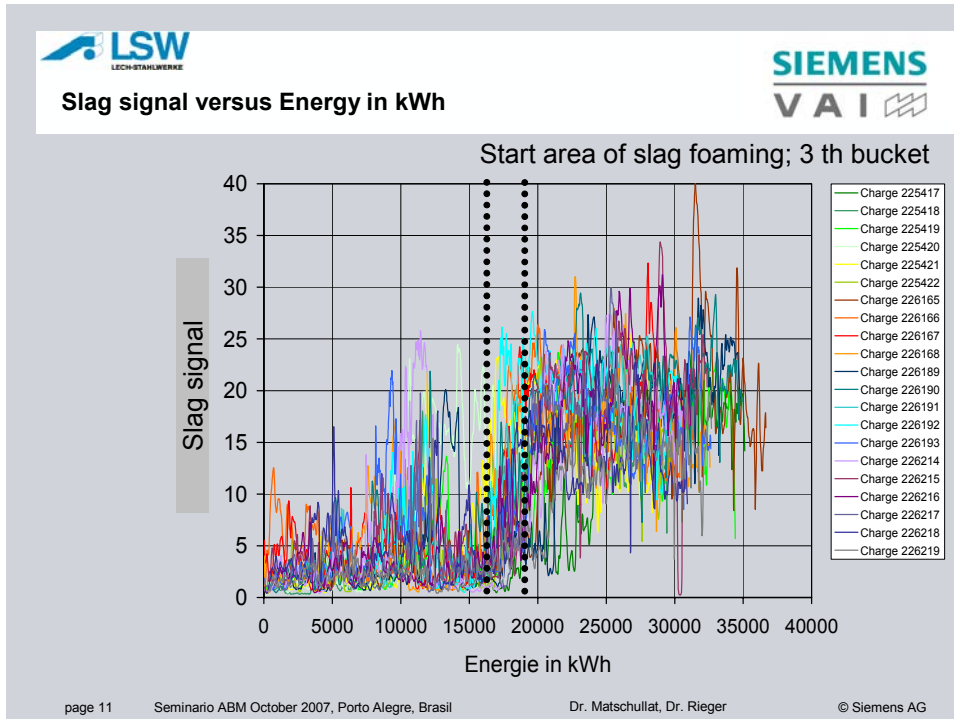


Figure 5: Slag signals versus electrical energy in kWh for different heats

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

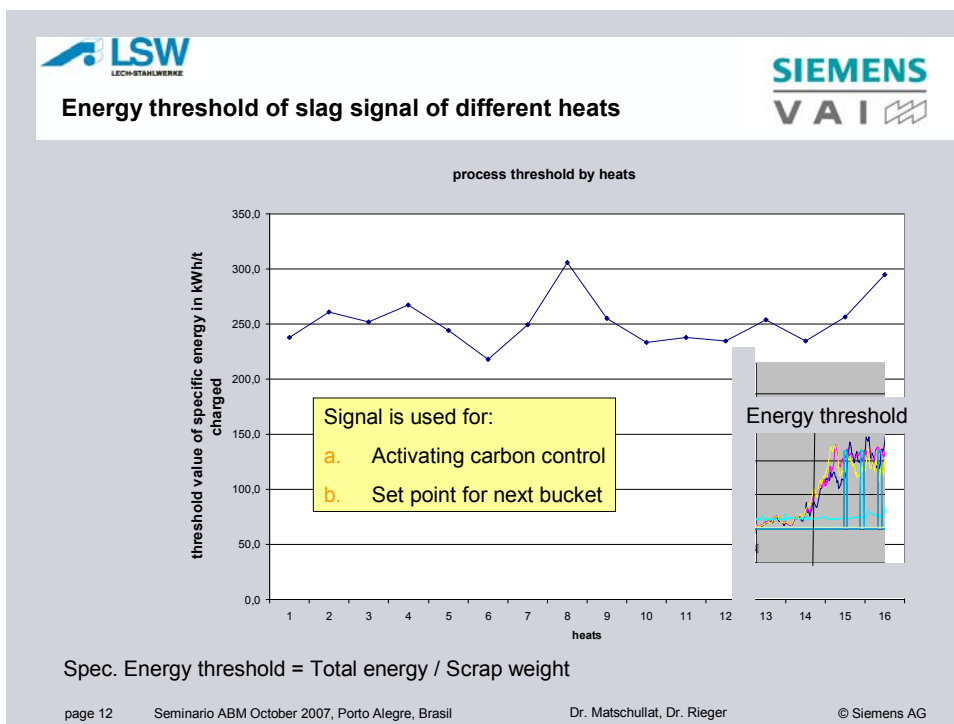


Figure 6: Energy threshold of slag signal of different heats

5 RESULTS WITH CARBON CONTROL AND BENEFITS

The commissioning of carbon control started on the 12 th. of February 2007. From this time the control is switched on and the operators were very familiar with from the first moment.

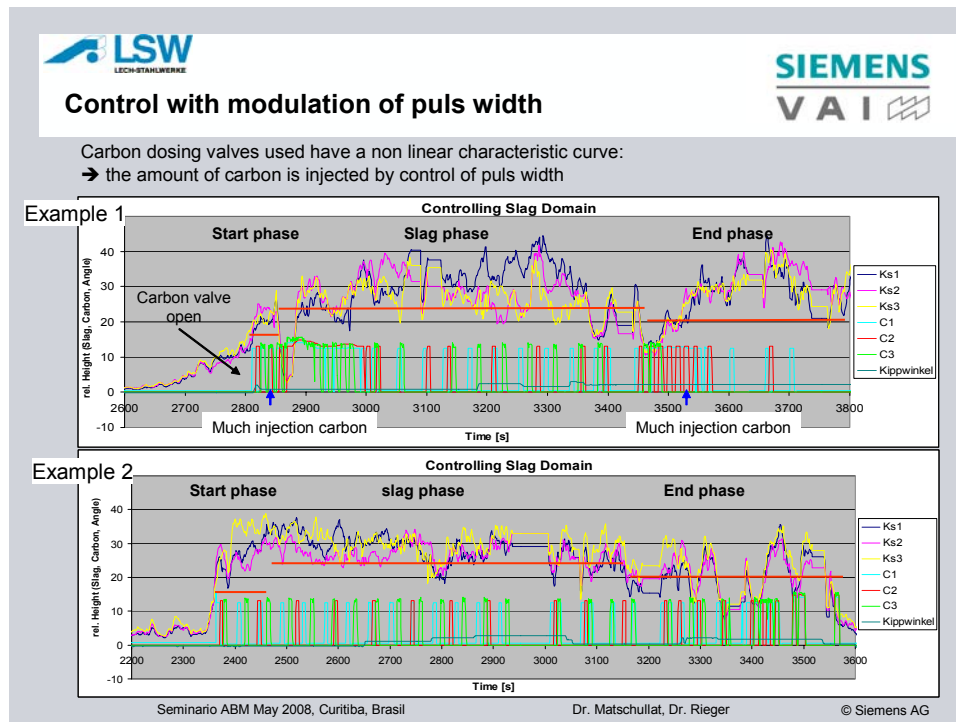


Figure 7: Carbon control with SIMELT FSM in the commissioning phase

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

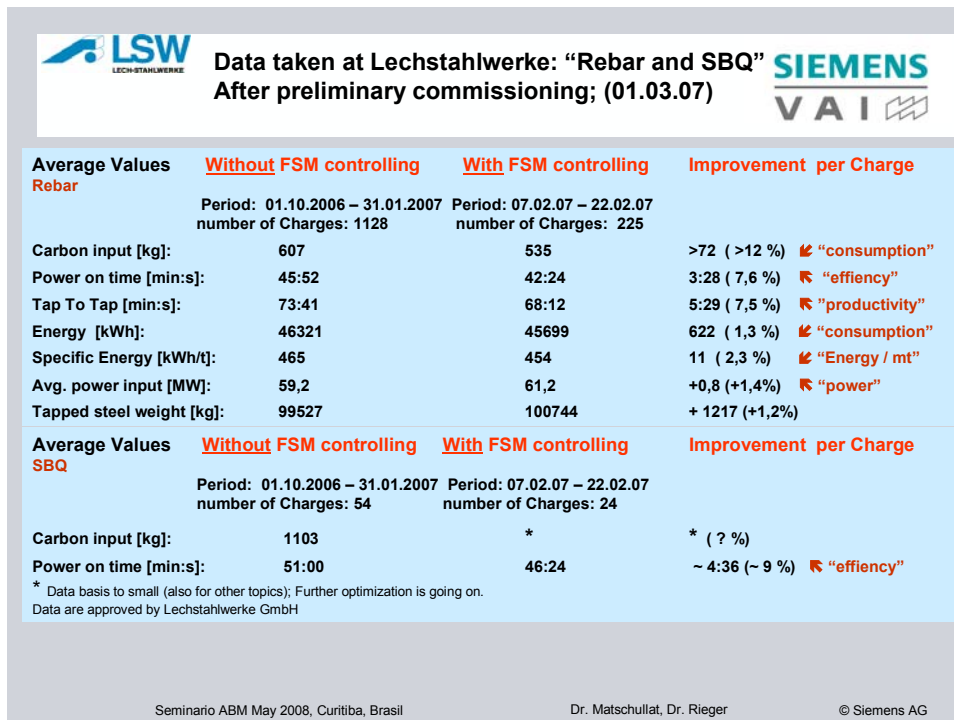


Figure 8: Benefits; Data taken at Lechstahlwerke GmbH

After some weeks with the Control algorithm one can make an summary due to the results:

- 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 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 behaviour 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.

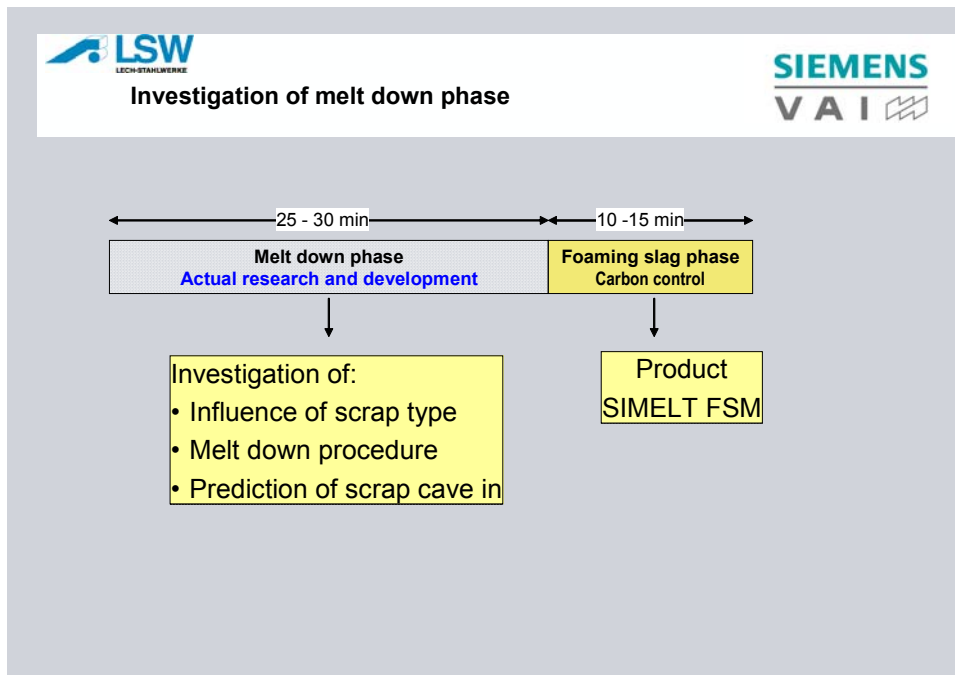


Figure 9: Investigation of melt down phase.

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.

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.

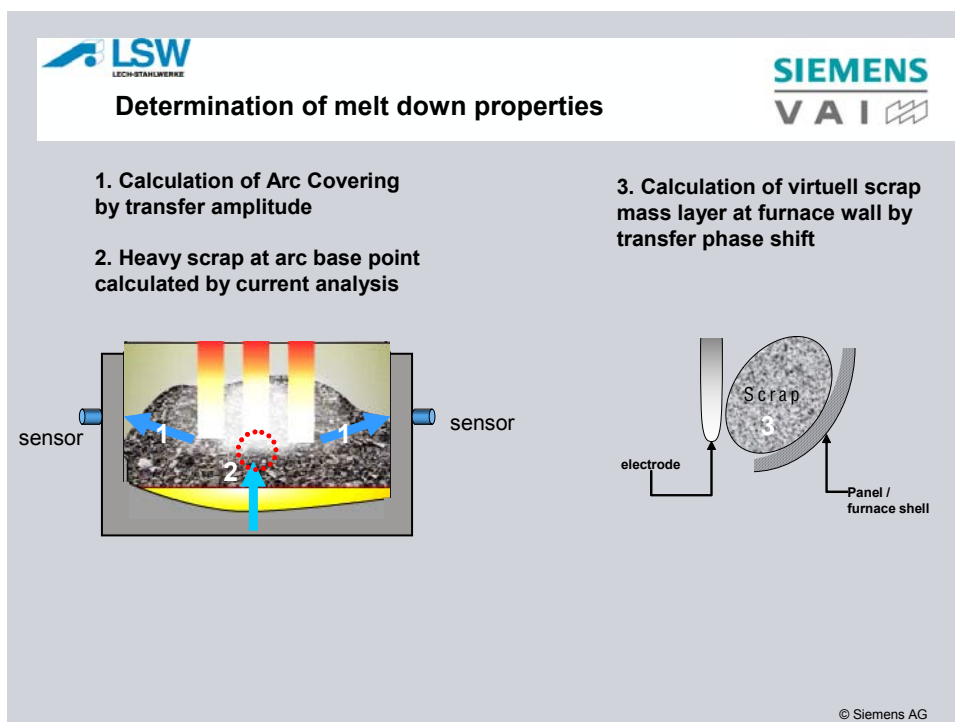


Figure 10: Determination of melt down properties

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 arc burning arc was detected

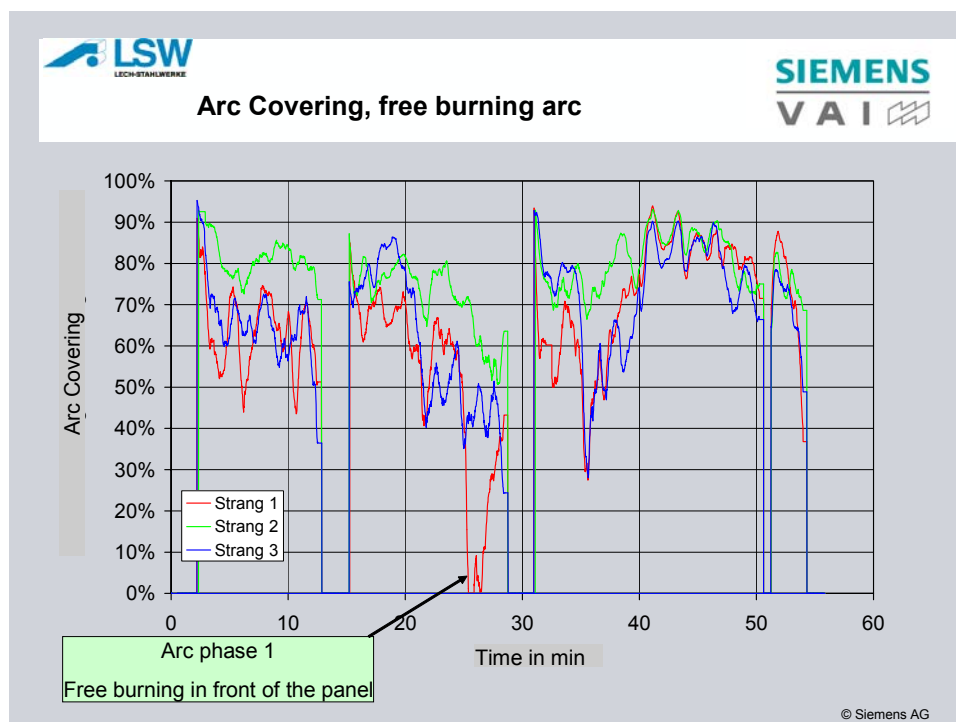


Figure 11: Basic HMI with qualitatively slag height and actual distribution of slag in the furnace.

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.

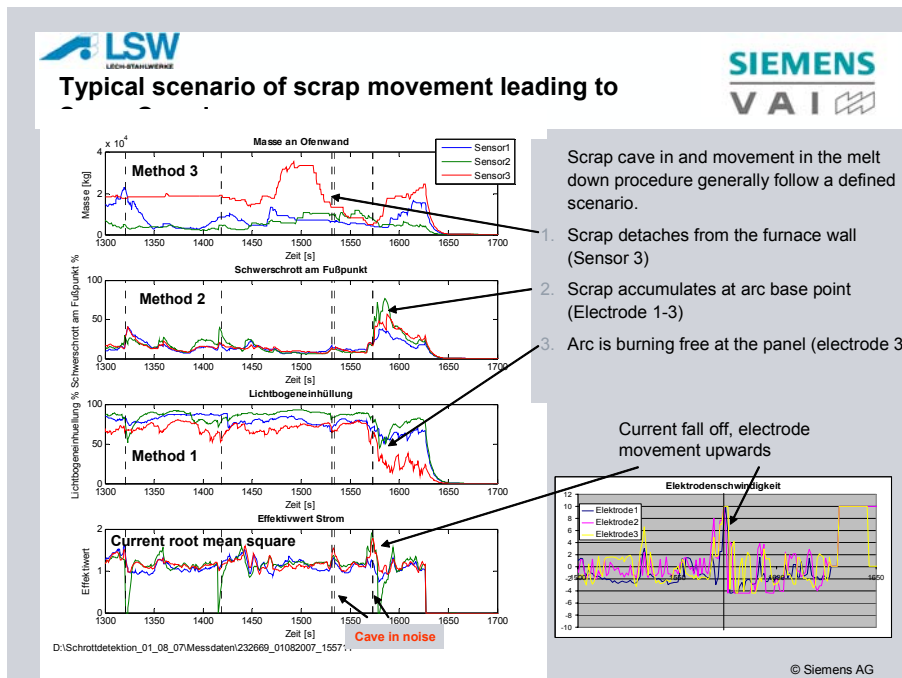


Figure 12: Typical scenario of scrap movement leading to scrap cave in and free burning arcs.

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 available 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 an beginning. It shows now 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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