SIEMENS DEVELOPS NEW METHOD OF MEASURING THE LEVEL OF FOAMING SLAG IN ARC FURNACES[1]

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Abstract
The Industrial Solutions and Services (I&S) Group and the Corporate Technology (CT) department of Siemens AG have developed a new method of measuring the changes in the level of foaming slag in arc furnaces over time and in the various parts of the furnace. The method is based on the measurement of structure-borne noise at the furnace shell. The signals picked up at several measuring points enable spatial mapping of the foaming slag around the electrode and panel. Series of tests carried out on a 70-tonne arc furnace of Lech-Stahlwerke GmbH (LSW) showed a very high match with visually determined levels of slag. With the help of the new measuring method, the plant controller will be able to meter the nutty slack and the oxygen - the foaming agents - in such a way that baring of the arcs will largely be avoided. This reduces electrode wear, improves the power intake in the arc furnaces and increases productivity.
Key words: Foaming slag; Level of slag; Electrode wear.

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Bare arcs cause increased electrode wear and undesired temperature increases in the walls of the furnace. Other consequences include lower energy efficiency, longer process times and thus reduced productivity. In order to envelope the arc, foaming slag is produced, whose level can be controlled by the metered addition of nutty slack and oxygen. Today, these foaming agents are added either by hand or according to an operating diagram defined in advance. These two methods, however, are no longer able to cope with the frequently changing operating conditions and are standing in the way of a largely automated procedure.
The steel industry would therefore like to see the development of measuring methods with the help of which the behavior of the foaming slag can be determined precisely over time and in respect of its location. The aim is to develop a closed-loop control circuit for metering the foaming agents and to integrate slag foaming into the arc furnace's higher-level automation system. Measuring methods available today either reflect slag foaming with insufficient precision or cannot be used in the rough environment of a steelworks with the required degree of reliability. The new measuring method developed by Siemens uses the structure-borne noise of the arc furnace as a measurement variable. The signals of acceleration sensors fitted to the walls of the arc furnace are amplified and transmitted to an evaluation unit via fiber-optic cables. Here, the current spatial slag distribution is calculated. The measuring system was tested in spring 2005 on a 70-tonne arc furnace of LSW in Meitingen, Germany. As a control, measurements were carried out with a video camera at the same time. A comparison of the two sets of results showed that they were very close together. Other measuring methods such as noise evaluation with a directional microphone or electrode current analysis were also investigated but their results were considerably worse.

INTRODUCTION

The topic of foaming slag in electric arc furnaces is one 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 in the end not led to successful detection of the foaming slag height and nor, therefore, to complete automation of the electric arc furnace process.

A Glance Back at the History

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. The danger of such a defect occurring again led to a pioneering new development at Siemens. 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. Various discussions were held with the Siemens research department (Corporate Technology). A partner was found for a series of experiments. This was Lech-Stahlwerke GmbH in Germany, a company with which Siemens is still pursuing further development today.

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)

More extensive tests were performed on furnace 1 at Lech-Stahlwerke GmbH.
Description of the characteristic data at furnace 1:

- ⇨ Product mix: 80% reinforcing bars, 20% SBQ grades
- ⇨ Average 52 min. tap to tap time
- ⇨ Tapping weight 73 mt
- ⇨ 3 bucket operation
- ⇨ Capacity of transformer was not fully used (75 MVA)
- ⇨ Revamping scheduled for March 2006
- ⇨ New furnace shell for 2 bucket operation with EBT
- ⇨ Dynamic compensation plant
- ⇨ Burner system with multi-point carbon injection

TEST PROCEDURE

The experimental setup looked like this:

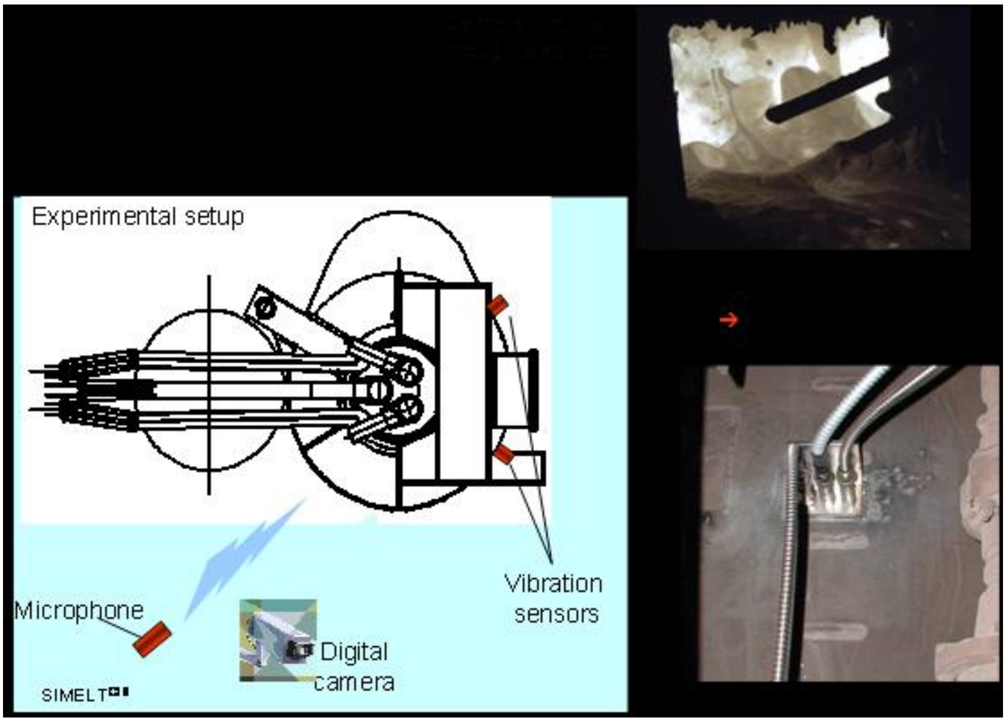

Figure 1. Experimental setup: vibration sensors, camera and microphone

It can be seen from the plan view of the furnace that a total of 2 sensors were used for the first development phase. Vibration sensors were attached to the furnace panel at phase 3 and phase 1, with an adapter plate having been welded to the panel. In test series 1 (there were 4 series altogether) the type of sensor was also investigated, with one type subsequently being chosen. A directional microphone was also set up in order to investigate this methodology as well. A high-resolution digital camera was mounted on the shop wall with a view through the lance manipulator, solely for verification purposes.

On Figure 1 you can see an example of an image taken by this camera.

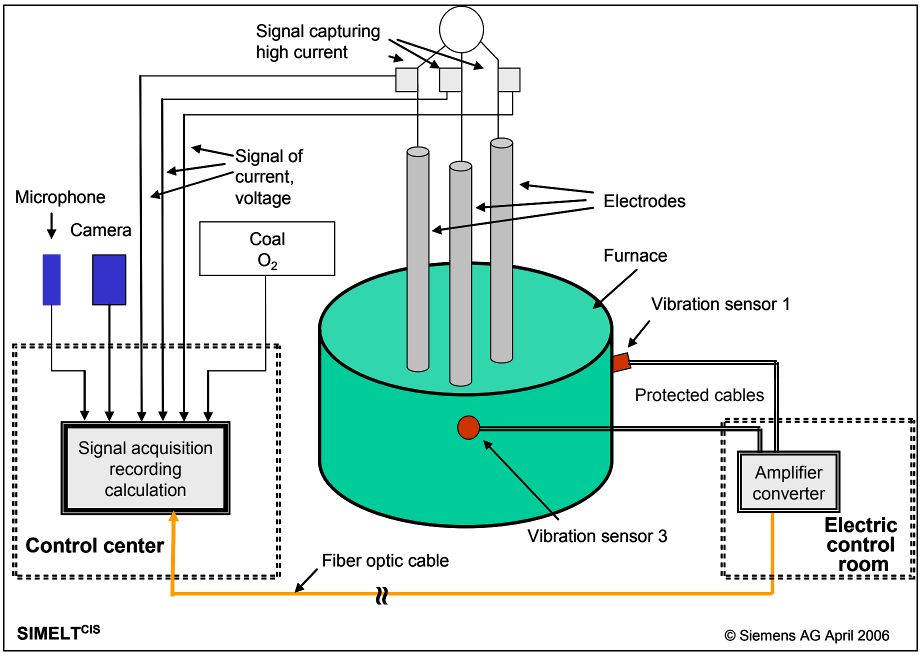

Figure 2. Measurement system

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 data was recorded at the furnace control center. Evaluation was carried out offline at Corporate Technology. In test series 1 and 2 only one sensor at phase 3 was examined. In the last two test series a sensor was added at phase 1, in order to determine the various foaming slag heights in the furnace.

Principle of evaluation and the transmission of sound/vibration:

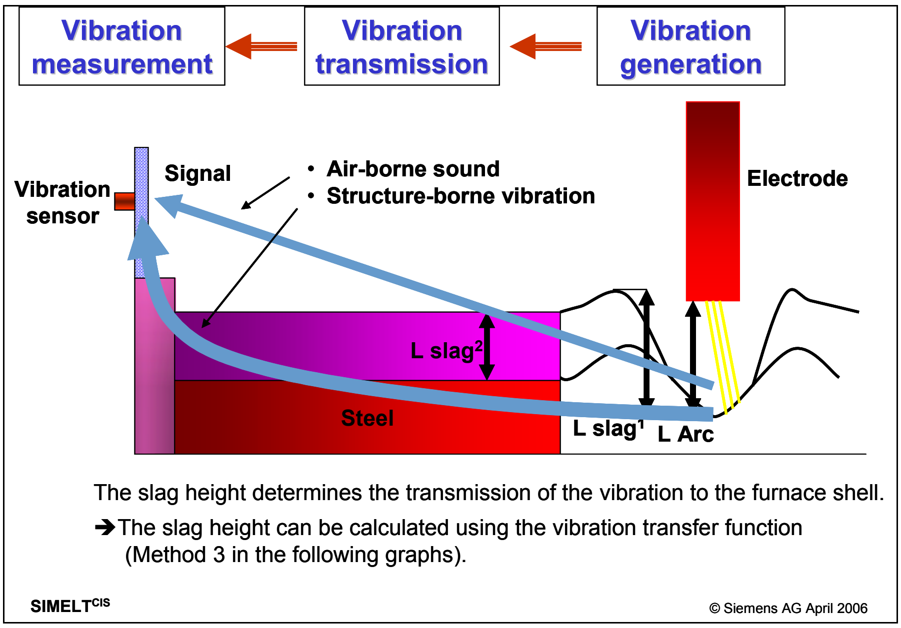

Figure 3. Principle of vibration evaluation

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 or slag phase.

RESULTS

In the first two test series the primary objective was to determine the feasibility of the sensor technology. For that reason, first of all only one sensor was examined at furnace phase 3. As mentioned at the beginning, this was also done by way of comparison with current analysis and directional sound analysis.

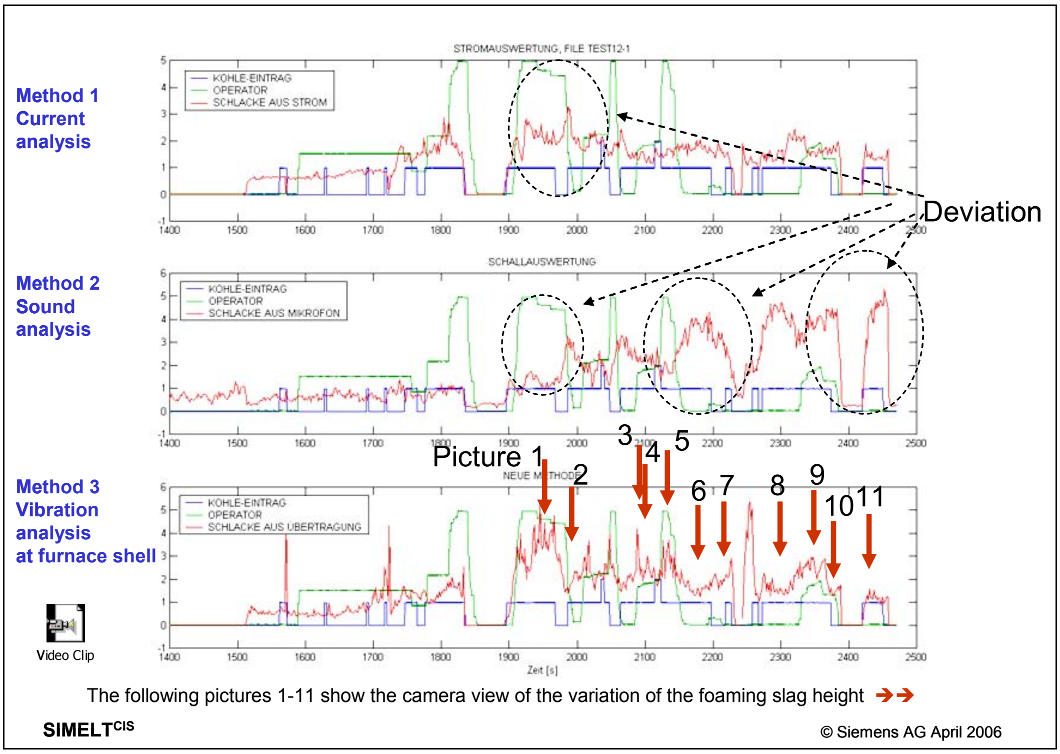

Figure 4. Comparison of methods for one example: foamy slag phase

The three different measuring methods are shown together in this illustration. The plot in the upper part is the current analysis (FFT), the middle one is the directional microphone method and the lower one represents the structure-borne sound method. Looking at the top two measuring methods you can discern deviations from the real behavior. The real behavior is defined by the evaluations of the video signals. The blue curves in each case represent the injection of oxygen and carbon, signals which are not used to produce the algorithm but to determine the plausibility. In addition, the operator’s personal impression is plotted as the green curve. As already mentioned, the methods described above have the disadvantage that the real trend of the foaming slag height does not correspond to the calculated trend in all aspects, which in the end in fully automatic operation would lead to inversion of the control characteristic. With the structure-borne sound method, on the other hand, the trend always corresponds to the real foaming slag trend, so that in this case the first attempt at a control algorithm, for example on a neural basis, shows promise.

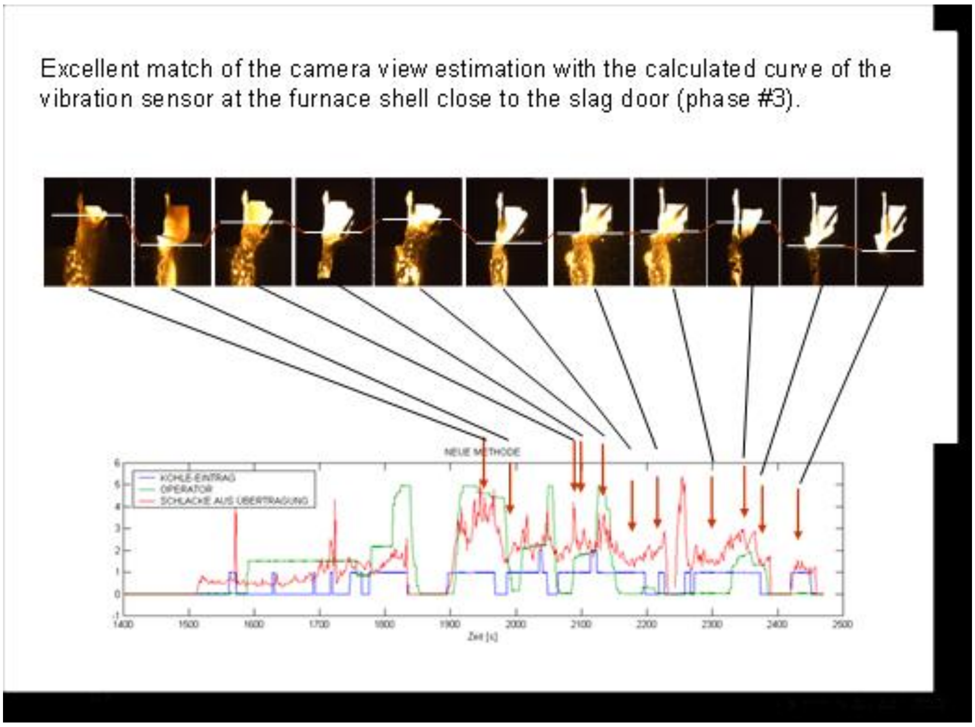

Figure 5. Comparison of the camera view with calculated curve

In this illustration the verification is presented using the example of the structure-borne sound method. Simultaneous image inputs from the image evaluation were assigned to certain data points, the “foaming slag signal”. The curve of the values obtained using the structure-borne sound method can be placed over the ascertained image data with very good reproducibility.

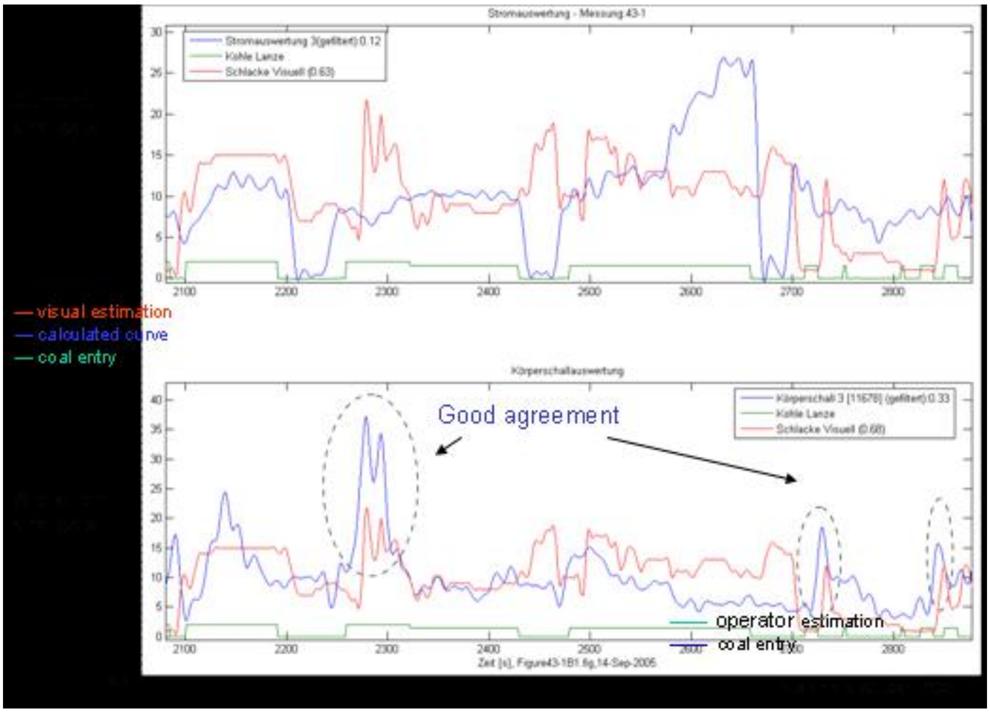

Figure 6. Comparison between current and vibration analysis: heat #219266

In the subsequent deliberations the directional microphone method is dispensed with as it has by far the poorest results. In the illustration above therefore only the comparison between current analysis and vibration analysis is shown, on the basis of heat #219266. The visual relationship can also be seen here (red curve). In this case, too, you can see the enormous deviations from the trend in the case of the current evaluation. The structure-borne sound method is plausible in respect of the trend.
Investigations with 2 vibration sensors (test series 3 + 4):

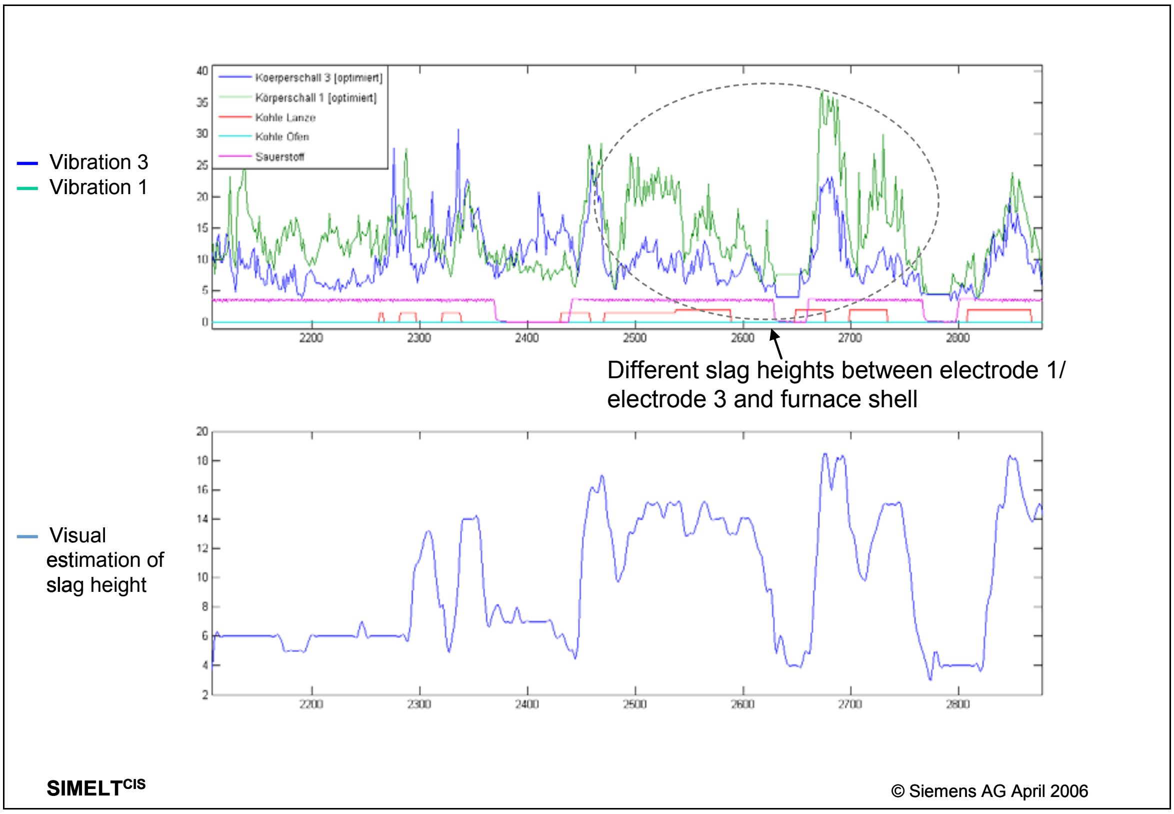

Figure 7.Spatial variation inside the furnace: comparison of sensors close to electrode 1 / electrode 3 (heat #219229)

In the last 2 test phases an additional structure-borne sound element was attached in the vicinity of phase 1 of arc furnace no. 1. The aim was to determine the uneven foaming slag conditions in the furnace, something that the operating personnel knew about from visual observations and also empirical values. In the illustration above a different level of foaming slag height can be clearly made out in the time period from 2480 sec to 2800 sec. An almost uniform curve is only obtained after a relatively long process time, however, i.e. after slag has already flowed out of the furnace.
Note on evaluation: The initial evaluations relate to one output signal (current) in relation to one element (structure-borne sound). In the subsequent deliberations this principle was modified to the extent that the influence of the three phases (3 current signals) was considered in relation to each structure-borne sound element, as shown in the next illustration.

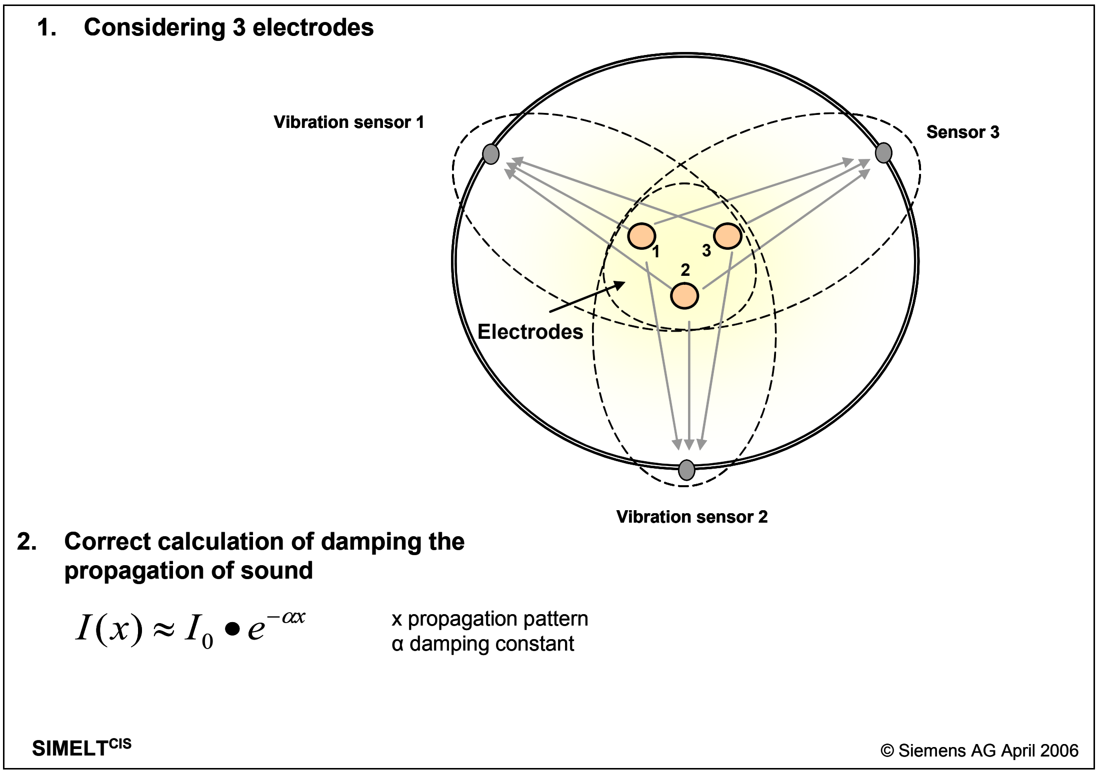

Figure 8. Extended calculations

The “new” results can be seen in the following illustration:

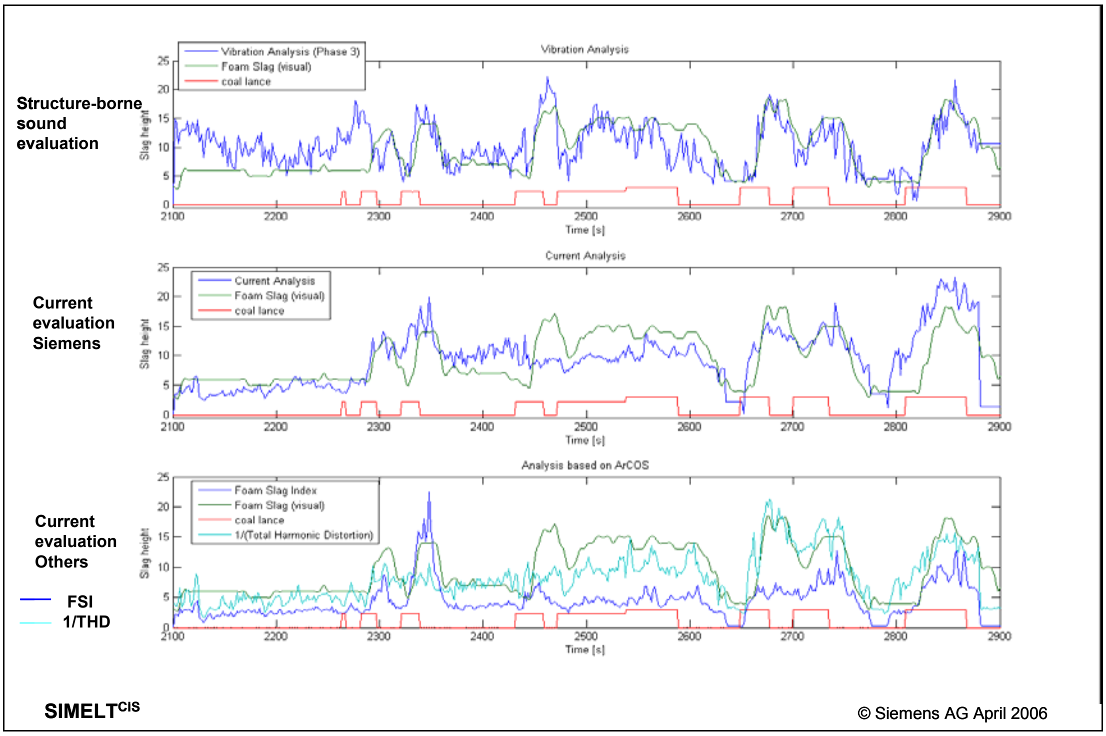

Figure 9. Comparison of new evaluation with other methods

Here, too, by far the best result was basically achieved with the structure-borne sound method in terms of trend and correlation. The FFT method with the parameters “others” (data from patents/literature) appears to be not applicable at all in this case.

Summary of results:

1. Vibration analysis on the furnace panel is capable of mapping the formation of foaming slag in space and over time.
2. Vibration analysis produces better results than current or microphone analysis.
3. The spatial distribution can be represented, and consequently the system can be controlled in the direction of greater uniformity by means of burners/injectors arranged in different locations.
4. Initially the detection system can be supplied on its own, because the visualization alone enables appropriate measures to be taken in the process in order to make the formation of foaming slag more uniform or to optimize it. This leads to a shortening of the tap to tap time even during an early phase.
5. Following completion of the development work, there will be no difficulty in loading the control algorithm that is under development for the fully automatic control of foaming slag formation into detection systems that have already been supplied, with no need to adapt the hardware or the detection software. Only the connection to the basic automation of the arc furnace has to be taken into account, along with commissioning.

FURTHER PROCEDURE

Figure 10. Movable prototype SIMELTCIS AC/NEC FSM

Sales release for detection on its own was granted in March 2006. Phase II, i.e. the commissioning of the prototype for online detection (shown in the picture) took place in April 2006. At present an analysis known as a line analysis is being run in which in addition to the foaming slag data all data required for operation of the furnace are also recorded from the basic automation in order to be able to draw up algorithms or patterns for a hybrid furnace control system. Generation and commissioning of the control algorithm will be completed by the end of September 2006, meaning that sales release for the control system can be granted in December 2006 at the latest.
Finally, take a look at the visualization of the prototype at Lechstahl:

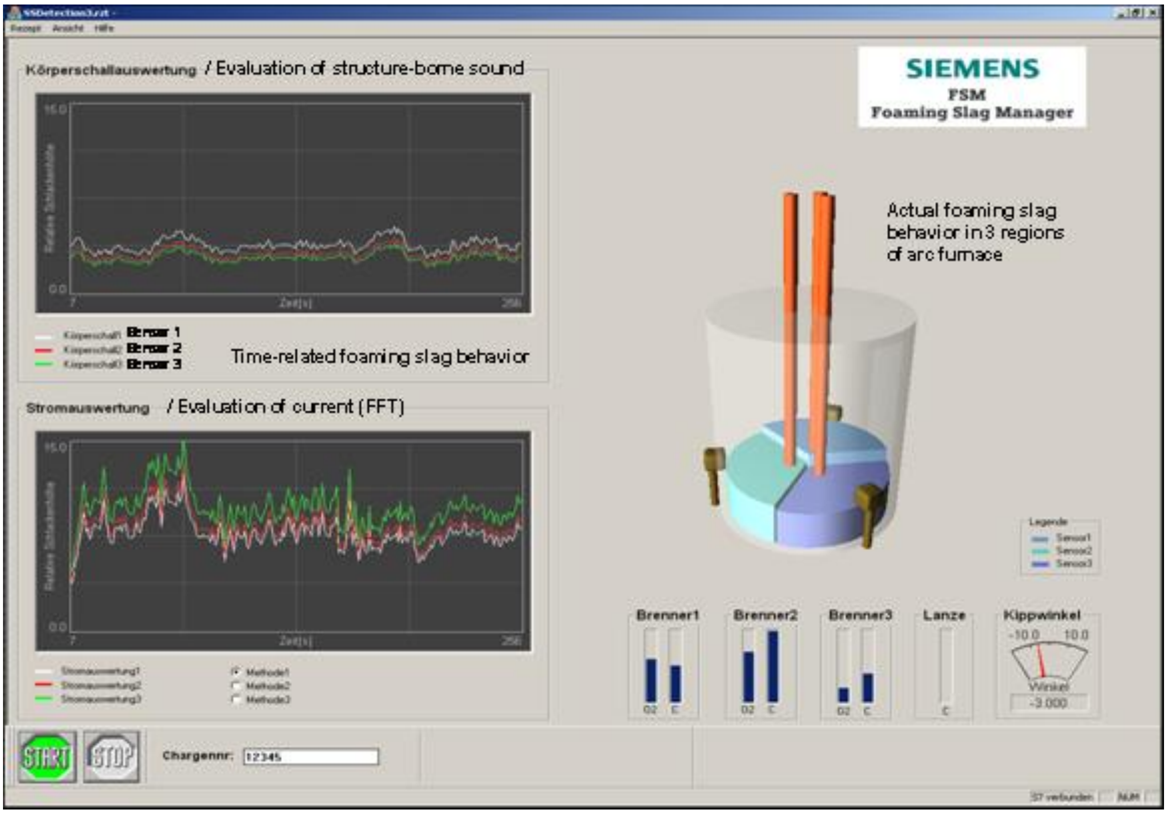

Figure 11. Foaming Slag Manager

The most important displays are the qualitative foaming slag height on the basis of structure-borne sound and current over time. In addition, the current foaming slag level is shown as a 3D pie chart in three sectors of the furnace. The present form of visualization will of course continue to undergo development in accordance with the circumstances during further development or as a result of discussions with customers.