The Ultra slag droplet detector

A new slag detector with 10 times higher sensitivity than previous detectors has enabled measurement of slag droplets flowing through the ladle to tundish nozzle before the main vortex starts. This enables high grade, inclusion sensitive steels to be produced without a hot heel practice and product downgrading at ladle changeover can be prevented.

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Slag carry over of oxidised ladle slag into the tundish was a major problem in steelmaking 20 years ago, however, with the application of electromagnetic slag detectors, slag carry over into the tundish was significantly reduced, resulting in a substantial improvement in steel cleanness and associated defects (See *Figure 1*). Products cast during ladle change which previously had been downgraded could now be used for higher grade applications, as reported by Thyssen, Sumitomo, LTV, Posco and others. Additionally, due to the change from subjective visual slag carry over control to an objective measurement, the residual steel in the ladles was also markedly reduced, and less carried over slag reduced the incidence of nozzle clogging.

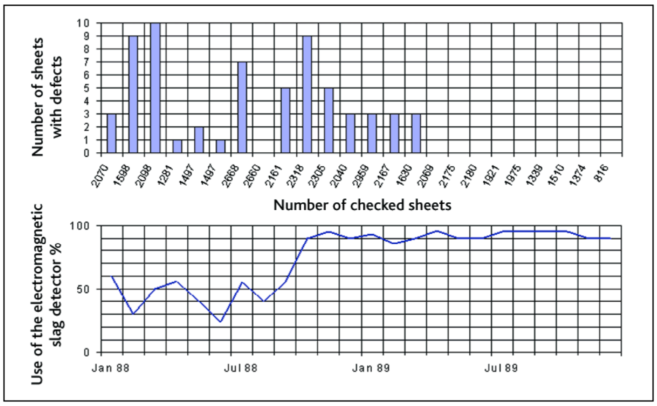
Only a few years after market introduction, this technology became standard equipment and today more than 300 continuous casting machines with over 3,000 ladles are equipped with electromagnetic slag detectors (see *Figure 2*).

Although the introduction of this technology was a significant step towards clean steel production, product specifications and cleanness requirements are continually increasing and there was interest in lowering slag carry over even further for special steel grades. In spite of the high sensitivity of the current electromagnetic slag detector, the measurement principle requires a certain slag portion entrained into the steel flow to become detected. In most ladle drainage processes the steel slag transition takes about 3-10 seconds to be completed.

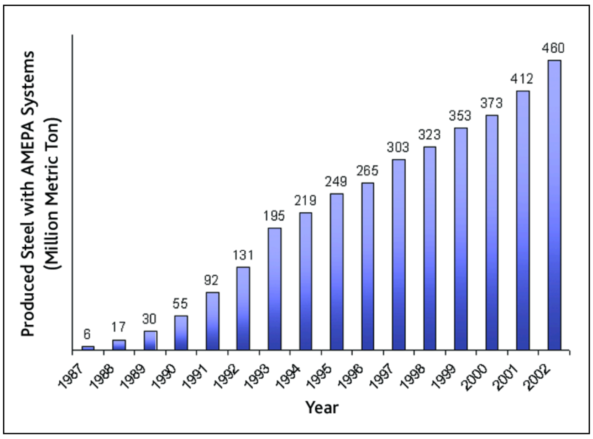
In 1995, a study was published by Sankaranarayanan and Guthrie about drainage experiments with an oil layer on water. They found that in the presence of weak azimuthal velocities, discrete oil droplets were entrained some time before the main vortex developed, which itself occurred late in the emptying process. If in steelmaking ladles such discrete portions of slag regularly flowed before the main vortex flow starts and, it was possible to detect them, a much more sensitive slag detector could be developed. Moreover, the smallest slag portion to be carried over could be minimised to practically zero. Since the current electro-magnetic slag detectors are unable to detect such small discrete portions, new ideas had to be investigated.

Basics of electromagnetic slag detection

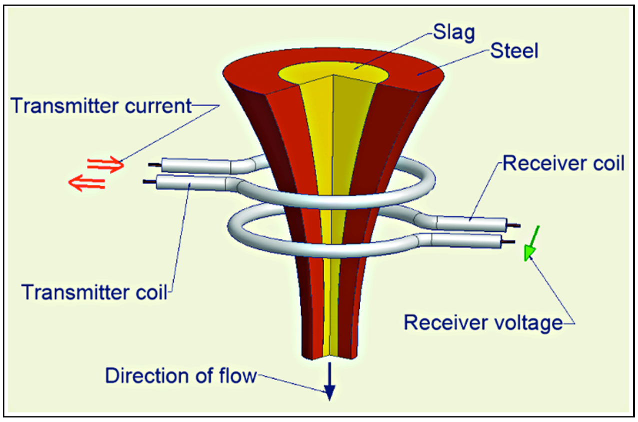
Due to the fact that the electrical conductivity of liquid steel is about 1,000 times higher than that of liquid



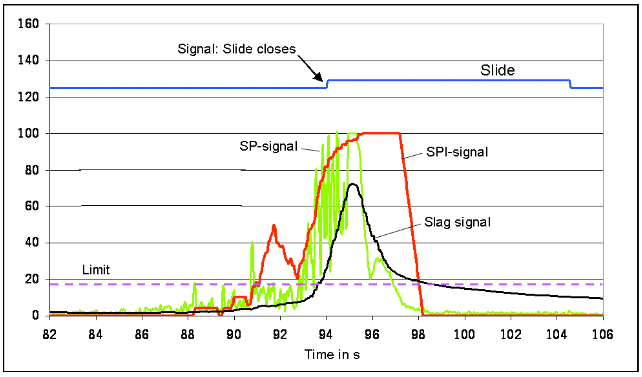
● **Figure 1** ***Improvement of cleanness for tinplate coils by electromagnetic detection***



● **Figure 2** ***Annual steel produced with Amepa slag detectors***



● **Figure 3** ***Basic measurement principle of electromagnetic slag detection***



● **Figure 4** ***Slag detection signal profiles***

slag, a transformer principle can be used to measure the entrainment of slag into the outflowing steel. By means of an AC transmitter coil, eddy currents are induced in the melt. The amplitude and the geometrical distribution of the eddy currents depend on the distribution of the electrical conductivity in the steel stream. Slag entrainment changes the electrical conductivity, which results in a change in the entire magnetic field which is transferred into a voltage by means of a receiver coil (see *Figure 3*).

Detection of small discrete portions of slag entrainment

In the case of a slag droplets flowing in the centre of the steel stream with a diameter of 20% of the nozzle diameter, an electromagnetic slag detector would need to be 50–100 times more sensitive than the existing ones to detect it. Simply increasing the amplification of the current slag detector to this extent is not possible. The small signals received by the detector coil are superimposed by noise and especially large signals created by temperature changes of the ferromagnetic metal parts near the sensor. An intelligent signal treatment, therefore, has to distinguish between signals coming from slag entrainment and temperature drifts. This also limits the maximum sensitivity of a slag detector. Additionally, whereas while the current slag detector has to deal with steel/slag transition times between 3 and 30 seconds, an instrument to detect discrete portions of slag travelling along the sensor has to be optimised with regard to the signal processing of small impulse signals in the millisecond range.

The improved electromagnetic slag detector

To detect these small impulse signals, a current slag detector was equipped with a new and faster main computer board, a second hardware channel and an additional signal processor board. The signal processing in the second channel was optimised for discrete slag portion detection. The second channel delivers a so-called 'Slag Particle Signal' which indexes the volume of the discrete slag portion. The first channel remained unchanged and delivers the known slag signal as in the former slag detector. The equipment was tested in the laboratory and then during field tests.

Plant measurement results with the improved slag detector

Figure 4 shows a typical signal profile – as published by Thyssen Krupp Stahl – generated by the conventional slag detection system (slag signal) and the new system (SP signal). The individual signal peaks of the SP signal are abstracted by means of an algorithm and converted into a new signal, the slag particle index (SPI) signal that is monitored against a set limit value. If the limit value is exceeded, a preliminary alarm is triggered, allowing the casting ladle to be closed via the slide gate. In the initial test phase however, the slide gate was still controlled by the conventional slag detection system. It can be seen that the SP signal of the new system in *Figure 4* has reacted perceptibly earlier to the incipient slag carry over than the system conventionally in use.

Clear signal fluctuations of the SP signal can be seen after 88 seconds following activation of the system during final casting of the ladle, whereas the slag signal of the standard system only records negligible values. The SPI signal exceeds the limiting value which triggers a slag preliminary alarm, as early as 91 seconds after activation while the slag signal of the conventional system only triggers an alarm at 93.8 seconds. This means that the slag carry over in this heat was detected approximately 2.8 seconds earlier than by the standard system. The total amount of slag carry over cannot, however, be reliably determined by taking the factors of time and the amount cast, as the slag carry over forms slowly and the ratio of slag volume to steel flowing in the tundish is not known for the ladle discharge.

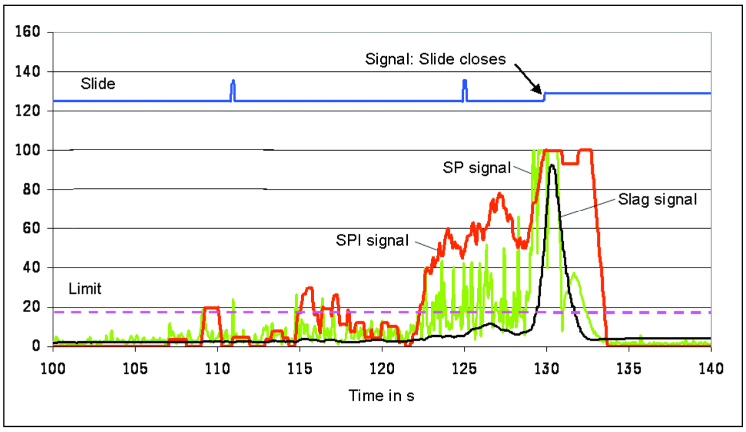
Tests using the new slag detection system showed that the transition between steel and slag flowing from the ladle into the tundish does not take place suddenly, but that there is a transition time in which initial traces of slag are already entrained in the steel flowing out of the ladle. The duration of this transition time can vary very significantly. *Figure 5* shows the signal profile of the conventional as well as of the new system during prolonged slag carry over. It can be seen that the SP signal displays considerable fluctuations after 107 seconds of system activation that are obviously caused by individual slag clusters drawn from the slag layer in the casting ladle. The slag signal of the conventional detection system only displays a signal drift that cannot be evaluated, and only exceeds the alarm limiting value 128 seconds after system activation. This means that the standard system allows certain slag quantities to enter into the distributor unnoticed that do not lead to closure of the slide gate because the quantities involved do not exceed the alarm limit. Such slag quantities are, as a rule, not deleterious for steels, even those of a higher quality grade, however, top quality steels intended for heavy-duty applications such as television masts and flow formed products, require absolute minimisation of non-metallic impurities.

Comparison of detection characteristics of both systems

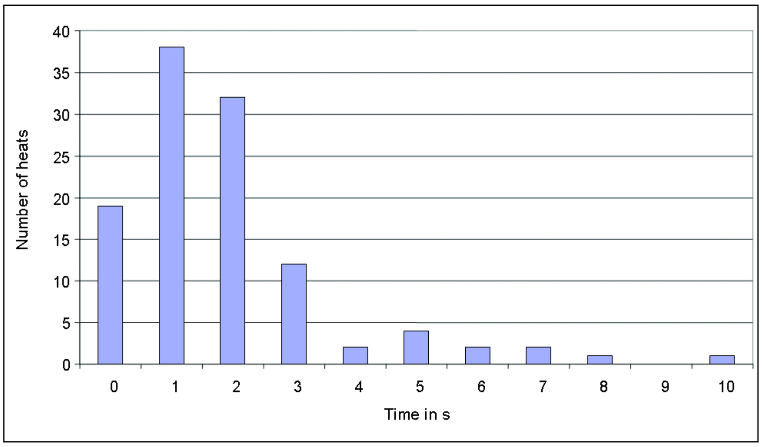
In order to compare the detection characteristics of both systems, the new slag detection system was run in parallel with the standard system and the detection times of the systems compared. *Figure 6* shows the distribution of the time delay points in slag detection between the new and the conventional system for the heats under investigation. It was shown that the test system detects slag on average between 1 and 2 seconds earlier than with the standard system. In a significant number of heats, slag carry over was detected significantly earlier by the new system. Rechecking the recorded signal profiles verified that slag carry over was detected considerably earlier in comparison with the standard system. This involves the effects already discussed in *Figure 5*, in which small slag threads are drawn from the slag layer by the flow of steel leaving the casting ladle.

Determining the quantity of slag carry over

Evaluation of the efficiency of the slag detection systems requires the development of measuring methods to record the slag carry over from the individual casting ladle in the tundish. Only by knowing the exact carry over quantities is it possible to make an evaluation and compare the individual measuring methods. In the ThyssenKrupp Stahl AG Bruckhausen steel works in Duisburg, the surface in the tundish is covered with a synthetic calcium aluminate slag to absorb non-metallic impurities from the steel, and with rice shell ash as thermal insulation. As part of the tests to evaluate the quality of the slag detection system, barium carbonate tracers were added to the ladle slags and strontium



● **Figure 5** ***Slag detection during slag particle carry over***



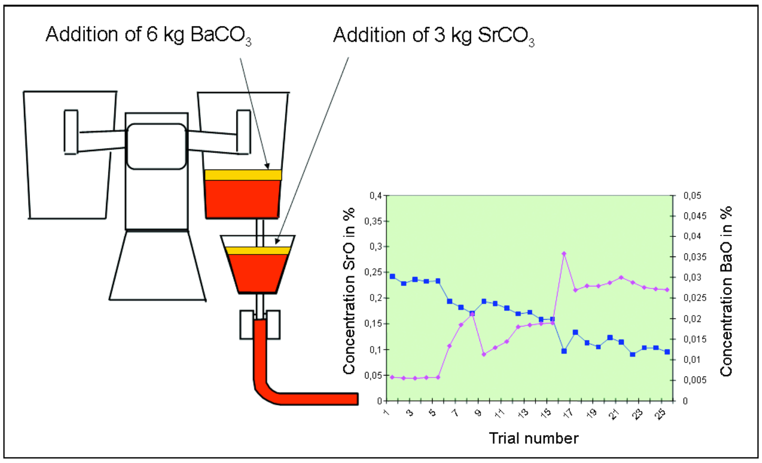
● **Figure 6** ***Improvement in detection time, new versus old system***

carbonate to the synthetic distributor slags. Proportional calculations enabled the amount of carried over ladle slag to be determined. *Figure 7* shows the procedure used to conduct the tracer tests.

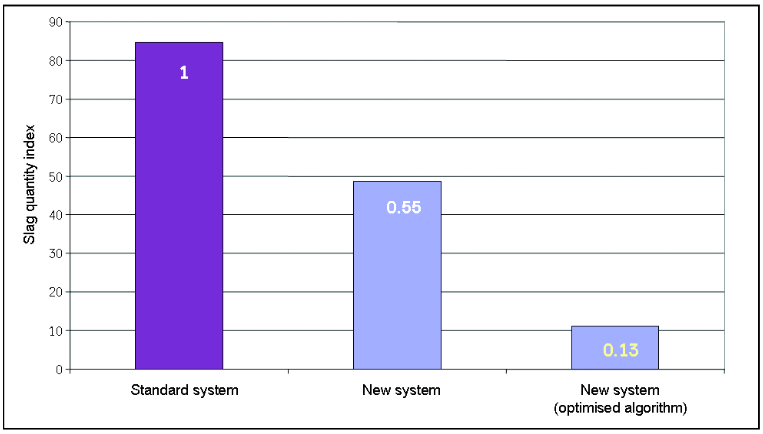
During the rinsing treatment in the secondary metallurgy process 6kg of barium carbonate were added to each ladle and stirred into the ladle slag. The synthetic slag added to the distributor was augmented with 3kg of strontium carbonate then, during the course of the sequence, slag samples were taken continuously from the tundish around the stoppers of strand 1 and strand 2. *Figure 7* shows the course of the strontium and barium oxide contents in the tundish slags during a casting sequence for five heats.

During the sequence the concentration of strontium oxide falls in the tundish slag due to the dilution caused by the carried over ladle slag and the burnt on rice shell ash, whereas the amount of tundish slag increases. The rise in the quantity of slag is also caused by precipitated non-metallic particles from the steel and the increasing eroded refractory brickwork from the tundish.

The barium oxide content rises over the course of



● **Figure 7** ***Slag carry over determination and results***



● **Figure 8** ***Comparison of slag carry over indices***

the sequence. In particular, strong rises in the barium oxide contents connected with a fall in the strontium content can be observed directly after the ladle transfers. These rises are occasioned by carried over ladle slag. On a localised basis there was a large increase in concentration followed by a falling barium concentration at the measuring point. This can be traced to the fact that the ladle slag mixes only slowly with the weakly flowing distributor slag. This means that the ladle slag leaving the shrouding tube produces 'slag islands' limited in duration and extent, so that slag samples have to be taken at several points and at different times to achieve reliable concentration readings.

Knowing the quantity of added synthetic slag to the tundish at the outset of the sequence permitted the profile of the carried over ladle slag quantity to be calculated relative to the above-mentioned measuring points. *Figure 8* shows the effect of the new system on the average quantity of slag carry over during ladle transfer. With the new ultra slag detection system further substantial reductions in slag carry over for the top steel qualities could be achieved.

Slag carry over minimisation versus yield-contradictory requirements

The signal of the new (slag particle) channel allows interruption of the outflowing steel stream before the main slag flow starts. If requested, it can be used to terminate draining as early as single portions of slag become entrained in the stream. Therefore the cleanness requirement for the most sensitive steel grades can be met in future by using the new instrument. On the other hand, closing the slide-gate early means an increase in residual steel in the ladle. Most steel grades do not require to be cast completely slag free, hence cleanness requirements and yield have to be optimised for each steel grade. This requires a slag detector that is able to control the carried over slag in a much wider range than previously. While maximum yield can be achieved by using the current main slag channel (no.1) to alarm and close the slide-gate, it is necessary to develop an algorithm to create a reasonable slag particle alarm based on the no.2 channel signal. Different approaches are currently under test.

The next generation of slag detectors will have two alarm channels. The main alarm channel remains the same as in the former instruments. Additionally, a so-called pre-alarm will be released when the slag particle portion passes an alarm trigger parameter set by the user. The alarm trigger parameter can be controlled based on steel grade by the user allowing optimum cleanness and yield for every heat in a wide range.

Summary and outlook

With a new enhanced electromagnetic slag detection method, it was discovered that during the final stage of ladle drainage small discrete portions of slag are regularly entrained into the outflowing steel stream some time before the main slag flow begins. The occurrence of these discrete slag droplets varies in frequency and time over a wide spectrum. The emergence of this effect indicates the formation of a vortex funnel flow. Detecting the flowing discrete slag droplets at an early stage enables the user to control the final drainage process much better. If the plant results gathered so far can be proved to be valid in general, grades with high cleanness requirements such as tin plate or tyre cord, can be cast with virtually no slag carry over. An enhanced electromagnetic slag detector is already in daily operation and is used to close the slide-gate automatically and early for slag-sensitive steel grades.

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