UP-TO-DATE MEASUREMENT DEVICES FOR CONTINUOUS CASTERS [1]

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Abstract
Continuous casting machines have to be adjusted properly to produce a high yield with good quality. The tools proving that start at the mold where the correct taper and width of the mold as well as the correct oscillation have to be checked. During casting, a mold monitoring system then shows the thermal and oscillation condition of the mold gives detailed analysis of the mold level and its surface and prevents breakouts. For the strand guidance, it is necessary to measure roll gap and roll rotation as well as segment alignment. Spray water of secondary cooling can be checked, too. The influence of all these measurements on the production of high quality is shown.
Keywords: Mold; Oscillation; Strand condition monitoring; Roll gap; Roll alignment; Spray water.

TECNOLOGIA DE PONTA EM DISPOSITIVOS DE MEDIÇÕES PARA MAQUINAS DE LINGOTAMENTO CONTINUO

Resumo
Maquinas de lingotamento continuou devem ser ajustados adequadamento para atingir alta produtividade com boa qualidade. As ferramentas para testar começam no molde, onde o taper correto e largura dos moldes e a oscilação correta devem ser verificados. Durante o lingotamento, o sistema de monitoramento do molde mostra a condição termica e da oscilação do molde, e providencia uma analise detalhada do nivel do molde e da superficie para evitar rompimentos. Para o alinhamento do veio e necessario a medição do gap dos rolos e tambem a rotaçõa dos rolos, e o alinhamento dos segmentos. Tambem e possivel a verificação da agua do spray para resfriamento secondario. A influencia de todas as medições na produção com alta qualidade esta sendo mostrado neste trabalho.
Palavras-chave: Molde; Oscilação; Monitoramento do veio; Roll gap; Alinhamento,; Água de resfriamento.

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Mold

1 Mold Checker – Measurement of mold inner contour and foot roll alignment

There are tree reasons for measuring the inner contour of the mold

- To avoid breakouts which can be caused by insufficient taper.
- To keep product quality high by casting with proper molds
- You do not want to exchange the mold before it is really necessary.

A first step to measure that wear is to measure the dimension of the mold in and perpendicular to casting direction at the bottom of the mold with a gauge.
If you want to know where wear starts, you have to make various measurements along the mold length.
On the one hand, this can be done by hand, but this is not very reproducible and usually takes a long time for two operators to make those measurements.
On the other hand, the MoldChecker is an automatic measurement device that measures the complete inner geometry of the mold, in a contactless manner with a laser.
The operator only has to position the MoldChecker on top of the mold and the measurement is done automatically by electric motors that turn the laser and guide it through the mold. This takes less time and human errors are minimized.

Figure 1: MoldChecker evaluation unit and measurement unit.

Another advantage of the laser system is that you typically do no have to change measurement heads when measuring different molds, like round and square molds.
Additionally, there is no need for an additional device to check gap and alignment of foot rolls, either. This measurement can be made together with the measurement of the mold.

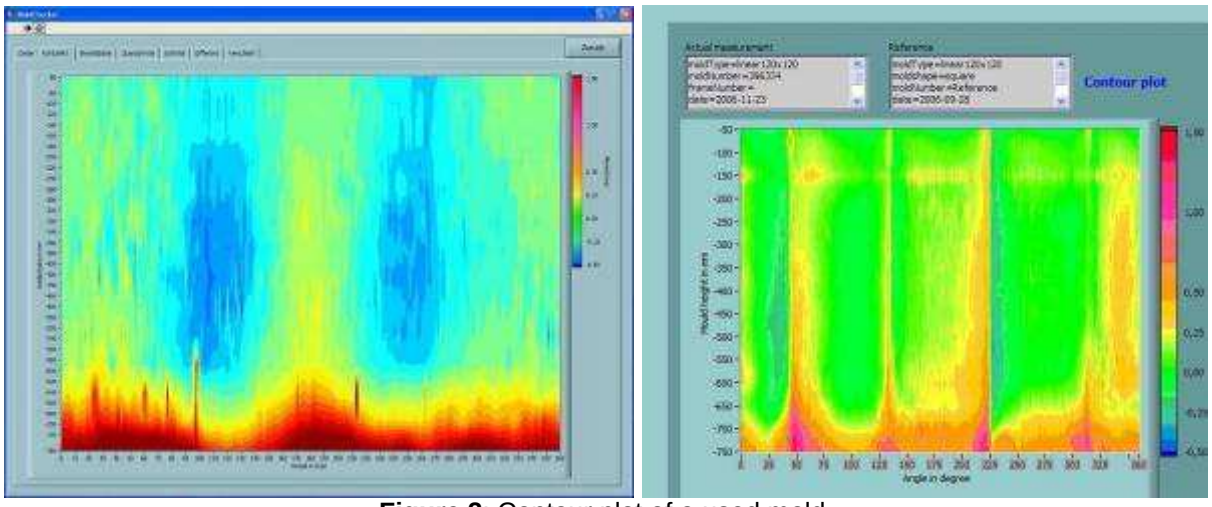

Figure 2: Contour plot of a used mold.

The advantage of complete 3D-measurement can be seen in **Figure 2**. It shows two unfold visualizations of the mold (on the x-axis) versus the height of the mold (on the y-axis). The different colors represent different levels of wear (red = more wear).
The left picture shows a round mold. A typical phenomenon on round molds is out-of-roundness. In the middle of the mold length where there is no severe wear, the mold shows yellow areas that indicate that the mold is too wide and blue areas that indicate that the mold is too small. So this mold has an elliptic cross section. This can only be figured out through the complete 3D-measurement of the inner contour. In the bottom of the mold, typical loss of taper is indicated by the red color.
The picture on the right shows a square mold with wear at the meniscus, on the bottom of the mold and in the corners, too.

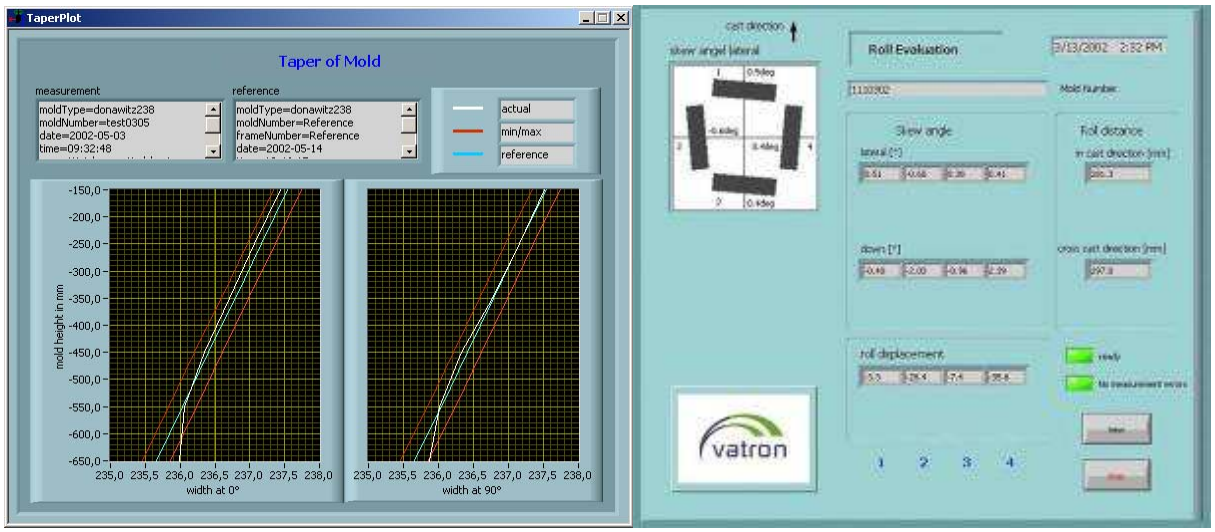

Figure 3: Taper plot and foot roll plot.

Additionally, the mold taper in casting direction and perpendicular to can easily be compared to the set-point curve and predefined limits.
The MoldChecker is also able to provide other important information, such as: gap, alignment and angles of foot rolls, all in just one measuring sequence. The relevant evaluation is shown in the right plot of **Figure 3**. Depending on the mold geometry, up to 3 rows of foot rolls can be measured.

Quality aspects:
It has been proven that there is a direct correlation between the wear of the mold and subsurface cracks.
Acciaierie Venete that is using the wear index concept for the management of the mold life figured out that 75% of the monitored molds could have had an extended life of +40% compared to the standard technological life based on the number of heats cast.
Besides, the importance of correctly adjusted foot rolls could be proven. Not only gap and alignment of foot rolls are important. If the foot roll is not parallel to the mold, the inclination of the foot roll causes increased, asymmetric wear of the mold.

2 Taper Checker – Verifying the narrow face taper

For slab casters, a complete 3d-measurement is not possible, but 3d-measurement of the mold narrow face and surrounding broad face should be possible soon.
Nevertheless, to guarantee a good heat transfer on the narrow faces and therefore to avoid breakouts, the taper of the narrow faces has to be checked every time prior to casting. In addition to operational safety, the taper is essentially for the support of the strand shell and mainly influences the friction between steel shell and mold.
If you select a too high taper, friction increases and corner cracks may occur.
If the taper is too small, the strand shrinks more than the mold width is reduced by the taper. The ferrostatic pressure deforms the narrow face so much that it finally has contact with the narrow face again. The stresses that are induced in the corners can lead to subsurface cracks.
Additionally, longitudinal cracks can also be affected by insufficient support of the narrow face of the slab.

3 Oscillation Checker – Inspect your oscillator

Proper casting powder and adequate oscillation are main factors for the quality of the slab and a sticker-free operation of the caster.
There are three main reasons why you should check your oscillator frequently:

- Verify that stroke and frequency of the oscillator are set correctly. It occasionally happened that after a change of a cylinder, the oscillator was oscillating with wrong or different strokes on both sides. After each maintenance of the oscillator, a check is essential.
- If guidance of the oscillator is not working properly, unnecessary forces are applied to the strand shell, which affects oscillation marks and slab quality. Deviation higher than 0.2 mm / 0.008 in may lead to a reduction of the slab quality, mainly caused by corner cracks.
- Additionally, the movement of the oscillator in and perpendicular to casting directions tells you a lot about the condition of your guiding system. So bearing problems or broken guidance springs are detected early. You can plan your maintenance on the oscillator more effectively and avoid dangerous and costly stops of the oscillator.

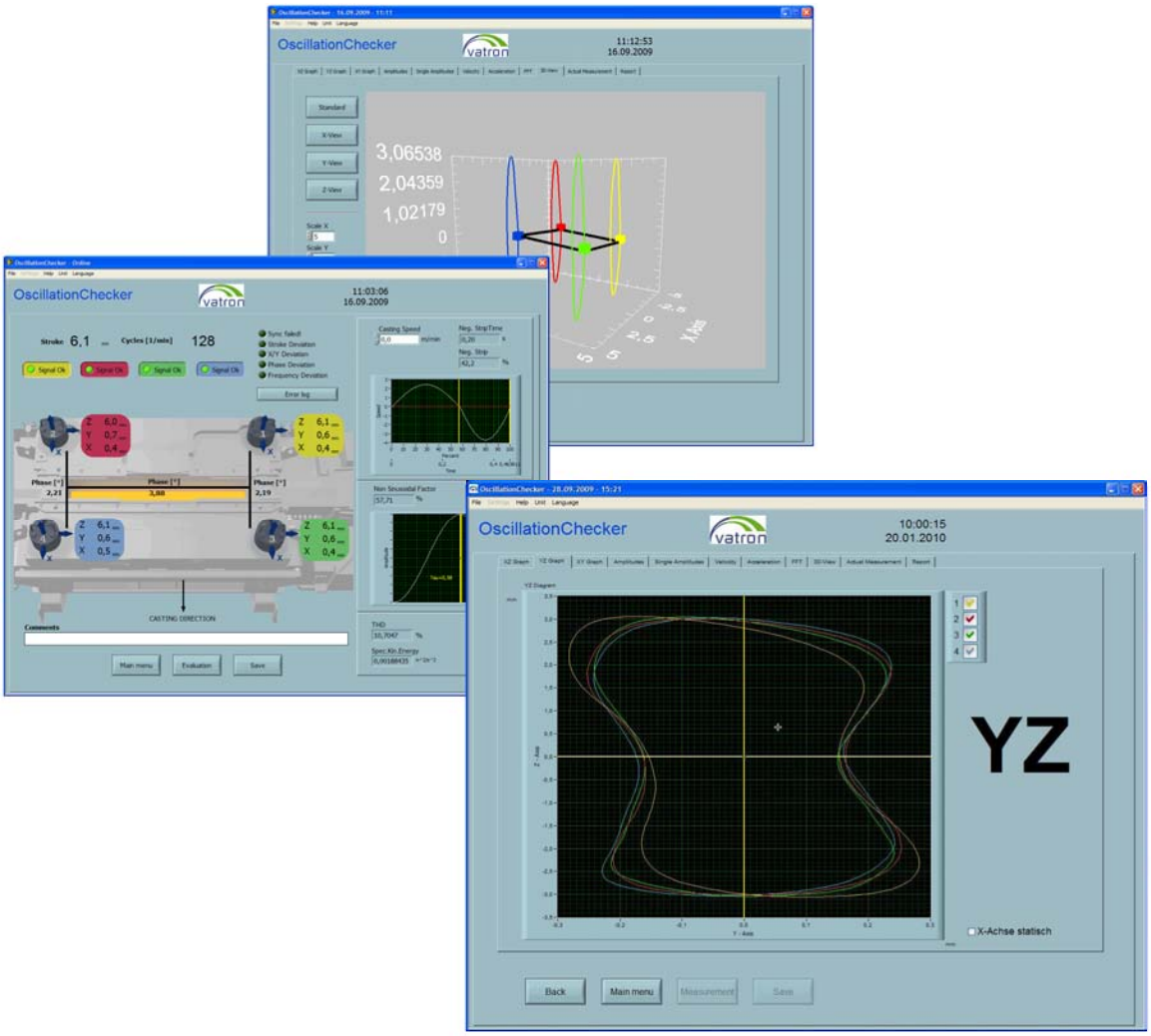

Figure 4: Online HMI and one of the evaluation screens of OscillationChecker.

In detailed evaluations the movements is all directions, frequency analysis and an animation of the movement can be observed.
Metallurgical information, like negative strip time or non-sinusoidal factor can be calculated, too and provide even more insight in the casting process.
There are two main concepts for checking the movement of the mold.

Table 1: Advantages of different concepts of oscillation measurement

	Inline	**Offline**
Principle	Sensors are mounted to the mold or the mold frame	One to four portable sensors are placed on the mold. Measurement is done during maintenance.
Advantages	• Continuously supervision of movement • Feedback on casting status • Alarms, if oscillator is not moving correctly.	• Only one measurement device for several caster • Measurement of alternative measurement positions easily possible • Less expensive

The Inline system additionally can be integrated into the MoldExpert.

4 MoldExpert - Mold Monitoring System

The MoldExpert is much more than a breakout prediction system; it stores and visualizes all mold relevant information in one system.
Beside its breakout prediction system that automatically adapts is limits according to the casting conditions to detect stickers more reliably under all conditions, it gives the operator a “look into the mold.
With colorful temperature representation of the mold, the steel flow inside the mold is visualized and problems with partly clogged SEN or SEN with holes can be seen. (See **Figure 5**)

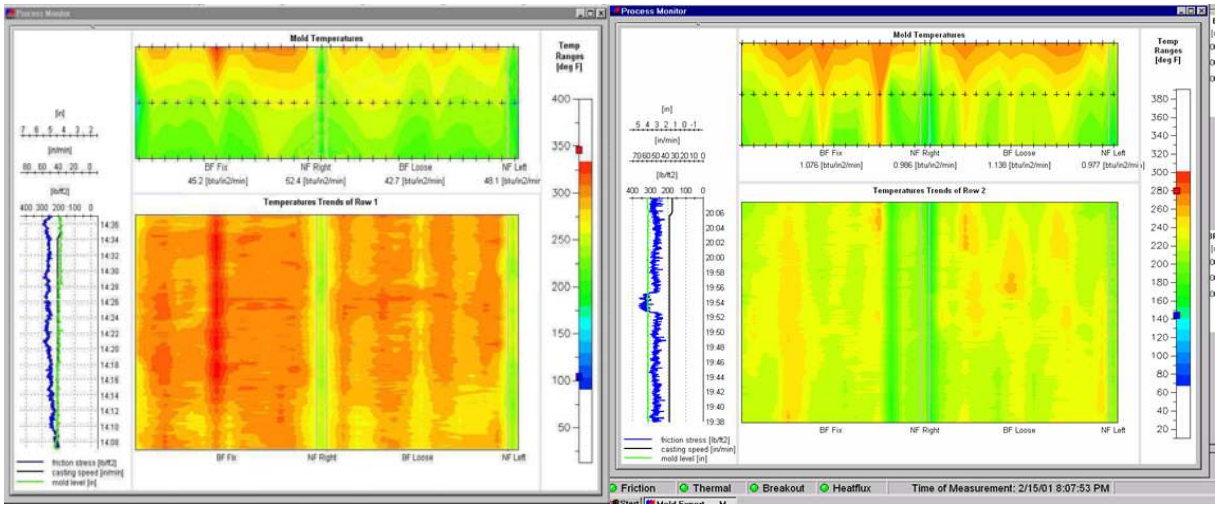

Figure 5. Contour plot of the mold showing hole in SEN (left side) and longitudinal crack, indicated by friction peak (right side).

On a caster with hydraulic oscillator, the friction between the strand and the mold can be calculated online.
Friction values together with the also calculated heat fluxes through the copper plates gives valuable information about the behavior of casting powder.
A sudden increase of friction can be an indication of a longitudinal crack (**Figure 5**, right) while heat fluxes below the limit can cause the most expensive kind of breakouts, the one where the steel shell is so thin that it ruptures below the mold.
With thermocouples in the copper plates, the heat fluxes and the friction, four sides of the strand are monitored very well. But a very important one, the surface of the strand is missing.
When the operator looks into the mold he sees a black surface of casting powder. Only if distribution of casting powder is extremely bad he visually can view the problem.
The situation changes if infra-red cameras are having an eye on the strand surface.
Uneven distribution of casting powder is detected much earlier, because with the infra-red camera a temperature image of the surface is available.

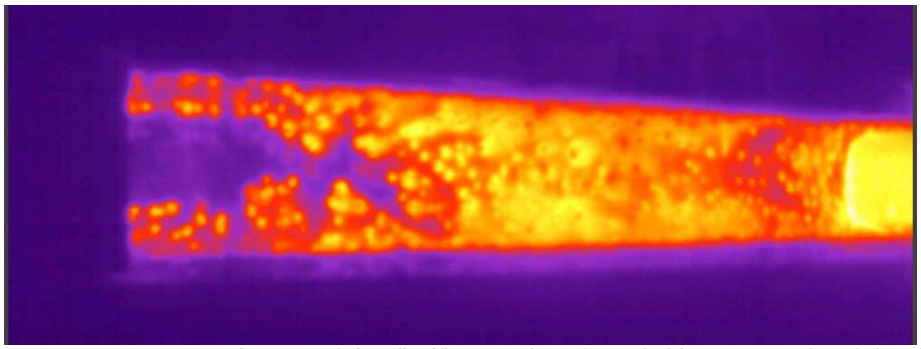

Figure 6: Temperature image of the (half) strand surface (with SEN on the right side)

This information can be evaluated by the operator or used to check or to control the addition of casting powder.

If you are facing problems like dynamic bulging (the mold level is oscillating and amplitude is increasing) you need a tool like the LevelExpert.
With its detailed analysis of the mold level and optionally withdrawal forces the LevelExpert determines the main frequencies of the mold level oscillation and tells the operator the part of the caster that is causing the bulging and how to react on that.

5 ThermocoupleChecker – Testing of thermocouples in the maintenance shop

Each breakout prediction system works only as well as the thermocouples perform. Of course, you only need 2 thermocouples at the position (where the sticker starts) to detect a sticker, but casting with non-working thermocouples is always a kind of gambling.
Only molds where all thermocouples are working should be used for casting.
If the test in the maintenance shop is not made carefully and you have to exchange the mold because of malfunctioning thermocouples, it typically results in 2 hours of production time loss for the mold exchange.
vatron provides the ThermocoupleChecker, a measurement tool that automatically guides the operator through the complete testing procedure.
First all thermocouples on that face are automatically checked for any open thermocouples, then the operator uses a torch to heat the spots on the copper plate where the thermocouples are located to verify proper working thermocouples.
In this way, the operator gains information if

- the thermocouple is installed in the correct place. He can see which thermocouple responds to the heating of the copper plate.
- the polarities of thermocouple wires are exchanged. The thermocouple temperature decreases if the thermocouple is heated.
- The thermocouple's electrical contact may be all right, but maybe it has no sufficient contact to the copper plate. Possible reasons may be dirt at the bottom of the hole where the thermocouple is inserted or a broken spring that presses a two-wire thermocouple against the copper plate. Then the thermocouple will not heat up or heat up too slowly.

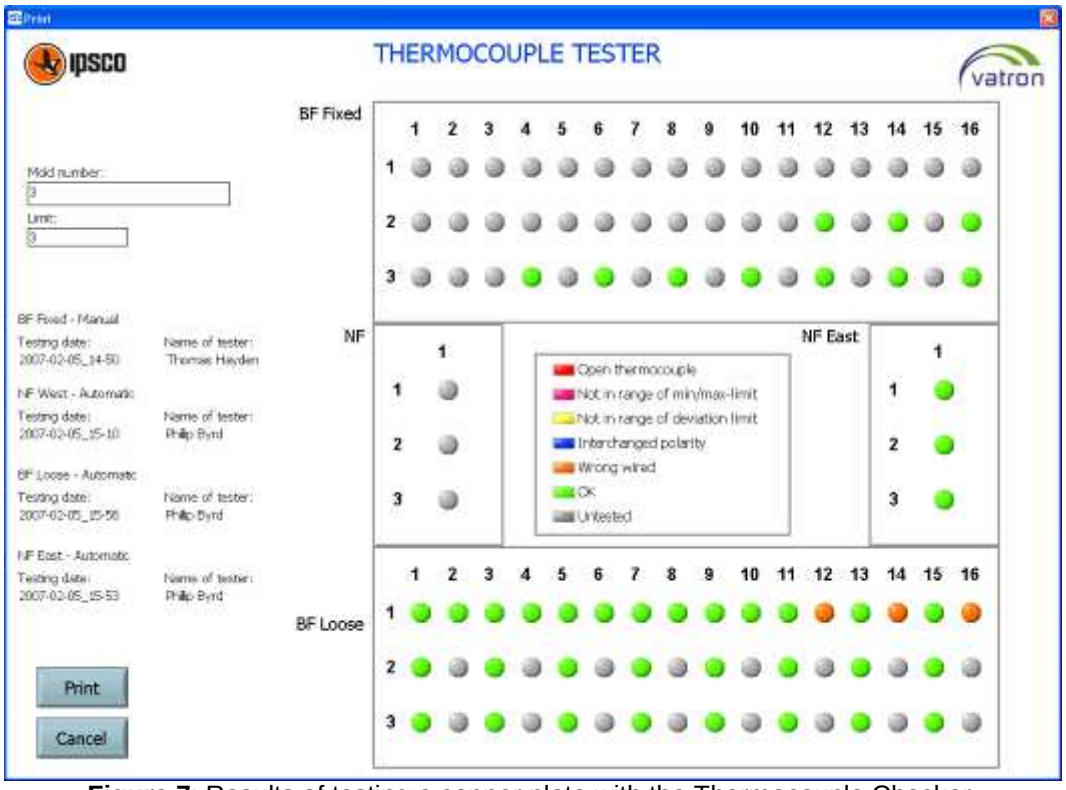

Figure 7: Results of testing a copper plate with the Thermocouple Checker.

As a result of the test with the Thermocouple Checker, a report is printed out that shows information of all tested thermocouples.

Strand Guidance

6 Roll Gap Checker – Strand condition monitoring

After the mold, the strand guidance and the secondary cooling is responsible for the transport of the slab and its final solidification.
The roll gap has to be measured to:

- check if the gap is set according to the shrinkage of the strand, or
- to calibrate the sensors within the segments (if the caster is equipped with automatic strand taper control)
- For maintenance purpose the gap measurement is indicating the roll wear.

The alignment measurement is necessary to:

- check the correct mounting of segments and
- clean the supports of the segments if not.

Improper gap and alignment lead to

- incorrect slab size
- cracks in slabs, which depend on steel grade and deviations of measurements from set-points

The roll rotation measurement helps to

- avoid damage of rolls because the rolls are not rotating caused by sticking bearings and to
- avoid scratches in slabs caused by non-rotating bearings

Compared to standard strand condition monitoring systems the vatron RollGapChecker additionally offers

- Pneumatic springs instead of conventional ones. These springs are necessary to compensate the bearing clearance. But only with pneumatic springs the force can e shut on and off at anytime which enables the RollGapChecker to easier enter and exit the caster and therefore to better measure the last segments.
- If for example, the measurement results are showing that the first straightener segment has a severe misalignment, then the operator keeps the RollGapChecker connected to the dummy bar and fixes the misalignment of the segment. He then runs the RollGapChecker again, but only as far as necessary to measure the re-aligned segment. In this way measurement time can again be reduced essentially.
- On Siemens VAI caster measurement results of a vatron RollGapChecker can be directly sent to the segment controller to calibrate the segments. In that way human errors are eliminated

It has been proven that measurements have been made more frequently since the new RollGapChecker was installed. Our customers, for example, do measurements on a two weekly basis and of course after each segment change.

7 Roll Gap Checker – Spray water tester

Additionally, the segments' secondary cooling must cool down the strand properly. Therefore all spray water nozzles have to spray on their desired positions.
The importance of a spray water measurement is often underestimated, but even the best cooling model works only as good as the nozzles are spaying on the strand.

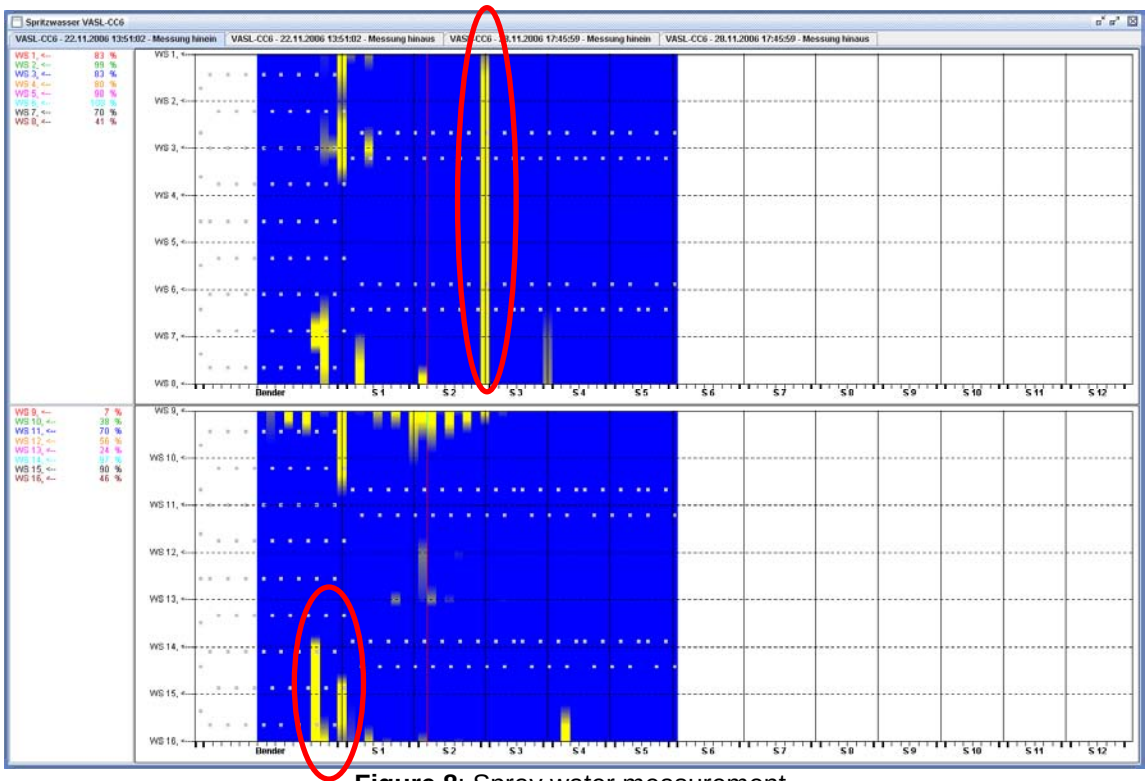

Figure 8: Spray water measurement.

Figure 8 shows a spray water measurement. The top plot shows the inner bow and the bottom plot the outer bow. The positions of the spray water nozzles are indicated

by the small grey dots. Sufficient water is marked by blue color while non-sufficient water is marked by yellow color.
The measurement shown was made after an operator checked the nozzles by optical inspection. Due to his opinion, all nozzles were spraying well.
But the RollGapChecker showed a different result.

- One measurement line is completely yellow (Encircled red in upper plot). An optical re-check exposed that the bar where the nozzles are mounted was bent. The nozzles had been spraying, but on the rolls and not on the strand.
- The encircled yellow (dry) region in the lower plot has been caused by nozzles whose spray pattern did not have the same angle on both sides and therefore the nozzles did not spray to the edge.

Especially on the outer bow a manual inspection is almost impossible.
Through our measurement principle and advanced algorithms, we can provide a spray water tester that is really reliable.

8 Conclusion

High quality slabs and billets can only be obtained if the caster works properly.
To guarantee a proper setup of the caster, the operator needs precise but simple-to-use tools to make the necessary measurements and adjustments on the caster.
If there are quality problems on the slabs, measurements on the caster are used to detect parts or equipments that cannot cause the problems, because they are working properly. With an elimination of proper working parts it is easier and much quicker to find the source of problem.
In this way poor or crab products are reduced and high yield can be achieved and payback of the measurement devices will be very short.

Acknowledgements

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