USE OF FBG OPTICAL FIBERS IN CC MOULD FOR BO DETECTION AND THERMAL EXCHANGE SUPERVISION
FIRST TRIAL IN A BROADFACE ON A STAINLESS STEEL SLAB CASTER

Etienne CASTIAUX – EBDS Engineering - Belgium
Renaud ROBERT – Aperam Châtelet - Belgium

Until recently, the temperatures in copper mould of continuous casters were done by the use of thermocouples. However, it is possible to use Bragg Grating in optical fibers (FBG) to measure temperature. This recent technology has the advantage to allow to have a lot of measuring points on one fiber, but has also disadvantages, notably related to the installation in the copper.
EBDS Engineering, a Belgian company active in sticker breakout detection and mould thermal monitoring, has studied an innovative and very simple way to install FBG fiber into a copper mould. In order to test this technology, we have equipped the broad face copper plate of APERAM Châtelet's stainless steel slab continuous caster with FBG. This allows to evaluate the potential of this type of measurement in a caster in the field of sticker breakout detection, as well as to evaluate the possibility of mapping the liquid steel flows into the mould.

KEYWORDS : CONTINUOUS CASTING, FIBER BRAGG, BREAKOUT DETECTION, THERMAL MONITORING, STEEL FLOWS

INTRODUCTION

EBDS Engineering is a Belgian company specialized in breakout detection system. Its system, since the beginning, has always comprised a mould thermal monitoring image, based on the deviations of each of the thermocouples. This thermographical image is constructed on the information given by the thermocouples installed into the mould. As the image moves down in accordance with the casting speed, and thanks to a innovative graphical construction (the image contains a realtime zone as well as an historical part), it will give the operator a nice and self-speaking animation what is happening into the mould.
Here below, as sticker represented on the Emerald BO detection program of EBDS:

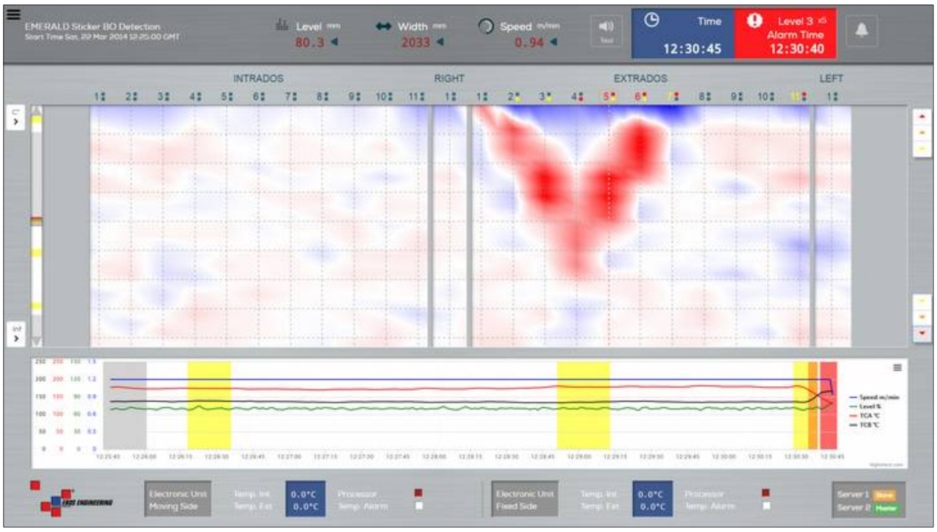

Fig.1 – Emerald BPS main screen with sticker on going

The "V" shape of the tear present onto the shell is clearly visible on the screen, and the operator can understand without doubt what is currently happening in the mould a this moment.

Even though the way of representing thermal exchanges in the mould can vary, the major limitation of this kind of image is for sure given by the number of measuring points (typically thermocouples) installed into the copper. Using thermocouples is presenting some downsides, and the mechanical modification is certainly a limiting factor for increasing the numbers of point of measurements.

Thermocouples in copper plates are presenting several disadvantages, that can be summarized as following:

- The reliability and the quality of the measurement depends on the quality of the mounting/maintenance work
- It is difficult, for mechanical issues, to increase significantly the number of measuring points. And related costs would increase also.
- Maintenance can be expensive in terms of manpower.
- The overall cost per measuring point can be quite high

For a few years now, we can hear about temperature measurement with Bragg grating filters in optical fibers. This could be a alternative solution to thermocouple measurement, but this technique has some constrains that have to be solved. In order to investigate this technology and its possible application to mould temperature monitoring, EBDS Engineering has started a partnership with the company FBGS (www.fbgs.com).
The principle of FBG can be summarized with this picture. For more detailed information, please check http://www.fbgs.com/technology/fbg-principle/ and http://www.fbgs.com/applications/temperature/

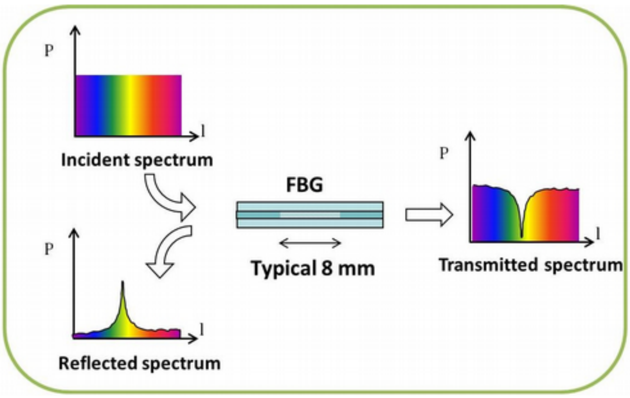

Fig.2 – Principle of FBG

A Bragg filter (which is an optical filter) is “inscribed” into the core of an optical fiber. This filter has the particularity to reflect back a precise wavelength spectrum. If the Bragg filter is exposed to heat, the reflected spectrum wavelength will deviate. It is then possible to measure this wavelength deviation and correlate it to the corresponding temperature.
The nice thing is that several Bragg filters, with different wavelength characteristics, can be inscribed along the same optical fiber. Each of these filter will be a specific temperature measuring point.
And so, with only 1 optical fiber, it is possible to measure, ALONG the fiber, quite a lot of different temperature measuring points.
EBDS Engineering has investigated the possibility to install several FBG fibers into a broadface copper plate of a slab caster, to evaluate possible replacement of the thermocouples for the BO detection system (Emerald), as well as to see if it was possible to visualize the steel flows into the mould. A partnership has been decided with APERAM Chatelet (slab caster - ferritec/austenitic/martensitic stainless steel grades) to test the development in casting conditions.

OPTICAL FIBER INSTALLATION CHOICES.

As a BO detection supplier, our interest in FBG is at first to increase the number of temperature measurements in the BO detection zone, which means in the region of 200 to 400 mm from the top of the mould.
As all phenomena are going from top to bottom, and as sticker is spreading ALSO horizontally, we consider it is more interesting, from a sticker detection point of view, to have more points on the horizontal axis, because this is where we can, with more confidence, confirm the spreading of a sticker pattern. So we are not in the philosophy to add thermocouples below, in a third row, for example, but we are pushing to have more measuring points on the usual rows.
To illustrate this, we can see here below a schematic of a classical sticker detection. The red “V” symbolizes the tear in the shell, and the blue zone the sticked part of it.

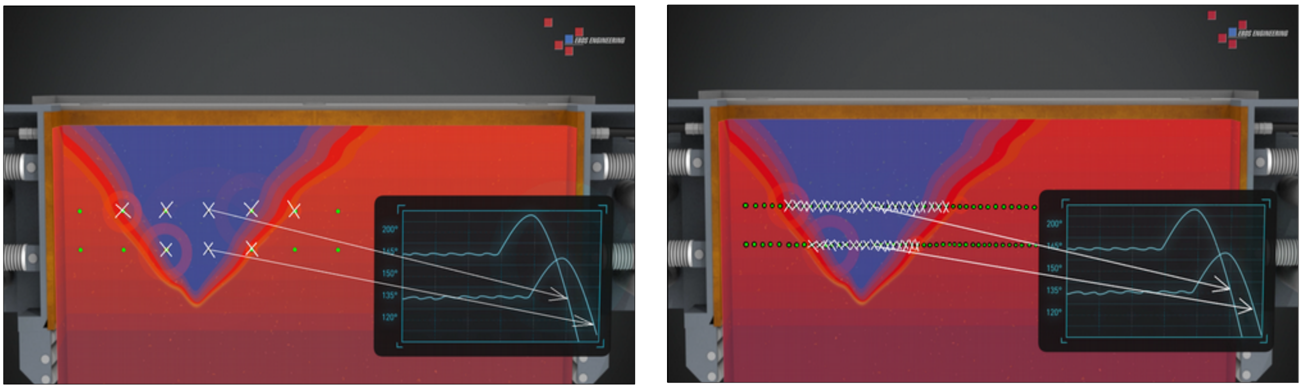

Fig.3 – Temperature measurement density – interest for BPS system

We can see that in this left picture of fig.3, a few temperatures measuring points are involved in the the sticker and should display the classical ‘up and down” pattern. We can understand that adding a row with the same density will add maybe a couple of measurements involved in the sticker.
However, on the right picture of fig.3, with an increase measurements density on the horizontal axis, we could confirmed many times more, with the “same” risk situation, the on-going sticker.

Having such density with thermocouples is not possible, because of mechanical concerns (this is probably why appeared the 3-row systems). This kind of temperature measurement density is only possible with FBG’s. But comes the issue to install them into the copper.
The main problem comes from the hole to be done to install fibers. The hole should be close to 1.5mm diameter, to install a FBG of 1mm diam. And to drill or manufacture a hole of 1.5mm of long dimensions is a challenge. But machining (or electro-eroding) holes of 1.5mm on 300mm or 400mm is possible. This is why most of the trials are done with vertically installed FBG [1],[2],[3],[4],[5].

Fig.4 – Deep drilling holes

From our point of view and target, this is not the right direction to work, because if we want to increase the density of measurement on the horizontal axis, we would need to install quite a lot of FBG fibers vertically. All the “optical cables” will arrive at the top of the copper plate, and will have to be guided/protected along the top of this plate. **This would create a reliability and cost issues.** Going into this direction is replacing a thermocouple cabling situation by an optical cabling situation. And similar downsides to the thermocouples usage will be kept, or even more increased.
The right way to increase the number of temperature measurements on the horizontal axis, for BO detection purpose, i**s to install the fiber horizontally**. But this supposes to machine, by a way or another, a small hole along the wide direction of the broadface plate.

Discussing with highly specialized machining shops showed this was possible. And this is the direction that EBDS Engineering took. Machining trials have been conducted into copper plates, and we achieve to drill on more than 2m long a suitable hole for FBG installation.

As we are willing to conduct trials in the field of BO detection, as well as for possible steel flows visualization, installing 2 fibers was not sufficient. We have so decided to install 4 optical fibers, each with 70 sensors, in the upper zone of one broadface plate.

The choosen positioning is the following:

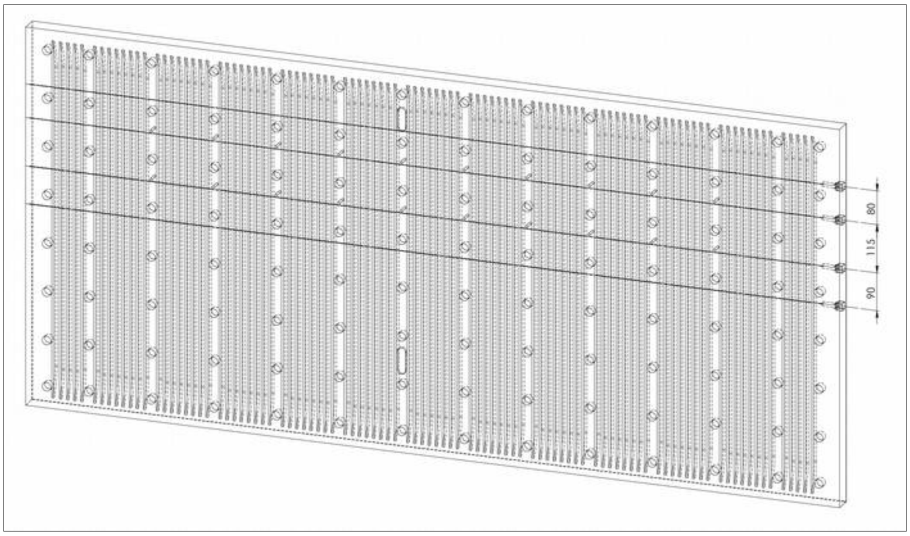

Fig. 5 - Fibers positions in the broadface

The upper fiber is at 145mm from the top of the plate. The 2 central fibers are positioned very close to the existing TC line, in order to be able to compare the both technology. The installation is 2mm deeper than existing thermocouple holes, and 15mm lower.

Fig.6 – Installation the fibers into the copper.

EBDS Engineering has choosen FBGS company, because FBGS' Draw Tower Grating® (DTG®) technology offers different unique features such as the possibility to seamlessly multiplex arrays of measurement points in short fiber lengths enabling temperature sensors with unprecedented measuring density. The Fig.7 is showing an exemplary optical spectrum comprising of 70 DTG®s customized to cover the 1460nm – 1620nm wavelength range.
Moreover, the primary fiber coating is only applied after the inscription of the DTG®s. The pristine mechanical strength of the optical fiber is consequently maintained regardless of the number of fiber Bragg gratings and their optical characteristics.
FBGS' "Ormocer®-T" coating was selected as this coating was optimized to limit unwanted, typically strain related, effects (for example humidity variations) influencing the temperature readings and overall measurement accuracy.

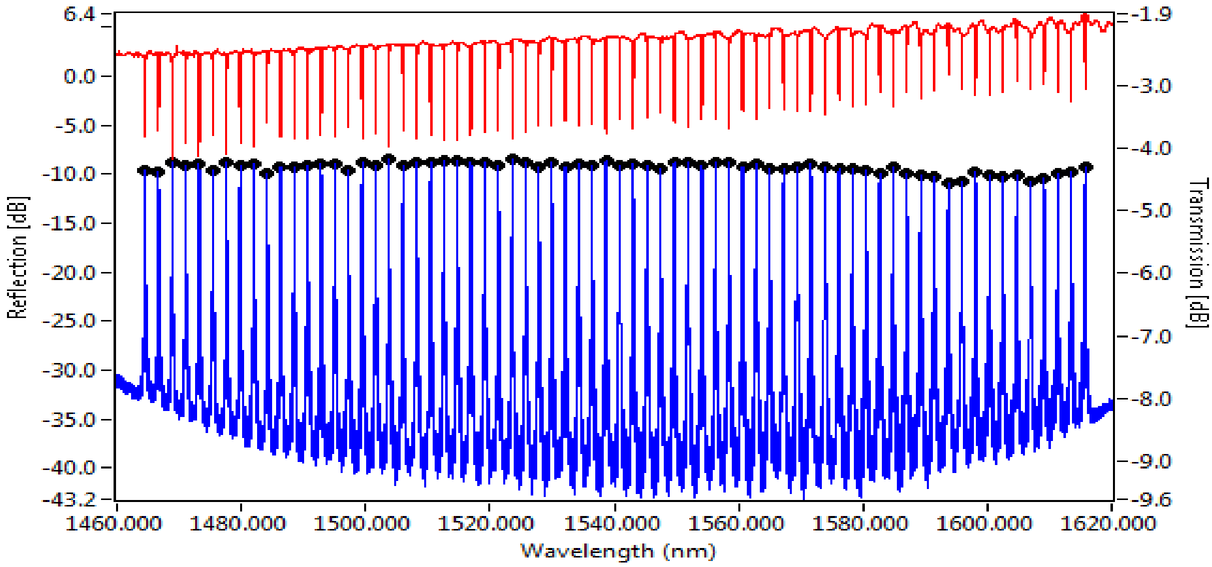

Fig.7 - Exemplary DTG® spectrum comprising of 70 measurement points multiplexed in ~2m fiber length.

The DTG®s were further stabilized (annealed) and installed in customized "TC-03" Temperature Sensors. An exemplary TC-03 sensor housing is shown in the image here below:

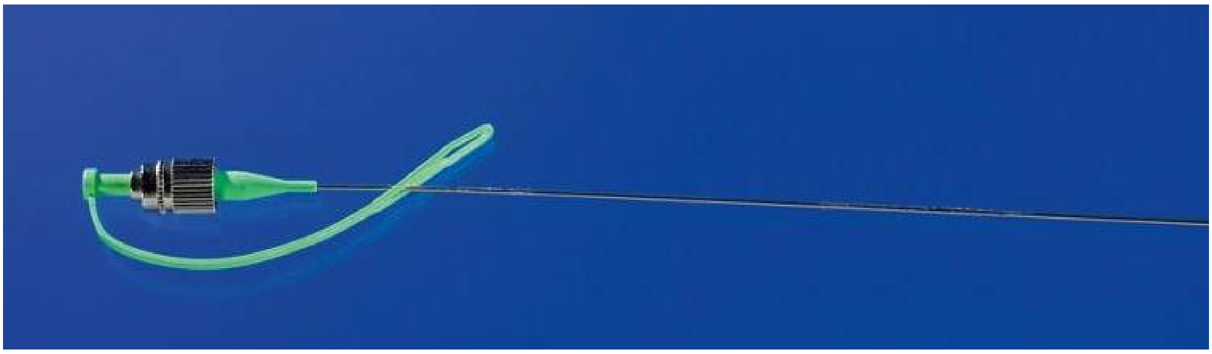

Fig.8 - Exemplary FBGS "TC-03" sensor housing.

The fibers are simply pushed into the holes (see Fig.6). Then, the optical main cable is connected, as well as a protection for connectors. The fibers installation time is less then 15 minutes.

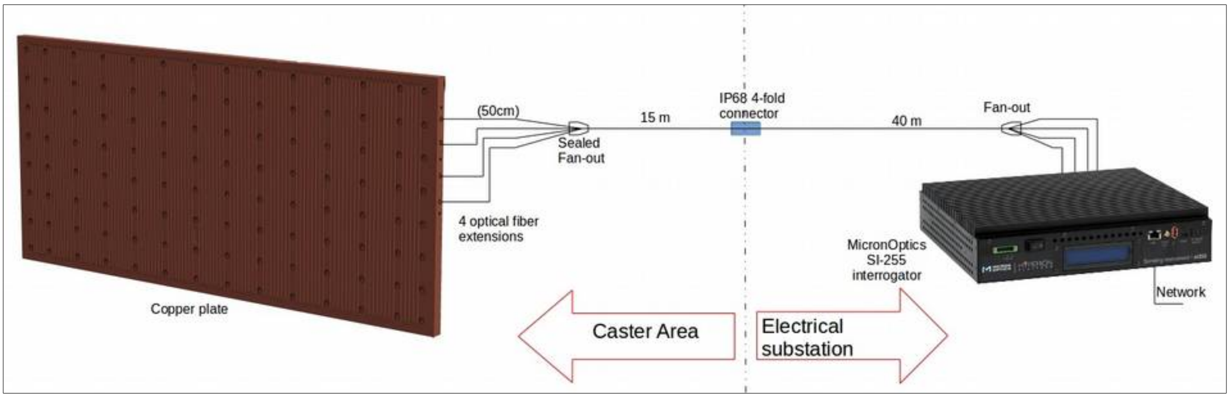

Fig.9 - The "optical layout" of the trial

STEEL FLOW VISUALIZATION.

We learned from the previous work of Tata Steel IJmuiden [1,2], that with a high density mapping of temperature measurement, it is possible to visualize quite effectively the steel flow in the mould, as well as abnormal flow behavior. For sure, even if this information - in our case - is not to tune a EMBr system, it is an information that every casting manager would like to have, in order to understand, and improve the quality of the cast products. We started our investigation with 4 fibers, but we can increase the numbers of fibers installed horizontally without additional difficulty.

The target of this first trial is to see if we can have some image that reflect what happens in the mould in terms of steel flows, and if positive, to qualify the flows dis-symmetry.
For this, we installed 4 fibers horizontally, and we developed a new software called “Emerald Flow” with a screen that displays all the temperature measurements collected from the fibers. It only displays the first top 500mm of the broadface.

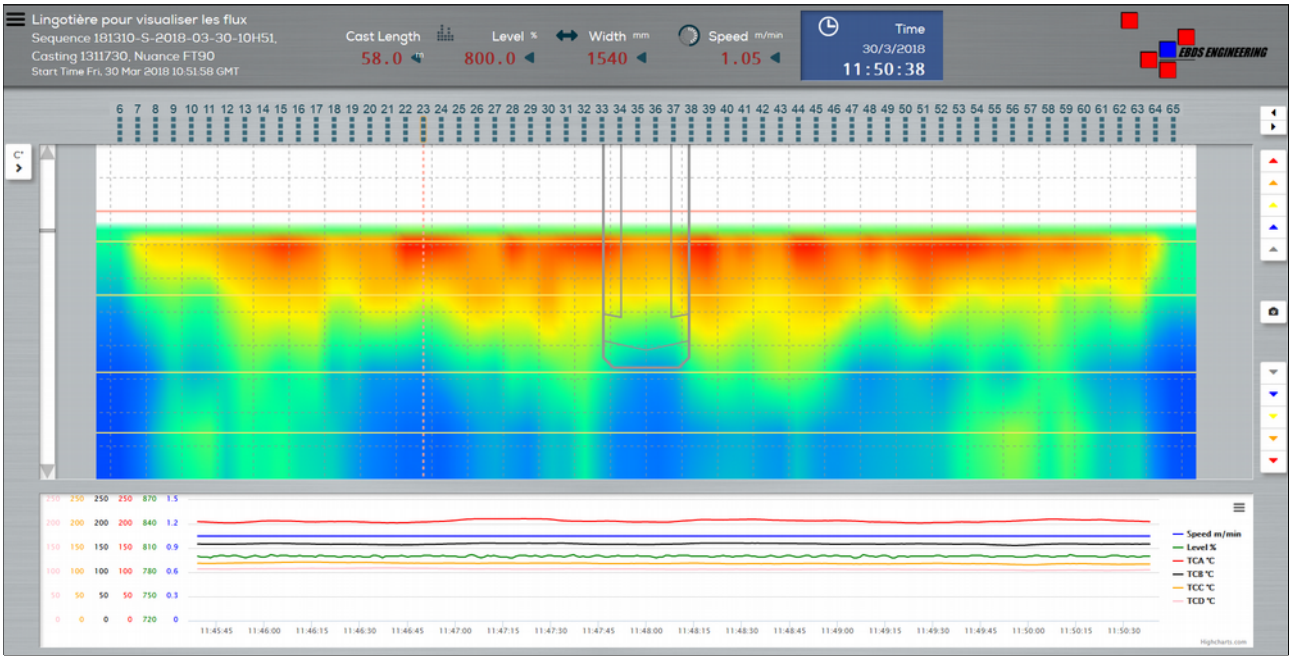

Fig.10 – Emerald FLOW operator’s screen

We can see in this image

- the full broadface (the image width changes in accordance with the current casting format);
- the SEN (its position moves in accordance with the current immersion depth)
- the mould level (red line) (its position moves in accordance with the measured mould level)
- The position of the 4 fibers (4 orange horizontal lines).
- Each dotted-line square is representing 5x5cm
- In this particular image, the casting width is set at 1540mm, and we can see that we have 59 sensors active per fiber (1 to 5, and 66 to 70 are out of current casting width range).

VISUALIZATION RESULTS

The visualization of the steel flow is quite impressive. It is obviously possible to see different “flow patterns” appearing along the sequence (see Fig. 11-12-13), as well as steady situation.
As expected, we could observe that some sequences have steady patterns situation, where other sequences have disturbed patterns situation. We can also observe that the immersion depth impact is not always visible.

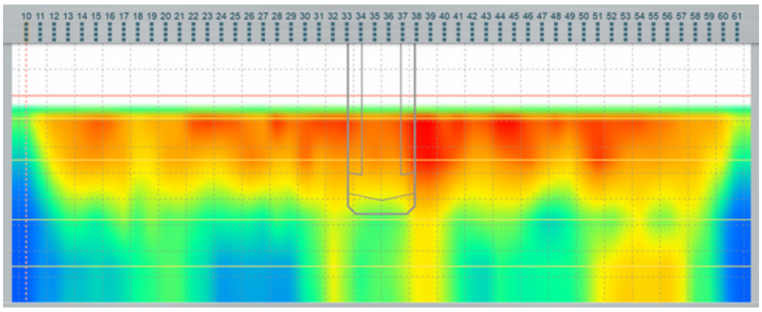

Fig.11 – Flow at 93m (05h27) – hot spot at right side

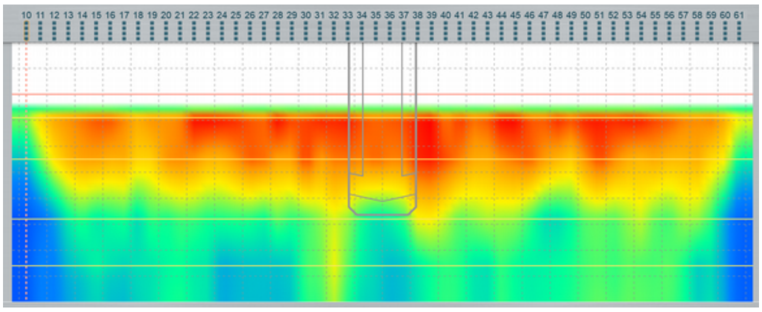

Fig.12 – Flow at 97m (05h31) – even situation

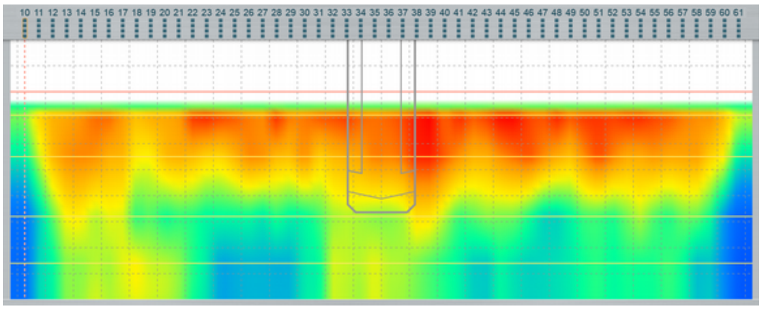

Fig.13 – Flow at 98m (05h32) – hot spot at left side

BREAKOUT DETECTION - FBG POTENTIAL

By replacing into the Emerald BPS the temperature values given by the TC, by the one given by the fibers, the density of measurement, on the horizontal axis, is increased by 6 in this particular caster: The distance between the thermocouples is 150mm, where the distance between the gratings is 25mm.

So we had to validate that the density of temperature informations that we collect from the FBG is suitable to increase the performance of the BO detection. In other words, we had to check if we were not "over-densifying" the measurements on the horizontal axis, regarding the metallurgical phenomena that are happening into the mould. Actually, it is not: the temperature curves are looking quite independent, even though the measuring points are quite close one to another (2.5cm).

The screen of the Emerald BPS has been adapted to the density of information. One can see on Fig. 14 that the "mobile face" is showing a lot of active sensors (pair #11 to pair #60, so 50 pairs active, where the fixed BF is only showing 8 pairs active (#2 to #9).

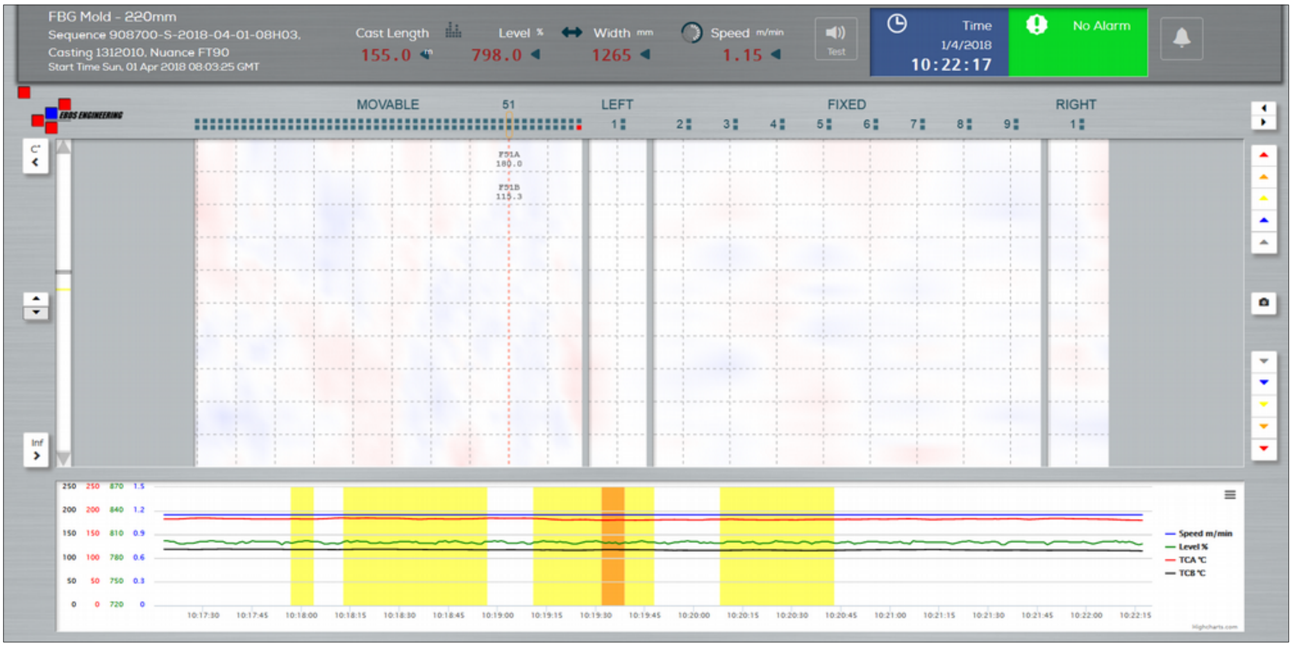

Fig.14 – Emerald BPS system with FBG's on Intrados.

Unfortunately, since we started the trial, up to the moment where we wrote this article, we did not had any sticker to detect, so we cannot confirm "in practice" our observations;

If it does validate, then we believe that we could evolve to a "one row" breakout prediction system, because the redundancy of confirmation on the horizontal axis will be much more effective, while decreasing the propagation time before slow-down (see Fig.15).

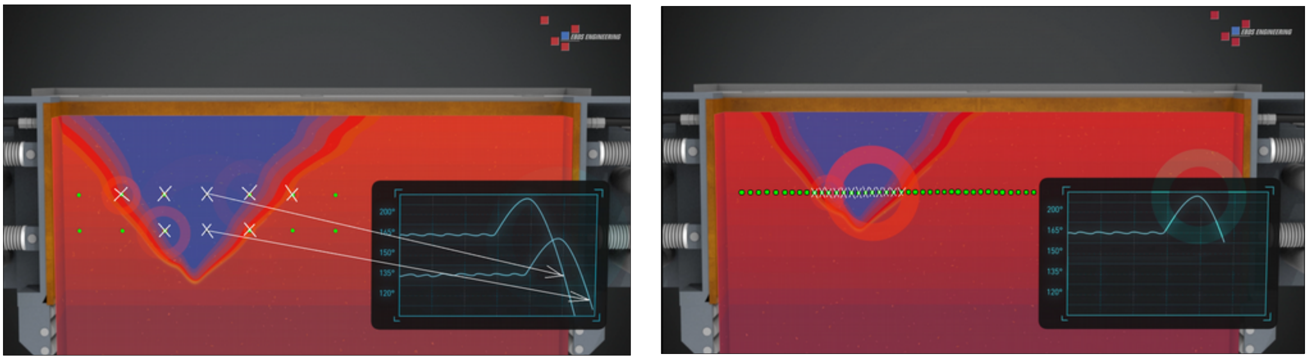
Fig.15 – 2 row BPS system with thermocouple (left), vs 1 row BPS system with FBG (right).

From the hardware point of view, the objective is also to reduce the cost of temperature measurement to the FBG only:

- Permanent sensor (stays in the plate)
- very fast installation (a few minutes)
- mounting technique independent from the water jacket
- Measurement reliability increased. No electrical connection issue, no water issue.

CONCLUSIONS.

Horizontally installed optical fibers is an effective and practical way to convert a mould from thermocouple T° measurement to Bragg Grating.
The installation of the fibers in the copper plates is very fast, and virtually eliminate all major disadvantages related to the use of thermocouples. EBDS Engineering has deposit a patent on this type of installation (Bragg grating fibers crossing the casting axis).
It is possible to visualize steel flows situation in the mould, and the BO prediction program will benefit of many more measuring points to confirm incoming stickers.
Quantification of the dis-symmetry of the flows will be the next step to feedback the flow characterization on the quality of the slab.

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