CONVERSION OF SLAB CASTING MOULD TO BRAGG GRATING OPTICAL FIBERS

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ABSTRACT:

Bragg grating optical fibers can replace, with significant advantages, the temperature measurements previously performed by thermocouples in a CC mould. Following a successful trial with a broad face equipped with 4 FBG fibers installed horizontally (4 x 70 measuring points) on a stainless slab caster, the plant has decided to convert its moulds from thermocouples to FBG temperature measurements. This paper describes, from a practical point of view, the first results of the conversion, focusing on the advantages of the FBG versus the thermocouples for the BPS system.

INTRODUCTION.

In the beginning of 2018, EBDS Engineering had the opportunity to install Bragg grating optical fibers (here after FBG) in a copper plate of a stainless slab caster (ferritic/austenitic/martensitic stainless steel grades).
With this first trial, 4 fibers were installed horizontally in the broad face, we were able to show that the fibers with the FBG could replace the thermocouples (for BO detection purpose); it was also possible, thanks to a newly developed image, to show the movements of the liquid steel in the mould [1].

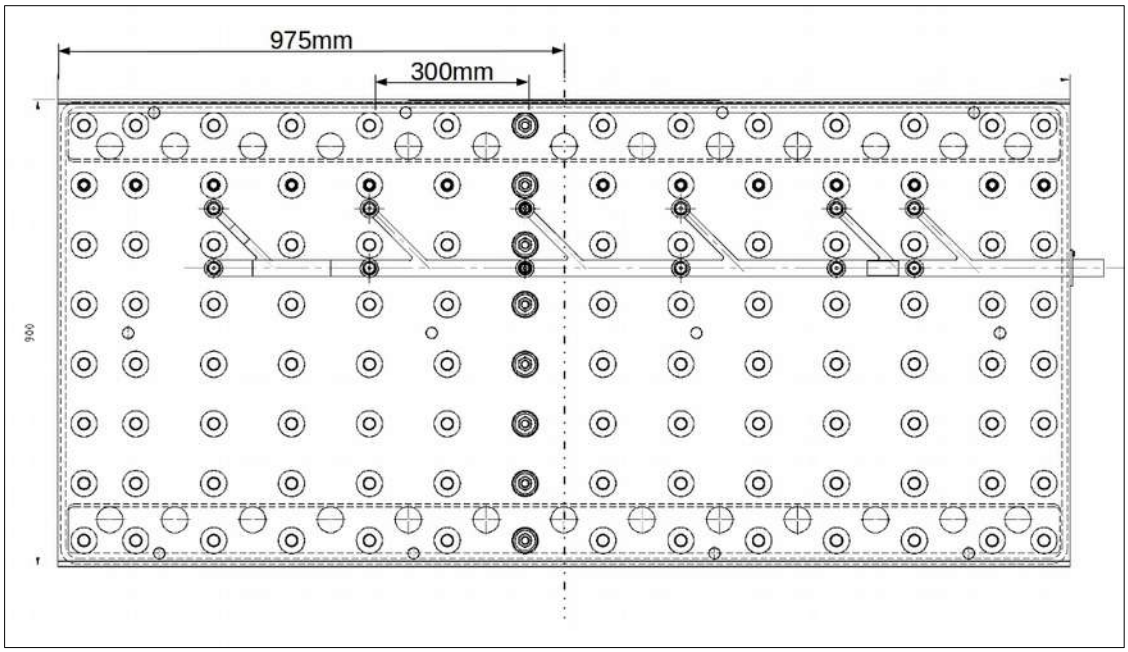
Following this successful trial, the plant has decided to progressively convert its molds to FBG optical fibers, following 2 goals:

- Reducing the cost of TC installation, while improving the BO detection temperature signals.
- Developing with EBDS Engineering a new qualification technique based on the mold steel flow movements characterization.

The present paper describe the first point of these 2 goals: The interest of replacing thermocouples with FBG for BO detection.

INITIAL SITUATION.

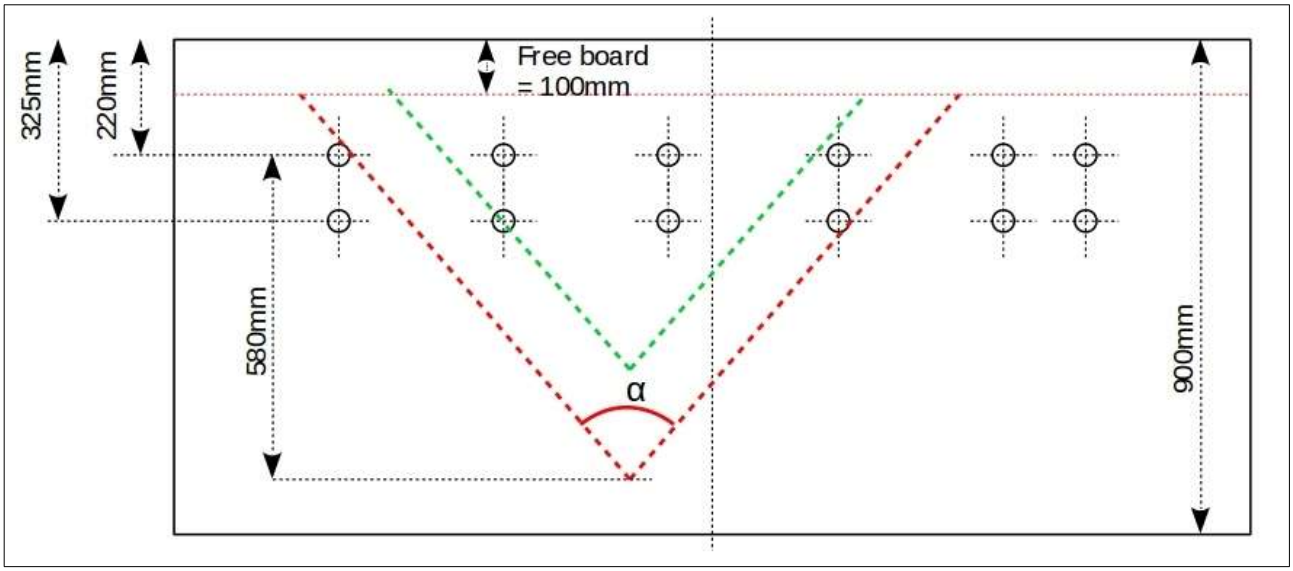
The caster was commissioned in 2006. It is a classical single strand VAI slab caster. The broad face copper plates are 1950mm wide, and were initially equipped with 6 pairs of TC per BF, and 1 pair on each narrow face.
The 6 pairs were not placed symmetrically to the center of the plates, and not distributed evenly.



Original TC lay-out – 6 pairs.

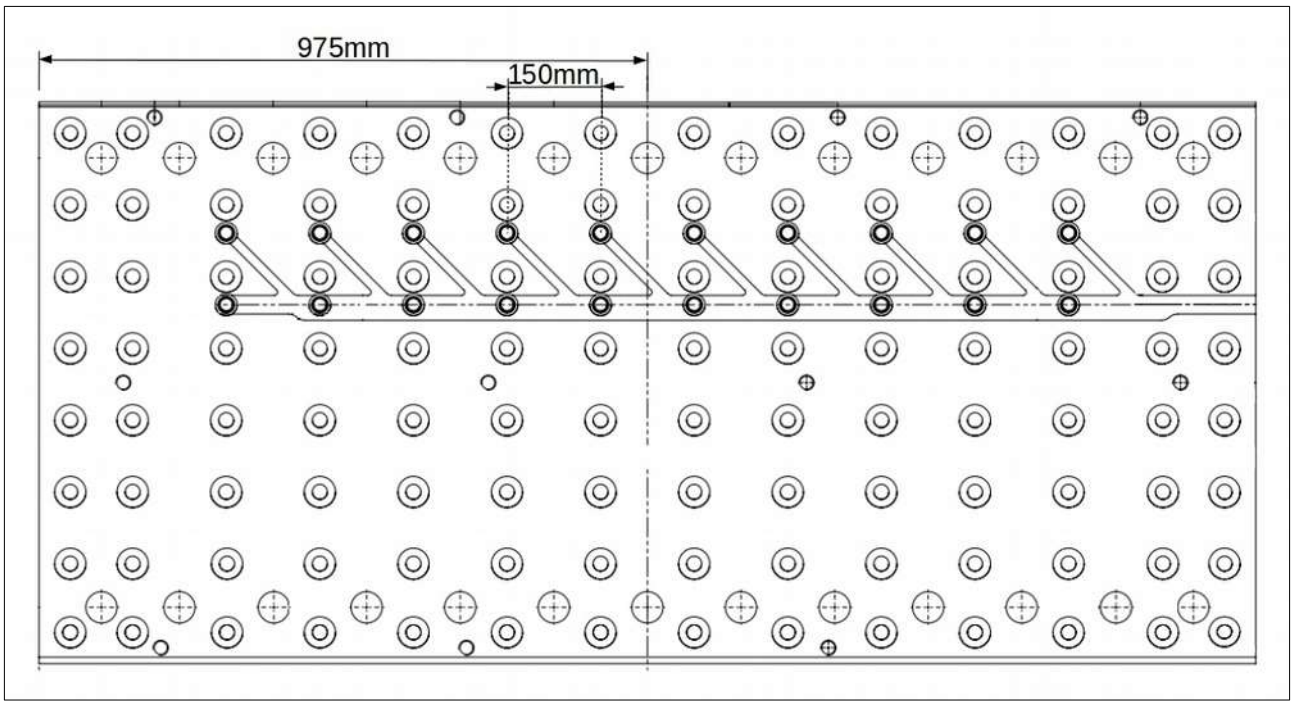
After 1 year of production, the existing VAI BPS system was replaced by the EBDS Engineering system.

From the sticker detection point of view, having 30 cm between each pairs of TC is quite big. As the BPS system is not only checking the vertical propagation of a possible sticker, but as well as a horizontal propagation, 30 cm lateral distance on one horizontal direction corresponds to 30 cm vertical displacement, provided the “V” is 90°C
Technically we consider that the sticker has to be detected at least 10cm before exiting the mould (red line here below); for sure this is already late, so the target is to detect sooner (e.g. 30 cm before bottom of the plate – green line here below) in order to be on the safe side, in case a Tc is not working,...



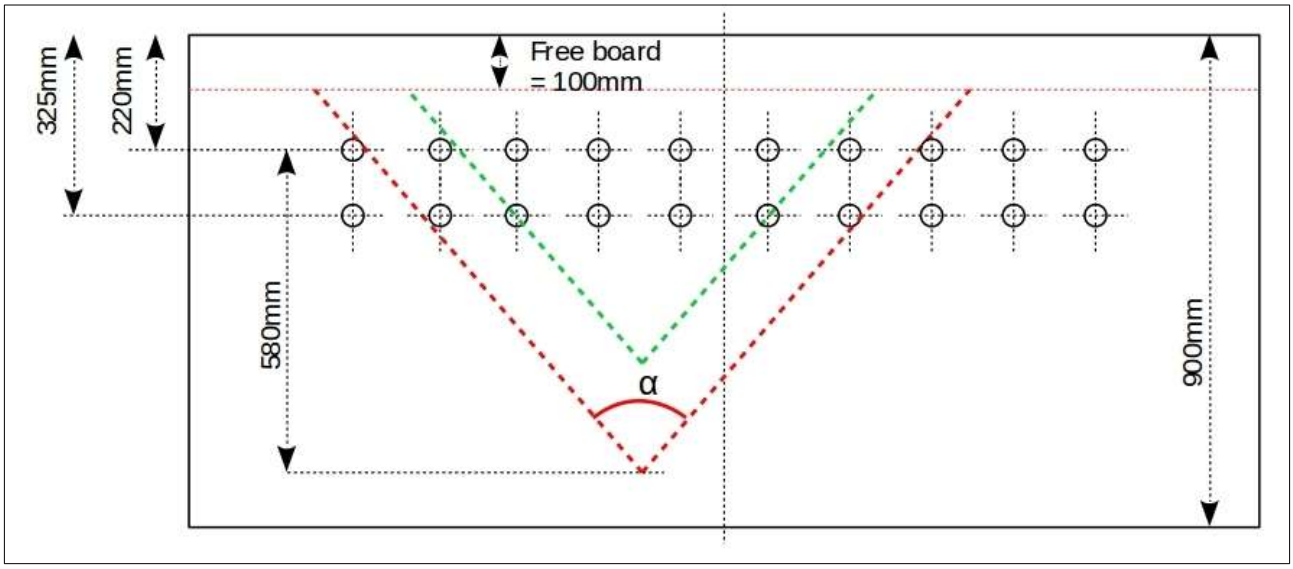
With an alpha angle close to 90°C (as on the schematic), we can see that a normal working point of the BPS will involve 4 TCs (actually 2 consecutive pairs) with the original VAI design. It means that the algorithms should not involved more than 2 consecutive pairs, otherwise, the caster would be quickly at risk if a TC is not working, or a TC is not giving a proper response to the sticker phenomena, etc...
This means that the slowdown decision has to be taken quite rapidly. And for sure, the risk for false alarms is increasing.

In the following years, the TC system of the caster has been improved under the recommendations of EBDS Engineering, by increasing their number of pairs from 6 to 10, with a symmetrical distribution vs the central axis of the mould.



Modified TC lay-out – 10 pairs.

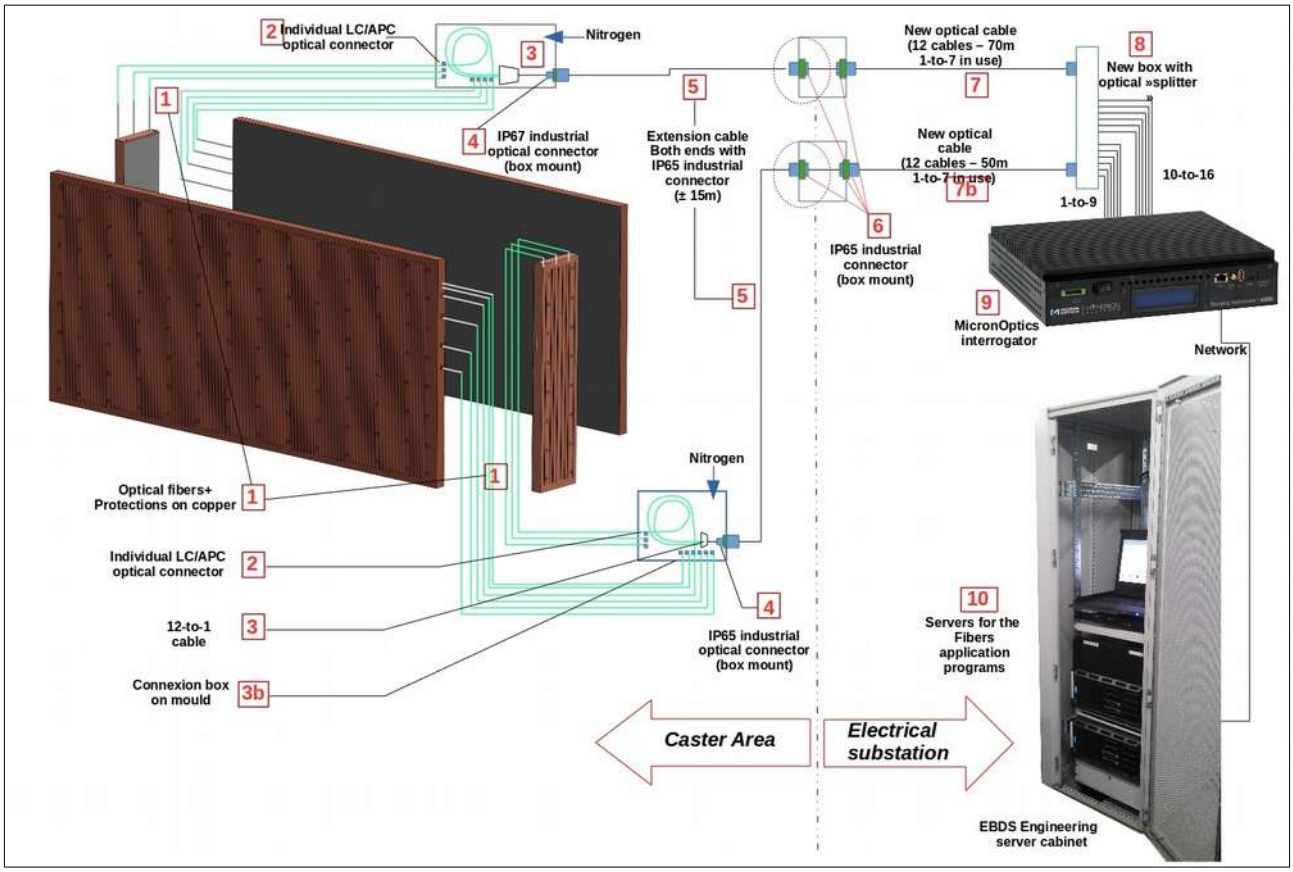
From a BPS situation point of view, the situation has been much improved:



We can see that, there are at least 1 pair added into the game, and sometimes even 1 TC more. This put the BPS system in a much better situation, as the algorithms can involve into 5 to 6 TC, without too much risk. This leads, in the case of the EBDS Engineering's EMERALD BPS system, to very few false alarms (+/- 4 per month as a average) and a very high sticker detection (>98%).

REPLACEMENT OF TC's BY FBG.

The layout of the FBG installation of the mould is the following:



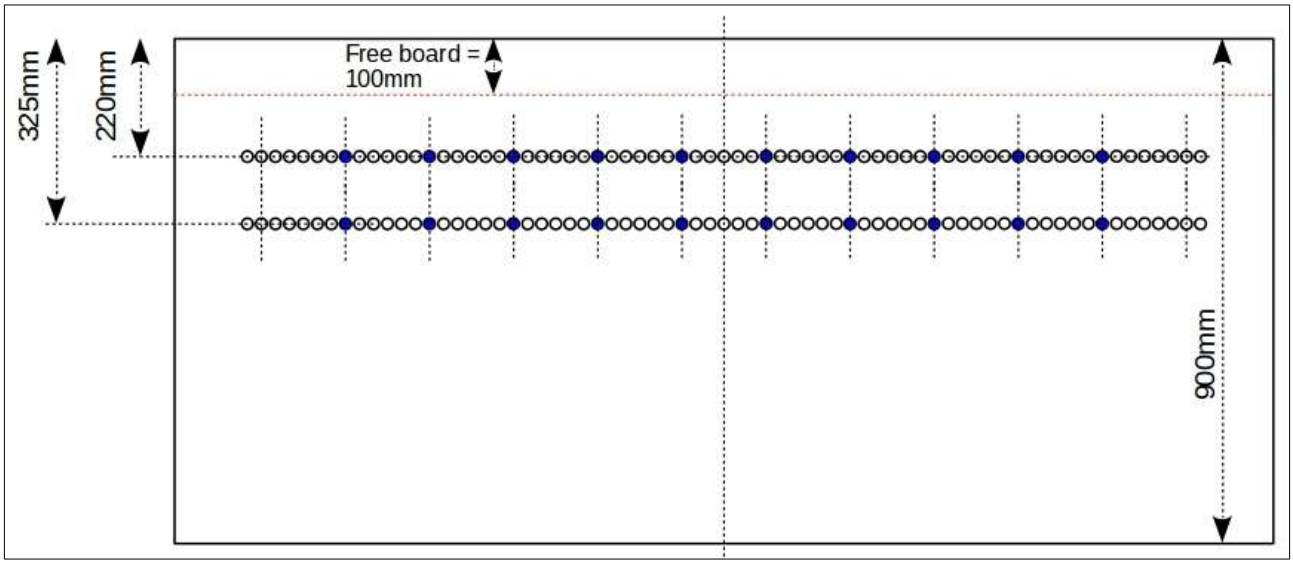
We have installed :

- **Narrow face** : 3 vertical fibers (1 in the middle - full height – 29 sensors; 2 in the corners, half height – 17 sensors each)

- **Broad face** : Intrados – 4 fibers with 70 sensors each (2.5cm between sensors)
  Extrados – 6 fibers with 70 sensors each (2.5cm between sensors)

The total numbers of sensors on the mould is 280+420+63+63 =826 sensors

Among the different FBG fibers that we have installed in the mould, we placed 2 fibers horizontally in each broad face at approximatively the same position from the top of the mould (2mm difference) than the 2 rows of TC used for the Breakout Prediction System. This is allowing to compare, online, the temperature signal given by the fiber sensors, to the thermocouple values.



The above picture shows the layout of the fibers for BPS, as well as (in blue) the position of the existing TC. We can see, as the distance from sensor to sensor is 2.5cm, that we increase the density of information by 6.

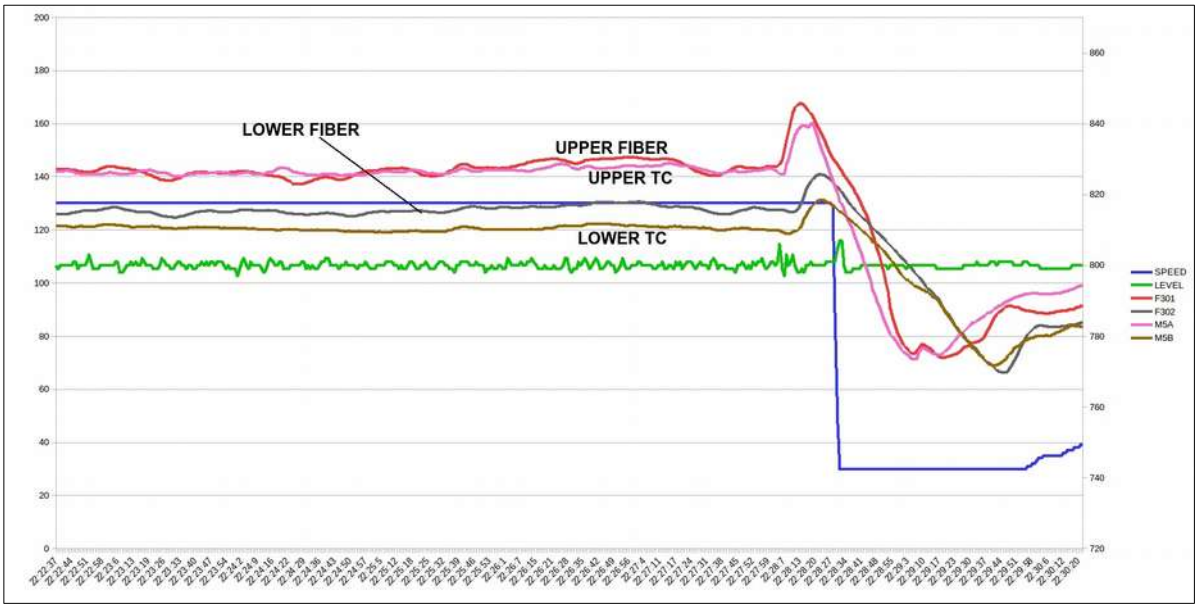
TEMPERATURE SIGNAL COMPARISON.

For the signal comparison, we shall use a sticker event, that has been recorded by the fibers and by the thermocouple system as well in parallel. It is so quite comfortable to compare the dynamic of the event in both system.

1. Temperature dynamic.

   When comparing temperature recorded by FBG sensors, close to the TC sensors, we can have a good idea of the quality of the signal given by the fibers, using the TC as the standard reference

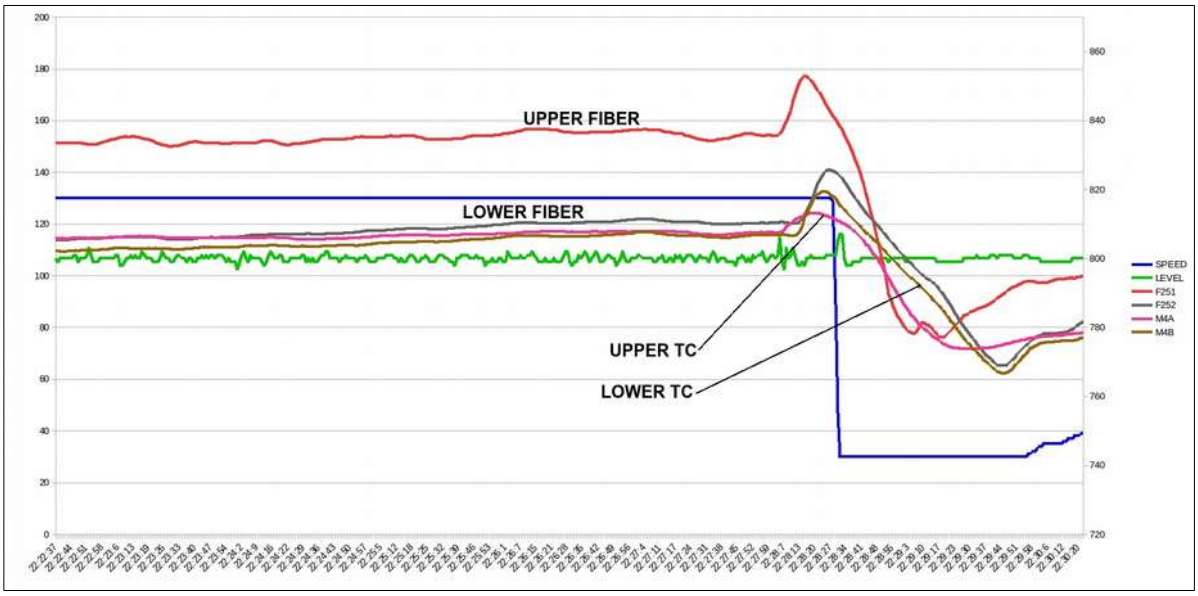
   It appears that the FBG sensors are more dynamic than the TC measurements [1], as can be seen in the following graphs:



This first graph shows the temperature recorded in the vertical axis of the mould that was at the tip of the “V” of the sticker; the different peaks are corresponding to the reaction generated by hot tear passing in front of the measuring points.

We can observe in this particular case that:

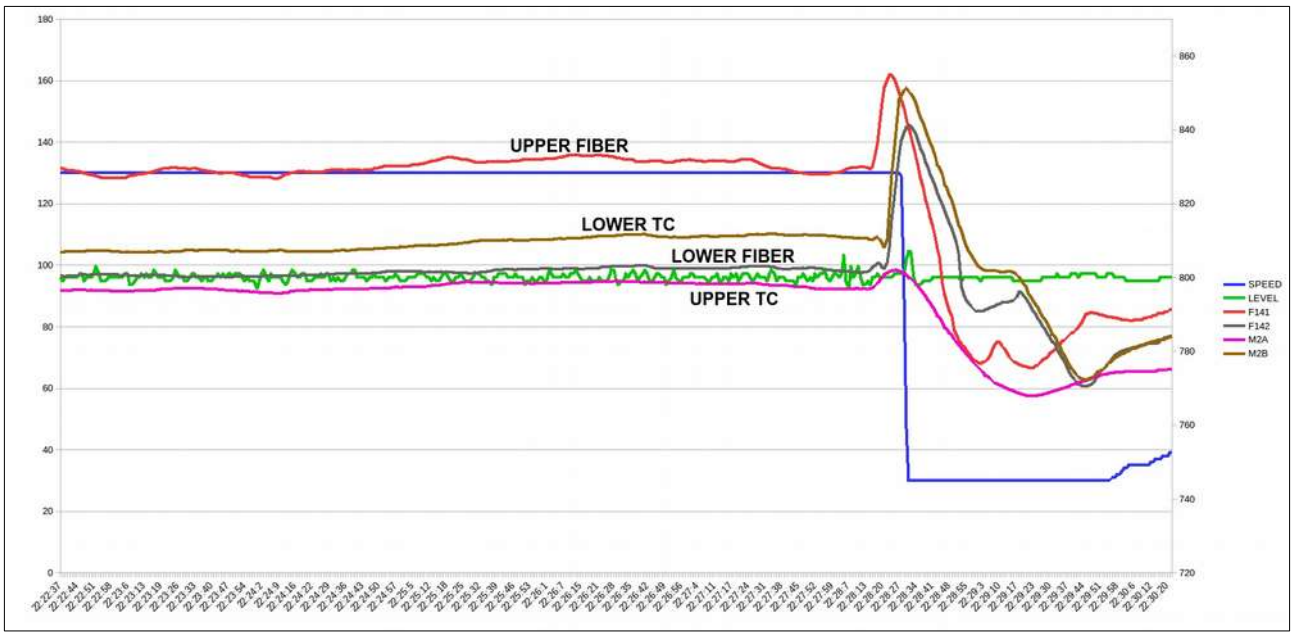
- The upper fiber measuring point and corresponding TC are giving quite similar curves in absolute T°, but the peak of the fiber is more pronounced than the TC one.
- The lower Fiber and TC are also similar in movement, but the fiber sensor records higher temperatures.



In this second “point-to-point” comparison, we are looking at the first pair of TC, on the left of the former one, and their corresponding fibers measurements.

We can observer in this particular case that:

- The upper fiber measuring point is ok, where the corresponding TC are giving very low and amortized signal.
- The lower Fiber and TC are similar in movement, but the fiber sensor records higher temperatures.



This third comparison corresponds to the second pair of TC on the left (from the first analysed). Again here, we can see a good response on upper fiber sensor, but not from the upper TC signal. Lower TC and corresponding lower FBG sensor are doing really similar.

We can do this comparison on all TC records, vs all fiber records, and we must reckon that the TC's dynamic is always equal or lower than the fibers response. We can notice also that when the dynamic is lower on the TC, most of the time, the T° level is also lower.

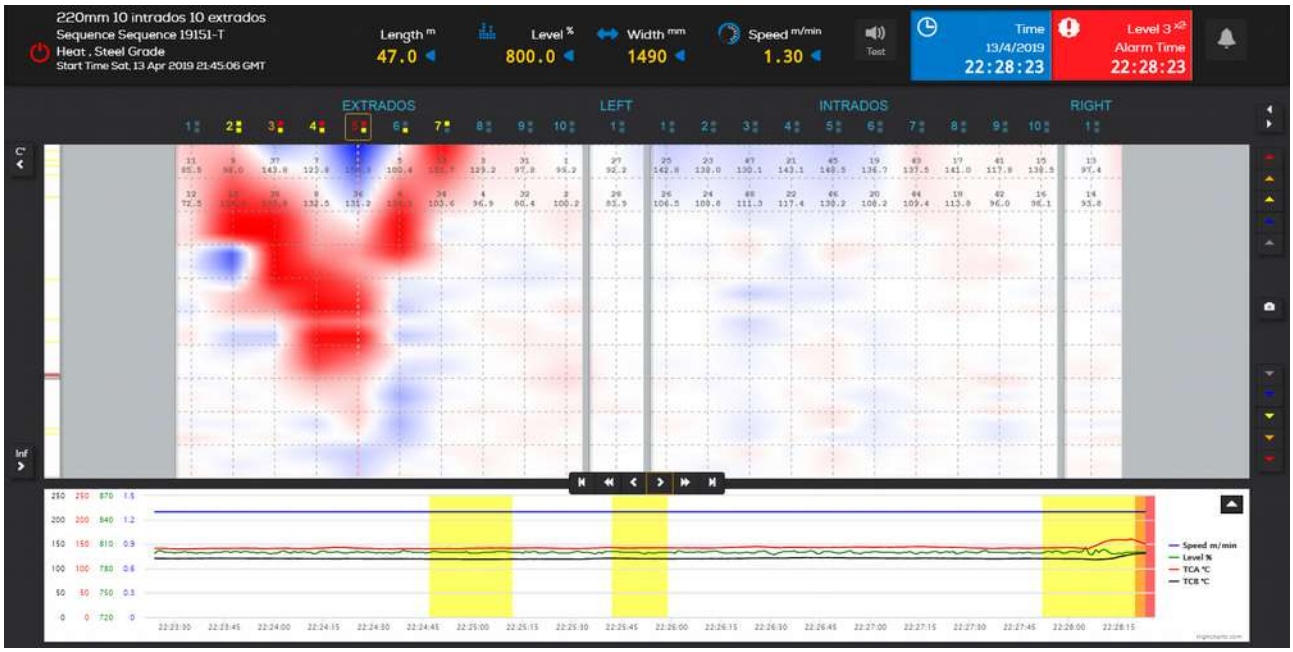
There are no fiber measuring points impacted by water infiltrations, where in this particular event, at least 1 TC was blocked at 100°C in water.

So at the end of the day, the fiber response and measurement reliability is definitely high than TC response.

2. Thermographical Image outlook

The sticking event is, in both system (Fiber/TC) well visible, thanks to the screen of the Emerald system. The screen is designed so that real-time and history are combined in order to let appear dynamically, on the thermographical area, an image of what is traveling down the mould.

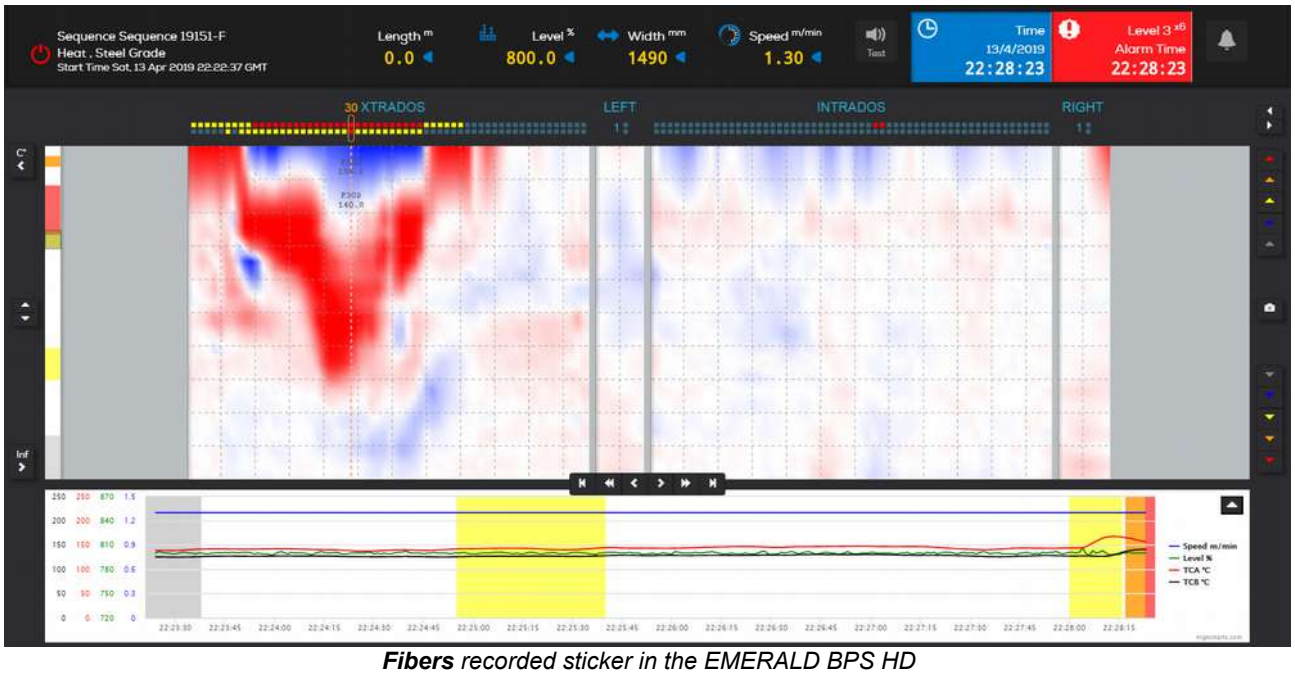
In the case of the TC recorded data's, the image is as on the next picture, at the moment of the BO alarm:



Thermocouple *recorded sticker in the EMERALD BPS*

It is clearly visible that a “V” shape – corresponding to the tear of the sticker in the shell - is propagating on the Extrados (Fixed) side.

The same event, at the same moment, recorded with the fiber sensors, is showing a similar image.

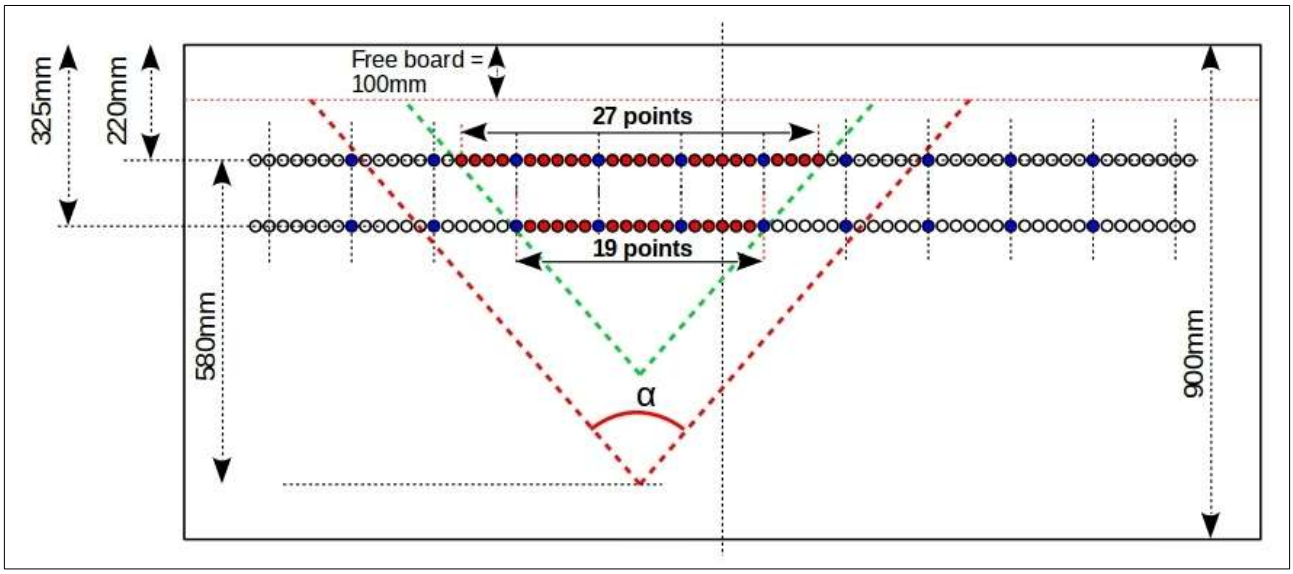


Fibers *recorded sticker in the EMERALD BPS HD*

Even though both screen are similar, one must please keep in mind that, at this precise moment, the red “V” zone in the image created with the TC information is built by 12 TC’s (6 pairs). There is a strong graphic interpolation between the pairs to achieve the nice red “V” shape, as we have one measuring point every 15 cm on the horizontal axis.
In the case of the fiber recorded sticker, the same red “V” shape is built, at the moment of the printscreen, with 68 measurements. So there is almost no graphical interpolation, as all the measuring points are close one to the other (2.5cm on the horizontal axis).
It is also visible the thermographical screen that, as the measuring resolution is much higher, a more precise pattern of the temperature deviations is visible.

BPS STRATEGY EVOLUTION.

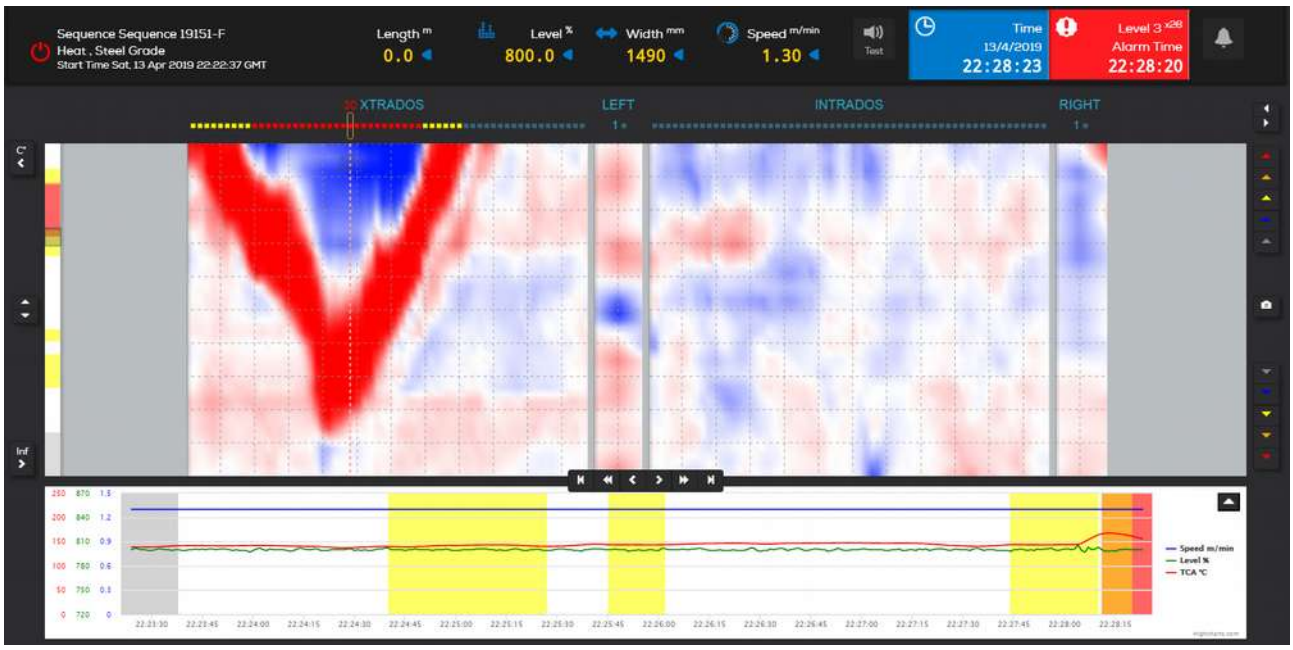
The nice thing with the fiber measurements is that one can choose the resolution of the system. In fact, as, in our case, the fiber is designed to be installed horizontally, the number of sensors that will be inscribed in the fiber will define the “resolution “ of the BPS system.



Coming back to the schematic of the number of measurements involved in a sticker detection, we can see that, moving from TC system to a horizontally installed fiber, the number of impacted measuring point can be incredibly increased while staying in the safe zone. In the upper picture, we can see that we move from 8 TC measures involved at a precise moment in the BPS detection (blue points) to 46 points with the fibers.

As the sticker is the only phenomena that will propagate horizontally in the mould (where all other phenomena are moving from top to bottom only), it is possible, with a sufficient density of measurements on the horizontal axis, to change completely the philosophy of the calculations, mostly based on the horizontal propagation. And so, one horizontal fiber could be enough for BPS system, provided the numbers of FBG is high enough.

To demonstrate this, we re-processed the fiber data’s into our Emerald BPS system, only using a “one fiber row” configuration. As can be seen on the next picture, the graphical result is the same, or even better:

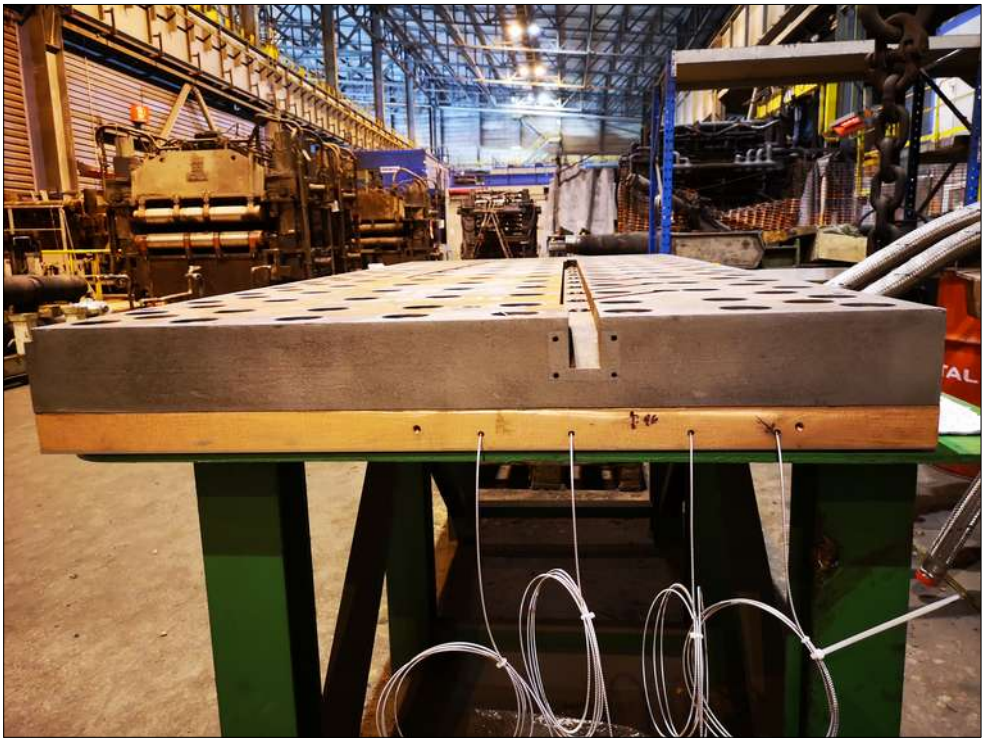


This shows that, instead of going into adding a third row of TC measurements, or more (which will involve only a few more measuring point into the detection – actually the lower and narrow part of the “V”-) like all the OEM’s are recommending, it is much more interesting to increase the numbers of measuring points on the horizontal axis. For sure, this can only be done “economically” if the fibers are horizontally installed.

EBDS Engineering is currently adapting its calculation engine to take advantage of a lot of measurements on the horizontal axis. This will still improve the performance of the its EMERLAD BPS system.

ON THE MOULD FIBER INSTALLATION.

EBDS Engineering has developed a easy way to install fibers in moulds. :



The picture above shows 4 fibers mounted horizontally into a broad face. The fibers are simply slided in the holes, and can be removed and replaced in a few seconds, at the mould workshop.

A simple stainless steel support/protection is mounted to protect the fibers.

All fibers are gathered at the workshop into a connection box, on the side of the mould; this box is connected to the caster with a IP65 quick coupling industrial optical plug.

Conclusions

The use of FBG optical fibers to measure temperature in copper plates of CC mould is giving out standing results, compared to the conventional thermocouple method. The FBG measurements are more dynamic and not sensitive to water; when placed horizontally in the broad face, the fiber allows a large numbers of temperature measurement in an horizontal line, which is perfect for breakout prediction algorithms.
Moreover the maintenance cost can be very effective.
If the density of temperature measuring points is high enough, a well designed BPS system could use only a single horizontal fiber to detect stickers, even more safely then 2 rows of thermocouples.
And last but not least, simply adding 2 more fibers in one BF will give the possibility to visualize the flow in the mould, with all the benefits coming from this technology

References

[1] 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 & Renaud ROBERT - 7th International Congress on Science and Technology of Steelmaking (ICS2018) – Venezia - Italy.