SIMPLE, INNOVATIVE FBG OPTICAL FIBER INSTALLATION IN COPPER PLATES FOR CONTINUOUS CASTER.

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Installing optical fiber in CC copper plates is becoming a must in temperature measurement. However the cost of the installation of the fibers is prohibitive, especially if installed vertically. EBDS Engineering has already developed a drilling technique to install fibers horizontally, which is already significantly cheaper than the vertical method: less fibers needed, less holes and extremely simple installation.
In order to simplify furthermore the plate preparation, as well as its associated costs, EBDS Engineering and CSN Carl Schreiber have developed a new method to replace the drilling: groove machining and re-filling with an copper insert.
A groove is made horizontally in the copper plate, and a corresponding copper insert is then placed to refill the slot; the insert is designed to leave a longitudinal space so that fibers can be introduced later on.
Two methods have been pursued to set the insert into the slot, so that the interface between the slot and the insert is not disturbing the heat extraction requested to the plate: Electron beam welding the insert after its placement, or using a specific profile for the groove and insert so that, once introduced in the groove, the insert is totally part of the plate. This paper will describe the second method, as well as the first results in casting conditions.

1) Introduction.

Temperature measurements in copper plates are done, because of the need of running a BPS system. This is the original target of thermocouple installation.

Typically, there are 2 rows of thermocouples, and the space between each TC column is around 150 to 250mm, where the distance separating the 2 rows is typically from 100mm to 150mm. So we have from 8 to 15 thermocouples in each row, depending of the size of the mold.
To install these thermocouples, there are mechanical constrains, due to the bolting of the plate to the water jacket; So it is not easy to increase the density of temperature measurement. To get more temprature readings, most of the OEM went from 2 rows to 3 rows, but this is not solving the real need for a BPS system: an high horizontal density of temperature measuring points (see [1]).

In fact, the sticker is the only phenomena that is spreading sideways in the mould. The “sticker signature” that can be found on a termocouple measurement while a sticker is passing in front should be preferably confirmed on the side TCs, than on the lower TC, because:

- everything goes down into a casting mold. So you can confirm a lot of “shit”, simply looking from top to bottom displacement.
- there are 2 thermocouples on the side of each TC showing the sticker signature, when there is only one below the concerned temperature measurement.

In the beginning of the 2010’s, the FGB fibers were being looked at, as a possible replacement for the thermocouples, because of the possiblity to increase the density of measurement. In fact, along a optical fiber, it is possible to install quite a lot of FBG filters, that will refect as many local temperature.
But there is a serious difference versus the thermocouple: all optical “sensors” are being placed along the fiber. This means that the fiber has to be placed parallely to the broadface, where a single thermocouple is placed typically perpendiculary to a broaddface.

As a consequence of this, every OEM that looked at this opportunity of fiber installation have chosen to drill vertically in the thickness of the broadface, from the top, and they are inserting fibers from top to bottom [2] [3] [4], for mainly these 2 reasons.

- The hole to be "drilled" has to be of a very small diameter, so the length that can be achieved has limitation; so horizontal deep drilling was not considered.
- Some OEM were already used to drill vertical holes to place thermocouples in the past (even if they were of bigger diameter).

The hole can be done by deepdrilling or by electro-erosion, but at the end of the day, all OEM choosed to go vertical.

When EBDS Engineering started to get involved in the FBG installation, as a possible replacement of thermocouples, it has been decided to go horizontal, mainly for 2 reasons:

- With horizontally installed fibers, you can get a lot of measurement on the horizontal axis with only 1 fiber, but if you go vertical, you can't, unless by drilling a lot of holes and installing a lot of fibers. And EBDS engineering's target was to get a lot of temperature on an horizontal axis.
- The exit of the fiber, when installed horizontally, is done in a safe, harmless location, but when all fibers are coming from the top of the plate, it is a nightmare to protect them and bring the signal out of the mold.

Only with these 2 considerations, vertical installation was not an option, and EBDS Engineering started to work on the horizontal installation.

2) Horizontal installation with the "groove / insert" technique.

The target of EBDS Engineering is to provide a simple, fast, industrial and cost-effective optical fiber installation.

- Simple: it means that an technician from the caster maintenance team should be able to install at the mold workshop the fiber himselfas well as the connectors, etc.... No need to send the plates back to the OEM when there is an issue (whatever it is) with the fibers.

- Fast: Installing a fiber should not take more than a minute.

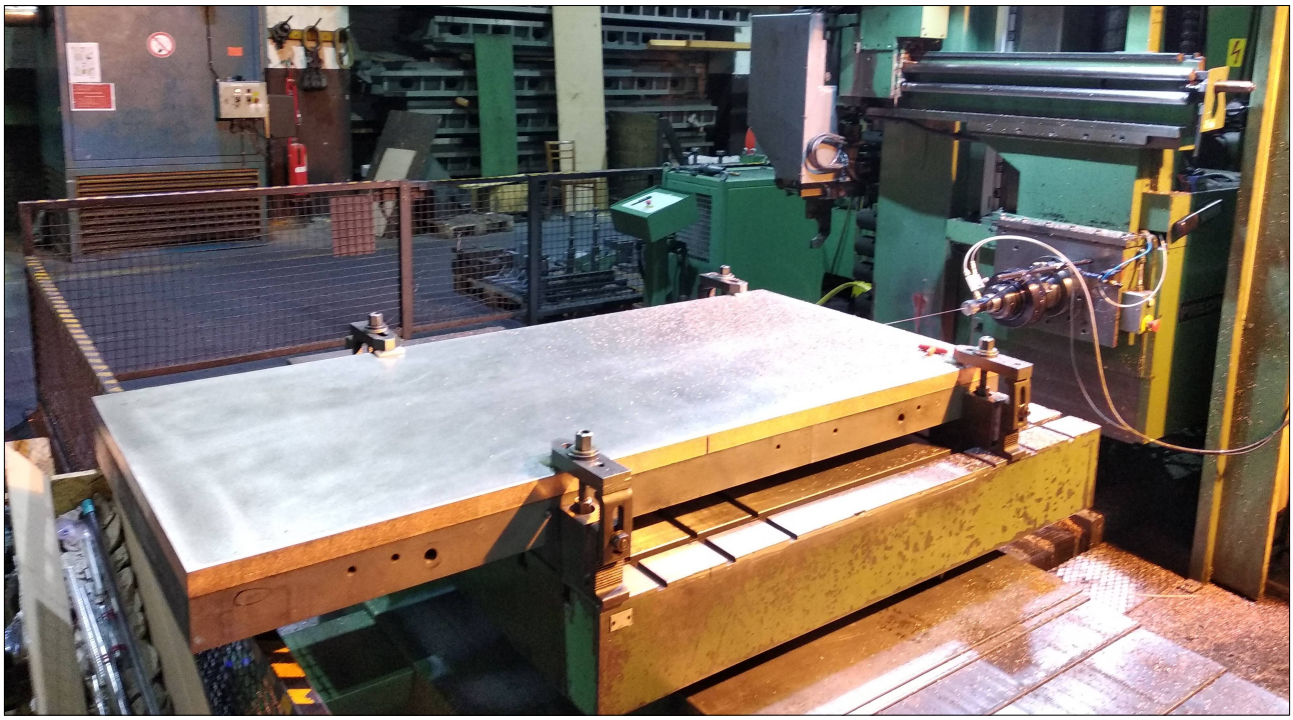
- Industrial: It is mandatory that the full layout must be industrial: this means that the operator should be able to maintain the whole system without particular assistance from OEM. Moreover, the layout must be simple.

- Cost-effective: the cost of using the fibers and their installation must be a fraction of the cost of using a thermocouple layout.

EBDS Engineering has achieved all these 3 first goals when using horizontal deepdrilling:

Only a few fibers are needed to replace the BPS system, the montage is taking some minutes, all fibers are exchangeable, the protection needed are really easy to set in place and is inexpensive.

The "weak" point was the preparation of the plate: deepdrilling holes along the broadface on the horizontal axis is taking time, and only a few shop world wide can perform this high precision operation.

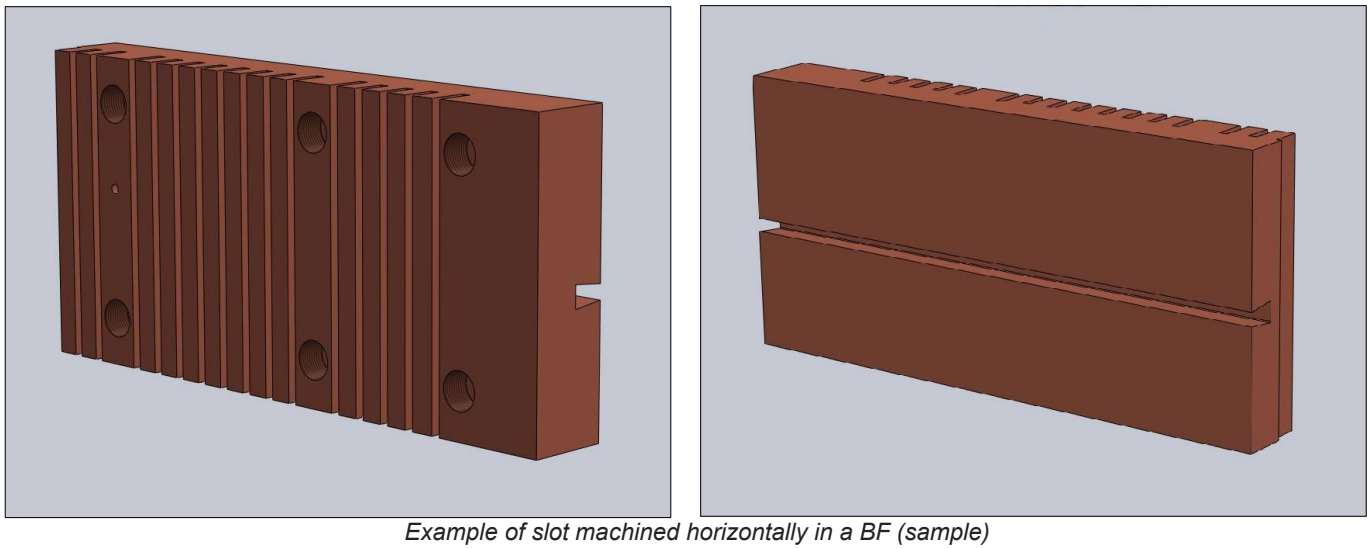


Deep drilling of a BF copper plate (1950 mm wide)

We solved this problem by abandonning the deep drilling technique and switching to our self-developed slot/insert technique.

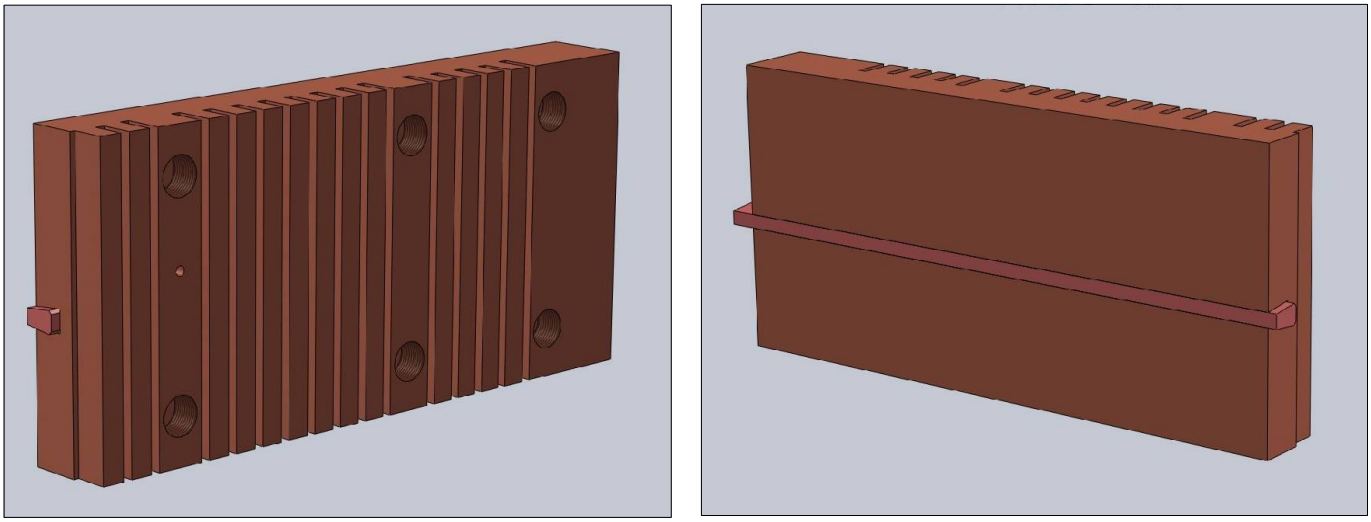
The target is to create a very horizontal tiny space in the copper plate, where the fiber can be later on installed. To do so,

1. A dovetail groove is machined on the hot face of the broadface plate:



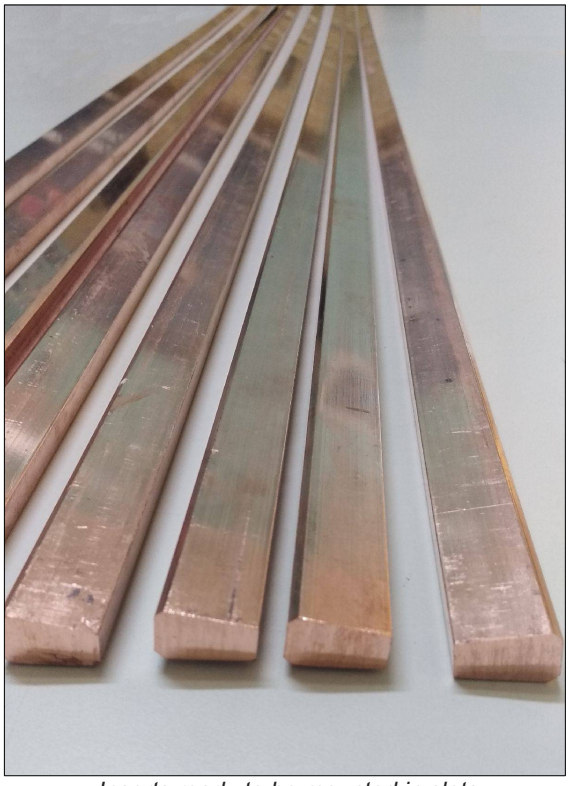
Example of slot machined horizontally in a BF (sample)

2. An insert, made of the same material as the plate, is placed into the goove:



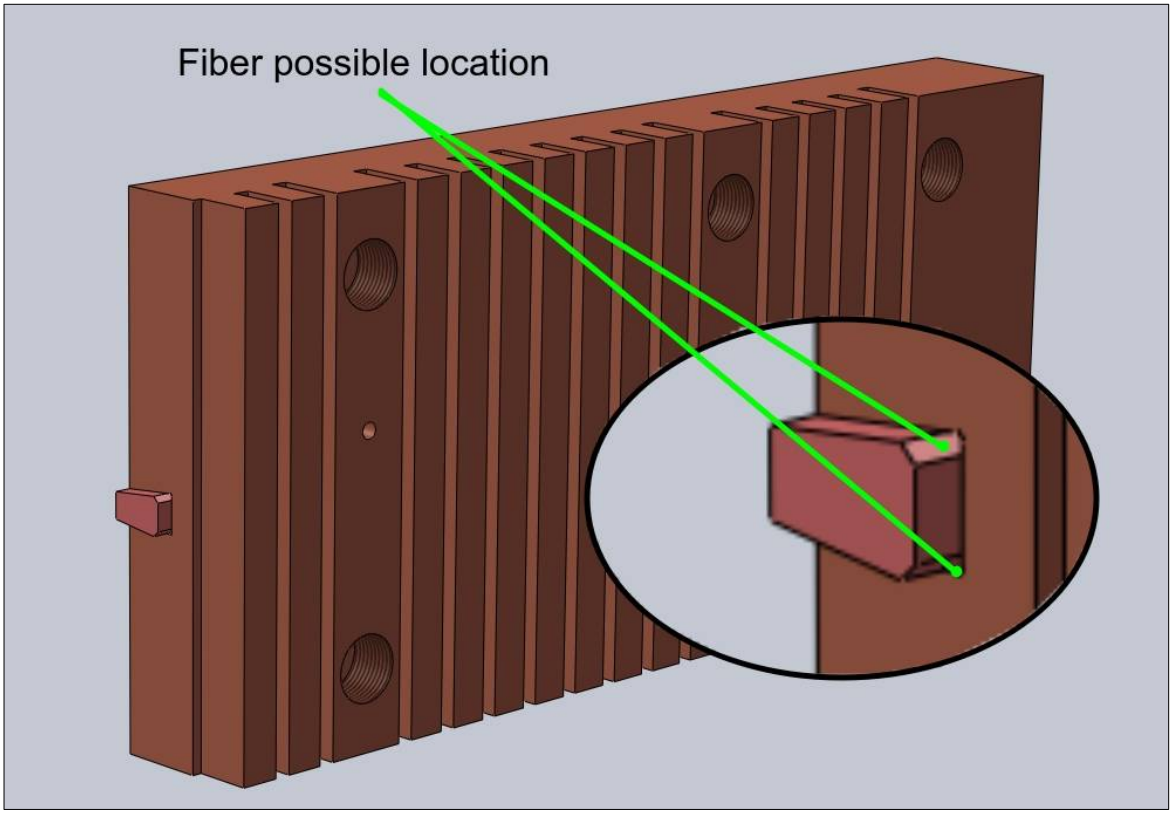
Example of insert placed into a slot in a BF (sample)

The insert is placed inside the groove in a extremely tight manner, so that heat transfer is insured without any issue.
This insert will remain in the plate its whole life. The plate can be machined as before, and the lifetime of the plate will remain same as before.

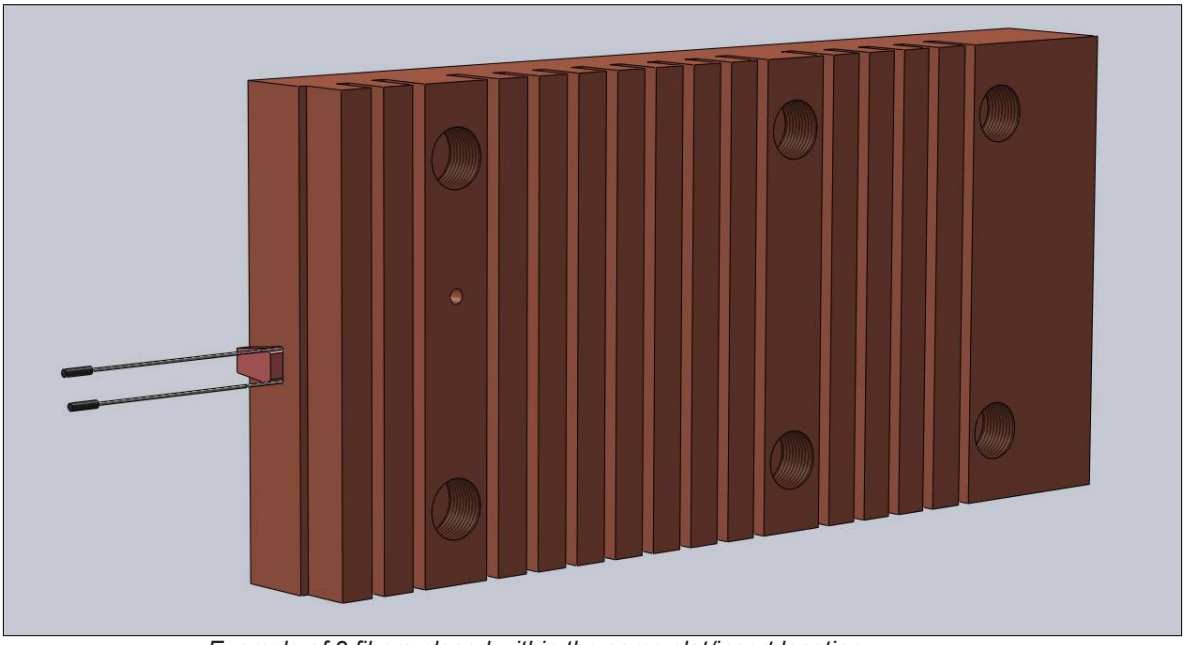


Inserts ready to be mounted in slots.

3. A room as been foreseen, with the insert profile, to allow a fiber to be installed



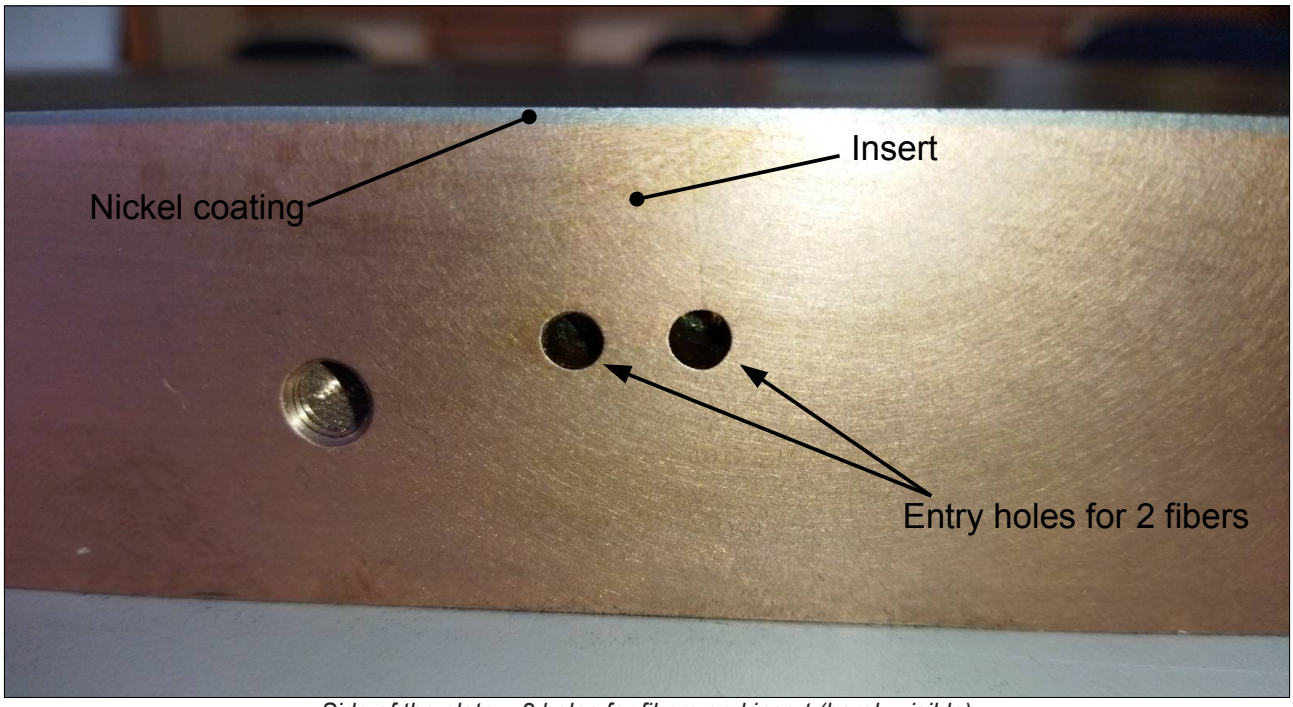
4. 2 fibers can be installed within the same insert location



Example of 2 fibers placed within the same slot/insert location.

This preparation technique of the plate, to allow fiber installation on the BF does not need any welding or any other additional operation to fix the insert into place. There is no limitation is width of plate, where deepdrilling could be limited and the cost of this plate preparation is reduced to the mininum.

The following picture shows the result of the modification on a copper plate: one can see the insert (barely visible) as well as the 2 entry holes where the fibers will be inserted.

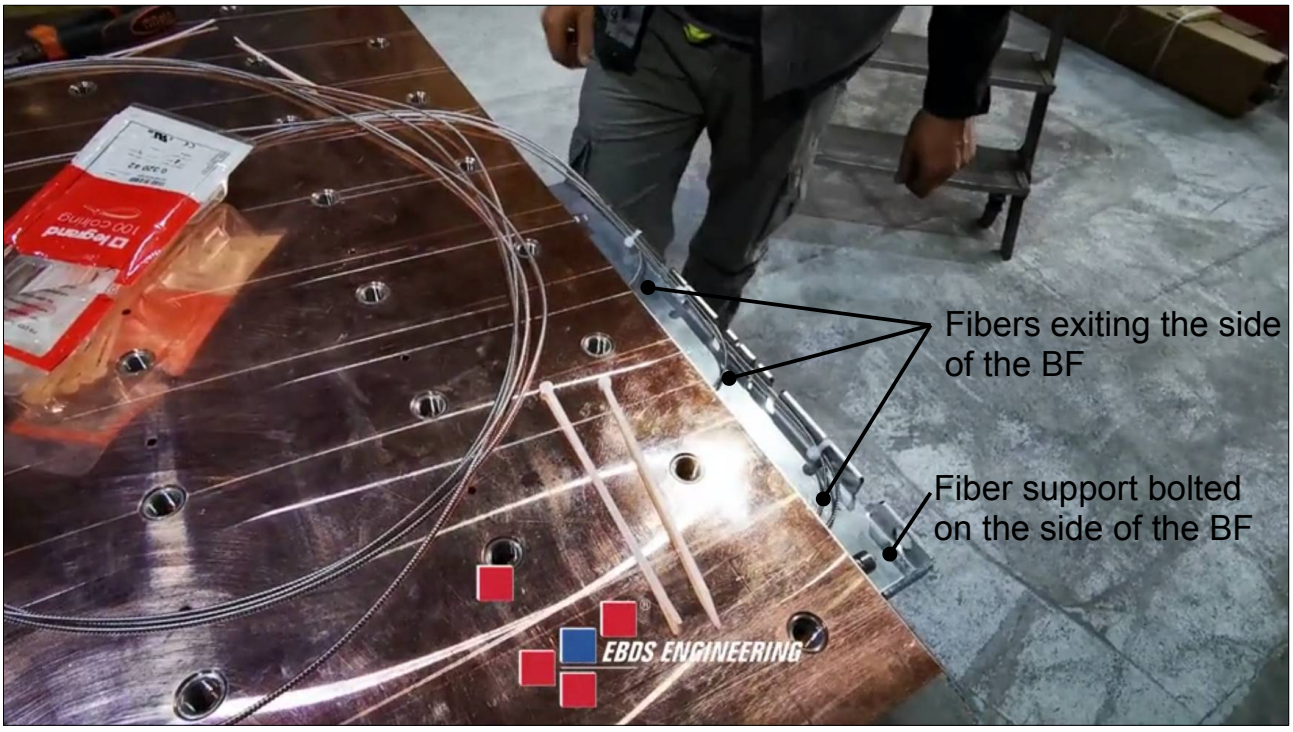


Side of the plate – 2 holes for fibers and insert (barely visible)

The entrance of the holes for the fibers are made of a wider diameter, to allow the junction between the fiber cappillary (1mm stainless steel tube) and the flexible protection hose to be inserted and protected.

The nickel coating is placed over the insert, after machining the plate. So the insert is not visible from the broad face surface, as it is behind the nickel layer.

When mounted, the fibers and the fiber support are as shown on the following picture:

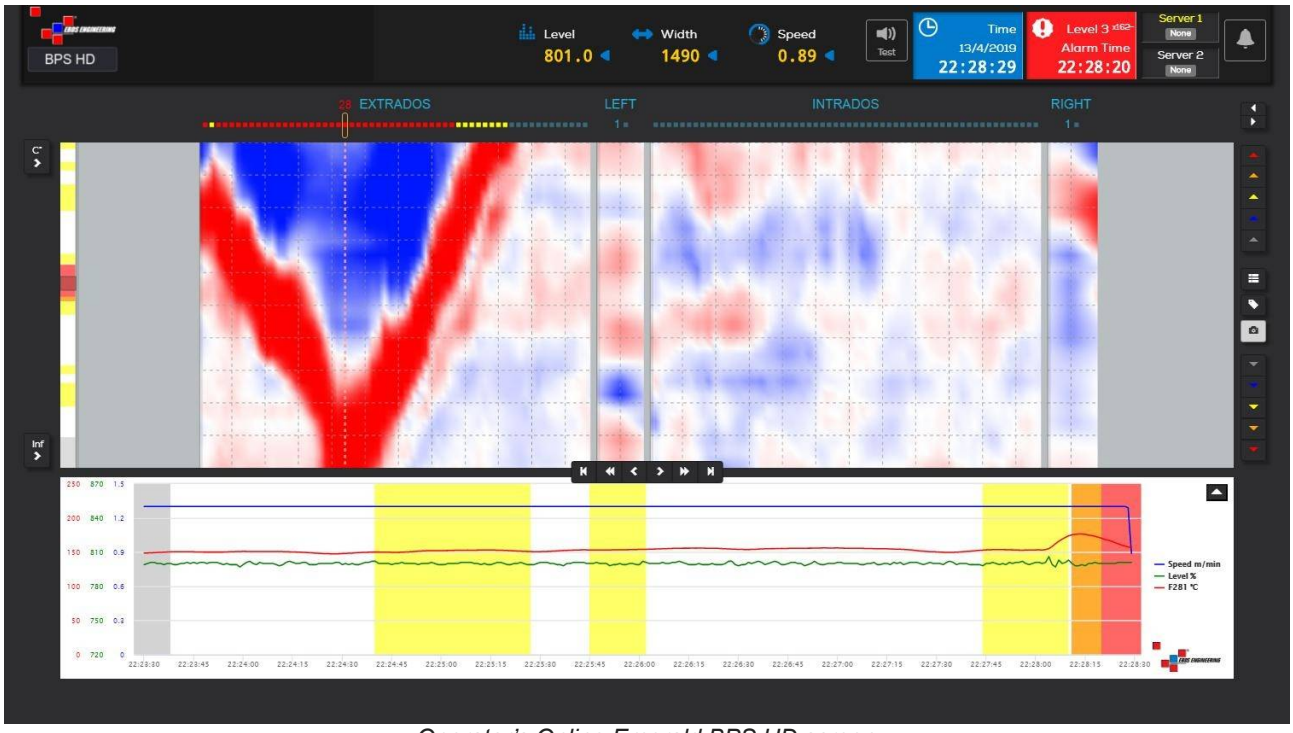


3) Breakout prediction adapted to the slot and insert technique.

As said earlier and shown in [1], sticker breakout prediction is typically based on a 2 row temperature measurement layout, because from mechanical point of view, it was difficult to have a great number of measuring points on one horizontal axis.

With the horizontal deep drilling technique or with this horizontal slot/insert technique, the problem is overcome: with one fiber, it is possible to have a BPS system running, thanks to the higher density of the measurements on the horizontal line, but also thanks to the quality of the temperature response of the FGB sensors.

Here below is a prinstscreen of the operator's Emerald BPS HD interface, of EBDS Engineering. A sticker is developping in the mold on the extrados BF. The program is running with 1 horizontal fiber only. One can see that the thermal response is excellent, and that the sticker is visible without any doubt.



Operator's Online Emerald BPS HD screen

The calculation of the detection, based only on the horizontal spreading of the sticker, is showing outstanding performances, because of the numerous possiblity of confirmation of the sticker profile on the side temperature measurements.
In the particular upper case, at the moment the BPS running on the TC released the BPS alarm, sticker is confirmed by the BPS system running on the fiber 162 times. As the confirmation strategy is more reliable, as we only work on the horizontal axis, with a high number of temperature values, we can virtually eliminate all the flase alarms.

Thanks to the fact that one slot can hold 2 fibers, we can have 2 fibers installed, one being the backup of the other one in case of a problem, without adding to the plate the machining of a second slot+insert. So we are in a real industrial lay-out, without additional costs.

At the end of the day, **one** groove/insert per broadface is enough, as a plate preparation, to allow to switch from a thermocouple system to the FBG fiber technology.

For sure, more slots can be added into the plate if the caster want to go for plate thermal vision, etc...

4) Conclusions.

The horizontal “slot+dovetail insert” technique is the most industrial technique to allow the casters to move from thermocouples to FBG optical fibers.

This solution is bringing the following advantages:

- The cost-of-use of the fibers (including the plate preparation) is much lower than the thermocouples lay-out.
- Can be retro-fitted on all existing caster and existing copper plate.
- The installation time of fibers in the plate is a few minutes.
- Fibers are re-usable, can be removed from a plate and placed in another plate, at the mold workshop without an problem
- The quality of the temperature measurement is nothing to compare with thermocouples:
  - No water disturbance
  - No electrical disturbance
  - Better heat response
  - much higher density of measurement on the horizontal axis

- Moving to “full mold thermal monitoring” with additional horizontal fibers is possible, as the equipement allows to get more fiber signal inputs, without excessive cost increase.

Please note that EBDS Engineering Sprl and CSN Carl SCHREIBER GmbH are patent pending on this slot/insert technique.

[1] Conversion of a slab casting mould to Bragg Grating optical fibers – Et. Castiaux; G. Zuliani – METEC-ESTAD 2019 – Düsseldorf – Germany

[2] A novel view on casting performance: application of fiber bragg gratings for slab casting - Ton Spierings , Jan Kromhout, Herman Hengeveld, Edward Dekker, Pieter Sturm, and Arnoud Kamperman – ECCC2017

[3] New sensor technology offers a sharp view on initial solidification: Mold Expert
Fiber- Oliver Lang, Nicole Oberschmidleitner, Christian Ortner, Martin Schuster - Primetals Technologies Austria – Hun 2019 – ESTAD 2019

[4] HD mold – A Wide Variety of Caster Assistance Tools for Enhanced Product Quality - M. Korzi, M. Arzberger,F. Fanghänel, D. Lieftucht, M. Langer, M. Reifferscheid – AIS Tech 2016