# FBG Optical Fiber trial at ArcelorMittal Poland Dąbrowa Górnicza.

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## Abstract.

ArcelorMittal Poland Dąbrowa Górnicza is a steel plant producing low carbon, medium carbon, low & medium alloyed, API, electro, HSLA, SP steels on a continuous caster.

To increase flat continuous caster safety and reduce BO's, AMP developed with EBDS a trial program – casting on CC equipped with a mold with 2 horizontal FBG Fibers rows per broad face, and sensors in each row – with aim to increase measurement accuracy.

The target of the trial is to verify the quality of the FBG measurements, as well as advantages of increasing in the resolution of the online thermal mapping of the mold during casting.

AMP plans to check reliability of Optic Fibers in comparison to standard use of TC's in mold, increased BPS Emerald performance in sticker detection and BO's prevention. The trial with developed in cooperation with EBDS Engineering, already monitoring the caster with its EMERALD BPS system, based on a thermocouple acquisition system.

## Introduction.

The #3 caster of ArcelorMittal Dąbrowa Górnicza is a 2 strand slab caster, vertical bending, supplied in steel with 300 tons ladles. The mold is 900mm high, and it is equipped since the startup with 3 rows of thermocouple sensors. There is a total of 84 thermocouples, all used for the BPS system. On the broad face, the horizontal distance between each thermocouple is 188mm. All thermocouples are installed through the mounting bolts of the plate to the water jacket.

Since mid 2021, the caster is monitored on both strands by EBDS Engineering's Emerald BPS program. It is giving full satisfaction, as there are less than 1 false alarm per strand per month, and all stickers are detected.

The optical fiber trial as several objectives that can be summarized here below:

- To verify the benefits of having more temperature sensors on the mold thermal map, as well as on the BPS system.
- To check the reliability of the optical fiber measurement on the long term use.
- To evaluate the ease of the installation and the work with fibers placed horizontally in the broad face plates.
- To evaluate the plate modification to install the fibers.

**Layout of the installation for the FBG trial.**

2 fibers are being installed horizontally in each broad face. Each fiber contains 45 sensors, with a distance of 50mm between each sensor.

The upper fiber is installed at 250mm from the top of the mold, and the lower fiber is 100mm below the upper one; Typically, the upper fiber is installed between the upper and middle row of TC, and the lower fiber, between the middle and lower row of TC.

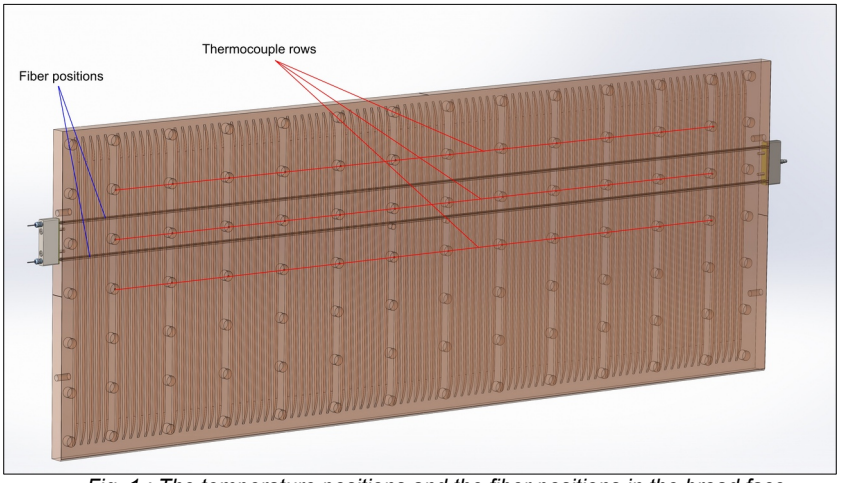


*Fig. 1 : The temperature positions and the fiber positions in the broad face.*

The technique of preparation of the plate to allow the fiber installation is a unique solution developed by CSN Carl Schreiber and EBDS Engineering:
A thin groove is machined horizontally all along the 2446mm of the hot face, where the fiber will have to be installed. This groove is then filled with a copper insert that is incorporating a groove to allow the later installation of the fiber. The insert is welded to the plate by electron beam welding technique. Once welded, the plate surface is machined, and then can be coated with the usual coating, as before.
With this “groove and insert” technique, the fiber can be of one piece.

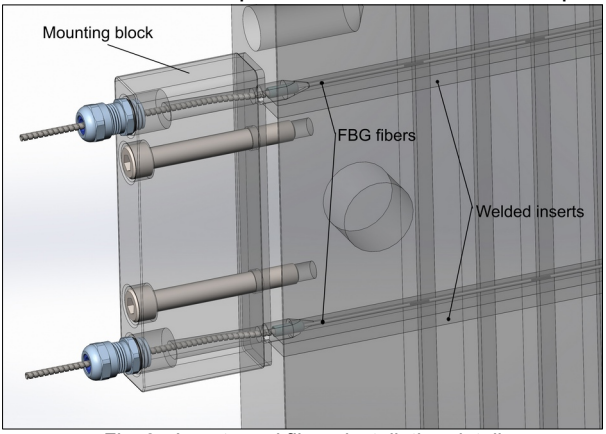


*Fig. 2 : Inserts and fibers installation details.*

Both broad face will receive a similar setup. The mounting blocks will be installed on the copper plates so that the fibers are exiting on the same “narrow face “side, as can be seen on the next picture:

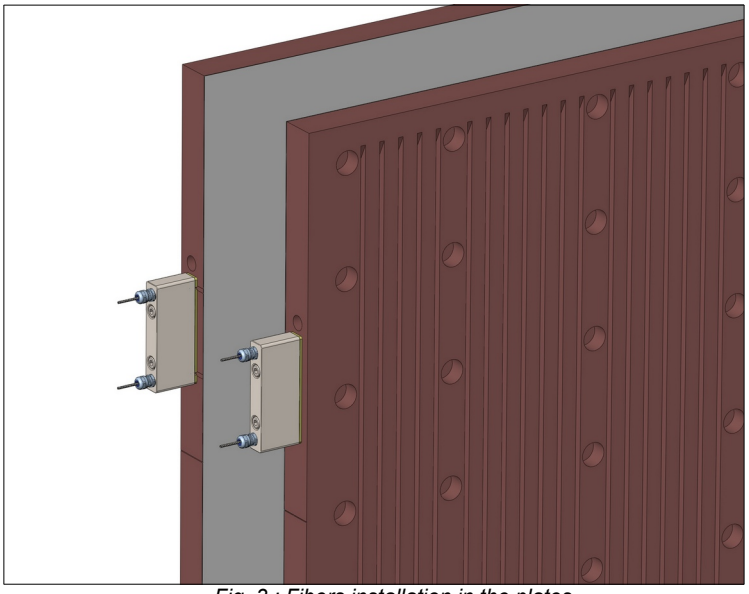

*Fig. 3 : Fibers installation in the plates*

The 4 fibers are being connected into a concentration box, placed on the mold (see fig 4.). This box is connected to the caster (when the mold is on the strand) via an industrial optical cable, using quick coupling connection system, to an intermediate connection cabinet (see fig 5.).

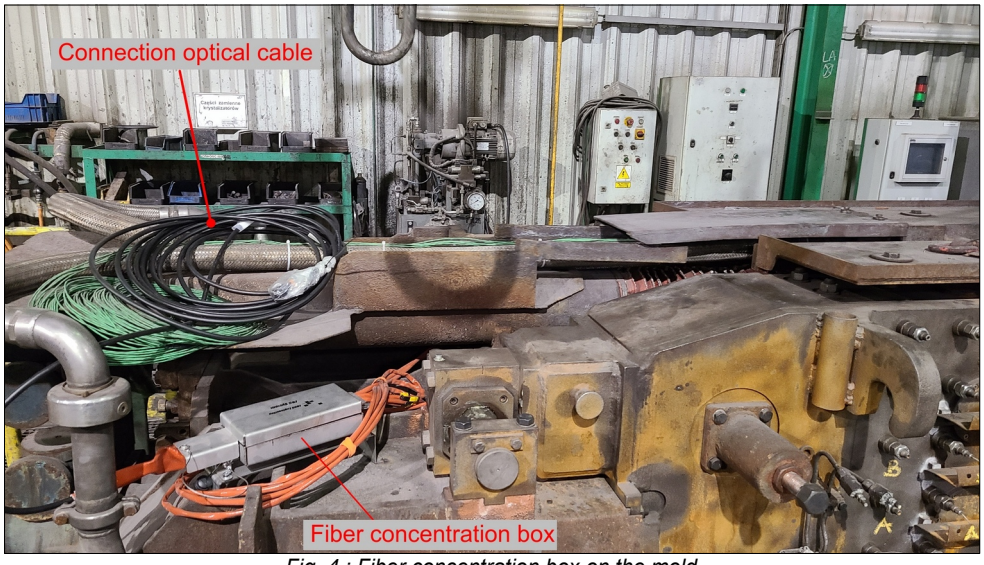


*Fig. 4 : Fiber concentration box on the mold*

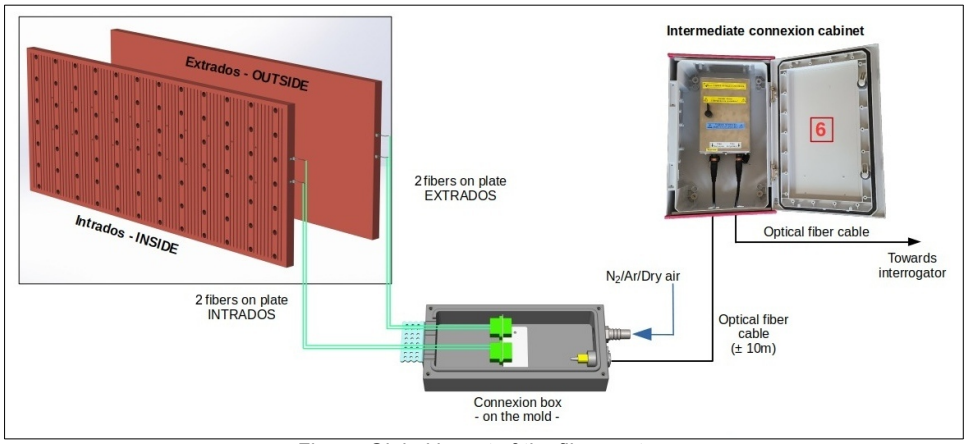


*Fig. 5 : Global layout of the fiber system.*

There are no optical FBG optical fibers installed on the narrow faces of the mold.

## BPS detection analysis and results.

The Emerald BPS system is displaying the thermographical image of the 4 plates of the mold, in relative temperature (Red→ temp. increase, Blue→ temp. decrease, White → everything stable).
Both BPS systems (with the thermocouples and with the fibers) are running at the same time, in parallel, in the BPS server.
As per the moment of writing this paper, we had 3 sticker detection happening on the strand where the mold was installed. Here below the images of one of them, one picture of each system, at the same moment.

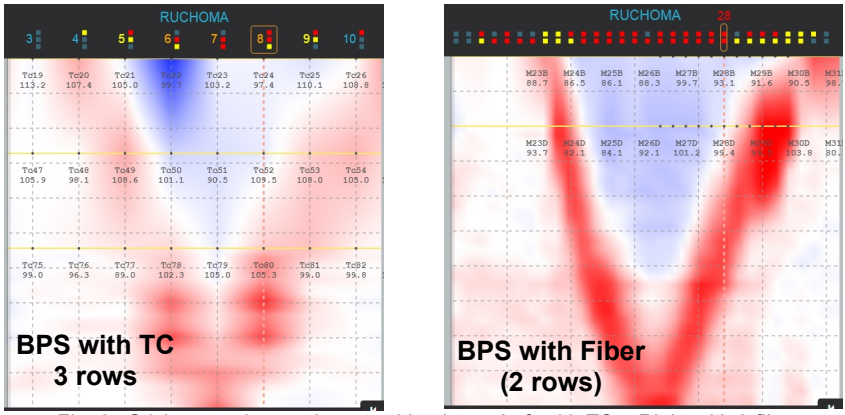


*Fig. 6 : Sticker passing on the movable plate – Left with TC – Right with 2 fibers.*

The quality of the temperature response of the fibers sensors are quite astonishing, and we can see that the thermographical image speaks for itself. The up-and-down temperature sticker signature is cleaner with the fibers, and the peak of temperature (when the tear is in front of the sensor) is more precisely defined with

the fibers, in comparison with the temperature response, where the peak of temperature is more flattened.

This is why the red “V” shape on the left side, drawn by the TC signatures, is less sharp than the right picture drawn by the fiber signals.
Using standard BPS calculations (with some vertical and horizontal confirmations), based on the 2 rows of fiber signals, is allowing to release the BPS sticker alarm on the fiber system sooner than the BPS with TC (3 rows) even though the first row of fiber is lower in the mold than the upper TC row. The detection takes place 5 to 10 seconds sooner with the 2 row fiber system, thanks to the increased number of sensors (1 sensor each 5cm for the fiber versus 1 TC each 18.8cm for the thermocouple).
As the BPS with fiber calculation engine can increase its number of confirmations, there are no false alarms with the 2 fiber BPS system (based on 1 month casting).

**One fiber BPS calculation.**
Using horizontal fiber for BPS detection is giving a serious advantage in terms of density of measuring points, and quality of measurement. However, unlike thermocouples, if the fiber is broken (or not working), all the values given by the fiber are lost.
On a 2 horizontal fiber layout, if the BPS calculation are “traditional” – which means involving detection of sticker pattern from top to bottom – and 1 fiber is suddenly not working, the BPS system is not working anymore (as confirmations cannot be performed) and the caster will not be protected.
To overcome this downside, EBDS Engineering is developing the 1 fiber calculation system, where the breakout prediction is based on the temperature signals given by one fiber only.

The principle of this detection is based on the fact the sticker is also propagating horizontally. Additionally, there are 3 strong advantages about this horizontal propagation:

- The first advantage is related that the sticker propagates on the left side AND on the right side. So it is possible to detect the sticker while looking in 2 directions. When using vertical propagation, there is only 1 direction (downwards) where the sticker propagates.
- The second advantage is the speed on propagation: the horizontal propagation is much faster than the vertical propagation. So it is possible to confirm the sticker faster on the horizontal axis than on the vertical axis.
- The third advantage is the smaller distance between sensors: As we are looking on 1 fiber only, the distance between the sensors is much smaller (50mm in our trial).

To illustrate this, let’s analyze the former sticker calculation results: The following image shows 11 pairs of sensors: 11 on the upper fiber, and their corresponding temperature from the lower fiber.

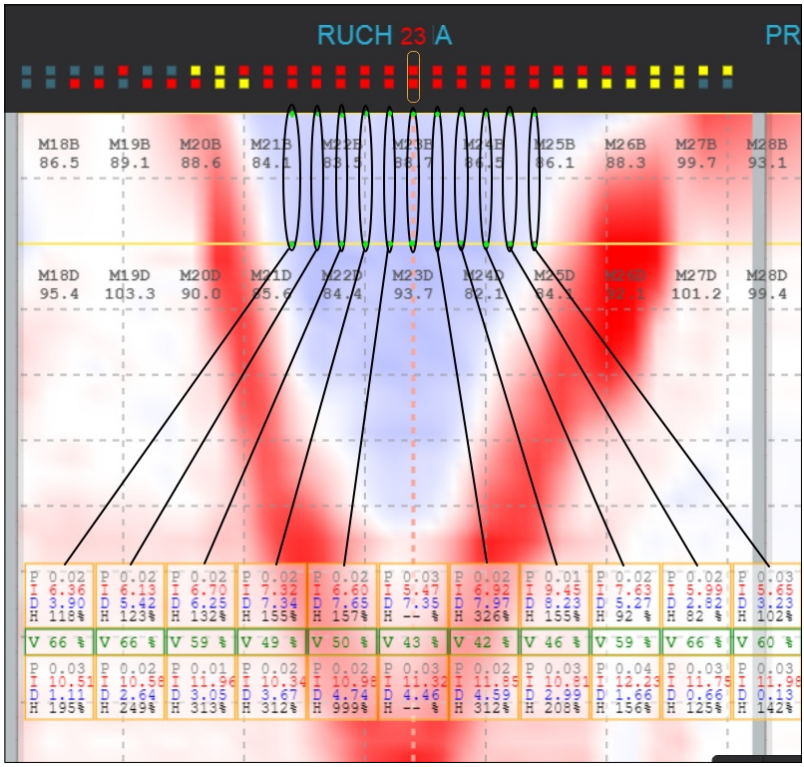


*Fig. 7 : Example of analysis of a sticker on a 2 fiber BPS system.*

All these 2 x 11 sensors are being impacted by the on-going sticker, as they are already “inside the “V” shape of the sticker (so in the sticked zone).
Let’s first interest ourselves in the results written in green (central line of the below table):

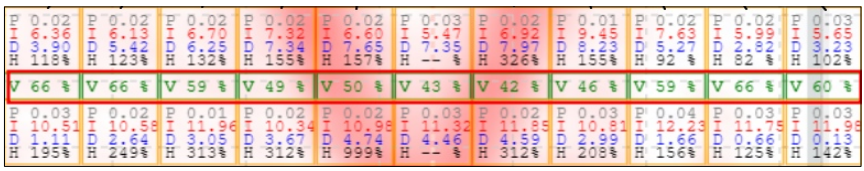


*Fig. 8 : Calculations results on a 2 fibers sticker detection – the vertical propagation.*

These figures, expressed in %, are showing the relative VERTICAL speed of the sticker vs the casting speed, for each of the 11 considered vertical pair of sensors. We calculate the speed of of the sticking situation by looking at the time needed between the 2 maximum of the T° curves. We know that the vertical speed of a sticker is approximately 50% of the casting speed, and this is what we see here: we are between 42% to 66%, which are consistent results with what is typically expected.

Now, let's consider the horizontal speed of transfer:

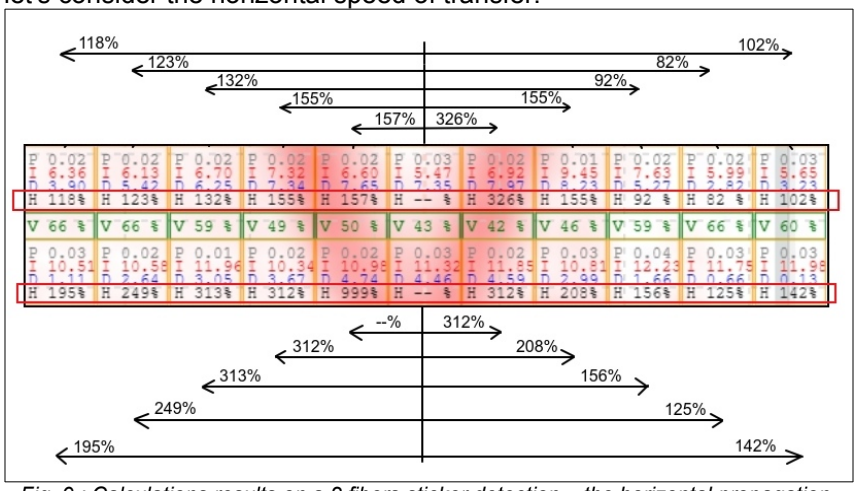


*Fig. 9 : Calculations results on a 2 fibers sticker detection – the horizontal propagation.*

The above n°9 picture shows the calculated horizontal relative speed of sticker propagation between the central vertical pair of measurements of the table, and all the pairs on the left and right side, for the 2 fibers. These are written in black in the above table.

We can see that the horizontal propagation is MUCH faster than the vertical propagation of the sticker. In the above situation, we can see that we are typically between 100% of the casting speed, up to 300%.

This observation confirms the idea that running the BPS system by detecting the sticker propagation on the horizontal axis will be always faster than on the vertical axis.

Running a BPS system with 2 horizontal fibers will then allow to make calculations purely horizontally on each fiber, and also vertically if the 2 fibers are working. So the calculation redundancy must lead to an improved BPS performance results, in any case.

During this fiber trial, different algorithms are begin tested to find an optimum for the pure horizontal detection.

**Copper plate situation.**

The copper plates were prepared by installing an insert into an horizontal groove, welded "in-situ" by electron beam welding.

The plates were not new, but still close to full copper thickness. The preparation consisted of the following operations:

- Removing the old Nickel coating
- Machining the 2 slots in each plate.
- Placing the inserts and welding them
- Machining the insert excess material
- Coating the plate and final machining.

This technique was a world premiere on copper plates for slab caster. After one month casting (approx. 105.000 tons in the mold), here is the visual aspect of the plate.

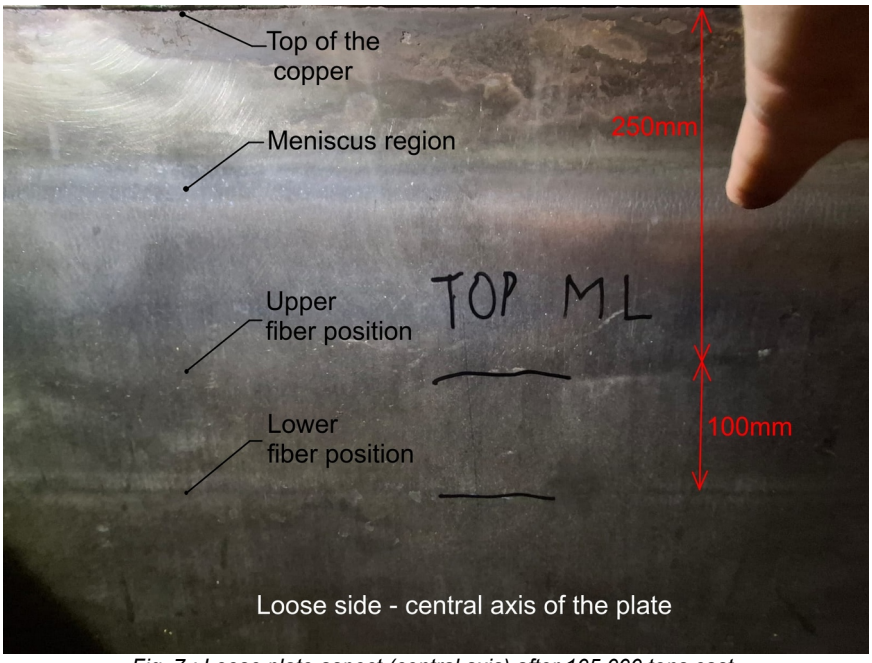


*Fig. 7 : Loose plate aspect (central axis) after 105.000 tons cast.*

We can see on this picture the top of the copper, the meniscus region (with very slight cracks, as can be expected); the 2 inserts position are barely visible. This confirms that the welded insert technique on the hot face is a perfect solution for preparing the plates for horizontal fiber installation.

**Conclusions.**

The on-going trial with the FBG optical fibers installed horizontally in the each broad face plates is giving promising results.

The quality of the FBG fiber measurement is excellent, and so far, after 1 month production through the mold (105.000 tons), there is no sign of any optical signal problem with the fibers. They are working as per the first day.

From a BPS development point a view, having a lot of measuring points on 2 horizontal axis is resulting in a much finer thermographical image. Additionally, it gives the opportunity to work on a new calculation engine, especially focusing on the horizontal propagation.

From a plate modification point of view, everything shows that the fiber installation behind a electron beam welded insert is working perfectly.

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