FIBER STRAND® : The most economical and practical method to install FBG optical fibers in copper plates of a continuous caster.

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Summary.

For quite a number of years now, there are attempts to switch from thermocouple temperature measurements in copper plates of continuous casters to Bragg grating optical fiber, without, we can say, a strong success, despite the excellent performance of FBG temperature sensors. The reasons for this may be related to several points: the cost of the preparation of the copper plates to be able to be equipped with fibers, combined with the costs related to the number of plates to be equipped; added to this, we can also say that it is a sensitive technology to work with in a mold's environment, especially with the special optical connectors and cables, etc…
In order to eliminate all these downsides, EBDS Engineering has developed an alternative way to install fibers on the caster: instead of equipping all the plates of all the molds and connect each mold when it is put on the caster, we are equipping each strand of the caster with the necessary set of fibers, and the fibers are automaticcally installed in the plates when the mold is set on the strand.
This technique is used in combination with copper plates prepared with inserts welded on the hot face, allowing the fibers to be installed horizontally along the full width of the plate.
This Fiber Strand® solution allows to equip only the strand with fibers (not all of the plates), eliminates all optical connectors in the harsh environment of the caster; moreover, the fibers are permanently connected to the signal processing unit (interrogator), whether or not there is a mold on the strand. And it completely eliminates the need to equip and test the plates at the mold area.

Introduction.

FBG fibers are for some years showing a significant interest if installed into copper plates of continuous caster. But installing fibers in mold copper plates of continuous casters is much more complex than thermocouples, mainly in relation with the intrinsic design of the 2 types of sensors:

- we can say that typically, a thermocouple has its sensing element (the hot welded spot) located at the tip of its body. So the installation will be done by pushing the tip of the sensor into the bottom of a hole where we desire to know the temperature. This has consequence that the thermocouple is typically installed perpendicularly to the copper plate.
  In the vast majority of the layouts, the thermocouple is coming from the outside of the water jacket, through mounting bolts.
  This is what we can see on the Fig. 1: a horizontal line of thermocouples, installed in a copper plate, all of them being installed through the water

jacket. The depth of measurement is related to the penetration of the tip of the thermocouple into the copper. The aim is to measure the temperature in the copper, between the water slot and the hot face.

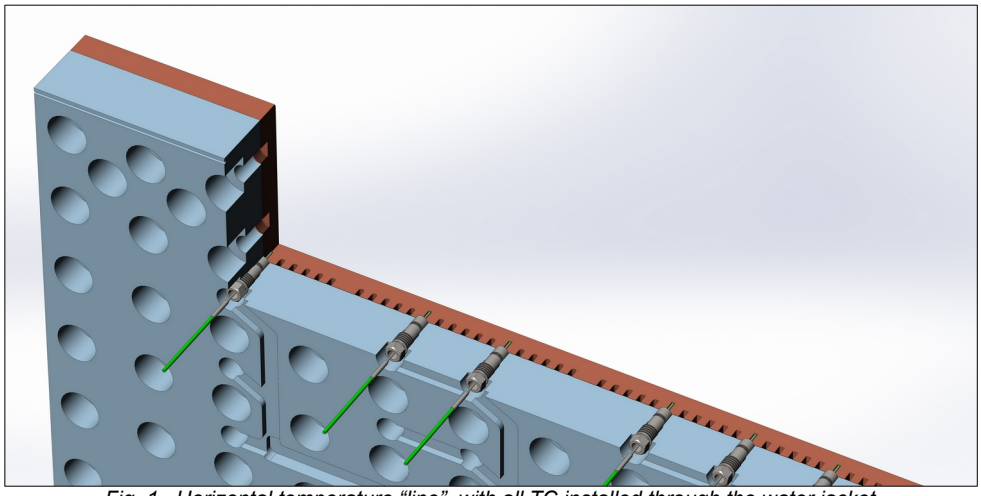

Fig. 1. Horizontal temperature "line", with all TC installed through the water jacket

- On the contrary, an FBG fiber will have all its sensing elements distributed all along an axis (the fiber). By construction, it cannot be installed by crossing the water jacket, but the fiber must be fully installed in the copper. The only way to do so is to insert the fiber from the side of the plate, either vertically, or horizontally.

So the fiber must be installed in a "long fine cavity" created in the copper plate, all along which the different temperature measurements will take place.

EBDS Engineering is exclusively installing fibers horizontally in copper broad faces for reasons previously explained[1] that can be summarized here below:

- Less fibers are needed (2 to 4 fibers per BF)
- Less plate machining/preparation is needed
- The entry point (side of the plate) is not exposed to harsh condition as is the top of the plate. The protection of the fibers is simple to implement.
- From a BPS point of view, it is much more interesting to have a lot of points on a few horizontal axis, than a lot of points distributed in many vertical axis.

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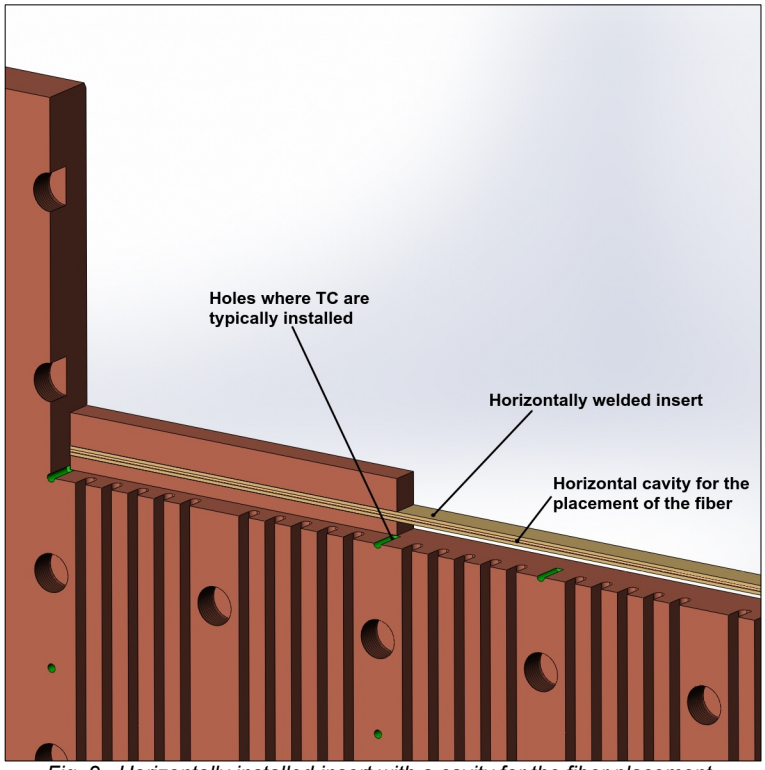

Fig. 2. Horizontally installed insert with a cavity for the fiber placement.

Nevertheless, fibers have to be introduced into the plate, and so far, the only proposed way is to have a significant numbers of plates prepared with fibers, mounted into spare molds.

This means that optical connections will have to be closed or opened when a mold is installed or removed from the strand, and an important number of fibers have to be handled at the caster/maintenance area.

Equipping a plate with FBG fiber.

EBDS Engineering is using FBG fibers that are mounted into stainless steel capillary tubes of Ø1mm external diameter. These “fiber assembly” are sealed, and can be manipulated by hand without any particular difficulty; Only the length that has to penetrate the plate is made of this stainless fine tube. The part of the fiber that will stay out of the copper will be protected by a corrugated stainless protection of +/- Ø 3mm.

- In the rest of the present paper, we shall speak about “fiber” when speaking about this capillary tube assembly containing the FBG fiber -

Once the copper plates have been modified to be able to receive fibers, we simply slide the fibers by hand into the prepared “hole”, and that’s it. The fiber extension

is attached so that the fiber cannot go out the plate during transport and casting, but that's all about it. The fibers can manually be removed from the plate and installed into another if needed.

So typically, a plate with some fibers installed (EBDS Engineering style) will be looking like this.

Fig. 3. Fibers installed on a horizontal axis in a copper broad face plate.

In addition, there will be for sure a concentration box etc… to gather all optical signals and send them to the interrogator.

In order to run with this installation method, it is necessary to pre-equip a significant number of plates with the necessary fibers, so that all the spares molds are ready with fibers.

The result is a multiplication in the number of optical fibers required to enable the entire mold fleet to work with FBG optical fibers.

Each time the mold is placed on the casting strand, the optical fibers it contains will have to be physically connected to the optical installation for processing the light signal - the interrogator - (which is a permanent installation). And each time the mold is removed from the strand, the optical fibers it contains will have to be disconnected from the fixed installed light signal processing installation.
This operation of connecting/disconnecting the fibers can easily generate a light signal transmission fault that is prohibitive to the proper operation of the fiber and the measurements it will provide (due to manipulating sensitive optical connectors into a harsh environment, etc.).

We have therefore 2 main downsides in relation with this typical standard fiber installation:

- There is a need to equip all molds with fibers, which impact the maintenance operation of the mold (workload) and the cost of the overall system (investment and spare parts).
- The mold that will be on the strand will have to be connected/disconnected each time it is installed/removed, which can lead to problems with the reliability of the connection and thus, the fiber installation.

FIBER STRAND® development - principle.

EBDS Engineering's philosophy is to supply simple and industrial solution; in this respect, we have developed a solution to eliminate the 2 downsides listed here above; we want to:

- avoid to "pre-equip" the plates and the plates/molds with fibers, by installing the fibers into the plates only when the mold has been placed on the strand.
- have a permanently connected fiber to the signal processing system (interrogator) so that no connection/disconnection of the optical fiber is needed.

As the fibers were previously introduced by hand into the plates, we are simply replacing this operation by an automatic operation that is described here below:

Plate and mold side equipment:

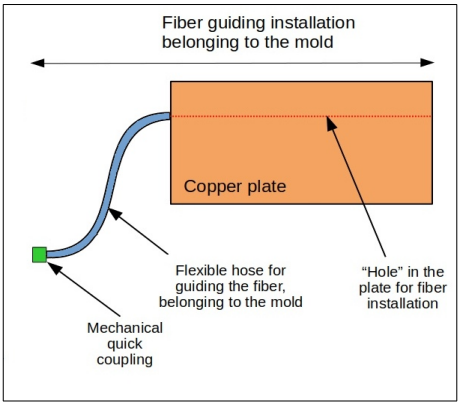

Fig. 4. Plate and mold side preparation

The mold is arriving on the strand without any fiber installed. This means that the BF plates are being prepared to receive a fiber (the "hole or cavity" to receive the fiber is present and ready), but it is empty.
Additionally, the BF plate is equipped with a flexible hose that will be used to guide the fiber into the plate, when the fiber will be inserted. This hose is equipped with a mechanical quick coupling at its free end (see fig. 4).

Strand side equipment:

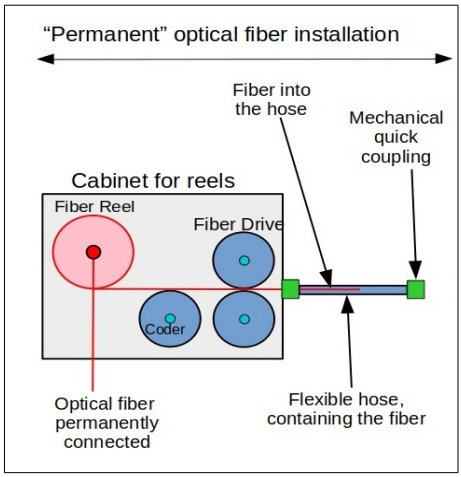

Fig. 5. strand side equipment

The strand side refers to the fixed installed part of the layout, that stays permanently with the strand. It is located outside the vapor chamber.

The principle is the following: the fiber, permanently optically connected, will be guided through a hose into position in the copper plate when the mold is on the strand. If the mold has to be removed, the fiber will be guided out of the plate, and "stored" into a reel (see fig. 5)

The connection between the permanent installation and the mold is a simple mechanical quick coupling for hoses.

The movement of the fiber is insured by a electric drive with position control.

So, when the mold comes on the strand, the 2 hoses can then be connected together as illustrated in fig. 6. :

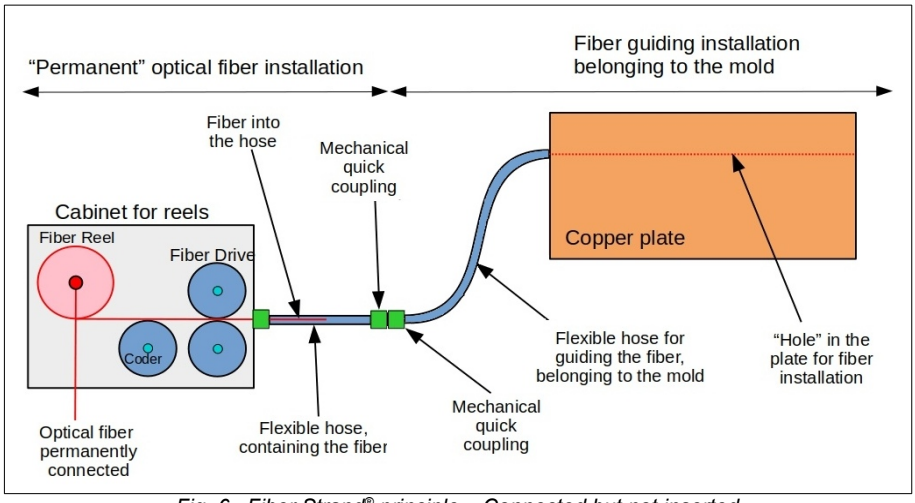

Fig. 6. Fiber Strand® principle – Connected but not inserted

Then, the fiber is slide into place into the plate, thanks to the motorized system equipping the cabinet with the fiber reel, as shown here below:

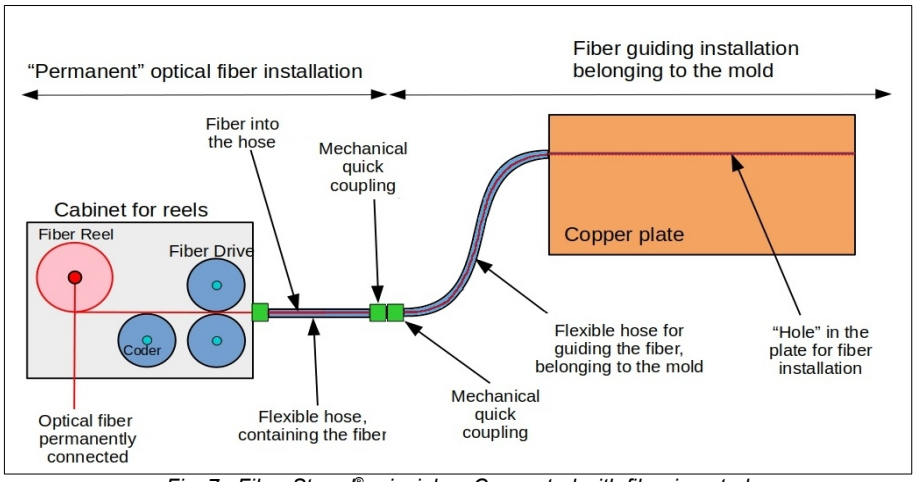

Fig. 7. Fiber Strand® principle – Connected with fiber inserted

FIBER STRAND® - Description of a typical layout.

Let's consider a mold, where we will install horizontally 2 FBG optical fibers per broad face; the plates will have to be prepared has shown on the below picture:

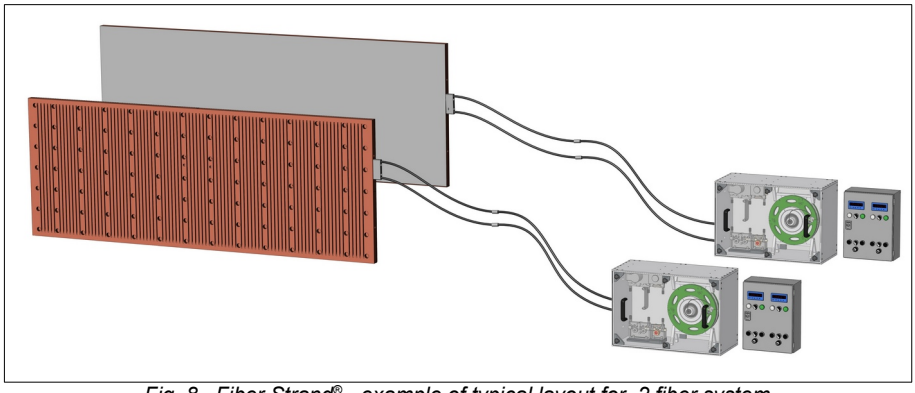

Fig. 8. Fiber Strand® - example of typical layout for 2 fiber system

One can see that each plate is equipped 2 flexible hoses. These hoses will be used to guide the fibers into the plate when the mold will be on the strand. There is nothing else than these parts to be mounted on the plates. One can understand the huge simplification of the mold preparation at the mold workshop.
When the mold is placed on the strand, there will be 4 mechanical quick coupling to connect in order to be able to place the fibers into the plates (2 per plates). We are using hydraulic hoses, so that we have robustness and good mechanical protection.

EBDS Engineering has developed a dedicated solution for this application: a cabinet containing a double optical fiber reel and their respective drive and control.

The insertion of the 2 fibers is controlled by separate controllers and is fully automated, as shown on the picture 8.
These cabinets are installed outside of the vapor chamber, where are typically installed the thermocouples acquisition cabinets.
Each plate is connected to a fiber cabinet. By turning 1 switch button, the operator can slide each fiber into the plate. The movement, the speed, the position of the fiber is fully monitored by a controller, so that the fiber is always positioned at the same place in the plate or in its parking position. When the mold need to be removed, the operator has to slide back all the fibers out of the plate. Once again, this is a fully automatic operation done by switching a button. Once done, the 4 quick coupling can be disconnected, and the mold can leave the strand.
Please note that the fiber does not need to be fully stored into the reel of the equipment. Once the fiber end reached the inside of the fix installed hose (right after passing the quick coupling), it can stay in this position, and the quick coupling can be opened.

Advantages of the FIBER STRAND® method

This way of installing the fiber, at the strand on the caster, instead of pre-equiping all the plates and molds, have significant advantages, listed here below:

1. There is no need to prepare and test mold with fibers at the mechanical workshop.
   The plates are only equipped with a couple of hoses, and that's it.
2. There are only 4 fibers in service to run the strand (in the case of our breakout prediction system). So the investment and maintenance cost is very significantly reduced.
3. There is no fiber manipulation to be done. Fibers are sensitive items, and manipulating them, even if they are in a stainless capillary, is taking a risk to damage them.
4. The 4 fibers are permanently connected to the interrogator. So there is a permanent supervision of the quality of the temperature readings, whether there is a mold on the strand or not.
5. There are no optical connection to be open or closed.
6. The fiber is always protected into a robust hose. We use typically a hydraulic hose.
7. It is possible to change a fiber within a few minutes, even while casting. The fiber is supplied on the reel that has been designed to fit the motorization cabinet.

Conclusion.

The FIBER STRAND® approach is the most simple and economical way to install FBG optical fibers in broad face copper plates of a slab caster, as the fibers are installed when the mold is set on the strand of the caster. It suppresses all the preparation work at the mold workshop, as there is nothing to install there anymore; it reduces the cost of the overall usage of the fibers to a lower value than the thermocouple cost, keeping the advantages of the increased number of measuring points on the horizontal axis for the BPS system.

The FIBER STRAND® is a registered trademark, and the FIBER STRAND® is patent pending.