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OMEGA-LIKE FIBER BRAGG GRATING SENSORS AS POSITION MONITORING DEVICE: A POSSIBLE PIXEL POSITION DETECTOR IN CMS ?

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Abstract

We make the exercise of considering the possible use of FBG sensors as a position device for the pixel detector of experiment CMS at LHC (CERN). We discuss the main features of FBG sensors, describe their use in HEP which we pionereed with the FINUDA experiment at DAFNE and developed for the BTeV experiment R& D at Frascati. We show results including long term stability, resolution, radiation hardness and characterization of Fiber Grating Sensors used to monitor structure deformation, repositioning and surveying of silicon detector in High Energy Physics. We discuss alignment issues in CMS silicon trackers and we evaluate a possible use of FBG sensors in the experiment.

1 INTRODUCTION

FBG (Fiber Bragg Grating) sensors are widely used in telecommunication as optical filters. For the first time we have used FBG sensors as optical, low-noise, high-resolution strain gauges to monitor structure deformation, repositioning, and surveying silicon (pixel and microstrips) detectors for HEP experiments at e^+e^- colliders (experiment FINUDA at Dafne, Frascati), as well as at hadron machines (BTeV at the Fermilab Tevatron). This note is organized as follows. In Sect.2 we show R&D results including long term stability, precision, resolution, radiation hardness and characterization. A novel device able to position and reposition a vertex detector with micron accuracy is described in Sect.3. We discuss in Sect.4 requirements for CMS pixel alignment, and, finally, very preliminary ideas for FBG use in Sect.5.

2 FBG SENSORS: LONG-TERM STABILITY AND RADIATION HARDNESS

FBG sensors have been used so far as telecommunication filters, as optical strain gauges in civil and aerospace engineering[1] and, only recently, in HEP detectors (FINUDA at DAFNE in Frascati, and BTeV at Fermilab in Chicago)[2]. The BTeV[3] detectors utilized FBG sensors to monitor online the position of the straw tubes, pixels, and microstrips. In BTeV, we also proposed a novel device (the Omega-like[2]) to precisely reposition the pixel structure in and out of the beams during accelerator stores. The Omega-like device is described in Sect.3.

The optical fiber is used for monitoring displacements and strains in mechanical structures such as the pixel support structure. A modulated refractive index along the FBG sensor produces Bragg reflection at a wavelength dependent on the strain in the fiber (Fig.3), permitting real-time monitoring of the support. Sensors are located in spots of maximal deformation, as predicted by FEA simulation. Figure 3 shows long-term behaviour of FBG sensors while monitoring micron-size displacements, compared to monitoring via microphotographic methods. Sensors have been tested for radiation damage. Fig.3 shows spectral response up to a neutron fluence of $1.6 \cdot 10^{13}$ 14-MeV neutrons/cm^2, corresponding to 6 months BTeV integrated dose.

3 THE OMEGA-LIKE REPOSITIONING DEVICE

FBG sensors have been also applied to instrument a novel repositioning device[2] with micrometric resolution. The Omega-like device (shown as prototype in Fig.33) followed the displacement of the pixel detector designed for the BTeV experiment which, at each accelerator store, has to be moved out and in of the beam-line. Fig.3 shows a Finite Element Analysis of the Omega-like device. FBG sensors are located on area of largest strain in order to maximize sensitivity. Results show how a repositioning precision of about 6 μm is reached. Work is in progress to reach the target 3 μm precision.

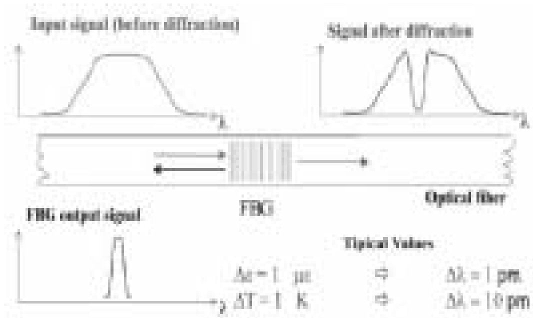

Figure 1: Principle of FBG sensors operation. A laser pulse is injected in the fiber and reflected selectively according to the grating pitch. Strain $\Delta\varepsilon$ changes the grating pitch thus changing the wavelength of reflected pulse. The sensors is also sensitive to temperature changes.

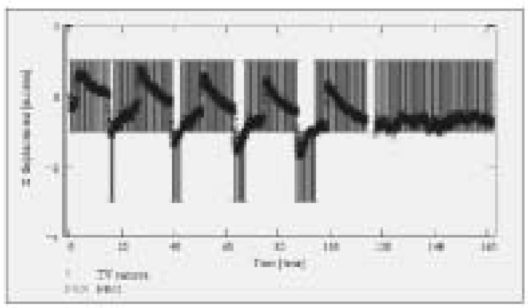

Figure 2: FBG long-term monitoring stability results. FBG output (crosses) is validated by TV camera (bars).

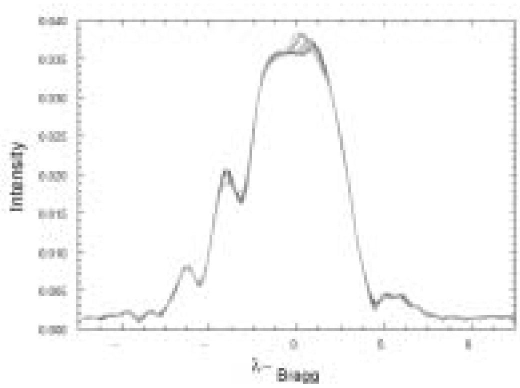

Figure 3: Radiation hardness of FBG sensors. Spectral response up to neutron fluence of $1.6 \cdot 10^{13}$ 14-MeV neutrons/cm^2, corresponding to 6 months BTeV integrated dose. No frequency shift is observed up to max irradiated dose.

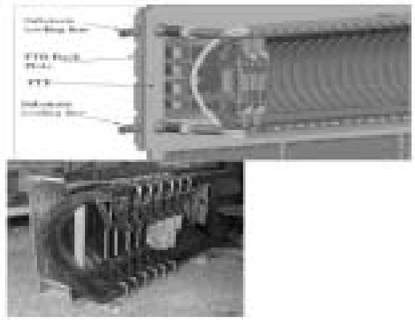

Figure 4: Sketch of BTeV pixel detector and its Carbon Fiber Reinforced Plastic support frame.

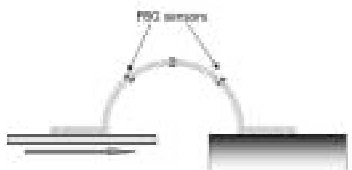

Figure 5: The Omega-like repositioning device, equipped with FBG sensors, follows the pixel support structure in and out of beam, assuring repositioning accuracy.

Figure 6: Finite Element Analysis of the Omega-like repositioning system. Sensors are located on the areas of larger mechanical strain in order to maximize sensitivity.

4 Alignment issues in the CMS tracker, and motivation for a positiong monitor system for the pixel detector

The CMS Tracker is a device of an enormous complexity. A precision alignment of the CMS tracking devices (pixel, microstrip and muon detectors) is one of the most challenging offline calibration task that CMS has to face. Looking at the studies done to determine a procedure for the alignment of the CMS tracking devices [4] one notes that the Pixel alignment is done by the track-based alignment only. On the contrary the microstrip detectors have also the Laser Alignment System.

We believe it is mandatory to explore the possibility of a positioning monitor system also for the Pixel detectors.

The large number of independent silicon sensors (about 15000) and their excellent resolution (10-50 μm) make the alignment of the CMS strip and pixel trackers a complex and challenging task. The residual alignment uncertainties should not lead to a significant degradation of the intrinsic Tracker resolution. Therefore the required accuracy of the alignment has to be at least equal to, but ideally better than, the ideal track parameter resolution [5].

While track-based alignment is the main source of alignment corrections for the tracker devices, also the Laser Alignment System (LAS) of the Microstrip detector will provide important information about the alignment of the high level support structures for the Microstrip detector [5]. Although the alignment corrections stemming from track-based and LAS alignment are usually defined at different levels of detector geometry granularity (i.e. the LAS provides corrections for support structures, while track-based alignment can align individual sensors), the framework provides a consistent treatment of the different alignment corrections to insure a well-defined reconstruction geometry [5].

During the LHC collider operation, track-based alignment will be performed by means of muons from $W^{\pm} \rightarrow \mu^{\pm}\nu$ and $Z^0 \rightarrow \mu^+\mu^-$ decays. With 1 to 2 million tracks CMS should have the statistical power to perform full alignment for the Tracker. This is accomplished in the low-luminosity scenario in 1 to 2 weeks of data taking [5].

Before the first data taking the alignment constraints of the Tracker are defined by the mechanical placement constraints and the information of the LAS. The combination of these two sources typically leads to alignment uncertainties of O($100\mu m$) for layers, discs, or equivalent large support structures. This level of uncertainty does not jeopardize an effective execution of pattern and, thus, ensures track reconstruction [4].

For the Tracker two different default misalignment scenarios have been considered and simulated [5]:

- **First Data Taking scenario:** this scenario is supposed to resemble the expected conditions during the first data taking of CMS (few 100 pb^{-1} of accumulated luminosity). It assumes LAS alignment of the larger structures of the strip tracker, alignment of the pixel detector using tracks, and photogrammetry survey of Tracker construction. No track-based alignment of silicon-strip detectors is possible due to insufficient high p_T tracks. Based on the experience from other experiments, the track-based alignment of the pixel detector would have reduced its placement uncertainties by a factor 10.

- **Long Term scenario:** it is assumed that after the first few fb^{-1} of data have been accumulated, a first complete track-based alignment down to the sensor level has been carried out, resulting in an overall alignment uncertainty of the strip tracker of $\sim 20\mu m$.

Table 1 and 2 shows the placement uncertainties used for the random shifts of the modules and of their lowest-level support structure (ladders, rods, rings and petals) for various tracker parts in the *First Data Taking* scenario [4]. As explained above, the numbers for the Pixel detector are best estimates, based on the assumption that a track-based alignment will reduce the alignment uncertainties given by the placement constraints (see Table 2) by an order of magnitude [4].

TOB	$\Delta[\mu m]$
Sensor vs Module	± 10
Module vs Rod	± 100
Rod vs Cylinder	$\pm \mathbf{100} - 500$
Cylinder vs Cylinder	$\pm 100 - \mathbf{500}$
TIB	
Sensor vs Module	± 10
Module vs Rod	± 200
Rod vs Cylinder	± 200
Cylinder vs Cylinder	$\pm 100 - \mathbf{500}$
TEC	
Sensor vs Module	± 10
Module vs Rod	$\pm \mathbf{50} - 100$
Rod vs Cylinder	$\pm \mathbf{100} - 200$
Cylinder vs Cylinder	$\pm 100 - \mathbf{500}$

Table 1: Placement uncertainties for laser-alignable Tracker parts before the LAS is used. The highlighted number corresponds to the more probable value.

5 FBG sensors in CMS pixel for alignment and positioning

From the estimates discussed in Sect.4 we infer the following requirements for the pixel alignment:

1. Mounting precisions requested for the installation of the pixel detector between $50\mu m \rightarrow 100\mu m$.

2. Barrel pixels need to be located at installation time with 50μm precision and no external access

3. Forward pixels have external access but repositioning is needed at each CMS stop and opening for maintenance (about twice a year)

TPB	$\Delta[\mu m]$
sensor within barrel module	±30 in 2D
module within ladder	±100 in 3D
ladder within one half-layer	±50 in 3D
half-layer within half-barrel	±100 in 3D
half-barrel within TPB	±300 in 3D
TPB within SiTK	±250 in X and Y
	±500 in Z
TPE	
sensor within disc blade	±25 in 2D
disc blade within half-disc	±50 in 3D
sensor within half-disc (after optical survey)	±25 in 3D
half-disc within disc-half-service-cylinder	±50 in 3D
disc-half-service-cylinder within TPE	±300 in 3D
TPE within SiTK	±500 in 3D
TID	
sensor within TID module	±5 in 2D
module within ring	±100 in 2D
	±250 in third dimension
ring within disc	±300 in 3D
disc within the TID	±400 in 3D
TID within TIB	±500 in 3D

Table 2: Placement uncertainties for Tracker parts for which LAS is not available. Uncertainties in 2D refer to uncertainties in the local plane, and 3D indicates that uncertainties are equal along the three axes. Errors are assumed to have a uniform distribution in the specified dimensions. Coordinates X and Y correspond to horizontal and vertical directions perpendicular to the beam, and Z is along the beam direction.

4. Alignment frequency needed is 10 min, vertexing takes at least 24 hours to signal an alignment change. Need an independent control system able to flag online alignment changes, and provide an estimate of the shift magnitude and direction

5. Need a method independent from track vertexing able to provide absolute alignment, now 200-300μm, getting closer to 5μm, the pixel precision.

The FBG sensors can definitively address items 1) to 4) above by installing sensors in the mechanical structure, and by using suitable Omega-like devices. FBG sensors can provide (as proved by the BTeV experience) alignment shift alarms and estimates of the shift magnitudes after the support mechanics they are connected have been characterized and modelled by Finite Element Analysis.

Absolute alignment of order 10μm is a more challenging task. The FBG sensors do have the precision and accuracy required, but a fixed reference point, whose alignement has to be determined independently from outside the detector, has to be found. A positioning monitor system based on FBG would dramatically improve the absolute alignment, now 200-300μm, and get very close to the required precision before the track-based alignment is run.

6 Conclusions

We have discussed features and experience of FBG sensors for position monitoring and positioning devices. We propose to study the possibility of using FBG sensors in CMS pixel. Roadmap to determine optimal use of FBG sensors would start from characterizing the mechanical support structure, to the verification of the required specifications, to the assessment of costs and schedule.

7 Acknowledgements

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