

TIPP 2011 - Technology and Instrumentation for Particle Physics 2011

One year of FOS measurements in CMS experiment at CERN

Zoltán Szillási^{1,a,b}, Salvatore Buontempo^c, Noémi Béni^{a,b}, Giovanni Breglio^{d,e},
Andrea Cusano^{f,e}, Armando Laudati^f, Michele Giordano^{1,e}, Andrea Saccomanno^d,
Dmitry Druzhkin^{h,i}, Andromachi Tsirou^b

^a Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Debrecen, P.O.Box 51. Hungary H-4001

^b CERN, CH-1211 Geneva 23, Switzerland

^c INFN Sezione di Napoli, Italy

^d Department of Biomedical, Electronic and Telecommunication Engineering, University of Naples Federico II, Via Claudio 21, Napoli, Italy

^e OptoSmart s.r.l., Via Pontano 61, Napoli, Italy

^f Optoelectronic Division-Engineering Department, University of Sannio, Corso Garibaldi 107, Benevento, Italy

^g Institute for Composite and Biomedical Materials (IMCB-CNR), 80055 Portici (NA), Italy

^h University Antwerpen

ⁱ Research and Development Institute of Power Engineering (NIKIET), Moscow

Abstract

Results are presented on the activity carried out by our research group, in collaboration with the SME Optosmart s.r.l. (an Italian spin-off company), on the application of Fiber Optic Sensor (FOS) techniques to monitor high-energy physics (HEP) detectors. Assuming that Fiber Bragg Grating sensors (FBGs) radiation hardness has been deeply studied for other field of application, we have applied the FBG technology to the HEP research domain. We present here the experimental evidences of the solid possibility to use such a class of sensors also in HEP detector very complex environmental side conditions. In particular we present more than one year data results of FBG measurements in the Compact Muon Solenoid (CMS) experiment set up at the CERN, where we have monitored temperatures (within CMS core) and strains in different locations by using FBG sensors during the detector operation with the Large Hadron Collider (LHC) collisions and high magnetic field. FOS data and FOS readout system stability and reliability is demonstrated, with continuous 24/24h 7/7d data taking under severe and complex side conditions.

© 2012 Published by Elsevier B.V. Selection and/or peer review under responsibility of the organizing committee for TIPP 11. Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords:

Fiber Bragg Grating (FBG), High Energy Physics, CERN, Large Hadron Collider, Compact Muon Solenoid (CMS)

1. Principles of the operation of the Fiber Bragg Grating

1.1. Theory

Fiber Bragg Gratings [1] are artificially fabricated periodic changes of the refractive index of the optical fiber. Due to the periodicity of the refractive index they behave as a λ -sensitive mirror.

¹Email: zoltan.szillasi@cern.ch

External fields, temperature and strain will change the characteristic parameters of light wave including amplitude, phase, and polarization. In the Fiber Bragg Grating (FBG), the center wavelength of reflected light is affected by changes in temperature and strain, which has been proposed and widely used as a sensing mechanism. The working principle of FBG is shown in Fig. 1.

The center wavelength of reflected light from FBG is given by the Bragg equation:

$$\lambda_{R1} = 2 \cdot n_{eff} \cdot \Lambda_1 \quad (1)$$

where n_{eff} , Λ_1 and λ_{R1} are the effective refractive index, period of grating and center wavelength of FBG respectively, and depend on temperature and strain. Strain influences λ_{R1} due to gratings period change and elastic-optic effect, and temperature influences λ_{R1} due to thermal expansion and thermo-optic effect, so the temperature or strain measurement can be realized by detecting the center wavelength of reflected spectrum.

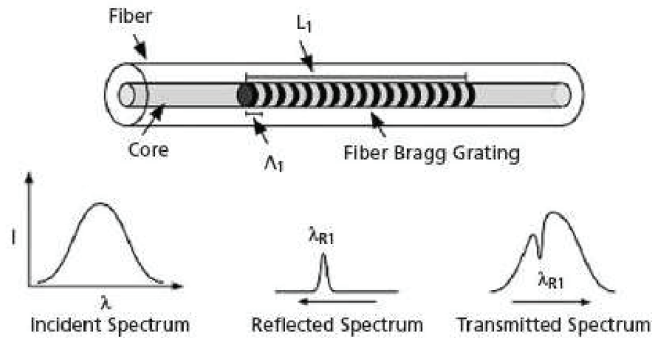


Fig. 1. Operation principle of the Fiber Bragg Grating

1.2. Principle of the sensing

The thermal and mechanical sensitivity of a fiber Bragg grating makes it to be useful in sensing application. To retrieve information from a FBG sensor a spectral normalization is needed to compare the measure out-coming from different sensors. Under the Bragg conditions, by considering the normalized lambda Bragg shift, the equation (1) becomes the following,

$$\Delta\lambda_{R1}/\lambda_{R1} = \Delta\Lambda_1/\Lambda_1 + \Delta n_{eff}/n_{eff} \quad (2)$$

In absence of strain onto the grating and considering only the temperature changes ΔT , the Bragg gratings period change $\Delta\Lambda$ due to thermal expansion can be written as

$$\Delta\Lambda_1 = \alpha \cdot \Lambda_1 \cdot \Delta T \quad (3)$$

the effective refractive index change n_{eff} due to thermo-optic effect makes can be written as

$$\Delta n_{eff} = \xi \cdot n_{eff} \cdot \Delta T \quad (4)$$

where α is the thermal expansion coefficient, ξ is the thermo-optic coefficient. Substituting equation (3) and (4) into (2), the center wavelength of FBG change due to temperature can be written as

$$\Delta\lambda_{R1}/\lambda_{R1} = (\alpha + \xi) \cdot \Delta T = K_T \cdot \Delta T \quad (5)$$

in which $K_T = (\alpha + \xi)$ is the temperature sensitivity of the FBG.

2. FOS in the CMS experiment

2.1. CERN, LHC and CMS

The European Organization for Nuclear Research (CERN) has been created to study of the physics of particles and forces that build up the world around us. During its more than fifty years CERN has made several discoveries that helped to establish the Standard Model of particles. In order to find the Higgs-boson, the last building brick of this model and to explore the physics beyond the Standard Model CERN has decided to build the Large Hadron Collider (LHC). LHC is designed to operate during the next two decades and to reach the unprecedented 7 TeV beam energy. Around the 27 km circumference of the LHC four gigantic experiments have been erected: ATLAS, CMS, Alice and LHCb. Since our group is involved primarily in the CMS the feasibility tests and the final installation of the FBG sensors has been done there.

Diameter of the CMS detector [3, 4] is about 14 m, while its length is about 20 m. It weighs about 12500 tons. Due to its weight the detector structure is sagged. In addition the operational magnetic field strength of the central solenoid of the experiment is 3.8 T that further distorts the structure. In order to ensure the safe operation these distortions must be monitored. Furthermore, temperature of the various detector parts must also be monitored in order to avoid unwanted effects in the detector operation.

2.2. FBG sensors in CMS and the readout

Part of the monitoring tasks above is performed by the FBG sensors. They are installed in both Bulkheads of the Tracker, on one side of the detector on the table and its support of the CMS subdetector called CASTOR and the Raiser structure (Fig. 2) of the Forward Hadron Calorimeter (HF). In the Bulkhead regions on both sides of the detector there are 10+10 temperature sensitive FBGs installed. Among them 4+4 are placed on the cable trays while the others are mounted on the Bulkheads themselves. Sensors installed on the CASTOR and Raiser regions are mainly strain sensitive ones, but there are temperature sensitive FBGs mounted on these structures, too. Their role is in the temperature compensation of the strain values. The total number of sensors to be read out is about 40. Each region occupies only one optical fiber therefore, the total cable number is four.

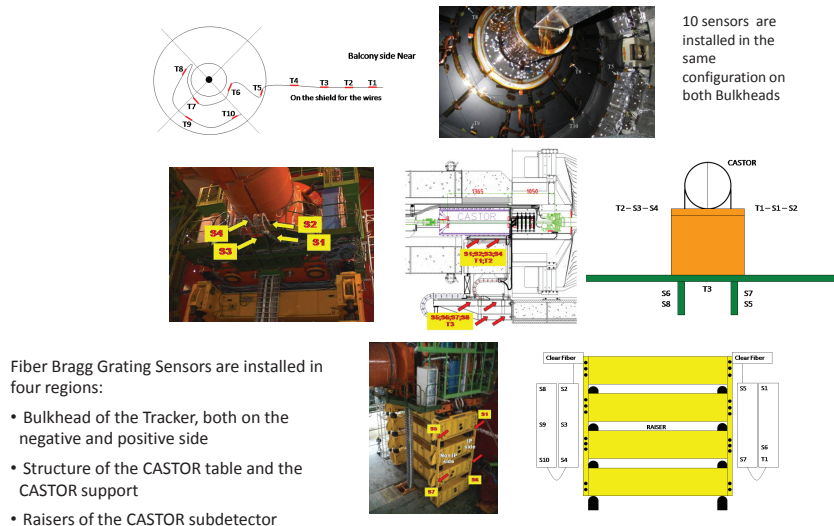


Fig. 2. FOS System installation on the CMS detector

The attenuation of the optical fibers is sufficiently low allowing the readout system to be placed on a more comfortable place where both the magnetic field and the radiation level is low enough to be operated

and maintained. Optical fibers installed on the Bulkhead of the CMS Tracker, CASTOR system and on the Raisers of the HF are then directed to the Underground Service Cavern (USC) about 120 meters away from the sensors. The USC is a member of the twin caverns of the CMS experiment and is isolated by means of radiation hazards from the experimental one that houses the detector itself. Being radiation safe, this cavern is accessible during the LHC operations as well. The optical fibers are read out by a MicronOptics sm125-500 optical interrogator [2] system that is equipped with an ethernet interface and can be accessed through a proprietary TCP/IP protocol. In order to reduce network traffic on the interrogator, it is connected to a mini private network created by the readout computer. This computer has another network interface installed as well, that allows the integration and sharing of the FOS system data with the CMS Detector Control System.

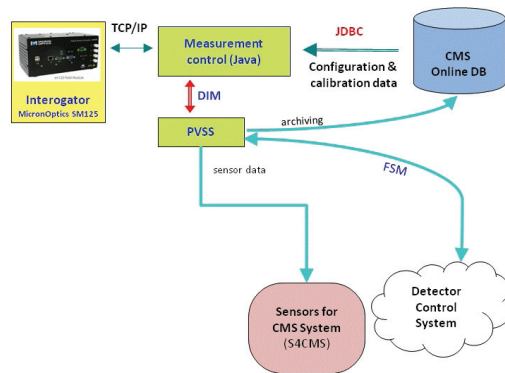


Fig. 3. Integration of the FOS into the CMS Detector Control System

In order to be able to be integrated into the CMS Detector Control System (DCS) (Fig. 3), the read out software uses the DIM protocol [5] that is a custom protocol over TCP/IP developed at CERN. DCS system of the CMS detector is implemented in the widely used PVSS [6] process management software language using the CERN built JCOPS framework [7]. In PVSS we also developed a module that connects to the read out software via DIM and then provides the quasi standard interface required by the experiment. This module besides the relaying commands to the FOS system is responsible for the archiving the recorded data into the CMS online Oracle database. This module is heavily used by the Sensors for CMS (S4CMS) project that collects and visualizes data from various subsystems to allow better understanding of the behavior of the CMS detector. Furthermore, the read out software is also able to dump the raw data into text files to allow offline analysis.

3. Results of the one year operation in 2010

3.1. Bulkhead temperature measurements

Temperature has been recorded continuously throughout the year (Fig. 4, left plot). On this picture large variations of the values can also be seen. They are in complete coincidence with the Tracker power cycles. Temperature change after the September technical stop reflects the change of the Tracker temperature settings. The observed accuracy of the measured reflected wavelength is around 1 pm. This value is determined by the accuracy of the peak finding algorithm of the system. This results in 0.1 K and 1 $\mu\epsilon$ measurement accuracy on the temperature and strain measurements respectively.

FOS temperature measurements on the Bulkheads were compared to those of the Tracker itself (but inside the Bulkhead thermal shield) measured by the Tracker Team. Good correlation is observed between the two data sets (Fig. 4, right plot), therefore validating the FOS technology. The source for the observable overshooting and the problems to the correlation are identified as the relatively large dead bands defined for the Tracker temperature data.

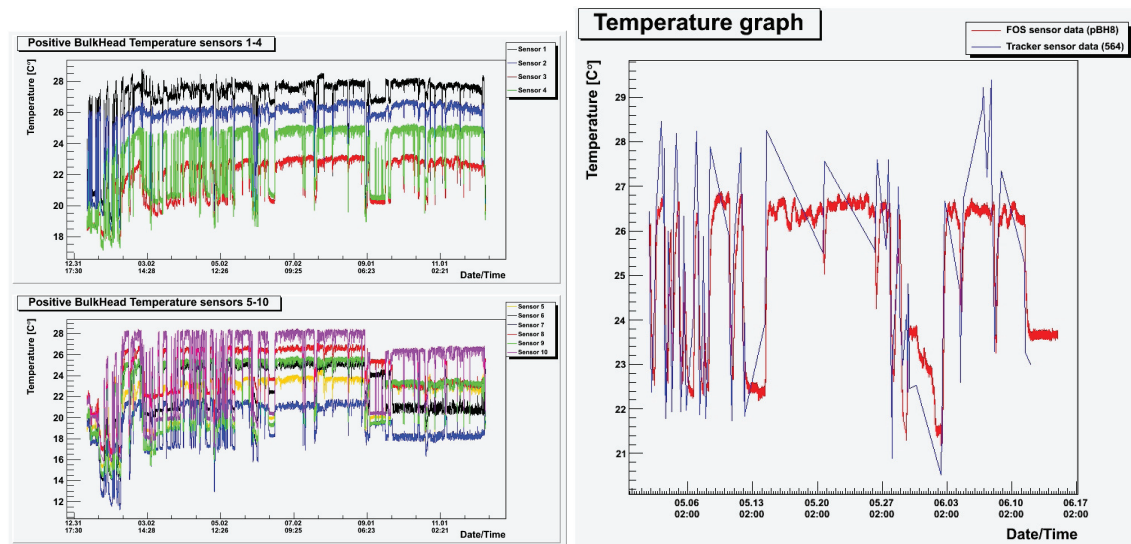


Fig. 4. Temperature measurements on the Tracker Bulkhead positive side. On the left graph all the measured data are shown as a function of time, while on the right side both the FBG and the Tracker's own PT100 measurements can be seen.

3.2. Results of the Raiser structure

Strain changes follow the CMS magnet cycles. Compression of the Raiser structure is observed on the IP side, while decompression of the same structure is seen on the non-IP side. Calculations showed that despite the relatively large shear displacements (~ 1.5 mm), the rotation centre is more or less coinciding with the internal beampipe support therefore no destructive force is exerted on the beampipe.

Raiser structure responds very similar to the successive magnet ramps. The only exception is the very first ramp when the final closure of the CMS structure happened. This final closure effect has also been observed inside the Barrel with the Hardware Muon Alignment System.

Strain measurements are always affected by the temperature. In order to eliminate the thermal expansion-caused fake strain, a calm period has been chosen when the change of the strain data is expected purely from the temperature variation. After this correlation is determined, raw strain data can be compensated.

The temperature compensation shows that the thermal expansion alone can not be responsible for the differences seen on the ramp up historical plots (left plot in Fig. 5). Instead, a long term baseline wandering is observed. However, if only the relative strain variation is calculated (right plot in Fig. 5), strain variation among the different magnet ramp ups falls in the order of the measurement uncertainty.

3.3. Results of the support structure of the CASTOR subdetector

The CASTOR detector has to be placed on a platform attached to the HF structure. In order to ensure the safe operation of the whole structure, the strains in this platform are to be measured. Unfortunately, with the available engineering simulation softwares it was impossible to calculate the overall effect of the gravity and the magnetic field on this platform. Therefore, at first a calculation has been performed at zero magnetic field for the gravity-only distortion that was validated by the FBG data. Then, the FBG data recorded in high magnetic field was used to calculate the strain distribution. Calculations showed that no destructive forces are exerted in this region.

4. Conclusion

The long-term monitoring of strains and temperatures in the CMS detector in 2010 was successfully performed. Temperature measurements in the Bulkhead regions of the Tracker detector were validated by

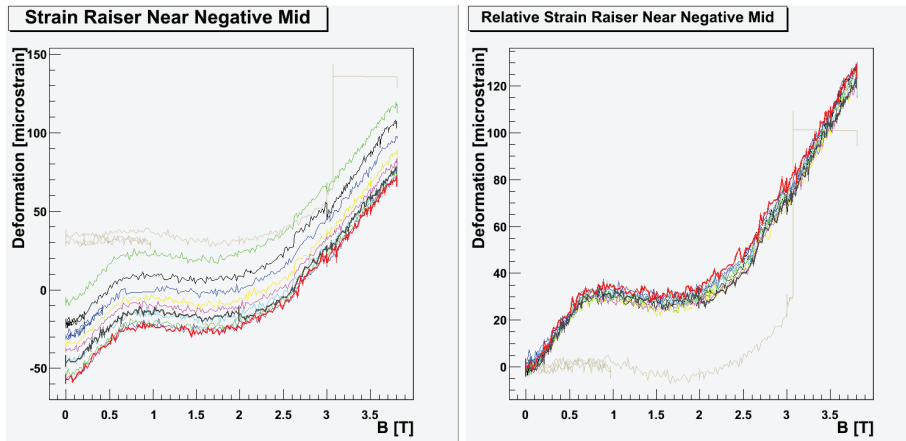


Fig. 5. Result of the temperature compensation of the Raiser's strain data. Left plot shows the temperature-compensated strain variations during each individual magnet ramp-up (curves with different colors), while on the right plot the relative variation of the strain for the same ramp-ups can be seen.

the Tracker's internal measurements. The strain measurements of the Raiser structure of the HF subdetector showed that no destructive forces are exerted on the beam pipe during the magnet ramp ups. The temperature compensation of the data showed that the strain evolution in the Raisers are nicely repeated during the successive magnet ramp activities. Using the FBG data the magnetic field-induced strain distribution at the CASTOR platform could be calculated.

The successful first year operation allowed our team to install further 60 sensors in the CMS experimental cavern to monitor the full temperature map of the cavern. They are assembled into only two fibers and read out by the same readout system.

5. Acknowledgements

Authors acknowledge A. Ball, P. Siegrist and W. Zeuner (CERN) for their continuous interest and support to the introduction of FOS technique in the framework of CMS detector. The technical support and very effective collaboration of J. Antunes, G. Faber and A. Gaddi (CERN) and T. Rodrigo (University of Cantabria) is also acknowledged for the installation of strain FOS and their data evaluation versus magnetic field cycles. F. Palmonari (INFN - Pisa) is acknowledged for his support in the installation of T FOS in CMS bulk head region and data evaluation. F. Glege, M. Hansen (CERN) gave a relevant contribution for full integration of the readout system in the standards of CMS central DCS. L. Petrazzuoli (University of Naples) has given a crucial contribution in the measurement campaign of FOS RH prototypes at CERN. We also would like to express our acknowledge to CERN and the Hungarian Scientific Research Fund (OTKA): NK81447 for their support.

References

- [1] K. Hill, B. Malo, F. Bilodeau, D. Johnson, and J. Albert, Bragg gratings fabricated in a monomode photosensitive optical bre by UV exposure through a phase mask, *Appl. Phys. Lett.* 62, 10351037 (1993).
- [2] <http://www.micronoptics.com/uploads/library/documents/Datasheets/Micron%20Optics%20sm125.pdf>
- [3] R. Arcidiacono et al., "CMS DCS design concepts", ICALEPCS 2005, Switzerland, Geneva, 2005.
- [4] CMS Collaboration (R. Adolphi *et al.*), "The CMS experiment at the CERN LHC", JINST 3:S08004.
- [5] DIM, a Portable, Light Weight Package for Information Publishing, Data Transfer and Inter-process Communication, Presented at: International Conference on Computing in High Energy and Nuclear Physics (Padova, Italy, 1-11 February 2000)
- [6] ETM, PVSSII - <http://www.etm.at>
- [7] JCOP framework - <http://itcobe.web.cern.ch/itcobe/Projects/Framework/welcome.html>