The Compact Muon Solenoid Experiment

Conference Report

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Design, Construction and Commissioning of the Upgrade Radiation Damage Monitoring System of the CMS Hadron Forward Calorimeters

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Abstract

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Recently, a new monitoring device based on solid state laser diode technology was designed, constructed and installed. The basic operational integrity was tested extensively prior to installation. The module was integrated into the front-end electronics in a similar way as the Phase I Upgrade LED calibration system.

Here we describe the details of the radiation monitoring system and present the commissioning and integration phases.

Index Terms—Forward hadron calorimeter, radiation damage monitoring system, calorimeter upgrade

I. INTRODUCTION

The Compact Muon Solenoid (CMS) [1] is a general-purpose detector designed to run at the highest luminosity provided by the CERN Large Hadron Collider (LHC). The CMS detector calorimeter has been designed to detect cleanly the diverse signatures of new physics through the measurement of jets with moderate precision and by measuring missing transverse energy flow. The CMS experiment has a 3.8 T superconducting solenoidal magnet of length 13 m and inner diameter 5.9 m. The magnet determines many of the features of the CMS calorimeters because the barrel and end-cap calorimeters are located inside the coil. Figure 1 shows a sketch of the CMS detector anatomy with a dedicated indication of the hadron calorimeters.

Coverage between pseudorapidities (η) of 3.0 and 5.0 is provided by the steel/quartz fiber Hadron Forward (HF) calorimeter. The front face is located at 11.2 m from the interaction point and the depth of the absorber is 1.65 m. The signal originates from Čerenkov light emitted in the quartz fibers, which is then channeled by the fibers to photomultipliers. The absorber structure is created by machining 1 mm square grooves into steel plates, which are then diffusion welded. The diameter of the quartz fibers is 0.6 mm and they are placed 5 mm apart in a square grid. The quartz fibers, which run parallel to the beamline, have two different lengths (1.43 m and

Fig. 1. A sketch of the CMS detector system showing hadron calorimeters (HCAL).

1.65 m) which are inserted into grooves, creating two effective longitudinal samplings. The so-called "short fibers" start 22 cm inside the absorber, hence are mostly sensitive to hadron interactions. HF has 900 towers and 1800 channels in the two calorimeter modules [2]. Details of the HF calorimeter design, together with test beam results and calibration methods, can be found in [3].

Being at the highest radiation areas of the CMS detector, the HF calorimeter is equipped with the radiation damage monitoring system of the quartz fibers. A certain number of quartz fibers are equipped with a special laser system where both the incident laser light intensity and the intensity of the laser light after traversing the quartz fiber can be measured with the same PMT in the same event. So far, the laser light was being provided with a laser system in the underground service cavern which is several meters away from the HF calorimeters. The light was then split into several fibers before it reached the HF calorimeter quartz fibers.

Recently, a new laser device was developed and implemented on the HF calorimeters. The module utilizes solid state laser diode technology and is based on HF Phase I LED calibration unit concept. The laser diode driver and the control circuit reside on a mezzanine mounted onto the QIE board. Optics mix the light and distribute the light to four output fibers. The module is completely compatible with HF Phase I electronics and software, and is installed in the HF front-end crates which are integrated to the HF calorimeters. The basic operational in-

tegrity of the recently produced modules was tested extensively in the laboratory prior to installation.

Here we describe the details of this novel radiation monitoring system.

II. DESCRIPTION OF THE HF RADIATION DAMAGE MONITORING SYSTEM AND THE NEED FOR THE UPGRADE

Figure 2 shows the old HF radiation damage (RadDam) monitoring system light distribution. The 351 nm laser light originates from the underground service cavern of CMS and is sent to the HF calorimeters through two separate fibers. Each fiber is then split into four to feed four wedges per HF. Each of these split fibers are further multiplied to seven through a wavelength shifter. These seven fibers go through capillaries to distribute the light to the special HF RadDam fibers which are installed inside the HF absorber. Figure 3 shows the HF RadDam principle which is based on the optical time-domain reflectometer technique. The wavelength shifted laser light comes to the capillary where it meets the 2.5 m long special HF RadDam fiber which is polished on both ends. The first reflection occurs in the capillary and the reflected light (S_1) is sent to the photomultiplier tube. The second reflection occurs at the other end of the HF RadDam fiber and this reflected light (S_2) reaches the photomultiplier tube 25 ns, i.e. 1 time slice in the 40 MHz CMS readout scheme, later than S_1 . Therefore, ideally, the two pulses can be measured in two consecutive time slices in the RadDam monitoring data. The ratio $R = S_2/S_1$ is a measure of the fiber transparency and depends on the accumulated dose and on the post data-taking time for recovery. In total, there are 56 RadDam fibers installed at 7 eta rings of 4 wedges in each HF.

Fig. 2. Old HF radiation damage monitoring system light distribution.

Figure 4 shows the observed signal loss in HF quartz fibers in 2011-2012 data taking period. The signal loss is expressed as a function of the total accumulated dose. Although, even at the high η region the loss is minimal, a continuous and reliable monitoring is necessary to measure the loss in-situ and apply relevant corrections to the data if necessary.

The continuous monitoring of the HF radiation damage requires a stable light source with minimal pulse width and jitter. The analysis of the data obtained with the old HF

Fig. 3. A sketch showing radiation damage monitoring principle with optical time-domain reflectometer technique.

Fig. 4. Observed signal loss in HF quartz fibers in 2011-2012.

laser system implied several challenges, the largest being the detailed measurement of the laser pulse timing with respect to the beginning of the data time slices, which is called the phase. Figure 5 shows an example signal phase determination with the old monitoring system. With successive data taking, an optimal phase in the stable region (the flat region between 15-20 ns of phase) was being determined. However, in the process of data taking, the phase also became a parameter that needed to be monitored. With an easy shift of the input laser timing conditions due to small interventions on the laser hardware and the overall timing conditions in the data taking such as new settings in the front-end and back-end electronics of the HCAL, the HF RadDam data taking could easily shift from the stable region to an intermediate region where the S_1 and S_2 being in two consecutive time slices condition is no

longer valid. In order to overcome these issues, a new laser light source, which is preferably closer to the detector and can be directly integrated into the front-end structure as in the case of the LED calibration system, producing a laser pulse which is narrow, fast, bright and reliable was developed.

Fig. 5. Example signal phase determination with the old monitoring system.

III. THE NEW LASER LIGHT SOURCE OF THE HF RADIATION DAMAGE MONITORING SYSTEM

The new light source is a daughter board mounted to an HF QIE card similar to the calibration unit LED driver. Figure 6 shows the schematic view of the laser daughter board as part of the QIE front-end card. The wavelength of the light is 450 nm, which also enables the removal of the wavelength-shifters. The upgrade HF RadDam light distribution is shown in Fig. 7.

Fig. 6. The schematic of the new QIE laser board.

There is a high flexibility of settings enabled by being an integral part of the upgrade front-end electronics such as the 32 ns delay range adjustable in 0.5 ns steps and the pulse

Fig. 7. A sketch of the upgrade HF radiation damage monitoring system light distribution and electronics chain.

width adjustable from less than 3 ns to 30 ns full width at half maximum. There is also an on-board PIN diode to independently monitor the performance of the light source. Figure 8 shows an example measurement of the laser pulse using this PIN diode as the blue colored pulse, which is approximately 5 ns wide. The red colored pulse is from the reflected light. Overall, the new laser light source is capable of producing a factor of 20 larger amplitude signals compared to the old laser light source.

Fig. 8. Laser signal as seen on an oscilloscope.

Following excessive testing in the laboratory, the new HF RadDam monitoring laser light source modules were installed on the HF's in the Year End Technical Stop 2017-2018. The system has been in successful operation since then. Figure 9 shows an example RadDam monitoring laser pulse from a dedicated data taking run. The horizontal axis is the time slice id each of which represents 25 ns, and the vertical axis is the signal amplitude. The first reflection pulse is in time slice 3 and the second reflection pulse is in time slice 4.

Fig. 9. Upgrade HF radiation damage monitoring system pulse from local data taking.

IV. CONCLUSIONS

A new light source was developed to replace the HCAL laser in order to provide sharper, brighter, and more stable pulses to the HF radiation damage monitoring system. Units have been built at Iowa, tested at CERN, and installed on the HFs in Year End Technical Stop 2017-2018. The light sources have been operated since installation with smooth, robust and reliable data taking. Work is ongoing in order to quantify the radiation damage in 2018 with the new system, as well as to quantify the recovery process in the long shutdown of CERN accelerators in 2019-2021.

REFERENCES

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