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The network of photodetectors and diode lasers of the CMS Link alignment system

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ABSTRACT

The central feature of the CMS Link alignment system is a network of Amorphous Silicon Position Detectors distributed throughout the muon spectrometer that are connected by multiple laser lines. The data collected during the years from 2008 to 2015 is presented confirming an outstanding performance of the photo sensors during more than seven years of operation. Details of the photo sensor readout of the laser signals are presented. The mechanical motions of the CMS detector are monitored using these photosensors and good agreement with distance sensors is obtained.

1. Introduction

A major part of the Compact Muon Solenoid detector (CMS) [1–4] is a powerful muon spectrometer [3] that identifies and measures muons over a wide range of energy from a few GeV up to several TeV. The CMS detector basically has a cylindrical symmetry around the LHC beam pipe, an overall diameter of 15 m, a total length of 21.6 m and weighs 12.5 kt (mainly iron flux return). At its heart, a 13 m long, 6 m inner diameter superconducting solenoid [2] provides a 3.8 T field along the beam axis and a bending power of about 12 Tm in the transverse plane. The field return consists of 1.5 m of iron layers interspersed with four muon stations in both the barrel and endcap regions that ensure full geometrical coverage and sufficient redundancy.

The accuracy required in the position measurement of the muon chambers is driven by the resolution desired in the momentum measurement of high energy muons. CMS is designed to achieve a combined (Muon System [3] and Tracker [4]) momentum resolution of 0.5%–1% for $p_T \approx 10$ GeV, 1.5%–5% for $p_T \approx 100$ GeV and 5%–20% for $p_T \approx 1$ TeV for the region $|\eta| < 2.4$. This momentum resolution requires the knowledge of the position of the chambers with a precision comparable to their resolution.

Simulation studies were performed [5] to quantify the importance of muon chamber location for the momentum resolution. The solenoidal magnetic field bends charged particles in $r\phi$, the most important coordinate for determining the muon momentum. Hence, the alignment system should reconstruct the position of the chambers within 150–300

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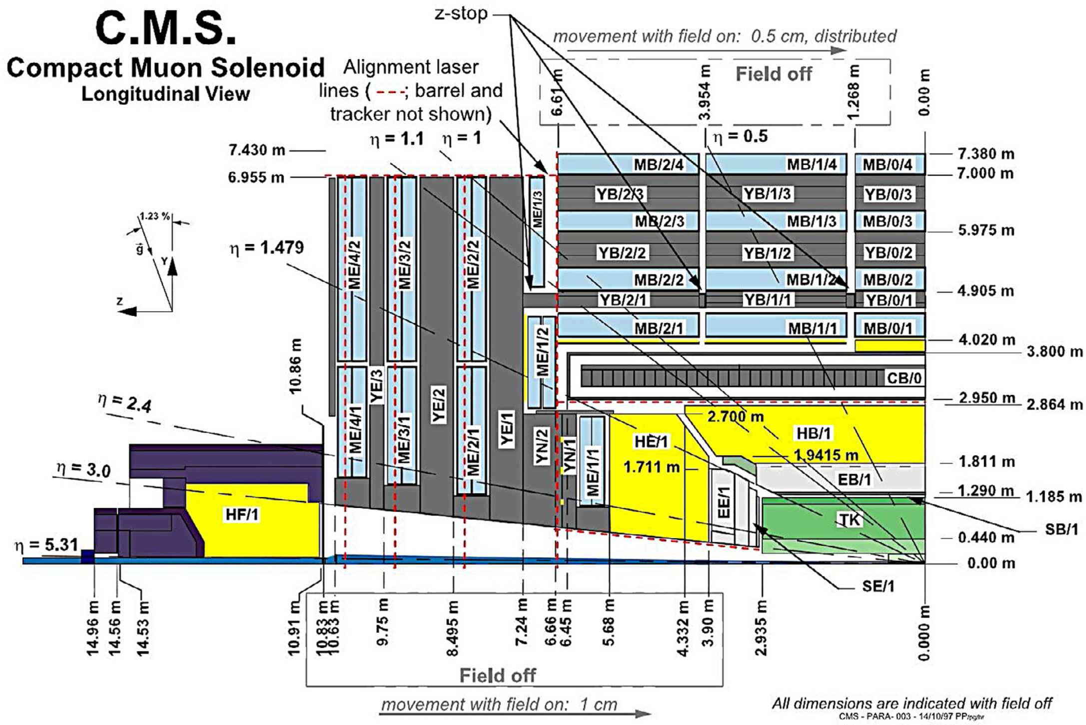

Fig. 1. Longitudinal view of one quadrant of the CMS detector. Laser lines (in dashed) used for the Alignment System are shown, except for the barrel region. The position of the Z-stops is also indicated. The floor of the detector has a small inclination of about 1.23% with respect to the gravity vector **g** as depicted in the small drawing on the left.

μm for MB1–MB4 and within 75–200 μm for ME1–ME4 (Fig. 1). The tighter constraints correspond to the first stations (MB1 and ME1) since the magnetic bending in the return yoke is reversed with respect to the magnetic field in the solenoid and hence the largest bending and best momentum determination is measured in the first stations. Since these stations are located immediately outside the magnet before the flux return they combine with the Tracker hits to achieve the measurement of the muon momentum.

During CMS operations, the movements and deformations of the muon spectrometer are surely larger than 100 μm. To monitor these motions, CMS is instrumented with an opto-mechanical alignment system that performs a continuous and precise measurement of the relative positions of the muon chambers as well as the position of the muon spectrometer with respect to the tracker, which is aligned independently.

In a previous document [6] the alignment system was presented, and, data taken during the two phases of the 2006 Magnet Test and Cosmic Challenge measured the effects of the ramp up and down in the magnetic field (magnetic cycle). It was shown that the Link system produces geometrical reconstructions of relative spatial locations and angular orientations between the muon chambers and the tracker body with a resolution better than 150 μm for distances and about 40 μrad for angles.

The structural equilibrium of the muon spectrometer was also investigated [7,8]. Using alignment data from the years 2008 and 2009, it was found that once the magnetic field intensity reaches 3.8 T, provided that the current in the coils remains unaltered, the mechanical structures reach equilibrium within the first 24 h. Structural equilibrium means that any displacement in any direction (axial or radial) remains within the short distance sensors resolution: ±40 μm and any rotation within the tilt sensors resolution: ±40 μrad. These structural equilibrium periods will be referred to as stability periods.

To achieve a precise multipoint position monitoring, one needs to measure and/or monitor accurately the space position of a laser beam at several points along its path. In such cases the simplest solution is to use transparent position sensors attached to the pieces whose spatial positions have to be monitored. When the expected independent motions of the pieces are big (i.e. from mm to a couple of cm) the active area of the sensors must be large.

This paper focuses on the description of the CMS Link alignment network of diode lasers and photosensors and presents a brief analysis of the corresponding recorded data during the physics runs in the periods 2008 to 2013 and in 2015. The goal is to show how the photosensors behave during the magnet cycles and the stability periods, how compatible these measurements are with previous studies [7] and how their data are used to help in the CMS geometrical reconstruction.

A short description of the CMS Alignment system is given in Section 2. The general layout, the electronic equivalence and the measurement principle of the amorphous silicon position detectors (ASPDs), as well as the readout electronics are shown in Sections 3, 4 and 5, respectively. A summary of the characteristics of the sensors, their average performance and the tests prior to their installation in CMS are described in Section 6, while Section 7 deals with the description of the network of photo sensors and diode lasers of the CMS Link alignment system. The interpretation of the motions detected by the light spot reconstruction is given in Section 8 and an analysis of those reconstructions during the magnet cycles and the stability periods is done in Section 9. Section 10 shows, with a few examples, how the CMS motions detected with the ASPDs, during the ramping of the magnetic field, correlate with those obtained from the distance-measuring potentiometers (short distance sensors) used in previous studies [6–8]. Finally, Section 11 summarizes the results.

2. The CMS alignment system

The CMS tracking detectors are grouped into four separate systems: two endcaps, the central barrel, and the tracker, which is inside the solenoidal coil. Different muon detection technologies are employed for the central and the endcap regions due to the different backgrounds and the varying intensity and homogeneity of the magnetic field. A