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AN EXPERIMENTAL SET-UP TO MEASURE THE LONG-TERM STABILITY OF LARGE – MIRROR SUPPORTS

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ABSTRACT

Precision of the Cherenkov ring pattern recognition and reconstruction relies, apart from other factors, on highly precise and stable positioning of the spherical mirrors, which focus the Cherenkov light cones produced by the particle to form ring-images on the focal plane. Prototypes of adjustable mirror mountings that hold the mirrors on the support structure have to be tested for their long-term angular stability, in order to ensure that the mirrors will not change their precisely adjusted positions inside the detector vessel. A method, together with a set-up, for such a measurement is presented. As an example, measurement results from a mirror support prototype developed for the RICH2 detector in LHCb are described and discussed.

INTRODUCTION

The optical system of a RICH (Ring Imaging Cherenkov) detector essentially consists of a large spherical mirror wall, which focuses the Cherenkov light cone onto photodetectors placed at the focal plane. Because of mechanical reasons, the mirror wall, having an area of several square meters, is formed by an array of smaller spherical mirrors. These mirrors are usually made of glass and have hexagonal shape with an area of the order of 0.1 m^2. Their thickness is typically less than 7 mm, as the fraction of radiation length represented by the mirror has to be kept as low as possible. Their weight amounts to ~2 kg. The mirrors are cantilevered from the supporting structure by means of adjustable supports.

The requirement for a high-resolution detector means that each single spherical mirror has to be precisely directed to the common focal point at the photodetector plane. The required precision in the LHCb RICH2 detector is 0.1 mrad [1]. It is necessary not only to adjust the tilt of all mirrors to this precision, but also to conserve these positions during the entire detector operational lifetime, this being several years. To check the time stability of the support, we have developed a method based on the differential measurement. Two laser beams are reflected from a beam splitter (reference beam) and from a small mirror fixed on the mirror support (sampling beam). The distance variations between the two beams are proportional to the intrinsic angular deviations of the mirror support and should be independent of temperature and mechanical effects on the optical bench.

We briefly present the properties of the first support prototype developed for the RICH2 of LHCb and then describe in detail the experimental set-up and discuss the first seven months long-term stability measurements.

MECHANICAL PROPERTIES OF POLYCARBONATE

The LHCb RICH2 requirement of robust, stable mirror supports, providing at the same time low fraction of radiation length, resulted in a decision to use Polycarbonate as material for the basic components of the adjustable support.

Polycarbonate (PC) is a thermoplastic polymer with a radiation length of 346 mm. It has good mechanical properties, high resistance to impact damage, good creep resistance up to 115 °C and it can easily be machined. Although the mechanical properties are in general well known, it is not proved that PC has a long term stability which could fulfil the requirements for the mirror support. Creep, stress relaxation and the effect of strain rate on yielding, are generally much more significant to polymers than they are to metals. The following figures show some of the long-term characteristics of PC [2]. Fig. 1a represents the creep modulus[1] as a function of time. The modulus decreased at 23 °C from 2233 MPa to 1645 MPa over 10^4 hours, the applied stress being 5.2 MPa. In the designed support prototype, stresses caused by the mirror weight are approximately an order of magnitude lower. A simple deformation calculation confirmed that the deformation and the resulting mirror angle deviation would still be within the specified limit after 10^4 hours. More data on PC (Fig. 1b) from another brand [2] do not show any unexpected change of creep modulus at least up to 10^5 hours. Data for such a wide time scale are obtained by performing the experiments at different temperatures and synthesizing a curve by using the time-temperature superposition rule [3].

The working principle of the prototype is as follows (Fig. 2a): The adjustment of the mirror tilts is enabled by a flexible membrane (a). The whole holder structure (b) is made of one piece of Polycarbonate, eliminating therefore clearances in the mechanism. It is mounted in a prepared hole in a structure (c), which will support all the mirrors and the mirror mountings. A plastic wedge (d) is pressed by a screw (e) into the PC structure, consequently pushing the central part of the holder (f) out of the axis position. The flexible membrane deforms elastically, therefore providing the return force necessary to hold the mirror (g) in place. This tilts around the center of the flexible membrane together with the central part of the holder. The angular tilt α is given by the formula: $\alpha = y / L$, where y is the displacement due to the wedge and L is the length of the PC support. The same principle is applied for horizontal and vertical tilts. A forthcoming paper will show in detail its design and its main adjustment properties.

THE EXPERIMENTAL SET-UP

Measurements were taken under conditions as close as possible to the conditions foreseen in the vessel of the RICH2 detector. The mirror support was loaded by a block of 1.7 kg, simulating the real mirror weight. Ambient temperature changes have the strongest effect on the mechanical behavior of the support. That is why temperature monitoring is incorporated, allowing to check possible temperature influence on the support deviations. To measure stability at the level of 0.1 mrad, the measurement itself must be more precise, say better than 0.01 mrad. The set-up was installed on a thick granite bench in an underground laboratory equipped with air circulation.

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[1] The term “creep modulus”, commonly used in polymer science, is somewhat misleading, in that it does not always represent true, irreversible creep behavior, but often merely anelasticity.

The set-up is shown in Fig. 2b. A 3.5 mW He-Ne laser (a) produces a beam, which is first expanded to ~20 mm and spatially filtered to extract only the TEM_{00} transverse mode (b). Such a diffraction-limited beam is then gently focused on a CCD by using a spherical mirror with 5 m focal length (c). Its spot size and intensity on the CCD can be changed by means of a diaphragm (d) inserted between the beam expander and the mirror (c). Half way between this mirror and the CCD, a beam splitter (e) is inserted. The reflected beam (called reference beam) is directed onto the CCD (i). The transmitted beam instead is reflected from a plane mirror (h) mounted on the support prototype (f), loaded with the weight (k), and again directed onto the CCD (sampling beam).

Tilt in the prototype support is therefore probed by measuring the distance between reference and sampling beam-spots, where the reference beam will provide differential compensation for all mechanical movements related to the environment, which includes effects like vibrations, thermal expansions, laser instabilities. Fig. 3a shows the two beam spots on the CCD and Fig. 3b shows their diffraction limited profile. For this measurement, the FWHM of the beam profile at the CCD plane was 0.39 mm. For any angle deviation α of the measured support, the reflected beam direction changes by 2α. Therefore, the horizontal and vertical angular deviations (Tilt) are given by

$$\alpha_h = \frac{x_s - x_r}{2L} \quad \text{and} \quad \alpha_v = \frac{y_s - y_r}{2L} \tag{1}$$

and the measurement resolution

$$\Delta\alpha = \frac{\sigma_{cog}}{L} \tag{2}$$

where $x_{s,r}$ and $y_{s,r}$ are the horizontal (vertical) coordinates, $\Delta\alpha$ is the resolution on the measured angle, σ_{cog} is the center of gravity precision of the beam spot on the CCD and L is the distance between plane mirror and CCD window. The measurement range is

$$\alpha_{Rh} = \frac{w}{2L} \; , \; \alpha_{Rv} = \frac{h}{2L} \tag{3}$$

Where α_{Rh} (α_{Rv}) is the angular range in horizontal (vertical) coordinates and w (h) is the width (height) of the CCD active area.

It is worth noting that the beam splitter (e) has to be much more stable than the prototype support (f). This is not trivial to achieve, as the expected tilts of (f) are already very small. It has been achieved by employing the smallest possible beam splitter on a heavy and short steel support. We used a standard CCD camera[2] with a $6.4 \times 4.8\ \text{mm}^2$ active area and a $8.5 \times 8.5\ \mu\text{m}^2$ pixel size. For a distance of 2.33 m between the beam splitter and the CCD window, the measurement resolution $\Delta\alpha$ should be $<5\ \mu$rad for a range α_{Rv} of 1.1 mrad. Vibrations have been minimized by careful choice of all the components constituting the optical bench. In particular, the table is of massive granite, offering high bending and torsion stiffness. Vibration transmission is attenuated by rubber suspension and foam dampers.

The measurement is fully automatic and is controlled by means of a personal computer. We used a frame grabber[3] for image data capturing and a DAQ card[4] for temperature monitoring. The status of the measurement can be checked through the computer network. A program especially developed for this purpose controls image data capturing and analysis. Every hour, the frame grabber integrates ten images during five seconds and the resulting image is saved on disk. Then the image is processed as follows. Every image contains two light spots generated by the sampling and reference beams (see Fig. 3). The program first finds the rough locations of both spots, then calculates their centers of gravity. The spots consist of hundreds of pixels and the precision on spot position is limited only by the existence of interference fringes; it was confirmed experimentally to be 5 μrad or better. Finally, absolute and relative horizontal and vertical positions are calculated. Three temperature probes are read and their averaged values are written to a file every minute.

MEASUREMENTS RESULTS

As an example of long-term stability measurement, the results of the first LHCb RICH2 mirror-support prototype are presented. The measurement has been taken over a period of seven months (approximately 5000 hours) and it is still running. Fig. 4 shows the temperature changes over the whole measurement time. The temperature range was between 17.5 °C and 22.8 °C . The long measurement interruption of 570 hours after 3000 hours was caused by a power cut before the Christmas holidays. Between the 300 and 1200 hours, it is possible to recognize temperature fluctuations with a 24 hours period. Absolute changes of both beam positions in vertical and horizontal coordinates are shown in Figs 5a and 5b. The range of the vertical movement is larger than the horizontal one, possibly due to gravity effects. It is

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[2] model Philips FTM800
[3] model Scion LG-3
[4] model NI PCI-1200

possible to observe a weak correlation between vertical beam movement and temperature variations.

The variations in vertical and horizontal coordinates of the distance between the two spots provide the tilt and therefore the stability properties of the support. This is shown in Figs 6a and 6b. A strong relaxation effect is seen during the first 120 hours in both vertical and horizontal tilt (see inset Figs 6a,b). It may be caused by stress relaxation in the mechanical parts immediately after installation and adjustments. Therefore on the final detector mirror wall, it will be essential to adjust the mirror positions after the relaxation effect. After removing the initial data affected by this effect, the support becomes stable with a range practically equal for both vertical and horizontal coordinates and with a maximum value of 0.03 mrad. This is well inside the final requirement of 0.1 mrad. Moreover, Fig. 7(a,b,c) shows the resulting histograms from Figs 4, 6a and 6b. The distributions show a fairly central peaked shape probably with a weak correlation with temperature. For the stability histograms (Figs 7b and 7c), the FWHM of the central peaks range between 5 to 10 μrad. It is also interesting to note the range of variation for the absolute beam positions (up to 2 mm) with respect to the relative beam displacements (less than 100 μm). Finally, from Figs 6a and 6b we can measure the resolution of the set-up to be in any case better than 5 μrad. After elimination of an interference fringe (which did not affect the measurement and was achieved at ~4500 hours) this resolution went down to 2 μrad. Substituting this value for $\Delta\alpha$ in Eq. (2), we calculate an effective value of σ_{cog} of ~5 μm.

CONCLUSIONS

We have developed a set up for mirror-support long-term stability characterization. It features high stability, precision and insensitivity to ambient temperature effects and vibration.

We have tested an LHCb RICH2 mirror support prototype for the last seven months. It is based on Polycarbonate and a forthcoming paper will show in detail its design. In agreement with the data found in literature for Polycarbonate, no strong time effect on stiffness has been observed. Temperature effects are more significant than creep is and a more definite result will be available only when the ambient temperature returns to the values measured at the beginning of the test. However, even with relatively big temperature variations of + 2 C, the stability of the support is after seven months well within the 0.1 mrad requirements of the LHCb RICH2 detector.

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REFERENCES

[1] LHCb, *“Technical Proposal”*, CERN/LNCC 98-4 LHCC/P4 (1998);

[2] Plastics Design Library, *“The Effect of Creep and other time related factors on plastics”*, Vol. I, Book A (1991), Norwich;

[3] A.I. Goldman, *“Prediction of the deformation properties of polymeric and composite materials”*, M. Shelef and R.A. Dickie Eds, (1994) Washington Am. Chem. Society.