Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Development of light-weight spherical mirrors for RICH detectors

F.C.D. Metlica

H.H. Wills Physics Laboratory, Department of Physics, University of Bristol, Tyndall Avenue, Bristol, BS8 1TL, UK

On behalf of the LHCb Collaboration

ARTICLE INFO

Keywords:

RICH
LHCb
Light-weight mirrors
Carbon-fiber
Beryllium

ABSTRACT

Glass-coated beryllium and carbon-fiber light-weight spherical mirrors, with radii of curvature of ~ 2700 mm, have been successfully developed and tested as part of the LHCb RICH experimental programme. The low mass mirror is necessary to minimize the amount of material within the LHCb spectrometer acceptance, with a requirement of less than 2% of a radiation length. Both technologies are suitable for light-weight mirror applications. The R&D and characterization of the mirrors are reported.

© 2008 Elsevier B.V. All rights reserved.

1. Introduction

Light-weight mirrors are required in RICH detectors whenever the material budget needs to be minimized to reduce particle interactions with the mirror material. Two promising light-weight technologies have been developed for the spherical mirrors of the RICH 1 detector of the LHCb experiment [1]: glass-coated beryllium and carbon-fiber. After a successful R&D programme in both technologies, the carbon-fiber technology was chosen. Three important parameters define the mirror optical quality: reflectivity, radius of curvature (R) and the average geometrical quality D_0 . The parameter D_0 is defined as the diameter of the circle at the mirror center of curvature (CoC) which contains 95% of the reflected light intensity from a point source placed at the CoC. The two mirror technologies have been characterized at CERN and both must satisfy the following requirements:

- **light-weight:** radiation length $< 2\%X_0$ and a nuclear interaction length $< 1\lambda_I$;
- **radiation tolerant:** no significant degradation of the mirror properties up to 10 kGy absorbed dose, equivalent to 10 years in the radiation environment of RICH 1;
- **fluorocarbon compatibility:** with the C_4F_{10} RICH 1 gas radiator;
- **structural rigidity:** the mirror does not deform under its own weight when supported;
- **optical quality:** $D_0 < 2.5$ mm, the radius of curvature is within 1% of its design value of $R = 2700$ mm, and the average reflectivity is $\sim 90\%$ in the 200–600 nm wavelength range.

2. Glass-coated beryllium technology

Beryllium ($Z = 4$) possesses unique properties ideal for light-weight applications, i.e. long radiation length, radiation hard, fluorocarbon compatibility, non-magnetic, light-weight and good rigidity. The principal disadvantages in using beryllium are the high manufacturing costs and its high toxicity which requires special safety measures during manufacturing and handling. Typical polished beryllium surfaces have an average surface roughness of ~ 20 – 30 nm rms resulting in only $\sim 50\%$ reflectivity in the visible and UV range. High reflectivity, $\sim 90\%$ in the visible and UV, can be obtained by glass coating a beryllium substrate and then polishing the glass surface with standard optical methods and then applying an aluminium reflective film.

Three small sized glass-coated beryllium prototypes [2] have been manufactured in Russia¹ and tested successfully at CERN. The first prototype is a circular flat mirror with a diameter of 95 mm and consists of a 10 mm thick beryllium substrate coated with a 1 mm glass layer, resulting in $3.6\%X_0$ and $D_0 < 0.1$ mm. The second prototype is also circular, with a diameter of 280 mm, consisting of a 5 mm thick beryllium substrate with a 1 mm glass layer coating and reinforced by a 20 mm thick rib-like structure, giving an average of $3.3\%X_0$. The rib-like structure ensures high mirror rigidity. Its D_0 is 0.85 mm and radius of curvature $R = 7926$ mm is close to the design value of $R = 8000$ mm. The third prototype is rectangular shaped, 375 mm $\times$ 300 mm. It consists of a 6 mm thick beryllium substrate and a 0.3 mm glass coating, giving $1.9\%X_0$. The measured D_0 is 0.41 mm and $R = 1696$ mm is very close to the design value of 1700 mm.

As a result of the success of the small-sized prototypes, a full-sized beryllium prototype was designed and manufactured so

E-mail address: Fabio.Metlica@cern.ch¹ Kompozit Joint Stock Company, Moscow.

Fig. 2. CFRP mirror sandwich honeycomb structure. The top skin which is glued onto the core cells is seen on the left.

areal density of $\sim 5 \text{ kg/m}^2$ and an aluminium plus silicon monoxide (Al + SiO) reflective coating. The demonstration mirror, a small mirror (M1) and a flat sample (F1) were exposed only to C_4F_{10} , while the other small mirror (M2) and flat sample (F2) were exposed only to radiation. No change in the optical and mechanical properties of the prototypes was measured after either exposure. The D_0 and R of the demonstration mirror ($D_0 \sim 1 \text{ mm}$, $R \sim 2205 \text{ mm}$) and the two small mirrors M1 and M2 ($D_0 \sim 0.8 \text{ mm}$, $R \sim 1890 \text{ mm}$) remained unchanged, as well as the reflectivity over the 200–600 nm range.¹¹ Also the mechanical properties of the flat samples (F1, F2) remained invariant, i.e. flexural rigidity (bending) $\sim 33 \text{ N/mm}$, tensile rigidity (pulling) $\sim 8 \text{ kN/mm}$ and average surface roughness¹² (R_a) $\sim 1.8 \mu\text{m}$. Furthermore, comparison of microscope photos ($\times 100$) after varying degrees of either exposure showed no noticeable change in the structure of the flat samples.

The CFRP technology proved to be very promising and it was chosen for RICH 1. The optical design consists of four spherical mirrors, $R = 2700 \text{ mm}$, supported by a CFRP frame. The frame is made of two C-like halves joined at the center top and bottom, with the LHCb beampipe passing through the center of the four mirrors, see Fig. 3. Each mirror is $\sim 640 \text{ mm} \times 835 \text{ mm}$ with an areal density of $\sim 5.5 \text{ kg/m}^2 (\sim 1.3\% X_0)$ and is supported by the CFRP frame at three points on the outer mirror corners, which lie outside the detector acceptance. The mirrors have a sandwich honeycomb structure, consisting of two outer CFRP skins with cylindrical core cells lying in between the skins as reinforcement (see Fig. 2). The two outer edges which support the mirror have square cells for increased reinforcement. The core cells and the skins are glued together. FEA¹³ studies have been carried out for the mirrors supported in the RICH 1 configuration, giving a maximum deflection to the unsupported mirror edge (near the beampipe) of $\sim 3.5 \mu\text{m}$.

The four production mirrors were characterized at CERN. The mirrors are of good optical quality having very similar D_0 and R values between mirrors: i.e. $D_0 \sim 1.2 \text{ mm}$ and $R \sim 2710 \text{ mm}$. Ronchigrams taken at CMA give straight lines indicating that the mirrors have a good spherical surface. The four production mirrors

Fig. 3. The four coated CFRP mirrors and CFRP support frame installed in RICH 1 with the beryllium beampipe at the center and two flat glass mirror arrays on the right.

were coated at SESO¹⁴ with Al(80 nm) + MgF_2 (160 nm),¹⁵ giving an average reflectivity of $\sim 90\%$ with the reflectivity being always $> 85\%$ over the 200–600 nm range. CMA's standard reflectivity coating is Al(80 nm) + SiO(80 nm) which gives a good reflectivity in the visible but did not quite meet the LHCb specification in the UV. The CFRP spherical mirrors were installed into RICH 1 in July 2007 in the LHCb underground experiment hall, now awaiting the LHC startup.

4. Summary

Two light-weight mirror technologies have been tested successfully: glass-coated beryllium and carbon-fiber (CFRP). The overall optical quality of the full-sized beryllium prototype mirror is good, $D_0 = 3.3 \text{ mm}$ and $R = 2675 \text{ mm}$. It is the first ever large-sized beryllium mirror, $\sim 400 \text{ mm} \times \sim 660 \text{ mm}$, with a thin beryllium substrate $\sim 4 \text{ mm}$, and a thin glass coating $\sim 0.4 \text{ mm}$ resulting in $\sim 1.6\% X_0$. Improvement in the quality of future mirrors is to be expected with the refinement of the manufacturing technique. Four large, $\sim 640 \text{ mm} \times 835 \text{ mm}$, CFRP spherical mirrors have been manufactured for the LHCb detector RICH 1 detector. They are of good optical quality, well within requirements: $D_0 \sim 1.2 \text{ mm}$, $R \sim 2710 \text{ mm}$, reflectivity $\sim 90\%$ (200–600 nm), $\sim 1.3\% X_0$, and prototypes have been tested successfully for radiation hardness and C_4F_{10} compatibility. CFRP was chosen for RICH 1 because, as well as meeting all the requirements, was also advantageous on grounds of delivery time and cost.

References

- [1] LHCb Collaboration, CERN/LHCC/2003-030, 2003.
- [2] F. Metlica, et al., Nucl. Instr. and Meth. A 570 (2007) 565.
- [3] R.C. Romeo, et al., Proc. SPIE 6273 (2006) 62730S.
- [4] R.N. Martin, et al., Proc. SPIE 6670 (2007) 667000.

¹¹ Demonstration mirror too large to measure its reflectivity.

¹² The surface is not of optical quality.

¹³ Finite element analysis software, SolidWorks.

¹⁴ Societe Europeenne de Systemes Optiques, Aix en Provence, France.

¹⁵ No uniformity coating tool used. The MgF_2 thickness varies from $\sim 160 \text{ nm}$ at the center of the mirror to $\sim 80 \text{ nm}$ at its periphery; similarly for the Al(80 nm).