**Precision optical systems for the new generation of RICH detectors**

M. Laub  EP/TA2, CERN

**Requirements on RICH mirrors**

Ring Imaging Cherenkov (RICH) detectors identify charged particles by measuring their velocity. The opto-mechanical system of the LHCb RICH detector shapes Cherenkov radiation emitted by a high-energy charged particle in the radiator medium, into a ring-image at the photodetector plane. It consists of concave spherical mirrors fixed by means of adjustable mounts on a supporting structure. These components have to fulfill two basic requirements:

- High precision and stability
- Low fraction of radiation length $X_0$

For example, better than 3 sigma $\pi/K$ separation in the momentum range $1-150$ GeV/c in the LHCb experiment requires a single photon resolution of $\sigma_\theta = 0.58$ mrad in RICH-2. To guarantee it, the precision of the opto-mechanical system has to be $\sigma \leq 0.1$ mrad. For focusing mirrors this requirement means a precision of the spherical reflective surface of $\sigma_\theta \leq 0.03$ mrad.

To minimize particle interactions, the thickness of the mirrors should not exceed 4 to 5 % of a radiation length $X_0$.

**Materials**

The requirement for the high precision of the reflecting surface represents a need of high rigidity of the mirror substrate structure, its small thermal dilatations, and good long-term stability. The rigidity $K$ of a thin mirror substrate is proportional to:

$$K = \frac{E t^3}{d^4}$$

where $E$ is Young’s Modulus of used material, $t$ is mirror thickness, and $d$ is its diameter.

<table>
<thead>
<tr>
<th>Material</th>
<th>$E$ [GPa]</th>
<th>$t$ [mm]</th>
<th>$s$ [mm]</th>
<th>$\sigma_\theta$ [mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>72.7</td>
<td>4.4</td>
<td>0.17</td>
<td>0.5</td>
</tr>
<tr>
<td>Perspex</td>
<td>19.3</td>
<td>17.5</td>
<td>26.9</td>
<td>46.3</td>
</tr>
<tr>
<td>Alumina</td>
<td>8.9</td>
<td>4.5</td>
<td>0.9</td>
<td>23.9</td>
</tr>
<tr>
<td>Plexiglas</td>
<td>75.6</td>
<td>17.2</td>
<td>0.31</td>
<td>76.1</td>
</tr>
</tbody>
</table>

**Technologies**

Simple glass substrate

Advantages of glass substrates are: no gas pollution, high radiation hardness and relatively well-known technology. Their disadvantages are fragility, weight, and poor cost-effectiveness. A thickness of 0.4 mm corresponding to 3 % of $X_0$ limits the maximum mirror diameter for which the substrate would be reliable.

Glass foam sandwich

The sandwich consists of two thin layers of glass and thicker layer of glass foam. The three layers are united under high temperature and pressure. The structure with two 0.2-mm glass layers and 40 mm of glass foam corresponds to 6 % of $X_0$. However, the technology is difficult and the gas pollution can be present.

**Achieved parameters**

- Diameter $R$ [mm] 6642 mm
- Relative amount of light [%] 20 30 40 50 70 80 90
- Spot size [mm] 1.66 mm
- Thickness [mm] 4.5 mm
- Dia. [mm] 502 mm
- Hexagon. Mirror
- Center of curvature 6.6 m.
- Value of slope errors taken over the mirror surface $σ_θ = 0.026$ mrad.
- Quantity $s(\sigma_θ/D)$ gives the rms value of slope errors taken over the mirror surface.

**Images**

- Image of one of OMEGA glass-foam sandwich mirrors.
- Spot from the first prototype of composite substrate.
- Measurement set-up.
- Mirror substrate installed on the measurement set-up.

**Measurement set-up**

- Mirror holder
- Mirror holder test
- Optical Disc
- Point source
- Plate source
- Laser source
- Image of point source on spot Radius of curvature $r = R$
- Image of one of OMEGA glass-foam sandwich mirrors.

**Materials used for manufacturing of lightweight mirrors.**

- Beryllium mirror
- Hexagonal and pentagonal glass substrates with diameter of circumference 520 mm, thickness 7 mm and radius of curvature 6.6 m.

**Composite mirrors**

We characterized a prototype manufactured by molding 2-mm layer of Acrylic and putting reinforcing structure of thin layers of carbon fibers, 3 mm of Nomex honeycomb and adhesives. This structure corresponded to about 1 % of $X_0$. Its possible gas pollution, radiation hardness and mechanical stability should be properly verified.

**Beryllium technique mirrors**

A thin layer of glass is machined and connected with grinded Beryllium base. The surface is then polished. The glass must have the same coefficient of thermal expansion as Beryllium. Beryllium is convenient for applications where fraction of $X_0$ should be significantly lower than 5 %. The handling of Beryllium requires special care.

**Conclusion**

The fully automatic set-up measures radius of curvature $r$, and average precision of the reflective surface. The point-like source is imaged via tested mirror into the spot on CCD. Distribution of reflected light intensity inside a circle at different diameters is evaluated and the quality parameter $D_3$ is defined as the smallest diameter inside which 95 % of reflected light is focused.