EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 88-157
9 November 1988

AN IMPROVED METHOD FOR MANUFACTURING ACCURATE AND CHEAP GLASS PARABOLIC MIRRORS

P. Baillon, A. Braem, G. Gendre, G. Muratori and C. Nichols

CERN, Geneva, Switzerland

Abstract

We have developed at CERN a cheap method for manufacturing accurate parabolic mirrors. These mirrors were needed for imaging to a ring the light generated by the Cherenkov radiation in the Ring Imaging Cherenkov detector (RICH) proposed by the DELPHI Experiment [1] at CERN. These mirrors are numerous (300). They are cut from a parabola 800 mm in diameter and have focal lengths ranging from 370 to 400 mm. The focal point needs to have a diameter smaller than 1.2 mm. They should have a good reflectivity in the UV region above 80% at 160 nm. A very good surface quality was required (an average roughness below 1 nm). In order to comply with these requirements and to produce these mirrors as cheaply as possible the conventional heat forming technique had to be thoroughly restudied and improved.

Submitted to Nucl. Instr. and Methods in Physics Research

PB/ed

1. INTRODUCTION

In the frame of the DELPHI Experiment at CERN [1], we had to fabricate six series of 50 paraboloid mirrors with a diameter of 800 mm (in the actual fabrication they were cut to the trapezoidal shape before the reflective coating was applied). The focal length had six different values ranging from 400 mm to 345 mm. The image size for a parallel beam illuminating all the mirror (ϕ 800 mm) should be $< \phi$ 1.2 mm. The mirrors should have a good reflectivity in the vacuum UV.

2. GENERAL DESCRIPTION OF THE FABRICATION TECHNIQUE

For manufacturing the mirrors shape, we formed a warm and soft glass plate against a parabolic mould. This heat forming technique is now classic [2]. By looking at every possible details we improved it: we tried to reach the required quality while keeping the production cost at a reasonable level.

The mould was cast in a special stainless steel alloy (figs 1,2) and machined to a precise concave parabolic shape ϕ 800 mm. A glass plate 6 mm thick with diameter ϕ 830 mm is placed on the mould and the assembly is heated in an oven at 610^0C. At this point, the glass is sufficiently soft to be slumped against the parabolic surface by sucking with a vacuum pump. Upon cooling, a blank is obtained. In the production [3], we cut that blank to the final dimensions. The reflective coating is vacuum evaporated in a special vacuum tank. This technique keeps the surface quality of the original plates. The glass was ordinary float glass and had a roughness of the order of 0.8 nm. A smooth surface is essential for reflectivity in the UV region and a roughness of no more than 1.6 nm is needed to ensure the diffusion of light below a few per cent. The glass thickness was constant within 0.2 mm and both faces were making an angle $<$ 0.4 mrad.

The high quality reflectivity in the vacuum UV was obtained at CERN by a coating of $\approx$ 80 nm of pure aluminium followed by a protective layer near 30 nm of MgF_2. Both layers were applied by vacuum evaporation on the concave surface of the parabolic shapes. The quoted thicknesses are coming from the thickness monitor of the evaporation plant. This monitor does not have absolute calibration.

The mentioned numbers were obtained by optimizing the reflectivity at 165 nm and does not necessarily correspond to the actual values.

3. MOULD FABRICATION

The fabrication of moulds starts with the manufacture of concave spherical shapes approximating the final parabola. They are cast in stainless steel. The type of steel was chosen to have a low thermal expansion coefficient ($13 \cdot 10^{-6}\ {}^{0}\mathrm{C}^{-1}$) close to that of the glass used ($8.5\ 10^{-6}\ {}^{0}\mathrm{C}^{-1}$). It has a high melting point and is known to have a relatively low carbon content and hence a low reaction rate with the glass. In the AFNOR code, it is designated as Z25C13-M (13% Cr, 0.3-0.6% C). The low reaction rate is important since the temperature is raised to 600⁰C. Ordinary carbon steel, in contact with glass at high temperature for several hours, combines with the oxides in the glass and produces disturbing bubbles of carbon dioxide at the back of the plate. The parabolic shape was machined on a numerically controlled lathe in CERN's Central Workshop and was then checked on a 3D measuring device at the metrology centre at CERN. The highest deviation from the parabola was 0.02 mm. The defects were long range and had little influence on the optical quality: the differences in slope introduced by those defects were at most 0.8 mrad, which enlarges the image by 0.3 mm at maximum. A similar type of defect was discovered later by optical examination of the aluminized mirrors and consisted of short wavelength oscillations with a period of 1-3 cm and an amplitude of $\simeq 5\ \mu\mathrm{m}$ resulting in a similar increase of the image size. The suspension of the mould in the oven was improved by supporting it on nine steel balls which were grouped three by three at the corners of three triangular plates, each plate being in turn supported by a single central ball. The balls were allowed enough freedom to roll so that the plates could change their size with no constraints. The purpose of this design was to hold the mould in nine points in order to reduce the deformation due to its own weight. The supporting points were evenly distributed under the mould and each of them, due to our particular arrangement, carries 1/9 of the weight. The distribution of the weight and the rolling ability are very important in order to keep the mould in shape at 600⁰C. The mould is covered with a small amount of boron nitride which acts as a releasing agent. With the type of steel used this coating is not really essential and it needs to be applied only once.

4. GLASS FORMING

The rim of the mould is flat over a width of ≈ 4 mm which supports the glass disc of ϕ 830 mm, 6 mm thick. A ring of stainless steel (ϕ 800 mm) is placed above the glass disc. Its weight prevents the air from penetrating under the glass when this volume is pumped out. The pressure differential across the glass plate is kept low during the warming up period in order to avoid breaking the plate. The pumping is done through a small hole drilled at the centre of the parabolic shape and from a 4 mm deep groove located ≈ 2 mm from the rim. The mould and the glass plate are placed in an oven. The temperature is raised slowly to 610 ^{0}C. At this point, the vacuum under the glass plate is increased. The glass, which is becoming soft, is rapidly pulled into the groove which acts as a vacuum seal. The air is fully evacuated under the glass and the disc slumps into the mould taking the parabolic shape. A vacuum gauge, installed half way between the centre and the edge, indicates when the operation is achieved. Before cooling down pumping is stopped. By sending pressurized air in small extendable bellows, the blocking ring is lifted thus freeing the slumped plate from the mould. The plate can now slide slightly thus compensating the difference of thermal expansion between glass and stainless steel. The total operation lasts ≈ 24 h equally shared by heating and cooling. Fig. 3 gives the temperature curve used at CERN.

5. PROTECTION OF THE GLASS

The glass disc has to be protected by two layers of stainless steel (fig. 2) from the infrared radiations emitted by the walls of the oven which are at a higher temperature than the mould. Without this shielding, the glass would break due to the thermal shock.

6. ALUMINIZATION

After careful cleaning by a traditional method, the mirrors are coated under high quality vacuum with a layer of 80 nm of ultra pure aluminium followed by a layer of MgF_2 of 30 nm. The aluminium evaporation is made within 1 s using a tungsten filament heated by an electrical current dissipating 3kW. The timing is controlled by an automatic pneumatic shutter. Immediately after the aluminization, another filament is switched on and 30 nm of MgF_2 are evaporated within 15 s.

7. RESULTS

7.1 Accuracy of the glass parabolic shapes

After forming, the glass shapes were measured at CERN. We measured the thickness of the glass in various locations by a sonic method. We compared the concave shape to the expected parabola with the 3D measuring machine. We found that the variations of thickness were of long range type (of the order of 0.2 mm over 200 mm). The maximum deviations from a parabola were also 0.2 mm, compatible with the variations of thickness of the plate. We attribute these deviations to the original variations of thickness of the plate and to the stretching of the plate on the mould. The maximum deviation observed on the measuring machine over 1 cm leads to a maximum variation of slope on the reflective surface of 1.6 mrad. This explains most of the 1 mm distortion observed at the focal point.

7.2 Image size

The size of the image was measured using a parallel beam, along the axis of the parabola, illuminating at least a region containing both the edge and the centre of the mirror. This parallel beam was generated by an auxiliary optical spherical mirror (ϕ 560 mm and 2673 mm focal length) with a point source (ϕ 0.4mm) at the focus. The size of the images, given by the parabolic mirrors after reflection, was measured by finding a hole which placed at the focal point allowed $\approx$ 90% of the light to pass. For this we used a 5 x 5 mm photocell close to the focal point and we compared the current released with and without various calibrated holes. We confirmed the measurement by scanning with a photosensitive cell moving through the image and recording, for each small displacement, the current given by the cell. The position of the cell was known by the number of pulses sent to a stepper motor used to displace the cell. The image sizes were found to be $\simeq$ 1 mm for a parallel beam along the axis illuminating various regions (ϕ 560 mm) of the mirror.

7.3 Reflectivity

Fig. 4 shows a typical reflectivity curve as a function of the wavelength for mirrors produced at CERN and coated as explained above in sect. 6. A new spectrophotometer was built for measuring the reflectivity of mirrors in the vacuum UV and is described elsewhere [4].

7.4 Production of the 300 mirrors

Ref. [3] will describe how the method exposed above has been transferred to industry. The overall quality measurement on the 300 mirror production will also be given there. Fig. 4 shows the average reflectivity for these mirrors and fig. 5 the distribution of the ratio of the light in a hole of ϕ 1.2mm over the total reflected light for the total sample.

Acknowledgements

We take the opportunity to thank here many people who contributed to the realization: C.Boudineau, R. Hanni, J. Penalver and F. Vair from the technical service, J.B. Franco, E. Gauman, B. Goret, G. Lecoeur, J. Perez, P. Quéru, J. Raynaud, E. Rosso, D. Soria-Bull and R. Timellini from the Experimental Facility Technical Assistance; D. Carminati, J. Dixon, J. Lecoultre and M. Price from the Experimental Physics Division. We also thank for their advice and support U. Amaldi, J. Allaby, M. Davenport, T. Ekelof, J. Séguinot, T. Ypsilantis. We are grateful to all the physicists who measured the mirrors: S. Anassontzis, M. Berggreen, J. Contreras, M. Denoreaz, S. Haider, F. Hahn, I. Herbst, W. Klempt, D. Langervelt, B. Pattison, D. Toet, D. Treille, K. Wilhelmsen and Y. Zolnierowski.

REFERENCES

[1] DELPHI 83-66/1; CERN/LEPC 83-3, 17 May 1983.

[2] A. Bevan et al., Nucl. Instr. and Meth. 203 (1982) 159 – 166.

[3] P. Baillon et al., to be published.

[4] P. Baillon et al., to be published.

FIGURE CAPTIONS

Fig. 1	Drawing of the mould and its suspension.
Fig. 2	Assembling of the vacuum ring with the heat shields.
Fig. 3	Temperature of the oven versus the time.
Fig. 4	Reflectivities measurement made at CERN on Bofors and CERN mirrors.
Fig. 5	Number of mirrors versus the ratio of light in a hole ϕ 1.2 mm.

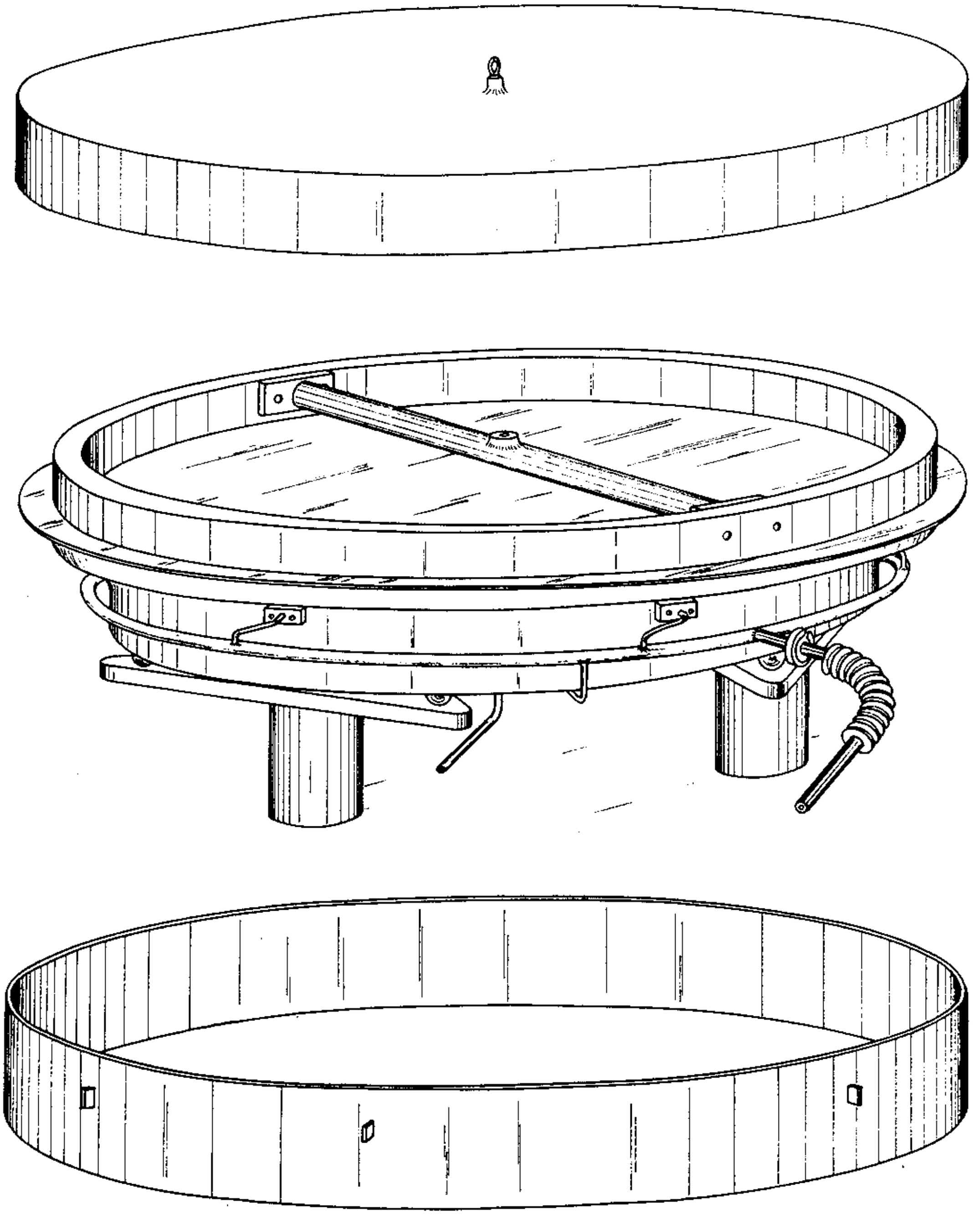

Fig. 1

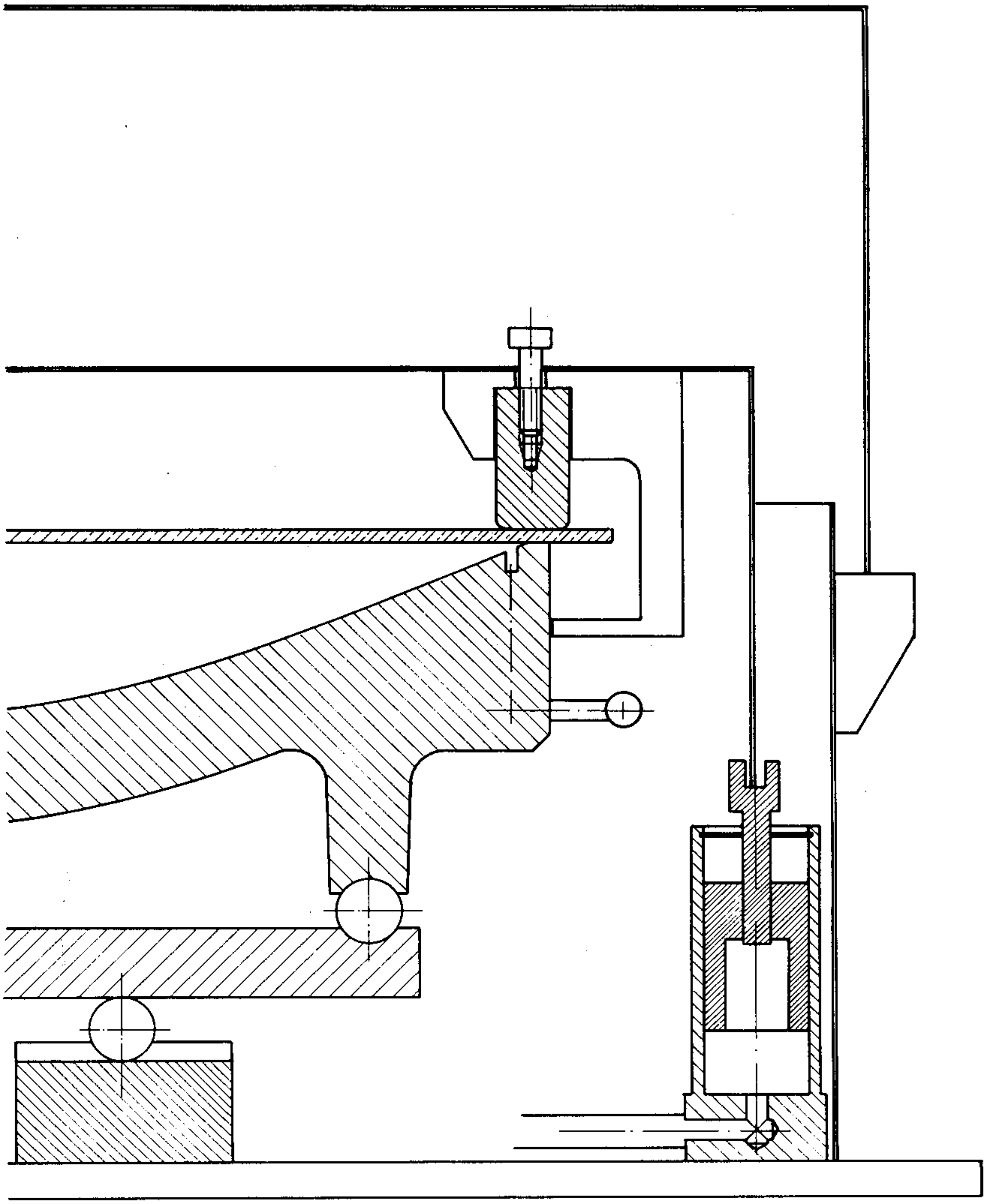

Fig. 2

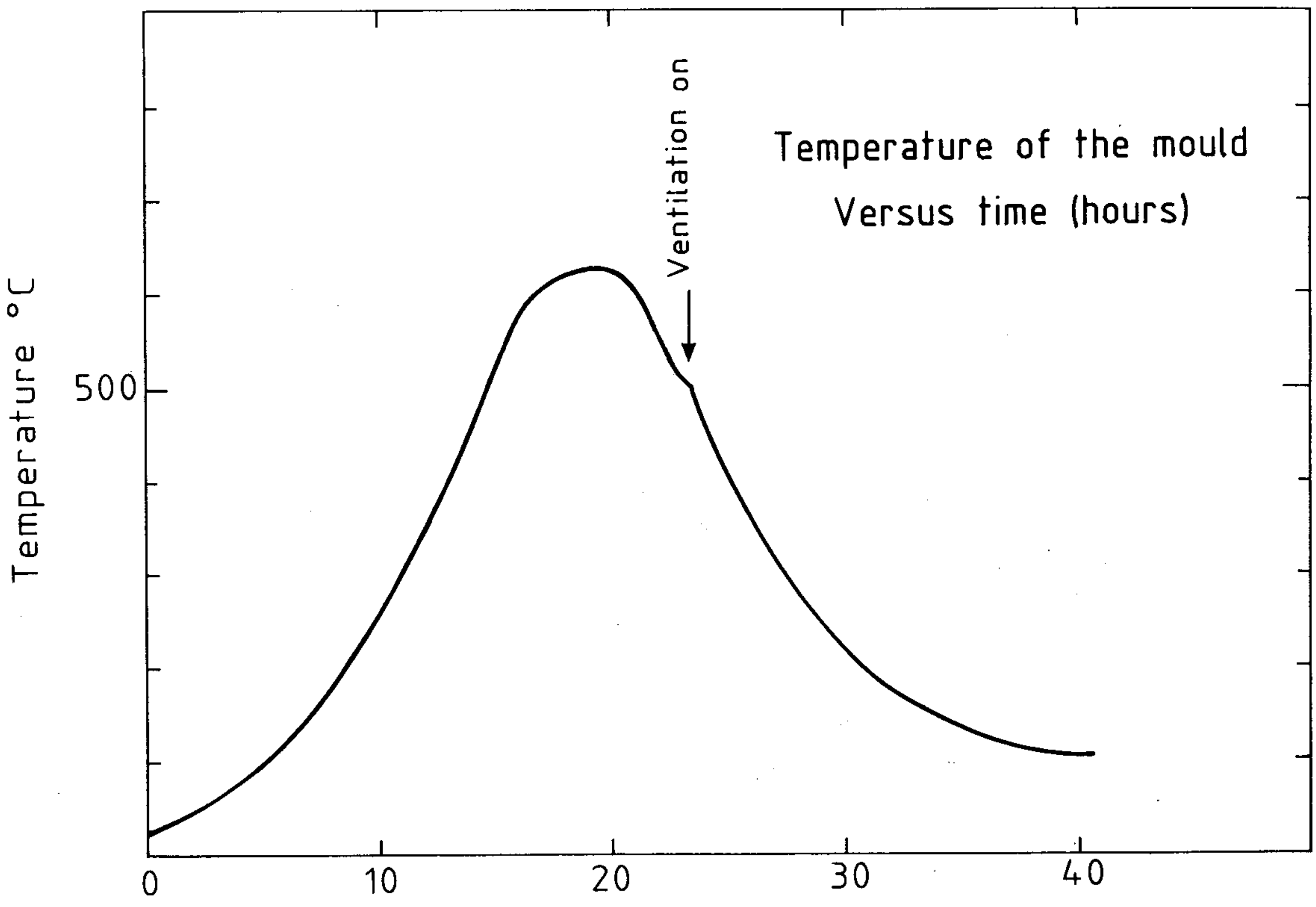
Temperature of the mould
Versus time (hours)
Ventilation on
Temperature °C
500
0
10
20
30
40

Fig. 3

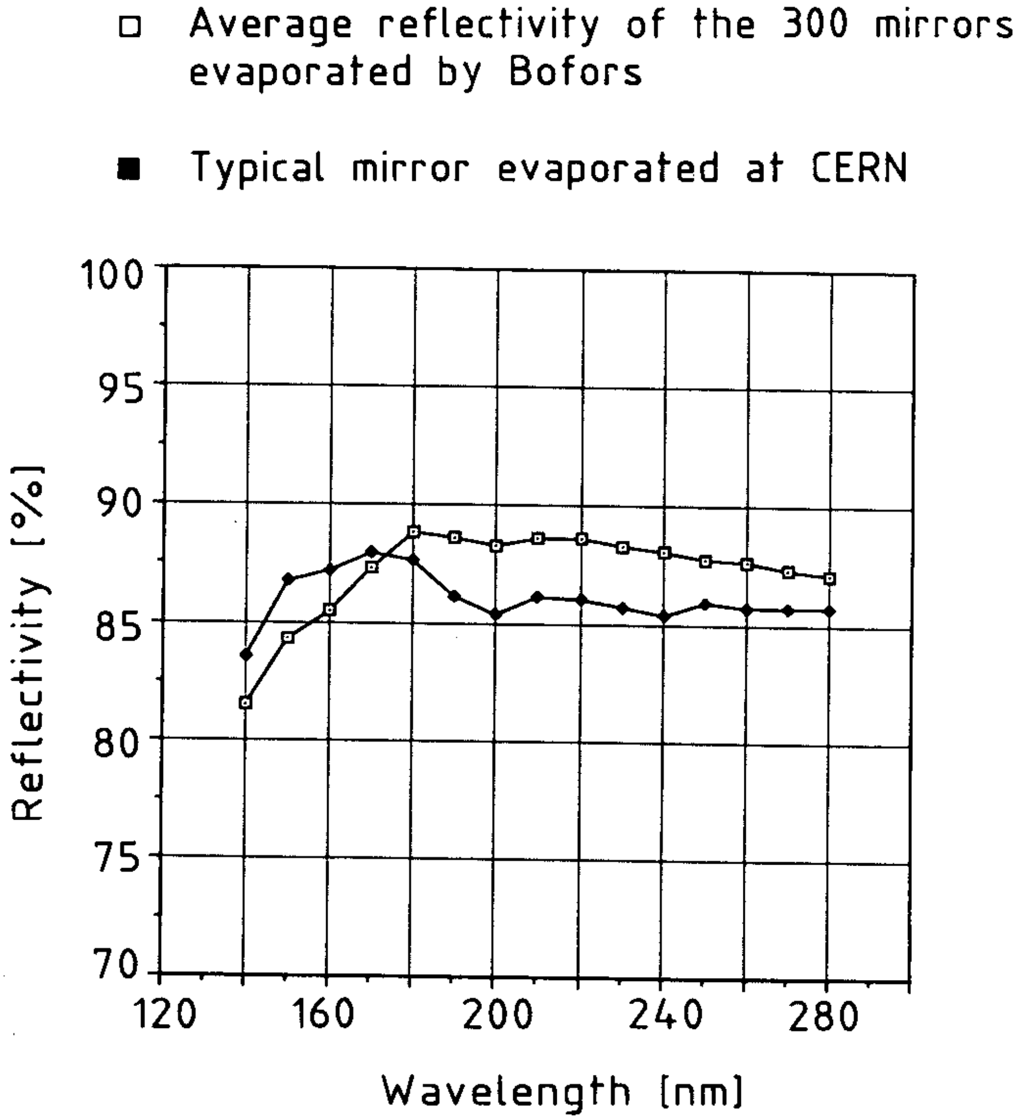
□ Average reflectivity of the 300 mirrors evaporated by Bofors
■ Typical mirror evaporated at CERN
Reflectivity [%]
100
95
90
85
80
75
70
120
160
200
240
280
Wavelength [nm]

Fig. 4

BARREL RICH MIRRORS
Focalisation test

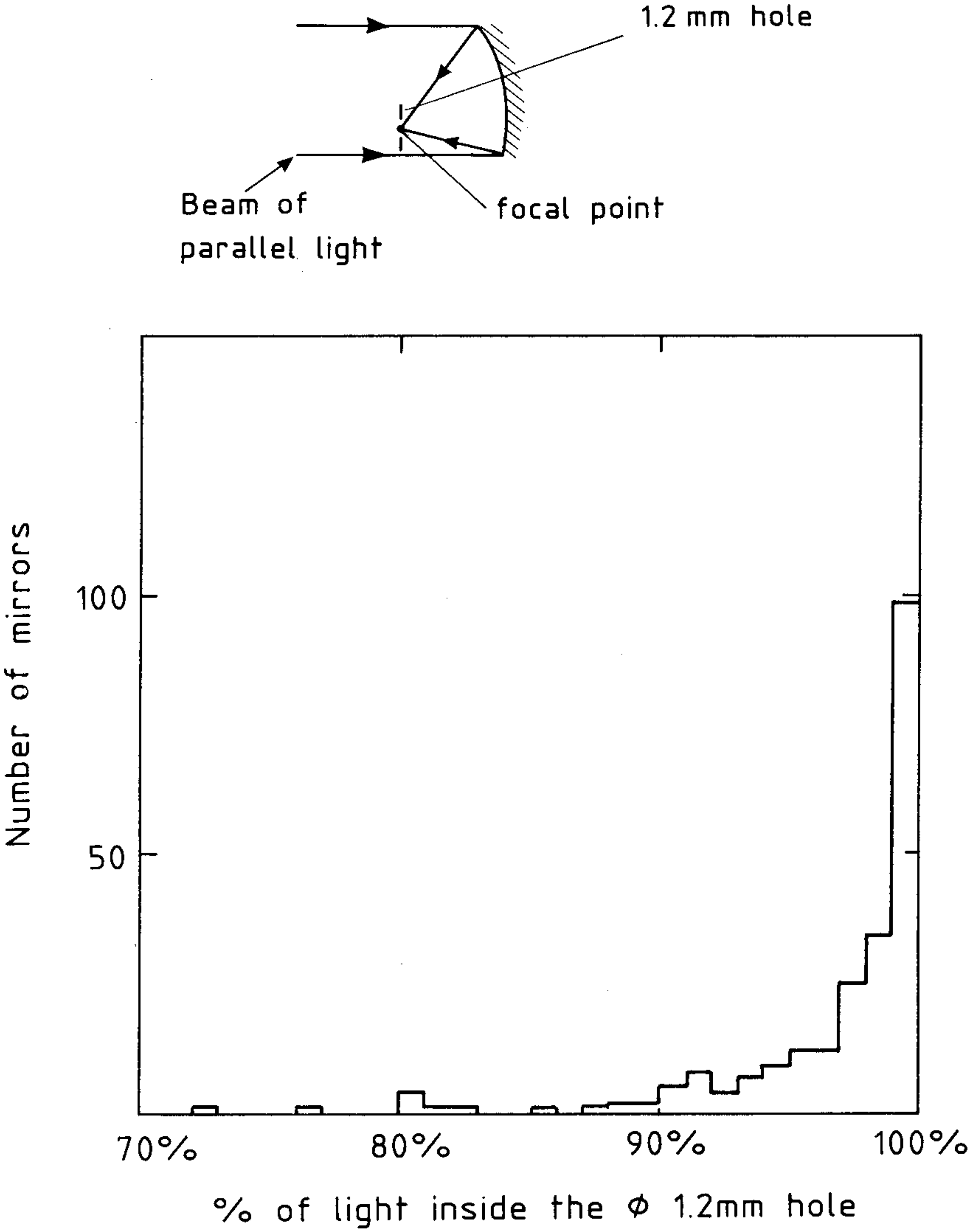

Fig. 5