The Reflecting Surface of the MAGIC Telescope

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Abstract

The MAGIC Collaboration is starting to operate the Čerenkov telescope with the largest reflecting surface, in order to lower the energy threshold well below 100 GeV. The MAGIC (Major Atmospheric Gamma Imaging Čerenkov) Telescope has a 17 m diameter parabolic surface F/1, consisting of 956 spherical aluminium mirrors ($50 \times 50\,\mathrm{cm}^2$ each). In this contribution, we describe the technology adopted to produce metallic mirrors and the methods used to measure the optical quality in terms of: reflectivity, radius of curvature, spot dimension and geometry.

1. Introduction

MAGIC[1] is one of the so-called *second generation* Čerenkov telescopes that aims to fill the observational gap between 10 GeV, the upper limit of satellite-borne experiments, and 250 GeV, the lower limit of contemporary ground-based detectors. Lower energy showers emit less Čerenkov light during their development in the atmosphere requiring therefore a more sensitive instrument to detect them. This is why it was decided to build a huge reflecting surface ($239\,\mathrm{m}^2$) in order to collect as much light as possible.

For the construction of such huge surface, moreover with parabolic shape, the MAGIC collaboration segmented the collecting mirror into 956 smaller elements ($50 \times 50\,\mathrm{cm}^2$), each machined to spherical shape with the curvature radius that matches better the required overall parabolic shape. The technology adopted for the construction of each element (called *raw blank*) is borrowed from airplane industry: it consists mainly of using an aluminium honeycomb core to confer the panel lightness and stiffness. More details can be found in sec. 2, while the qualitative description of the produced mirrors will be given in sec. 3.

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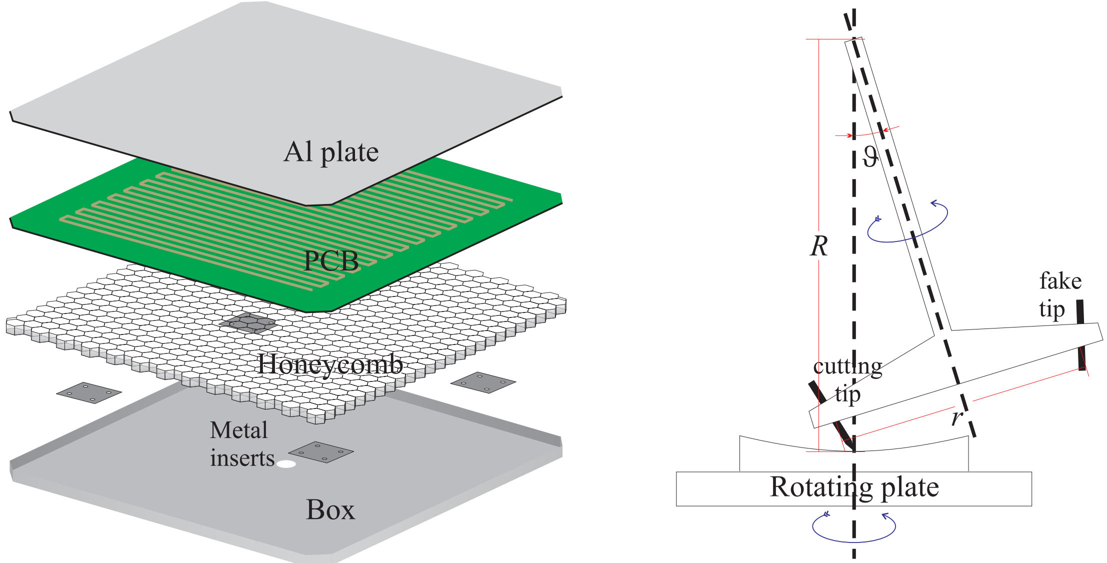

Fig. 1. Exploded view of the *raw-blank* structure (*left*). Sketch of the milling tool and the rotating table (*right*).

2. The Mirrors

MAGIC mirrors are made of AlMgSi1.0 plates 5 mm thick, machined to spherical shape and polished by diamond milling[2]. Al plates are glued together with an Al-honeycomb inside a thin Al-box and the assembly, called *raw blank*, weights around 4 kg. The reflecting surface is divided into various zones with different radii of curvature ($34.125 \div 36.625$ m) to match the parabolic shape of the dish. After the diamond milling, front plates are quartz coated against scratches and aging. All the mirrors are grouped onto panels that contain 3 or 4 elements and each panel can be moved and aligned by an active mirror control system. Each mirror is also equipped with a heating system to prevent ice and dew formation.

2.1. Raw blank production

Raw blanks are composed of a 1 mm Al 3003 box, 2.5 cm high, containing the Al 5052 honeycomb of 2.5 cm of thickness and the heating printed circuit board (PCB). Four small plates, 5 mm thick, are embedded into the honeycomb just in contact with the outer box. They will host four screws each, to fix the finished mirror to a panel. The box is then closed with the aluminium plate. Final assembly of the raw blank parts is done using three layers of 3M glue foils between box, honeycomb, PCB and front plate (see fig. 1. *left*). The gluing procedure consists in a 4-hour cycle, during this time the raw blanks, closed in an evacuated bag, are heated to 120° and stand to 3 atm of pressure. Up to 12 mirrors can be made in the same gluing cycle.

2.2. Premilling and diamond polishing

Diamond milling is a lengthy operation: production can somewhat be speeded up by *premilling* raw blanks to the proper spherical shape. The accuracy of the final premilled shape is better than a tenth of millimetre. The milling is done using an appropriate "T"-shaped tool, a so-called *fly-cutter*, as shown in fig. 1 (*right*). If the raw blank is put onto a rotating plate, the final shape is a spherical surface of radius R according with the formula: $R = \frac{r}{\sin\vartheta}$ where r is the radius of curvature of the milling tool and ϑ is the angle betweeen the rotating axis of the milling tool and that of the plate.

The diamond milling of the surface is done by the LT Ultra company (Aftholdelberg, Germany). The geometry of the milling procedure is similar to the one shown in fig. 1. (*right*), but with a different set-up and a bigger tool diameter. After diamond milling, the roughness of the surface becomes of the order of 10 nm *r.m.s.* and the overall reflectivity, in the visible, is between 85% and 90%. The shape accuracy is of the order of the micrometer.

3. Optical quality of the mirrors

A CCD camera (15-bit resolution, linear) free to move along a graduated rail, was used to measure the optical properties of each produced mirrors. The camera is a ST5 from SBIG, cooled and coupled to a 470 ± 10 nm interferometric pass-band filter to reduce stray light and make measurements possible also in the daylight. The optical properties of the mirror, in terms of the size of a LED reflected image, were checked alongside with the measurement of its effective curvature radius.

For the measurement, the light of an ultrabright blue LED (470 nm, 3 mm ∅) is reflected by the mirror under study onto a white screen: the reflected image, the "spot", is analysed by the CCD camera. The centre of the screen and the LED are at a distance of ~ 40 cm, and symmetric with respect to the mirror axis. The distance between the mirror and the LED (and between the mirror and the screen) is twice the focal (or the curvature radius) of the mirror itself, in such a way that a point image is reflected again into a point image. To study the spot evolution around the focal point, a total of $8 \div 10$ background-subtracted pictures have been taken every 10 cm around the nominal focal position.

Each background-subtracted picture, as downloaded from the camera, consists of a 320×240 matrix of values proportional to the light collected in each pixel. The most important parameter, in our analysis, to be extracted from the data is the R_{90}, that is the radius of the circle, taken from the centre of gravity of the spot, containing 90% of the total, reflected light. As the picture is taken

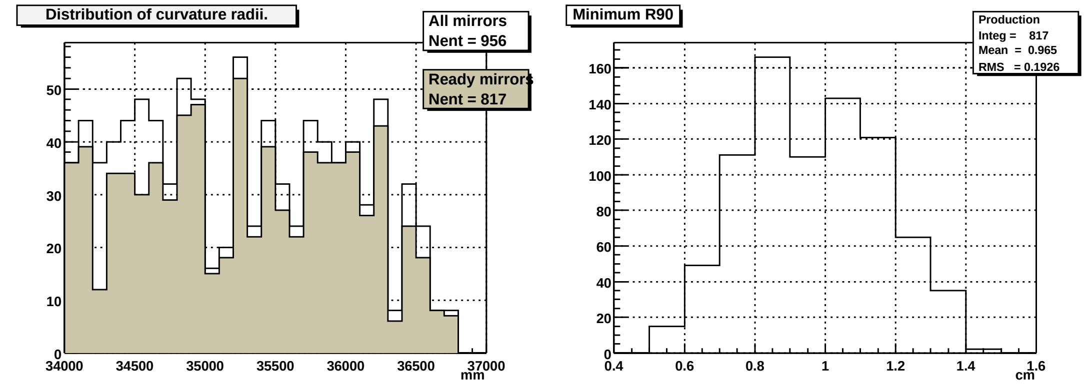

Fig. 2. Distribution of the curvature radii for all the 956 mirrors (*left*). Distribution of R_{90} for the measured production mirrors (*right*).

at twice the focal, when focusing light rays coming from *infinity* the spot is actually half the size of the measured one. This means that 90% of the light from a parallel beam will be focused, on average, within a circle of 1 cm of diameter (see the distribution in fig. 2. *left*) or less than half of the MAGIC pixel size (PMTs of 1"∅).

A mirror is accepted, and later quartz-coated, only if its R_{90} is below 1.3 cm. On exceptional occasions some mirrors with larger R_{90} have been accepted, as can be seen in fig. 2. (*right*).

The effective radius of curvature is defined operatively to be the distance between the spot (or the source) and the mirror centre where the R_{90} reaches the minimum value. Fig. 2. (*left*) shows the expected and achieved distribution of the radii of curvature of the mirrors. The effective radius of curvature is taken into account for the correct positioning of the mirror onto the parabolic dish, having to match the local mean radius of curvature of the paraboloid.

4. Acknowledgements

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5. References

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