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The Mirrors for the MAGIC Telescopes

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The MAGIC Telescope has the largest reflecting surface, among other Cherenkov detectors, in order to have an energy threshold well below 100 GeV. In this contribution, we describe the technology used for the production and the optical qualities of the surface currently mounted onto the telescope. MAGIC features now 964 square mirrors, 50 cm by side, each of spherical shape. We present also a new technology that, producing pre-shaped panels, will finally yield lighter mirrors and can even be applied to make bigger mirrors of 1 m by side.

1. Introduction

The MAGIC telescope[1] features a huge reflecting surface[2] of 236 m^2 and overall parabolic shape, which allows detected photons to keep the correct timing information. The surface was segmented into 964 smaller elements (50 cm × 50 cm), each machined to spherical shape with the curvature radius that better fits the required parabolic shape. Each element is an aluminium honeycomb core *sandwiched* between two outer Al-layers using laminating adhesives. The sandwich, called *raw blank*, is later worked and polished with milling machines. Details can be found in sec. 2, while the optical properties of the mirrors can also be found in sec. 3.

2. The Mirrors

MAGIC mirrors are mainly a 5-mm thick AlMgSi1.0 plate, pre-machined to spherical shape and polished with a milling tool equipped with a diamond tip of *large* ($\sim$ 1 m) curvature radius. Plates are glued to an Al-honeycomb inside a thin Al-box making up the *raw blank* of $\sim$ 4 kg of weight. The reflecting surface is subdivided into zones with varying curvature radii ($34.125 \div 36.625$ m) to match the parabolic shape of the dish. After diamond milling, front plates are coated with a hard, transparent protective layer against scratches and aging. Mirrors are then grouped in 3 or 4 onto panels 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 assembled in Padova are composed of a 1-mm thick Al 3003 box, 2.5 cm high, containing the Al 5052 honeycomb of 2.0 cm of thickness and the heating printed circuit board (PCB). Four small plates, 5-mm thick, are embedded into the honeycomb and glued to the outer box. They 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.

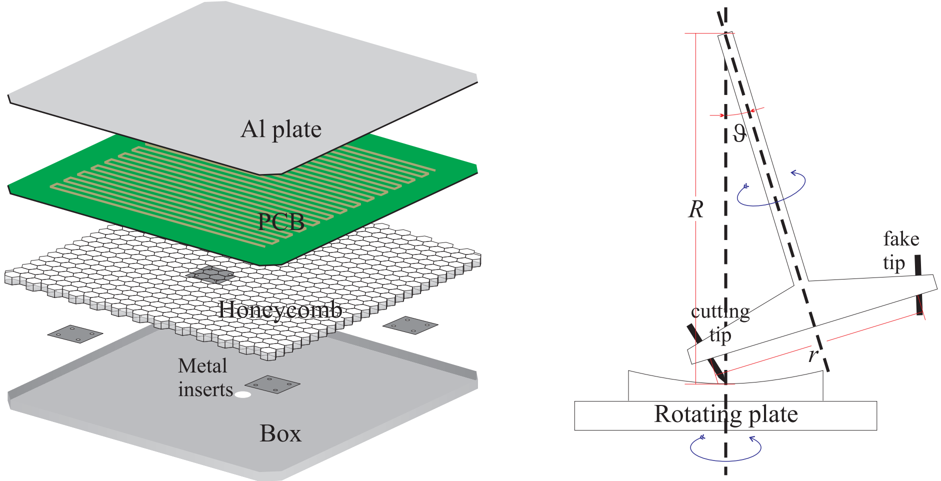

Figure 1. Exploded view of the *raw-blank* structure (*left*). Sketch of the milling tool and the rotating table (*right*).

About a quarter of the actual mirrors were machined from raw blanks made by MPI, which used a very similar assembling method. Their behaviour is quite similar to the mirrors made using raw blanks produced in Padova.

2.2 Premilling and diamond polishing

Production starts with a rough, but quick, *premilling* of the raw blanks with an accuracy of better than $\frac{1}{10}$ mm. The machining is done by fixing the raw blank onto a rotating plate and using a “T”-shaped tool, the *fly-cutter*, as shown in fig. 1 (*right*). The final shape is a spherical surface of radius $R = \frac{r}{\sin\vartheta}$ where r is the radius of the milling tool and ϑ is the angle between the rotation axis of the milling tool and that of the plate.

The diamond milling of the surface is done by the LT Ultra company (Aftholderberg, Germany). After diamond milling, the roughness of the surface is well below 10 nm *rms*, as can be seen in fig. 2 (*left*) for a typical profile analysed with a commercial surface roughness tester. From the same picture one can also see one *step* of the milling machine, that can follow the desired profile at a level of the micrometer.

After coating, the overall reflectivity of the mirrors is between 85% and 90% in the visible band (see fig. 2 *right*). Once all mirrors are mounted in place, the actual reflectivity of the whole surface can be measured. Different measurement techniques agree, estimating the light collection efficiency to be $77\% \pm 4\%$[1].

2.3 Pre-shaped raw blanks

To further reduce production times, we investigated the feasibility of assembling pre-shaped raw blanks. Using pre-shaped raw-blanks, two major issues could be improved:

- the thickness of the Al slab, needed for the milling, was reduced from 5 to $1 \div 2$ mm;
- *premilling* could be completely skipped.

Pre-shaped mirrors are assembled, as the old one, in an *autoclave* environment, but are sandwiched between two curved moulds, that shape the final raw blank with the requested curvature radius, between 34 and 36 m.

Let us remind that, in this range, the *sagittae* vary ~ 0.2 mm. Therefore, we can produce all pre-shaped raw-blanks with just one *gross* curvature radius and let the diamond milling machine refine them by removing just a minimal amount of material. This results in a faster, and less expensive, overall procedure.

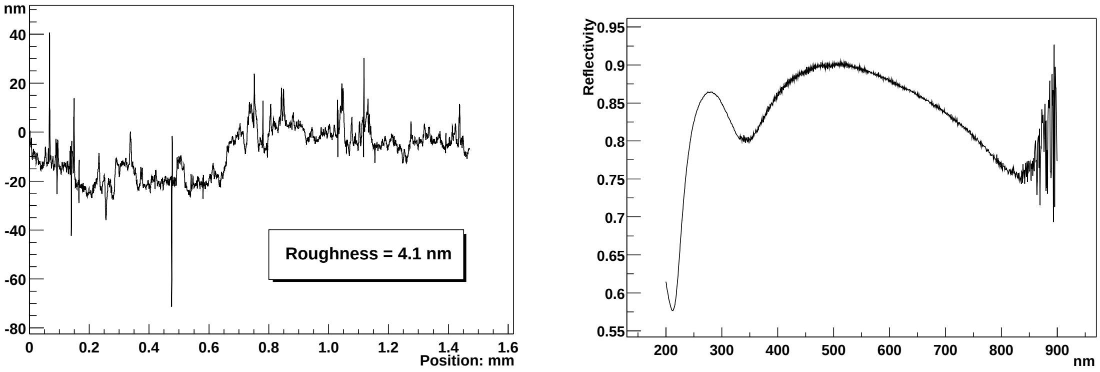

Figure 2. Roughness (*left*) and optical reflectivity (*right*) of a sample taken from a MAGIC mirror after milling and coating. In the roughness diagram, the actual profile (measured in nanometers) is plotted against the position (in millimeters).

2.4 Larger raw blanks and mirrors

Working with thinner, but pre-curved, Al-plates also makes the assembling and machining of larger mirrors easier: in fact, a $1\,\mathrm{m} \times 1\,\mathrm{m}$ spherical mirror of $\sim 34\,\mathrm{m}$ of curvature radius requests that $\sim 4\,\mathrm{mm}$ of material would have to be removed from its centre if it were assembled with a flat plate, whereas virtually no material at all is removed from pre-shaped mirrors. Moreover, as MAGIC currently uses panels hosting four fixed mirrors each for active optics, increasing the mirror size also eliminates the necessity to use back-panels, as the mirrors themselves could be controlled with minor refinements to the actual active optics device.

Larger mirrors have nevertheless some drawbacks. In fact, MAGIC is made up with many small spherical mirrors that best fit the desired overall parabolic shape: increasing mirror size makes the fit harder, at least for the outer mirrors, where the requested paraboloid differs more from a sphere. Astigmatic mirrors can adapt better to parabolic shapes, but their production can be quite difficult, and for MAGIC-II[3], if machining of astigmatic mirrors does not prove to be feasible via the diamond milling technique, it could be envisaged the construction of a mixed-size surface, with 1-m mirrors in the inner rings and 50-cm ones outside.

3. Optical quality checks of the mirrors

To check the optical quality, we use an ultrabright blue LED that is reflected by the mirror under study onto a white screen: the reflected image, the *spot*, is analysed with a CCD camera. The centre of the screen and the LED are at a distance of $\sim 40\,\mathrm{cm}$, and are symmetric with respect to the mirror axis. The distance between the mirror and the LED (and between the mirror and the screen) is equal to the nominal curvature radius (or twice the focal length) of the mirror itself, in such a way that a point image is reflected again into a point image.

For the quality check we compute 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 at twice the focal, when focusing light-rays coming from *infinity* the spot is actually half the size of the measured one. Looking at fig. 3, the result is that 90% of the light from a parallel beam will be focused, on average, within a circle of 1 cm of diameter, or less than half of MAGIC pixel size (PMTs of 1”∅).

The effective radius of curvature is defined operatively as the distance between the spot and the mirror where the R_{90} is minimum. It is the effective radius of curvature that is taken into account for the correct positioning of the mirror onto the parabolic dish, having to match the local mean curvature radius of the paraboloid.

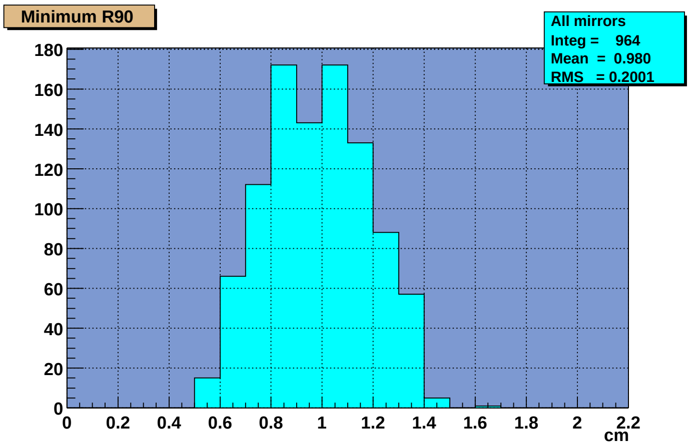

Figure 3. Distribution of R_{90} for the actual MAGIC mirrors.

4. Conclusions

The reflecting surface of the MAGIC telescope is operating in open air already for some years. During this period, few percents of it were damaged by water infiltrations inside the sandwich structure. Due to the extremely bad weather conditions of last winter, the continuos changing of state between water and ice had the effect of detaching some of the aluminium plates from the raw blanks structure. Maintenance and substitution of damaged mirrors is now on-going. Moreover, an improved sealing has been now devised in order to prevent water creeping inside the mirror structure.

On the other hand, even in these extreme weather conditions, with also strong wind blowing and *calima* (Sahara sand particles with $5 \div 10\,\mu\text{m}\,\varnothing$), the hard surface seems to resist quite well: samples coming from mirrors that had to be substituted evidenced no change in local reflectivity.

Few mirrors made from pre-shaped raw-blanks are already installed on MAGIC and survived safely the last exceptionally-hard winter. In the near future it is foreseen to install also some larger 1-m mirror, in order to test the technology and adopt it for the construction of MAGIC II.

5. Acknowledgements

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