

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 (50×50 cm² 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.

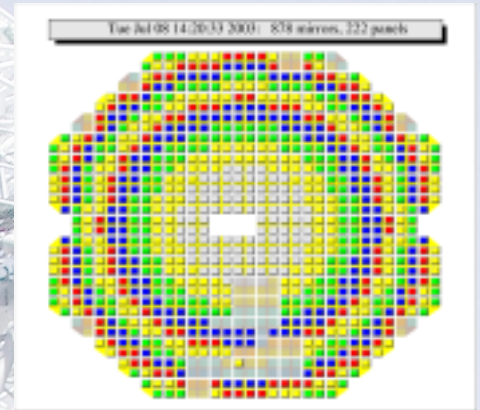
Introduction

MAGIC 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 m²) 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 (50×50 cm²), 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.



The MAGIC Telescope: May 1st 2003.



Updated situation of available mirrors. Yellow panels are ready.

Reflecting elements

MAGIC mirrors are made of AlMgSi1.0 plates 5-mm thick, machined to spherical shape and polished by diamond milling. 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±36.625 mm) 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.

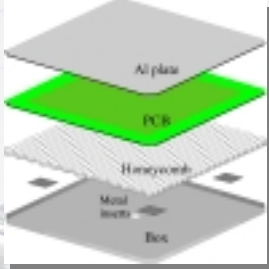
Raw blanks are composed of a 1-mm Al 3003 box, 2.5 cm high, containing the Al 5052 honeycomb of 2.5 cm of thickness and the heating printed circuit board (PCB). Four small plates, 5 mm thick, are embedded into the honeycomb just in contact with the outer box. They will host four screws each, to fix the finished mirror to a panel. Then the box is 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. 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.

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 ultra-bright blue LED (470 nm, 3 mm Ø) is reflected by the mirror under study onto a white screen: the reflected image, or 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 back into a point image. To study the spot evolution around the focal point, 8×10 background-subtracted pictures were taken every 10 cm around the nominal focal distance.

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 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 or less than half of the MAGIC pixel size (PMTs of 1" Ø).



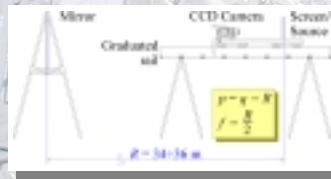
Schematic drawing of a MAGIC raw-blank.



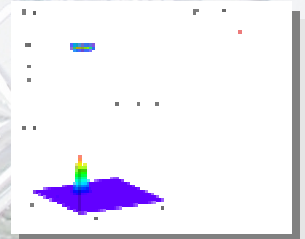
The autoclave with few raw-blanks assembled.

Diamond milling is a lengthy operation: production can somewhat be speeded up by *pre-milling* raw blanks to the proper spherical shape. Accuracy of the final premilled shape is better than 0.1 mm. Milling is done using an appropriate "T"-shaped tool: the *fly-cutter* shown below. The final shape is a spherical surface of radius R according to the formula: $R = r / \sin(\theta)$ where r is the radius of curvature of the milling tool and θ the angle between the rotating axis of 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 the picture, 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.



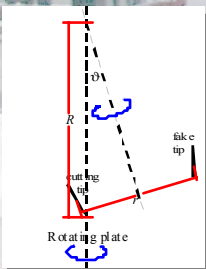
Schematic drawing of the measuring set-up.



Summary plot for a spot measurement.

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 the distribution below. The effective radius of curvature is defined operatively to be the distance between the spot (or the source) and the mirror centre where the

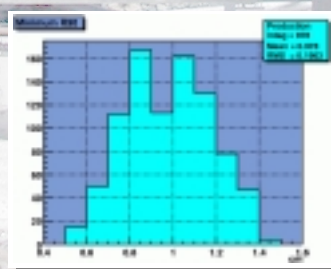
R_{90} reaches the minimum value. The distribution below, shows the expected and achieved distribution of the radii of curvature of the mirrors. The effective radius of curvature is taken into account for the correct positioning of the mirror onto the parabolic dish, having to match the local mean radius of curvature of the paraboloid.



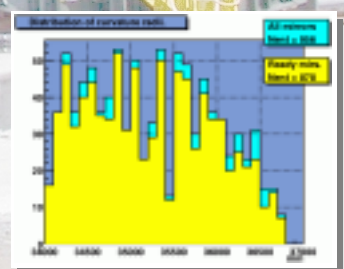
Fly-cutter technique with the "T"-shaped tool.



The pre-milling done at the Padova workshop.



Distribution of the R_{90} of the available mirrors.



Distribution of the radii of curvature.