The Tracking System Of The MAGIC Telescope

Thomas Bretz[1], Daniela Dorner[1] and Robert Wagner[2] for the MAGIC Collaboration
(1) Universität Würzburg, Institut für theoretische Physik und Astrophysik, Am Hubland, D–97074 Würzburg, Germany
(2) Max–Planck–Institut für Physik, Föhringer Ring 6, D–80805 München, Germany

Abstract

For the MAGIC telescope, with its weight of 60 tons and moment of inertia of around $3000 \cdot t \cdot m^2$, a pointing and tracking system has been commissioned. The telescope can perform very fast slews with angular velocities of $180°/20s$ about the altitude axis and $180°/30s$ about the azimuth axis. Tracking velocities of much less than one revolution per day can be achieved without an indexing gear. Applying a bending correction algorithm, tracking can be done with a precision better than 1.5 armin given by half the pixel diameter of the MAGIC camera using 14-bit shaft encoders. For higher precision and cross checks, a starguiding system is currently being tested. The starguider measures the pointing position from constantly looping over the differences between stellar positions determined by a CCD image and those recorded in standard star catalogues. Preliminary analysis of a camera oscillation monitor with 0.4 arcmin resolution shows stable mechanical behaviour of the PMT camera.

1. Introduction

One of the main design goals was to have a fast slewing mode to respond to Gamma Ray Burst (GRB) alerts from satellite monitors such as SWIFT within seconds. Typical burst durations [5] of long bursts are between 10s and 100s, some might last even for hours, and generally the bursts show afterglow emission which can be traced for many days after the prompt phase. Moreover, a few seconds are already lost when computing the position of a GRB during the alert, transmitting the position to the ground, and distributing it to the MAGIC site. Thus, a telescope must be able to point to the alert position, which is randomly distributed on the sky, in a time as short as 20 seconds. The challenge is a great one, the telescope has a weight of about 60 tons and a mechanical diameter of about 20 meters.

For the fast slewing mode angular velocities of $90°/10s$ are required, while

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also tracking a source with less than 90°/6h (which is about three orders of magnitude slower) must be possible. As fast slewing can result in oscillations of the PMT camera, a detector recording these oscillations to be able to correct for in the analysis is mandatory. For cross-checks and tracking-error corrections a starguiding system has also been installed. It is not only capable of determining tracking corrections but can determine the exact pointing position (if known better than 1.5° in advance) by comparing with a star catalog (currenty SAO).

2. The pointing and tracking system

2.1. Hardware installations

For fast slewing high-power, digitally controlled servo motors are used. The azimuth axis, which carries a weight of about 60 tons, is equipped with two 11kW motors, while the elevation axis, which is almost balanced and has a weight of about 20 tons, has one 11kW motor. The high-performance frequency converters measure the current motor position with a rotary encoder on the motor main axis at a rate of 1kHz. The digital control allows for smooth and fast accelerations (decelerations). The position of the telescope is measured in the mechanical telescope frame by three absolute 14-bit shaft encoders. Two of them have been mounted at each end of the elevation axis, one on the telescope central (azimuth) axis. With this configuration it is possible to measure the telescope position with an accuracy of better than 0.02° and to track a star with even higher precision. With two shaft encoders at the elevation axis it is possible to check for a torsion of the dish carrying the mirror panels. Measurements of this effect (see fig.1.) have shown that almost no distortions exist, except for one in a zenith angle range which will not be used for measurements but only for maintanance.

2.2. Bending correction

Corrections for mechanical deformations or any other deviation from an ideal Alt-Az telescope frame (such as axes misalignement) are vital for the control of the pointing accuracy (0.01° for MAGIC). We employ the bending model of Wallace [3,4], which is a state-of-art model for optical telescopes with much higher demands on precision. First attempts to determine the coefficients for the correction matrix transforming the celestial frame to the actual telescope frame are currently done at La Palma.

2.3. The starguider

In order to check the pointing accuracy and to establish a starguided operative mode, a high sensitivity video system has been installed. The starguiding system consists of a video camera with a sensitivity of 0.0003lux. Optimum performance is obtained for 5s exposures, detecting stars down to 10.7th magnitude

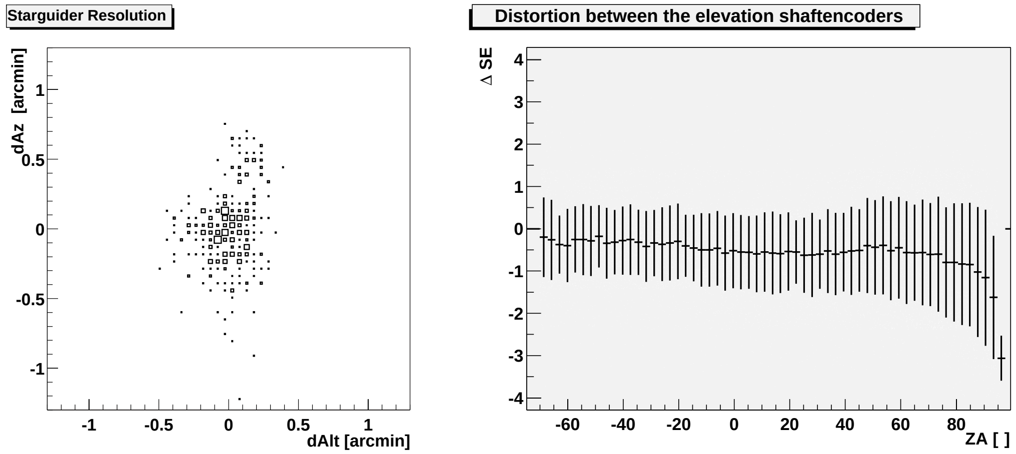

Fig. 1. The left plot shows the resolution of the starguider. 250 data points were recorded in about 20 minutes at a zenith angle of about 60°. After data taking the tracking error has been substracted. The x- and y-axis of the histogram are the detected detected position offset in Alt/Az coordinates. The right plot shows the recorded torsion between the two shaft encoders of the elevation axis versus the zenith angle as a profile histogram.

at half moon. In the large (5° × 3°) field of view typically more than 50 stars useful for starguiding can be found. For positions near the Zenith, a higher frame rate would be desirable to follow the star field rotation, however for most positions movements during tracking are comparatively slow. Since gamma-ray sources are known to be very dark (<20th magnitude) or even invisible, an ordinary star-lock mode fixing a star in the center of the camera is impossible. Comparison of the detected stars with the picture which should be visible for the present pointing position calculated from a star catalog determines the positional offset. Doing this results in a position accuracy better than 15 arcsec. (see fig.1.). Since the pointing position of the telescope is generally not the same as the one of the starguiding system, a bending correction as determined for the MAGIC telescope is mandatory. Once in starguiding mode, the pointing and tracking precision will be much smaller than pixel size.

2.4. The camera oscillation monitor

The short integration time (<70ns) taking a picture of an air shower allows for correcting oscillations of the PMT camera. Expecting oscillations in the range of the width of one PMT (1.5cm) we can measure these oscillations by a video camera. This video camera is taking pictures with a frequency of 25Hz of six LEDs fixed around the camera center in a circle. Taking all combinations of three LEDs out of six one can calculate 20 circles analytically. Knowing the radius of the circle one can reject wrongly detected points in the field of view. Averaging

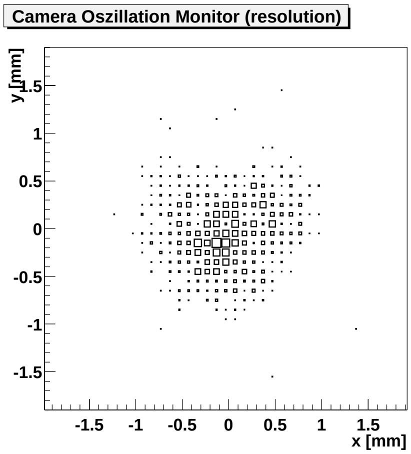

Fig. 2. This histogram illustrates the resolution of the camera oscillation monitor system. The data were recorded while the telescope did not move. In a period of 15 minutes about 2000 data points were recorded. A data point is the position of the PMT camera in x and y as calculated from the detected LEDs.

all circles results in a resolution better than one third of a CCD pixel. In physical measures this translates to a value in the range of millimeters (see fig.2.) which is far better than the necessary resolution of half the diameter of one PMT.

3. Conclusion

The pointing and tracking system of MAGIC has shown the expected performance, raising the opportunity to soon use MAGIC as a GRB follow-up telescope. Calibration measurements are still proceeding to determine the correction matrix of the bending model and the starguider telescope. The mechanical behaviour of the PMT camera seems to be rather stable and well under control.

4. References

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5. Acknowledgment

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