Test of an Active Mirror Control for Cherenkov Telescopes

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Abstract

The recent progress in VHE γ-astronomy can nearly entirely be attributed to large air Cherenkov telescopes with high quality imaging detectors. The trend towards larger mirror collectors and better optical quality puts severe demands on the rigidity and precision of the mirror support structure. Active mirror control opens a promising alternative to an excessively heavy and costly mirror support frame. Here we report on a test of the active mirror control for the proposed 17 m ø MAGIC telescope.

1. Introduction

The recent discoveries and progress in very high energy (VHE) γ-ray (shortcut γ) astronomy were nearly entirely achieved with large air Cherenkov telescopes using fine pixelized photomultiplier cameras for image analysis (IACTs). The development of IACTs is still ongoing and a significant potential for improvement of the sensitivity is visible (see the relevant reports of this workshop). Todays trends are towards larger diameter mirror collectors and towards finer pixelized cameras which, in turn, put more stringent requirements on the optics of the telescopes. When increasing the diameter the rigidity conditions influence over-proportionally the costs and the weight of the mirror support dish. Alternatively, active mirror control (AMC) permits to build an instrument with relaxed rigidity. Similar trends are already pursued for some time in large diameter optical telescopes. In the last two years we have investigated and tested a few approaches for active mirror control for IACTs. Here we want to report about tests of an AMC design for the 17 m ø MAGIC telescope project. A detailed description can be found in (Wacker, 1997).

2. Design Considerations

The proposed 17 m ø MAGIC telescope project (see for example contribution to this conference) has the following mirror parameters (only those relevant to this test)

- tessellated 17 m ø mirror
- 936 lightweight all-aluminium mirrors of size 49.5 x 49.5 cm^2 (+ 40 triangular mirrors)
- focal length f = 17 m

- parabolic mirror profile (individual elements spherical)
- point spread function < 8 mm (for pixel diameter of 17 mm)
- mirror support dish of < 5 ton weight
- AMC adjustment time < 10 minutes

3. The Active Mirror Control Design Idea

The original design concept has been presented in 1995 (Bradbury et al. 1995a, Bradbury et al. 1995b). The concept is shown in figure 1.

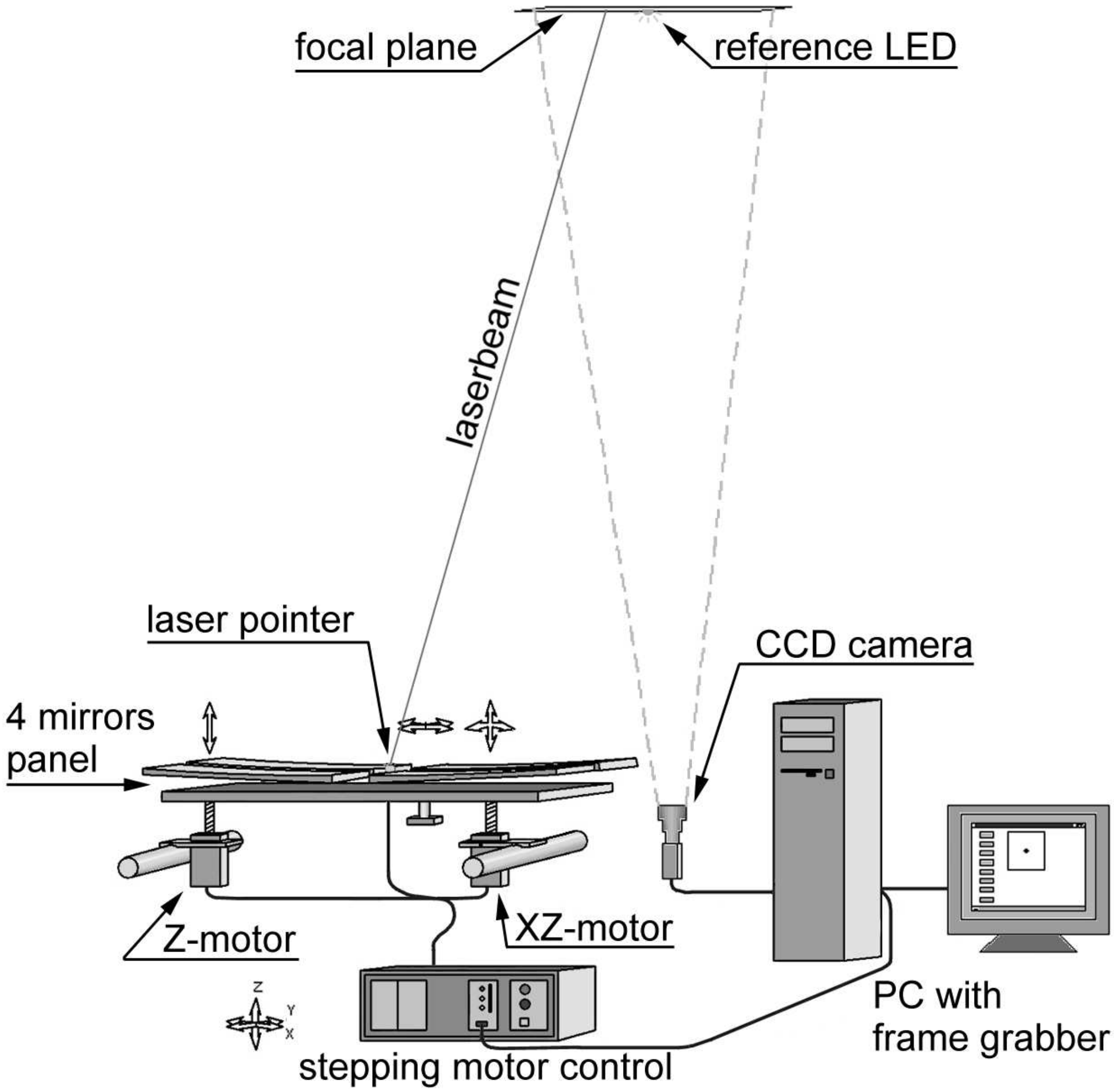

Fig. 1: Schematic drawing of the active mirror control.

Four 49.5 x 49.5 cm^2 mirror elements are mounted on a 95 x 95 cm^2 light weight aluminium sandwich panel (20 mm thick, 0.5 kg). In the centre of the panel a small laser diode is mounted in an adjustable rig. It is assumed that the panel position on the mirror support frame is known and both the 4 mirror elements and the laser pointer can be pre-adjusted on a test set-up such that their foci will overlap in the camera centre. Each panel is mounted onto 3 adjustment elements, two of which are driven by stepping motors. All three elements are fixed to the panel by ball-bearing universal joints. Fig.2 shows one of the motor drive adjustment elements. One of the motor driven adjustment screws has no lateral freedom while the second motor drive can swing around one axis. The third adjustment screw has full freedom to swing laterally by using a second ball-bearing universal joint. The third adjustment screw is set manually during the installation phase. The second important element is a CCD camera linked to a PC via a frame grabber card. The CCD camera will be mounted near the centre of the mirror dish and will view the telescope camera. For the adjustment the white, diffuse reflecting camera cover will be swung in front of the camera. The CCD camera will measure the spot of the laser beam and, according to its displacement with respect to the nominal position, will drive the stepping motors and readjust the mirror panel. The chain: 'Laser beam - CCD camera - PC with frame grabber - stepping motor drive - stepping motors' form a closed loop regulating circuit. Because of some possible small bending of the masts holding the photomultiplier camera as well as a possible tilt of the CCD camera we plan to install a tiny LED in the camera centre and a few LED markers at the circumference of the camera. The red LEDs serve as reference marker of the camera position.

4. The Experimental Setup and the Test

Tests have been performed with a single panel with 4 mirrors of 50 x 50 cm^2 size. The panel was mounted on a 3 x 3 m section of the MAGIC space frame. This section was assembled from steel tubes instead of the carbon fibre tubes, planned for the final version. As stepping motors we used Escap P 520 254 004 motors. These motors were linked to the 16 mm threaded control rod via a planetary gear (1:134 reduction, Escap R 40 14.0). The planetary gear's play and the step size correspond to about 10 micron error in the panel tilt, i.e., in a focal point shift of ca. 0.35 mm. As laser-pointer we used the type LDM 115 677/1 from Imatronic (emission wavelength 677 nm, 1 mW, round spot). The laser pointer is switched on/off under control of the PC. The laser spot is viewed by a CCD camera (type OS-65D, system CCIR, 1/3" CCD with 752 x 582 pixels). The camera images were read out by a Pentium 150 controlled framer grabber card (MATROX Meteor). We have written a software program that allowed us to analyse the image, to calculate the necessary correction parameters and send them to the stepping motor drive system (Isel C-142-4) via RS 233. The CCD camera was adapted to a zoom lens with f = 18-108/2.5. The telescope camera cover was replaced by a white cardboard mounted at 23 m distance. Fig. 3 shows the test rig.

The adjustment sequence for an arbitrary de-adjusted mirror (laser spot displaced by 10 to 20 cm) is the following:

1. The program triggers the camera cover to be swung into the 'close' position.
2. The program switches on the camera reference LEDs and determines from the CCD image the centre of the camera

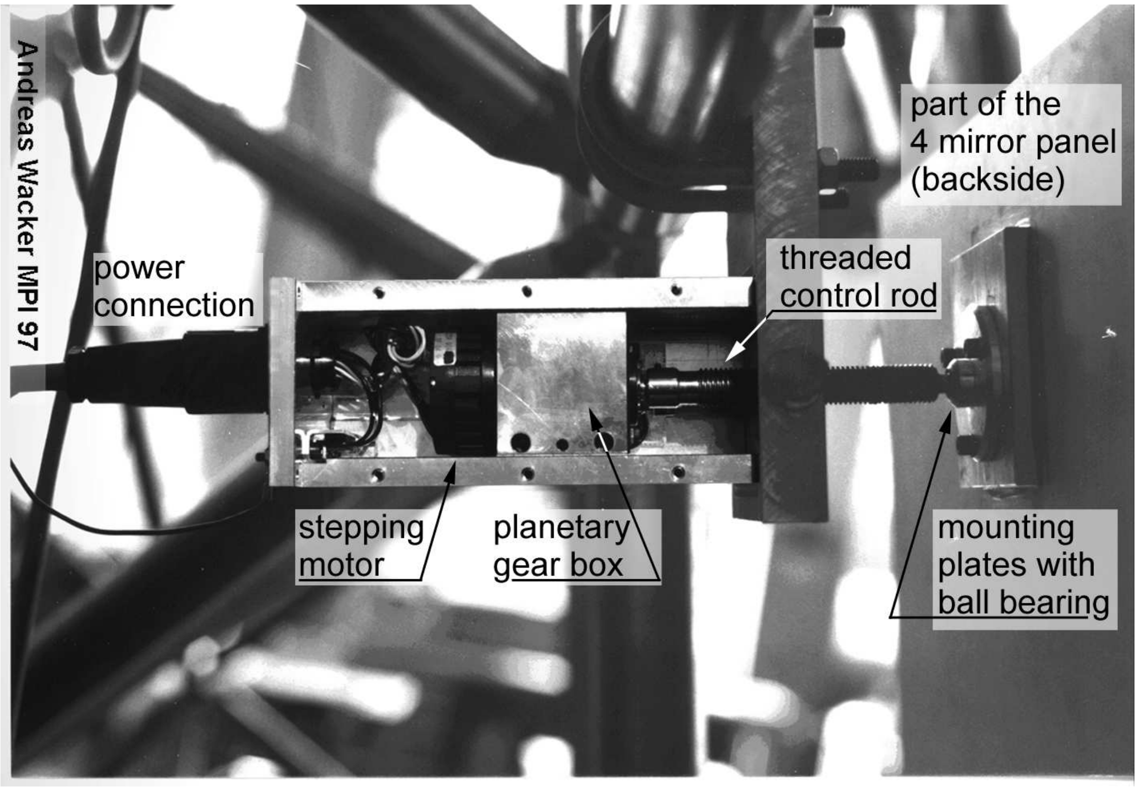

Fig. 2: The picture shows the mechanical construction to fix and move the mirror panel.

3. The computer loops through the program until the panel under study is found and switches on remotely the laser pointer

4. The displacement of the laser spot with respect to its nominal position is recorded by the CCD camera

5. The software analyses the picture, calculates the necessary number of steps for the two motors and sends the corresponding signals to the stepping motor controller, which activates the motor and executes the steps. During this action the laser pointer can be switched off and the adjustment of the next panel could in principle be started. The system is powerful enough to handle the corrections of up to 8 - 10 mirrors simultaneously.

6. After the first adjustment cycle is completed, the cycle will be repeated once more to make some fine corrections.

7. After completion the laser is switched off and, if necessary, the telescope camera opened.

Tests have shown that it takes 1 - 2 seconds for the size of correction expected for the 17 m ø mirror. Furthermore the tests have shown that the laser spot position could be adjusted to $<$ 2 mm at screen distance of 23 m, i.e. to about one CCD pixel when using the largest magnification of the given zoom lens.

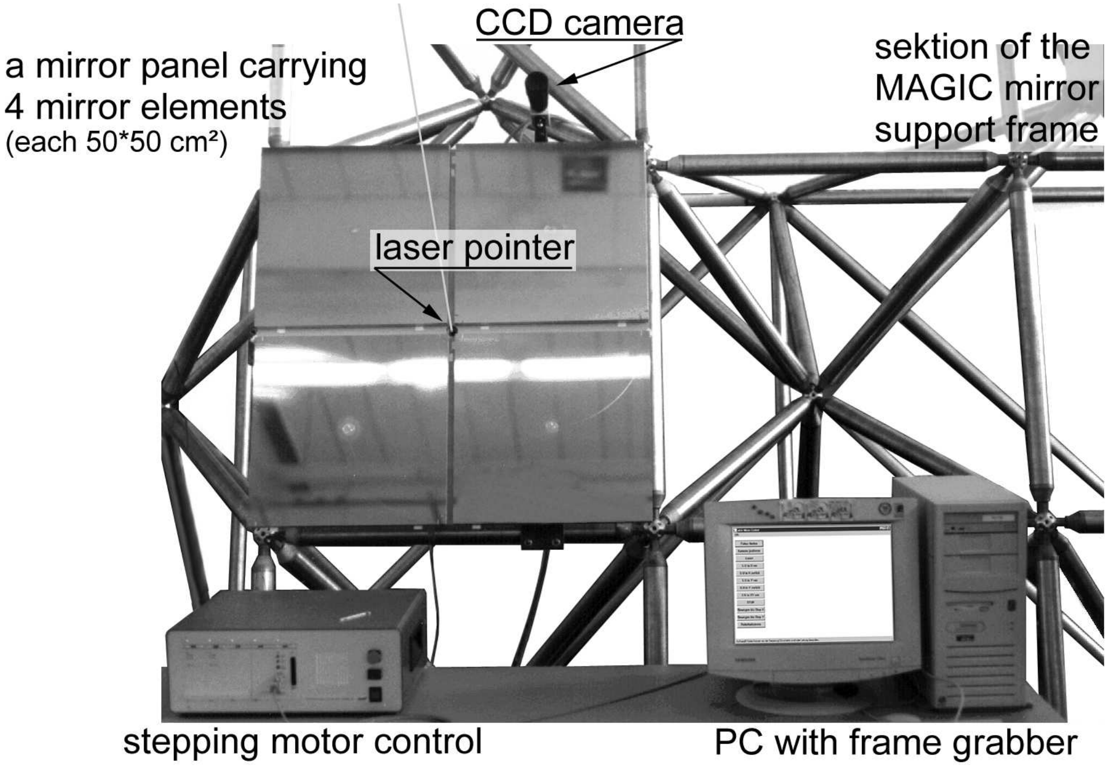

Fig. 3: The Picture shows all components, which were used for the test.

5. Discussion

With the above described setup we could demonstrate the principle. Without any further change of the concept we could achieve a precision needed for the MAGIC telescope, i.e., an adjustment to one tenth of the pixel size. The necessary adjustment time for a single mirror panel of 1 - 2 sec. converts to a time well below the original target of 10 min for a fully de-adjustment mirror. In practise not all panels need to be adjusted and we estimate that the adjustment of the remaining ones could be completed within 1 -2 min. Also it seems possible that after some training the displacement as a function of the telescope's declination angle will be known and corrections can be executed directly and only step 6 of the above described procedure might be necessary. The system is precise enough that for a larger magnification and/or a finer pixelized CCD a more precise adjustment is possible

6. Prospects for the Future

Although the above AMC is very simple and works fast we would like to mention some further improvements and alternatives. MAGIC will have 242 panels to be adjusted. In order to minimise the connection and cables some multiplexing is needed. Instead of using one motor controller for all panels one could install a local "intelligent" controller for each panel and a supply bus (Data and pover supply). All local controllers would work under the CAN bus protocol. In such a configuration one needs to send the card/mirror panel identification code from the PC in order to activate the relevant laser pointer and the motors. An example of such a card is the ISEL interface card which incorporates INTEL-8032 microprocessors. We would like to mention that it is not necessary to coincide the laser spot with the mirror panel spot. The laser could be adjusted to focus onto a separate reference mark outside the telescope camera field of view when the actual panel's focus is in the centre of the photomultiplier camera. This allows to check the correct adjustment during observations provided the scattered light of the laser pointers is not disturbing the measurement. A narrow band interference filter with its centre wavelength matched to the emission line of the laser-pointer and LEDs will suppress stray light entering the CCD camera.

7. Conclusion

A simple method for active mirror control in large diameter Cherenkov telescopes has been tested. AMCs allow to overcome mechanical deformations of the mirror support frame under changing loads during operation. It is furthermore possible to operate the telescope under optimised optics for different shower distances in the atmosphere, defocus the mirror in case of accidental pointing towards the sun or to carry out special studies. Also the method allows for simple checks of individual panels, respectively mirror segments by steering them out of the general focus onto special measuring cells.

The material cost for the elements for one panel is about 300 - 400 $ excluding the PC, the CCD camera and the motor controller.

8. Acknowledgements

This work was supported in part by the German Ministry of Education and Research BMBF (contract no 05 3MP664/7)

References

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