Performance of the reflector of the CANGAROO-III imaging atmospheric Cherenkov telescope

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Abstract

The second 10m-diameter telescope of the CANGAROO-III project was completed in December 2002. The reflector is a tessellated paraboloid which consists of 114 spherical mirror segments with a f/d ratio of 0.8. In order to obtain light-weight, durable segments, we have been working on development of FRP (Fiber Reinforced Plastic) composite mirrors since 1995. These segments are all equipped with a remote-control alignment system and their optical axes were aligned using bright stars as standard light sources.

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The status of FRP mirror developmental work and the total performance of the reflector after the alignment are reported.

1. Design of the reflector of CANGAROO-III telescope

The main frame of the CANGAROO-III 10m reflector is a paraboloid with a focal length of 8m, whose design is inherited from an existing radio telescope [1]. The reflector surface was tessellated with 114 spherical mirror segments (Fig. 1.) and an effective area of 5.7×10^5 cm^2. Each FRP composite segment weighs only 5.6 kg for an 80 cm diameter and the total weight of the reflector is reduced to 6.6 tonne. The orientation of each segment is accurately aligned with a remote-control system driven by stepping motors. The spot-size of the reflector is determined both by this alignment accuracy and by the image quality of each segment, and was $0°.20$ (FWHM) for our first telescope, while a value of $0°.1-0°.2$ is desirable for the efficient separation of γ/hadron showers.

Fig. 1. Design of the CANGAROO-III reflector.

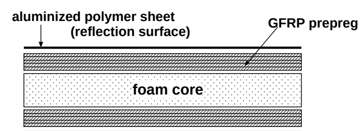

Fig. 2. Layer structure of a FRP mirror segment.

2. Manufacturing/Quality control of FRP mirror segments

We have been working on development of FRP composite mirror segments in cooperation with Mitsubishi Electric Corporation since 1995. Since fine surface tuning by grinding cannot be applied to auto-clave molded FRP products, improvement of surface control accuracy and productivity has long been the issue.

Our FRP composite mirror has a symmetrical layer structure (Fig. 2.) with the curvature radius and surface accuracy determined by the rigidity balance between these composite materials. As for the production of our second telescope, the surface of every FRP mirror was measured with 1μm accuracy and the information was fed back into the manufacturing process. After some layer

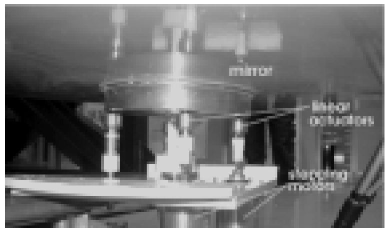

Fig. 3. Alignment system of a segment.

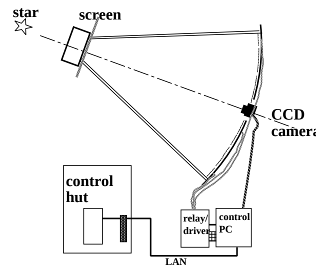

Fig. 4. Setup of the alignment work.

parameter tunings we succeeded in removing relatively high-frequency deformations (or large-angle reflection) and the final deviation from a sphere can be well represented by $C(r/40)^n \sin(2\theta)$ (r, θ in polar coordinates and C, n are parameters obtained for each segment), which looks like a "saddle". About 70% of the recent FRP products have spot-size of $0^\circ.14$ (FWHM) for on-axis incident rays.

The image quality of the ith segment(C_i), which is defined as the photon concentration within a $0^\circ.09$ diameter camera pixel, should be estimated after their "orientation" θ_i and "position" l_i on the main mirror dish were allocated. $C_i(\theta_i, l_i)$ was estimated by a ray-trace calculation using 3D measurement data and the arrangement of all the 114 segments were optimized using software based on the Genetic Algorithm so that $\sum_{i=1}^{114}(\theta_i, l_i)$ was maximized.

3. Alignment of the segments using a bright star

Alignment system Every segment is equipped with a remote-control system using linear actuators driven by stepping motors (Fig. 3.). A segment is clamped at the center and sustained by 2 sets of actuator-spring shaft pairs, so its orientation is determined by the tilts around these 2 orthogonal axes. The designed resolution and dynamic range of the motion are $0.5''$ and $1^\circ.4$, respectively. Reproductivity and motion linearity of the system was measured at the test assembly and confirmed to be within the measurement error of $0^\circ.02$.

Alignment procedure We used bright stars as standard light sources for the alignment work of our second telescope. While the telescope tracks a star, a CCD camera views the images of the segments in the focal plane(Fig.4.). A motion of a certain segment was detected by taking 2 CCD frames before and after the motion and comparing them. All the actions were directed from operators inside the control hut and total time required for the whole procedure is about (exposure time+CCD readout time)×(typical iteration)×(number

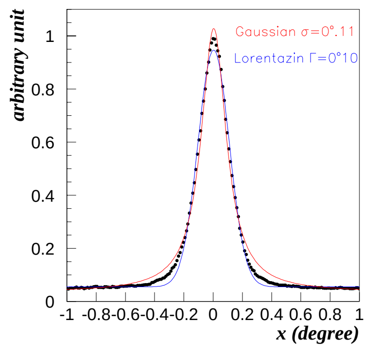

Fig. 5. Spot-size of the second telescope.

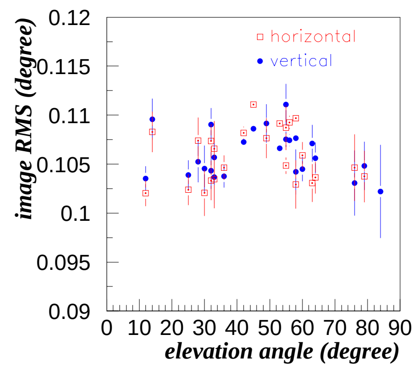

Fig. 6. Elevation dependence of spot-size.

of mirrors)$\leq$ 7 hours of good conditions (clear, moon-less night). This is much reduced from "1 week for 60 mirrors", which was the case for our first telescope.

4. Performance of the second reflector of CANGAROO-III

The spot-size of the second telescope after the alignment in November 2002 is 0°.21 (FWHM) (Fig. 5.), which is comparable to that of the first telescope. Further fine tuning would narrow the spot-size down to 0°.18. We measured the spot-size for 25 stars which have elevation angles from 15° to 85° in order to check the effect of gravitational deformation of the telescope on the image quality. The correlation coefficient between elevation angle and spot-size in horizontal/vertical direction was -0.1 and 0.1 respectively (Fig. 6.) and it was confirmed that gravitational effects can be neglected for the second telescope.

5. Summary

Our understanding on the nature of surface deformation of FRP spherical segments progressed through the developmental work for the second telescope. We introduced a new method into the alignment work of the reflector, which significantly reduced loadwork and labor time.

6. References

1. Kawachi, A. et al., Astropart. Phys. 14, 261-269 (2001)