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R&D of the Fresnel optical system for the TUS space detector

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Abstract: The space TUS detector of UV fluorescence light radiated by EAS of Ultra High Energy Cosmic Rays (UHECR) is under preparation. The TUS optical system will consist of the Fresnel mirror-concentrator of ~2 sq. m. and 256 PMT pixels as the photo receiver at the mirror focal surface. The 2 PMT pixel prototypes were tested and used for data taken at the "Universitetsky-Tatiana" and Compass-2 satellites. The R&D study of the Fresnel mirror production is presented.

Introduction

The TUS (Tracking Ultra-violet Set up) mission is now planned for operation at the Small Space Apparatus (SSA) separated from the main Foton-4 satellite, to be launched in 2009-2010. SSA is a new platform being designed for operation with space instruments having mass 50-100 Kg, power consumption of 60-100 Wt at the orbits of 400-500 km altitudes. The platform will be oriented in space according to a scientific task. In the transportation mode the SSA is placed above the Foton-4 body so that the TUS mirror could be accommodated in its full size of 1.8 m diameter. The TUS mirror and photo receiver are shown in Fig. 1 in operation modes (for more details see Tkatchev et al [1], this conference)

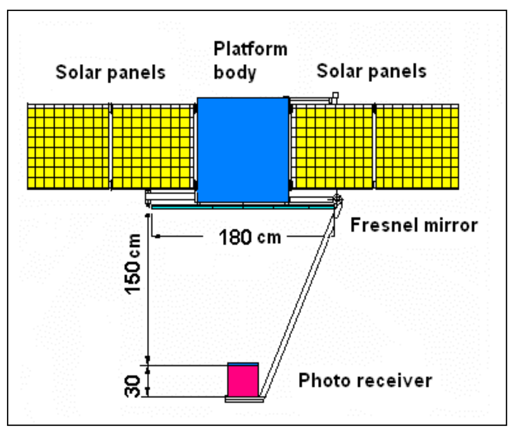

Figure 1: TUS detector as the Small Space Apparatus.

Status of Fresnel mirror production

In the new design the mirror-concentrator displayed in Fig.2 consists of 6 Fresnel and a central parabolic mirror segments. The complicated shape of the Fresnel mirror might be the reason of its defocusing due to anisotropy of thermoelastic response of its elements while heating and freezing at the orbital flight. To reduce this anisotropy the mirror is made of two parts: the reflective part and a rigid support plane seen in Fig.3. In a new design the full mirror area is 2 m^2, the focal distance is 1.5 m.

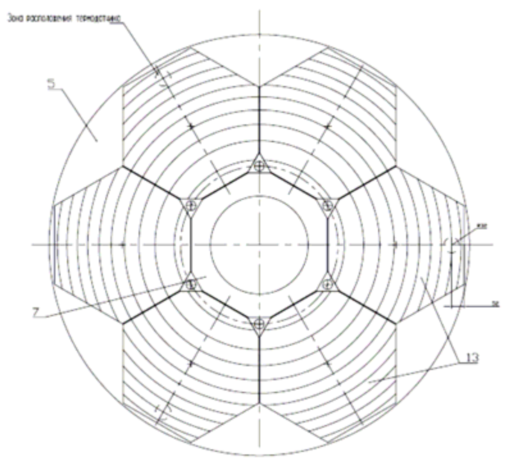

Figure 2: The technical drawing of the TUS segmented Fresnel mirror of 2 m^2 area ready for the production.

Selection of material and construction

The material and construction types of the mirror modules are chosen to satisfy the requirements of the mirror geometrical stability within the temperature fluctuations ± 60 ^{0}C in the open space. Two honeycomb superlayer construction is chosen as shown in Fig. 3. Such a construction gives the possibility to minimize the mirror weight. Each superlayer has 3 layer honeycomb structure with 0.5 mm base coats that provides the maximal flexural rigidity with minimal weight.

Figure 3: Structure of the carbon plastic mirror: 1 – aluminum honeycomb, 2 – reflective superlayer, 3 – support superlayer.

The main "know how" is the production of the reflective superlayer. The first two steel molds of the Fresnel mirror module were fabricated at a machine tool without the DNC. The 3D-drawing of the mold is shown in Fig. 4 and the mold itself may be seen in Fig.5. The base layer shaping and the reflective superlayer gluing was fulfilled on the steel mandrel.

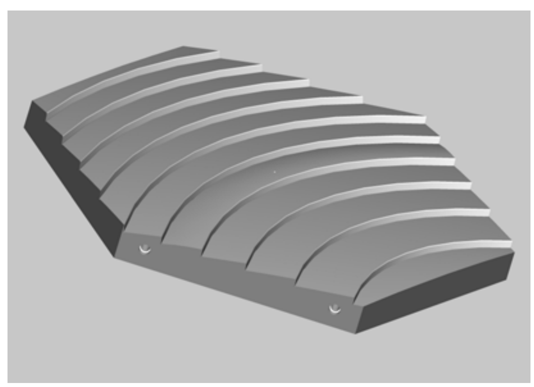

Figure 4: 3D-drawing of the mold for the Fresnel modules production.

At the beginning the skin plates were mould that is used lately for gluing of 3 layer reflecting superlayer. The skin plates of glass cloth and epoxy resin were fabricated by c hardened prepreg method and underpressure conditions: 0.8÷1.0 kg/cm^2 during 24 hours.

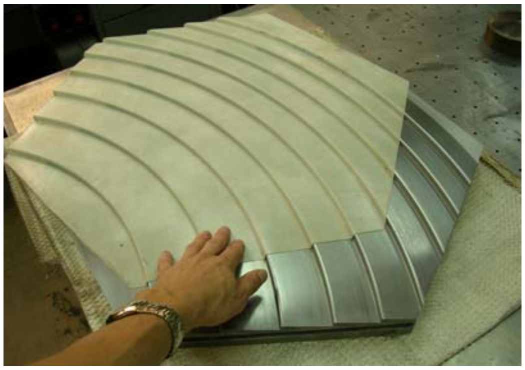

Figure 5: The steel mold and skin plate that is used for fabrication of the reflective superlayer.

Simultaneously aluminum reflective elements of mylar film were cut out with templates separately for each ring of the mirror and covered by protection layer. These reflective elements and the cold-hardened prepreg of carbon-cloth and epoxy resin were fixed on the mold surface. The cloth bundles of the carbon-cloth were oriented with $\pm 22.5^0$ with respect to symmetry axis of the mold. The next step was to put on the base layer prepared in a such way the antiadhesive film and then the skin plate of glass cloth and epoxy resin above. The formation process was again at underpressure conditions: 0.8÷1.0 kg/cm^2 during 24 hours.
Then the skin plate was removed and the base layer surface was checked without removing it from the mold. The next step was to put the cold-hardened glue on the base layer surface and the honeycomb strips prepared separately for the each ring properly.

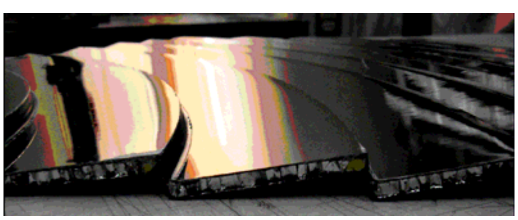

Figure 6: The honeycomb structure and the carbon mirror reflective part.

Then the skin plate and the antiadhesive film were put on the honeycomb strips. The base layer and the honeycomb strips were glued in the same conditions: at underpressure 0.8÷1.0 kg/cm^2 during 24 hours.
After the dismantle of the vacuum rigging and the visual checking of “unbonds”, the end base layer was formed and glued to honeycomb layer simultaneously to provide the equidistance of the base layers and more good gluing that was checked by the ringing method. In Fig. 6 the mirror fragment is shown and one could see its structure. The first Fresnel mirror that is shown in Fig. 6 and Fig. 7 gives the focal spot of ≈20 mm at the distance 1.5 m for Sun as a light source. Some imperfectness of the mirror was naturally found in both the mold surface and its technological details due to the mirror production procedure.

Measurements of the mirror parameters

The special ECLIPCE tool and PC with dedicated software used to check the production of the steel mold and Fresnel mirror modules as shown in Fig. 7 provides 3D –measurements with accuracy of ~5 microns for the complicated surfaces in the volume about 0.7x0.7x0.3 m^3.

Figure 7: Prof. J.Cronin has inspected the special tool ECLIPCE for precise 3D-measurements of the mold and Fresnel mirror segments.

The electronic mirror 3D-drawing of Fig. 4 needs a precise on-line measurement of its shape with help of ECLIPCE device. Such measurements help us to improve the quality of the mirror and are also of importance for the MC simulation of the TUS optics.

The special software package for the analysis of the ECLIPCE raw data of the mirror and mold measurements was developed. In the Fig. 8 the results of the first steel mold measurements are presented.

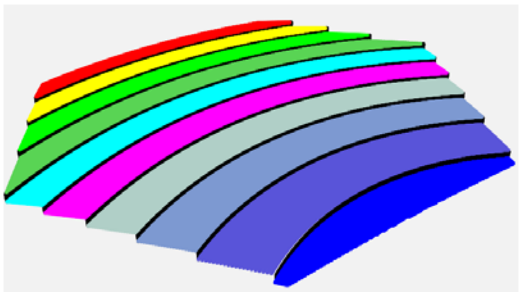

Figure 8: The results of the mold measurements with the ECLIPCE device.

The size and position of focal spots for all the Fresnel mirror rings are obtained for the first steel mold and fitted with parabolic formula

$$Z = a + b*R + c*R^2$$

where "c" parameter is connected with focal distance "f" by c = 1/(4*f). Results of the raw data 2D-fit are presented in the Table 1 for a part of a measured set of the *x*-, *y*-, *z*- points.

Table 1.

Ring number	a a_{theor}, mm	b b_{theor}	f f_{theor}, mm
1	22.92±0.03 20	-.01±0.00 0	1633+_3 1510.00
2	26.00±0.02 29.87	0.03±0.0 00	1258±0.7 1519.87
3	34.07±0.02 39.68	0.03±0.0 00	1277±0.6 1529.68
4	35.43±0.02 49.43	0.06±0.0 0	1493±0.6 1539.43
5	60.25±0.02 59.12	0.00±0.0 0	1539±0.6 1549.12
6	69.91±0.02 68.75	0.00±0.0 0	1549±0.5 1558.75
7	79.23±0.02 78.33	0.00±0.0 0	1566±0.6 1568.33
8	88.92±0.03 87.86	0.3±0.0 0	1570±0.6 1577.86
9	98.52±0.03 97.34	0.00±0.0 0	1580±0.5 1587.34
10	107.68±0.0 2106.76	0.0±0.0 0	1595±0.5 1596.76

Conclusion

In 2005 the small prototype of the TUS detector with UV detector comprising one pixel of the TUS receiver was launched on board of the "Universitetsky-Tatiana" satellite (see, Garipov et al, [2]) and successfully tested.
The TUS full scale mission is now planned for operation at the Small Space Apparatus to be launched in 2009-2010.
Two steel molds were produced up to now with a facility without DNC control and a few Fresnel mirror modules of epoxy resin and carbon plastic were fabricated and tested up to now. In the Fig. 4 the 3D-drawing of the mold that will be used for the new Fresnel mirror modules production is shown. The new modified steel mold is under production now with the DNC facility. The aim is to produce and test the technological Fresnel mirror of carbon plastic during this year.

References

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[2] Garipov G., Khrenov B., Panasyuk M., Tulupov V., Salazar H., Shirokov A., Yashin I., Astroparticle Physics 24 (2005) 400-408.