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Performances investigation and material selection of PMT magnetic shields for the space experiments with GRIS and PING-M instruments

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Abstract. PMT performances significantly change under the influence of magnetic field. Even the relatively weak geomagnetic field, which typically value is about 0.5 gauss, has an appreciable effect. Gain variations of PMT with 76 mm photocathode diameter may reach 10-20 % depending on spatial orientation. Therefore, it is necessary to apply magnetic shields for PMT response stability enhancement. The performances investigation of magnetic shields made of steel, permalloy and amorphous metallic alloy ribbon for PMT with 51 and 76 mm photocathode diameters was carried out. Based on obtained data the choice of magnetic shield was made.

1. Introduction

Photomultiplier tubes (PMTs) are very sensitive to the external magnetic field and their characteristics significantly change under the influence of magnetic fields. Even the relatively weak geomagnetic field, which typically value is about 0.5 gauss, has an appreciable effect [1]. Magnetic shields of different materials such as permalloy or amorphous metallic alloy (AMA) ribbon can be used to reduce the influence of magnetic field on PMT gain. PMT shields also have additional functions such as protection from ambient light and eliminating the influence of an external electric field [2].

In this study PMT gain variations under the influence of geomagnetic field with different configurations of magnetic shields have been investigated. The main purpose of investigation is selection the material and configuration of the PMT magnetic shields for GRIS [3] and PING-M [4] instruments that currently under development in the Astrophysics Institute of NRNU MEPhI.

A new type of magnetic shield made of AMA ribbons KNSR with 40 μm thickness made by Central Design Bureau of special radio materials [5] is presented.

It is well known that metals and alloys have a crystal lattice and strictly ordered arrangement of atoms. The amorphous metallic alloys feature is the absence of strict periodicity in the amorphous state. It is considered that the strict periodicity for unlimited long distance in the positional relationship of atoms absence in amorphous metallic alloys leads to isotropy of the magnetic properties [6]. However, amorphous alloys have anisotropic magnetic properties in reality, and exposed to thermal processing to decrease it. An important advantage of amorphous alloys is the opportunity to mix various chemical elements with over a wide range concentration changing, which improved physical, chemical and mechanical properties [7]. Therefore various designs of the amorphous alloys have a number of especial properties: high strength and hardness, high permeability, low coefficient of temperature dependence, etc. In this way amorphous metals are increasingly used in different fields due to its magnetically soft properties.

2. Experimental setup

In this study scintillation detectors (figure 1) based on Hamamatsu R6233-100 and R6231-100 PMTs with diameter of photocathode 76 mm and 51 mm respectively, and the cylindrical $LaBr_3$(Ce) experimental sample with dimension ∅25x25 mm, grown at the ISSP RAS [8] were used. The investigated shields wholly cowered PMTs bodies.

PMT output is directly connected to the pulse signal processor "Green Star" SBS-77 that had served as an amplifier–shaper and the amplitude-to-digital converter [9]. Spectra were accumulated and analyzed in the ESBS-7x program. Measurements were carried out with radioactive source ^{137}Cs.

Independent measurements of magnetic field suppression by the magnetic shields have been carried out using setup based on three-axis digital magnetometer Honeywell HMR2300 (figure 2). This magnetometer consists of three magneto-resistive sensors which oriented in orthogonal directions to measure the X, Y and Z vector components of a magnetic field. HMR2300 can measure magnetic field in the range of ±2 gauss and has accuracy 0.01 – 0.52% of full scale in the range of ±1 gauss [10].

Figure 1. The $LaBr_3$ (Ce) crystal with R6231-100 and R6233-100 PMTs detector assembly.

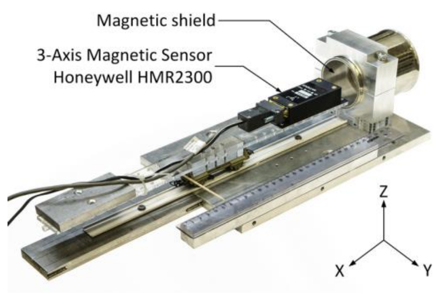

Figure 2. HMR2300 magnetometer based setup.

3. Types of magnetic shields

The magnetic shields of different shapes and designs for R6231-100 and R6233-100 PMTs have been investigated. Following samples of shields were studied for R6233-100 PMT: aluminum shield (A), steel shield (B), shield based on multilayer film nanostructures (C), the AMA ribbons shield (D) and Hamamatsu E989-15 shield (E). The Aluminum shield (F), two AMA ribbons shield (G and H) and Hamamatsu E989-05 shield (I) for R6231-100 PMT were investigated as well.

The A and F shields does not protected from the magnetic field practically. These only have mechanical and light protection purposes.

The B shield made of steel grate St3 with low carbon concentration and its composition similar to the technically pure iron. Permeability of St3 is relatively low. The shield has 2 mm thickness and 314 g weight.

The C shield consist of 10 layers of magnetic material (permalloy FeNi) with thickness 50 μm alternating with 9 layers of 5 μm copper (Cu) electrolytically deposited on an aluminum base. The weight of the shield with the aluminum base is 182 g.

The D, G, and H shields made of AMA ribbons which are fixed on an aluminum base. In order to provide electrical contact of the ribbons their edges were glued with conductive adhesive. The D shield has the 112 g weight (about 25 g weight of AMA) and made of two AMA ribbons layers. The second layer glued on the first one in orthogonal direction. The G shield made of a single layer of AMA ribbons, which is parallel to the axis of PMT and the H shield consists of one layer of the ribbons perpendicularly oriented to the axis of the PMT. The weight for both G and H shields is 75 g, and the weight of AMA ribbon is about 10 g.

The E and I standard Hamamatsu shields made of 0.8 mm permalloy, which have the weight 200 g and 135 g respectively.

4. Methods and results of the measurements

4.1. Measurements with three-axis digital magnetometer

The investigations of the geomagnetic field suppression by the magnetic shields were carried out with three-axis digital magnetometer HMR2300, which was fixed on a trolley moving on guide rails (figure 2). Experimental setupis constructed of nonmagnetic materials – aluminum and plastic. The distance between magnetic sensor and shields fixed with pointer attached to the trolley.

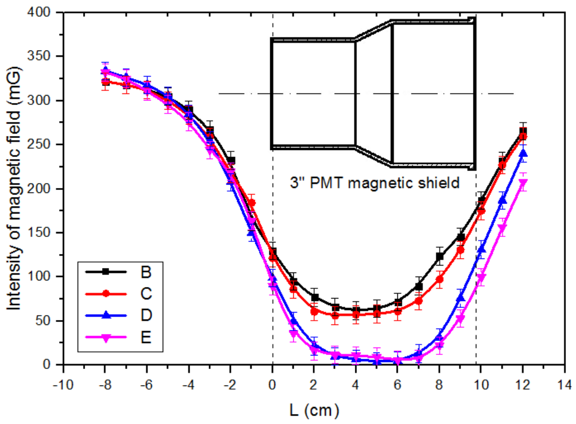

Figure 3. The suppression of geomagnetic field by B, C, D and E shields of R6233-100 PMT (lines connecting points are guide to the eyes only).

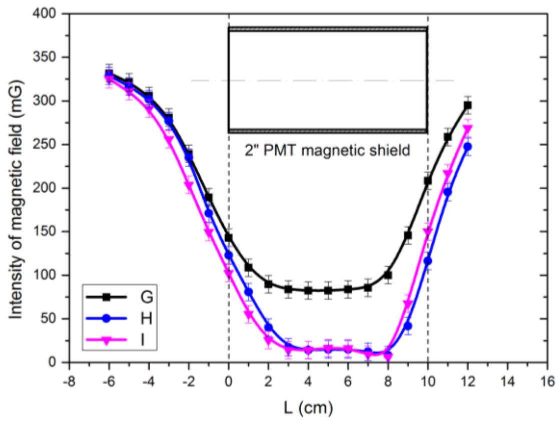

Figure 4. The suppression of geomagnetic field by G, H and I shields of R6231-100 PMT (lines connecting points are guide to the eyes only).

The value of the geomagnetic field was 330-350 mG at the point of measurements. The figures 3 and 4 show that the suppression of geomagnetic field by B and C shields of R6233-100 PMT is about 3 times like G shield made for R6231-100 PMT. The geomagnetic field suppression of the rest shields is not less than 100 times, which is the lower limit of digital magnetometer HMR2300. Measurements analysis of three components of the field showed that G shield (with parallel AMA ribbons) has two order of magnitude worse suppression of the magnetic field transverse component (directed perpendicular to the axis of the shield) than H shield with perpendicular AMA ribbons. Suppression of the other components for these shields is comparable. The sensitivity of magnetometer is not enough to determine truly suppression value of the magnetic field for D, E, H and I shields. Additional information can be obtained by direct measurements of magnetic field suppression degree of the shields in various designs using the detector assemblies.

4.2. Investigations of PMTs gain variations for different configurations of magnetic shields under influence of the geomagnetic field

The measurements of ^{137}Cs source peak position (662 keV) in spectrum at different orientations of detector axes (total 24 orientations for one measurement series) were carried out to investigate the PMT gain variations under the influence of the geomagnetic field. The Z axis is directed along the PMT axis. The X axis directed perpendicular to the Z axis in the plane of the photocathode. The combination of 6 main orientations were used in measurements, there are: up, down, north, south, west, east. One of the Z axis directions was selected and the X axis rotated around the Z with an interval of 90 degrees. Then direction of Z axis was changed and with X axis performed the same actions. For example, figure 5 shows the up-north direction (when the Z axis is directed up and the X-axis to the north). The relative deviations of ^{137}Cs peak from the mean value were calculated for each of the orientation position in the geomagnetic field:

$$Si = \frac{Aev - Ai}{Aev},$$

where A_{ev}– mean peak position, *i* – number of measurements in the series.

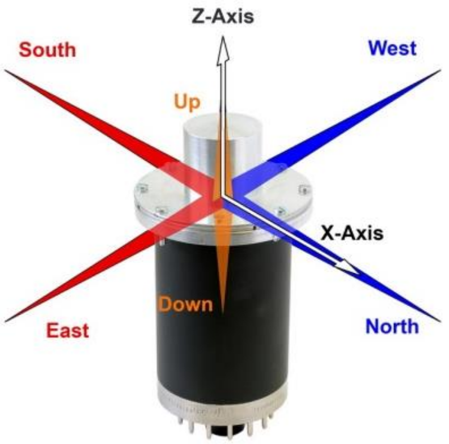

Figure 5. Detector orientation: up – north (Z axis is directed to the up and X-axis to the north).

Table 1. Measurement results.

PMT	Shields	δ_g ,%
R6233-100	A (Aluminum)	16±4
	B (Steel)	3.7±0.8
	C (Multilayer film)	5.0±1.3
	D (2 AMA ribbon)	0.7±0.2
	E (Ham. permalloy)	0.5±0.1
R6231-100	F (Aluminum)	10±4
	G(parallel AMA)	2.0±0.8
	H(perpendicular AMA)	0.25±0.05
	I (Ham. permalloy)	0.20±0.01

According to the relative deviation the mean gain variation (δ_g) for each shield calculated:

$$\delta_g = 2\sqrt{\frac{1}{n}\sum S_k^2},$$

where *n*=8; S_k– relative deviation of orientations, which doesn't includeany combinations with up and down directions, since deviations in these orientations are relatively small. The measurement results are shown in table 1.

Data obtained by magnetometer and results represented in table 1 show that the shield G with the parallel arrangement of AMA ribbons has not less than an order of magnitude worse magnetic field suppression than shields with perpendicular arrangement of the ribbon such as D and H, which ones show suppression comparable to permalloy Hamamatsu shields.

5. Conclusion

The shield selection implemented as a result of balanced compromise between the suppression of the external field and the mass-dimensional characteristics of the shields. The geomagnetic field suppression of steel and multilayer film nanostructures shields is not enough. The shields with AMA ribbons (D, H) and permalloy Hamamatsu shields (E, I) demonstrated comparable performances. The amorphous metallic alloy ribbon shields can be made of any size and shape (which is convenient in terms of the detector design). As opposed to a permalloy shield, the light weight ribbons can be fixed on mechanical construction of a detector setup.

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References

[1] De Vore P *et al.* 2014 Light-weight flexible magnetic shields for large-aperture photomultiplier tubes *Nucl. Instrum. Meth.* A **737** 222

[2] Hamamatsu Photonics K.K. Editorial Committee 2006 *Photomultiplier tubes: Basics and Applications, 3rd Edition* (Iwata: Hamamatsu Photonics K. K. Electron Tube Division)

[3] Kotov Yu D *et al.* 2015 Solar gamma-ray spectrometer GRIS onboard the International Space Station *J. Advances in Space Research* **56** 1797

[4] Kuznetsov V D 2011 *Interhelioprobe Project. Workshop Proceedings Tarusa* (Moscow) (Original Russian title: *Proekt Intergeliozond. Trudi rabochego soveshaniya Tarusa* (Moskva: Rotaprint IKI RAN 192))

[5] Central Design Bureau of special radio materials: *http://ckbrm.ru*

[6] Kikalo B 2006 *Atomic structure of amorphous alloys and its evolution* (Moscow: Moscow institute of steel and alloys) p 338 (Original Russian title: *Atomnaya struktura amorfnih splavov i ee evolucia* (Moskva: Moskovskiy institut stali i splavov))

[7] Pavlenko T P and Tokar M N 2013 Analysis and study of amorphous alloys properties *J. Electrical engineering and electromechanics* **5** 45

[8] Institute of Solid State Physics RAS: *http://issp.ac.ru*

[9] Belousov P V *et al.* Structure of Spectrometric complex SCS “Green Star”: *http://greenstar.ru*

[10] URL: *https://honeywell.com*