Conference of Fundamental Research and Particle Physics, 18-20 February 2015, Moscow, Russian Federation

Application prospects of multilayer film shields for space research instrumentation

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Abstract

We have studied the magnetic properties of multilayer film cylindrical configuration shields (MFS) based on NiFe / Cu. The studied samples were prepared by electrode position. MFS were constituted by alternating layers of NiFe and Cu, deposited on an aluminum cylinder with diameter of 4 cm, length of 13 cm and 0.5 cm thickness. The thickness of each ferromagnetic layer varied from 10 to 150 μm, and the thickness of Cu layers was 5μm. Five-samples in which the number of ferromagnetic layers varied from 3 to 45 and copper – from 2 to 44 were tested. The best shielding efficiency was achieved at the maximum number of layers and comprised about 102. Permalloy multilayer foil shield at the same total thickness has several times less efficiency in comparison with MFS. The description of a prototype of the charged particles telescope for space application is presented. Results of its testing regarding sensitivity to the constant magnetic field are described.

Keywords: multilayer shields, constant magnetic field, telescope counters.

1. Introduction

Creating effective shields for protection against constant magnetic fields is a highly relevant scientific and technical challenge. This is confirmed by the fact that, for scientific purposes and various devices (sensors and electronic circuits, and etc.) sensitive to negative effect of constant magnetic fields, the shields are used widely. On
the other hand, magnetic sources are increasingly used in scientific and applied researches. Some of them have magnetic field intensity up to several Tesla.

This task is especially acute in particle and astroparticle physics. For example in experiments on accelerators of elementary particles (LHC CERN, Tevatron FermiLab) where, for instance, PMTs, which are very sensitive to influence of magnetic fields, are combined with superconductor magnets. In the experiments constant magnets are also often used on spacecraft as part of scientific equipment (Magnetic Spectrometer PAMELA).

Theory and practice of magnetic shields creation have been developing for many decades, and as a result, a conclusion has been reached that multilayer magnetic shields have considerable advantage in comparison with monolithic shields. However, it is technologically difficult to create such shields for protection of objects with complex geometric configuration. The technology for electromagnetic shields manufacturing based on multilayer film electro-deposited structures was created in the Scientific and Practical Materials Research Centre of National Academy of Science of Belarus. This technology allows eliminating these disadvantages and creating magnetic film shields with high shielding properties. This work is devoted to investigation of shielding characteristics of such shields, research of their efficiency with Russian PMT-85 and estimation of prospects of these shields application in the equipment for space purposes.

It has long been demonstrated that multilayer shields have shielding factor significantly higher than monolithic shields at the same amount of magnetic-soft material. However producing a multilayer shield from foil for a shielding element of complex configuration is difficult. Using the electro-deposition technology significantly simplifies the creation of such shields and allows a high degree of shielding from constant magnetic fields and electromagnetic radiation [1, 2].

In this case, it is possible to shield the elements of complex configuration or small dimensions. When the number of magnetic material layers is 45 and the thickness of each layer is 10 μm, and they are separated by layers of copper 5 μm each, the shielding factor is greater than 100 [3].

2. Multilayer film magnetic shields for protection of PMT

Initially, measurements were made of the influence of the magnetic field on the amplitude of the output signal from an unshielded PMT-85 when it was exposed to a magnetic field, along three mutually perpendicular axes of the PMT.

![Graph showing the dependence of the relative amplitude of the output signal of an unshielded PMT-85 on the magnetic field along the axes (X, Y, Z). Axis Z is parallel to the cylindrical shield. Experimental errors are located within the experimental points.](image-url)
We have measured the relative amplitude of the output PMT signal \((U/U_0)\) and the output pulse amplitude resolution \((U_0 - \text{output signal amplitude of the PMT without magnetic field})\). Our measured values \((U/U_0)\) for unshielded PMT-85 perpendicular and parallel to the external magnetic field are shown in Fig.1.

In weak magnetic fields with induction \(0.1 \div 0.5\) mT for perpendicular and parallel orientations, we observe a reduction in the amplitude of output signal by 20% and 1% from the maximum, respectively. In magnetic fields of \(2\div3\) mT the amplitude of the output signal decreases by 95% (perpendicular orientation) and 60% (axial orientation).

The results of these measurements confirm the strong dependence of the gain of the PMT-85, even at relatively low magnetic field strengths, especially when it is oriented perpendicularly to the Z axis. This emphasizes need to use again magnetic shields to ensure efficiency of the PMT in the presence of a magnetic field.

Shielding efficiency measurements of the photomultiplier tube performed by using five multilayer film shields with different numbers of layers - the total thickness of the soft magnetic material was 450 μm in each shield and for the permalloy shield the total thickness of foil was 500 μm. More detailed descriptions of these shields are shown in table 1.

Table 1. Characteristics of the shield samples.

| Sample    | Magnetic layer thickness (μm) | Number of magnetic layers | Total thickness of magnetic layer (μm) | Thickness of copper layer (μm) | Number of copper layers | Total thickness of copper layers (μm) | Total shield thickness (μm) |
|-----------|-----------------------------|---------------------------|---------------------------------------|--------------------------------|-------------------------|-------------------------------------|--------------------------|
| MFS no.1  | 150                         | 3                         | 450                                   | 5                              | 2                       | 10                                  | 460                      |
| MFS no.2  | 90                          | 5                         | 450                                   | 5                              | 4                       | 20                                  | 470                      |
| MFS no.3  | 45                          | 10                        | 450                                   | 5                              | 9                       | 45                                  | 495                      |
| MFS no.4  | 22.5                        | 20                        | 450                                   | 5                              | 19                      | 95                                  | 545                      |
| MFS no.5  | 10                          | 45                        | 450                                   | 5                              | 44                      | 220                                 | 670                      |
| Permalloy | 100                         | 5                         | 500                                   | no                            | no                      | no                                  | 500                      |

Fig. 2. The relative amplitude of the PMT-85 output signal, for different types of shields, depending on the external magnetic field in the direction of the magnetic field perpendicular to the Z axis. Experimental errors are located within the experimental points.
Fig. 2 displays the dependence of the relative output signal amplitudes of the PMT-85 on the magnetic field, perpendicularly to the Z axis with various types of shielding. In practice, all studied samples of MFS eliminate the negative effect of a magnetic field values up to 0.5 mT, with a decrease in U no more than 1%–2%. For magnetic fields in the range of values 2–4 mT, and depending on the MFS type, the decrease in U may reach 10%–40%. The best shielding was obtained with sample no. 5, for which the decrease in PMT output signal amplitude did not exceed 10% at 2 mT.

The shield made from permalloy does not provide sufficient protection for the PMT. The measured reduction in U for a magnetic field of 0.1–0.5 mT oriented perpendicularly to the Z axis reached 5%–10%; however, for a magnetic field of 2–3 mT, this value rose sharply to 50%–80%.

Evaluation of the effect of shielding on the output characteristic of the PMT-85 was also carried out by measuring the amplitude resolution of the pulses from the photomultiplier. Fig. 3 shows the dependence of the amplitude resolution of pulses distribution (K) on magnetic field for PMT-85 with different magnetic shields.

The data show that for unshielded of PMT-85, the K value is degraded by 20% in magnetic fields at an induction up to 1 mT and decreases by a factor of 2.5-3 as the induction increases to 1 - 2.5 mT. Amplitude distribution of PMT-85 pulses with a permalloy shield was virtually unchanged for magnetic field of magnitude up to 2.5 mT. However, increasing the magnetic induction from 2.5 to 4 mT leads to degradation in performance by a factor of 2.5. The most stable results for the amplitude resolution of PMT-85 pulses are obtained using MFS shields. In magnetic fields with induction of 0.2 to 4 mT, the K values for MFS sample № 1 - 4 only slightly vary from 1.1% to 1.3%. The amplitude resolution for MFS sample no.5 practically does not change in fields up to 4mT.

Fig. 3. Dependence of the amplitude resolution of PMT-85 pulses on the induction of magnetic field without shield and with shields of aluminum, permalloy and MFS no. 1 – 5, with direction of the magnetic field perpendicular to the Z axis. Experimental errors are located within the experimental points.

3. Telescope «Nanomag»

The prototype of a scintillation detector system «Nanomag» using a combination of PMT-85 with shields against magnetic fields and without shields was designed and developed for assessment of the prospects of multilayer film shields application in space equipment. The tests were performed with this device in laboratory conditions. The device is a telescope of two scintillation counters connected in coincidence. Each scintillation counter has four PMTs, two of which are magnetically shielded and the other two are not protected. Each of these pairs is also working in coincidence. For electromagnetic shielding of PMT-85 was used MFS no. 5, which showed the best shielding efficiency of the constant magnetic field during of their tests. Fig. 4 shows one of the scintillation counters «Nanomag». 

![Fig. 4. One of the scintillation counters «Nanomag».](image-url)
The structure of the scientific equipment (SE) «Nanomag» prototype includes:

- Scintillation detector system (SDS);
- Electronic system of registration of events (ESRE);
- Power supply system (SEP);
- System of measurement of a magnetic field (SMMF);
- Control unit (CU);

Telescope «Nanomag» is designed for registration of charged particles of cosmic radiation in the vicinity of the Earth, including burst of particles from the Earth's radiation belt, in order to study the correlation between the bursts of charged particles precipitating from the Earth's radiation belt, and earthquakes.

Structurally, the prototype of the scintillation detector system is designed in the form of the parallelepiped presented in Fig. 5. Overall dimensions of the detector system (470 × 258 × 164 mm3) are determined by the arrangement of its blocks and elements. The aperture of telescope «Nanomag» is 120 degrees. Weight - 8.5 kg.

During the ground tests were registered the counting rate and the energy spectra for 2 information channels of the telescope «Nanomag» using signals with protected and not protected by the electromagnetic shields of PMT, as well as the magnitude of the magnetic field interacting with the shield using the program «Nanomag.exe» which is a part of the control test equipment (CTE).
Fig. 5. General views the prototype of scintillation detector system configuration (A) with cover and (B) without it.

Fig. 6. Dependence of the relative amplitude of the PMT’s pulse from the magnetic field for the protected and not protected information channels of SE «Nanomag». Experimental errors are located within the experimental points.

The testing results showed that the information channel of prototype SE «Nanomag», protected by electromagnetic shields works in magnetic fields with induction up to ±4 mT (±40 Gs) practically without deterioration of the characteristics, while the information channel which isn't protected by electromagnetic shields does not operate in magnetic fields with induction higher than ±1.5 mT (±15 Gs).

4. Conclusion

Thus, the shields based on multilayer film structures have a high efficiency of constant magnetic field shielding. The testing results showed that multilayer film structures can successfully protect the PMT from the constant magnetic fields with induction up to 2 mT, which can be used for land-based applications (modern accelerator experiments, nuclear medicine, and so on), as well as for on-board equipment spacecraft.
Acknowledgements

The authors would like to thank prof. A. M. Galper for interest in this investigation and for helpful comments.

References

[1] Grabchikov S., Sosnovskaya L., Sharapov T. Multilayer electromagnetic shield. Patent RB no.11843 on 01.28.2009.
[2] Dmitrenko V., Batishchev A., Grabchikov S. et al. Multilayer shield to protect the photomultiplier tubes and the method of its application. Patent for an invention, RB no.2474890 from 10.02.2013.
[3] Dmitrenko V., Phyo W., Vlasik K. et al. Electromagnetic shields based on multilayer film structures. Bull. Russ. Acad. Sci. Phys. 2015;42(2):43.