Space Radiation Superconducting Shields

2014 J. Phys.: Conf. Ser. 507 032033

(http://iopscience.iop.org/1742-6596/507/3/032033)

Journal of Physics: Conference Series **507** (2014) 032033 doi:10.1088/1742-6596/507/3/032033

Space Radiation Superconducting Shields

R.Musenich[1], V.Calvelli[1], S.Farinon[1], W.J.Burger[2], and[1] R.Battiston[3]
[1]INFN, via Dodecaneso 33, 16146 Genoa, Italy
[2]Dipartimento di Fisica, Università di Perugia, Perugia, Italy
[3]INFN-TIFPA and Dipartimento di Fisica, Università di Trento, Trento, Italy

E-mail: riccardo.musenich@ge.infn.it

Abstract. The interest on shields to protect astronauts I long term missions against GCR has recently grown and several projects have been funded. Due to their large mass, passive shields for large volume habitable modules are no longer an option and the attention is focused on the more complex, technologically challenging active systems. Among the possible solutions, the most promising is based on huge superconducting coils having a bending power sufficient to deflect out of the habitat charged particles with kinetic energy in the order of 1 GeV. Toroidal magnet systems based wound with Ti clad MgB_2 conductor is proposed and described.

This work is supported by INFN (SR2S-RD) and co-funded by the EU FP7 SR2S Project.

1. Introduction

It is well known that deep space is a hostile environment for human beings: although the spacecraft habitable modules are designed to supply astronauts with all the necessary for their life and to protect them by the sun light and micrometeorites, shielding of the cosmic rays is still an open problem. Cosmic rays, high energy, massive particles of solar or galactic origin, represent a serious threat for the health of crews of future, long term missions in the deep space. The adsorbed dose during a solar particle event (SPE) would be fatal by acute radiation syndrome while the continuous flux of galactic cosmic rays (GCR) exposes the crew to a high risk of develop a cancer [1]: the measurements taken during the voyage of the Mars Science Laboratory show that the dose, due to the GCR, adsorbed by an astronaut into a non-shielded spacecraft is 1.84 mSv/day [2]. SPE are very intense, short bursts of relatively low energy (1-100 MeV) particles, mainly protons, so that it is possible to protect the astronauts recovering them in a passive shelter, made by a material of sufficient thickness, for the duration of the event. A protection from CGR is much more difficult to design as they are composed by protons and ions having a wide energy spectrum with its maximum around 500 MeV/nucleon. Moreover, as the flux is continuous, a CGR shield must surround the whole habitat. As long trips require large habitable volumes, the mass of passive shields is very high and (several hundred tons), so the attention is focused on active systems, which require electric or magnetic field to deflect the charged particles [3], [4].

1 To whom any correspondence should be addressed.

Among the possible solutions, the most promising is based on huge toroidal magnets having a bending power sufficient to deflect out of the habitable module charged particles with kinetic energy in the order of 1 GeV. The operation environment requires a system fulfilling peculiar characteristics: first of all it must be light and power saving, so it is mandatory to use superconducting coils. Moreover, it must be stable and must safely guarantee an endurance of at least 2 years. These requirements orient the choice of the conductor towards HTS coated conductors or Titanium clad MgB_2.

2. The Superconducting Magnet System

The Space Radiation Superconducting Shield is composed by a large barrel toroid surrounding the habitable module as schematically shown in figure 1. The rear side of the spacecraft is passively shielded by the engine and propellant tanks. The front can be shielded either passively by a module containing equipments and supplies or actively by an end cap toroid.

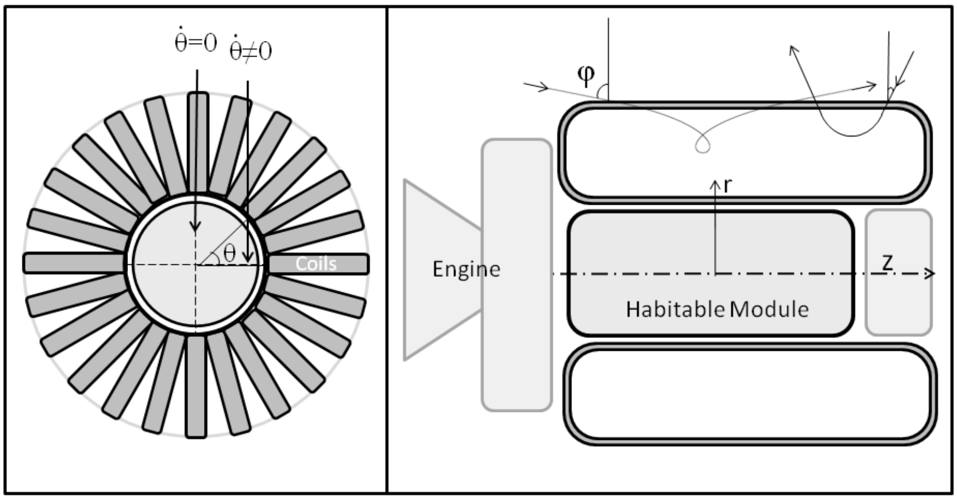

Figure 1. Schematic view of the Space Radiation Superconducting Shield. The trajectories of two particles with different angle of incidence φ are shown.

In the case of a particle moving in the r-z plane, i.e. having zero angular velocity, the motion equations in an ideal toroidal field have an analytical solution [5]. It can also be demonstrated that a particle with zero angular speed is the most penetrating one, so the shielding power of the toroid can be written as:

$$\Xi = \int_{R_i}^{R_e} B_\vartheta \, dR = \frac{\mu_0 I}{2\pi} ln \frac{R_e}{R_i}. \quad (1)$$

The shielding power can also be written as a function of the particle properties and of the angle of incidence φ:

$$\Xi = \frac{m_0}{q} c\sqrt{\gamma^2 - 1}(1 - sin\varphi), \quad (2)$$

where m_0 is the rest mass, q the charge and γ is the Lorentz factor. The analytical solution allows calculating the cut-off energy that, in the worst case, i.e. when $\varphi = -\pi/2$, is:

$$\mathrm{K}^* = \frac{m_0}{\eta} c^2 \left(1 - \sqrt{\frac{q\Xi}{m_0 c^2 (1 - sin\varphi)}}\right), \quad (3)$$

where η is the number of nucleons. Assuming an isotropic flux and using the spectra of the CREME database [6], an ideal, infinitely long toroid, with Ξ=5 T·m is able to shield almost 80% of the particle. In case of a real toroid, we have to take into account the azimuthal ripple of the magnetic field.

However, if the number of coils is large enough (≥12 if the internal radius is less than 3 m), the shielding power is not affected by the ripple and the approximation of ideal toroid can be used [5].
Starting from a cylidrical habitat 4 m diameter, 10 m long, our choice is oriented toward a magnet composed of 24 racetrack coils having a winding pack 0.55 m wide and 0.05 m thick as shown in figure 2. The dimensions have been chosen in order to minimize the stray field in the cabin and the maximum field at the conductor.

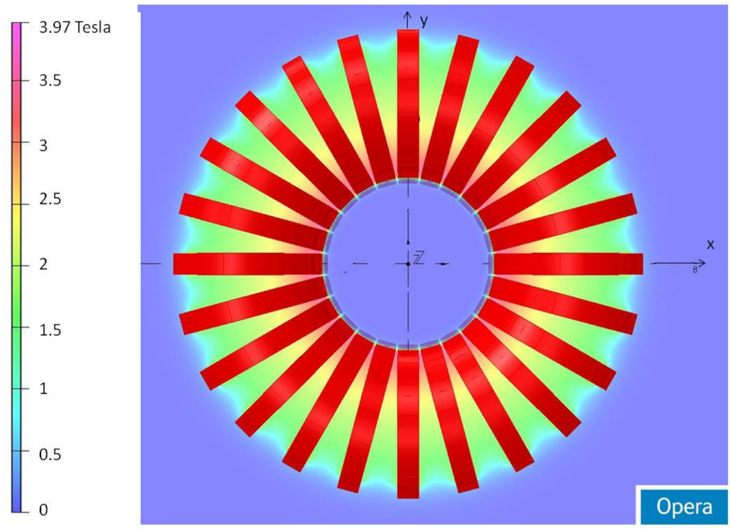

Figure 2. Field map. The toroid is designed to keep the peak field at the conductor less than 4 T and to minimize the stray field in the habitable module.

The outer radius is determined by the cargo launcher size. A heavy launcher with a 9.2 m diameter, 17 m long cylindrical hold, called SLS block II is planned to be operative in the thirties [5]. This opens up two possible scenarios: a compact magnet to be sent in a single launch and a magnet divided in sectors to be separately launched and assembled in orbit. As shown in figure 3, dividing the magnet in 4 sectors the outer radius will be 6.3 m, while a division in 6 sectors leads to 9.5 m.

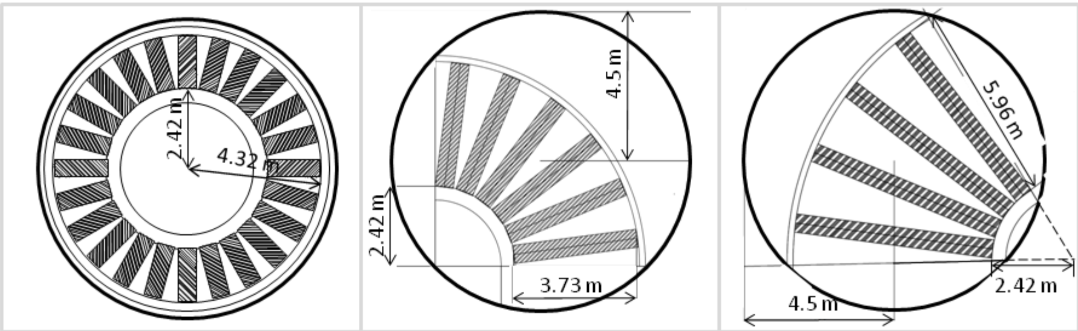

Figure 3. Scheme of the magnet inside the launcher hold (bold circle). Left to right: entire magnet, a quarter and one sixth.

A further subdivision increases the complexity of the system without a significant gain in terms of shielding power. Table 1shows the shielding power and the cut-off energy of the 3 different solutions obtained limiting to less than 4 T the maximum flux density at the conductor.

Considering only the deflection of the incoming particles due to the magnetic field, the shielding power of the compact magnet seems to be sufficient to protect a crew for more than two years, however, monte carlo simulation have shown that a large part of dose is due to the secondary particle generated by the interaction of CGR with the materials [8].

Table 1. Characteristics of the different magnet solutions.

Sectors No.	Outer diameter (m)	Shielding power (T·m)	Cut-off energy (MeV)
1	8.6	5.4	300
4	12.3	8.3	645
6	16.8	11.4	1000

3. Conductor

The conductor is a Ti clad MgB_2 tape, bonded with pure aluminum strips, having 10 mm^2 section area (15% MgB_2, 40% Ti, 45% Al). Such a conductor is light, 3400 Kg/m^3, and allows avoiding helium cryogenics. Solid hydrogen contained in tanks connected with the coils can be used both as cryogen and as passive radiation shield. Conductor prototypes are at present under development at Columbus Superconductors in Genoa, Italy.

The current density being limited to $J=70\ A/mm^2$, the total conductor length ranges between 1479 Km and 1770 Km, while the masses of the windings are 49 to 58 tons including the insulation depending on the configuration.

4. Conclusions.

In the perspective of interplanetary manned missions in the near future, superconducting magnets are a serious option to protect crews from cosmic rays. Possible solution have been devised based on MgB_2 based conductors.

5. References

[1] F.A.Cucinotta and M.Durante, "Cancer Risk from Exposure to Galactic Cosmic Rays: Implications for Space Exploration by Human Beings" *Lancet Oncol.* **7**, 431-435, 2006.

[2] C. Zeitlin et al. "Measurements of Energetic Particle Radiation in Transit to Mars on the Mars Science Laboratory", *Science* **340**, 1080-1084, 2013.

[3] Hoffman, J.A., Fisher, P. and Batischev, O., "Use of Superconducting Magnet Technology for Astronaut Radiation Protection", NIAC Phase I Final Report, Contract CP 04-01, 2005.

[4] P.Spillantini et al., "Shielding from Cosmic Radiation for Interplanetary Missions: Active and Passive Methods", *Radiation Measurements*, **42**, 4 – 23, 2007.

[5] R.Battiston, W.J.Burger, V.Calvelli, V.I.Datskov, S.Farinon, R.Musenich, "Superconducting Magnets for Astroparticle Shielding in Interplanetary Manned Missions" *IEEE Trans. on Appl. Supercond*. **23** (3), Art. No. 4101604, 2013.

[6] Cosmic Ray Effects on Micro Electrons, https://creme.isde.vanderbilt.edu/CREME-MC.

[7] http://www.nasa.gov/pdf/664158main_sls_fs_master.pdf

[8] W.J.Burger et al., "Active Magnetic Shielding for Long Duration Manned Space Missions". to be published in the Proceedings of the 6th IAASS Conference, Montreal, 2013.