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*Review article*

# Preliminary proposal to build a magnetic cancellation system for satellite magnetic tests in Venezuela

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**Abstract:** A very preliminary proposal to make up a system that cancels the magnetic field of Earth for executing satellite magnetic tests in Venezuela is made. Firstly, it is reviewed general satellite magnetic status considering electrical currents in it and possible magnetic domains in the structure and equipment is reviewed. After checking some magnetic cancellation systems, it is concluded that an optimal option to be selected is a Merritt 4-coil system because it offers good uniformity of magnetic field in a large relative volume. After some considerations and taking into account the usual size of a small satellite, the size of the coils should be around 32 meters. Finally, some considerations about the movement of the Earth's magnetic poles are taken into account.

**Keywords:** Merritt coils, magnetic field, magnetic moment, vertical component, horizontal component.

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## 1. Introduction

The objective of this work is to establish which items would be taken into account to build a satellite magnetic test facility in Venezuela. Firstly, it is considered a general magnetic status of a satellite, specifically referred to small satellites, and then it is proposed a system of coils to cancel the Earth's magnetic field. Some basic calculations are executed to estimate the characteristics of these coils and then a system is proposed.

## 2. Materials and Methods

In a satellite, electrical currents circulate through equipment and cables. An electrical current generates a magnetic field perpendicular to the direction of the flow of the electrical current.

A framework of trajectories of electrical currents inside equipment and cables generates a satellite magnetic field, which is associated with different modes of operation of the satellite, creating a dipolar magnetic momentum of the satellite. Besides that, materials that make up a satellite can have a residual and permanent dipole magnetic momentum. Based on that, the satellites could be regarded as heterogeneous domains of magnetic dipoles. These magnetic dipoles can be added as independent vectors, generating a total dipolar magnetic momentum characteristic of the satellite under study. In the following figure this idea is presented:

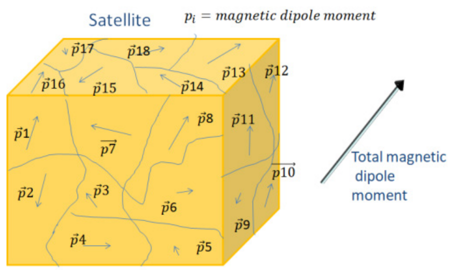


**Figure 1.** A very first approximation of the magnetic status of satellites.

In orbit, the Earth's magnetic field will exert a torque on the satellite because its total dipole magnetic moment has not been compensated or reduced. This torque will generate perturbations in the attitude of the satellite (its movement around its center of mass). So, in the process of development of the satellite, it is measured its total dipole magnetic moment and then it is compensated by installing small magnets on strategic places on the satellite. Consequently, it is necessary to measure the total magnetic moment of the satellite in a clean electromagnetic environment, which implies cancelling the Earth's magnetic field in the region in which the test is executed.

Based on this argument, the objective is to reduce the total dipole magnetic moment of the satellite. One way to achieve it is to submit the satellite to an oscillatory magnetic field at a high frequency. Thus, the magnetic dipoles get aligned from the different magnetic domains in opposite directions, such that the vector summations of the dipolar magnetic moments cancel each other. Then, the satellite magnetic moment should be made smaller.

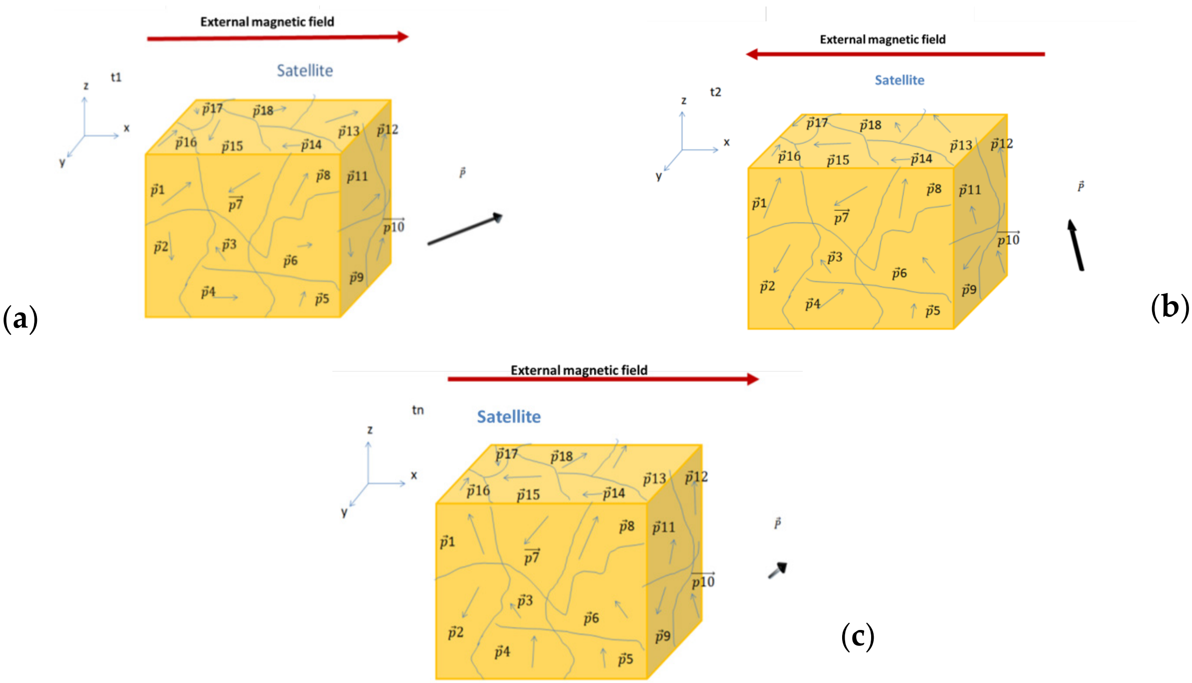


**Figure 2.** In (a), (b), (c) it is shown the sequence to reduce the total magnetic dipole moment of the satellite. It is assumed that the magnetic dipole moments change its direction when an external magnetic field is applied.

A graphical representation of this idea is presented: at the instant t1, the satellite is submitted to an external magnetic field in the X-direction; the dipolar magnetic moments from different magnetic domains would try to get alienated to the direction of the external magnetic field. Then, the direction of the external magnetic field is inverted and then the dipole moments of the satellite would try to get aligned again. The oscillatory magnetic field is executed at high frequency such that at the instant tn, after several cycles, the magnetic domains would be distributed approximately equally in +X and –X-directions. This operation is repeated in Y and Z.

As this study is concerning building a satellite magnetic test facility, it is necessary to consider that the magnetic environment near the equator differs from the magnetic environment in the north and south hemispheres. Thus, it wonders about the possible design of coils in order to remove the vertical and horizontal magnetic component of the Earth's magnetic field in a specified volume, in Venezuela.

## 3. Results

### *3.1. Propositions to cancel the Earth's magnetic field*

It is proposed to build a magnetic test facility for small satellites at about 8 degrees latitude north. So, the vertical component of the Earth's magnetic field should be greater than the value on the equator.

In the beginning, it was considered three kinds of arrangement of coils to cancel the horizontal component of the Earth's magnetic field. These include Helmholtz coils, square coils, Merritt coils systems, and Ruben coils systems. From (Abbott, 2015; Herceg, Juhas, & Milutinov, 2009; Kirschvink, 1992; Magdaleno, Olivares, Campero, Escalera, & Blanco, 2010; Merritt, Purcell, & Stroink, 1983; Pourtau & Terral, 2005), and as we are interested in obtaining uniformity in the distribution of the magnetic flux density generated inside these coils, the Helmholtz coil and the square coils are not taken account. The Ruben coils system offers a good solution with respect to the uniformity of the magnetic flux density at the centre of the system. However, there are some results that discuss it and imply higher costs for building this system. Therefore, it is analyzed in this paper implementation of the Merritt coil system.

### *3.2. Values of Earth's magnetic field in Venezuela*

Values of vertical component Hv and horizontal component Hh of the Earth's magnetic field in the probable facility location in Venezuela according to (" IGRF Model (13th Generation)", 2019) are:

$$Hv = 16.9\ \mu T \tag{1}$$

$$Hh = 27.15\ \mu T \tag{2}$$

According to these values, the magnitude of the vertical component of the Earth's magnetic field is not zero, nor is its value much smaller than the horizontal component. Therefore, it implies that the system of cancellation of the Earth's magnetic field as the vertical as the horizontal component should be similar.

### *3.3. Coil systems proposed*

Previously, it was considered two kinds of system of coils: one for the cancellation of the vertical component and another for the cancellation of the horizontal one. However, as it has to achieve a uniformity of the magnetic flux density in a specific volume (in this volume is the satellite for executing the test) then, it has decided to choose the same kind of system of coils for the vertical component and the horizontal component.

According to (Herceg et al., 2009; Merritt et al., 1983), a Merritt

4-coil system provides a good uniformity of magnetic flux density, and it is a very well-known system in the scientific community. This system achieves a good uniformity in the magnetic flux density when the number of turns in the inner coil is 0.423514 times the number of turns in the outer coil. Also, the separations between inner coils and outer coils follow the next expressions:

$$a/d=0.12866 \tag{3}$$

$$b/d = 0.505492 \tag{4}$$

And the relationship between a, b and d is illustrated in the following figure:

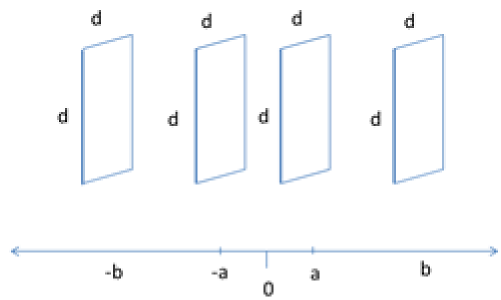


**Figure 3.** Illustration of arrangement of coils for cancellation the horizontal component of the Earth's magnetic field.

In the beginning, implementing a square coil system of three coils was considered. In that way, the uniformity of the magnetic flux density does not sacrifice, and costs would be reduced compared with an implementation of a four-coil system. However, uniformity in the magnetic flux density is a characteristic that must be assured.

Also, according to (Magdaleno et al., 2010), a Merritt 4-coil system, which d has a value of 89.75 cm and volume V of 730882.65 $cm^3$ according to their calculation, it is obtained a volume of 50 $cm^3$ of the uniform magnetic flux density inside this system. This is a ratio of just $6.84x10^{-5}$. Taking into account this architecture, if the size of the coil is adjusted to 32 m, then it is obtained:

$$V=2d^3\cdot 0.505492$$
$$V=33127.92\ m^3 \tag{5}$$

So, if d has a value of 32 m, then just a volume V of 2.26 $m^3$ should provide a uniform magnetic flux density. However, the dimensions of small satellites are very near to 1.31 m. Therefore, for this initial proposal, this value is used. Also, it has to be mentioned that according to (Herceg et al., 2009; Kirschvink, 1992), the volume V associated with the uniformity of the magnetic flux density looks to be larger.

Taking into account the following equation to calculate the magnetic flux density B at the center of the system (Magdaleno et al., 2010):

$$B=(1.795\cdot 10^{-6}\cdot N\cdot I)/d \quad (6)$$

It may be speculated that the value of the electrical current through one turn of the inner (I′) and outer (I) coils could be adjusted to 1.5 amperes, and d is 32 m. Then, the values for N, the number of turns for the outer coil, and consequently N′ the numbers of turns for the inner coil are related by (Herceg et al., 2009; Kirschvink, 1992):

$$N'\cdot I'/N\cdot I=0.423514 \quad (7)$$

**Table 1.** Numbers of turns for the coils.

| Magnetic flux density | N (outer coil) | N′ (inner coil) |
|---|---|---|
| (Vertical component) 16.9 µT | 200.85 ≈ 201 | 85.06 ≈ 85 |
| (Horizontal component) 27.15 µT | 322.67 ≈ 323 | 136.65 ≈ 137 |

If the direction of the axis in figure 3 is parallel to the direction of the Earth's magnetic field according to the direction of a compass, this work proposes an arrangement of coils oriented vertically to cancel the vertical component of the Earth's magnetic field. The following figure illustrates this idea. It is noted that the value of d should be the same for the horizontal and vertical orientations.

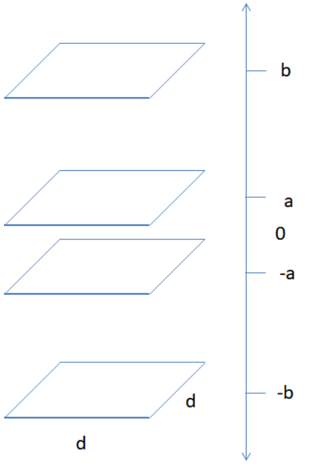


**Figure 4**. Illustration of arrangement of coils for cancellation the horizontal component of the Earth's magnetic field.

### *3.4. Other considerations*

Until this moment, just two sets of Merritt 4-coils have been considered: one set to cancel the vertical component of the Earth's magnetic field and another one to cancel the horizontal component of the Earth's magnetic field because the arrangement of the coils would be built such as these are aligned to the direction of the north magnetic pole. This supposition does not take into account a scenario in which the Earth's magnetic poles move (Witze, 2019).

Based on that, it is suggested to add a third set of Merritt 4-coils to be used to compensate for changes in the direction of the horizontal component of the Earth's magnetic field. However, at this moment, it cannot be assured what kind of coils could be utilized and its characteristics such that accomplish uniformity in a generated magnetic flux density.

Also, additional reviews must be done related to power consumption, electrical resistances of coils, inductances, and other parameters related to magnetic dipole moment (Abbott, 2015; Lackey, 1968; Mehlem, 1978).

## 4. Discussions

After considering different kinds of coil systems, the Merritt 4-coil system is suitable to cancel the Earth's magnetic field. We could have considered Merritt's 3-coils system to cancel the vertical component of the Earth's magnetic field to reduce costs. However, it would imply reducing the uniformity of magnetic flux density generated inside coils, which could conduct non-suitable magnetic measurements on satellites under study. Additional studies related to what kind of materials could be used to build the system, the generation system for the electrical current, vibrations of the coils, and other issues have to be executed.

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