Study on Anti-Magnetic Pollution Ability of Ni-Cd Battery

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Abstract. Ni-Cd battery pack is an important part of spacecraft, and its performance is easily affected by the changing magnetic field. In order to grasp the anti-magnetic pollution ability of the battery pack, this paper conducted a charge and demagnetization test study on the battery pack in a magnetic field environment simulation site by adjusting the intensity, frequency, waveform and other magnetic parameters to investigate the charging and demagnetizing effect of the battery pack. The results show that the Ni-Cd battery pack has weak resistance to magnetic pollution and is easily magnetized. In addition, when the magnetic strength is 4.5 mT and the frequency is 1.5 Hz, the demagnetization in three directions of the Ni-Cd battery pack can be well accomplished. This study provides a reference for the use of Ni-Cd battery packs in the magnetic environment and the removal of magnetic pollution effects.

1. Introduction
The spacecraft project is large, complex, and difficult to maintain. Once an accident occurs, it will cause huge losses. Therefore, the reliability and safety of spacecraft have always been the top priority of development. The space magnetic field[1-2] is one of the elements that constitute the spacecraft's orbital operating environment, and the spacecraft itself has a variety of magnetic components that exhibit a certain overall magnetism. The magnetic effect of the space magnetic field on the spacecraft[3] will seriously affect the operation of some important components of the spacecraft, as well as its own attitude control, and will also have a huge impact on the operation of on-orbit related magnetic tests. Therefore, it is crucial to accurately describe and evaluate the magnetism of spacecraft components.

With the development of the space industry, higher requirements have been placed on the magnetism of satellites. For example, some satellites used to explore earthquake precursor information, space environment monitoring and forecasting, and earth system science research. They have much stricter magnetic indicators than ordinary satellites. Satellite components must be subjected to magnetic testing, including charging and demagnetizing tests, magnetic compensation, etc. Because the magnetic field strength and frequency required for the component demagnetization test directly affect the effect of the magnetization and demagnetization, it is of great significance to the magnetic control level of the satellite to study the parameters of the magnetization and demagnetization test of the magnetic sensitive components in the satellite.

The nickel-cadmium battery is one of the main sources of satellite magnetism, and is also a component of satellites that is susceptible to magnetic pollution[4]. It supplies energy before, during and during satellite launch, and is an important energy storage device for spacecraft. If the magnetic
control is not accurate, it will affect the normal operation of the spacecraft. This paper studies the magnetic state of nickel-cadmium battery packs in different charging and demagnetizing environments, which plays an important role in the use of nickel-cadmium battery packs in abnormal magnetic environments and the reliability of satellites.

2. Magnetization characteristics of battery pack

2.1. Analysis of magnetization mechanism

The magnetic properties of nickel-cadmium battery packs are mainly derived from the nickel metal. Cadmium is a diamagnetic substance with weaker magnetism, while nickel is a typical ferromagnetic material. Under the action of an external magnetic field, it can generate the same strong additional magnetic field as the external magnetic field, which is self-magnetization. There are two mechanisms of magnetization: the displacement of the magnetic domain walls; the uniform rotation of the magnetic moments of the magnetic domains[5]. The magnetization curve of the ferromagnetic material is shown in figure 1. The magnetization of the ferromagnetic substance increases with the increase of the applied magnetic field $H$ until it saturates $B_s$. The whole magnetization process is divided into 4 stages: "1" is the reversible magnetization stage. For ferromagnetic materials, the mechanism of this stage is mainly the domain wall displacement; "2" is the irreversible magnetization stage, that is, if an external magnetic field $H$ is applied When it reaches 0, the magnetization $B$ will not return along the original path, but will decline along another curve, as shown by curve ab in figure 1; "3" is approaching the saturation stage, then the rotation of the magnetic domain magnetic moment plays a major role; "4" is the saturation magnetization stage.

Iron, cobalt, and nickel are all ferromagnetic materials. In contrast, nickel is weak in ferromagnetism and its spontaneous magnetization is $521 \times 10^{-4}$ T. In the magnetization stage, the reversible process is very short, so the magnetic properties of nickel will change greatly in a relatively small magnetic field.

2.2. Magnetization test

Magnetization is to add a DC constant magnetic field to the measured component. The choice of magnetic field strength is mainly to consider the maximum environmental field that the spacecraft may experience during processing, transportation, environmental testing and launch, and to understand the impact of the harsh magnetic environment on the spacecraft, and investigate its ability to resist magnetic pollution. In the magnetization test, DC magnetization is generally used to stabilize the magnetic field, the magnetic induction intensity is between 0.5~2mT, and the value of the geomagnetic field is only 0.05mT, which has little effect on the magnetization effect. In order to make the test more accurate, the magnetization tests of nickel-cadmium battery packs with different strengths were conducted under zero magnetic field. The main purpose was to investigate their ability to resist magnetic pollution. The specific results are shown in table 1.
Table 1. Measurement results of magnetic moment under different magnetization intensity

| Number | Magnetization (mT) | Magnetic moment / (mA⋅m²) |
|--------|-------------------|--------------------------|
|        | Mₓ                | Mᵧ                        | Mₜ | M    |
| 1      | 1.0               | 11                        | 16   | 244 | 245 |
| 2      | 1.5               | 50                        | 535  | 129  | 553 |
| 3      | 2.0               | 125                       | 1210 | -90  | 1220 |

From the above test on the magnetic moment of the battery pack, the magnetism of the nickel-cadmium battery pack is very susceptible to interference from the magnetic field, and the amount of magnetic change in the environmental magnetic field of 1 ~ 2 mT is more than 5 ~ 6 times. The reason why the cadmium nickel battery pack has such a big change is mainly caused by the nickel metal in the battery.

3. Demagnetization characteristics

3.1. Demagnetization mechanism analysis

AC demagnetization is generally used for component demagnetization. The magnetization state of the medium follows a hysteresis loop that is smaller than one time, and finally returns to the unmagnetized state, demagnetizing residual magnetism, as shown in figure 2.

The main parameters that affect the demagnetization effect of the battery pack are the demagnetization form, demagnetization direction, demagnetization frequency, and demagnetization intensity. A high frequency does not necessarily have a good demagnetization effect, which can be considered to be caused by the skin effect and eddy current loss of the material. Eddy current is the induced current generated by the material during demagnetization. The current flow line is a closed vortex. When a strong eddy current flows in the metal, a large amount of Joule heat will be released, resulting in energy loss. According to the law of conservation of energy, the energy required to change the orientation of the magnetic domains inside the material will naturally be reduced, so the demagnetization effect is reduced.

In the alternating magnetic field, there will be a skin effect phenomenon[6]. As the frequency increases, the amplitude of the magnetic induction intensity gradually concentrates on the surface of the material, which may make the conductor material completely without a magnetic field, and the magnetic field is concentrated on the surface of the conductor material in the thin layer, this is the skin effect. The size of skin effect is usually expressed by skin depth $\Delta$:

$$\Delta = \sqrt{\frac{2}{\omega \mu_0 \sigma}} = \frac{503}{\sqrt{f \mu \sigma}}$$

(1)

In the formula, $f$ is frequency, $\mu$ is magnetic permeability and $\sigma$ is electrical conductivity. It can be seen from equation (1) that the higher the frequency, the greater the induced electromotive force, the higher the electrical conductivity, and the larger the eddy current, and the more obvious the skin effect. Therefore, in the demagnetization test, it is necessary to select an appropriate demagnetization frequency, which can not only achieve a good demagnetization effect, but also reduce eddy current losses.

The choice of demagnetization intensity is mainly to see whether the energy of the demagnetization field is greater than the energy of the magnetic field of the demagnetization material, that is to say, only when the magnetic induction intensity of the demagnetization field at the material is greater than the magnetic induction intensity at the material surface, the demagnetization has an effect, but the magnetic induction at the material surface The intensity is difficult to measure. The magnetic field of the material can be regarded as the magnetic field of the dipole. The magnetic field generated by the dipole is:
\[ B(r, M) = \frac{\mu_0}{4\pi} \left[ \frac{2(M \cdot r)}{r^3} - \frac{M}{r^5} \right], \quad (\mu_0 \approx 4\pi \times 10^{-7} \text{Tm} / \text{A}) \] (2)

Where \( M \) is the magnetic moment of the magnetic source and \( r \) is the displacement vector from the magnetic source to the detection point. It can be seen from equation (2) that the magnetic induction intensity decays according to the third power of radius \( r \). Set the material center as the coordinate origin, the distance between the material boundary and the coordinate origin is \( r_0 \), the distance between the magnetic field measuring point and the coordinate origin is \( r_1 \), and the measured magnetic induction intensity is \( B_1 \), then the magnetic induction intensity \( B_0 \) of the material surface is:

\[ B_0 = B_1 \left( \frac{r_1}{r_0} \right)^3 \] (3)

After calculating the magnetic induction intensity of the material surface, the appropriate demagnetization field can be selected according to this value. As long as the selected amplitude is larger than the magnetic field on the material surface, there will be no significant difference in demagnetization effect.

3.2. Demagnetization test

The experiment is carried out in the environment of zero magnetic field. By adjusting the parameters of the magnetization and demagnetization system, including magnetization intensity, demagnetization direction, demagnetization frequency, demagnetization waveform, demagnetization intensity, etc., the magnetic moment change of the nickel-cadmium battery group is measured by fluxgate magnetometer.

3.2.1. Effect of demagnetization direction on demagnetization effect.

Add demagnetization field with frequency \( f=0.5\text{Hz} \), time \( t=100\text{s} \) and intensity \( H=4.5\text{mT} \) in three directions of the storage battery. The results are shown in Table 2.

| Number | Direction | Magnetic moment / (mA·m²) |
|--------|-----------|--------------------------|
|        |           | \( M_x \) | \( M_y \) | \( M_z \) | \( M \) |
| 1      | \( x \)   | 70        | 550        | -35        | 556   |
| 2      | \( x, y \)| 20        | 110        | -30        | 116   |
| 3      | \( x, y, z\)| 10        | -15        | -10        | 21    |

From the data in Table 2, it can be seen that the demagnetization in one direction or two directions cannot completely achieve the demagnetization effect. Experiments show that although the demagnetization test is to break up the inherent orientation of the domain in the material, only the change of the magnetic moment in the demagnetization direction occurs. Therefore, it is necessary to demagnetize the product in three directions in the demagnetization test.

3.2.2. Effect of demagnetization frequency on demagnetization effect.

AC demagnetization is to place the object under test in an alternating electric field which attenuates according to a certain rule (linear or exponential), the frequency of the AC magnetic field will affect the demagnetization effect when the test piece is stationary. Set the demagnetization time and intensity unchanged, change the demagnetization frequency, and test the magnetic moment of the battery. See Table 3 for the specific data.

| Number | Frequency /(Hz) | Magnetic moment / (mA·m²) |
|--------|----------------|--------------------------|
|        |                | \( M_x \) | \( M_y \) | \( M_z \) | \( M \) |

Table 2. Measurement results of magnetic moment under different magnetization directions

Table 3. Measurement results of magnetic moment under different magnetization frequency
It can be seen that with the increase of demagnetization frequency, the demagnetization effect is gradually improved, but when the frequency reaches 2.0 Hz, the demagnetization effect decreases. From the test results, there is no obvious difference between the demagnetization frequency of 0.5 ~ 1.5 Hz for the battery, and the effect is good. This shows that the demagnetization frequency is not directly proportional to the demagnetization effect.

3.2.3. Effect of demagnetization mode on demagnetization effect.

The moment tooth wave and triangle wave can be decomposed into sine waves of different frequencies. In the demagnetization process, the higher the frequency is, the greater the eddy current loss will be, and the corresponding demagnetization effect will be less obvious. Therefore, single frequency low-frequency sinusoidal waveform is selected to reduce the influence of high-frequency harmonics in the AC magnetic field. See Table 4 for the test results of linear attenuation and exponential attenuation in sine wave.

Table 4. Measurement results of magnetic moment under different magnetization mode

| Number | Mode         | Magnetic moment / (mA·m²) |
|--------|--------------|----------------------------|
|        |              | | Mx | My | Mz | M   |
| 1      | Linear       | 10 | 3  | -6 | 12 |
| 2      | Exponential  | 12 | 2  | -9 | 15 |

It can be seen from the test results that the demagnetization effect of linear demagnetization and exponential demagnetization is not very obvious, and the difference between them is not significant. In the process of test, the exponential attenuation is generally used.

3.2.4. Effect of demagnetization intensity on demagnetization effect.

The demagnetization test is to reduce the area of hysteresis curve to 0 gradually and continuously by reducing the hysteresis loop periodically, so that the magnetic domain of the material is arranged irregularly. In the process of demagnetization, the strength of demagnetization field will decrease with time until it is 0. The demagnetization strength here refers to the maximum value of demagnetization field. Add the demagnetization field with f = 0.5Hz, t = 100s and strength H gradually changing to the battery. See Table 5 for the test results.

Table 5. Measurement results of magnetic moment under different magnetization intensity

| Number | Intensity/(mT) | Magnetic moment / (mA·m²) |
|--------|---------------|----------------------------|
|        |               | | Mx | My | Mz | M   |
| 1      | 3             | -6 | 17 | -40 | 44 |
| 2      | 4.5           | -9 | 15 | -35 | 39 |
| 3      | 5             | 16 | 7  | 8   | 20 |

It can be seen from the test that the choice of demagnetizing magnetic field will directly affect the demagnetization effect. The maximum amplitude of the initial magnetic field strength is equal to or greater than the maximum coercive force of the material, so the saturation remanence can be removed well. The selection of the initial magnetic field value is low, which can not play a good demagnetization effect, but the magnetic field value is too large, which may affect the components containing magnetism, and make their working performance decline. From the data point of view, demagnetization of 3 ~ 5 mT has achieved good results, indicating that the nickel-cadmium battery
group is easier to demagnetize. Because of the existence of nickel, the initial permeability of nickel is high, the domain wall is thick, the coercive force and spontaneous magnetization are low, it is easy to reach saturation magnetization, and it is easy to demagnetize.

4. Conclusion

Through the study of the charge and demagnetization test of nickel-cadmium battery, the following conclusions can be drawn. In the field of magnetization, due to the existence of nickel metal, the magnetic properties of nickel-cadmium batteries are easily disturbed by the environmental magnetic field, easy to magnetize and weak in anti-magnetic pollution. In terms of demagnetization, nickel-cadmium batteries are easy to be affected by demagnetization direction, frequency and intensity. Under the intensity of 3 ~ 5 mT, demagnetization can have a better demagnetization effect, generally 5 mT is selected. Secondly, the demagnetization effect in three directions is better than that in one or two directions. In addition, the larger the demagnetization frequency is, the better the demagnetization effect is not necessarily. The frequency is better at 1.5 Hz, which not only achieves good results, but also reduces the eddy current loss. Finally, for the battery, there is little difference between linear demagnetization and exponential demagnetization.

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