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PASSIVE MAGNETIC STABILIZATION SYSTEMS FOR SPACECRAFT

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Introduction

In outer space, it is very important to keep the spacecraft in balance. Since they are designed for specific purposes, they need to be stabilized all the time or this stabilization system needs to be automated. For example, remote sensing of the earth, soil research of different continents, climate research, etc. In addition to long-term and reliable devices, the value for money is important. And then all the problems begin. Often the cause of the problem is: high price, not a high-quality product, energy consumption, very short duration of operation of devices, etc.

The problem of creating an inexpensive, reliable and cheap satellite control system is the main relevance of my article. Especially when it comes to choosing orientation sensors that are sufficiently reliable, accurate, long-term, and preferably if they do not consume energy from fuel. Because the magnitude of the disturbing forces and moments is much higher during stabilization, significant energy costs are required to compensate for them. An orientation system that uses sensors that do not require energy is called a passive orientation system. The main ones are: gravity, aerodynamic and electromagnetic sensors of the orientation system.

The aim of the article is to find suitable options for controlling and stabilizing the spacecraft, while the devices should not be energy-intensive and should be long-term.

Research question is: What passive orientation systems should be used to make the spacecraft last long and not be expensive?

The following tasks have been set:

1. to study of microsatellites and their passive attitude control system.
2. to search results can be used in the management of Kazakhstan's spacecraft.
3. to research of extendable rods and stacking devices, as well as transformable spiral structures.
4. to study of the motion of spacecraft with a new passive orientation system with movable rods.
5. to course of the research, find more suitable options for spacecraft in terms of price and quality.

There are experimental methods for specifying the obtained data and calculations.
The main argument is to find decent instruments of the orientation system, so that they are long-term, not energy-intensive and stable in the space environment.

Literature Review

The technological development of spacecraft in the 20th century was associated with an increase in their mass, size and energy. Now, in the 21st century, the technological development of spacecraft is associated with microminiaturization-a reduction in mass, size and energy consumption.

For example, consider the TNS-0 nanosatellite. TNS-0 is a nanosatellite that has a relatively cheap cost and has a durable and high-quality design. The purpose of the launch is to conduct experiments to test the ability to control the spacecraft via the GLOBALSTAR global communication system, use the COSPAS-SARSAT radio beacon to determine the location of the satellite in orbit, test the elements of the orientation system and launch the satellite into orbit.

The satellite is equipped with a passive magnetic orientation system consisting of a strong permanent magnet and a set of hysteresis rods. The orientation system prevents chaotic rotation with uncontrolled speeds and ensures the orientation of the satellite's longitudinal axis along the local geomagnetic field strength vector. (Ilyin A.A, 2006)

The TNS-0 nanosatellite was successfully launched into orbit on March 28, 2005 from the International Space Station (Ilyin A.A, 2006). To obtain information about the satellite's rotational motion, several simple solar sensors and a horizon sensor are installed. To determine the orientation, the readings of three solar sensors-photodiodes-were used. The measurements could be carried out in real time and transmitted when communication with the satellite is possible, or another measurement program could be installed that allows you to accumulate sensor readings during the round (no more than 1000 points), and then receive them during the next communication session.

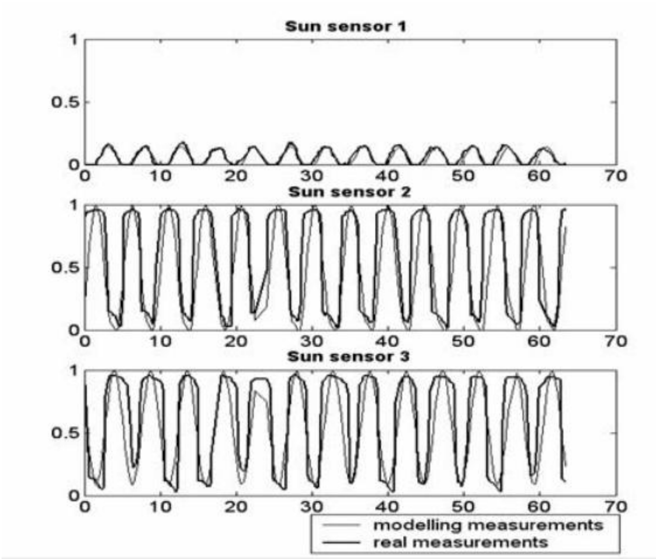


Figure 1. Data from 28.03.05, 09: 42 and simulation results (Ivanov D.S., 2017)

The TNS-0 No. 2 satellite has a passive magnetic orientation system, similar to the orientation system of the TNS-0 No. 1 satellite, which consists of a set of hysteresis rods for damping the angular twist after launch from the ISS and a permanent magnet located along the axis of symmetry to orient this axis along the local geomagnetic field induction vector (Ivanov D.S., 2017).

After the transients are completed and the angular velocity is damped, the satellite's axis of symmetry will track the magnetic induction vector. The satellite is equipped with sensors-a three-axis magnetometer, a set of photodiode solar sensors, an ultraviolet solar sensor and an infrared horizon sensor. According to their measurements, the angular motion of the device will be determined using ground-based processing of telemetric information from the satellite (Urlichcih Y.M., 2005). In this whole system, a permanent magnet plays an essential role.

To ensure the restoring and damping moments, a passive magnetic orientation system is installed on the TNS-0 No. 2 nanosatellite. The restoring moment is realized by means of a permanent magnet. To solve the problem of energy dissipation of the perturbed motion of the satellite relative to its center of mass, a damping device consisting of hysteresis rods made of soft magnetic material was chosen as the simplest and most reliable in operation.

Due to the uneven rotation of the geomagnetic induction vector B in inertial space and the change in its modulus when the satellite's center of mass moves in orbit, it is fundamentally impossible to ensure the exact orientation of the satellite's longitudinal axis along this vector. Mathematically, this is manifested in the presence of time functions in the right part of the equations describing the satellite's oscillations relative to the vector B due to the non-inertial coordinate system associated with the geomagnetic field induction vector, in which the satellite's motion is considered (Karpenko S.O., 2010).

The permanent magnet must provide such a magnitude of the restoring moment that it dominates in comparison with the gravitational and aerodynamic moments. In this case, the value of the dipole moment should not fall in the region of external and parametric resonances. External resonances are caused by the proximity of the natural vibration frequencies of the satellite relative to the center of mass to the frequencies of the change in the driving moment. Parametric resonance is caused by a periodic change in the natural frequency of oscillations due to a systematic change in the modulus of the vector B.

Methodology

1. Permanent magnet

To ensure the restoring and damping moments, a passive magnetic orientation system is installed on the TNS-0 №2 nanosatellite. The restoring moment is realized by means of a permanent magnet. To solve the problem of energy dissipation of the perturbed motion of the satellite relative to its center of mass, a damping device consisting of hysteresis rods made of soft magnetic material was chosen as the simplest and most reliable in operation.

The characteristic parameter that determines the amplitude of the forced and frequency of natural oscillations of the satellite relative to the vector B is the dimensionless magnetic parameter η, which is defined as the ratio of the characteristic value of the restoring magnetic moment mB_0 to the value $A\omega_0^2$:

$$\eta = \frac{mB_0}{A\omega_0^2}$$

Here m - is the modulus of the dipole moment vector of the permanent magnet, B_0 - is the modulus of the geomagnetic field induction vector at the equator, A - is the equatorial moment of inertia of the satellite, and ω_0 - is the angular velocity of the satellite in orbit.

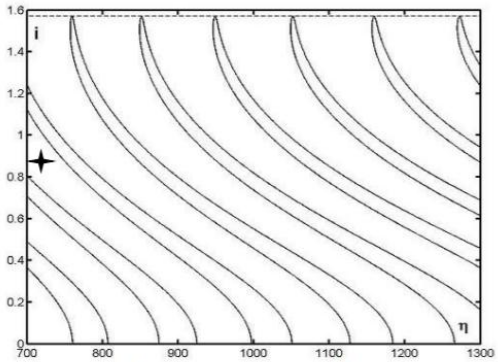
For the values of the magnetic parameter of several hundred or even thousands, namely, for TNS-0, we encounter such a case, it is advisable to use asymptotic methods. Figure 2 shows the branching curves in the plane (η, i) obtained using the asymptotic formula (here i - is the inclination of the orbit in radians, u - is the latitude argument).

$$\eta = \frac{\pi^2 k^2}{a_s^2} \pm \frac{\pi p\left(\frac{\pi}{2}\right) k}{a_s^2} + \frac{p^2(\frac{\pi}{2})}{4a_s^2} + \frac{q(\frac{\pi}{2})}{4a_s^2} + O(k^{-1})$$

$$a_s = \int_0^{\pi/2} \sqrt{N(s)}ds\ , \qquad q_1(u) = \int_0^u q_1(s)ds, \qquad p = \int_0^u \sqrt{p(s)}ds$$

$$N = \sqrt{1 + 3\ sin^2 i sin^2 u}, \qquad N_1 = \sqrt{1 + 3sin^2 u}$$

The coefficients a_s, p(π/2), q_1(π/2) depend on the inclination of the orbit. The meaning of using branching curves when selecting the magnet parameters is as follows: it is necessary to avoid getting the system parameters in the vicinity of the curves, where there is an increase in the oscillation amplitude.



Magnetic parameter η, without unit

Figure 2. Branching curves in the vicinity of η=1000 and the value of the magnetic parameter for TNS-0 №2

According to the results of the calculations, a magnet in the form of a cylinder with a height of 34 mm and a base radius of 4.5 mm was selected, the magnet induction is B = 1.3 T.
The dipole moment of a magnet is determined by the formula:

$$m = \frac{VB}{\mu_0}$$

where V - is the volume of the magnet, μ_0 - is the magnetic constant. Thus, the dipole moment m of a permanent magnet is 2.2 A * m^2. At the values of the equatorial moment of inertia of the satellite about A ≈ 6.2 10^{-2} kg·m^2 and an orbit with an altitude of 500 km (ω_0 = 1.144 *10^{-3} c^{-1}, B_0 = 2.61 * 10^{-5} T), the magnetic parameter of the satellite is η = 710. Thus, for the inclination of the ISS orbit o i = 51,7^0 = 0,9 rad parameter η lies between the two resonance curves, as shown in Figure 2, which makes it possible to predict the small amplitude of the satellite's axis of symmetry oscillations relative to the vector B during flight tests.

2. Hysteresis rods

Unlike a permanent magnet, whose efficiency is actually proportional to the magnitude of its dipole moment, the efficiency of the rods depends on many factors: their volume and elongation, the material used, and the placement scheme.
Of the soft magnetic materials available on the market, one of the most effective and affordable is selected — the 79NM grade molybdenum-permalloy alloy. The calculated characteristics of the processed material from which the rods are made are given in Table 1.

Table 1. Material parameters of the hysteresis rods

Initial magnetic permeability μ_{r_in}	Maximum magnetic permeability $\mu_{r\ max}$	Coercive force H_c, A/m	Saturation induction B_s, T
60 000	164 000	0.96	0.74

If the distance between parallel identical rods is more than 0.3 – 0.4 of their length, their mutual influence can be neglected. If the rods are located closer to each other, this effect affects the mutual demagnetization of the rods and, consequently, in reducing their effectiveness as a damper. At a distance equal to 0.02 of the length, two rods are equivalent to one. The rods, which are located perpendicular to each other, have almost no effect on each other. To avoid the influence of a permanent magnet, the hysteresis rods are arranged in planes perpendicular to the magnetic moment vector. For this purpose, the rods are mounted on the upper and lower bases of the housing, made in the form of a cylindrical hexagon as shown in Figure 3. The number and location of the rods are chosen based on the design possibilities and to maximize the efficiency of the rods, which is proportional to their length and inversely proportional to the distance between them.

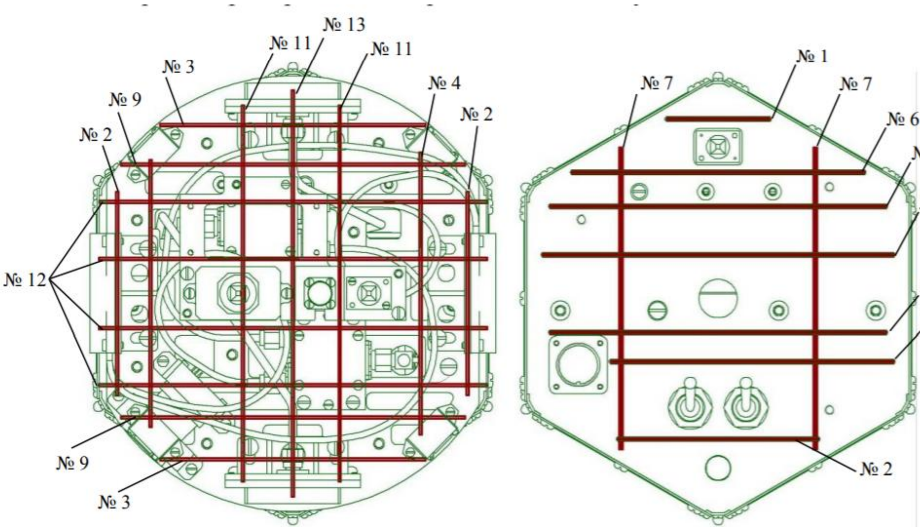


Figure 3. The location of the hysteresis rods on the bases of the TNS-0 №2 housing (on the left – the upper base of the housing, on the right-the lower base of the housing)

The hysteresis rods have a square cross-section with a side of a = 1mm. The length and number of rods are shown in Table 2. The efficiency of the rods is determined by the amount of energy dissipated. This energy can be estimated from the area of the hysteresis loop under laboratory conditions. However, due to the demagnetization effect, the smaller the length of the rod, the smaller the area of the loop, as can be seen in Fig. 4. Also, as mentioned above, energy dissipation is worse with a decrease in the distance between parallel rods due to mutual influence (Fig. 5). The hysteresis losses of the rod without considering the mutual influence can be estimated as the hysteresis losses of the S_{gist} volume unit multiplied by the volume V,

$$E_{loss} = S_{gist} * V$$

where S_{gist} - is the area of the loop when the rod is remagnetized in a geomagnetic field (geomagnetic induction is about H = 40 A/m).

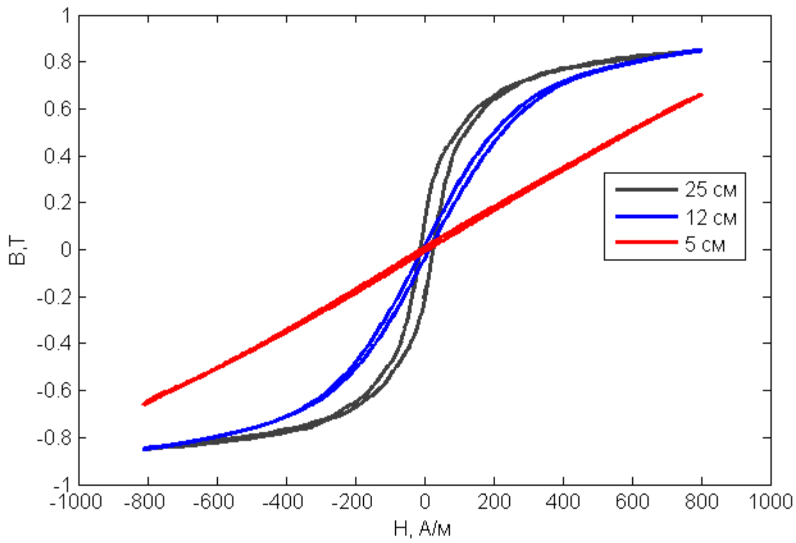


Figure 4. Hysteresis loops for rods of different lengths

Table 2 presents estimates of the hysteresis losses at the coercive force of the rods $H_e = 2$ A/m. The total hysteresis losses are the sum of the losses of each rod and are equal to $E_{loss} = 1.9 * 10^{-6}$ J.

Table 2. Parameters of the hysteresis rods

№	Length, mm	Quantity, pcs	Hysteresis losses, E_{loss}, 10^{9} J
1	42	1	8.4
2	82	3	32.8
3	108	3	54.0
4	114	1	68.4
5	116	1	69.6
6	120	1	72.0
7	124	2	74.4
8	138	2	82.8
9	140	2	98.0
10	144	1	100.8
11	152	2	106.4
12	158	4	118.5
13	164	1	123.0

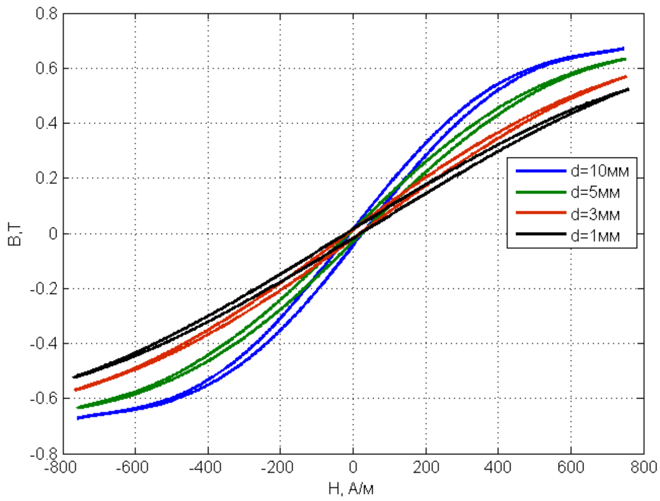


Figure 5. Hysteresis loop of five rods with a length of 12 cm
at different distances between the rods

Conclusion

The results obtained show that the passive magnetic orientation system of the TNS-0 №2 nanosatellite after the launch of the device will provide damping of the initial angular spin and movement of the satellite's axis of symmetry following the Earth's magnetic induction vector. The sensors installed on board will allow you to determine the angular movement of the satellite during flight tests and not only to track how the orientation system works, but also to predict communication sessions with ground stations when the satellite will not only be in the field of view, but also oriented by the antenna in the required way. In addition, processing sensor measurements on the Ground will allow testing algorithms for autonomous angular motion detection for future missions using an active magnetic orientation system based on magnetic coils.

Literature

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