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Samara State Aerospace University
(National Research University)

Space Engineering Department

A. V. DOROSHIN

**THE MAIN PRINCIPLES OF SPACECRAFT/SATELLITES
ATTITUDE STABILIZATION**

Electronic Textbook

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Authors: **Doroshin Anton V.**

Doroshin, A. V. The main principles of spacecraft/satellites attitude stabilization = **Принципы стабилизации пространственного положения космических аппаратов и спутников** [Electronic resource]: Electronic Textbook / A. V. Doroshin; The Ministry of Education and Science of the Russian Federation, Samara State Aerospace University. - Electronic text and graphic data (0.732 Mb). - Samara, 2013. - 1 CD-ROM.

The textbook gives a short description of principles of attitude stabilization of spacecraft and satellites (also dual-spin spacecraft).

The textbook is a part of the Masters programme for education directions 161100.68 «Motion Control Systems and Navigation».

This educational textbook (the main aspects of dynamics, spacecraft's schemes with corresponding pictures/figures) is based on the well-known material collected and broadly presented in the book [1], additionally described in the paper [2] and at the [Gunter's Space Page](#).

The material prepared at the Space Engineering Department.

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THE MAIN PRINCIPLES OF SPACECRAFT/SATELLITES

ATTITUDE STABILIZATION

I. Gravitational stabilization.

The principle of the gravitational stabilization is based on the property of dumbbell shaped rigid bodies and spacecraft (SC) (fig.1) turn down along the gravity force.

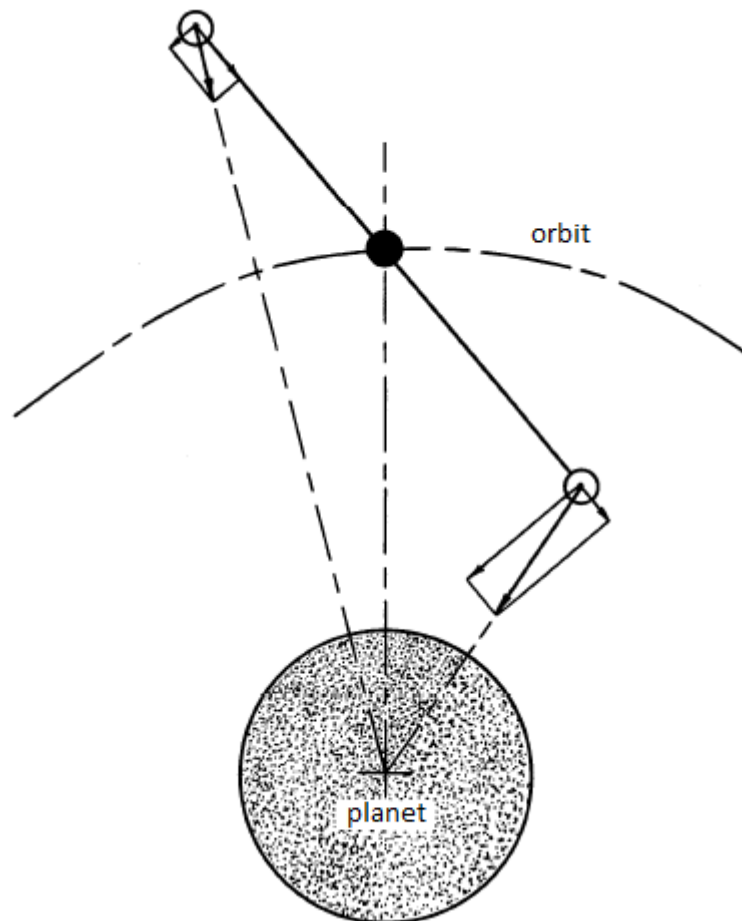


Fig.1 – Gravitational stabilization principle

The difference between the gravity forces applied to the dumbbell's mass-points causes to the torque initiation which is turned the dumbbell to the “vertical” position. This position is stable equilibrium position.

Satellites with different inertia moments (general inertia moments) have four stable equilibrium positions corresponded to the coincidences of the SC's "maximal inertia axis" with the planet-radius-vector and the SC's "minimal inertia axis" with the normal to the orbit-plane. Certainly, the unstable position of the dumbbell is possible – it corresponds to its coincidence with the tangent to the orbit.

There are the following main tasks:

1. The changing of the SC's inertia ellipsoid with the help of attachment of long hollow rods with weights on the tips.
2. The damping of oscillations of the SC around its mass center near the equilibrium position.

The damping of oscillations can be fulfilled with the help of additional equipment for the energy dissipation (e.g. a toroidal zonary tank with a viscous liquid) – the relative motion of the viscous liquid creates the fluid friction which dissipates the oscillations' energy. It is possible to use the D.E.Okhocimsky's scheme (fig.2) of the oscillation damping. This scheme of the satellite's oscillation damping works via elastic (springs #3 in fig.2) dissipative attachment of a second body (paired bars #2 in fig.2) to the main satellite body (#1 in fig.2) by a spherical linkage (point P in fig.2).

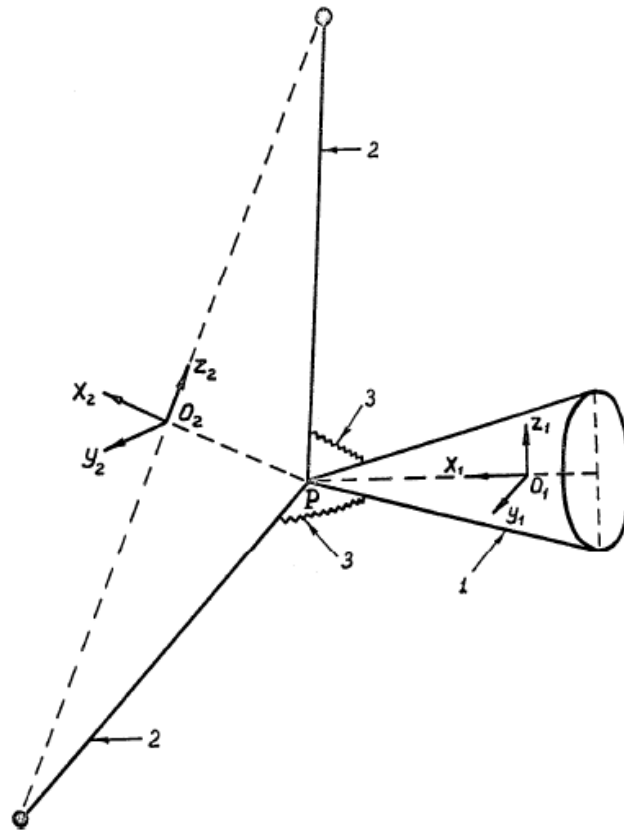


Fig.2 - D.E.Okhocsimsky's scheme of satellites stabilization

Also a quite effective damper can be realized based on the magnetic principle. Such dampers are placed on free end points of the gravitation stabilizing bar. The *magnetic damper* (fig.3) consist from two spheres (an internal and an external sphere) separated by a layer of viscose liquid. The internal sphere contains the magnet system. The external sphere is faced with diamagnetic bismuth. The relative spheres centering is provided by the repel action of centering magnets and the bismuth layer.

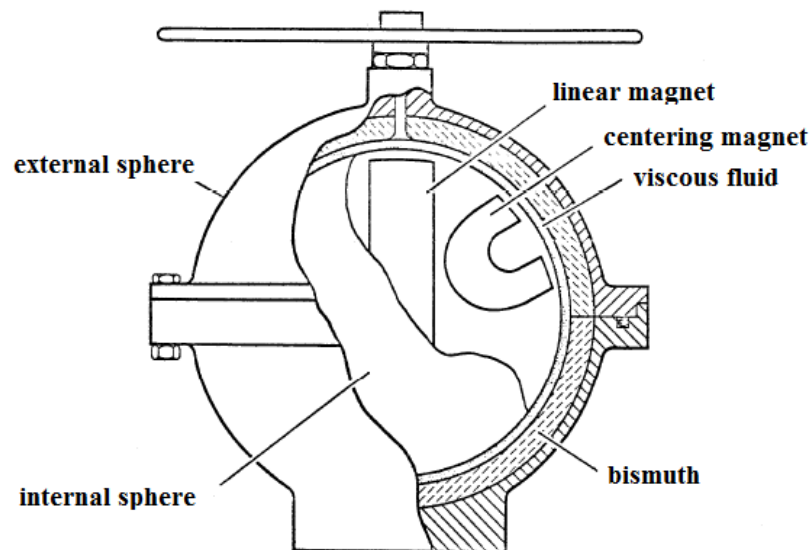


Fig.3 – The magnetic damper

The linear magnet interacts with the geomagnetic field; this interaction leads to the relative rotation of the spheres and the energy dissipation due to viscose friction and Foucault currents.

Gyro-damping of the SC oscillation is possible. This type of dampers uses the gyroscopes with viscous-elastic connections to the main satellite's body; then the relative rotation of the main body and gyroscopes creates the precession of gyroscopes and corresponding energy dissipation in viscous-elastic connections.

Also in the purpose of the oscillations *damping hysteresis bars* can be applied. In these cases the hysteresis bars are placed into SC. The hysteresis bars interact with geomagnetic field and dissipate the oscillations energy.

Examples of the SC/satellites with gravitational stabilization

It is possible to present some examples of using the gravitational stabilization in real spacecraft's missions.

1. «OREOL» SC; USSR; three-axial gravitational stabilization; lounched 21.09.1981. Length of the grvitational bar 17m; magnetic damper.

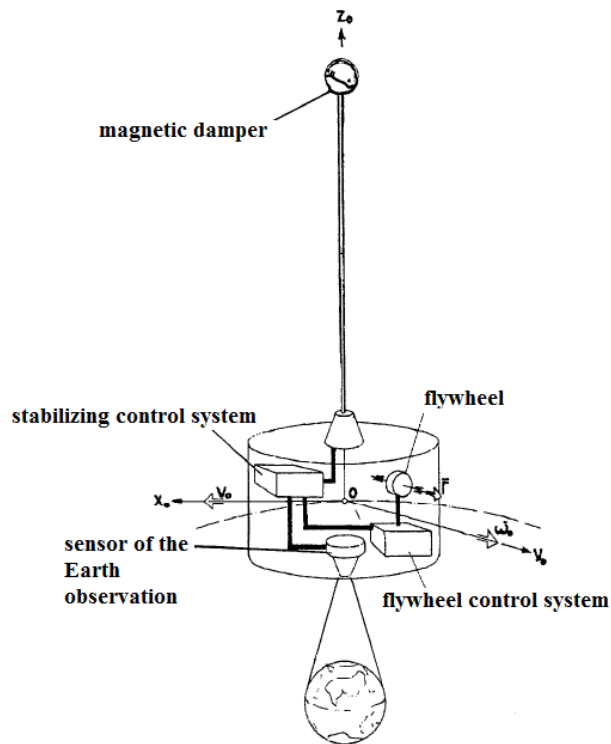


Fig.4 – OREOL-3 SC

2. «COSMOS» (Intercosmos) SC; USSR; one-axis gravitational stabilizations; length of gravitational bar 12m; magnet damper; 1982.

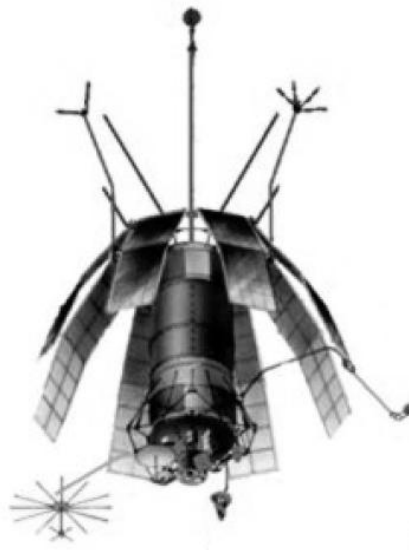


Fig.5 – Intercosmos-20

3. GEOS (Geodetic Earth Orbiting Satellites); USA; gravitatonal bar 15m; magnet damper;

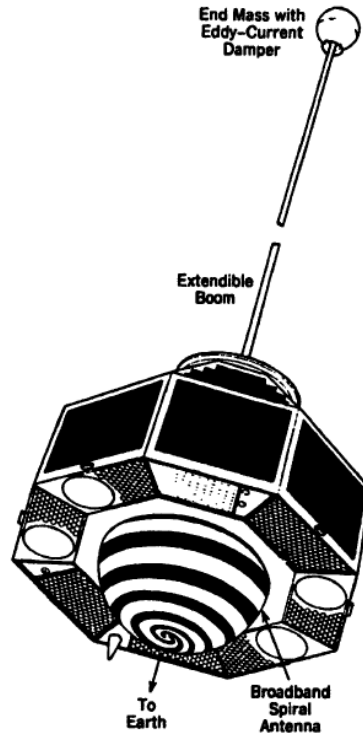


Fig.6 – GEOS

4. **RAE** (Radio Astronomy Explorer); USA; 1968.

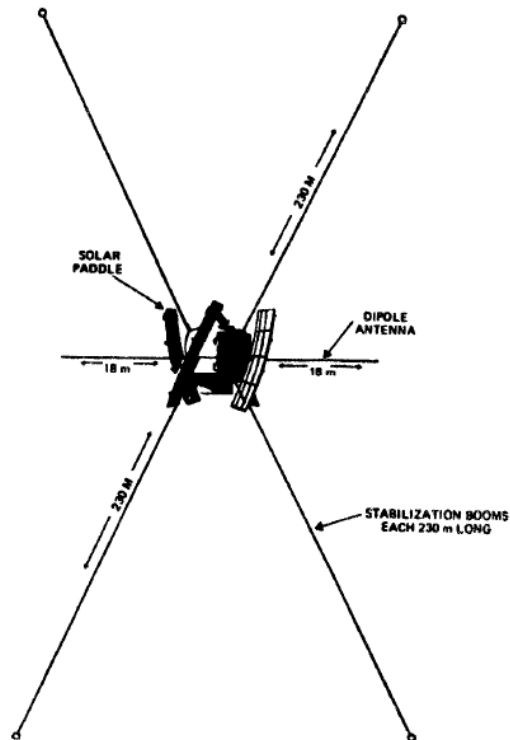


Fig.7 – RAE-1

5. EOLE; France (CNES); damping hysteresis bars; 1971.

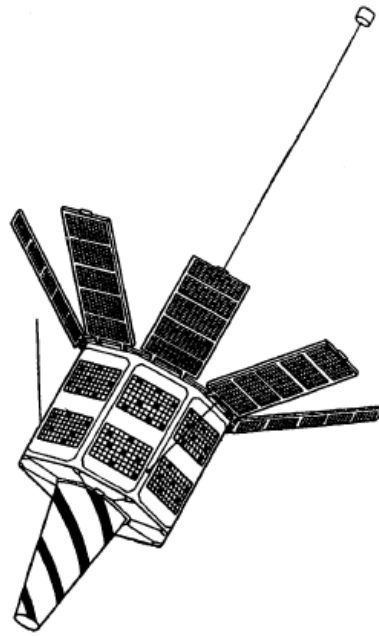


Fig.8-EOLE

II. Aerodynamic stabilization.

The aerodynamic stabilization based on the aerodynamical properties of SC/satellites' constructions and on the interaction with the remnant of the discharged atmosphere (SC's altitudes between 200-600 km). This type of the stabilization is used for support of the SC's position «along orbital motion». As an example we can indicate the SC «Cosmos-149» (1967), which had the tail unit and gyro-dampers.

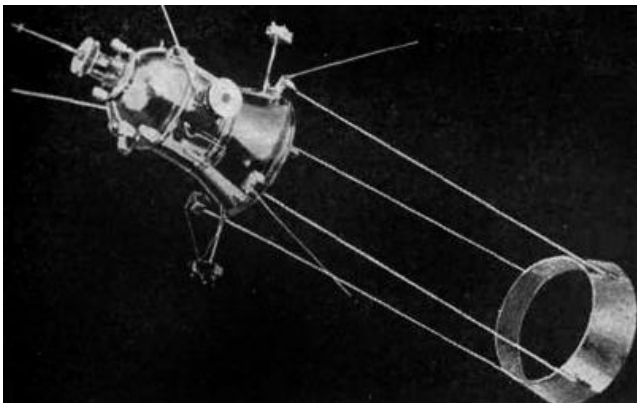


Fig.9 – Cosmos-149

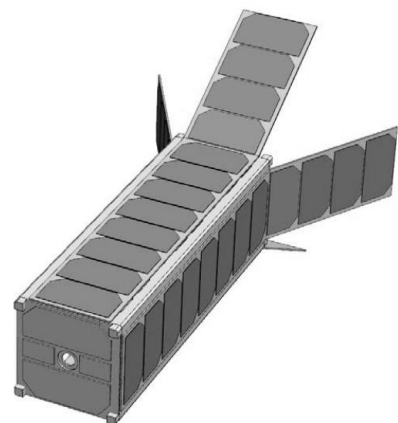


Fig.10 – Construction concept for nanosatellite

III. Spin (gyroscopic) stabilization.

The spin stabilization based on the gyroscopic property of rotating bodies/SC/satellites.

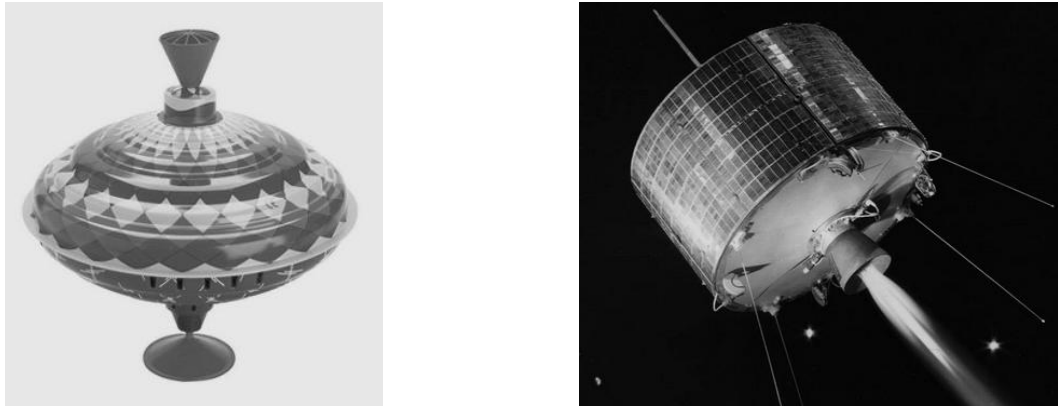


Fig.11 – spin stabilized motion

It is the well-known fact that the rotation around big-inertia-axis is stable even at presence dissipative forces – this corresponds to the «major-axis-rule».

If we place into SC the fast rotating stabilizing rotor then we need not make spinup of the main SC's body which contains the antennas telescopes and other equipment for monitoring/communication/investigation. This construction scheme called as «dual-spin spacecraft/satellite» (DSSC).

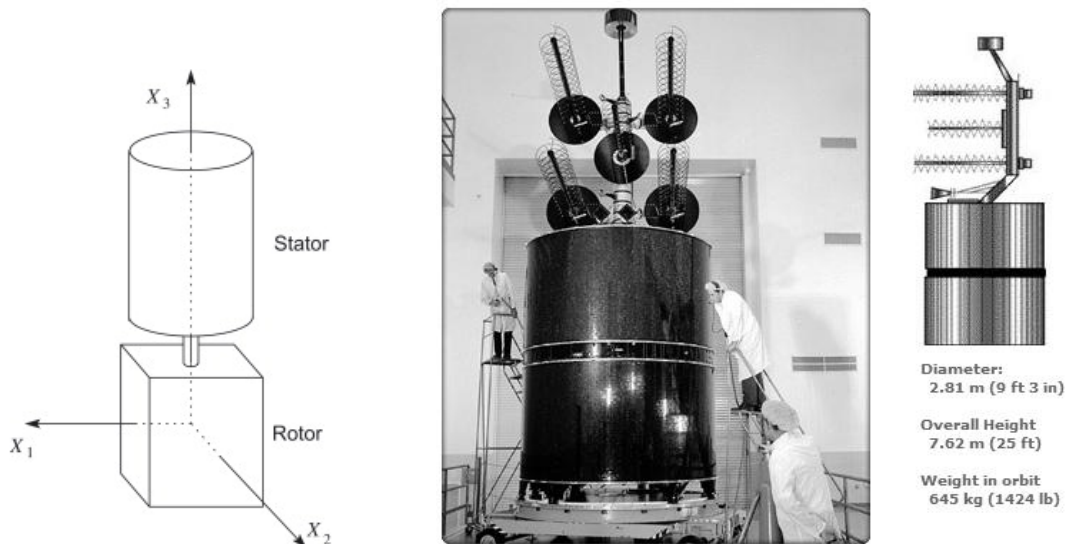


Fig.12 – Dual-spin spacecraft construction and real DSSC «TACSAT I»

The dual-spin construction-scheme is quite useful in the practice during the history of the space flights realization; and it is possible to present some examples

of the DSSC, which was used in real space-programs (most of them are communications dual-spin satellites and observing geostationary satellites).

This is the long-continued and well successful project “Intelsat” (the Intelsat II series of satellites first launched in 1966) including the 8th generation of geostationary communications satellites and the Intelsat VI (1991) designed and built by Hughes Aircraft Company. Also one of the famous Hughes’ DSSC is the experimental tactical communications dual-spin satellite TACSAT-I which was launched into synchronous orbit in 1969. The “Meteosat”- project by European Space Research Organization (initiated with the Meteosat-1 in 1977 and operated until 2007 with the Meteosat-7) also used the dual-spin configuration spacecraft. The spin-stabilized spacecraft with mechanically despun antennas was applied in the framework of GEOTAIL (the collaborative mission of Japan JAXA/ISAS and NASA, within the program “International Solar-Terrestrial Physics”) launched in 1992; the GEOTAIL spacecraft and its payload continue to operate in 2013. Analogously the construction scheme with the despun antenna was selected for Chinese communications satellites DFH-2 (STW-3, 1988; STW-4, 1988; STW-55, 1990). The well-known Galileo mission’s spacecraft (the fifth spacecraft to visit Jupiter, launched on October 19, 1989) was designed by the dual-spin scheme. Of course, we should indicate one of the world's most-purchased commercial communications satellite models such as Hughes / Boeing HS-376 / BSS-376 (for example, the “Satellite Business Systems” with projects SBS-1, 2, 3, 4, 5, 6 / HGS-5, etc.): they have spun sections containing propulsion systems, solar drums, and despun sections containing the satellite’s communications payloads and antennas. Also very popular and versatile dual-spin models are the Hughes’ HS-381 (the Leasat project), HS-389 (the Intelsat project), HS-393 (the JCSat project).

The DSSC usually is used for the attitude stabilization by the partial twist method: only one of the DSSC's coaxial bodies (the «rotor»-body) has rotation at the «quiescence» of the second body (the «platform»-body) – it allows to place into the «platform»-body some exploratory equipment and to perform of space-

mission tests without rotational disturbances. Moreover, one of the widespread types of the DSSC is the axial DSSC, where the axisymmetric rotor is aligned with the principal axis of the platform-body.

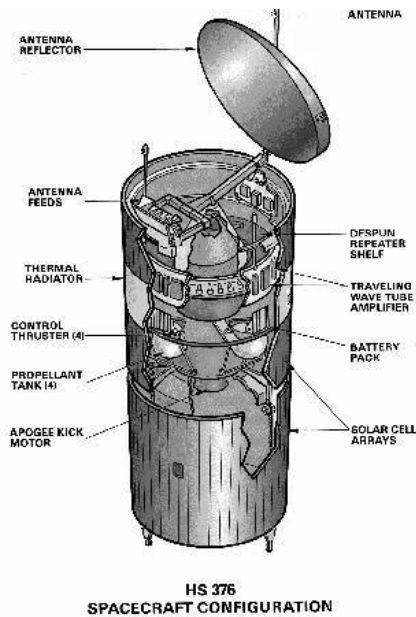


Fig.13 – [HS 376](#) scheme



Fig.14 – HS-389 [Intelsat-6](#) [Boeing]



Fig.15 – HS-389 [SDS-2](#) [NRO]

The DSSC are usually placed into the orbit with zero relative rotor angular velocity, and then a spinup engine provides an internal torque from the «platform»-body to the «rotor»-body along the common rotation axis of the DSSC's coaxial bodies. The effect of the axial torque is to spin up the rotor and despin the platform, thereby transferring all or most of the angular momentum to the rotor. Usually the spinup torque is constant; also this torque is switched off right after the angular momentum transferring. However, for maintaining of the constancies of the rotor's relative angular velocity the DSSC's control system can form the corresponding stabilizing internal torque. This scheme of the angular momentum translation (from the platform-body to the rotor-body) is called as the classical spinup maneuver.

Analogously with the previous cases various dampers in the DSSC also are used (magnetic dampers, hysteresis bars, spring-mass dampers, etc.).

IV. Magnetic stabilization.

The magnetic SC stabilization usually is used in the framework of space missions with investigation of the ionosphere, the Earth's radiation belts, the solar wind in the Earth's magnetosphere. In such cases the spatial orientation and corresponding stabilization along geomagnetic field's power lines is quite applicable. This type of stabilization is realized based on the magnetic property of the SC construction (with internal strong constant dipole magnets) and its interaction with the geomagnetic field. Also into magnetic SC hysteresis rods can be placed for the damping of the residual oscillations after SC separation from the upper-stage of the rocket.

Many magnetic SC were placed into orbits (e.g. TRANSIT, INJUN, TTS, ESRO, OSCAR-8, AZUR, EXOS, MS-T3, «Intercosmos-14», MAGION, Munin, etc.).

Also the magnetic stabilization can be used as preparation stages for other types of stabilizations. In this case electromagnet systems used immediately after the separation from rocket; and after achievements of equilibrium positions the SC initiate its main stabilization scheme.

Thus, we have described the main types of the attitude stabilization of SC/satellites at realizations of different space missions.

References

[1] – Applied celestial mechanics and motion control. Collection of papers dedicated to the 90th anniversary of the birth of D.E.Okhocimsky / Editors: Eneev T.M., Ovchinnikov M.U., Golikov A.R. – Moscow, Keldysh Institute of Applied Mathematics (Russian Academy of Sciences), 2010. - 368p. - ISBN 978-5-98354-007-1 (Прикладная небесная механика и управление движением. Сборник статей, посвященный 90-летию со дня рождения Д.Е.Охоцимского / Составители: Т.М.Энеев, М.Ю.Овчинников, А.Р.Голиков. — М.: ИПМ им. М.В. Келдыша, 2010. — 368 с).

[2] – Doroshin A.V. Chaos and its avoidance in spinup dynamics of an axial dual-spin spacecraft // Acta Astronautica, Volume 94, Issue 2, February 2014, Pages 563-576.