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Method of Controlling an Object in Space by an Isolated Power System using Counter-Rotating Paired Flywheels

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Abstract

The study analyzes the use of technological methods of attitude control of an engineering object inside possible environments of the earth and outer cosmic space. The effects of independent power sources including mechanical, aerodynamic, reactive ones on the object are neglected. The proposed method for the orientation controlling and monitoring of an object in space uses the accumulated kinetic energy by counter rotating paired flywheels as well as a gyroscopic effect. The assessment of the limiting power dynamic characteristics of flywheels is carried out.

Keywords: attitude control, kinetic storage, recuperation, paired flywheels

Introduction

The research of kinetic methods for stabilizing engineering objects using a gyroscope began to develop since the beginning of the last century [1]. One of the first technical implementations of spatial stabilization was carried out by Shilovsky who used the example of the development of a gyrocar in 1907 [2]. Later, a gyrocar weighing 2750 kg was introduced with a 600 kg flywheel that ensured balance. Brennan demonstrated a prototype of a single-rail train for 50 passengers and traveled along one rail to maintain balance using a gyroscopic system [1]. A group of developers in the last 50 years have designed gyrocars with a mass of up to 300-900 kg at a speed of 160-200 km/h using internal combustion engines and electric motors with a capacity of up to 80 hp. Oter than this, different kinds of gyroscopic systems have been widely developed [3-5].

Various engineering objects of aerospace, land, surface, and underwater transport use the attitude control that requires additional and independent energy sources. The use of the isolated power system for accumulating and using (recuperating) kinetic energy is an urgent problem. This allows to ensure the independent consumption of mechanical energy for spatial orientation and to comply with modern requirements for environmental safety. The use of opposite rotating flywheels allows achieving high speeds of rotation and significant kinetic energy with the stability of their basing area.

The next step in the development is the creation of engineering and technical objects using the capabilities of the kinetics storage device and the method of control or stabilization of the object without the use of mechanical, aerodynamic, or reactive systems [6].

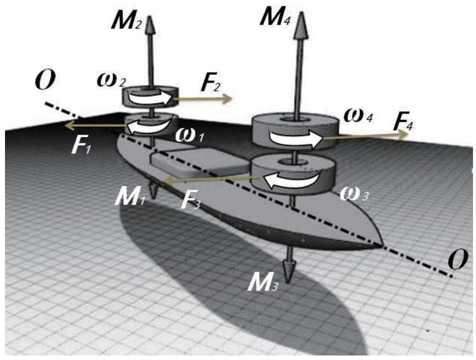
Technological model of attitude control ensuring for an engineering object in space

In an isolated system, the use of two flywheels ensures a possible turn of the object in space but only in one plane. We proposed a method for orienting an object in different planes using the force of a lever relative to the shell of a load-bearing object at a different dynamic mode of counter-rotating paired flywheels (Fig. 1). Then, the stabilization of an object in space is obtained from the changes in acceleration (deceleration) of various pairs of flywheels (rotating towards each other) with axes passing through the center of gravity of the control devices.

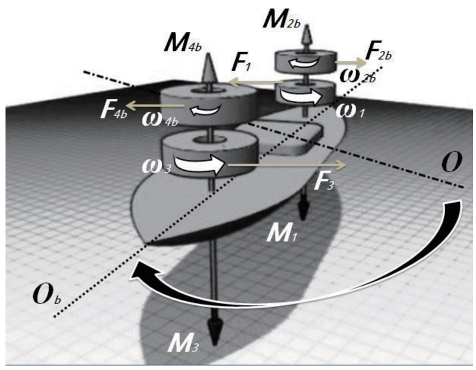
The proposed system of full-fledged control and management of an object in space does not require additional interaction with external power. It becomes an important alternative way of orienting various engineering and technical objects of aerospace, overland, surface, and subsea vehicles.

Figure 1 represents the platform of an engineering facility with two pairs of flywheels mounted on it. Flywheel disks rotating in different directions with speeds $\omega_1,\ldots,\omega_4$ can generate significant applied mechanical forces $F_1,\ldots, F_4$ and the corresponding moments of force $M_1,\ldots, M_4$ and impulse.

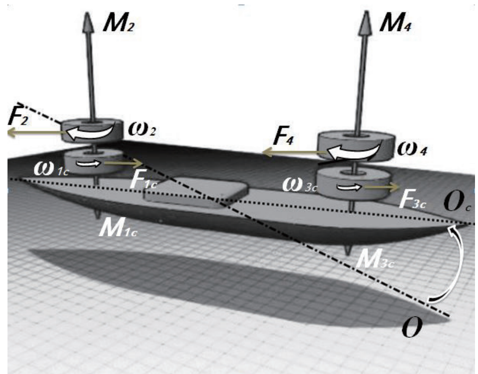
The proposed system determines the stable position of the object in space. The accumulated kinetic energy of revolution bodies determines the potential for its recuperation into other thermal and electromagnetic forms of energy when the angular velocity changes. Previously, there were used orientation methods for space objects, implemented by at least two separate flywheels with transverse axes of rotation [8-9]. A new constructive element is the introduction of paired flywheels [6], which make it possible to efficiently accumulate kinetic energy using an isolated power plant at a load-bearing engineering facility. Figure 1(a) represents the initial spatial position of the isolated structure with kinetic units installed on it with groups of flywheels #1, #3, and #2, #4 with the same directions of rotation, respectively.



a



b



c

Fig. 1. Schemes for changing the initial spatial orientation of engineering object (a) when braking a group of flywheels #2 and #4 with a turn to the left (b) and respectively for ones #1 and #3 - to the right (c).

When braking flywheels #2, #4 (Fig.1(b)) or #1, #3 (Fig. 2(c)) occurs, the extraction of kinetic energy for mechanical recuperation for the transfer impacts on the body engineering object. The lever arms of both pairs of flywheels are determined by the distance from the rotation axes accordingly to the “bow” and “stern” part of the bearing platform. The interaction between isolated kinetic power plants (at least two) makes it possible to perform the required actions: rotate or fix an engineering object.

The kinetic energy storage by flywheels takes place without the participation of the engineering object. The dynamics of the rotational and synchronous movement of flywheel groups # 1, # 3, or # 2, # 4 determines the most efficient mode of generating the required mass moment of inertia for attitude control of all structures. Placing additional groups of flywheels with transverse axes of rotation makes it possible to move the object in its vertical plane. The use of flywheels with big rotation speeds to create significant mass moments of inertia of a bearing engineering object causes limitations on the choice of materials that must have high strength characteristics.

Limit materials’ strength characteristics of the kinetic storage

By using the fundamental equation of rotational motion dynamics, computational and theoretical estimates were performed for torques with the maximum permissible speed of rotation of the flywheel by the factor of destruction.

To model the maximum permissible mechanical moment, a rotating flywheel carbon (with the limit value of circumferential stress at break up to ~730 GPa [10]) has been viewed as advanced material. Upon reaching deformation Δx ~ 8 mm in a flat carbon sample, critical changes in the structure occur (Fig. 2).

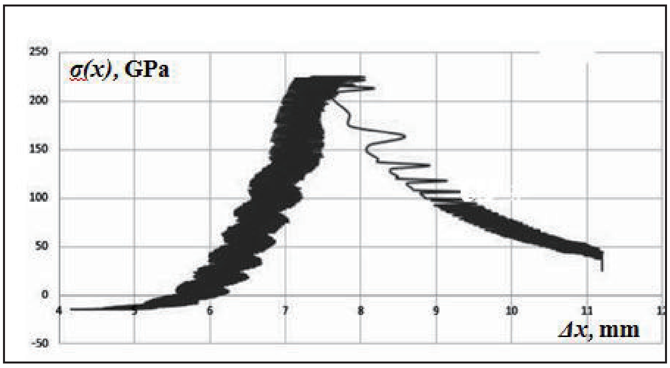


Fig. 2. Graph of the dependence of mechanical stress σ(*x*) vs sample deformation Δx for the carbon-fiber disk.

Calculations for a carbon-fiber disk (with a thickness of 50cm, a diameter of 200cm, and a mass of 314kg) showed that the rotation speed of the flywheel should be limited by the value up to $3.3x10^4$ rpm.

The resulting estimates suggest that the generated power load for these types of structural materials is sufficient for transmitting force moment ~$2x10^4$ N·m to the shell engineering object within 1000s, in continuous monitoring of orientation, including fixation or a predetermined turn in a certain plane.

Conclusion

The proposed technology for controlling the orientation of engineering objects in space is energetically effective in the dynamics of the rotational motion of isolated kinetic accumulators of several pairs of flywheels with oppositely directed rotation. The method of controlling the orientation in space can be used for providing urgent compensation of power loads in case of catastrophic external impact such as

- fixing the movement of tower cranes
- control of the turning modes of aircraft during takeoff and landing
- monitoring skidding of vehicles in case of accidents, etc.

These attitude controls (without the use of additional mechanical, aerodynamic, or jet systems) increase the energy efficiency of the processes of the passage of a spacecraft in dense layers of the atmosphere, movement of a hypersonic

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vehicle, management of sub water, surface combatant and aircraft without the use of keels, ailerons, and other known control elements. The performed assessments of the strength characteristics of paired rotating flywheels show sufficient time intervals (up to tens of minutes) for changing the orientation of an engineering facility with compensation of power loads up to hundreds of kN, with acceptable dimensions of structures for the storage of kinetic energy in vehicles.

The engineering objects that use only accumulated kinetic energy for orientation control without electric batteries, internal combustion engines, or any other heat power plants is a promising development of environment-friendly equipment and vehicles.

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