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AUTOMATED MEASURING STAND FOR SPACECRAFT CONTROL

Abstract. The aim of the work is to increase the level of metrological support for automated measurement and computation complexes for mass geometry parameters (MGP) of spacecraft (SC) by combining the measurements of mass, center of mass (CM) position, and components of the tensor of inertia (TI) on a single piece of equipment. The problem of high cost, low unification, and high operational expenses of traditional separate-base test benches is being solved. A combined scheme is proposed, which integrates the method of forced balancing in an unstable position for measuring static MGP and the physical pendulum method with an elastic coupling for dynamic MGP. The key innovation is the replacement of expensive aerostatic bearings with standard rolling bearings, incorporating a developed system for active compensation of dissipative forces (friction)]. An experimental prototype of the "AMIK" test bench confirmed the achievement of high accuracy indicators, equivalent to those of separate-base benches.

Key words: mass geometry parameters (MGP), spacecraft (SC), center of mass (CM), moment of inertia (MOI), tensor of inertia (TI), combined test bench, friction compensation.

Introduction. The task of a spacecraft's (SC) control system is to ensure its stable movement along a given trajectory. The reliability of this system directly depends on the accuracy of the input mass geometry parameters (MGP): mass, center of mass (CM) position, and components of the tensor of inertia (TI) [4]. MGP control is a mandatory procedure during the final assembly stage of the SC. Modern MGP test benches are divided into traditional (measuring a single parameter) and combined [3]. Traditional benches have high accuracy but are characterized by high operational costs, a low level of unification, and require manual operation. Existing combined benches are either low-accuracy (domestic) or extremely expensive (foreign) due to the use of complex aerostatic bearings for friction compensation [1]. Thus, the aim of the work is to increase the level of metrological support for automated MGP measurement and computation complexes by combining the measurements of mass, CM, and TI on a single piece of equipment, achieving a high level of accuracy (horizontal $CM \pm 0.1\%$, axial $MOI \pm 0.1\%$), and reducing operational and production costs.

Methods and Materials. As a result of analyzing existing methods, a combined test bench scheme was chosen. For measuring static MGP (mass and CM), the method of forced static balancing of the moving system in an unstable equilibrium position was selected. The scheme (Fig. 1) involves tilting the platform (1) with the object (9) relative to an axis (5) until the total CM is above the tilt axis. By measuring the tilt angles at four plan-table positions (0° , 90° , 180° , 270°), all three CM coordinates are calculated. Mass is determined by an additional measurement using a counterweight.

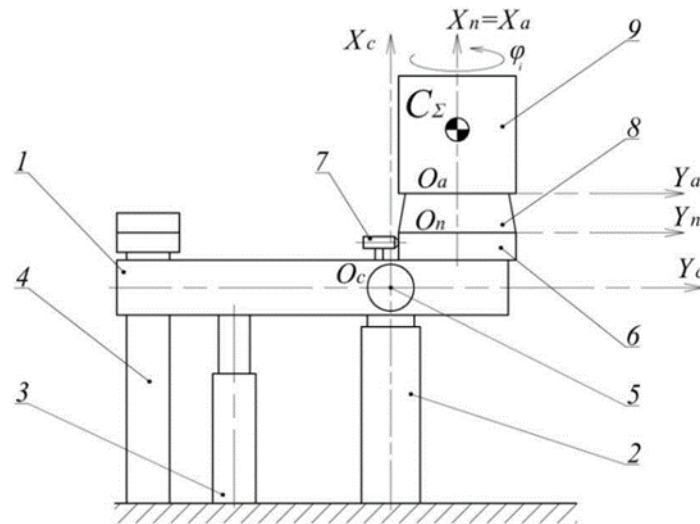


Fig. 1. Schematic diagram of center of mass coordinate measurement (1 - platform, 5 - tilt axis, 9 - test object)

For measuring dynamic MGP (moments of inertia), the pendulum method with an elastic coupling (inverted physical pendulum method) was chosen. The oscillation axis is aligned with the bench's tilt axis, and oscillations are generated by a spring unit.

The key problem for combined benches is friction in the supports, which introduces errors in both static measurements (stiction moment) and dynamic measurements (energy dissipation, oscillation damping, period change). Instead of expensive aerostatic bearings [1], it is proposed to use standard rolling bearings combined with an active friction compensation system [2].

The support design (Fig. 2) implements the principle of "decoupled bearings." An electric motor (6) forcibly rotates or oscillates an intermediate shaft (4), breaking the adhesive bond in the support bearings (3).

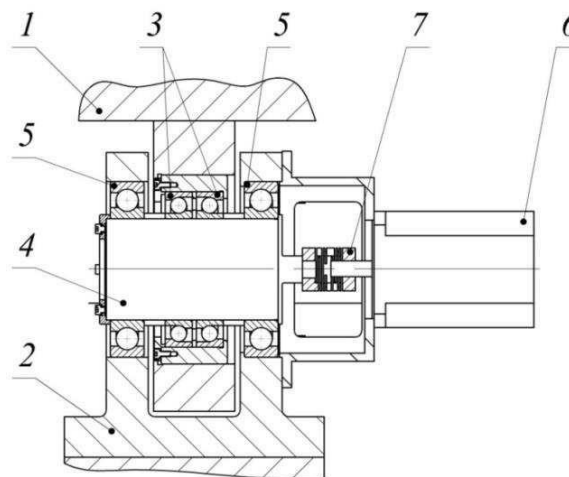


Fig. 2. Schematic design of the support with friction compensation (3 - support bearings, 4 - intermediate shaft, 6 - electric motor)

During static measurements (CM), a vibrational friction reduction mode is activated. During dynamic measurements (MOI), a tracking system with feedback on the tilt angle is engaged. A PID controller manages the motors, synchronizing their movement with the platform's oscillations. This fully compensates for energy dissipation and creates stable, undamped self-oscillations [2], allowing the period to be measured with high precision (Fig. 3).

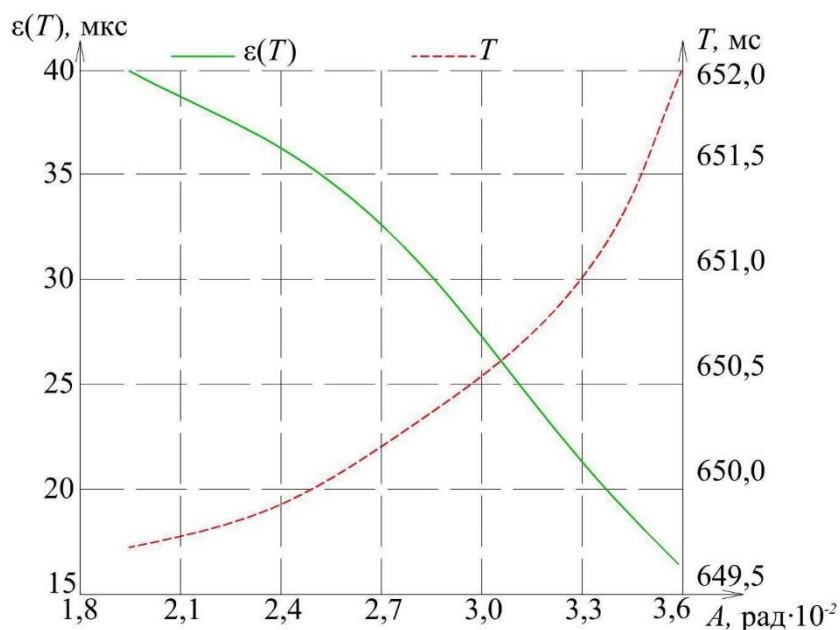


Fig. 3. Empirical dependencies of the period (T) and random error ($\epsilon(T)$) on the amplitude (A) with active friction compensation

Conclusions. A combined complex for measuring MGP (mass geometry parameters) of spacecraft on a single piece of equipment has been developed, addressing the problems of high cost and low unification of traditional test benches.

The key innovation is the replacement of expensive aerostatic bearings with standard rolling bearings, combined with a system for active friction compensation.

This made it possible to achieve high metrological accuracy, equivalent to separate benches, which was confirmed by the "AMIK" experimental prototype. The work opens the way for creating cost-effective and automated MGP control complexes.

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