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ENERGY ANALYSIS OF A SOLAR ARRAYS DEPLOYMENT PROCESS AT GROUND TESTS OF MECHANICAL DEVICES ON ACTIVE GRAVITY COMPENSATION SYSTEMS

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Introduction

Creation of the modern spacecraft large-scale transformable structures, such as solar arrays and antennas, involves ground testing of their functions on the special test workbenches, which simulate weightlessness conditions with high accuracy. The workbench should provide the development process in the ground conditions with the lowest possible level of interaction with the test structure for minimal energy loss. The most perspective workbenches in this regard is the active gravity compensation systems (AGCS) with the trolley tracking actuator systems and the automatic control systems of gravity compensation forces in the suspension cables [1].

Figure 1 schematically shows a general view of the workbench for ground testing of the mechanical devices of the deployment solar arrays. The mechanic part of the workbench is a trolley system with cable suspensions, which moves in a horizontal plane and tracks the movements of the panels, frames and bars during deployment process.

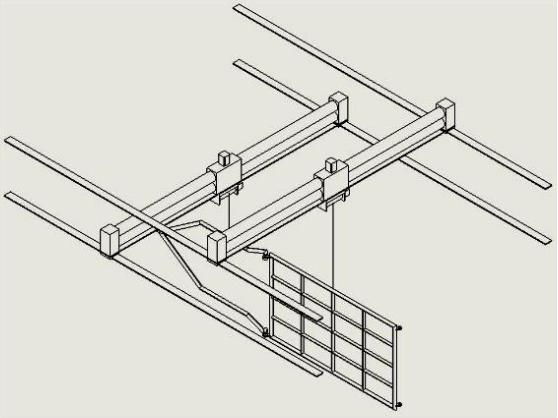

Fig. 1. The scheme of the solar array gravity compensation on operation position

The workbench includes the next base devices:

- The trolleys of the longitudinal-transverse movements and the gravity compensation, which are the main electromechanical assemblies of the AGCS and used for compensating the weight of suspended solar array elements in their longitudinal and transverse movements of deployment process.
- The profile rail double guides for the longitudinal movement of the trolleys.
- The two-coordinates sensors of a suspension cables deviation concerning a vertical.
- The tensile force sensors of the suspension cables.

The gravity compensation of each deploying solar array element is provided by the two tracking systems and automatic control stabilization systems (ACSS). The tracking systems support the vertical position of the suspension cable during the deployment process. The ACSS supports the minimum delta between the solar array element weight and the tension power of the suspension cable.

The current practice of design and maintenance of such systems assumes a modelling system, which allows analyzing the collaborative work of the workbench and the solar array, counting their kinematic and dynamic characteristics, assessing the accuracy and quality of the weightlessness simulation.

In this paper, we present an example how information can be obtained from the modelling system and put into practice relative to the real spacecraft structure.

Energy analysis basics

Ground testing of the transformable structures involves authenticity assessment of the results. Energy characteristics sufficiency of bearing elements, which provide deployment of structures, is one of the important results. Besides, the most valuable characteristics are the peak forces and moments of the structure. Their excessive values might be failure cause of the solar array elements.

The results of testing would be convincing enough if we knew that the processes of the testing object are alike as in-space system processes. In other words, the environment does not have significant impact on energy performance of the structure. This requirement is set as maximum relative energy loss limit, which is related to testing structure and environment interaction.

Let us add a parameter which evaluates energy loss during development process of the solar array. Assume that kinetic energy of the free mechanical system $E_1(t)$ is known at any specific time. This value can be calculated by mathematical model of the free mechanical system development in weightlessness conditions. Kinetic energy $E_2(t)$ of the workbench and solar array can be calculated by modelling system. Otherwise, it can be obtained from an experimental data of ground testing by evaluating linear and angular velocities and forces of each solar array element and joint. Difference between these values $\Delta E(t) = E_1(t) - E_2(t)$ determine a dependence of the solar array kinetic energy from the environment in time. Relative energy loss can be found as follows:

$$k(t) = \Delta E(t) \big/ E_1(t) \qquad (1)$$

Equation (1) characterizes relative energy loss of the mechanical system during ground testing from the free mechanical system in weightlessness conditions.

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Evaluation of the workbench energy

Solar array is a holonomic system with *n* degrees of freedom. It consists of elements which we are represented as solid bodies with known mass-inertia parameters [2]. Each of them connected to one another as kinematic pair of fifth class. Kinetic energy of the mechanical system W is a kinetic energy sum of every element W_i :

$$W = \sum_{i=1}^{n} W_i, \qquad i = \overline{1, n}. \qquad (2)$$

Figure 2 shows kinematic scheme of solar array in process of deployment in the horizontal plane. Let us assume that angles $\varphi_i, i = \overline{1, 4}$ are generalized coordinates.

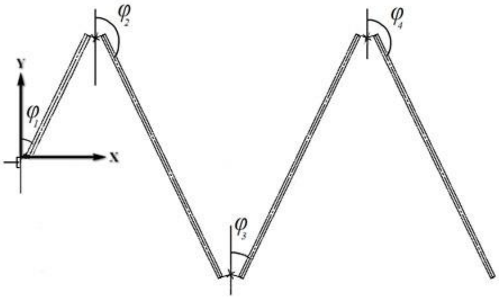

Fig. 2. General arrangement of solar array

First element performs rotational movement according to (3). The other elements of the system a plane-parallel movement according to (4).

$$W_1 = J_1 \frac{\dot{\varphi}_1(t)^2}{2}, \qquad (3)$$

$$W_i = J_i \frac{\dot{\varphi}_i(t)^2}{2} + m_i \frac{V_i(t)^2}{2}, i = \overline{2, 4}, \qquad (4)$$

where J_1 – first solar array element (shaft) moment of inertia relative to axis of rotation, J_i – central moments of inertia, $\dot{\varphi}_i(t)$ – angular velocity of each element, m_i – mass of each element, $V_i(t)$ – linear velocity of each element center of mass.

Let us assume that each element, except of first, performs only plane-parallel movements and can be represented as simple rods, which have following moments of inertia:

$$J_1 = \frac{1}{3} m_1 l_1^2, \qquad (5)$$

$$J_i = \frac{1}{12} m_i l_i^2, \quad i = \overline{2, 4}. \qquad (6)$$

Information about angular and linear velocities is taken from the results of solar array deployment modeling by Matlab/Simulink.

As an example, figure 3 shows the total kinetic energy values in two variant of modeling with different conditions. First curve (blue) represents modeling during ground tests. Second curve (red) represents solar array deployment in weightlessness conditions. Third curve (green) represents energy difference between in-space and ground conditions.

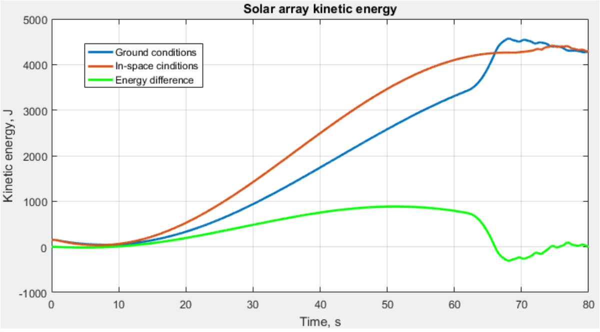

Fig. 3. Total kinetic energy values of solar array deployment in-space and ground conditions

Figure 3 shows that until solar array are completely deployed and locked (65 second) system movement is happening with incremental energy loss. At the moment of locking energy loss has reached 15%.

Energy loss is not significant after full deployment and it approaches to zero during oscillation damping of solar array.

Conclusions

On that stage of AGCS modeling the results show how aerodynamic, gravity forces and workbench itself affect the process of solar array deployment. The results would be used to determine AGCS model adequacy relative to real the workbench. Almost every bit of information might be obtained from AGCS model the way kinematic energy values was taken.

References

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2. I.K. Shpyakin, Modeling of a Solar Arrays Deployment Process at Ground Tests of Mechanical Devices on Active Gravity Compensation Systems / S.A. Maykov, A.M. Malyshenko, A.V. Voronin // 2nd Russian-Pacific Conference on Computer Technology and Applications (RPC 2017), Vladivostok, Russia, 25-29 September, 2017 (Unpublished).