Vestnik of Don State Technical University. 2019. Vol. 19, no. 4, pp. 317–327. ISSN 1992-5980 eISSN 1992-6006
Вестник Донского государственного технического университета. 2019. Т. 19, № 4. С. 317–327. ISSN 1992-5980 eISSN 1992-6006

MACHINE BUILDING AND MACHINE SCIENCE
МАШИНОСТРОЕНИЕ И МАШИНОВЕДЕНИЕ

UDC 62-83 https://doi.org/10.23947/1992-5980-2019-19-4-317-327

Background for modeling the dynamic characteristics of advanced spacecraft drives considering the operation of oscillators [*]

A. N. Sova[1], M. I. Stepanov[2], V. A. Sova[3], A. I. Bykov[4]**
[1, 2] Moscow Automobile and Road Construction State Technical University, Moscow, Russian Federation
[3] Bauman Moscow State Technical University, Moscow, Russian Federation
[4] Lavochkin Association, Khimki, Russian Federation

Теоретические основы моделирования динамических характеристик приводов перспективных космических аппаратов с учетом функционирования осцилляторов[***]

А. Н. Сова[1], М. И. Степанов[2], В. А. Сова[3], А. И. Быков[4]**
[1, 2] Московский автомобильно-дорожный государственный технический университет, Москва, Российская Федерация
[3] Московский государственный технический университет имени Н. Э. Баумана, Москва, Российская Федерация
[4] Научно-производственное объединение имени С. А. Лавочкина, Химки, Российская Федерация

Introduction. Precision elements of the target equipment and sensitive elements of the stabilization and orientation system of the advanced spacecraft are considered in the framework of this research. A method and software for modeling the dynamic characteristics of these elements are developed and validated. At that, the processing data results from the experimental studies on active and passive oscillators are taken into account.
Materials and Methods. It is shown how the method of weightlessness provides simulation of the conditions that as much as possible conform to the real-time use of advanced space vehicles, precision structural elements, target equipment and their drives. Schemes of the corresponding experimental facilities are presented. Mathematical modeling methods, techniques of machine mechanics and dynamics are applied. Basic parameters of the proposed design dynamics, which are governing parameters in terms of the implementation of the target functions of the spacecraft, are calculated. Rational versions of layout and approximate cycle patterns of the operation of advanced space vehicles are formed to reduce microperturbations from driving gear with rotating masses.
Research Results. A simulation technique for the dynamic characteristics of the drives of advanced space vehicles considering the regular oscillator operation is developed and validated. A complex of methods is presented for solving the problems of identifying dynamic parameters of a mathematical model of an advanced spacecraft based on the processing data results obtained through the experimental testing of active and passive oscillators. Two types of vibration from flywheel en-

Введение. В рамках данного исследования рассмотрены прецизионные элементы целевой аппаратуры и чувствительные элементы системы стабилизации и ориентации перспективных космических аппаратов. Обоснованы и разработаны метод и программно-алгоритмическое обеспечение моделирования динамических характеристик указанных элементов. При этом учтены результаты обработки данных по экспериментальным исследованиям активных и пассивных осцилляторов.
Материалы и методы. Показано, как метод обезвешивания позволяет воссоздать условия, максимально соответствующие реальной эксплуатации перспективных космических аппаратов, прецизионных элементов конструкции, целевой аппаратуры и их приводов. Представлены схемы соответствующих экспериментальных установок. Использованы методы математического моделирования, методы механики и динамики машин. Рассчитаны основные параметры динамики предлагаемой конструкции — определяющие с точки зрения реализации целевых функций космического аппарата. Сформированы рациональные варианты компоновки и примерных циклограмм функционирования перспективных космических аппаратов с целью снижения микровозмущений от приводных устройств с вращающимися массами.
Результаты исследования. Обоснован и разработан метод моделирования динамических характеристик приводов перспективных космических аппаратов с учетом функционирования штатных осцилляторов. Представлен комплекс методик решения проблем идентификации динамических параметров математической модели перспективных космических аппаратов с учетом результатов обработки данных, получаемых при экспериментальной отработке активных и пассивных осцилляторов. Отмечены два вида вибрации от двигателей маховиков. Первый: по ко-

[*] The research is done within the frame of the independent R&D.
[**] E-mail: slsova@mail.ru, madi.1965@mail.ru, vladislavsovaa@gmail.com, bykovartem1994@yandex.ru
[***] Исследование выполнено в рамках инициативной НИР.

gines are noted. The first type is according to the commands of the position control and stabilization control system. The second type is due to residual imbalance from the solar constant meter. It is shown how these vibrations affect the dynamic characteristics of the gyro mounting seats and of the multispectral scanner for hydrometeorological support of the spacecraft. The data obtained are meant to solve the problems of assurance of the dynamic accuracy of advanced space vehicles.
Discussion and Conclusions. A technique for modeling the dynamic characteristics of advanced space vehicles when operating in the precision orientation mode is proposed. The solution is based on the results of theoretical and experimental studies presented in the paper, and it considers the operation of standard oscillators. The implementation of this method is brought to software and algorithmic support for assessing the dynamic characteristics of standard oscillators of an advanced space vehicle. Recommendations to reduce the effect of active oscillators are established. Initial data are selected to determine the dynamics of advanced space vehicles from the point of view of fulfilling their target functions. The layout and approximate cycle patterns of the operation of advanced space vehicles to identify the driving gear with rotating masses as sources of micro-perturbations are proposed.

мандам системы управления ориентацией и стабилизацией. Второй: обусловленный остаточным дисбалансом, от измерителя солнечной постоянной. Показано, каким образом эти вибрации влияют на динамические характеристики посадочных мест гироскопического измерителя вектора угловой скорости и многозонального сканирующего устройства гидрометеорологического обеспечения космического аппарата. Полученные данные предназначены для решения задач обеспечения динамической точности перспективных космических аппаратов.
Обсуждение и заключения. Предложен метод моделирования динамических характеристик перспективных космических аппаратов при функционировании в режиме прецизионной ориентации. Решение основано на представленных в статье результатах теоретико-экспериментальных исследований и учитывает работу штатных осцилляторов. Реализация указанного метода доведена до программно-алгоритмического обеспечения оценки динамических характеристик штатных осцилляторов перспективного космического аппарата. Обоснованы рекомендации по снижению влияния активных осцилляторов. Выбраны исходные данные для определения динамики перспективных космических аппаратов с точки зрения выполнения их целевых функций. Предложены компоновка и примерные циклограммы функционирования перспективного космического аппарата с целью выявления приводных устройств с вращающимися массами как источников микровозмущений.

Keywords: amplitude of oscillations, damping ratio, dynamic accuracy, spacecraft, mathematical simulation, method, micro-perturbation, displacement, precision stabilization, drive, software and algorithmic support, velocity, acceleration, oscillation frequency.

Ключевые слова: амплитуда колебаний, декремент затухания колебаний, динамическая точность, космический аппарат, математическое моделирование, метод, микровозмущение, перемещение, прецизионная стабилизация, привод, программно-алгоритмическое обеспечение, скорость, ускорение, частота колебаний.

For citation: A.N. Sova, et al. Background for modeling the dynamic characteristics of advanced spacecraft drives considering the operation of oscillators. Vestnik of DGTU, 2019, vol. 19, no. 4, pp. 317–327. https://doi.org/10.23947/1992-5980-2019-19-4-317-327

Образец для цитирования: Теоретические основы моделирования динамических характеристик приводов перспективных космических аппаратов с учетом функционирования осцилляторов / А. Н. Сова [и др.] // Вестник Донского гос. техн. ун-та. — 2019. — Т. 19, № 4. — С. 317–327. https://doi.org/10.23947/1992-5980-2019-19-4-317-327

Introduction. At the present stage of development of the aerospace industry, some practical tasks of maintaining the dynamic accuracy of the angular and linear movements of precision structural elements (PSE) and target equipment (TE) of advanced spacecraft (SC) under the impact of internal disturbance sources, remain relevant. Such sources are devices, tools and drives of the spacecraft and scientific hardware. Moving and rotating masses of the specified equipment under the precision guidance modes generate vibrational disturbances [1, 2]. In the course of theoretical and experimental studies, a complex of the following particular research problems was solved [3, 4].

1) Analysis of the requirements for modern spacecraft with precision stabilization depending on their purpose and the scientific hardware installed on them. The goal is to unify these requirements.

2) Classification and analysis of the major sources of internal disturbances. The goal is to determine the most active vibration sources and to identify the possibility of weakening and (or) eliminating their effects.

3) Validation and development of experimental methods and means for determining micro-perturbations, as well as methods for their mathematical modeling.

4) Conducting experiments to determine the dissipative properties of spacecraft structures at low levels of displacement (of order of 0.5 microns).

5) Validation and development of sufficiently accurate mathematical models of spacecraft and scientific hardware for the analysis of dynamic accuracy in both the low-frequency and medium-frequency regions of disturbances.

6) Validation and development of mathematical modeling methods to study dynamic accuracy considering the experimentally determined parameters of perturbations.

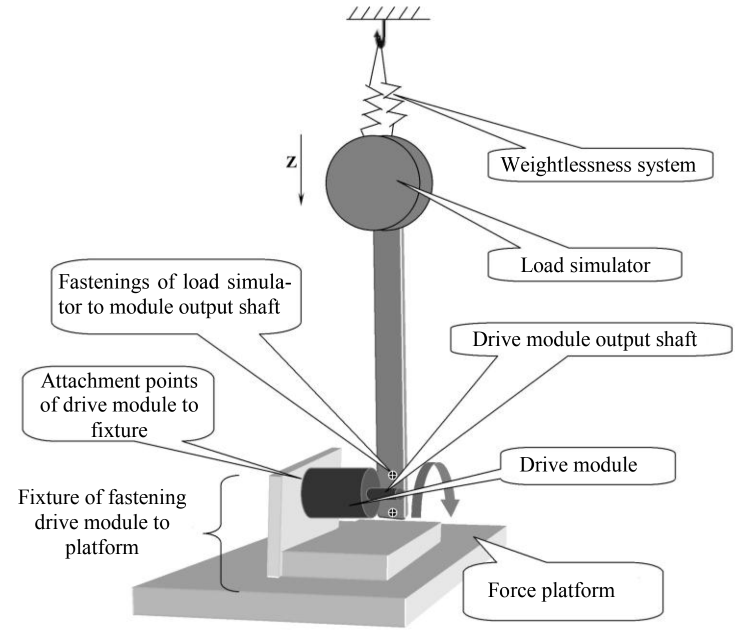
7) Analysis of the study results on dynamic accuracy and general requirements for its parameters for an advanced spacecraft including TE. Following this analysis, to justify and develop subrequirements for vibration activity of the major sources of internal disturbances.

Materials and Methods

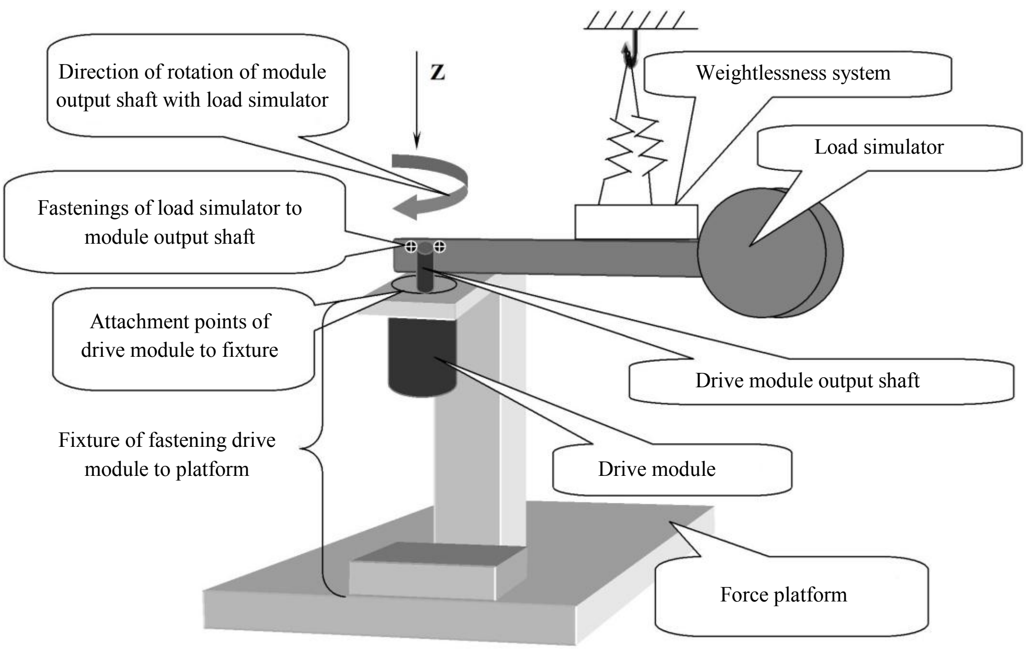
Research objective. Schemes of experimental facilities are proposed, the implementation of which using the method of weightlessness provides conditions that are most compliant with the actual operation of advanced SC, PSE, TE and their drives [3–5]. Mathematical simulation and experiments enabled to validate and develop proposals on correcting the dynamic characteristics of PSE and TE of advanced SC under the effect of internal disturbance sources.

Methods for solving the research problem. To solve the research problems, mathematical model approaches, techniques of mechanics and dynamics of machines were applied. A method for modeling the dynamic characteristics of advanced SC when operating under the precision guidance mode considering the operation of standard oscillators and a method for processing the experimental study results of micro-perturbations are proposed.

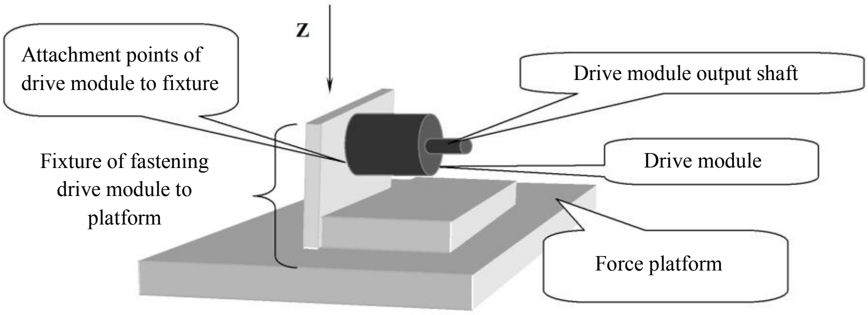
Pilot unit schematic. To solve these problems, experimental research schemes are implemented (Fig. 1).



a)



b)



c)

Fig. 1. Schemes for conducting an experiment on a power test bench with load on the output shaft of the drive module: *a*) horizontal axis of rotation; *b*) vertical axis of rotation; *c*) load on output shaft J = 4.75 kgm^2

Experimental studies on the selected schemes provided assessing the influence of the gravity field effect and the weightlessness system on the valid signal [5–8].

Research Results

Method for modeling the dynamic characteristics of advanced spacecraft drives taking considering the operation of standard oscillators. To provide dynamic accuracy, the research procedure presented in Fig. 2 [8–11] is specified.

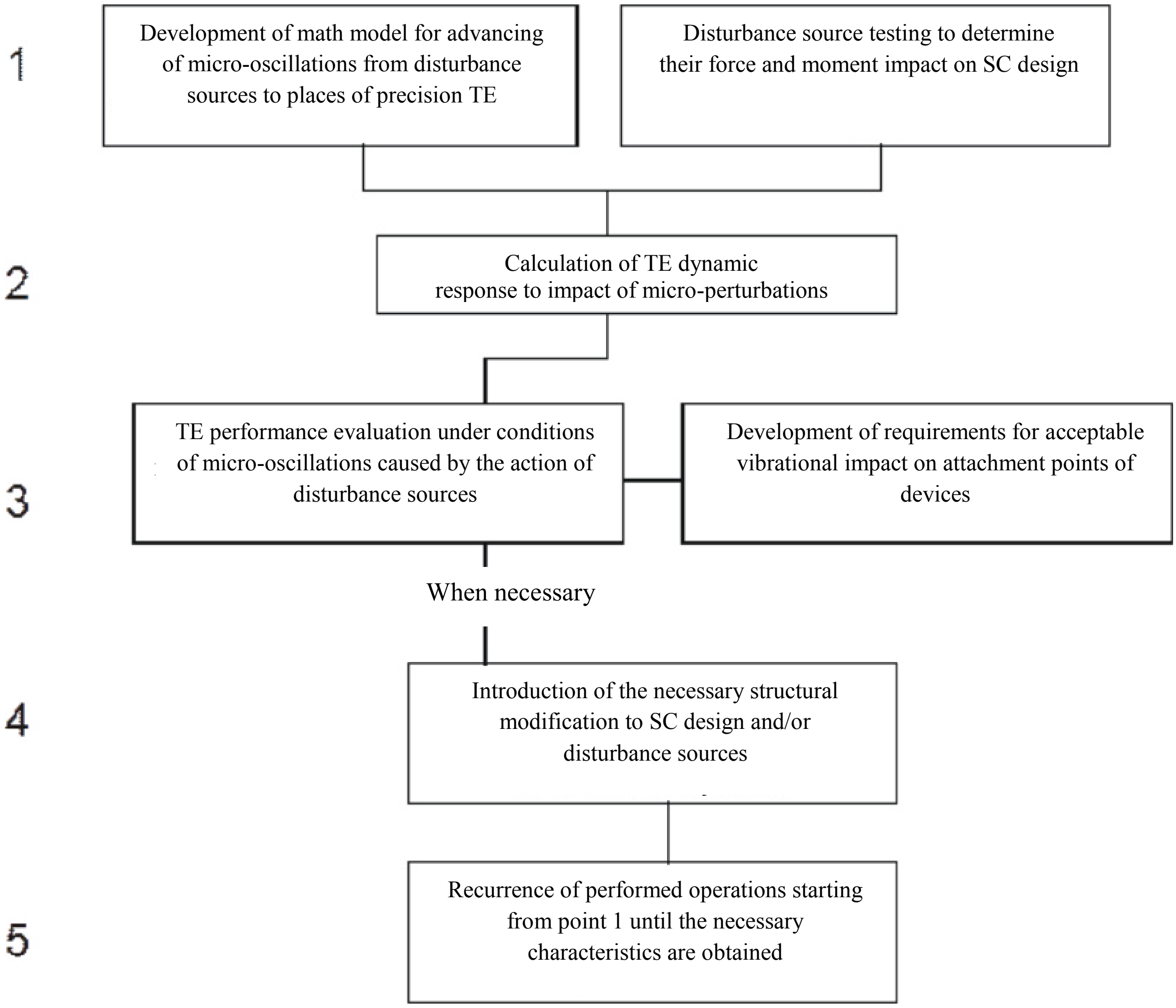


Fig. 2. Research procedure adopted under the development of dynamic accuracy

In addition, micro-perturbations of physical free-scale models of the advanced SC were experimentally investigated. When analysing the information obtained through the experimental testing of active and passive oscillators, problems arise in identifying the dynamic parameters of the product mathematical model. This paper presents ways and methods to solve these problems.

Method for processing the experimental study results of micro-perturbations of advanced SC. The technique for determining the major parameters of a dynamic circuit assumes that the obtained free motion sample is a general solution to a system of linear differential equations, that is, it has the form [3, 4, 7, 8]:

$$y(t) = \sum_{j=1}^{n} A_j e^{-\delta_j t} \sin(2\pi f_j t + \varphi_j), \quad (1)$$

where n is the total number of desired components in the sample; A_j is the amplitude of the contribution of the j-th tone; δ_j is where n is the total number of desired components in the sample; A_j is the amplitude of the contribution of the j-th tone; f_j is the frequency of the j-th tone; ϕ_j is phase of the j-th tone of oscillations; t is time.

It is necessary to bring this dependence as close as possible to the vibrational part of the signal from the device obtained via telemetry channels [7, 8]. To fix the identified signal, the following prior operations should be conducted [3, 4, 7, 8, 10, 11]:

- to assign the area of telemetric information at angular velocities or angles, where oscillations determined by the impact of liquid filling are observed;

- to remove from the received signal the low-frequency and constant components due to the angular movement of the spacecraft relative to its centre of mass (produced through filtering the low-frequency component and (or) removing the polynomial trend corresponding to solid-state forms of product motion);

— to bring the signal to a constant recording interval;

— to determine frequency ranges of the major harmonic components of the signal based on the fast Fourier transform algorithm;

— to displace the signal so that the time of the first measurement in the studied part of the signal corresponds to the beginning of the time axis (this is necessary for a correct assessment of dissipative and phase characteristics).

The converted signal is used as a tabulated function (x_i) when it is approximated by a dependence to determine the process parameters. When selecting parameters, the least-squares method is used. The parameters A_j, δ_j, f_j and φ_j are determined through minimizing [3, 4, 7, 8]:

$$\sum_{i=1}^{m} (x_i - \sum_{j=1}^{n} A_j e^{-\delta j \times t_i} \sin(2\pi f_j t_i + \varphi_j))^2 \to \min, \quad (2)$$

where x_i is the value of the signal obtained through processing the test results; t_i are time points corresponding to measurements of x_i; m is the number of measurements; A_j is the amplitude of the contribution of thge j-th tone; δ_j is damping factor of the j-th tone; f_j is frequency of the j-th tone; ϕ_j is phase of the j-th tone.

The simulation results and experimental studies consider the following key factors:

— the number of harmonic components occurring in the sample under study;

— proximity of the frequency arrangement of these components;

— the length of the sample (it determines and provides reliable estimation of the required number of periods of motion at the lowest frequency);

— signal recording step (it determines the required number of points on the period of motion of the highest frequency);

— spread of the amplitudes of single motions of the sample components;

— presence of unobservable input effects in the sample.

It is understood that all these factors are interdependent, and their influence on the accuracy and reliability of the result is determined by their combination. Therefore, the study is carried out for each factor with variation of the others.

The developed method was tested under the operation of oscillators, as a result of which force factors affect the attachment points. When determining the frequency response function (FRF) of forces and moments (operation of the module at the nominal pulse frequency of the step motor (SM) 130 Hz) with account of the kinematic circuit of the structure, the following sequence of module development was used:

— selection from the data array of the most characteristic measurement results (selection criteria included peak amplitudes of the measured power parameters and the maximum set of peaks in the FRF of the power parameters);

— analysis of the measurement results of the external background and oscillations of the fastening and weightlessness systems in the frequency domain to identify frequencies of noise signals;

— compiling a list of noise frequency ranges for each power parameter;

— filtration of the power parameter variation in the selected results of measuring the noise frequency ranges from the initial processes (a special application package is used);

— saving the measurement results of the filtered processes and analysis of their spectra to identify the main oscillators of the kinematic chain of the module.

Separate module development steps are described in [3, 4, 7, 8, 10, 11].

According to the diagrams presented in Fig. 1, the forces and moments at the module mounting points for three load cases on the output shaft with inertia values: 1) J_1 = 1.53 kgm^2; 2) J_2 = 6.1 kgm^2; 3) J_3 = 7.6 kgm^2, were measured.

The purpose of the experiments is to determine how the torque peaks relative to the axis of output shaft rotation depend on the value of the load inertia on the shaft, and then to make a forecast on the torque value for the standard load. When determining this dependence and torsional rigidity on the output shaft of the module, measurements of the moment M_z relative to the axis of rotation of the output shaft were taken for analysis.

Torsional rigidity was determined from the formula:

$$c = J_i 4\pi^2 f_i^2 , \tag{3}$$

where J_i is load inertia on the output shaft, kgm^2; f_i is the lowest frequency of torsional vibrations relative to the axis of rotation of the output shaft, Hz; i is the number of the load case on the output shaft of the module.

From the useful signal of the moment (filtration), a process was separated in which this moment changes at the lowest eigenfrequency of torsional vibrations. This provided the determination of the decrement of vibrations.

The decrements of torsional vibrations of the output shaft at the lowest eigenfrequency with different load cases were determined from the formula:

$$\delta = \frac{1}{n} \ln(A_m / A_{m+n}) , \tag{4}$$

where A_m is the acceleration amplitude on the m-th oscillation cycle; A_{m+n} is the acceleration amplitude on the $(m + n)$-th oscillation cycle; n is the number of vibrational cycles taken for analysis.

When determining the rigidity of the output shaft and the decrements of torsional vibrations at the lowest eigenfrequency, the following sequence of actions was used.

1) Selection of the three most characteristic processes of changing the moment M_z for three load cases on the output shaft of the module.

2) Determination of the lowest eigenfrequency of torsional vibrations. In this case, the frequency range, within which the value of the lowest eigenfrequency of torsional vibrations assumedly falls, is determined from the maximum amplitude in the FRF of the moment M_z. Using narrow-band filtering, narrow frequency ranges in the selected region are analysed (the criterion of the lowest eigenfrequency of torsional vibrations among the analysed filtered processes is a monotonic decrease in amplitude in time and with no beating).

3) Values of the lowest eigenfrequency of torsional vibrations and the moment of inertia of the load using formula (3) determine the rigidity of the output shaft.

4) From the obtained time process of the amplitude variation of torsional vibrations at the lowest eigenfrequency, the values A_m, A_{m+n}, n, are determined, and from the formula (2), the decrement of these oscillations is specified.

Specifics of processing the research results of the impact of power factors arising from the operation of oscillators on the attachment points. The format of the primary measurement data is automatically converted to a format convenient for graphical presentation and analysis of information. The application of a special program can significantly reduce the time of preprocessing of measurement results. To exclude noise signals from the original process, a special application package is also used.

For each of the measured power parameters (F_x, F_y, F_z, M_x, M_y, M_z), not only noise signals (e.g., a line electrical interference at a frequency of ~ 50 Hz or a stable external ground disturbance within the frequency range from 16 to 17.5 Hz) are common with all of them, but also their own ones due to the influence of the weightlessness systems and drive mounting. For each of the power parameters, an average of twelve frequency ranges should be excluded. Accordingly, in each set of measurement results selected for analysis, it is required to exclude different sets of noise signals for each of the power parameters if the problem of determining the dynamic characteristics of the module considering the kinematic circuit is solved (in this case, the analysis of the measured force parameters within a wide frequency band from 0 to 200 Hz). Criteria for selecting the force factor measurement results are as follows: peak amplitudes of force parameters; maximum set of peaks in the amplitude-frequency characteristics of power parameters.

When processing the measurement results in the problem of determining the module rigidity on the output shaft and the decrement of oscillations at the lowest eigenfrequency, it is necessary to separate a process, in which the power parameter variation occurs at the lowest eigenfrequency of torsional vibrations, from the initial signal (filtering). This procedure is successfully implemented in a special package of application programs [3–4].

Methodology for selecting characteristic test modes and the corresponding measurement results. The main test patterns and operating modes (pulse frequency of a SM is 130 Hz) of the module were selected with account of the maximum approximation to the operating conditions of the spacecraft in orbit. Criteria for choosing the most characteristic modes to solve the problem are the following:

— no load on the output shaft;

— vertical axis of rotation of the output shaft;

— the sampling frequency of the measurement data is at least 500 Hz (the frequency band under examination is from 0 to 200 Hz).

The selection criteria for the measurement results to determine the dynamic characteristics of the module due to the kinematic chain are:

— peak amplitudes of the measured power parameters;

— the maximum set of peaks in the FRF of power parameters.

Methodology for selecting characteristic modes and measurement results to determine the rigidity and decrement of torsional vibrations of the output shaft of the module. The criteria for the selection of characteristic modes to solve the task are:

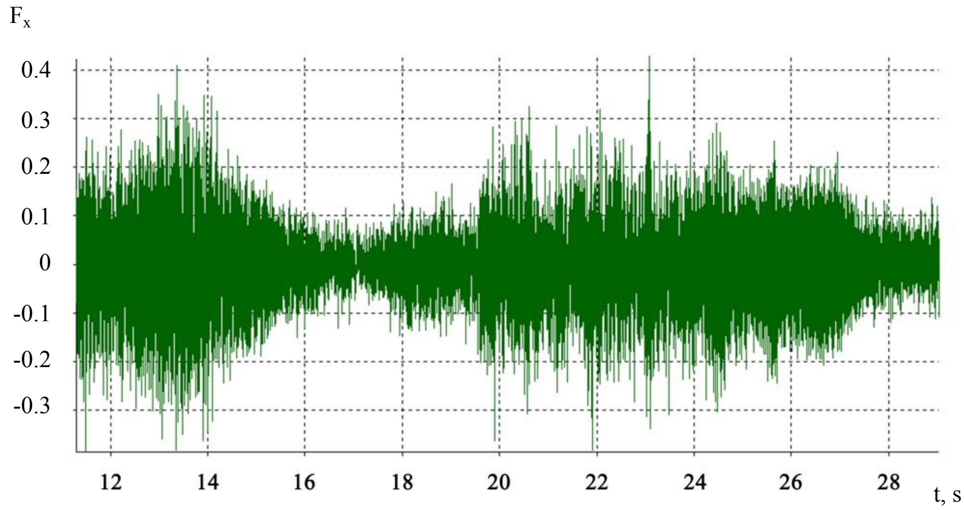
— vertical axis of rotation of the output shaft (see Fig. 1, *b*);

— three load cases on the output shaft (load value of at least 0.5 kgm^2);

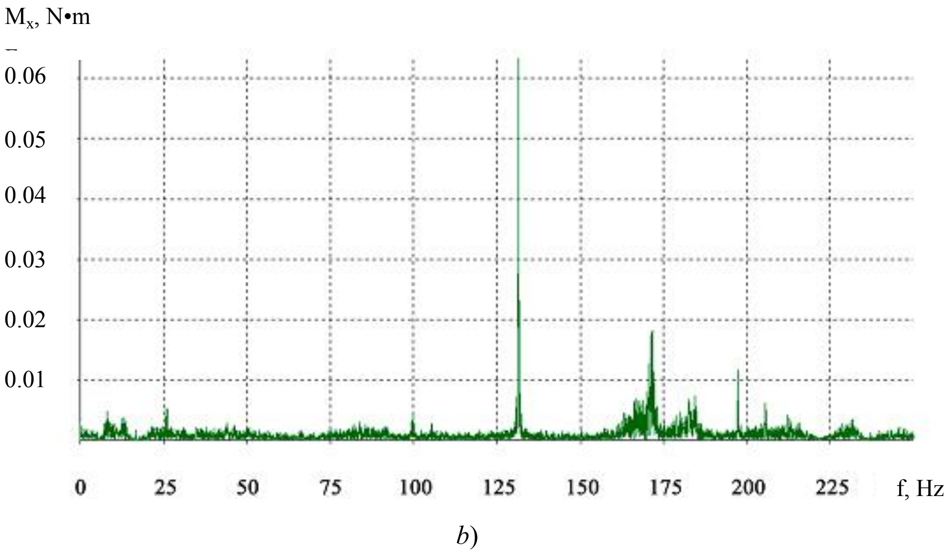
— sampling rate of measurement data is not less than 50 Hz (the studied frequency range is from 0 to 10 Hz).

The file selection criterion is peak amplitudes of the measured moment M_z.

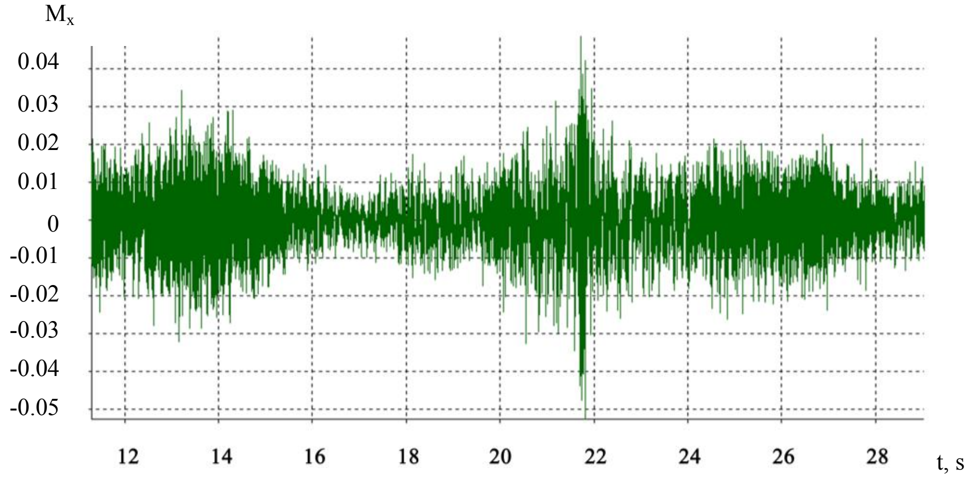
Methodology for determining the dynamic characteristics of a module considering the kinematic chain. After processing the initial measured signal, a useful signal is formed, which reflects the dynamics of the kinematic chain links of the module under the SM operation at a frequency of master pulses of 130 Hz. Analysis of the FRF of each of the power parameters (F_x, F_y, F_z, M_x, M_y, M_z) detected the main frequency bands at which the increased amplitudes of these parameters took place. As a result of the studies, time processes and spectra for the forces F_x, F_y, F_z and the moments M_x, M_y, M_z were determined. Fig. 3 presents examples of time processes and spectra for the force F_x and moment M_x.



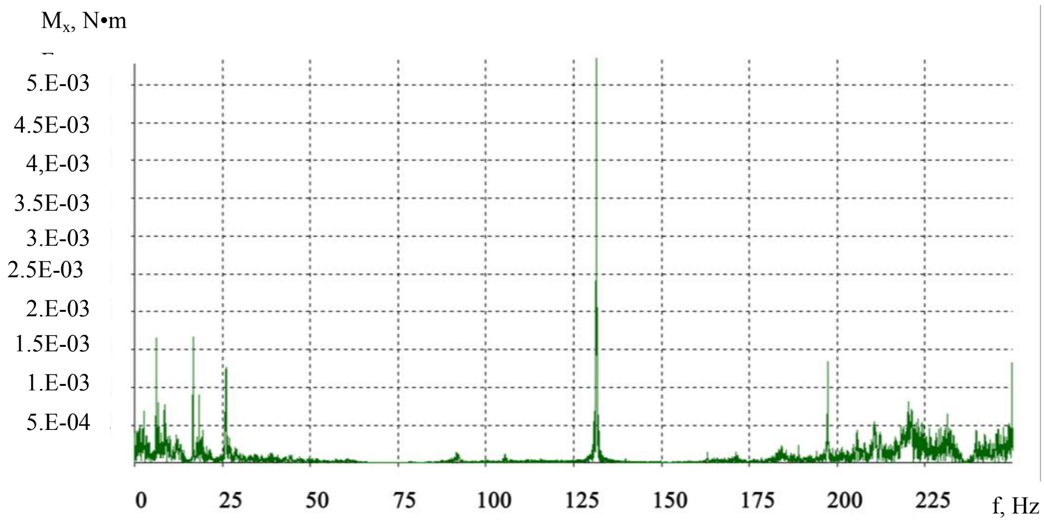
a)



b)



c)



d)

Fig. 3. Time process (*a*) and spectrum (*b*) of force F_x; time process (*c*) and spectrum (*d*) of the moment M_x at a frequency of SM 130 Hz

Results of determining the dynamic characteristics of the module at the lowest eigenfrequency of torsional vibrations of the output shaft. The calculation results are given in Table 1.

Table 1

Frequency characteristics on the parameters of forces F_x, F_y, F_z and moments M_x, M_y, M_z when the module operates at the SM pulse frequency of 130 Hz

№	Load parameter	Frequency *f*, Hz (average value of load amplitude is indicated in brackets)
1	F_x, N	0.5÷0.9 (0.014); 5÷6.1 (0.08); 8.2 (0.04); 12.3 (0.03); 26.2 (0.04); 45 (0.022); 91(0.02); 105 (0.014); 130 (0.39); 170 (0.01); 205 (0.04)
2	F_y, N	5÷6.1 (0.014); 8.2 (0.02);12.3 (0.02); 26.2 (0.044); 45 (0.014); 91 (0.017); 130 (0.47); 170 (0.02); 205(0.04)
3	F_z, N	0.5÷0.9 (0.07); 26.2 (0.04); 45 (0.015); 91 (0.04); 130 (0.1); 170 (0.02)
4	M_x, N•m	0.5÷0.9 (0.01); 8.2 (0.0025); 12.3 (0.03); 26.2 (0.025); 91 (0.0026); 105 (0.003); 130 (0.3); 170(0.001); 205 (0.0045)
5	M_y, N•m	5÷6.1 (0.016); 8.1 (0.0062); 26.2 (0.016); 45 (0.004); 91 (0.008); 105 (0.005); 130 (0.075); 170 (0.01); 205 (0.0055)
6	M_z, N•m	0.5÷0.9 (0.0025); 5÷6.1 (0.005); 18.5 (0.004); 26.2 (0.011); 45 (0.006); 105 (0.0018); 130 (0.3); 170 (0.015)

After processing the initial measured signals by the proposed method, data were obtained to determine the rigidity of the output shaft from the formula and decrements of torsional vibrations. The analysis of torsional vibrations of the module output shaft was carried out for moments of inertia: 1.53 kg·m^2; 6.1 kg·m^2; 7.6 kg·m^2. In the studies of torsional vibrations of the module output shaft, two situations were compared:

— SM is on, and the kinematic chain is in operation;
— SM is off.

In the first case, the lowest eigenfrequency of torsional vibrations is lower than in the second case. The analysis results are given in Table 2.

Table 2

Results of determining rigidity of the module output shaft with load at the lowest eigenfrequency

Load inertia, kg·m^2	The lowest eigenfrequency of the system, Hz		Output shaft rigidity, N·m/deg	
		During module operation		During module operation
1.53	6.2	5.3	40.5	29.6
6.1	2.63	2.34	29.1	23
7.6	2.44	2.1	31.2	23.1
29	1.22	1.07	31	23

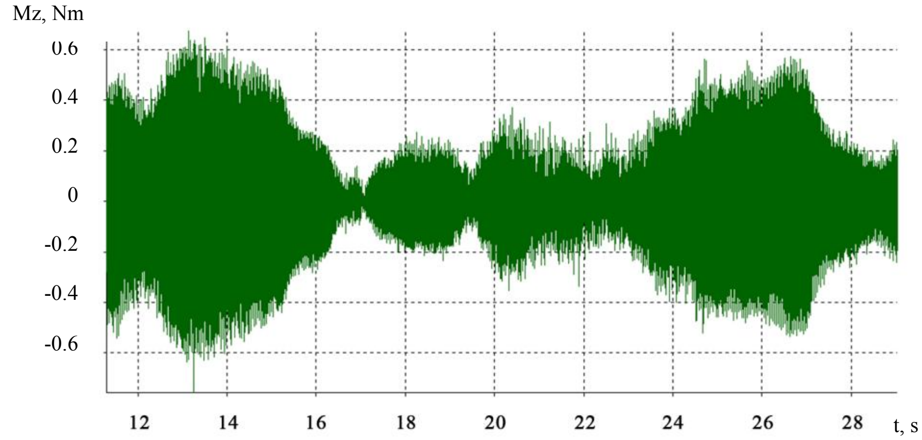
The obtained averaged values of the amplitudes of the moments *Mz* and decrements of vibrations for the lowest eigenfrequencies of the system are given in Table 3.

Table 3

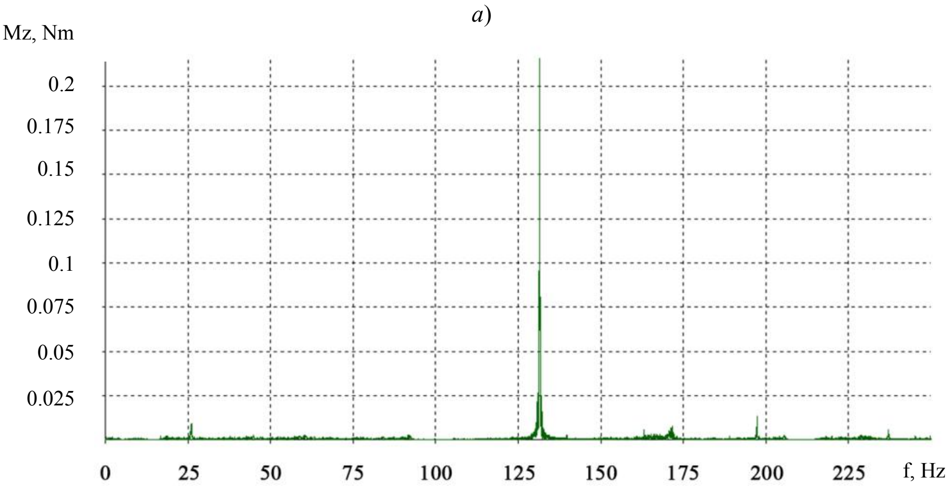
Torsional vibration decrements and averaged moment amplitudes relative to the axis of rotation of the output shaft

Load inertia, kg·m^2	Amplitude *Mz*, N·m	Decrement of vibrations
1.53	0.022	0.06
6.1	0.115	0.14
7.6	0.14	0.14
29	~0.5	0.14

Examples of the time process of the moment *Mz* and its spectrum for the case of load on the module output shaft J_2 = 7.6 kgm^2 are presented in Fig. 4.



a)



b)

Fig. 4. Graphs of the time process (*a*) and spectrum (*b*) of the moment *Mz* for the case of load on the module output shaft J_2 = 7.6 kgm^2

Discussion and Conclusions. The studies enabled to determine the dynamics of the drives of an advanced SC and its components as sources of internal disturbances. The analysis of the research results showed that to reduce the influence of active oscillators on the dynamic accuracy of an advanced SC under the precision orientation mode, it is necessary:

- to conduct experimental validation of the initial data on the on-board sources of disturbances;

— to carry out an experimental study on the dissipative characteristics and structural rigidity characteristics of an advanced SC;

— to develop criteria for assessing the impact of actions of the airborne disturbance sources on the target operation of an advanced SC in the frequency band up to 100 Hz;

— to refine a midfrequency dynamic model of an advanced SC based on the results of experimental studies;

— to analyse the sensitivity of the onboard instruments of an advanced SC to vibrations and to develop requirements for the vibration activity of micro-disturbance sources;

— to determine the vibration activity of sources of vibration disturbances: a reaction wheel (RW), an MSU-GS mirror drive, an ISP-2M solar constant meter.

The results of theoretical and experimental studies provided the solution to the problems listed below.

1) Analysis of sources of micro-perturbation:

— analysis of the composition, operating modes and characteristics of onboard sources of micro-disturbances;

— assessment of vibration disturbances of the SC structure generated by electromechanical executive bodies (EMEB);

— assessment of the moments created by RW according to the commands of the stabilization and attitude control system (SACS);

— assessment of the vibration disturbances of the SC structure generated by a multizone scanning device for hydrometeorological support (MSD-HS);

— assessment of vibration disturbances of the SC structure generated by a solar battery (SB) drive;

— evaluation of vibration disturbances of the SC structure generated by a high gain antenna (HGA) drive;

— assessment of the vibration disturbances of the SC structure generated by a solar constant monitor (SCM-2M).

2) Assessment of the dynamic characteristics of the mounting seats of the gyroscopic angular velocity sensor (GAVS) of the advanced SC under vibration effects from SCM-2M, as well as from:

— MSD-HS,

— RW (vibrations due to the SACS commands and residual imbalance).

3) Evaluation of the dynamic characteristics of the MSD-HS mounting seats of an advanced SC under disturbances from RW by the commands of the SACS, RW, caused by a residual imbalance, SCM-2M.

References

1. Yefanov, V.V., Zakharov, A.V. Fobos-Grunt. Proekt kosmicheskoy ekspeditsii. V 2 t. T. 1. [Fobos-Grunt. Space Expedition Project. In 2 vol. Vol. 1.] Moscow: Lavochkin Association; Russian Space Research Institute, 237 p. (in Russian).

2. Yefanov, V.V., Zakharov, A.V. Fobos-Grunt. Proekt kosmicheskoy ekspeditsii. V 2 t. T. 2. [Fobos-Grunt. Space Expedition Project. In 2 vol. Vol. 2.] Moscow: Lavochkin Association; Russian Space Research Institute, 345 c. (in Russian).

3. Yefanov, V.V., Shevalev, I.L. Proektirovanie avtomaticheskikh kosmicheskikh apparatov dlya fundamental'nykh nauchnykh issledovaniy. V 3 t. T. 1. [Design of automatic spacecraft for basic scientific research. In 3 vol. Vol. 1.] Yefanov, V.V., Pichkhadze, K.M., eds., 2nd revised ed. Moscow: MEI-Print, 2013, 492 p. (in Russian).

4. Yefanov, V.V. Proektirovanie avtomaticheskikh kosmicheskikh apparatov dlya fundamental'nykh nauchnykh issledovaniy. V 3 t. T. 1. [Design of automatic spacecraft for basic scientific research. In 3 vol. Vol. 1.] Khartov, V.V., Yefanov, V.V., eds., 2nd revised ed. Moscow: MEI-Print, 2014, 544 p. (in Russian).

5. Rybak, A.T., et al. Teoreticheskie osnovy rascheta sistemy upravleniya gidravlicheskogo privoda stenda dlya ispytaniy porshnevykh gidravlicheskikh tsilindrov. [Theoretical background of hydraulic drive control system analysis for testing piston hydraulic cylinders.] Vestnik of DSTU, 2019, vol. 19, no. 3, pp. 242−249 (in Russian). https://doi.org/10.23947/1992–5980–2019–19–3–242–249.

6. Sova, A.N., et al. Predlozhenie po resheniyu problemy vibrozashchity pretsizionnoy optiko-elektronnoy apparatury kosmicheskogo apparata «SPEKTR-UF». [Proposal for solving the problem of vibration protection of precision optical-electronic equipment of the SPECTR-UV spacecraft.] Electromechanical matters. VNIIEM studies, 2013, vol. 135, no. 4, pp. 17–20 (in Russian).

7. Sova, A.N. Metod i algoritmy matematicheskogo modelirovaniya vibroaktivnosti kosmicheskikh apparatov

s uchetom vnutrennikh istochnikov vozmushcheniy na osnove rezul'tatov eksperimental'nykh issledovaniy. [Method and algorithms of mathematical modelling of vibroactivity of space devices taking into account of internal sources of perturbations based on the results of experimental researches.] Dvoynye tekhnologii, 2019, no. 3 (88), pp. 52–56 (in Russian).

8. Sova, A.N. Metod i rezul'taty matematicheskogo modelirovaniya mekhanicheskikh vozdeystviy dvigateley-makhovikov kosmicheskikh apparatov na osnove rezul'tatov eksperimental'nykh issledovaniy. [Method and results of mathematical modelling of mechanical impacts of flywheel engines of space apparatus based on the results of experimental researches.] Dvoynye tekhnologii, 2019, no. 3 (88), pp. 57–63 (in Russian).

9. Sova, A.N., et al. Sovremennoe sostoyanie i napravleniya primeneniya magnitozhidkostnykh tekhnicheskikh sredstv i sistem v raketnoy i raketno-kosmicheskoy tekhnike. [Current state and directions of application of magneto-liquid technical means and systems in rocketry and rocket and space equipment.] Metal Science and Heat Treatment, 2014, vol. 14, part 1, pp. 92–102 (in Russian).

10. Chebotarev, V.E., Fateev, A.V. Osobennosti orientatsii navigatsionnykh kosmicheskikh apparatov. [Features of orientation of navigating spacecrafts.] Spacecrafts and Technologies, 2018, vol. 2 (24), pp. 84–87 (in Russian).

11. Chebotarev, V.E. Proektirovanie kosmicheskikh apparatov sistem informatsionnogo obespecheniya. V 2 kn. Kn. 2. Vnutrennee proektirovanie kosmicheskogo apparata. [Spacecraft design for information support systems. In 2 books Book 2. Internal design of the spacecraft.] Krasnoyarsk: Reshetnev University Publ. House, 2006, 140 p. (in Russian).

Submitted 01.09.2019
Scheduled in the issue 05.11.2019

Authors:

Sova, Aleksandr N.,
Head of the Transport Plants Department, Moscow Automobile and Road Construction State Technical University (MADI) (64, Leningradskiy Pr., Moscow, 125319, RF), Dr.Sci. (Eng.), professor, full member (academician) of the Russian Academy of Cosmonautics named after K. E. Tsiolkovsky,
ORCID: https://orcid.org/0000–0002–0213–6978
slsova@mail.ru

Stepanov, Mikhail I.,
professor of the Transport Plants Department, Moscow Automobile and Road Construction State Technical University (MADI) (64, Leningradskiy Pr., Moscow, 125319, RF), Dr.Sci. (Eng.), professor,
ORCID: https://orcid.org/0000–0003–0331–5246
madi.1965@mail.ru

Sova, Vladislav A.,
student of the Theoretical Computer Science and Computer Technology Department, Bauman Moscow State Technical University (5/1, 2-ya Baumanskaya ul., Moscow, 105005, RF),
ORCID: https://orcid.org/0000–0002–8431–2233
vladislavsovaa@gmail.com

Bykov, Artem I.,
postgraduate student of the “Scientific and Production Association named after S.A. Lavochkin” JSC
(24, Leningradskaya ul., Khimki, Moscow Region, 141400, RF),
ORCID: https://orcid.org/0000–0001–9972–7389
bykovartem1994@yandex.ru