УДК 534.1, 621.81-192

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ERGONOMIC ASPECTS OF TEST OBJECTS OF THE SPATIAL STRUCTURE ON THE VIBRATION RELIABILITY

In-process on the base of the use paradigm of ergonomics approach a «man-machine-environment» is created structures of the systems of tests on multicoordinate external mechanical influence as it applies to the objects of spatial structure. Thus systems of oscillation tests parameters of multicoordinate vibration of platform of stand reproducing of extreme properties of multidimensional vibrations of object is provided affecting. Reproducing at the stand tests of the most dangerous from point of refuse object is in this case provided on oscillation reliab ility of the mode of tests. Amplitudes of vibrations of object in the direction of both basic and attended co-ordinates become maximally possible. The underscores of indexes of oscillation activity of object are eliminated, which are diagnosed at stand tests, and, consequently, and unforeseen refuses on oscillation reliability in exploitation.

Key words: *oscillation (vibration) reliability, ergonomics, object of tests, method of tests, flow diagram of setting*

Problem statement

The majority of apparatus and assemblies, devices of machines, constructions, industrial buildings and structures that are created and produced by energy, machine engineering, transport, aviation, aerospace, radio, electronic, instrument engineering, shipbuilding, electrical industries represent a set of installed on the supporting structure (housing assemblies) units, blocks, and belonged to the class of spatial structure objects (SSO), which mechanical scheme is considered to be spatial reference system of inertial, elastic and dissipative elements. This scheme shows the nodes, assembly units of products of fine-precision mechanics, electromechanical devices that are fitted into the housing via dampers and experience the negative impact of the current spatial multi-axis vibration in the process of exploitation [1, 2].

In our time the study of parameters of vibration velocity and vibration survival of structures, parts of structures, buildings and units, which belong to the class of spatial structure objects and experience the impact of vibration load in real world conditions is based on single-axis amplitude-frequency and amplitude-time characteristics, and the research and testing of such SSO on vibration reliability are connected with single-axis (vertical horizontal, vertical) vibration stands. As a result, the parameters of SSO vibration reliability do not consider the mechanisms of synergistic effect, and their tests are inadequate to operational conditions, which leads to erroneous estimation of the parameters of vibratory activity of structures, components, assemblies, their stress state, reduce the quality of research in the physics of vibration failures, and the reliability of the results of research and testing, leads to unexpected failure of SSO as for vibration reliability in operation [3,4].

Analysis of the recent researches and publications

Nowadays, the structures of vibration test systems are commonly used in single-axis stands of horizontal, vertical and oblique vibration [1]. In this case the structure of vibration test system during its creation includes: a method of bench testing, the way of representation of a given vibration, methods of reproduction and bench testing adjusted for structural parameters of the platform, test object, as well as types of vibromeasuring converters. Thus in the works [2,4] it was shown that the non-use of stands and VTS for multi-axis mechanical effect leads to an increase in 2 and more times of the vibrational load duration to the test object, and also reduces the fidelity of its operational vibration condition. This research shows only the features of the further use of VTS for SSO and is considered to be a fundamental principle for further development of this scientific field.

In addition the results of two-axis and multi-axis loading in comparison with testing methods of single-axis vibrostands for three-dimensional SSO show that the amplitudes of the translational vibration of the object have differences of 1.5 times or more in parameters of the amplitude spectrum of the translational vibration of the object [2-4]. However, these studies are purely analytical and do not give a response to features of structural and technical identification.

It is known (modification D of the US standard MIL-STD) that more than 55% of aviation equipment failures are due to incomplete consideration of the factors of simultaneously acting external mechanical and climatic influences, that is, ignoring the synergistic effect of amplitude, temporal and frequency parameters of the components of exposure, that is due to the lack of conditions of the synergetic (mutually reinforcing) impact of individual factors. These principles were tested and their application had a positive effect. For example, their usage in testing of fatigue performance and stability of electronic equipment of the Apollo visits to the moon by a Shuttle vehicle upon the program "space Shuttle", as well as reliability testing of aircraft equipment according to the program CERT [2-4]. But the nature of the use of the synergetic effect of these external influences in terms of bench laboratory tests at the level of technical support is not considered here.

The impact of parameters on the harmonic resonance and conversely, as well as changes in the amplitude resonant harmonics are reviewed in the works [5-12]. However, the innovative component of integrating the results obtained in these studies is not introduced.

Besides in the work [4] the research does not define the structure of VTS that provides SSO testing as for multi-axis vibration adjusted for the synergy effect and its parameters. This limits the application of VTS in practice.

The objective statement of the article.

In the work the structures of test systems of multi-axis external mechanical effect concerning the objects which belong to the class of spatial structure objects based on the paradigm of "man-machine- environment" ergonomic approach are developed. In this context vibration test systems influencing the parameters of multi-axis vibration platform stand provide the playback of the extreme properties of the SSO spatial fluctuations. In the case of bench testing the playback of the most dangerous test mode in terms of failure of the object on vibration reliability is provided. Vibrational amplitudes of the object in the direction of the main (active forced) and coincident (unactive forced) coordinates become the highest possible. Underestimation of indicators of oscillating activity of the object that are diagnosed at bench trials, and, therefore, unexpected failures of the vibration reliability in operation are excluded. As a result the reliability of studies of the SSO vibration failure physics as well as their operational reliability are increased.

Presentation of the basic material.

We define block diagrams of the VTS, providing scientific research statements, respectively as: Structure 1 and Structure 2.

Let’s consider the schematic synthesis for three-dimensional VTS using the Structure 1. In the case of frequency transfer function of the mechanical system, including three-axis vibration stand and three-dimensional test object, it has the form

$$v_i(j\omega_k) = W_{ii}(j\omega_k)\cdot q_i + \sum_{N_2} W_{iN_2}(j\omega_k)\cdot q_{N_2}(j\omega_k) \qquad (1)$$

$$(i=1,2,3),\ (N_2 = 2,3;1,3;1,2),$$

where $v_i(j\omega_k) = B_{ik}e^{j\beta_{ik}}e^{j\omega_k t}$ – the SSO vibration signals, $W_{ii}(j\omega_k) = |W_{ii}(j\omega_k)|\cdot e^{j\gamma_{ii}(\omega_k)}$ – SSO transfer functions, $q_i = A_{ik}\cdot e^{j\varphi_{ik}}\cdot e^{j\omega_k t}$, φ_{ik} – block phase response with the transfer function $W_{ik}^{Ph} = 1\cdot e^{j\varphi_{ik}}$ in the i-input channel of the system.

Block diagram of the VTS, which corresponds to equation (1) at the frequency of the tests ω_k, is shown in Fig.1. Here, each of the input q_i and output coordinates v_i has its own excitation frequency $\omega_{v_i res}$, in which,

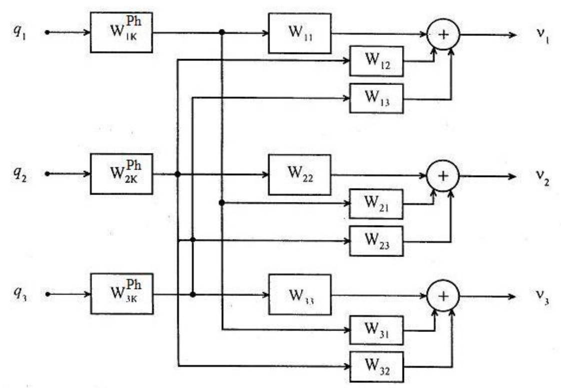

Fig. 1. A block diagram of the VTS

$B_{ik} = \hat{A}_{ik}^{*} = \max$.

Analyzing the functioning of the VTS under given condition we’ll receive the following: if as a unit W_{ik}^{k} apply adjustable phase-shifter signal of the i- frequency channel $\omega_k = \omega_{v_i res}$, the performance ratio is

$$\gamma_{ii}(\omega_k) + \varphi_{ik} = \lambda_{iN_2}(\omega_k),$$

where the phase characteristic function is

$$\sum_{N_2} W_{iN_2}(j\omega_k)\cdot q_{N_2}(j\omega_k),$$

the oscillation amplitude of the mechanical system in the direction of the output coordinate v_i is maximum.

VTS scheme shown in Fig. 1 implements SSO test method (Method 1), which algorithm can be formalized in the following set of steps.

Step 1. At the lower range value ω_l of the operating frequency $\Omega = [\omega_l - \omega_u]$ at the test point of the spatial vibration stand platform a multi-axis vibration of a predetermined amplitude $\bar{q}_n = \{q_{n_1}, ..., q_{n_N}\}'$ is reproduced. In this case the phase displacements between the coordinate components q_{n_i} are supported by zero points.

Step 2. At the same time changing the frequency of excitation ω make the determination of the resonant frequencies of the test object $\omega_{v_i res}$, by analyzing its amplitude and frequency characteristics $v_i(\omega)$ $\left(i = \overline{1, N}\right)$ when $\left|q_{n_i}(\omega)\right| = const$.

Step 3. At the resonant frequencies of the test object make the change of phase shift (for the coordinate v_i the phase shift varies in the "own" channel q_{n_i} and the value $\varphi_{N_2 k}$ is determined), enforcing the conditions under which the amplitudes of the object vibrations in the direction of the *i*-analyzed coordinate take the largest value.

Step 4. In testing the control point of the vibratory stand platform reproduce vibration process with the set values of the resonant frequencies of the object $\omega_{v_i res}$ and the phase shift $\varphi_{N_2 k}$ between the vibration components of the platform.

The VTS, which is implemented according to the scheme in Fig. 1, differing by simplicity of technical implementation, because for each coordinate v_i no more than one unit with the transfer function W_i^{Ph} in the channel q_i is applied, achieves the required results only if the magnitudes $\gamma_{iN_2}(\omega_k)$ when $N_2 = \mathrm{var}$ do not depend on the magnitude N_2. This is done in the spatial mechanical systems [1-4] related or close to symmetrical class.

These drawbacks are excluded in the VTS, which block diagram (Structure 2) has been built with regard to the statements of Method 2. In this equation (1) is reduced to the form [4]:

$$B_{ik} \cdot e^{j\beta_{ik}} \cdot e^{j\omega_k t} = \left|W_{ii}(j\omega_k)\right| \cdot e^{j\gamma_{ii}(\omega_k)} \cdot A_{ik} \times$$
$$\times e^{j\varphi_{ik}} \cdot e^{j\omega_k t} + \sum_{N_2} \left|W_{iN_2}(j\omega_k)\right| \times$$
$$\times e^{j\gamma_{iN_2}(\omega_k)} \cdot A_{N_2 k}{}^{j\varphi_{N_2 k}} \cdot e^{j\omega_k t}$$
$$\left(i = \overline{1,3}\right), \quad (N_2 = 2, 3; 1, 3; 1, 2). \qquad (2)$$

The VTS block diagram corresponding to the equation (2) at the frequency ω_k, is shown in Fig. 2.

In this scheme, the condition $B_{ik} = \hat{A}_{ik}^{*} = \max$ is achieved by the impact on the magnitude $\varphi_{N_2 k}$, which should satisfy at a frequency $\omega_{v_i res}$ the equation $\gamma_{iN_2}(\omega_k) + \varphi_{N_2 k} - \gamma_{ii}(\omega_k) - \varphi_{ik} = 0$.

In addition, for each coordinate v_i N – 1 blocks with transfer function $1 \cdot e^{i\varphi_{ik}}$ are applied. For example, for the frequency $\omega_{v_i res}$ of the coordinate v_1 in the channels q_2 i q_1 of the scheme in Fig. 2 we use

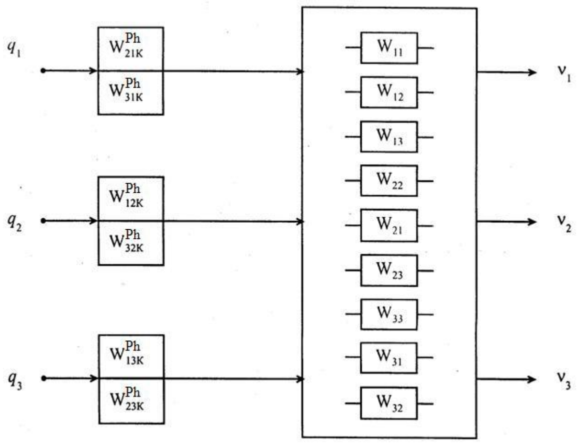

Fig. 2. A block diagram of the VTS

the blocks W_{12k}^{Ph} i W_{13k}^{Ph}, where the index k corresponds to the frequency of testing $\omega_{v_1 res}$. A Similar functions are performed by the blocks W_{21k}^{Ph}, W_{31k}^{Ph}, W_{23k}^{Ph}, W_{32k}^{Ph} of the structural scheme.

The algorithm of the test method (Method 2), which technical implementation approach is shown in Fig.2, is formalized in the following way.

Steps 1 and 2 of the Method 2 are coincided with steps 1, 2 of the Method 1.

Step 3. At the resonant frequencies of the object $\omega_{v_1 res}$ perform the change of phase displacements in turn at all N_2 = N – 1 of the connected channels q_{nN_2} ("connected" shifts of phases), ensuring the fulfillment of the conditions under which the oscillation amplitude of the object in the direction of the i-analyzed coordinate at each stage of the phase shift regulation becomes maximum.

Step 4. Testing the control point of the vibration stand platform reproduce vibration mode with set object resonance frequencies $\omega_{v_i res}$ and "connected" phase shift $\omega_{v_{ik} res}$ between the components of the vibration platform.

Technical implementation of the marked regime tests is carried out using the system vibrotesting circuits play amplitudes and phases of vibrating processes, search and playback re-resonance vibrations of the object.

One of the options the system vibrotesting system presented in Fig.3-where 1, 2, 3 - according vibrofeeders and two-coordinate translational vibration platform; 4, 5 - vibrofeeders control units 1, 2; 6 - tested object spatial structure; 7 - measuring transducer angular vibrations of the object; 8, 9, 10, 11 - translational vibration transducers object platform 6 and 3; 12 - switch; 13 - vibroteter; 14 - Analyzer amplitude-frequency characteristics; 15 – frequency tester; 16 - faze tester; 17 - harmonic oscillations generator; 18 - managed faze rotator; 19 - Key; 20 - Operator researcher; U_{1H}, U_{2H} - generator output 17; U_f - 15 freqvency tester output signal proportional to the current frequency; U_{OP1}, U_{OP2}, U_{OP3} - control signals operator 20.

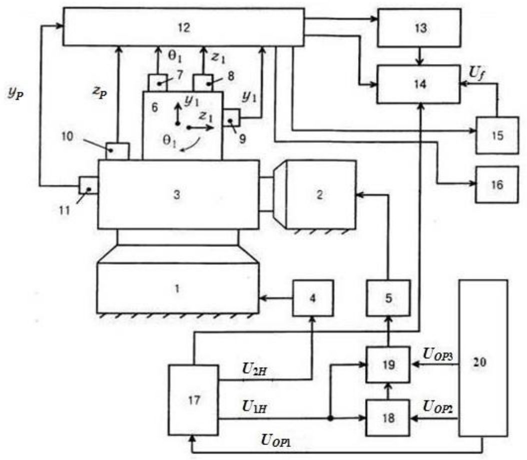

Fig. 3. A block diagram of the VTS

Vibration test system operates in three modes: resonant frequency search mode; resonant phase shift search mode; mode you-trials on vibroreliability.

Search mode resonant frequencies.

In this mode, the search and definitions for each coordinate y_1, z_1, θ_1 object test their resonant frequencies $\omega_{y_1 res}, \omega_{z_1 res}, \omega_{\theta_1 res}$. To do this, the output signals U_{1H}, U_{2H} of the same generator frequency serves 20 operator input device 4 and control unit 5 through faze rotator 18 and the key19 Next key via the operator vibrotester 13 20 U signal $OP1$ is installed on the bottom of the range of operating frequencies specified normative document mentioned oscillation amplitudes $A^*_{y_p}$ i $A^*_{z_p}$ and platforms, providing the help of faze rotator 18 (signal operator U_{OP2}) zero phase shift between the signals y i z. This evidence: A_{y_p} i A_{z_p} is controlled through the chain: Switch - vibrotester (vibrotester 13 has one input, so the switch 12 has connected to it the desired signal), and the testimony phase shift between processes y i z – through the chain: chain: Switch – faze tester. Next, the operator 20 performs simultaneous scanning frequency signals U_{1H}, U_{2H} block 17 in the range of operating frequencies, supporting, affecting the amplitude U_{1H} i U_{2H}, of the amplitude A_{y_p} i A_{z_p} amplitude $A^*_{y_p}$ i $A^*_{z_p}$ and set and levels affecting faze rotator 18 - Zero-headed phase shift and analyzing unit 14 frequency characteristics $A_{y_1}(\omega)$, $A_{z_1}(\omega)$, $A_{\theta_1}(\omega)$ of the object connecting it with the switch 12 and outputs vibrotester converters 7, 8, 9. in this case, the input signal analyzer 14 U_f, is proportional to the current frequency $\omega_{y_1 res}, \omega_{z_1 res}, \omega_{\theta_1 res}$ take freqvencies ω, with which $A_{y_1}(\omega)$, $A_{z_1}(\omega)$, $A_{\theta_1}(\omega)$ are maximumi. The frequency are measured by freqvency microtron 15.

Then comes the search mode resonant phase shift.

In this mode, the operator 20 for generator 17 originally set for both signals and U_{1H} i U_{2H}, for example-freqvency $\omega_{z_1 res}$ and ratio: $A_{y_p} = A^*_{y_p}$, $A_{z_p} = A^*_{z_p}$ i $\theta = 0$. Then performed using 18 faze rotator varying phase shift range ($0 \le \theta \le 2\pi$), maintaining $A_{y_p} = A^*_{y_p}$, $A_{z_p} = A^*_{z_p}$ and analyzing for vibrotester using 13 characteristics A_{z_1}. As the resonance phase shift $\alpha_{z_1 res}$ taking phase shift, A_{z_1} in its maximum value. The value of the phase shift is tested with faze tester16..

This operation is repeated similarly for frequencies $\omega_{y_1 res}$ i and determining accordingly $\alpha_{y_1 res}$ i $\alpha_{\theta_1 res}$.

The next test is vibrosafety mode.

In this mode, stand on the platform for each channel reflect vibration excitation signals.

$$y = A^*_{y_1} \sin\left(\omega_{y_1 res} t + \alpha_{y_1 res}\right) + \\ + A^*_{y_2} \sin\left(\omega_{z_1 res} t + \alpha_{z_1 res}\right) + \\ + A^*_{y_3} \sin\left(\omega_{\theta_1 res} t + \alpha_{\theta_1 res}\right),$$

$$z = A^*_{z_1} \sin \omega_{y_1 res} t + A^*_{z_2} \sin \omega_{z_1 res} t + A^*_{z_3} \sin \omega_{\theta_1 res} t,$$

where $A^*_{y_i}, A^*_{z_i}$ (i = 1,3) – set normative document object amplitude at the resonant frequencies.

$\omega_{y_1 res}, \omega_{z_1 res}, \omega_{\theta_1 res}$.

This output signal generator U_{2H} fed to the input control device 5 passing faze rotator 18. . Provides operator 20 is a result of the relevant switching key 19. This object 6 is being tested simultaneously on the three resonant frequencies $\omega_{y_1, z_1, \theta_1 res}$. The result is a three-dimensional test ops at vibrosafety mode, the most dangerous in terms of the parameters of vibration rejection and vibro strength that excludes understated performance assessment vibrosafety facility in operation.

Conclusions. The importance of the work carried out in the pre-research is established features of display synergistic effect in relation to the spatial structure of objects with a multi vibrating influence of the supporting structure of relatively-vibrosafety to problems. The results obtained which is built on the base of paradigm-ergonomic approach "man-machine-environment" that must be considered when determining operational regulatory regime, and the object. Ignoring synergistic effect-they coordinate components in the case of a multi-vibro pressure reduces the durability and reliability of the facility.

It should also be noted that during bench testing on vibrosafety consider options fluctuations hull product sold vibration platform two-co, development and implementation belongs to the urgent problems of modern testing equipment. In practice the results are used to work at solving vibro stability problems, vibro strength vibration and the spatial structure of objects that are exposed to a multi mechanical load.

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ЭРГОНОМИЧЕСКИЕ АСПЕКТЫ СИСТЕМ ИСПЫТАНИЙ ОБЪЕКТОВ ПРОСТРАНСТВЕННОЙ СТРУКТУРЫ НА ВИБРОНАДЕЖНОСТЬ

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Созданы структуры систем исследований и методы испытаний на вибронадежность, которые воспроизводят при стендовых испытаниях наиболее опасный с точки зрения отказов объектов на внешнее механическое вибрационное воздействие в эксплуатации, а также эргономических требований в эксплуатации. Практическое значение полученных результатов проявляется при решении задач виброустойчивости, вибропрочности объектов пространственной структуры, предназначенных для эксплуатации в условиях многокоординатного нагружения.

Ключевые слова: *вибронадежность, эргономика, объект испытаний, метод испытаний, структурная схема установки.*

ЕРГОНОМІЧНІ АСПЕКТИ СИСТЕМ ВИПРОБУВАНЬ ОБ'ЄКТІВ ПРОСТОРОВОЇ СТРУКТУРИ НА ВІБРОНАДІЙНІСТЬ

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Створено структури систем дослідження та методи випробувань на вібронадійність, що відтворюють при стендових іспитах найбільш небезпечний з погляду відмов об'єктів на зовнішній механічний вібраційний вплив, а також ергономічних вимог в експлуатації. Практичне значення отриманих результатів проявляється при вирішенні задач вібростійкості, віброміцності об'єктів просторової структури, призначених для експлуатації в умовах багатокоординатного навантаження.

Ключові слова: *вібронадійність, ергономіка, об'єкт випробувань, метод випробувань, структурна схема установки.*