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ASSESSING THE IMPACT OF TRANSVERSE VIBRATIONS OF PNEUMATIC BUILDINGS ON THE PARAMETERS OF THE SPATIAL VIBRATION FIELD OF THE DRIVE SYSTEM

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ОЦЕНКА ВЛИЯНИЯ ПОПЕРЕЧНЫХ КОЛЕБАНИЙ КОРПУСОВ ПНЕВМОЦИЛИНДРОВ НА ПАРАМЕТРЫ ВИБРАЦИОННОГО ПОЛЯ ПРОСТРАНСТВЕННОЙ СИСТЕМЫ ПРИВОДОВ

The article deals with the description of spatial drive system based on the mechanism-hexapod and designed to manipulate engineering objects. The drive system has an executive body in the form of a platform and six drives with tilt bases and pneumatic cylinders. Spatial drive system is implemented as a prototype. It is evidenced that some pneumatic actuators have free play interface that cause the emergence of high-frequency transverse vibrations of buildings cylinders. The calculated design scheme for the description of transverse vibrations of shells and cylinders and a mathematical model are developed. The model takes into account thenon-linear properties of free play joints of individual drive and hinges. The connection between thetransverse vibrations of buildings and pneumatic vibration executive body is outlined.
The mathematical model is implemented in the form of a computational procedure. The calculations of transient spatial system drives are preformed. The vibration processes in the drives and the corresponding fluctuations in the executive body are defined for the characteristic pulse torque loading platform. The form and motion parameters are analyzed.
The calculation results are compared with the results of special experimental studies. The adequacy of the model is confirmed and parameters of oscillatory processes in the system are refined.
On the basis of the research the mathematical model has been developed in order to estimate the parameters of the stochastic field vibratory drive system. Qualitative and quantitative evaluation of the effect of random transverse vibrations of cylinders on the parameters of the field of spatial vibration of the drive system is presented.
Keywords: drive system, air cylinder, variations housing micro movements rod, a mathematical model, frequency, experiment, test, simulation, random vibration.

Introduction

Spatial drive systems, including air, have little static and dynamic rigidity. It is stipulated by the circuit design tools and the design of the actual drive. Low levels of rigidity cause the emergence of dynamic oscillation processes in spatial system drives. Processes are of the high frequency and cause intense vibration field of the executive body and other major components of the drive system. Therefore, assessment of the impact on the overall vibration pneumatic vibration field of the drive system is an urgent scientific problem.

The problem definition deals with the improvement of the spatial system drives quality indexes. The solution is to improve the static and dynamic characteristics of the drive system. This is accomplished by studying the characteristics of data, identifying specific modes of drive system operation. Particularly important is the identification of the dynamic characteristics of the spatial features of the drive system. Dynamic characteristics determine vibration field of spatial elements and units of the drive system. The problem of determining the parameters of vibration field is common to many spatial mechanisms.

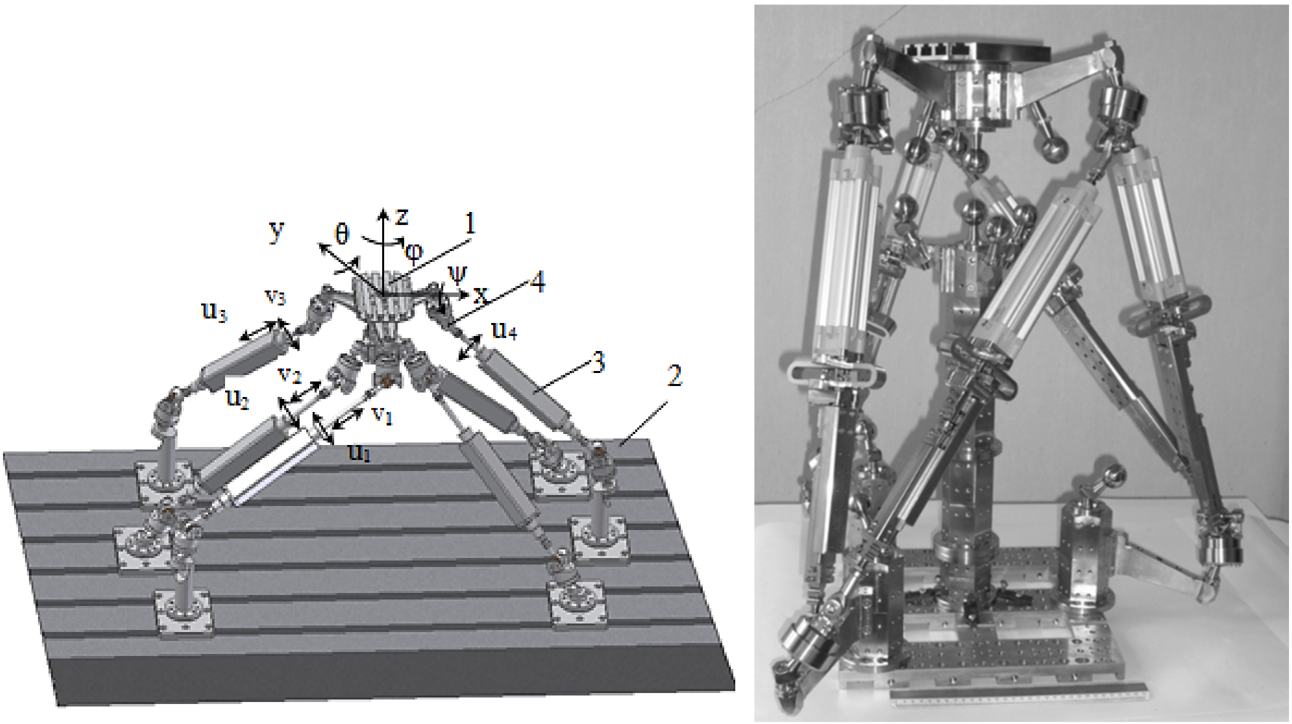
The problem is related to important scientific and practical tasks of engineering. Defining the parameters of the field of drive system spatial vibration is the basis for solving a number of scientific and practical tasks of modern technological equipment development. In particular it concerns the development of highly dynamic drive systems for spatial manipulation of objects in engineering.

Analysis of the latest research and publications confirmed the relevance of research areas and existence the large number of publications on the scientific direction. The spatial design concepts drive systems are available in literature. [1] Questions of use and functionality of the process equipment based on spatial drive system are discussed. [2] Considerable attention is paid to the geometric accuracy and rigidity of spatial drive systems [3] .The analysis of motion law of space drive systems is carried out [4]. The presence of significant dynamic loads on the system and their parameters determination are confirmed [5]. It is evidenced that the electronic components of the drive system to a large extent determine their dynamic properties. [6] A number of literature sources is devoted to the study of the dynamic characteristics of the space of the drive system [7, 8]. In some publications the dynamics of actuators is discusses [9, 10]. Research field of spatial features of vibration of the drive system in the literature is not found.

The overall assessment of the impact of fluctuations of individual components of the drive system for the spatial parameters of vibration field of the executive body is an unsolved problem. In particular, transverse vibrations of pneumatic cylinders, which form the spatial system drives, demonstrate significant effect on the vibration of the executive body. Objective of the research presented in this paper is to evaluate the effect of transverse vibrations of buildings on the parameters of pneumatic vibration field in the spatial system drives.

The goals of research are the analysis of the spatial drive system, to construct a mathematical model, to determine the parameters of vibration field and to assess the effect of random transverse vibrations of pneumatic buildings on the parameters of the spatial vibration of the drive system.

Spatial analysis of the developed drive system. Developed spatial system is designed to manipulate objects in space. The drive system has an executive body established on the basis of one (Fig. 1 a).



a *b*

Fig. 1. Spatial drive system designed to manipulate objects:
***a* - structural scheme of the system, *b* - the look of the prototype**

Executive body is set on six pneumatic cylinders 3 which have articulated support 4.

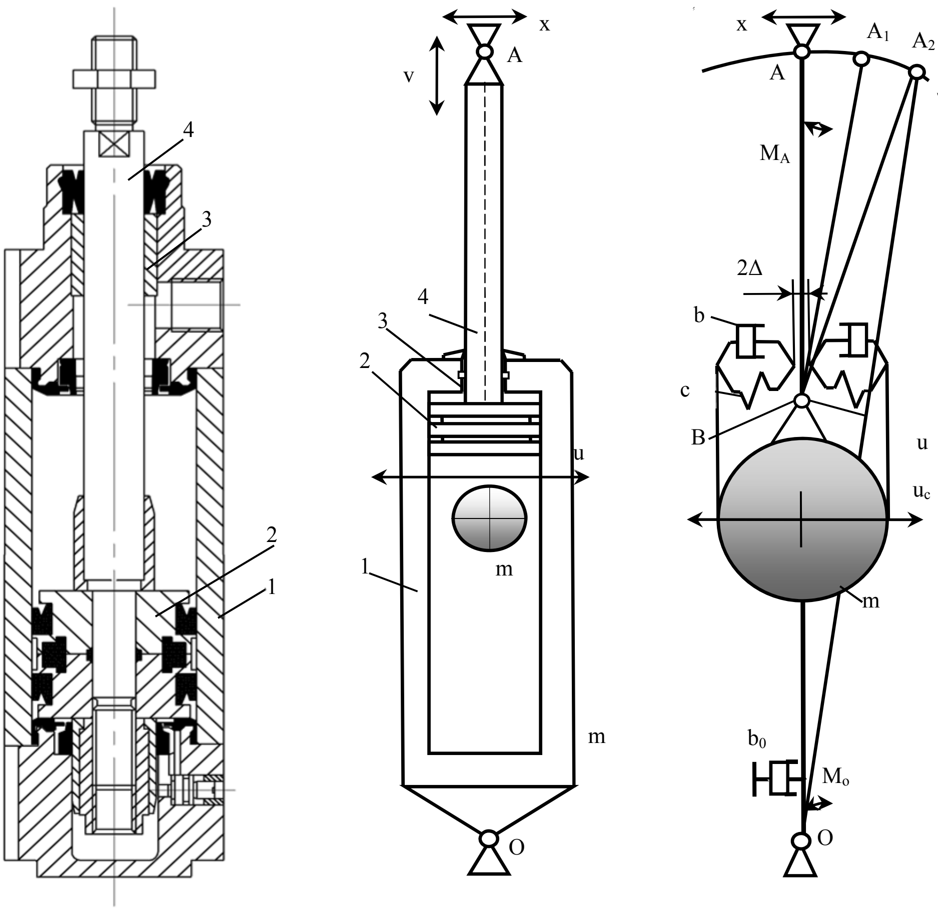
Between housing and stocks cylinders there are gaps. Therefore, under dynamic loads to the actuator a transversely relative angular displacement rod and cylinder body occur (Figure 1 indicated by arrows u_1). Moving the rod relatively to the body increases with the output shaft. At maximum output shaft transverse displacements u_1, u_2 are the highest. At low output shaft movement is minimal (u_3).

The drive system is realized as a test sample (Fig. 1 b). To fix the housing cylinders special devices are used. They allow the installation of air cylinder body movement relatively to the hinge. You can set the desired start position of the executive body of the spatial system drives.

Cross-angled rod displacement occurs relatively to the body within gaps between the piston rod 2 and 4, and surfaces 3 of the cylinder body 1 (Fig. 2a). In this case, there are seals and deformation of the contact surfaces.

The concept model of a dynamical transverse displacements of the air cylinder body based on the analysis of the design is developed (Fig. 2b).

Between the housing 1 and the piston cylinder 2 there is a backlash. Similarly, there is a gap between the guide rod bushing 3 and 4. Within these gaps cylinder body moves towards u. Displacement occurs under dynamic disturbances mainly upper hinge A. The basic dynamic perturbations are transverse displacement x of supported rod. The longitudinal movement of the hinge v has little effect on the transverse displacement hull. So the longitudinal movement of the hinge can be ignored.



a *b* *c*

Fig. 2. Constructive implementation of (*a*) construction diagram (*b*) and dynamic (*c*) the transverse angular vibrations of air cylinder housing

Moving of the cylinder body towards u is accompanied by the emergence of resistance forces. We have the positional force (hardness) and dissipative force (friction). For small displacements of the rod, that occur within the gap Δ, the stiffness strength is negligible (Fig. 2 c). In sampling gap stiffness forces are soaring. Therefore, we have two heterogeneous nature of displacement cylinder body. They are moving low resistance within the gap Δ, and after sampling gaps moving with increased resistance to movement. The cylinder has a spherical bearing. Therefore, in case of transverse displacements the friction torque M_o and M_A occur in the pivot bearing. Considering the current dynamic loads the corresponding dynamic model of lateral motion is available as the reduced single-mass system with elastically dissipative bonds (see Fig. 2 c).

A mathematical model for parameters determination the vibration field of spatial drive system

For small displacements of the cylinder body (y<Δ)dynamic equation is applied in a simplified linear form

$$m\frac{d^2u}{dt^2} = c(x-u) + b\left(\frac{dx}{dt} - \frac{du}{dt}\right) - b_0\frac{du}{dt} \tag{1}$$

where x - moving the upper hinge, **c,** m - the equivalent stiffness and mass of the system with the movements of the body within the gap Δ; b - the equivalent resistance coefficient of the upper hinge and interface with the housing stock; b0 - equivalent resistance coefficient to the drag coefficient of the lower hinge. We transform the equation (1) according to Laplace, introducing new constants. In this case, we find the transfer function of the transverse vibrations of the cylinder body in the form of:

$$W(s) = \frac{U(s)}{X(s)} = \frac{1+\tau s}{T^2s^2 + 2\xi Ts + 1}, \tag{2}$$

where $T = \sqrt{\frac{m}{c}}$, $\xi = \frac{(b+b_0)}{2\sqrt{mc}}$, $\tau = \frac{b}{c}$

Lateral motions of the cylinder body change the distance between the pivot bearing. These displacements are much smaller than the transverse displacement, but they have a significant effect on the position of the executive body of the drive system. Consider the geometric relationships between the transverse movement of the cylinder barrel and the change in the distance between the centers of the joints. For small amplitudes of the oscillations a cylinder can be considered as swivel two rods AB and OB (see Fig.2c).

Of geometric ratio:

$$v = AB + OB - \sqrt{AB^2 - u^2} - \sqrt{OB^2 - u^2}$$

This bias dependence of the joints v deflection from the cylinder body transverse movement is highly nonlinear. We expand the ratio into a Taylor series in the neighborhood of u = u*, which is the average displacement of a cylinder body with respect to the zero position. With the only linear components of the expansion we obtain the following:

$$v = v_0 + K_u u\,,$$

where $v_0 = AB + OB - \sqrt{AB^2 - u^{*2}} - \sqrt{OB^2 - u^{*2}}$

$$K_u = \frac{\partial v}{\partial u}\Big|_{u=u^*} = u^*\left(\frac{1}{AB} + \frac{1}{OB}\right).$$

With sufficient accuracy we can take $v_0 \approx 0$, respectively:

$$v = K_u u \tag{3}$$

High-frequency oscillatory processes in the individual drives are caused by the dynamic movements of the executive body. Position of executive is characterized by column vector spatial coordinates $[x_i]$. Components of the vector coordinates are progressive platform movement x, y, z, and transverse angular displacement ψ θ φ (Fig. 1 a). Between the vector changes ℓ-coordinate $[v_j]$ and vector platform position, components of which are vibrating rod displacement cylinders, there is the following vector-matrix ratio.

$$\lfloor x_i \rfloor_6 = \lfloor n_{ij} \rfloor_{6\times 6} \cdot \lfloor v_j \rfloor_6\,, \tag{4}$$

where $\lfloor n_{ij} \rfloor$ is a square matrix of dimension 6 which establishes a connection between the vectors of the coordinates platform $\lfloor x_i \rfloor_6$ and moving cylinders.

Disturbing power factors affect the actuator drive systems. They cause vibration displacement executive random. These movements are added to the displacements due to transverse vibrations cylinders. Accordingly, the resulting movements are a sum of vectors.

Transverse vibrations housing cylinders are caused by disturbances that operate in the plane perpendicular to the axis cylinder. Therefore, not all executive movements influence the occurrence of transverse vibrations of buildings cylinders. Only cross platform movement x, y, and torsion vibration platform φ are significant. In the first approximation, we can take a disturbing factor in the form of a linear combination of significant platform movement x, y, φ.

With the account of this fact, the structural mathematical model has been formed to determine the effects of transverse vibrations of cylinders in the vibration field of spatial parameters of the drive system (Fig. 3).

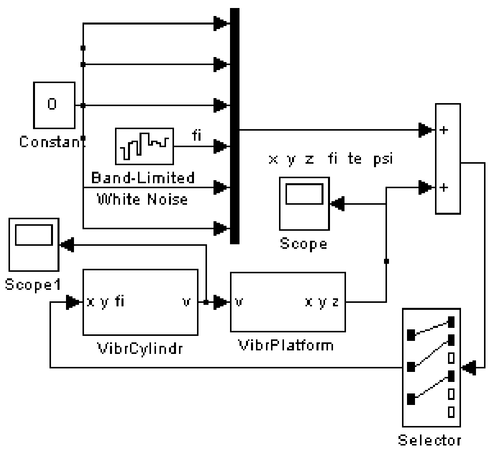


Fig. 3. Structural mathematical model to determine the effects of transverse vibrations of cylinders on the position of the executive body

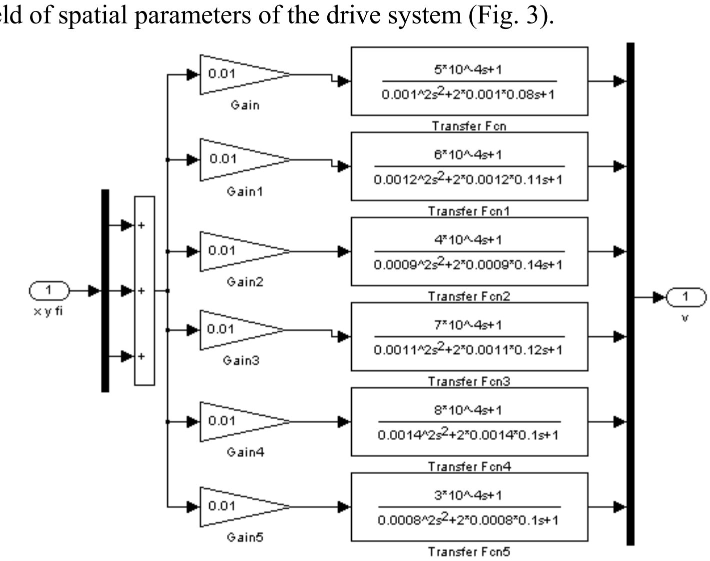
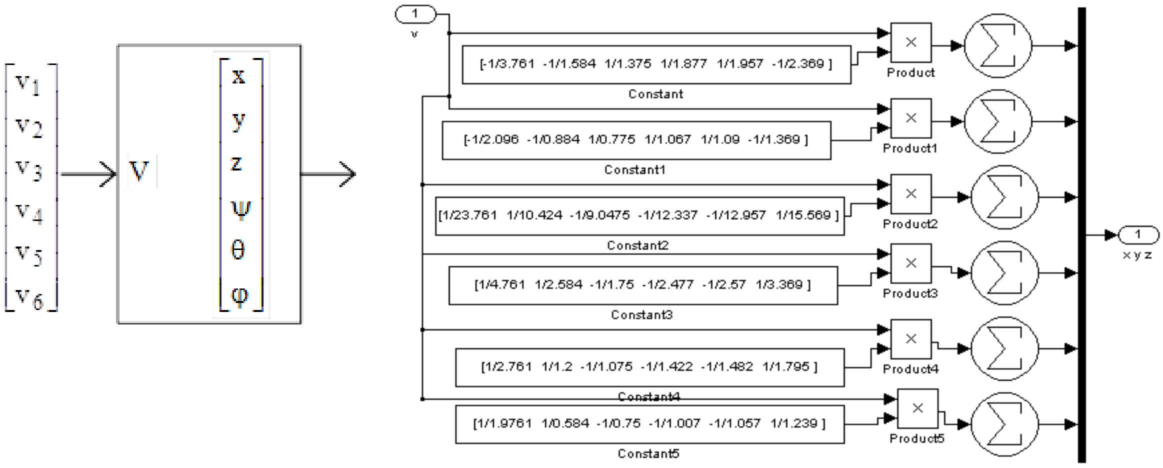


Fig. 4. The structure of the unit, which determines the dynamic micro movements hinges cylinders due to transverse vibrations of their bodies

The position of the executive body is characterized by a vector of spatial coordinates platform [xyz fi te psi]. In the simulation, the initial values of the components of the zero vector are specified. Change of the spatial coordinates of the platform due to the transverse vibrations of buildings cylinders are calculated by the unit VibrCylindr. According to this value the length changes of each cylinders via the block VibrPlatform we determine the actual position of the platform. Fluctuations in housing cylinders occur under the influence of disturbing factors in the form of lateral motion tilt base cylinders. These transverse displacement of supports are hinged at the displacement in the plane of the platform supports. These displacements are determined by the platform coordinates x, y, fi. Therefore, the unit Selector is installed in the mathematical model, and this unit forms the perturbing vector feedback on the dynamic system of individual cylinders. Some model blocks implement the dynamic relationships of the model parameters. Block VibrCylindr (Fig. 4) forms six cylinders vector micro moving, which are due to transverse vibrations of their buildings.

Dynamic transverse vibrations housing unit are calculated by TransferFcn. Gain Blocks provide proportional transformation of transverse to longitudinal displacement hulls micro movements rod cylinders according to ratio (3). The output of the block is a vector (v), the components of which define each of the motorized cylinders.

Motorized cylinders leads to corresponding changes in accordance with the provisions of the platform dependence (4). Vector-matrix dependence is implemented in the structure of VibrPlatform (Fig. 5).



a *b*

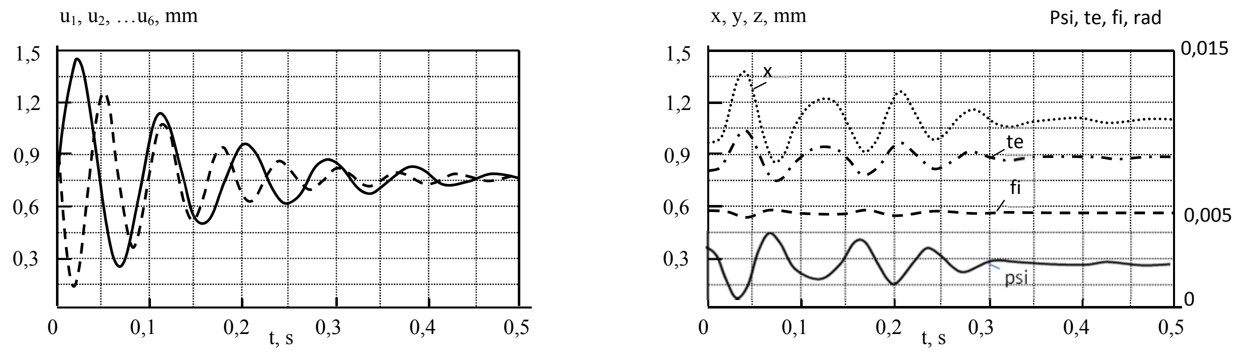
Fig. 5.The structure of the block, which implements the calculation parameters platform position changes in the result of dynamic micro moving rod cylinders

The unit has six identical circuits which ensure the multiplication of the vector of the motorized cylinders on vector row of N, which is included in the formula (4). Each row of the matrix is formed in the corresponding module Constant. Respectively, at the output of the vector coordinates platform x, y, z, ψ, θ, φ is calculated.

Assessing the impact of transverse vibrations of cylinderson the vibration field of the drive system

A mathematical model has sophisticated vector feedbacks. They create a cross-parametric nonlinear parametric bonds in vibration systems of individual cylinders. Therefore, a separate issue is devoted to the development of a mathematical model of checking the stability of the computational procedure. To test the stability the calculations of the model problem have been carried out under pulsed change of angular velocity about the axis of the platform z.

The calculations of transient processes in a dynamic system confirm the stability and convergence of computing procedure (Fig. 6).



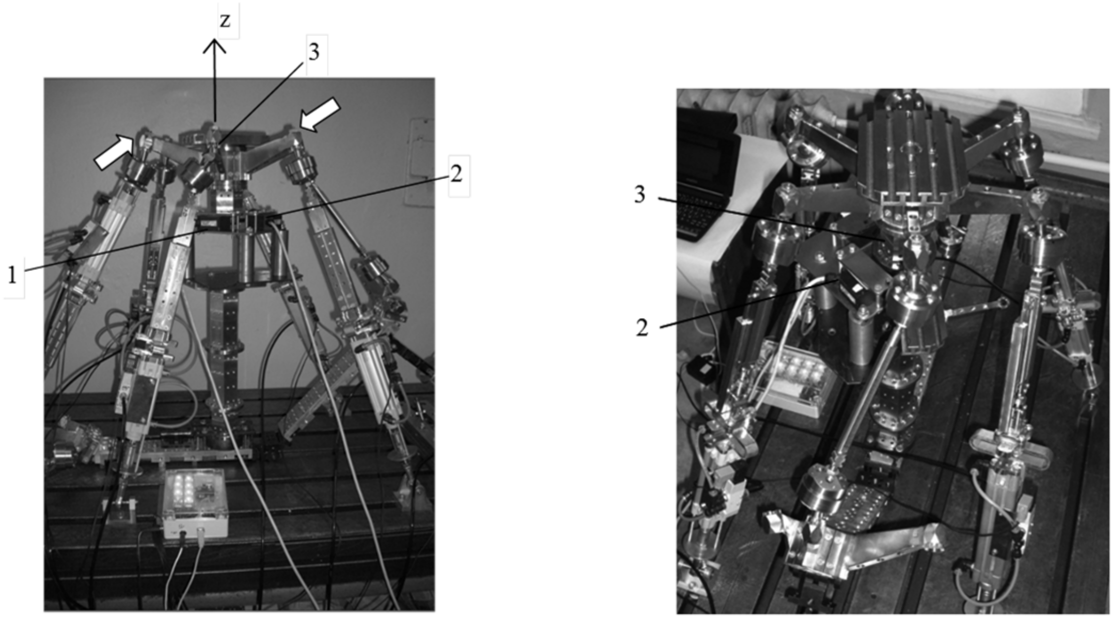
a *b*

Fig. 6. Transitional housing pneumatic vibration processes (*a*) and the corresponding platform movement with pulsed change of angular velocity platform with its rotation with respect to the z-axis

Oscillation periods buildings cylinders are 0.06 ... 0.11 s. This corresponds to the natural frequencies of vibration 9 ... 17 Hz. Recovery time of transverse vibrations housing cylinders is in the range of 0.25 ... 0.4 s. Fluctuations occur independently of each air cylinder. The mutual influence of the cylinders vibrations is little observed.

Fluctuations platforms are more complex processes with variable damped oscillation period (see Fig. 6b). The cross-platform movement x and y are most intense. Vertical displacements z are negligible. Periods of vibration platform in the x, y, z are close to each other and are 0.06 ... 0.09 s. Changes in the oscillation period are systematically observed in the initial part of the process and correspond to a frequency within the 11 ... 17 Hz. At the end of the oscillation frequency of the oscillatory process is stabilized at 16 ... 18 Hz. This corresponds to the upper level of the natural frequencies of air cylinders (17 Hz). Estimated damping platform is 0.35 ... 0.45. This is somewhat longer than the damping housing cylinders.

To verify the adequacy of the developed mathematical model, experimental measurements of executive movements relative to the base under dynamic loading system were performed. Contactless high-sensitivity laser triangulation distance meter Series RF603-10/2 were used to measure the displacement of the executive body. The meter has a working range of 2 mm with an accuracy of 0.2 microns. Two meters 1, 2, mounted in two mutually perpendicular directions x and y at a distance of 11 mm from the control of the executive body of the cylindrical surface 3 (Fig. 7) were used.

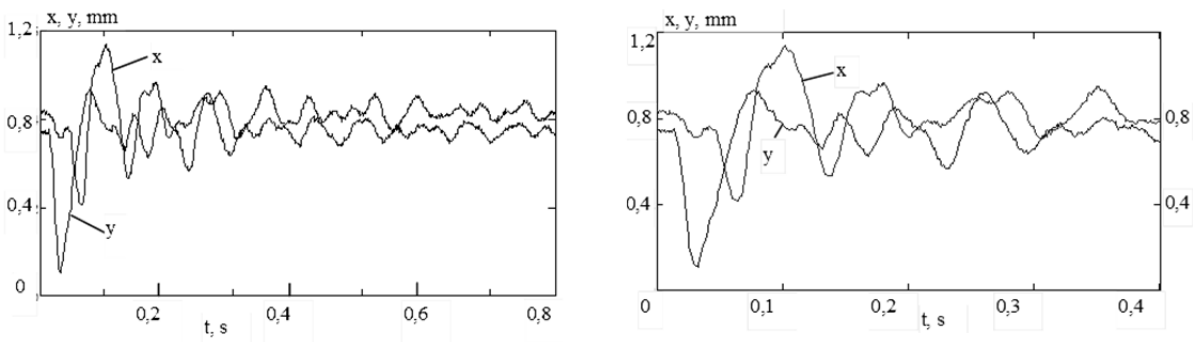


a *b*

Fig. 7. Laser-meter dynamic movements of the executive body of the spatial system drives: *a* - front view, *b* – side view

During the experimental measurements the dynamic displacements x were defined at the executive body (platform) relatively to the base under shock loads of the executive body. Shock loads were created at the same time on the console of the bracket of the executive body in the directions shown by arrows. At the same time the impulse moment load toward the axis z was performed, and thus the momentum change in the angular velocity of rotation of the body relative to the axis z.

The measured transverse displacements of the executive body are damped oscillatory processes (Fig. 8).



a *b*

Fig. 8. Experimentally measured platform movement at the moment of shock directions: *a* - the damping of oscillations, and *b* - the structure of the oscillatory process in the initial period

Measured oscillatory processes have basic oscillation periods 0.045 ... 0.09 s, which corresponds to 11 ... 22 Hz. In the process there are basic harmonic components with frequencies of 17 and 16 ... components with frequencies of

46 ... 48 Hz. Base frequency 16 ... 17 Hz corresponds to the calculated (see Fig. 6). The emergence of the midrange of the order of 20 ... 22 Hz is due to inaccurate determination of the elastic properties of the interface between dissipative drive components.

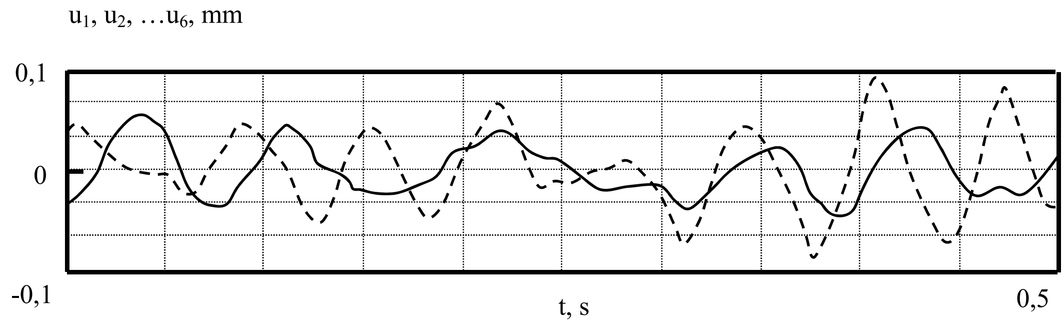
Decay time of the experimentally measured oscillation processes is 0.6 ... 0.8 s, which is slightly higher than the calculated values identified in Fig. 6.

Considering the complexity of the dynamical system and the processes taking place in it, the correspondence between the calculated and experimental data is satisfactory, and developed mathematical model is adequate to the actual spatial system drives.

Modeling the processes of spatial vibration of the drive system under random loadings

The platform of the drive system has a constant vibration field micro moving. It causes a constant vibration of the cylinders, which in its turn stimulates the platform vibration. To model the process the kinematic excitation was used in the form of broadband random process the angle changes of swing relatively axis z. The angle changes were specified by unit Band - Limited White Noise (see Figure 3).

The resulting lateral displacement hulls of pneumatic cylinders and related platform movement are complex stochastic processes (Fig. 9).



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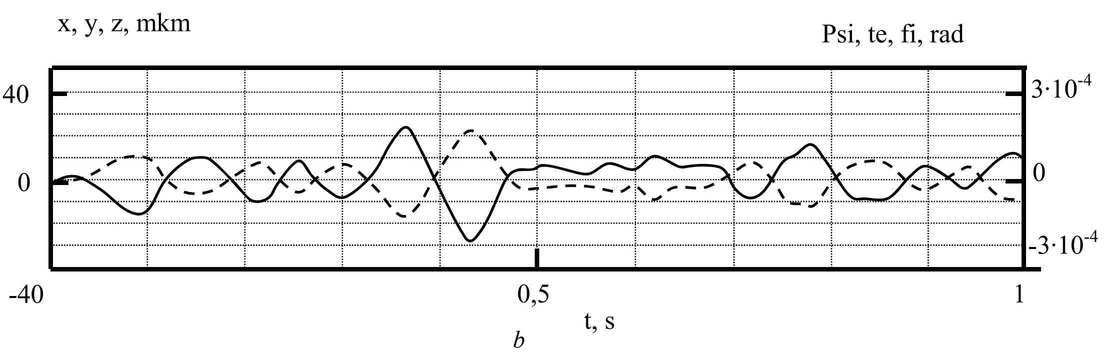

b

Fig. 9. Random transverse displacement hulls cylinders (*a*) and the corresponding spatial displacement of the executive body (platform) of clients (*b*)

Transverse displacement hulls cylinders is a random process in which the main harmonic at 12 ... 18 Hz is traced. The amplitude of the transverse vibrations of pneumatic buildings varies widely, reaching 0.1 mm. Transverse vibrations are made by all.

Phase oscillations of individual cylinders are close. Thus fluctuations cylinders have a frequency close to the natural frequency of the pneumatic housing (see Fig. 6). High frequency random fluctuations housing cylinders cause intense vibration field of spatial reasons. This gives rise to high-frequency oscillations of the executive body of the drive system (see Fig. 9 b). They are characterized by amplitude of movement within 0.04 mm. In the random fluctuations of the executive body the basic harmonic component at 16 ... 18 Hz is observed. Both progressive and cross-angular variations of the executive body have basic harmonic components of close frequencies. Moving executive in different directions is close to the in-phase.

Random vibration processes of transverse displacement and displacement hulls pneumatic executive body have a wide range of high frequency component. Amplitude of high frequency is much less than the amplitudes of basic harmonics.

Findings

1. It was found that the spatial drive system has a specific dynamic mode, which means the appearance of transverse vibrations of shells of pneumatic cylinders, due to the presence of free play interfaces between buildings rods and cylinders.
2. Transverse vibrations housing cylinders are caused by the disturbing factors in the spatial drive system and decay in the absence of them. The amplitudes of the oscillations depend on the intensity of the dynamic disturbances and can be up to 1 mm at the vibration frequency 16 ... 18 Hz.
3. Transverse vibrations of cylinders under the influence of random perturbations lead to the appearance of a random vibration field of the drive system. In this case, the executive body of the drive system performs complex vibratory motion, in which the harmonic components at 12 ... 18 Hz with amplitudes of the 0.04 mm are observed.
4. As future ongoing research we should examine the special vibration modes in the spatial system of actuators, which are caused by the presence of closed circular partial dynamical systems.

Аннотация. *Рассмотрена пространственная система приводов на основе механизма-гексапода предназначенная для манипулирования объектами машиностроения. Система приводов имеет исполнительный орган в виде платформы и шесть приводов с шарнирными опорами и пневматическими цилиндрами. Пространственная система приводов реализована в качестве опытных образцов. Показано, что отдельные пневматические приводы имеют люфтовые сопряжения, которые приводят к возникновению высокочастотных поперечных колебаний корпусов пневмоцилиндров. Построена расчетная схема для описания поперечных колебаний корпусов пневмоцилиндров и разработана математическая модель. Модель учитывает нелинейные свойства люфтовых соединений деталей отдельного привода и шарниров. Установлена связь поперечных колебаний корпусов пневмоцилиндров и вибраций исполнительного органа.*

Математическая модель реализована в виде вычислительной процедуры. Проведены расчеты переходных процессов в пространственной системе приводов. Для характерного импульсного моментного нагружения платформы определены расчетные колебательные процессы в приводах и соответствующие колебания исполнительного органа. Дан анализ вида и параметров колебаний.

Результаты расчетов сопоставлены с результатами специально проведенных экспериментальных исследований. Подтверждена адекватность разработанной модели и уточнены параметры колебательных процессов в системе.

На основе выполненных исследований разработана математическая модель для оценки параметров стохастического вибрационного поля системы приводов. Дана качественная и количественная оценка влияния случайных поперечных колебаний пневмоцилиндров на параметры вибрационного поля пространственной системы приводов.

Ключевые слова: Система приводов, пневмоцилиндр, колебания корпуса, микроперемещение штока, математическая модель, частоты, эксперимент, проверка, моделирование, случайные вибрации

Анотація. *Розглянута просторова система приводів на основі механізма-гексапода призначена для маніпулювання об'єктами машинобудування. Система приводів має виконавчий орган у вигляді платформи і шість приводів з шарнірними опорами і пневматичними циліндрами. Просторова система приводів реалізована в якості дослідних зразків. Встановлено, що окремі пневматичні приводи мають люфтові з'єднання, які приводять до виникнення високочастотних поперечних коливань корпусів пневмоциліндрів. Побудована розрахункова схема для опису поперечних коливань корпусів пневмоциліндрів і розроблена математична модель. Модель враховує нелінійні властивості люфтових з'єднань деталей окремого приводу та шарнірів. Визначено вплив поперечних коливань корпусів пневмоциліндрів на вібрації виконавчого органу.*

Математична модель реалізована у вигляді обчислювальної процедури. Проведені розрахунки перехідних процесів в просторовій системі приводів. Для характерного імпульсного моментного навантаження платформи визначені розрахункові коливальні процеси в приводах і відповідні коливання виконавчого органу системи. Виконаний аналіз виду і параметрів коливань.

Результати розрахунків зіставлені з результатами спеціально виконаних експериментальних досліджень. Підтверджена адекватність розробленої моделі та уточнені параметри коливальних процесів в системі. На основі виконаних досліджень розроблена математична модель для оцінки параметрів стохастичного вібраційного поля системи приводів. Виконана якісна і кількісна оцінка впливу випадкових поперечних коливань пневмоциліндрів на параметри вібраційного поля просторової системи приводів.

Ключові слова: Система приводів, пневмоциліндр, коливання корпусу, мікропереміщення штока, математична модель, частоти, експеримент, перевірка, моделювання, випадкові вібрації

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