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ASSESSMENT OF DYNAMIC CHARACTERISTIC OF UNSTABLE OBJECT AT CONSTANT REGIME

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It is propound a new method of assessment casual parameters of complex, unstable, moveable object for problems with structural identification of own object and synthesis of optimal, by structure, object stabilization system.

Keywords: helicopter, methods of evaluation of dynamic characteristics, system, system “helicopter – pilot – cargo – environment”, unstable object.

Розглянуто можливість організації моніторингу аеродинамічного стану літака в польоті. Визначено, чим відрізняються сили, які діють на неушкоджене крило та при його пошкодженні сторонніми об’єктами. Обґрунтувано склад груп датчиків для діагностування аеродинамічного стану літака в польоті.

Ключові слова: вертоліт, методи оцінки динамічних характеристик, нестабільний об’єкт, система, система «вертоліт – пілот – вантаж – навколишнє середовище».

Introduction

As the analysis of world aviation shows systematic increase in competition in circle of major aircraft equipment, manufacturers makes constantly seek new methods and technology processes to achieve optimal quality of aircraft. Solution of such problems for processes of navigation and flight control requires significant financial and human resources, now, becomes evident the need to modernize some existing aircraft designs, such as helicopters with external cargo suspension.

Complexity of navigation and control of the helicopter cargo suspension linked as dynamic features of the object management and with different stochastic properties of revolting factors in flight. The mode of being helicopter in the air with cargo suspension is one of complex, insufficiently studied and responsible. Creation of hard stabilization helicopter, especially with cargo suspension, is with special interest. As it is known, helicopters – a fundamentally unstable multidimensional dynamic objects [1; 2], and dynamics models of such object stabilization and influences used in practice, not give a chance of achieving a high degree of stabilization in specific, responsible far-flight modes. In stabilization problems with the helicopter cargo suspension situation even more complicating. Expediency of studies in this area is conditioned by the wide use and polyhedral of helicopters in almost all spheres of human activity (mining, agriculture, construction, cargo transportation, passengers transportation, the study of minerals, etc.). The problem of automatic rigid stabilization of the helicopter with cargo suspension in mode of being in the air reasonable to split into separate stages:

1. Experimental evaluation of dynamic characteristics of stochastic-flight helicopter navigation parameters that characterize the “input-output” of the helicopter cargo suspension as object of stabilization.
2. Structural identification of helicopter dynamics model as the object of stabilization and acting on him uncontrollable stochastic perturbation in mode of being in the air.
3. Synthesis of optimal structure and parameters of the stabilization of the helicopter cargo suspension in mode of being in the air.

Known from literature [1; 2] examples of solving stabilization of the helicopter usually does not take into the real nature of stochastic perturbations,

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acting on it in different modes of flight, and the fact unstable object. All this leads the need to find means of solving the problem discussed in the preface. One of these tools can be a synthesis of optimal structures of stabilization of an object based on known tests with models of the object dynamics and stochastic perturbations acting on it in real flight.

Analyzing operation methods of flying device [1; 2], can be said that they do not include the whole range of influences that operate on aircraft flying in standard mode. Consider the situation of operation a helicopter with cargo suspension in mode of being in air, when there are additional forces and moments on the motion of the external cargo suspension, causing additional instability of the helicopter.

The reasons for this instability of helicopter in the standard mode flight, as with external cargo suspension, and without it, today, are not known, so to set in possibility of high accurate stabilization of the helicopter in the standard mode of cargo flight suspension is problematic.

One of the reason for the instability of the helicopter cargo suspension is a glidering features of helicopter [1; 2] (no symmetry, rudder screw). Its role in instability is playing external perturbation, as from cargo suspension, so and from environmental perturbations that have stochastic character.

Goal of the article – to review the first phase of solution rigid stabilization problem, namely evaluation received during special tests of dynamic stochastic characteristics flying-navigation parameters of helicopter that characterizes the “input-output” of the helicopter with cargo suspension as the stabilization object.

Main part

Let’s introduce the concept of Helicopter – Pilot – Cargo – ENVIRONMENT (HPCE) diagram of such object shown in figure.

Under investigation case of motion of helicopter might write transposed by Laplace or Fourier system of ordinary differential equations look

$$\mathrm{P}x = \mathrm{M}u + \xi + \psi, \qquad (1)$$

where P and M – matrix dimensions respectively, and whose elements are polynomials of the arguments (Laplace) or (Fourier);

x – n-dimensional vector of reaction helicopter on controlled ξ, uncontrolled ψ disturbance and leading influence of a pilot u;

u – m-dimensional vector of controlling stochastic influences (influence of a pilot autopilot);

ξ – n-dimensional vector controlled stochastic perturbation, caused by movement of cargo;

ψ – n-dimensional vector of uncontrollable external stochastic perturbation, acting on a helicopter with a cargo in mode of being in the air (e.g., turbulent wind).

The system of equations (1) fully describes the system HPCE as stabilization object. In the studied case unknown matrices P and M, and dynamic models of vectors u, x, ξ and ψ. Signal vectors can be fixed in the process of model experiment.

Analyzing the helicopter control one can fix the structure vectors of system HPCE that is necessary to evaluate in process and determine their structure for necessary tests:

$$u' = [\delta_\vartheta \quad \delta_\gamma \quad \delta_\varphi \quad \delta_g]; \qquad (2)$$

$$\xi' = [\vartheta_g \quad \gamma_g]; \qquad (3)$$

$$x' = [x \quad y \quad z \quad \vartheta \quad \gamma \quad \varphi], \qquad (4)$$

where δ_ϑ – longitudinal deviation of control knob;

δ_γ – lumbar deviation of control knob;

δ_φ – deviation angle of pedals;

δ_g – deviation of gas;

ϑ_g – pitch angle of cargo oscillation;

γ_g – angle of roll cargo oscillation;

y – linear deviation of the helicopter in the transverse plane;

z – linear deviation of the helicopter in height;

ϑ – helicopter pitch angle;

γ – angle of roll of the helicopter;

φ – helicopter’s angle of yaw.

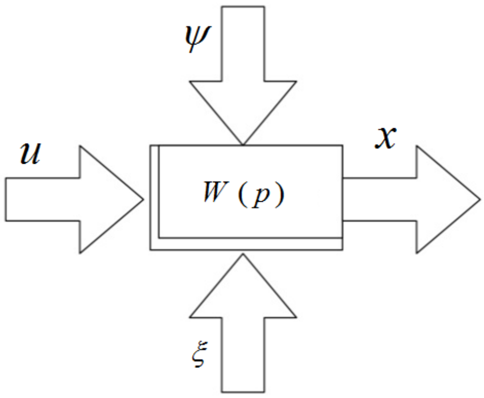

Diagram of HPCE

Stages of successful solution of the dynamic characteristics of vector's stochastic signals HPCE define this way:

1) separation of the arrays variable deterministic signals and random stationary ergodic components of signals, received during a special mode testing;

2) accounting known regulations of theory of random ergodic processes determining the correlation and mutual correlation functions centered random components of the investigated signals;

3) using Fourier transform correlation and mutual correlation functions, spectral determination of the mutual spectral density of the investigated signals;

4) graphical representation of the computer calculated the mutual spectral density of the investigated spectral signals using special software;

5) based on generalized method of image approximation logarithmic characteristics of the spectral dependence and mutual spectral densities shortened mathematical expressions;

6) determination of structures of the investigated vector signals u, x and ξ;

7) using the theorem of Wiener-Hinchyna definition of matrix structure of spectral densities and mutual spectral vectors study of random signals;

8) fill the mathematical elements of the matrix spectral and mutual spectral density, which elements are spectral and the mutual spectral density of the investigated signals.

For the special mode tests is developed a special technique which has the following form:

1) choice of preparation and measurement platform for the helicopter (kinoteodolity are established, marks center of area, marks the helicopter center of mass);

2) installation of special equipment on helicopter to measure deviations cargo suspension;

3) selection of cargo suspension spherical shape (typical load, with parameters of mass about 10–15 % of the mass of the helicopter).

This method of conducting a special mode testing was tested and used for the helicopter Mi-8 MTV with cargo suspension in mode of being in the air. Offered method of conducting special tests has a meaning and in the case of studying of any other helicopter with cargo suspension in mode of being in the air and assistance to obtain all the necessary incoming information that characterizes the state of stochastic systems HPCE.

During the mode test has been received vector components of stochastic signals that determine the "input-output" as the subject of helicopter stabilization. All registered signals have stochastic character (and deterministic, and random components), so expression (2) – (4) can be written as:

$$u = u_0 + u^0 = \begin{bmatrix} \delta_\vartheta \\ \delta_\gamma \\ \delta_\varphi \\ \delta_g \end{bmatrix} = \begin{bmatrix} \delta_{0\vartheta} \\ \delta_{0\gamma} \\ \delta_{0\varphi} \\ \delta_{0g} \end{bmatrix} + \begin{bmatrix} \delta^0{}_\vartheta \\ \delta^0{}_\gamma \\ \delta^0{}_\varphi \\ \delta^0{}_g \end{bmatrix};$$

$$\xi = \xi^0 + \xi_0 = \begin{bmatrix} \vartheta_g \\ \gamma_g \end{bmatrix} = \begin{bmatrix} \vartheta^0{}_g \\ \gamma^0{}_g \end{bmatrix} + \begin{bmatrix} \vartheta_{0g} \\ \gamma_{0g} \end{bmatrix};$$

$$x = x^0 + x_0 = \begin{bmatrix} x \\ y \\ z \\ \vartheta \\ \gamma \\ \varphi \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ z_0 \\ \vartheta_0 \\ \gamma_0 \\ \varphi_0 \end{bmatrix} + \begin{bmatrix} x^0 \\ y^0 \\ z^0 \\ \vartheta^0 \\ \gamma^0 \\ \varphi^0 \end{bmatrix}.$$

Using known methods of separating signal for deterministic and random components [3; 4] one have to do the initial processing of all registered signals.

Using only the random component defining not random characteristics of random signals such as spectral and mutually-spectral density investigated signals.

Using expressions (2) – (4) and theorem Wiener-Hinchyna, composed matrix of spectral and mutual spectral densities investigated vectors:

$$S = \begin{bmatrix}
S_{\delta_\vartheta\delta_\vartheta} & S_{\delta_\gamma\delta_\vartheta} & S_{\delta_\varphi\delta_\vartheta} & S_{\delta_g\delta_\vartheta} & S_{\vartheta_g\delta_\vartheta} & S_{\gamma_g\delta_\vartheta} & S_{x\delta_\vartheta} & S_{y\delta_\vartheta} & S_{z\delta_\vartheta} & S_{\vartheta\delta_\vartheta} & S_{\gamma\delta_\vartheta} & S_{\varphi\delta_\vartheta} \\
S_{\delta_\vartheta\delta_\gamma} & S_{\delta_\gamma\delta_\gamma} & S_{\delta_\varphi\delta_\gamma} & S_{\delta_g\delta_\gamma} & S_{\vartheta_g\delta_\gamma} & S_{\gamma_g\delta_\gamma} & S_{x\delta_\gamma} & S_{y\delta_\gamma} & S_{z\delta_\gamma} & S_{\vartheta\delta_\gamma} & S_{\gamma\delta_\gamma} & S_{\varphi\delta_\gamma} \\
S_{\delta_\vartheta\delta_\varphi} & S_{\delta_\gamma\delta_\varphi} & S_{\delta_\varphi\delta_\varphi} & S_{\delta_g\delta_\varphi} & S_{\vartheta_g\delta_\varphi} & S_{\gamma_g\delta_\varphi} & S_{x\delta_\varphi} & S_{y\delta_\varphi} & S_{z\delta_\varphi} & S_{\vartheta\delta_\varphi} & S_{\gamma\delta_\varphi} & S_{\varphi\delta_\varphi} \\
S_{\delta_\vartheta\delta_g} & S_{\delta_\gamma\delta_g} & S_{\delta_\varphi\delta_g} & S_{\delta_g\delta_g} & S_{\vartheta_g\delta_g} & S_{\gamma_g\delta_g} & S_{x\delta_g} & S_{y\delta_g} & S_{z\delta_g} & S_{\vartheta\delta_g} & S_{\gamma\delta_g} & S_{\varphi\delta_g} \\
S_{\delta_\vartheta\vartheta_g} & S_{\delta_\gamma\vartheta_g} & S_{\delta_\varphi\vartheta_g} & S_{\delta_g\vartheta_g} & S_{\vartheta_g\vartheta_g} & S_{\vartheta_g\gamma_g} & S_{x\vartheta_g} & S_{y\vartheta_g} & S_{z\vartheta_g} & S_{\vartheta\vartheta_g} & S_{\gamma\vartheta_g} & S_{\varphi\vartheta_g} \\
S_{\delta_\vartheta\gamma_g} & S_{\delta_\gamma\gamma_g} & S_{\delta_\varphi\gamma_g} & S_{\delta_g\gamma_g} & S_{\gamma_g\vartheta_g} & S_{\gamma_g\gamma_g} & S_{x\gamma_g} & S_{y\gamma_g} & S_{z\gamma_g} & S_{\vartheta\gamma_g} & S_{\gamma\gamma_g} & S_{\varphi\gamma_g} \\
S_{\delta_\vartheta x} & S_{\delta_\gamma x} & S_{\delta_\varphi x} & S_{\delta_g x} & S_{\vartheta_g x} & S_{\gamma_g x} & S_{xx} & S_{yx} & S_{zx} & S_{\vartheta x} & S_{\gamma x} & S_{\varphi x} \\
S_{\delta_\vartheta y} & S_{\delta_\gamma y} & S_{\delta_\varphi y} & S_{\delta_g y} & S_{\vartheta_g y} & S_{\gamma_g y} & S_{xy} & S_{yy} & S_{zy} & S_{\vartheta y} & S_{\gamma y} & S_{\varphi y} \\
S_{\delta_\vartheta z} & S_{\delta_\gamma z} & S_{\delta_\varphi z} & S_{\delta_g z} & S_{\vartheta_g z} & S_{\gamma_g z} & S_{xz} & S_{yz} & S_{zz} & S_{\vartheta z} & S_{\gamma z} & S_{\varphi z} \\
S_{\delta_\vartheta\vartheta} & S_{\delta_\gamma\vartheta} & S_{\delta_\varphi\vartheta} & S_{\delta_g\vartheta} & S_{\vartheta_g\vartheta} & S_{\gamma_g\vartheta} & S_{x\vartheta} & S_{y\vartheta} & S_{z\vartheta} & S_{\vartheta\vartheta} & S_{\gamma\vartheta} & S_{\varphi\vartheta} \\
S_{\delta_\vartheta\gamma} & S_{\delta_\gamma\gamma} & S_{\delta_\varphi\gamma} & S_{\delta_g\gamma} & S_{\vartheta_g\gamma} & S_{\gamma_g\gamma} & S_{x\gamma} & S_{y\gamma} & S_{z\gamma} & S_{\vartheta\gamma} & S_{\gamma\gamma} & S_{\varphi\gamma} \\
S_{\delta_\vartheta\varphi} & S_{\delta_\gamma\varphi} & S_{\delta_\varphi\varphi} & S_{\delta_g\varphi} & S_{\vartheta_g\varphi} & S_{\gamma_g\varphi} & S_{x\varphi} & S_{y\varphi} & S_{z\varphi} & S_{\vartheta\varphi} & S_{\gamma\varphi} & S_{\varphi\varphi}
\end{bmatrix}$$

Thus, the task of evaluation of dynamic characteristics of stochastic influences controlled perturbation of cargo suspensions, and reactions on them of the helicopter was reduced to the creation of analytical models, which determine the matrix and spectral elements of matrix and the mutual spectral densities [3–5].

The basis of spectral estimates and mutual spectral densities of signals laid determine the correlation and mutual correlation functions of random processes, with further Fourier transformation.

Using the method of generalized logarithmic frequency characteristics, one can create analytical models of all elements above the matrix.

Conclusions

Thus, methods of evaluation of dynamic characteristics, suggested in this work enables to consider the problem of stabilizing a moving objects with a qualitatively new way, identifying the real stochastic disturbing influences, acting on the helicopter with the cargo suspension in mode of being in the air. Using obtained spectral and mutual spectral density, the possibility in the future to get the optimal structure for stabilizing the helicopter with the cargo suspension in mode of being in the air, conducting identification procedures and synthesis of stabilization system.

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