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Experimental studies of the influence of elastic-dissipative parameters of engine mounting units on the dynamic characteristics of the "wing model – elastic pylon – engine" system

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Abstract: A feature of modern heavy transport aircraft is their layout with engines on elastic pylons under the wing, with the fuel tanks located in the wing consoles. In this case, the main elastic tones of the aircraft's own oscillations, which determine its dynamic response to external disturbing influences, include the so-called motor tones (vertical and horizontal (lateral) oscillations of engines on elastic pylons). A new type of flutter has appeared – pylon, which for some aircraft determines the critical flutter speed of the aircraft as a whole. The main reason for this phenomenon is the low oscillation damping of the engine on the pylon under the wing. Therefore, research aimed at modernizing the engine mounting points on the pylon in order to reduce the level of elastic oscillations during aircraft operation seems relevant. One of the possible ways to solve this problem is to use the concept of a freed engine, when the engine attachment points to the pylon are modernized, providing more effective damping of engine oscillations. In order to confirm the possibility of practical implementation of these solutions, corresponding experimental studies were carried out on an experimental setup developed by the authors. A design of engine mounting units has been developed that allows specified displacements of the engine relative to the pylon during forced elastic oscillations of the system, which includes a hinged suspension, installation of additional elastic elements and hydraulic dampers.The article presents the results of studies of the influence of elastic-dissipative parameters (partial frequency of natural oscillations and partial decrement of oscillations) of an engine mount on an elastic pylon on the dynamic characteristics of the dynamic system "wing model – elastic pylon – engine". It is shown that by introducing specially designed engine suspension units on pylons, it is possible to significantly change the dynamic characteristics (frequencies and amplitudes of natural oscillations) of the elastic system as a whole. Thus, the amplitudes of oscillations of the engine's center of mass in the region of motor tones decrease by 3...7 times during forced harmonic oscillations.

Key words: elastic-dissipative parameters of the suspension, dynamic characteristics, frequency and amplitude of natural oscillations, amplitude-frequency characteristics.

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Экспериментальные исследования влияния упругодиссипативных параметров узлов крепления двигателя на динамические характеристики системы «модель крыла – упругий пилон – двигатель»

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Аннотация: Особенностью современных тяжелых транспортных самолетов является компоновка с двигателями на упругих пилонах под крылом, при этом основная масса топлива размещена в консолях крыла. В этом случае в число основных упругих тонов собственных колебаний летательного аппарата (ЛА), которые определяют его динамический отклик на внешние возмущающие воздействия, входят так называемые двигательные тона (вертикальные и горизонтальные (боковые) колебания двигателей на упругих пилонах). Появился новый вид флаттера – пилонный, который для некоторых летательных аппаратов определяет критическую скорость флаттера ЛА в целом. Основная причина этого явления заключается в низком демпфировании колебаний двигателя на пилоне под крылом. Поэтому представляются актуальными исследования, направленные на модернизацию узлов крепления двигателей на пилоне с целью снижения уровня упругих колебаний при эксплуатации ЛА. Одним из возможных путей решения данной задачи является использование концепции освобожденного двигателя, когда проводится модернизация узлов крепления двигателя к пилону, обеспечивающая более эффективное демпфирование колебаний двигателей. С целью подтверждения возможности практической реализации данных решений проведены соответствующие экспериментальные исследования на разработанной авторами экспериментальной установке. Разработана конструкция узлов крепления двигателя, допускающая заданные смещения двигателя относительно пилона при вынужденных упругих колебаниях системы, которая включает шарнирный подвес, установку дополнительных упругих элементов и гидравлических демпферов. В статье приводятся результаты исследований влияния упругодиссипативных параметров (парциальной частоты собственных колебаний и парциального декремента колебаний) подвески двигателя на упругом пилоне на динамические характеристики динамической системы «модель крыла – упругий пилон – двигатель». Показано, что путем введения специальным образом сконструированных узлов подвески двигателей на пилонах представляется возможным существенно изменить динамические характеристики (частоты и амплитуды собственных колебаний) упругой системы в целом. Так, амплитуды колебаний центра масс двигателя в области двигательных тонов уменьшаются в 3…7 раз при вынужденных гармонических колебаниях.

Ключевые слова: упругодиссипативные параметры подвески, динамические характеристики, частота и амплитуда собственных колебаний, амплитудно-частотные характеристики.

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Introduction

A layout with engines on elastic pylons under the wing is widely used on modern heavy transport aircraft. Such a layout possesses some important aerodynamic, integrity and service benefits, but there also are some significant drawbacks [1–8]. Thus, the new forms of pylon flatters occur [1, 2, 4], gyroscopic effects of engines in operation affect dynamic system parameters significantly [2–4, 6], particularly, there is a gyroscopic connect between symmetric and asymmetric oscillation tones. The main reason for this phenomenon is the low oscillation damping of the engine on the pylon under the wing, as in fact mode energy dissipates by construction and inner system damping. Therefore, research aimed at modernizing the engine mounting points on the pylon in order to reduce the level of elastic oscillations during aircraft operation seems relevant [9]. The research run by the authors showed that it is possible to increase the system dynamic features by using the concept of a freed (loosely mounted) engine [3]. The engine attachment points to the pylon are modernized, providing more effective damping of engine oscillations. Special elastomeric damping hardware elements are also implied in the mounting system. In this case the gyroscopic and dynamic functions of elastic oscillations dissipator in "wing – elastic pylon – engine" system are joined in the engine [10–15]. The results of experiments on the oscillation dissipation method principal materialization opportunity and efficiency are presented in the following article.

Research methods

Research was run at the specially developed experimental setup. There is the setup schematic diagram in Figure 1, where *1* – rigid foundation; *2* – wing model (Mi-8 main rotor blade); *3* – pylon; *4* – mounting units to wing model; *5* – engine mounting unit to the pylon; *6* – engine; A – evocation block; *7* – electrodynamic vibrator; *8* – harmonic signal generator; B – register block; *9* – transition sensory picker; *10* – booster; *11* – register equipment.

There is a fundamental oscillation frequency spectrum (frequency correlation, spectrum position sequence), specific to a modern heavy transport aircraft wing, in the setup. The engine is based on standard TS-21 turbo starter by freed turbine mounting unit replacement for a fixed converging jet pipe. Rotor and thrust rotation

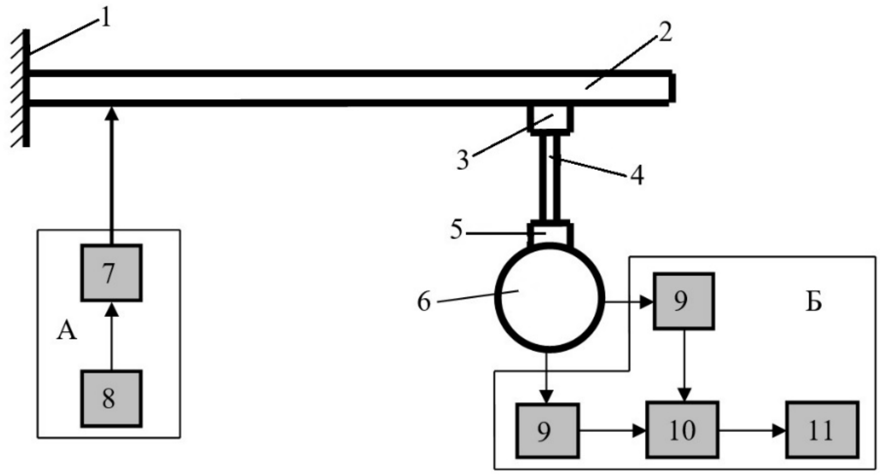


Fig. 1. Schematic diagram of the experimental setup

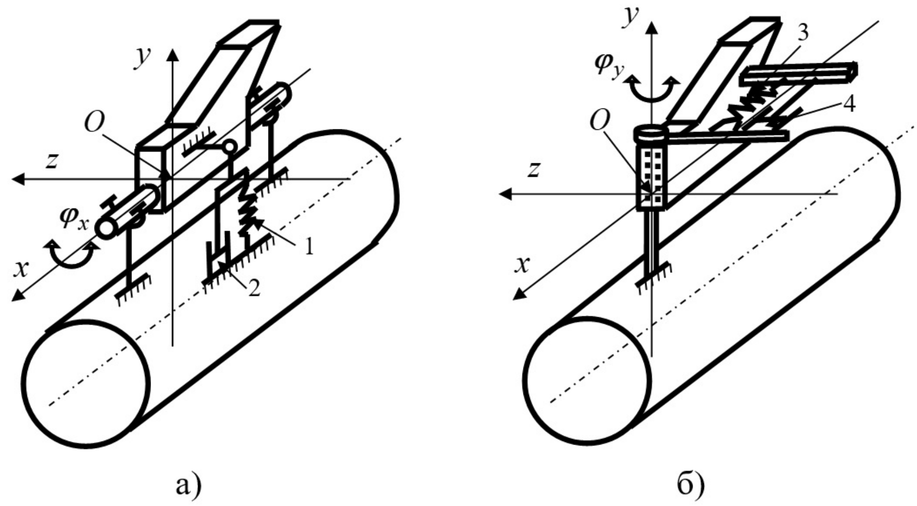
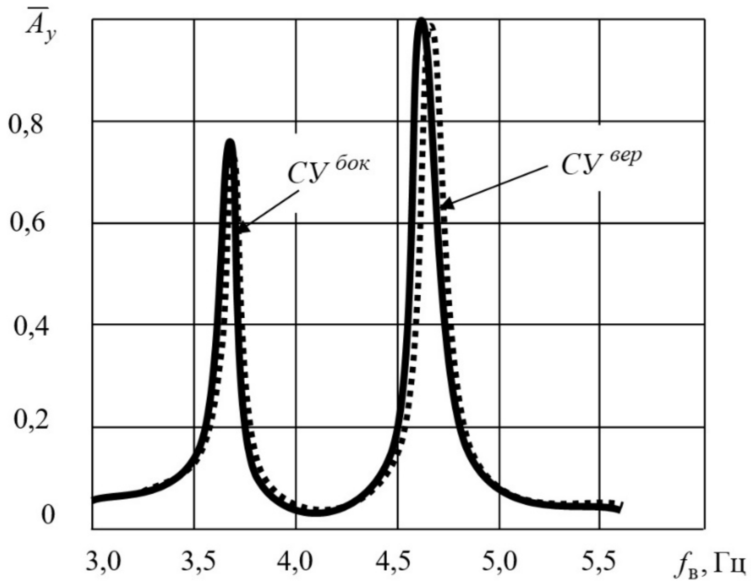


Fig. 2. Constructive diagram of the engine mounting units on the pylon:
a – the engine is conditionally freed relative to the *Ox* axis; *б* – the engine is conditionally released relative to the *Oy* axis;
1, *3* – elastic element; *2*, *4* – hydraulic damper

frequency change was reached by jet pipe outlets of different face use and fuel introducing change, respectively. Engine basic specifications: mass is 22.4 kg; rotor axial moment of inertia is 0.0078 kg·m^2; rotor nominal spinning frequency is 515 Hz; rotor spinning frequency change range is 405…515 Hz; nominal engine thrust is 235 H; thrust change range is 162…235 H; maximum jet pipe temperature is 1120 K.

The engine is attached to the pylon by special replaceable mount, which allows to change elastic dissipation engine attachment parameters. The two mounting unit variants were used, showed schematically in Figure 2, *a*, *b*. *Oxyz* coordinate system is connected with mounting unit, at the same time *Oy* axis passes through engine mass center. There is the mounting scheme of an engine, freed relative to the *Ox* axis in Figure 2 (conversion angle φ_x).

We manage to vary partial parameters of the engine mounting units to the pylon by changing the rigidity of the elastic element *1* and hydraulic damper *2* damping coefficient: oscillation fre-



СУ^{lat,} СУ^{ver}, Hz

Fig. 3. Normalized frequency response of vertical oscillations of the engine at the center of mass in the region of motor tones (solid line – calculation, dashed line – experiment)

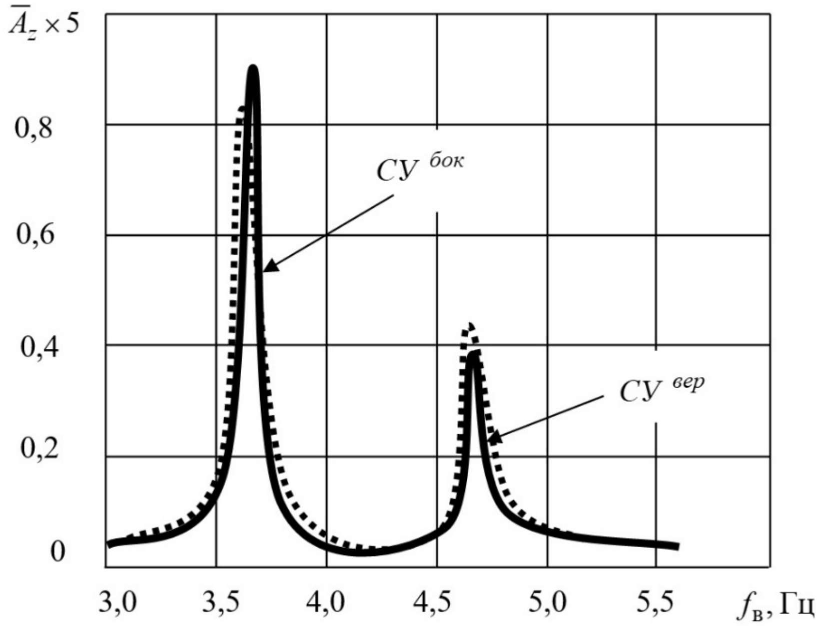
quency relative to axis $Ox - f_x$ and logarithmic decrement of oscillation fading δ_x. There is an attachment of an engine, freed relative to *Oy* axis (φ_y conversion angle). Engine oscillation frequency relative to axis $O_y - f_y$ and logarithmic decrement δ_y depend on elastic element *3* rigidity and hydraulic damper *4* damping coefficient. Partial attachment parameters dependence on the elastic element rigidity values and damper damping coefficients was being investigated on the special setup.

There were the following methods of experimental studies. Stimulated wing model oscillations with an engine on a pylon in frequency range of f_B = 1,5...6,5 Hz were triggered by the A block. The B register block was used for engine mass center oscillation amplitudes detection in planes A_z and A_y – horizontal and vertical planes respectively. Amplitude frequency responses (AFR) were made for the engine in both planes, which was based on the results obtained. The following parameters were changed: the rotor kinetic moment H_p; engine thrust R; elastic and dissipative attachment parameters f_x, δ_x, f_y, δ_y. The results were processed in accordance with GOST P 8.736-2011.

Results of the research

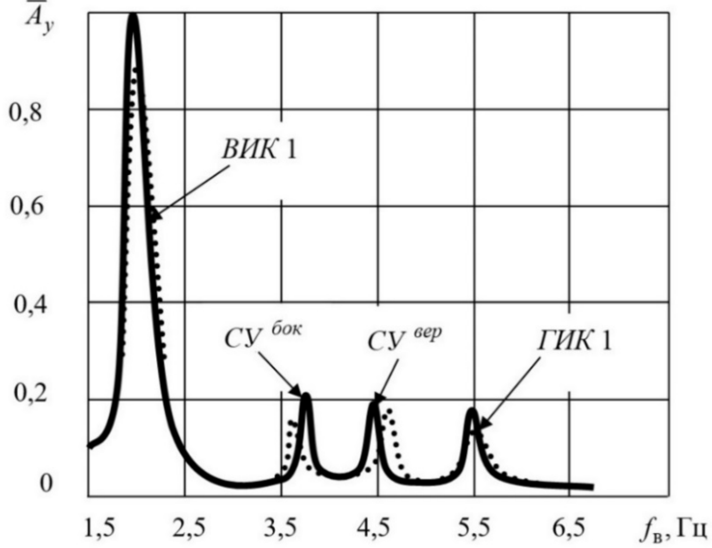
There are the general experiment results shown in Figures 3…8. Thus, there are AFRs for an engine in operation attached rigidly on a pylon in Figure 3 and Figure 4 (engine thrust is nominal, rotor spinning frequency is maximal) in planes $\bar{A}_z$ and $\bar{A}_y$ – horizontal and vertical planes respectively, gained by calculations (solid line) and experiment (dashed line). AFRs are normalized by engine mass center vertical oscillation amplitude by its vertical oscillation $CУ^{ver}$ tone. There is a satisfactory calculation and experimental data convergency.

There are experimental AFRs for the four fundamental elastic tones for the engine not running (solid line) and the running one, attached rigidly (dashed line) in Figure 5 and Figure 6, where VWB1 is a vertical first tone wing tortion; $CУ^{lat}$ are horizontal (lateral) engine oscillations; $CУ^{ver}$ are vertical engine oscillation and first tone wing camber; HWB1 is a horizontal first tone wing bending. Normalization is run by A^{max}_y for VWB1 tone for the engine not running. We can see that the effect of engine in operation is a kind of increase in all engine tones dissipa-



$СУ^{lat,} СУ^{ver}$, Hz

Fig. 4. Normalized frequency response of horizontal (lateral) engine oscillations in the center of mass in the area of motor tones (solid line – calculation, dashed line – experiment)

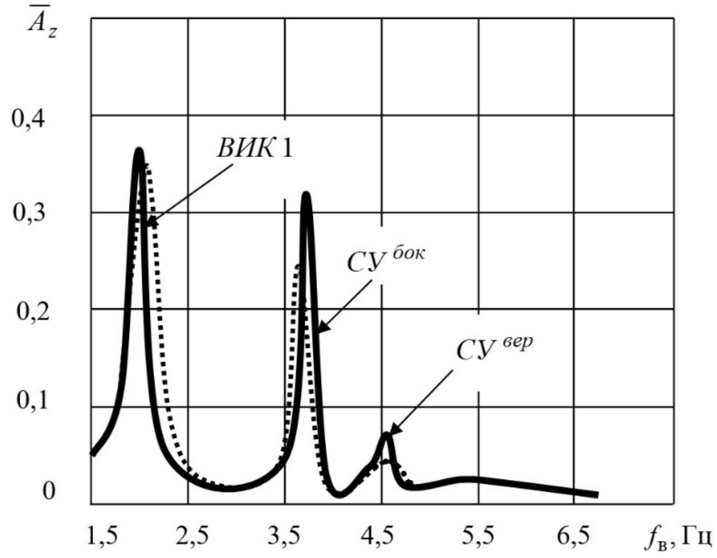


VWB1, $СУ^{lat,} СУ^{ver}$, HWB1, Hz

Fig. 5. Normalized experimental frequency response of vertical oscillations of the engine at the center of mass (solid line – the engine is not running, dashed line – the engine is running)

tive features, along with divergence in motor tones by frequency axis.

There are AFRs of engine mass center vertical oscillations in the region of motor tones by its rigid attachment to the pylon (solid line) and partial parameter setting valuations (the "n" index) of the attachment ($f^n_y = 1.95$ Hz; $\delta^n_y = 1.2$) in Figure 7. There are the same dependencies for engine mass center oscillations for ($f^n_x = 2.5$ Hz, $\delta^n_x = 0.8$) in Figure 8. AFRs normalization for Figure 7 and Figure 8 match the one for Figure 5 and Figure 6. Experimental data analysis allows



VWB1, HWB1, СУ^{lat,} СУ^{ver}, Hz

Fig. 6. Normalized experimental frequency response of horizontal (lateral) oscillations of the engine at the center of mass (solid line – the engine is not running, dashed line – the engine is running)

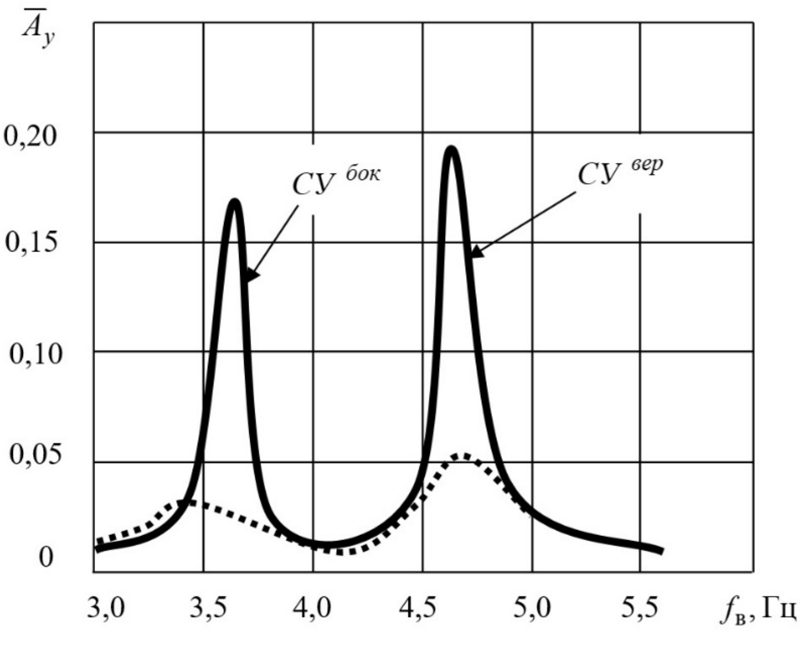


Fig. 7. Normalized experimental frequency response of vertical oscillations of the engine at the center of mass in the region of motor tones (solid line – rigidly mounted engine, dashed line – with suspension settings)

to claim that while running the freed engine method and its attachment setting parameters the significant decrease (3…7 times) in motor tones oscillation amplitudes is expected. The same results were gained by calculation [1–3].

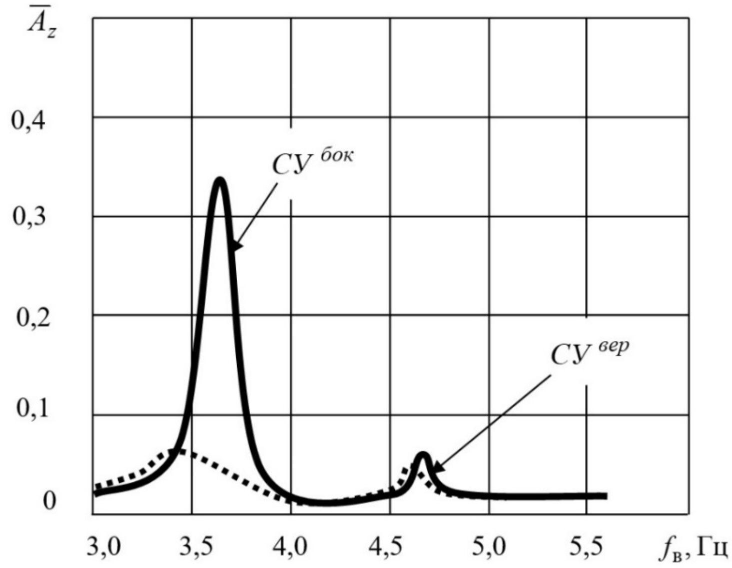


Fig. 8. Normalized experimental frequency response of horizontal (lateral) oscillations of the engine at the center of mass in the region of motor tones (solid line – rigidly mounted engine, dashed line – with suspension settings)

Conclusion

The results of experiment studies showed, that the freed engine method is one of the perspective directions, allowing to reduce significantly the dynamic loads on modern transport aircraft construction elements. In this case we manage to choose such engine mounting unit parameters (elastic element rigidity and hydraulic damper damping coefficient), which will allow to reduce 3…7 times engine mass center vertical and lateral oscillation amplitudes in the sphere of motor tones.

References

1. **Jorgensen, L., Saki, H.** (2023). Design of aero engine structure. Bachelor's thesis. University West. Uppsala, Sweden, 65 p.

2. **Zichenkov, M.C., Ishmuratov, F.Z., Kuznecov, A.G.** (2018). Studying the gyroscopic forces and structural damping joint impact on the wing flutter of the aeroelastic EuRAM model. *Aerospace MAI Journal*, vol. 25, no. 4, pp. 86–95. (in Russian)

3. **Ovchinnikov, V.V., Petrov, Yu.V.** (2017). Numerical methods for the study of aircraft aeroelasticity: Monography. Moscow: Izdatelskiy dom Akademii imeni N.Ye. Zhukovskogo, 160 p. (in Russia)

4. **Ovchinnikov, V.V., Petrov Yu.V.** (2020). Study of running engines inertial and gyroscopic properties influence on the dynamic system engine-pylon-wing structural capabilities. *Civil Aviation High Technologies*, vol. 23, no. 3, pp. 63–72. DOI: 10.26467/2079-0619-2020-23-3-63-72

5. **Fujino, M., Oyama, H., Omotani, H.** (2003). Flutter characteristics of an over-thewing engine mount business-jet configuration. *In: 44th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference. AIAA 2003-1942*, pp. 1–12. DOI: 10.2514/6. 2003-1942

6. **Waitz, S., Hennings, H.** (2015). The aeroelastic impact of engine thrust and gyroscopics on aircraft flutter instabilities. *In: International Forum on Aeroelasticity and Structural Dynamics*, IFASD-2015, pp. 1–15.

7. **Wang, L., Wan, Z., Wu, Q., Yang, C.** (2012). Aeroelastic modeling and analysis of the wing/engine system of a large aircraft. *Procedia Engineering*, vol. 31, pp. 879–885. DOI: 10.10 16/j.proeng.2012.01.1116

8. **Zettel, S., Boswald, M., Winter, R.** (2023). Jet-engine vibration model for the estimation of pylon-wing interface loads. *DAGA*, pp. 628–631.

9. Vermel, V.D., Zichenkov, M.Ch., Koryakin, A.N., Paryshev, S.E. (2020). Study of an experimental prototype simulating a mechanical vibration damper with rotational friction pairs. *Journal of "Almaz – Antey" Air and Space Defence Corporation*, no. 4 (35), pp. 77–86. DOI: 10.38013/2542-0542-2020-4-77-86 (in Russian)

10. Serov, M.V., Averyanov, G.M., Alexandrova, S.G. (2013). Experience of using vibration theory to practical issues of application of inertial dynamic vibration absorbers. *Izvestiya MGTU "MAMI"*, no. 1 (15), pp. 118–124. (in Russian)

11. De Silva, C.W. (2007). Vibration damping, control, and design. 1st ed., CRC Press, 634 p.

12. Ünker, F., Çuvalci, O. (2015). Vibration control of a column using a gyroscope. *In: Procedia-Social and Behavioral Sciences*, vol. 195, pp. 2306–2315. DOI: 10.1016/j.sbspro.2015.06.182

13. He, H., Xie, X., Wang, W. (2017). Vibration control of tower structure with multiple cardan gyroscopes. *Shock and Vibration*. 2017. Vol. 2017. Article ID 3548360. 11 pp. DOI: 10.1155/2017/3548360 (accessed: 03.09.2023).

14. Soleymani, M., Norouzi, M. (2021). Active gyroscopic stabilizer to mitigate vibration in a multimegawatt wind turbine. *Wind Energy*, vol. 24, issue 7, pp. 720–736. DOI: 10.1002/we.2599 (accessed: 03.09.2023).

15. Sitnikov, D.V., Buran, A.A. (2021). The active dynamic vibration damper in nonstationary operation of a vibroactive unit. *Omsk Scientific Bulletin*, no. 4 (178), pp. 13–17. DOI: 10.25206/1813- 8225-2021-178-13-17

Список литературы

1. Jorgensen L., Saki H. Design of aero engine structure. Bachelor's thesis. University West. Uppsala, Sweden, 2023. 65 p.

2. Зиченков М.Ч., Ишмуратов Ф.З., Кузнецов А.Г. Исследование совместного влияния гироскопических сил и конструкционного демпфирования на характеристики флаттера крыла аэроупругой модели EuRAM // Вестник МАИ. 2018. Т. 25, № 4. С. 86–95.

3. Овчинников В.В., Петров Ю.В. Численные методы исследования аэроупругости летательных аппаратов: монография. М.: ИД Академии имени Н.Е. Жуковского, 2017. 160 с.

4. Овчинников В.В., Петров Ю.В. Исследование влияния инерционных и гироскопических свойств работающих двигателей на прочностные характеристики динамической системы двигатель-пилон-крыло // Научный Вестник МГТУ ГА. 2020. Т. 23, № 3. С. 63–72. DOI: 10.26467/2079-0619-2020-23-3-63-72

5. Fujino M., Oyama H., Omotani H. Flutter characteristics of an over-the-wing engine mount business-jet configuration // 44th AiAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference. AIAA 2003-1942, 2003. Pp. 1–12. DOI: 10.2514/6.2003-1942

6. Waitz S., Hennings H. The aeroelastic impact of engine thrust and gyroscopics on aircraft flutter instabilities // International Forum on Aeroelasticity and Structural Dynamics. IFASD-2015. Russia, Saint Petersburg, 2015. Pp. 1–15.

7. Wang L. Aeroelastic modeling and analysis of the wing/engine system of a large aircraft / L. Wang, Z. Wan, Q. Wu, Ch. Yang // Procedia Engineering. 2012. Vol. 31. Pp. 879–885. DOI: 10.1016/j.proeng.2012.01.1116

8. Zettel S., Boswald M., Winter R. Jet-engine vibration model for the estimation of pylon-wing interface loads // DAGA. 2023. Pp. 628–631.

9. Вермель В.Д. Результаты исследований опытного образца механического демпфера вибраций с вращательными парами трения / В.Д. Вермель, М.Ч. Зиченков, А.Н. Корякин, С.Э. Парышев // Вестник Концерна ВКО «Алмаз – Антей». 2020. № 4 (35). С. 77–86. DOI: 10.38013/2542-0542-2020-4-77-86

10. Серов М.В., Аверьянов Г.М., Александрова С.Г. Опыт применения теории колебаний к практическим вопросам применения инерционных динамических гасителей колебаний // Известия МГТУ «МАМИ». 2013. Т. 3, № 1 (15). С. 118–124.

11. De Silva C.W. Vibration damping, control, and design. 1st ed. CRC Press, 2007. 634 p.

12. Ünker F., Çuvalci O. Vibration control of a column using a gyroscope // Procedia-Social and Behavioral Sciences, 2015. Vol. 195. Pp. 2306–2315. DOI: 10.1016/j.sbspro.2015.06.182

13. He H., Xie X., Wang W. Vibration control of tower structure with multiple cardan gyroscope [Электронный ресурс] // Shock and Vibration. 2017. Vol. 2017. Article ID 3548360. 11 pp. DOI: 10.1155/2017/3548360 (дата обращения: 03.09.2023).

14. Soleymani M., Norouzi M. Active gyroscopic stabilizer to mitigate vibration in a multimegawatt wind turbine [Электронный ресурс] // Wind Energy. 2021. Vol. 24, iss. 7. Pp. 720–736. DOI: 10.1002/we.2599 (дата обращения: 03.09.2023).

15. Ситников Д.В., Бурьян А.А. Система виброизоляции с активным динамическим гасителем колебаний при нестационарном режиме работы поршневой машины // Омский научный вестник. 2021. № 4 (178). С. 13–17. DOI: 10.25206/1813- 8225-2021-178-13-17

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