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THE STRESS-STRAIN STATE ASSESSMENT OF THE HEAT EXCHANGE UNIT DAMPER OF THE AIR HANDLING AIRCRAFT PRIMARY SYSTEM

Ua В роботі вирішується задача оцінки напружено-деформованого стану заслінки теплообмінного вузла первинної системи обробки повітря сучасного транспортного літака, яка знаходиться в системі підготовки повітря. Система підготовки повітря призначена для відбору повітря від маршової установки двигуна або допоміжної силової установки, подальшої його обробки та транспортування в систему життєзабезпечення.При аналізі напружено-деформованого стану реальних авіаційних конструкцій, з урахуванням граничних умов та режимів навантаження, аналітичні методи розрахунку не завжди є ефективні, тому в даній роботі були застосовані чисельні методи дослідження. На основі метода скінченних елементів був проведений аналіз напружено-деформованого стану заслінки теплообмінного вузла з урахуванням всіх конструктивних особливостей. Використовувались тривимірні скінченні елементи, які найбільш точно відповідають розрахунковій схемі. Чисельний аналіз напружено-деформованого стану дає можливість визначити небезпечні області напружень, де можуть виникнути втомні тріщини і відбутися руйнування.

En The work solves the problem of the stress-strain state estimation of the heat exchange unit damper of the primary air handling system in modern transport aircraft, which is located in the air preparation system. It’s designed for air sampling from the engine's cruise unit or auxiliary power unit, its further processing and transportation to the life support system. When analyzing the stress-strain state of real aircraft structures, taking into account boundary conditions and load modes, analytical calculation methods are not always effective , therefore, numerical research methods were used in this work.Based on the finite element method, the stress-strain state analysis of the heat exchange unit damper was carried out, taking into account all the design features. Three-dimensional finite elements were used, which most accurately correspond to the calculation scheme. Numerical analysis of the stress-strain state made it possible to determine dangerous areas of stress where fatigue cracks may appear and destruction may be occur.

Introduction

In connection with the development of aircraft construction, the task of assessing the stress-strain state of the heat exchange unit damper of a primary air treatment modern transport aircraft is relevant.

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This system is designed to take air from the cruise engine or auxiliary power unit, further process it and transport it to the life support system.

The system includes pipelines and units for the air preparation system in the wing and fuselage, center plane, gargrot, in the tail part of the fuselage, and in the compartment of the auxiliary power plant.

The pipelines of the system are made of sheet stainless steel and titanium alloy, heat-insulated with fiberglass and lined with fiberglass.

The air sampling subsystem (ASS) ensures air sampling from engines with the necessary parameters and supplying it to the distribution line to consumers. Two ASS are installed on the plane, connected to each other by a pipeline and a ring valve in the center plane. Pipelines and units are mounted on the engines and in the engine pylons.

Formulation and solution of the problem

The location in three-dimensional space is as follows: the model is installed through eyelets with the help of levers, which in turn are connected to fasteners on the body. Through the upper flange with the help of bolts, the damper is connected to the heat exchanger. Fig. 1 shows a model of the heat exchange unit damper.

The damper, in addition to its own geometry of the body, consists of a body (1), a cover (3), three blades – two outer ones (5) and the middle one (6) fixed on the shafts (7, 8) with rivets (13), and a mechanism for turning the blades (18).

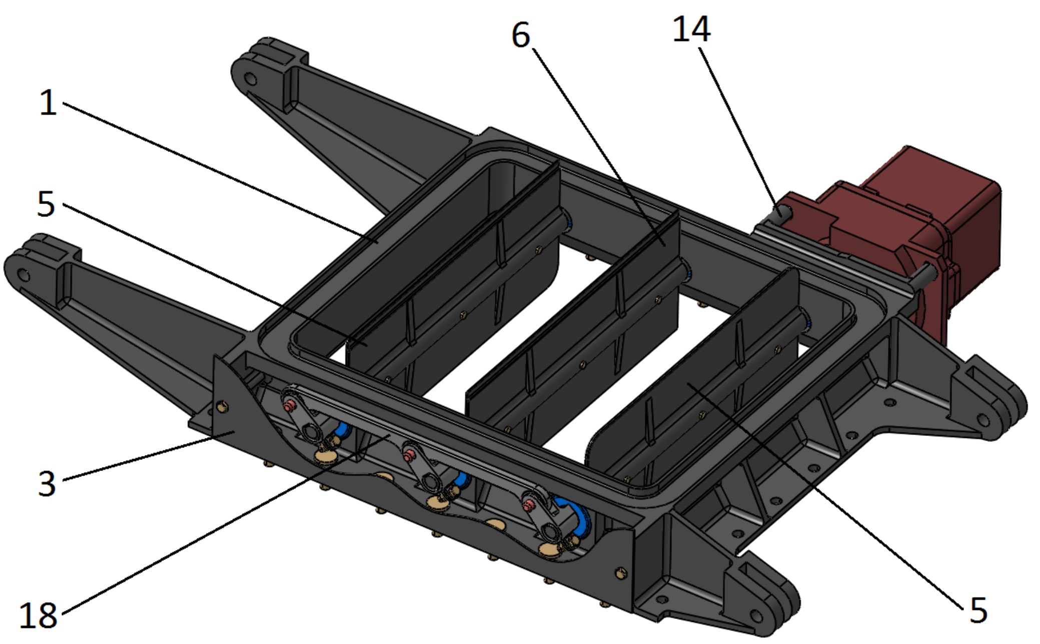

Fig. 1. Damper of the heat exchange unit

Fasteners allow the eyelets to move only angularly along the axis of the eyelet holes. The body receives two types of load – excess pressure applied to the blades, which in turn transmit the load to the holes under the shafts of the blades and then to the eyelets of the fasteners, and inertial loads from the weight of the system, which is applied to the point of contact between the damper body and the heat exchanger.

The task of assessing the stress-strain state was carried out using the finite element method [1 - 4]. A three-dimensional element – a tetrahedron was used to study the stress state of the heat exchanger valve body [5, 6]. All six deformation components are taken into account in the three-dimensional case. Let's write the matrix of deformations using geometric equations in the form:

$$\{\varepsilon\} = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial w}{\partial z} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \frac{\partial v}{\partial z} + \frac{\partial w}{\partial x} \\ \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \end{Bmatrix}. \tag{1}$$

Maybe write it down:

$$\{\varepsilon\} = [B]\{\delta\}^{\varepsilon} = \left[B_i, B_j, B_m, B_p\right]\{\delta\}^{\varepsilon}. \tag{2}$$

Using the ratio (1) - (2) we obtain:

$$[B_i] = \begin{bmatrix} \frac{\partial N_i}{\partial x} & 0 & 0 \\ 0 & \frac{\partial N_i}{\partial y} & 0 \\ 0 & 0 & \frac{\partial N_i}{\partial z} \\ \frac{\partial N_i}{\partial y} & \frac{\partial N_i}{\partial x} & 0 \\ 0 & \frac{\partial N_i}{\partial z} & \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial y} & 0 & \frac{\partial N_i}{\partial x} \end{bmatrix} = \frac{1}{6V} \begin{bmatrix} b_i & 0 & 0 \\ 0 & c_i & 0 \\ 0 & 0 & d_i \\ c_i & b_i & 0 \\ 0 & d_i & c_i \\ d_i & 0 & b_i \end{bmatrix}. \tag{3}$$

The rest of the matrices are obtained by simply permuting the indices.

The initial deformations, such as those due to thermal expansion, can be written in the usual way in the form of a six-component vector, which has for isotropic thermal expansion a simple form:

$$\{\varepsilon_0\} = \begin{Bmatrix} \alpha\Delta T \\ \alpha\Delta T \\ \alpha\Delta T \\ 0 \\ 0 \\ 0 \end{Bmatrix}, \tag{4}$$

where α is the coefficient of linear expansion, and ΔT is the average heating temperature for the element.

In the general case, the elasticity matrix has the form:

$$\{\sigma\} = \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{Bmatrix} = [D]\left(\{\varepsilon\} - \{\varepsilon_0\}\right), \tag{5}$$

where the elasticity matrix for an isotropic material has the form:

$$[D] = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} = \begin{bmatrix} 1 & \frac{\nu}{1-\nu} & \frac{\nu}{1-\nu} & 0 & 0 & 0 \\ \frac{\nu}{1-\nu} & 1 & \frac{\nu}{1-\nu} & 0 & 0 & 0 \\ \frac{\nu}{1-\nu} & \frac{\nu}{1-\nu} & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2(1-\nu)} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2(1-\nu)} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2(1-\nu)} \end{bmatrix} \tag{6}$$

The submatrix with indices *rs* of the stiffness matrix has a dimension of 3 × 3 and is determined by the relation:

$$\left[k_{rs}\right]=\left[B\right]^{T}\left[D\right]\left[B_{s}\right]V\,, \tag{7}$$

where V is the tetrahedron volume.

The nodal forces due to the initial deformation are written in the form:

$$\left\{F\right\}_{\varepsilon 0}^{e}=-\left[B\right]^{T}\left[D\right]\left[\varepsilon_{0}\right]V \tag{8}$$

or for the i-th component: $\left\{F_{i}\right\}_{\varepsilon 0}^{e}=-\left[B_{i}\right]^{T}\left[D\right]\left[\varepsilon_{0}\right]V$.

The distributed volume forces can again be their X, Y, Z components. As before, it can be shown that if the volume forces are constant, then the components of their resultant are distributed evenly over the nodes of the element.

After analyzing the existing software products, based on the conditions of the task and the available technical capabilities, it was decided to use the ANSYS [7] program to assess the stress-strain state of the damper.

To calculate the overall strength of the damper body, the load from the excess pressure of the air preparation system and the load from mass forces are taken into account. Excess pressure is applied to the shaft holes in the form of a load from the bearings. The load of mass forces is applied to the mounting flange of the heat exchanger in the form of a distributed load.

The pressure force of the mass forces must be distributed over the entire surface of the heat exchanger mounting flange:

$$P=\frac{P_{y}}{S_{f}}=\frac{1225}{0{,}028094}=43650\text{Pa}\,;$$

where P_y is the estimated inertial load on the damper body; S_f is the area of the heat exchanger mounting flange.

The force of excess pressure is applied to the eyelets of the damper axes. The load on the damper body is shown in Fig. 2.

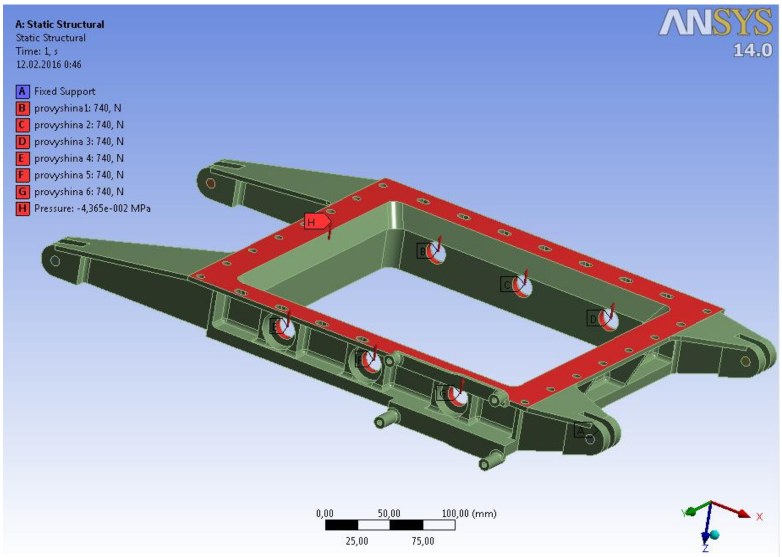

Fig. 2. Load on the damper body

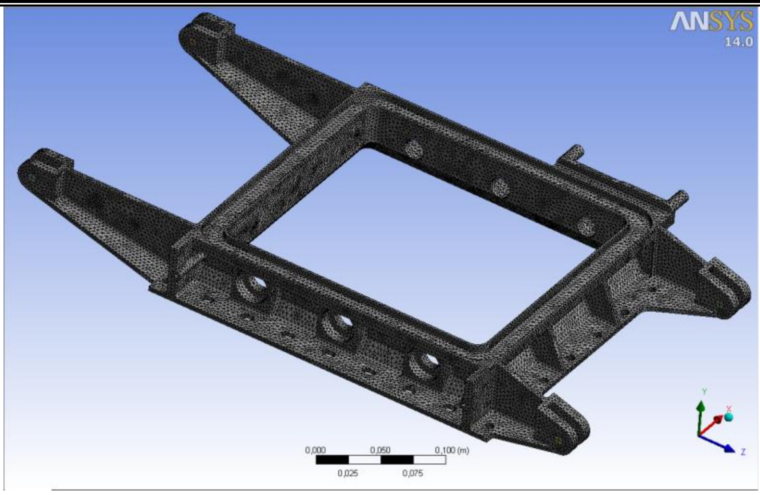

Fig. 3. Finite element model of the damper

After creating a finite-element model of the damper (Fig. 3), the stress-strain state was calculated. The obtained results are displayed graphically. The interactive presentation of the results allows you to analyze the stress-strain state of the structure [8]. Thus, Fig. 4, Fig. 5 show respectively the distribution of equivalent stresses according to Misses and the distribution of displacements

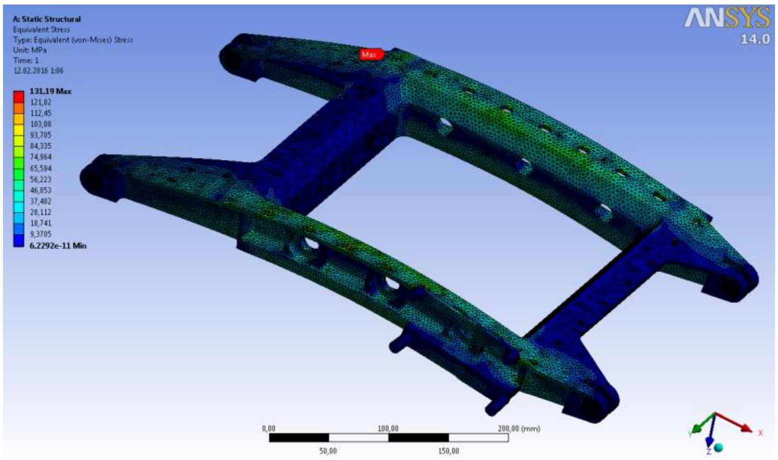

Fig. 4. Distribution of equivalent stresses according to Misses

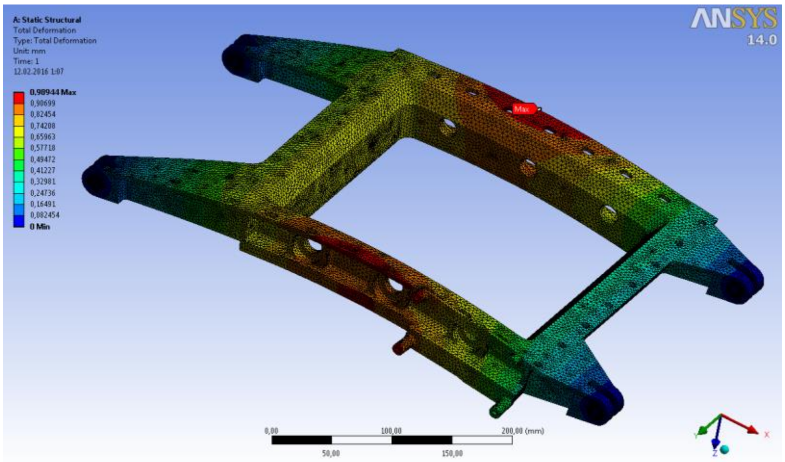

Fig. 5. Distribution of movements

It can be seen from the obtained calculations that the maximum effective stress is in the detail:

$$\sigma^{p}_{\max} = 131{,}2 \text{ mPa}$$

The largest displacement from design loads:

$$f_{\max} = 0{,}989 \text{mm}.$$

Conclusions

In the work, based on modern numerical methods, an analysis of the stress-strain state of the damper of the heat exchange unit was carried out, taking into account all design features. This allowed for dangerous stress areas where fatigue cracks could develop and failure could occur. The calculation of the stress-strain state of this part of the aircraft was carried out using the finite element method in the complex of ANSYS programs. Three-dimensional finite elements were used. Based on the calculation data, it is possible to give recommendations on the optimization of the damper of the heat exchange unit from the point of view of strength.

Reference

1. *Zienkiewicz O. C., Taylor R. L.* The Finite Element Method. Volume 1: The Basis. – Oxford: BH, 2000. – 689 p.
2. *Zienkiewicz O. C., Taylor R. L.* The Finite Element Method. Volume 2: Solid Mechanics. – Oxford: BH, 2000. – 459 p.
3. Bathe Klaus-Jürgen. Finite Element Procedures. Second Edition, published by K.J. Bathe, Watertown, MA, 2014. – 1043 p.
4. *Дубенец В. Г., Хильчевский В. В., Савченко О. В.* Основи методу скінченних елементів. – Чернігів, ЧДТУ.– 2003. – 346 с.
5. *Trubachev S. I., Alekseychuk O. N.* Numerical simulation of bellows compensators stress-strain state in air in-take system. Інформаційні системи, механіка та керування – № 21, 2019, – с. 80-85. DOI: https://doi.org/10.20535/2219-3804212019194279.
6. *Trubachev S. I., Alekseychuk O. N.* The stress-strain state of gondola mounting bracket of a transport aircraft //Механіка гіроскопічних систем, № 40, 2020. – с. 117–123. DOI: https://doi.org/10.20535/0203-3771402020248782.
7. *Moaveni S.* – Finite Element Analysis Theory and Application with ANSYS, Pearson, 2008 – 868.
8. Механіка руйнування і міцність матеріалів: Довідн. пос. / Під заг. ред. В. В. Панасюка. Т. 9 : Міцність і довговічність авіаційних матеріалів та елементів конструкцій / О. П. Осташ, В. М. Федірко, В. М. Учанін, С. А. Бичков, О. Г. Моляр, О. І. Семенець, В. С. Кравець, В. Я. Дереча. Під ред. О. П. Осташа, В. М. Федірка. – Львів: Сполом, 2007. – 1068 с.