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DEVELOPING A NEW APPROACH IN DIAGNOSTIC METHODS OF TECHNICAL STATE OF PROPELLER OF GAS PUMPING UNIT

1. INTRODUCTION

When gas pumping unit (GPU) is stopped and the propeller is dismantled, the control of the technical condition of the blades in the propeller of (GPU) such as compressors of low and high pressures, turbine high and low pressures, pumps is normally made by direct measurement or optical visual inspection, magnetic testing and dye-penetration test, so based on which a decision on repairing of blades by restoring their geometrical sizes or the replacing the blades is made. At the same time mathematical methods for calculating the parameters of subsonic flow around wing airfoils – in particular, the method of discrete vortices [1], the method of integral equations [2] developed and widely used. In this study various types of flow – of continuous stationary, non-stationary, non-stationary in the model boundary layer, etc. – depending on the nature of the problem are solved. The main results concerning the implementation of these techniques as a set of program products were made in the late of 20th century, but they are constantly being improved through the development of appropriate software and the improvement of the running speed of computer faculties. This makes it necessary to study the aerodynamic processes that occur in the operation of propeller of GPU and research the possibilities of using modern methods of subsonic aerodynamic flows of gas both for its technical state evaluation and determination of the effectiveness of the GPU.

2. TECHNICAL STATE OF PROPELLER OF GAS PUMPING UNIT

Such factors as the nature of the flow of the blades and their configuration -small linear size, subsonic speed of the blades assist to make a reasoned decision regarding the use of

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continuous flow model of planar blade airfoil uncompressed ideal fluid under stationary models and develop efficient computer algorithms for computing basic aerodynamic characteristics of the investigated airfoils, which are the resistance coefficient, lift force and engine torque, as well as to assess the dynamics of changes of these parameters in the wear of the blade.

For the first time the mentioned above models and the results are used during the technical state evaluation of structural elements of GPU in their actual operation in compressor stations. Solving Fredholm integral equation of the second order with respect to the tangent velocity components [6], we have the following:

$$V_\theta(\theta_0) = \frac{1}{\pi}\int_0^{2\pi} V_\theta(\theta) K(\theta;\theta_0) d\theta + 2\frac{\partial\Phi}{\partial\theta}(\theta_0) \quad (1)$$

where V_θ is the tangent to the airfoil of the blade velocity components, $K(\theta,\theta_0)$ is kernel of the integral equation:

$$K(\theta;\theta_0) = \frac{[y(\theta)-y(\theta_0)]x'(\theta_0)}{(y(\theta)-y(\theta_0))^2+(x(\theta)-x(\theta_0))^2} - \frac{[x(\theta)-x(\theta_0)]y'(\theta_0)}{(y(\theta)-y(\theta_0))^2+(x(\theta)-x(\theta_0))^2} \quad (2)$$

where $x(\theta), x(\theta_0), y(\theta), y(\theta_0)$ are coordinates of the points in the corresponding airfoil values, θ is the polar coordinate, $\Phi(\theta_0)$ is the potential flow [7], which is incident to airfoil:

$$\Phi(\theta_0) = (x(\theta_0)\cos\alpha + y(\theta_0)\sin\alpha)V_\infty \quad (3)$$

where V_∞ is the gas stream velocity at a sufficient distance from the airfoil, α is the angle of attack. Components of $V_\theta(\theta)$ and aerodynamic characteristics can be determined by equations:

$$C_x = -\int_0^{2\pi}[1-\frac{V_\theta^2(\theta)}{x'(\theta)^2+y'(\theta)^2}]y'(\theta)d\theta \quad (4)$$

where C_x is the coefficient of drag of the blade;

$$C_y = \int_0^{2\pi}[1-\frac{V_\theta^2(\theta)}{x'(\theta)^2+y'(\theta)^2}]x'(\theta)d\theta \quad (5)$$

where C_y is the coefficient of lift force;

$$C_{mz} = \int_0^{2\pi}[1-\frac{V_\theta^2(\theta)}{x'(\theta)^2+y'(\theta)^2}]\times (x(\theta)x'(\theta)+y(\theta)y'(\theta))d\theta \quad (6)$$

where C_{mz} is coefficient of torque.

At solving formulas (4)–(6) transitions were made – the velocity vector with real length of the basis vectors into the physical components and unit vectors of bases into the curvilinear coordinates, in which the estimates are made. Specified model the numerical solution of the problem of plane-parallel flow of wings airfoil is [3].

The cross section airfoil of the blade is a wing small thickness airfoil $\left(\frac{\delta}{L}\right)$~0.1–2, where δ is maximum thickness airfoil, L is maximum length of the wing chord. In associated with the airfoil coordinate system is constructed similar view function $f(\theta)$ that defines the geometry function. In the degree coordinate system geometry airfoil is defined as follows:

$$\begin{cases} x = \frac{1}{2}\cos\theta + \frac{1}{2} = \cos^2\frac{\theta}{2}, \\ y = f(\theta), \qquad\qquad 0 \le \theta \le 2\pi, \end{cases} \tag{7}$$

where θ is the polar angle.

The mentioned approach allows us to construct an analytic representation of functions based on the following two assumptions:

- the front edge of the airfoil is part of an ellipse, with the upper and lower surface airfoil is given by an ellipse of varying eccentricity;
- other sectors of the upper and lower surface of the blade airfoil is modeled using the Hermite polynomial terms of continuity airfoil is modeled by a function that is the point of interface with elliptical sector is continuous with its two derivatives.

The approach mentioned above allows us to significantly improve the accuracy of the simulation airfoil blades and calculate aerodynamic parameter blade airfoils, which are operated for a long time. Filed algorithm is implemented as a set of programs. Test calculation results are presented in Figures 1 and 2.

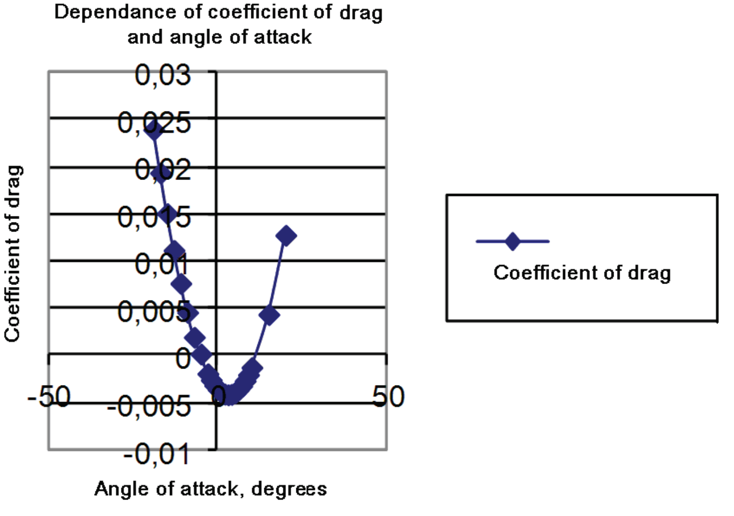

Fig. 1. Dependence of drag on the angle of attack at the constant shape of the airfoils

It was founded that by changing the angle of attack the coefficient of the drag increases in absolute value, and the nature of the growth is determined by the geometrical characteristics of the airfoil. There is the angle of attack at which the resistance is minimal. The results concerning the airfoil for which the front edge of the top piece is an ellipse with a small half-axe 0.045, and at the bottom – with a small half-axe 0.015.

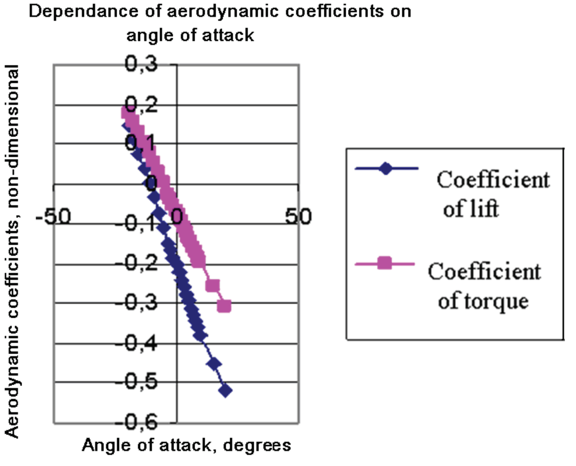

Fig. 2. Dependence of the lift and torque on the angle of attack at the constant shape of the airfoil

The monotonically change of lift and torque coefficients depends on the change of the angle of attack, moreover change strongly depends on the shape of the airfoil.

Many researches were made, such are:

- also, the dependence of the parameters on the degree of wear of the upper surface of the blade was found; the discontinuous change parameter values at corresponding values of the major axis of an ellipse that models the upper surface was found;
- it was shown the dependence of these parameters C_x, C_y and C_{mz} on the degree of wear of the lower surface of the blade; the dependence of change parameter values on corresponding large values of semi-axis of an ellipse that models the lower surface was found, which is based on a monotonous decrease of relevant characteristics when wear of lower front edge of blade increases;
- the dependence of these parameters on the degree of wear of the upper and lower surfaces of the blade was shown; dependence of change parameter values on corresponding large values of the semi-axis of the ellipses that model upper and lower surfaces was found, the results indicate simultaneous wear of upper and lower airfoil blade cause the more intense change of C_x, C_y and C_{mz} parameters than the wear of one part of the edge of blade;
- the dependence of aerodynamic parameters on the degree of wear of the upper and lower surfaces of the blade at different values of the angle and variable shape of airfoil was found; monotonous change of parameter values at corresponding large values of semi-axis of ellipses that model upper and lower surfaces was found.

The value of angle of attack allows us to simulate different degrees of curvature of airfoils, replace the three-dimensional problem solving by sequence of one-dimensional aerodynamics considering changing the length of the blade and its size and torsion.

Using formula (7), the area of the cross-sectional airfoil of a blade S can be found as follows:

$$S = \frac{1}{4}\pi\varepsilon_1\varepsilon_2 + \frac{1}{4}\pi\varepsilon_3\varepsilon_4 + \int_{\varepsilon_1}^{1} f_3(x)\,dx + \int_{\varepsilon_3}^{1} \left|f_4(x)\right|dx \tag{8}$$

The first addend is the area of a quarter of an ellipse, the second - fourth of the ellipse, the third – integral polynomial of the third degree, fourth – integral module of the polynomial. All those integrals can be obtained from the following formula (7). These formulas can be used to calculate the moments of inertia of the cross section about the axis Ox and Oy. The formula for the moment of inertia about the axis Ox is:

$$I_x = \iint_{D_1} y^2 ds \tag{9}$$

Taking to account (7) it is possible to receive:

$$I_x = \int_0^1 dx \int_{\varphi_1(x)}^{\varphi_2(x)} y^2 dy \tag{10}$$

where the functions $\varphi_1(x)$ and $\varphi_2(x)$ can be presented as:

$$\varphi_1(x) = \begin{cases} f_2(x) & 0 \le x \le \varepsilon_3 \\ f_4(x) & \varepsilon_3 \le x \le 1 \end{cases} \tag{11}$$

$$\varphi_2(x) = \begin{cases} f_1(x) & 0 \le x \le \varepsilon_1 \\ f_3(x) & \varepsilon_1 \le x \le 1 \end{cases} \tag{12}$$

In such cause, when $\varepsilon_1 < \varepsilon_2$, the formula (10) can be written as:

$$I_x = \int_0^{\varepsilon_3} dx \int_{f_2(x)}^{f_1(x)} y^2 dy + \int_{\varepsilon_3}^{\varepsilon_1} dx \int_{f_4(x)}^{f_3(x)} y^2 dy + \int_{\varepsilon_1}^{1} dx \int_{f_4(x)}^{f_3(x)} y^2 dy \tag{13}$$

Using formulae:

$$I_y = \iint_{D_2} x^2 ds \tag{14}$$

it is possible to calculate the momentum of inertia relative to Oy.

Calculations for the interpolation of data, calculation of areas and moments of inertia (usually to the axis Ox), are made for blade airfoils at the initial time of the operation and after a period of operation, it is necessary to stop the propeller to evaluate the airfoil shape configuration.

A number of simplifying assumptions is to be made to derive the differential equation of vibration of the blade, which is following [4]:

- centers of gravity practically identical to centers of rigidity of cross section of blades,
- the resistance is proportional to the first power of velocity vibrations blades,
- size of cross-section of the blades are small compared to their length.

The differential equation of forced vibration of variable cross section of blades is following:

$$\frac{E}{\rho S l^4} \frac{\partial^2 \left(I \frac{\partial^2 y}{\partial \xi^2} \right)}{\partial \xi^2} + \frac{\partial^2 y}{\partial t^2} + 2h \frac{\partial y}{\partial t} = \varphi(\xi, t) \tag{15}$$

where l is the blade height, E is modulus of elasticity of the blade material, I is minimum cross-sectional moment of inertia, ρ is the density of the blade material, S is cross-sectional area, $\xi = \frac{x}{l}$ is relative coordinate on the horizontal axis, which coincides with the axis of the blade $0 \le \xi \le 1$, x is the distance along the x-axis, y is the distance along y-axis, $2h\rho S \frac{\partial y}{\partial t}$ is the intensity of the resistance; h is damping, $2h = c$ is the intensity of the external load.

At the initial moment the blade deformed and has a certain velocity vibration, i.e. at $t = 0$:

$$y = a(\xi); \ \frac{dy}{dt} = b(\xi) \tag{16}$$

Breaking conditions at the base blade – and the deflection angle is zero, i.e. at $\xi = 0$:

$$y = 0; \ \frac{dy}{dt} = 0 \tag{17}$$

Breaking conditions are at the vertex of the blade depends on the object of study (blade or bag). If the top of the blade is free, then $\xi = 1$:

$$\frac{\partial^2 y}{\partial \xi^2} = 0; \ \frac{\partial^2 y}{\partial \xi^2} = 0 \tag{18}$$

If the vertex of the blade supported, then $\xi = 1$:

$$y = 0; \ \frac{\partial^2 y}{\partial \xi^2} = 0 \tag{19}$$

If the vertex of the blade rigidly restrained, then $\xi = 1$:

$$\frac{\partial^2 y}{\partial \xi^2} = 0; \ \frac{\partial y}{\partial \xi} = 0 \tag{20}$$

Similarly, the fluctuation processes considering the blade with the supported vertex, free vibrations of blades with fixed vertex, forced vibrations of single blades are studied, where there is a necessary to take into account the change of breaking and initial conditions. The equation of vibration in all of these cases mentioned above consists of quantities such as the area and moment of inertia of the cross-sectional airfoil that allows the study of the effect of change of these characteristics on the parameters of the vibrations. The software was created and test calculations were conducted that confirm the possibility of studying all vibration processes mentioned above and the analysis of the influence of the shape of the airfoil on the nature of the vibration processes.

3. CONCLUSIONS

In the study method of reproduction of blades airfoil was proposed, various conditions of fluctuation of propeller of GPU were studied, also relevant software was developed. This software allows us to construct the shape of the blade and its vibration process (forced, free), calculate area and inertia momentum on which vibration processes depend.

Now, comparison of one or more blades at different moments of time is enabled. To create this program developed mathematical model was used, which allows to reproduce real shape of the blade of GPU and process of its vibration on the basis of which method of evaluating technical state of propeller of GPU at the process of operation can be made.

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