CALCULATION BY PROBABILISTIC METHODS OF LOCATING PIN ASSEMBLY OF ROTOR BLADES IN THE CONSTRUCTION OF AIRCRAFT COMPRESSORS AND TURBINES

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Abstract: *Compressor and turbine blades, used in the construction of aircraft turboprop engines, are very important constructive elements, by their functional role, and complex by geometric parameters, mechanical and gas-dynamic factors. This paper aims to present a method of probabilistic design of the assembly between the rotor disk and the compressor and turbine blades.*

Keywords: turboprop engine, compressor, turbine, removable assembly.

1. INTRODUCTION

The way of assembling and fixing the rotor blades is one of the many factors that must be taken into account in calculating their strength, in addition to the design of the blade resulting from gasodynamic and technological conditions, pressure variation during engine operation, due to conditions of gas flow through the engine, the operating time imposed on the blade and the variability of the operating mode of the aircraft engine.

The rotor blades of the compressors and turbines can be assembled on the disc by means of removable, trapezoidal, "dovetail", "T"- shaped or by means of cylindrical pins (Fig.1).

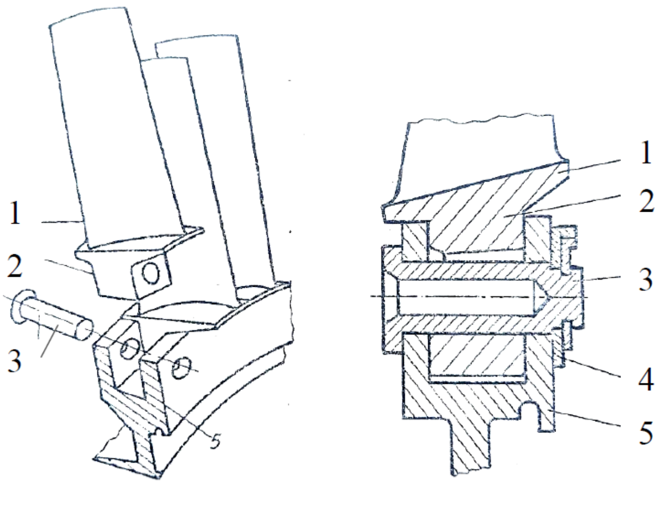

FIG. 1. Assembling and fixing the rotor blades by cylindrical pins [4]
1 – rotor blade, 2 – base of blade, 3 – cylindrical pin, 4 – lock washer, 5 - disk

2. CALCULATION BY PROBABILISTIC METHOD OF LOCATING PINS ASSEMBLY

In the constructive variant in which the assembly of the rotor blades is done by means of the locating pins, they are stressed during shear operation, the predominant stress and respectively crushing. The shear stress occurs due to the centrifugal force, which has a maximum value in the maximum engine speed.

The centrifugal force at the base of the blade, if the blade is of constant section, (FIG. 2) is determined by the relation [7]:

$$F_c = \frac{\rho\omega^2 A}{2}\left(R_e^2 - R_i^2\right) \tag{1}$$

$$F_c = \rho\omega^2 A\left(R_e - R_i\right)\left(\frac{R_e + R_i}{2}\right) \tag{2}$$

or,

$$F_c = \rho\omega^2 A R_m l \tag{3}$$

where:

ρ - density of the blade material,
ω - angular velocity;
A - area of the section at the base of the blade;
R_m - average radius of the blade;
R_e - outer radius of the blade;
R_i - radius from the center of the disc to the base of the blade;
l - length of the profiled body of the blade.

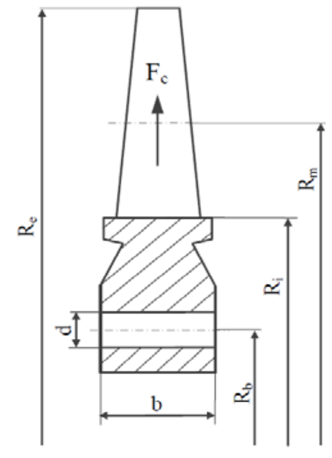

FIG. 2. Primary geometric parameters of the rotor blades [4]

The centrifugal force has a maximum value if the engine speed is maximum, respectively at operating mode with maximum air flow.

In the sizing calculations of the analyzed assembly, the intervening random variables are identified, namely:

- stress characteristic to which the blades are exposed, during operation;
- mechanical characteristics of the material used in the construction of the blades;
- execution tolerance of the pins used;
- charges to which the rotor blades of the compressors or turbines are subjected.

The probabilistic design of the analyzed assembly is made starting from the imposition of a certain value as high as possible of the reliability, *R(t)=k*, knowing that the actual stress that appears during operation and the allowable stress hold known distribution laws.

The shear stress of the full section cylindrical pin is described by the relation [6]:

$$\tau_f = \frac{F}{n \cdot A} \tag{4}$$

where,

τ_f - the actual shear stress of the pin;
F - centrifugal force at the base of the blade;
A_1 - the shear section of the pin;
n - number of shear sections.

Based on the recommendations of the specialized literature [3], a certain value of the coefficient of variation of the outer diameter of the pin is adopted:

$$C_{vd} = \frac{\sigma_d}{m_d} = k_1 \tag{5}$$

resulting:

$$\sigma_d = k_1 \cdot m_d \tag{6}$$

The standard deviation of the shear stress of the blade pin σ_{τ_f} is determined by the relation:

$$\sigma_{\tau_f} = \frac{1}{n}\sqrt{\left(\frac{\partial \tau_f}{\partial F}\right)^2 \cdot \sigma_F^2 + \left(\frac{\partial \tau_f}{\partial A}\right)^2 \cdot \sigma_A^2} \tag{7}$$

$$\sigma_{\tau_f} = \frac{1}{n}\sqrt{\frac{m_F^2 \cdot \sigma_A^2 + m_A^2 \cdot \sigma_F^2}{m_A^2}} \tag{8}$$

or: $$\sigma_{\tau_f} = \frac{1}{n m_A}\sqrt{\sigma_F^2 + \left(\frac{m_F}{m_A} \cdot \sigma_A\right)^2} \tag{9}$$

the pin displaying a circular section, there results:

$$\sigma_{\tau_f} = \frac{1}{n\frac{\pi m_d^2}{4}}\sqrt{\sigma_F^2 + \left(\frac{m_F}{\frac{\pi m_d^2}{4}}\frac{\pi}{4}2m_d\sigma_d\right)^2} \tag{10}$$

$$\sigma_{\tau_f} = \frac{t}{m_d^2} \tag{11}$$

where, t represents a constant of known values.

The reliability of the cylindrical pin, generally of a constructive element, is given by the relation [2]:

$$R(t) = P(\sigma_{\tau_{adm}} - \sigma_{\tau_f} \rangle o) \tag{12}$$

$$R(t) = \frac{1}{\sqrt{2\pi}}\int_0^\infty e^{-\frac{z_0^2}{2}}dz \tag{13}$$

where z_0 is expressed by:

$$z_o = -\frac{m_{\tau_{adm}} - m_\tau}{\sqrt{\sigma_{\tau_{adm}}^2 + \sigma_\tau^2}} \tag{14}$$

$$z_o = -\frac{m_{\tau_{adm}} - \frac{m_F}{m_A}}{\sqrt{\sigma_{\tau_{adm}}^2 + \sigma_\tau^2}} \tag{14'}$$

or: $$z_o = -\frac{m_{\tau_{adm}} - \frac{4m_F}{\pi m_d^2}}{\sqrt{\sigma_{\tau_{adm}}^2 + \sigma_\tau^2}} \tag{14''}$$

By imposing a certain value of reliability, as high as possible, $R(t)=k$, according to the regular given distribution, the value $z_0=k_2$ is obtained, thus resulting:

$$k_2 = -\frac{m_{\tau_{adm}} - \frac{4m_F}{\pi m_d^2}}{\sqrt{\sigma_{\tau_{adm}}^2 + \sigma_\tau^2}} \tag{15}$$

Analyzing the relation above, it is observed that the terms $m_{\tau_{adm}}, \sigma_{\tau_{adm}}, m_F, \sigma_\tau$ have known values, resulting in a quadratic equation in m_d:

$$m_d^2\pi(k_2\sqrt{\sigma_{\tau_{adm}}^2+\sigma_\tau^2}+m_{\tau_{adm}})=4m_F \tag{16}$$

The solutions to this equation are:

$$m_d^2\pi(k_2\sqrt{\sigma_{\tau_{adm}}^2+\sigma_\tau^2}+m_{\tau_{adm}})=4m_F \tag{16}$$

$$m_{d_{1,2}}=\pm\sqrt{\frac{4m_F}{\pi k_2\sqrt{\sigma_{\tau_{adm}}^2+\sigma_\tau^2}+m_{\tau_{adm}}}} \tag{17}$$

Only the positive solution is adopted, since it represents a positive geometric magnitude.

Considering that the distribution of dimensions follows, in the most probable case, a regular law, then the values of the diameter of the pin, *d* fall in the domain [5]:

$$T_d=6\sigma_d=\left(m_d-3\cdot\sigma_d;m_d+3\cdot\sigma_d\right) \tag{18}$$

and the required diameter of the rotor blade assembly pin can be determined:

$$d=m_{d_1}\pm\frac{T_d}{2}=m_{d_1}\pm\frac{a_{s_d}-a_{i_d}}{2} \tag{19}$$

where a_{s_d} and a_{i_d}, represent the upper and respectively, lower, deviations of the nominal dimension of the pin diameter.

3. CONCLUSIONS

The use of probabilistic methods in the design of resistance structures, including aviation ones, ensures the optimal dimensioning of the constructive elements that have an important functional role. As a side effect of applying this method, there are also constructive elements with a lower mass, as well as savings of materials and time for their realization.

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