1.8.26. THEORETICAL AND EXPERIMENTAL VALIDATION OF THE MODEL OF RADAR SIGNAL REFLECTED FROM STRUCTURES CONTAINING ROTATING ELEMENTS IN RESPECT TO THE PROBLEM OF REMOTE RADIO-WAVE VIBRO-DAGNOSTICS

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At monitoring vibration of ventilators incorporated in complex technical systems (industrial and residential ventilation units, processor unit etc.), using radio wave methods, e.g., Doppler radars, the reliability of validating the efficiency of the corresponding algorithms of recognizing the technical state of a unit depends on the relevancy of modeling the reflected signal. While modeling the signals of secondary Doppler modulation from the objects with rotating parts – propellers, turbines and compressor stages, one has to take into account both the variability of device construction and a wide range of propeller sizes and their angular velocities, which considerably complicates the modeling.

Let us consider the process of back radio wave scattering by a propeller, further generalizing the results to any other construction or configuration of propeller. To analyze the signals reflected by the propeller let us imagine a physical model of a target in the form of a point reflector (bush) and linear reflectors (propeller blades), cylinders with the length R_l fixed at one end in point B and rotating with angular velocity Ω_β (fig. 1).

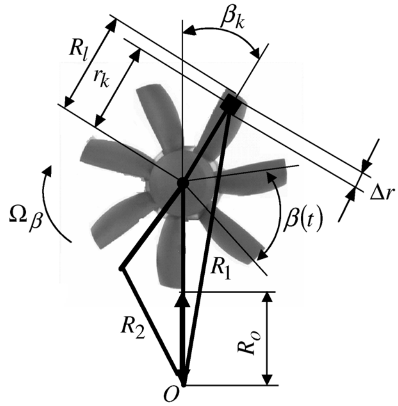

Fig. 1

We may model a blade as a set of elementary reflectors dr. The distance between the vantage point O and elementary reflector located on the blade k at a constant distance from the fuselage R_0 will be

$$R_1 = \sqrt{(R_0 + R_l) + R_l + 2(R_0 + R_l)R_l \cos(\beta_k)}; \tag{1}$$

$$R_2 = \sqrt{(R_0 + R_l) + R_l - 2(R_0 + R_l)R_l \cos(\beta_k)}, \tag{2}$$

where R_l – is the distance from rotation center to the elementary reflector.

At the same time $\beta_k = \Omega_\beta t + k\beta(t)$, where $\beta(t)$ is the angle between adjacent blades, its variance in time is neglectable; $k = 0, 1, ..., N–1$ is a blade number; N is the number of blades. Differentiating (1) and (2) by time we obtain the speed of the distance change relative to two opposite local reflectors:

$$\dot{R}_1 = -\frac{2\Omega_\beta (R_o + R_l)R_l \sin(\beta)}{R_1};$$

$$\dot{R}_2 = \frac{2\Omega_\beta (R_o + R_l)R_l \sin(\beta)}{R_2}.$$

Then $\Delta\dot{R} = 2\Omega_\beta (R_1 + R_2)(R_1 R_2)^{-1}(R_o + R_l)R_l \sin(\beta)$. Taking into account that the Doppler frequency shift is defined by the expression $F_D = 2\dot{R}/\lambda$, where λ is the radar wave length, we get an expression for the Doppler fluctuation spectral width

$$\Delta F = \frac{4\Omega_\beta}{\lambda}\left(\frac{R_1 + R_2}{R_1 R_2}\right)(R_o + R_l)R_l \sin(\beta),$$

where $R_0 >> R_l$ (which can be easily reached by choosing the radar location).

It is clear that the maximum spectrum width of the Doppler fluctuations is $\Delta F_{\max} \approx \approx 4\Omega_\beta R_l \lambda^{-1}$. As the propeller angular velocity is limited by the value $\Omega_\beta = V_{\max} / R_l$, then $\Delta F_{\max} \approx 4V_{\max} / \lambda$ [1].

In the paper [2], for a continuous probing signal of the frequency $\omega_0 = 2\pi c / \lambda$, a signal reflected from the blade is described as follows:

$$\begin{cases} u_{\ln}(t) = \sum_{k=0}^{N-1} U_{\ln} \dfrac{\sin\{m\cos(\Omega t + k\beta)\}}{m\cos(\Omega t + k\beta)} \cos((\omega_0 + m\Omega)t + \varphi_0); \\ u_{lo}(t) = \sum_{k=0}^{N-1} U_{lo} \dfrac{\sin\{m\cos(\Omega t + k\beta)\}}{m\cos(\Omega t + k\beta)} \cos((\omega_0 - m\Omega)t + \varphi_0), \end{cases}$$

where $U_l = U_r R$ is the amplitude of a signal reflected from the blade; $m = 2R / \lambda$, $\varphi_0 = –4\pi R_0 / \lambda$.

The signal reflected from the present model consists of a periodic sequence of pulses from the approaching and moving away blades. The pulse duration of both blades is $\tau_u = \lambda / \Omega_\beta R$; assuming that $\Omega_\beta = V_{\max} / R$ one may conclude that duration of a signal reflected from a blade of any length in steady state depends only on the wave length of a probing signal $\tau_u = \lambda / V_{\max}$. Taking into account z-fold multiplication, the spectrum width of Doppler fluctuations becomes $\Delta F_{\max} \approx 8\pi F R_l / \lambda$ and its periodicity – $T_p = = (zF)^{-1}$.

Hence the time-and-frequency structure of the radar signal reflected from a ventilator is mainly determined by the number of blades, their kinematical characteristics, aspect angle and the length of the illuminating wave.

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