CALCULATION OF THE PARAMETERS OF AN ORTHOGONAL ROTOR IN A OPEN FLOW

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At present, under conditions of no effective mechanism regulating economic relations, of no centralized funds for the development of energy resources in almost the entire territory of Russia, the question arises acutely of using the energy of renewable resources by means of maximally cheap, but at the same time sufficiently effective, converters. Some such variants of a power plant converting the energy of flows in both open air and water flows are orthogonal rotors (ORs) developed on the basis of airfoil profiles [1, 2, 3, 4].

The Research Institute of Power Structures (NIIES) jointly with the State Planning, Surveying, and Research Institute (Gidroproekt) as a result of research and development designed ORs for a open flow based on a NASA-type airfoil profile having energy parameters considerably exceeding foreign analogues. The ORs were investigated in open flows by numerical and physical methods at NIIES as well as at the experimental facilities of the E. N. Zhukovskii Central Aerohydrodynamic Institute (TsAGI); the performance characteristics were obtained, the operating characteristics were plotted, the lines of limitation and guaranteed indices were determined, and the influence of the scale effect on the maximum energy indices was determined.

Before we proceed to presentation of the method of determining the parameter of ORs, it is necessary to say several words about the performance characteristic taken as the design one.

Figure 1 shows the performance characteristics $C_N(U_h)$ obtained by the method of mathematical modeling of the process of interaction of the OR with the flow (curve 1), flow test in a hydraulic flume of a small-scale model of an OR (curve 2), and wind-tunnel test of a large-scale model (curves 3 and 4) under free-flow conditions.

The performance characteristic (curve 1) was obtained with the use of the steady aerodynamic characteristic of the airfoil profile obtained in a wind-tunnel test at a Reynolds number determined with respect to the chord length of the blade and velocity of the flow past the blade $Re_{b,f} = 1 \cdot 10^6$ under conditions of a low degree of turbulence of the flow (0.2-2.0% [5]). The performance characteristics of a large-scale model (curves 3 and 4) in the range of Reynolds numbers determined with respect to chord length of the blade and its linear velocity $Re_{b,t} = (3.3-8.4) \cdot 10^5$ were obtained within the same limits with respect to degree of turbulence of the flow. Figure 2 shows the dependence of the maximum value of the power utilization factor $C_{N,\text{opt}}$ on the Reynolds number $Re_{b,t}$ under the conditions of which each of the characteristics was obtained. The Reynolds number $Re_{b,t}$ corresponding to the optimal regime of curve 1 and proportional to $Re_{b,f} = 1 \cdot 10^6$ will be $\sim 1.5 \cdot 10^5$ (A, Fig. 2) and, consequently, the range of Reynolds numbers in Fig. 2 become represented by values from the minimum to the prototype under conditions of a low degree of turbulence of the flow.

The experiment in the hydraulic flume (curve 2) [7] was conducted under conditions of a higher degree of turbulence of the flow for Reynolds numbers $Re_{b,t} = 1.5 \cdot 10^5$. The value of turbulence intensity for hydraulic flumes is 5-10% [8]. It is known that an increase of the initial turbulence of the flow is accompanied by an improvement of the aerodynamic indices of NASA-type airfoil profiles with a thickness ratio $\varepsilon$ up to 18% [9]. Under natural conditions in a water flow the intensity of the initial turbulence is 5-20% [10]. In this sense the performance characteristic obtained in the hydraulic flume is closest to the real one under natural flow conditions. However, taking into account that curve 2 was obtained under conditions of small Reynolds numbers $Re_{b,t}$ the characteristic obtained under conditions of Reynolds numbers close to the prototype was taken as the design one for the basic energy indices of the OR (curve 1, Fig. 1).

*In view of the absence in publications known to the author of data on wind-tunnel studies of the proposed design of an OR, the performance characteristics of an OR (curves 3 and 4) [6] taken from conditions of equality of the solidity $\sigma$ and aspect ratio of the rotor $\lambda_d$ for all variants of investigating the OR are used in the present article for a comparative analysis.
Fig. 1. Dependence of the power utilization factor of the flow $C_N$ on the relative blade speed $\bar{U}_b$: 1) calculation according to D. N. Militeev's model, $Re_b, t = 1 \cdot 10^6$; 2) experiment in hydraulic flume, $Re_b, l = 1.5 \cdot 10^5$ [7]; 3) experiment in wind tunnel, $Re_b, l = 3.3 \cdot 10^5$ [6]; 4) experiment in wind tunnel, $Re_b, l = 8.4 \cdot 10^5$ [6].

Fig. 2. Dependence of the maximum power utilization factor of the flow $C_{N, opt}$ on the Reynolds number determined with respect to the chord length of the blade and linear velocity of the blade $Re_b, t$: (3) experiment in wind tunnel at TsAGI with model of OR [6]; Δ) calculation (point A).

Fig. 3. Dependence of the rotor area $S$ on the design flow velocity $U_0$ for a series of unit rotor powers $N_r$.

Fig. 4. Dependence of the rotor speed $n$ on the design flow velocity $U_0$ for a series of unit powers $N_r$. 