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WIND POWER UNITS 'S PROTECTION OF ROTARY TYPE IN UNFAVOURABLE CLIMATE CONDITIONS

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Transition to alternative energy sources is a universal tendency and it is realized with broad political support of many countries, including in the Republic of Kazakhstan. In this regard there is a problem of use of the power equipment in unfavourable climate conditions. Contribution of wind power plant (WPP) in winter time in Northern, Central and East Kazakhstan is fraught with very serious consequences. There multi-day blizzards (snow-storms) leading to drift by a sleet of open surfaces of the device with the subsequent formation of a dense snow and ice armor are frequent, such as, it happens to WPP. At big frosts freeze through bearings, as a result of WPP fails up to destruction under the pressure of a wind. Below it is considered how this problem is solved on the example of wind driven generator in Kazakhstan.

Keywords: thermal protection, Reynolds analogy, coefficient of hydraulic resistance, Darieus wind turbine, NASA 0021.

Introduction

Contribution of wind power plant (WPP) in winter time in Northern, Central and East Kazakhstan is fraught with very serious consequences. There multi-day blizzards (snow-storms) leading to drift by a sleet of open surfaces of the device with the subsequent formation of a dense snow and ice armor are frequent, such as, it happens to WPP (see a photo in fig. 1). At big frosts (20-35 degrees C) freeze through bearings, as a result of WPP fails up to destruction under the pressure of a wind.

At the Physical department of Kazakh State Women's Teacher Training University within the last 10-12 years researches of wind power unit of rotary type with the working blades executed in the form of the wing NASA profile – 0021 [1], including works on thermal protection of the rotating device elements that allows to support them in a dry and warm state under any adverse meteo conditions are conducted. Interest in wind turbine units to Darieus [2] is caused not only simplicity of their production, but, first of all, opportunity to receive high efficiency of wind power $\xi = 0{,}7$ from the same disk area [2].

Experimental technique

For studying of regularity of heat exchange of the wing NASA 0021 profile with the air stream running on it at a rotary motion of the wind turbine the reduced hollow model representing an element of the wing NASA profile from a copper plate 0,2 mm thick was made. Length of an element of a wing profile $l = 35{,}15 \times 10^{-2}$, a chord in $= 3{,}25 \times 10^{-3}$ m. In a middle part of a metal experimental table there was a special rotary mechanism which allowed to establish an element of a wing profile at any angle to the air stream accumulating on it from an exhaust outlet of a wind tunnel (0,3 x 0,12 sq.m). The experimental table was established so that to provide of an overrunning stream only on the studied object. On an internal cavity of an element of a wing the warmed-up air from the muffle furnace at four values of its expense (0, 00103 m^3/s, 0, 00153 m^3/s, 0, 00203 m^3/s, 0, 00253 m^3/s) proceeded.

2 big series of experiences were carried out under identical conditions. In one series the element of a wing was turned in relation to a stream in one party ($0 \le +\varphi \le 16^0$), in the second

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series - in another ($0 \leq -\varphi \leq 16^0$). Processing joined arithmetic-mean values of data. A restriction $+/-\varphi \leq 16^0$ it is connected with that at rotation of the wind turbine to Darieus the maximum angle of attack doesn't exceed this size. In total 400 experiments were made.

As shown in [3], under the influence of centrifugal forces in hollow elements of the rotating wind turbine spontaneously there is a natural ventilating movement of air. The way of thermal protection of a wind power unit is based on this effect. In the experiments described above action of centrifugal forces was replaced with forcing of the warm air to the canal having a form of the wing NASA 0021 profile. Thus it was succeeded to establish also coefficient of hydraulic resistance of such channel [4, 5]

$$\zeta = 4{,}62 \cdot Re_u^{\ -0{,}488}\ , \qquad (1)$$

$$Re_u = (u_{mid} \cdot d_э) / \nu\ ,$$

where u_{mid} - average flow rate, $d_э$ - airfoil effective diameter, ν - kinematic viscosity of the air.

Theory

The angle of attack φ does not influence on heat exchange because of small change interval φ as shown in experiment. Main role belong to velocity of attack V and consumption of warm air Q.

In experiments were studied difficult cross heat exchange with variable temperature along length of flowing canal taking place by linear law

$$T = T_0 - (T_0 - T_1)\frac{z}{l} = T_0 - (T_0 - T_1)\bar{z}\ , \qquad (2)$$

where T_0 and T_1 - accordingly air temperature on coming in and coming out from canal.

Fig.1. Crimea. Ay-Petri wind turbine in winter

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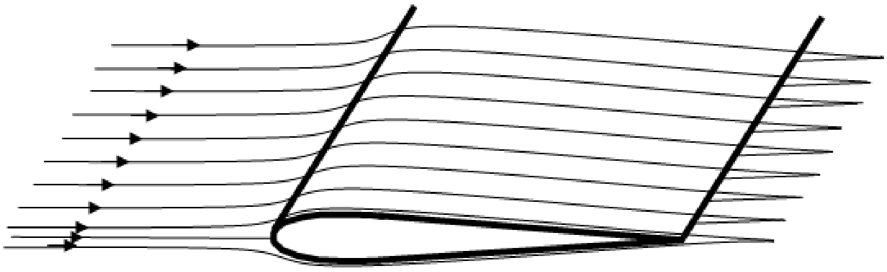

Fig.2. Scheme of continuous flow of NASA profile wing

In common case heat transfer of canal to surroundings described with two equations

$$q_{w1} = \alpha_{w1} F_1 (T - T_{w1}) \tag{3}$$

$$q_{w2} = \alpha_{w2} F_2 (T_{w2} - T_{\infty}), \tag{4}$$

where α - heat-transfer coefficient, indices 1 and 2 shows internal and external meaning of value, at that

$$q_{w1} = q_{w2} . \tag{5}$$

In view of smallness of researching model walls thickness may be accepted $F_1 = F_2 = F$ and $T_{w1} = T_{w2} = T_w$. Obviously, because of invariability of conditions of heat exchange by length of canal, temperature of wall also submits to linear law

$$T_w = T_{w0} - (T_{w0} - T_{w1})\,\bar{z}, \tag{6}$$

which means $T - T_w = T_0 - T_{w0} = T_1 - T_{w1} = \text{const}$.

Two equations (3) and (4) is not enough to find 3 unknowns α_1, α_2 и T_w. This problem can be solved by Reynolds analogy which is correct both for continuous longitudinal flow of naked plate and in case of flow in canal. In first case (external sum) heat transfer law is written

$$q_{w2}(x) = \tau_{w2}(x)\, c_p\, (T_w - T_{\infty}) / u_{\infty}, \tag{7}$$

In second case (internal sum)

$$q_{w1} = \tau_{w1}\, c_p\, (T - T_w) / u_{mid} . \tag{8}$$

In case of continuous flow of NASA 0021 wing profile with vertical flow in narrow interval of attack angle change can be consider the process of heat transfer that follow to relation (7), directing coordinate “x” along perimeter of wing “Φ”

$$q_{w2}(\Phi) = \tau_{w2}(\Phi)\, c_p\, (T_w - T_{\infty}) / V.$$

The scheme of wing flow is shown on Fig.2.

As known [6], $\tau_{w2}(x) = 0{,}0296 \cdot \mathrm{Re}_x^{-0{,}2} \cdot \rho u_{\infty}^2$ where $\mathrm{Re}_x = u_{\infty} x / \nu$. In our case $\mathrm{Re}_x = \mathrm{Re}_v = \dfrac{V\Phi}{\nu}$, $\tau_{w2}(\Phi) = 0{,}0296 \cdot \mathrm{Re}_v^{-0{,}2} \rho V^2$.

It is also known [5], for channel flow $\tau_{w1} = \zeta \dfrac{\rho u_{cp}^2}{8}$.

Equating (7) and (8) to each other we can find

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$$\mathrm{T}_{w} = (\mathrm{T} + \Omega\, \mathrm{T}_{\infty}) / (1 + \Omega), \tag{9}$$

where
$$\Omega = \frac{\tau_{w2} u_{cp}}{\tau_{w1}} V = 0.0512 \frac{d_{э}}{\Phi} \frac{\mathrm{Re}_{v}^{0.8}}{\mathrm{Re}_{u}^{0.512}}.$$

Relying on (2), (6) and taking into consideration that Ω is not depending from $\bar{z}$ we can write final formula

$$\overline{\mathrm{T}}_{\mathrm{w}} = \frac{\overline{\mathrm{T}} + \Omega T_{\infty}}{1 + \Omega}, \tag{10}$$

where
$$\overline{\mathrm{T}} = \frac{\mathrm{T}_0 + T_1}{2}, \quad \overline{T}_W = \frac{T_{w0} + T_{w1}}{2}$$

The methods of physical modeling based on similarity theory of hydrodynamic and heat-mass exchange processes on model and real object of heat exchange [6-11]. That is why it is natural to ascertainment the dependence of Nusselt criteria (Nu_2) from Re_{v} and Re_{u} , where $Nu_2 = \frac{\alpha_2 \Phi}{\lambda}$ defining heat transfer from lateral surface of researching element of NASA 0021 wing profile to running external flow on it

$$\mathrm{q}_0 = \rho \mathrm{u}_{\mathrm{mid}} \mathrm{SCp}\,(\mathrm{T}_0 - \mathrm{T}_1) = q_{2} = \alpha_2\, \Phi\, (\overline{\mathrm{T}}_W - \mathrm{T}_{\infty}),$$

where $\overline{T}_W$ is defined from formula (10). Taking for air that Pr = 1, $C_p = \frac{\lambda}{\mu}$ it is easy to find

$$Nu_2 = \frac{\alpha_2 \Phi}{\lambda} = \frac{T_0 - T_1}{T_0 + T_1 - 2T_{\infty}} \frac{\Phi\, \mathrm{Re}_u + 0.0128 d_{э}\, \mathrm{Re}_V^{0.8}\, \mathrm{Re}_u^{0.488}}{2l} \tag{11}$$

Processing of experimental data showing changes of function $\frac{T_0 - T_1}{T_0 + T_1 - 2T_{\infty}}$ and submits to similar linear law

$$\frac{T_0 - T_1}{T_o + T_1 - 2T_{\infty}} = 0.638 - 1.8 * 10^{-5}\, \mathrm{Re}_u. \tag{12}$$

Putting (12) to (11), we finally obtain

$$Nu_{и} = (0.32 - 9 \cdot 10^{-6}\, \mathrm{Re}_u) \frac{\Phi\, \mathrm{Re}_u + 0.0128 d_{э}\, \mathrm{Re}_V^{0.8}\, \mathrm{Re}_u^{0.488}}{l}. \tag{13}$$

Conclusion

The criteria dependence (13) is correct for all cases of heat transfer of NASA 0021 airfoil to free stream, if its internal cavity where warm air flows also has a shape of NASA 0021. Herewith it is possible to create the airfoil from any material with wall thickness Δ, which should be considered as a flat slab.

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Designations

$z = z / l$ - the dimensionless coordinate, along the length l of the testing wing element, F - channel's area surface, Φ - airfoil perimeter.

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