

ЖЫЛУ ФИЗИКАСЫ ЖӘНЕ ТЕОРИЯЛЫҚ ЖЫЛУ ТЕХНИКАСЫ ТЕПЛОФИЗИКА И ТЕОРЕТИЧЕСКАЯ ТЕПЛОТЕХНИКА THERMOPHYSICS AND THEORETICAL THERMOENGINEERING

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K.Kussayinov¹, N.K.Tanasheva^{1,2}, N.N.Shuyushbayeva²,
Yu.N.Ryzhykh³, Yu.O.Stepanova¹, S.B.Bagdatova¹

¹Ye.A.Buketov Karaganda State University;

²Sh.Ualikhanov Kokshetau State University;

³The National Research Tomsk State University, Russia

(E-mail: sanduyo@mail.ru)

Simulation of airflow pattern of two rotating cylinders

The article discusses calculations of numerical simulation of airflow pattern of two rotating cylinders at low wind speed. The authors obtained universal dependences on aerodynamic characteristics of the incoming flow rate at a constant angular velocity. They also found aerodynamic characteristic of rotating cylinder in a turbulent air stream and analyzed the flow pattern of two rotating cylinders, vorticity field, drag and lift coefficients.

Key words: numerical simulation, rotating cylinders, aerodynamic characteristics, flow pattern, turbulent flow.

Introduction

Currently the advent of high tech industrial and domestic installations leads to an increase of energy consumption for the maintenance of electricity consumers. The decrease of coal, oil and natural gas reserves forces us to search for a new alternative source of energy. These sources include devices running on solar, wind and water energy.

It is difficult to use hydro energy in our country because there are few large rivers used to build hydro-power. Since we have many areas where the wind blows regularly, one of the research directions is devoted to the study of wind energy and the devices based on it.

The first attempts to create such devices were made in early 90's. The wind-driven electric plant constructed by A.V. Bolotov [1–4] is widely used nowadays and is constantly susceptible to any wind direction and to velocity due to gyroscopic effect at rotor rotation in which an increase of turbine power occurs via the guiding unit.

Another popular installation today is construction of Russian scientist N.M. Bychkov. It is wind turbine with rotating cylinders, using the Magnus effect in its operation, characterized by the lift appearance (the Magnus force) during cylinder rotation in a crossflow. This force used to rotate wind wheel, similar to lift of the blade, but it has a much greater value [5].

Methods of measurement

In this article we consider numerical simulation of two parallel air flow rotating cylinder in the chamber of wind turbine. We received the values of aerodynamic characteristics of installation. The experimental research [6] conducted in wind turbine T-1-M with open working area, diameter of which was 500 mm. Air flow velocity was changing in the range between 2,5 m/sec and 10 m/sec. The incipient turbulence was 3%. Diameters of the tested cylinders was 100 mm, velocity of rotation 100/1500 rpm. Drag and lift forces were measured by three-component aerodynamic balance.

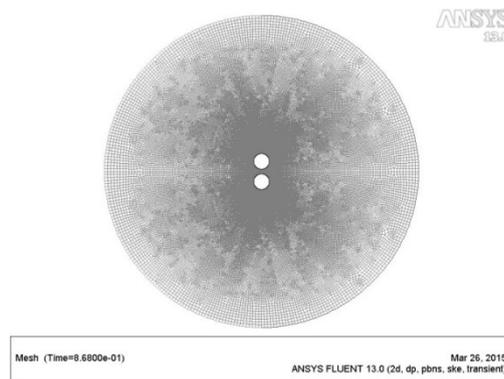


Figure 1. Numerical simulation area

The settlements for numerical simulation flow of rotating cylinder were made using software package Ansys Fluent. The finite-difference grid of two rotating cylinder was built in the Gambit 2.3.16 software. Analytical grid with concentration to cylinder surface was used (Fig. 1). Cylinders were placed in the center, the distance between them was 2 cm. The number of cells was 130 000 thousand. Angular velocity and rotating direction were given.

The system of equations describing the flow of gas is represented in the form:

$$\frac{\partial \vec{V}}{\partial t} + (\vec{V} * \nabla) \vec{V} = \vec{F} - \frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{V} \quad (1)$$

$$\text{div} \vec{V} = 0.$$

Boundary conditions. Boundary conditions *at the wall*.

No slip condition.

$$\vec{V} = 0; \quad \frac{\partial k}{\partial n} = 0, \quad \varepsilon_p = \frac{C_\mu^{3/4} \cdot k_p^{3/2}}{k \cdot y_p} \quad (2)$$

where $k = 0, 4187$ — the Karman's constant; index P — refers to the center of the cell wall of difference grid.

Boundary condition *at the input*.

$$U = U_{in}; V = 0.$$

Turbulent flow parameters are defined by specifying the intensity of turbulent pulsations I and hydraulic diameter D_{hyd} :

$$k = \frac{3}{2} (I \cdot V_{inlet})^2; \quad \varepsilon = C_\mu^{3/4} \cdot \frac{k^{3/2}}{\ell}; \quad \ell = 0.07 \cdot D_{hyd} \cdot I = 3\%$$

Boundary condition *at the outlet*:

$$\frac{\partial \phi}{\partial x} = 0.$$

Standard set of empirical constant (1) used for k - ε model is usually default in the computing package:

$$C_\mu = 0.09, C_{\varepsilon 1} = 1.44, C_{\varepsilon 2} = 1.92, \sigma_k = 1.0, \sigma_\varepsilon = 1.3.$$

The measurement environment was taken in accordance with aerodynamic tube size. It is a spherical area with the model inside it (Fig. 1).

Discussion of the results

A picture of pressure distribution in numerical integration (Fig. 2) and current line (Fig. 3) was obtained in the course of numerical simulation.

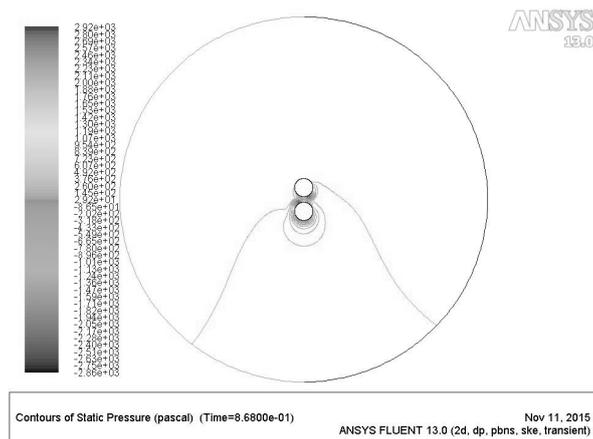


Figure 2. Full pressure distribution area

Figure 2 shows that at the point of contact of pressure pattern of each cylinder there is a high pressure between cylinders and rarefaction zone outside the cylinders.

There is current line distribution area in Figure 3, we can observe formation of two circulation areas. One circulation area is in the lower part of cylinder as it moves in a clockwise direction, and the second area is on the top of the cylinder as it moves counterclockwise. We can say that they are symmetrical relative to the symmetry axis that goes through the center of cylinder. And we may assume that eddyfree zone would occur between two circulating areas.

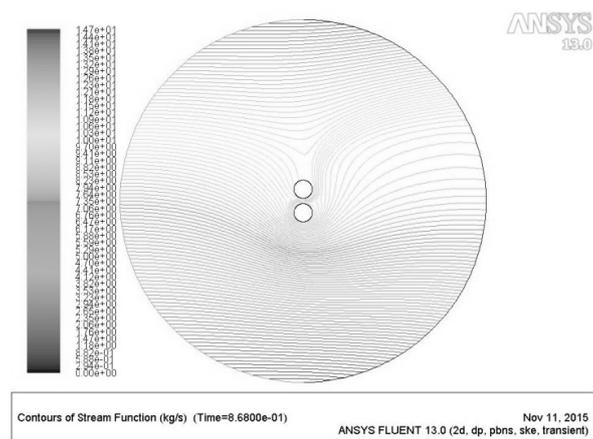


Figure 3. Current line distribution area

Figure 4 and 5 show the dependence of drag and lift force on incoming flow rate at turbulence intensity of 10% and at a constant angular velocity of 1000 rpm.

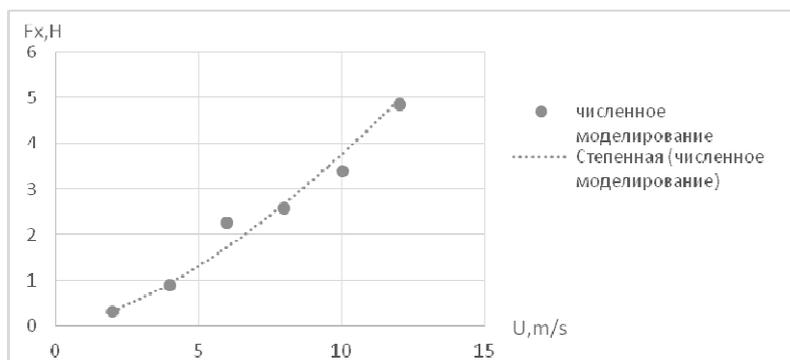


Figure 4. Dependence of drag and lift force on incoming flow rate at angular velocity of 1000 rpm

Numerical experimentation data approximated by power law relationship: $F_x = 0.1116 \cdot V^{1.5289}$. As incoming flow rate increases, the drag force also increases. Numerical experimentation data shown in figure 5 approximated by polynomial dependence $F_y = -0.2257V^2 + 4.9479V - 3.7068$. From the graph, we can see that the drag force increases as the incoming flow rate increases, but as it reaches its maximum value of 10 m/sec, it starts to decrease.

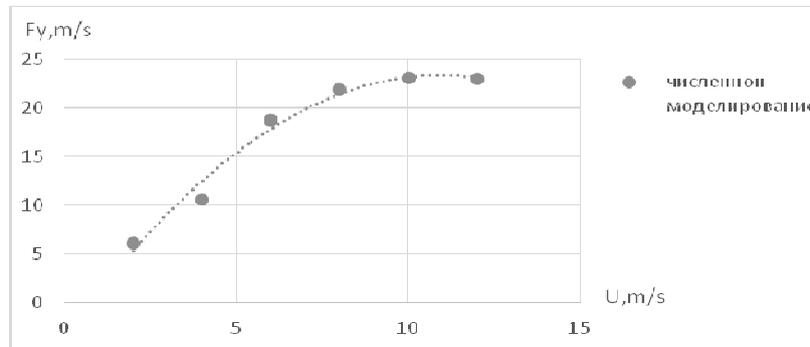


Figure 5. Dependence of drag force on incoming flow rate at angular velocity of 1000 rpm

Figure 6 shows the dependence of drag coefficient on Reynolds number at a constant angular velocity of 1000 rpm. Numerical experiment data approximated by power law relationship $C_x = 160.81 \cdot Re^{-0.471}$. Drag coefficient decreases as Reynolds number increases.

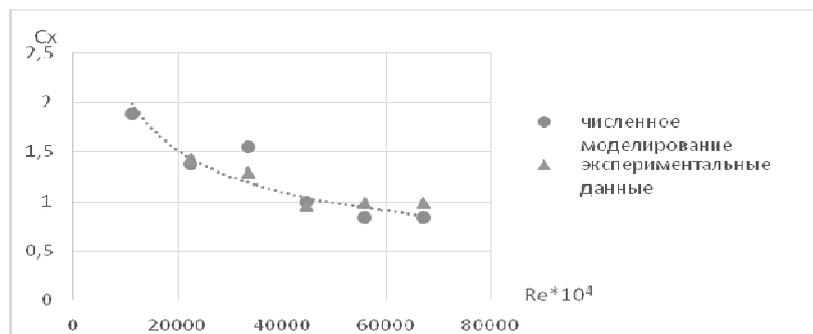


Figure 6. Dependence of drag coefficient on Reynolds number at angular velocity of 1000 rpm

Figure 7 shows the dependence of lift coefficient on Reynolds number at constant angular velocity of 1000 rpm. Numerical experiment data approximated by power law relationship: $C_y = 3e + 0.6Re^{-1.202}$. Lift coefficient decreases as Reynolds number increases, but with further increase of Re, we may assume that lift coefficient would reach its maximum and would not decrease any more.

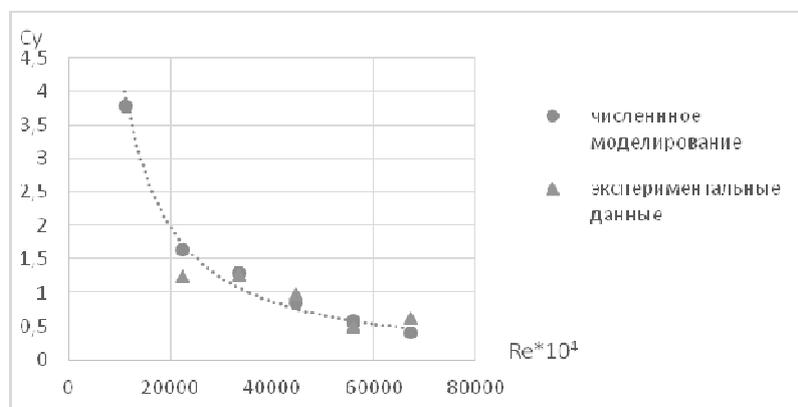


Figure 7. Dependence of lift coefficient on Reynolds number at angular velocity of 1000 rpm

Summary

Thus, the pattern of full pressure distribution in numerical integration was obtained. It has been established that the air flow around two rotating cylinders leads to the occurrence of high pressure area in the point of contact of pressure fields of each cylinder, and rarefaction zone outside the cylinder. Universal dependences of aerodynamic characteristics on incoming flow rate at a constant angular velocity were obtained based on numerical simulation and conducted experiment. It also included airflow pattern around two rotating cylinder explaining the behavior of aerodynamic characteristics.

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Қ.Құсайынов, Н.К.Танашева, Н.Н.Шуюшбаева,
Ю.Н.Рыжих, Ю.О.Степанова, С.Б.Бағдатова

Ауаның ағынымен екі айналмалы цилиндрлерді орап ағуын модельдеу

Мақалада желдің аз жылдамдығы кезіндегі айналмалы екі цилиндрлерді ауа ағынымен орап ағуының сандық модельдеу есебі келтірілген. Авторлармен тұрақты бұрыштық жылдамдық кезінде жүріп өтетін ағын жылдамдығынан аэродинамикалық сипаттамалардың эмбебап тәуелділіктері алынды. Сондай-ақ ауаның турбулентті ағынында айналмалы цилиндрлердің аэродинамикалық сипаттамалары айқындалған. Екі айналмалы цилиндрдің орап ағуы, құйындалу өрісі, кетеру күші мен маңдай алды кедергі коэффициенттері жан-жақты талданды.

К.Кусаиынов, Н.К.Танашева, Н.Н.Шуюшбаева,
Ю.Н.Рыжих, Ю.О.Степанова, С.Б.Бағдатова

Моделирование картины обтекания двух вращающихся цилиндров потоком воздуха

В статье приведен расчет численного моделирования обтекания потоком воздуха двух вращающихся цилиндров при малых скоростях ветра. Авторами статьи получены универсальные зависимости аэродинамических характеристик от скорости набегающего потока при постоянной угловой скорости. Также получены аэродинамические характеристики вращающихся цилиндров в турбулентном потоке воздуха. Проанализирована картина обтекания двух вращающихся цилиндров, поля завихренности, коэффициенты лобового сопротивления и подъемной силы.

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