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DEVELOPMENT A SAIL TYPE WIND TURBINE FOR AUTONOMOUS ENERGY SUPPLY ACCORDING CLIMATE CONDITIONS

Sakipova S.E.¹, Jakovics A.², Gendelis S.², Kambarova Zh.T.¹, Kussaiynov Ye.K.¹¹E.A.Buketov Karaganda State University, Universitetskaya Str.28, Karaganda, 100028, Kazakhstan, sesaule@mail.ru²University of Latvia, Zellu Str.8, Riga, LV-1002, Latvia, andris.jakovics@lu.lv

The paper discusses the problem of creating autonomous power supply system based on renewable resources according to climatic conditions. The authors studied the characteristics of climate and wind energy potential in Kazakhstan and Latvia and considered the possibilities of creation of a device to convert wind energy at low speed wind. The paper describes an experimental model of a wind turbine with flexible sails. Initial tests of a sail type wind turbine model with dynamically changeable sail shape were carried out at a wind tunnel. The dependencies of the drag force and traction force at various speeds and directions of airflow were obtained. The assessment of the prospects for use of small wind turbines for individual energy supply in both countries was considered.

Keywords: renewable resource, wind energy potential, sail type wind turbine, flexible sail; drag force, traction force.

Introduction

Now it is quite possible to supply the necessary energy for human activity, using advanced ways of renewable energy. The worldwide demand for energy keeps increasing and this is particularly true in most rapidly developing economies [1-4]. The most suitable alternative energy source is the wind. In view of the problems surrounding the supplies of conventional fossil fuels and their volatile prices, wind energy is an indigenous power source which is permanently available in every country in the world. Unlike fossil fuels, wind energy is virtually inexhaustible, widely available everywhere and more environmentally friendly.

In recent years the power growth rate of wind-driven power plants (WDPP) in the world has averaged 26%, which is much higher than the power growth rate of all other types of power plants. Experts claim that every five years, this figure will be doubled, and by 2020 to 18-20% of the entire energy in the world will be produced by the wind [5].

Currently, when the European Commission proposed a complete abandonment of nuclear energy, the program to reduce traditional energy sources is supported at the state level. The aim of the European Union (EU) countries is to increase the share of the wind power up to 20% of total energy consumption by 2020. Some EU countries have already achieved these targets, and wind power engineering is one of the fastest growing industries. In September 2012 the European Wind Energy Association (EWEA) has announced that the total installed capacity of wind power stations in the EU came up to 100 GW, half of which had been put to work in the previous six years. It is important that this amount of installed capacity is enough to provide electricity to 57 million residential buildings throughout the year, [5].

As an EU member Latvia has an obligation to implement 23% Renewable Energy Resource (RES) of the total energy consumption by 2020 [6]. In Kazakhstan national objectives were posed; according to them, in 2024 it is planned to produce 5 TWh of energy from renewable sources [7]. These facts indicate that the energy consumption in cities and large enterprises increasingly use RES, including wind power. At the same time detached small household buildings and homes outlying the central power transmission lines are neglected. Today, Kazakhstan has about 200000 farms, of which 90 % have no access to centralized power supply. The cost being a vital factor for determining how any power project will be feasible. For example, in the Ref. [4] authors demonstrated that grid-connected wind power plant will be technically and financially viable and

competitive only at a certain minimum feed-in-tariffs together with some incentives. The monthly mean wind speeds at various were used to determine the annual energy production of wind farm.

Actually, at long range electrical power networks maintenance, electric power losses of electricity amount to almost 30%. This makes centralized power supply to remote consumers unprofitable. In Kazakhstan the potential of renewable energy sources is not still adequately used, and the development of renewable energy sources would be particularly effective for power generation at the local level, as well as for small distributed loads [8]. Thus, the development and creation of small wind-driven power plants operating at low wind speeds and adapted to the climatic conditions, are relevant both in Latvia and Kazakhstan. The problem is that wind turbines generally do not operate efficiently under conditions of low winds, i.e. at a wind speed of less than 3 m/s. The use of commercial wind turbines of small or medium power is uneconomical, since they do not operate at such wind speeds.

A comparative analysis of data on wind energy potential in Latvia and Kazakhstan

The proportion of wind power engineering in total energy consumption in Kazakhstan, as well as in Latvia is less than 1%. Introduction of technologies for converting wind energy still remains a problem, since, despite the different geographical location, in most parts of these countries there are areas with values of an average annual wind speed of about (3-4) m/s. Latvia has a high potential of wind energy only along the coast of the Baltic Sea. You can see on wind map of Latvia that areas with the greatest wind speeds are only in the coastal zone of the Baltic Sea and in the northern part of the eastern coast of the Gulf of Riga. Wind speed in these areas reaches 5.1-6.8 m/s and more [9, 10]. Width of the area with strong winds on the coast of the Baltic Sea is 15-20 km, and in the area of the Gulf of Riga is about 10-15km. This picture of wind potential is confirmed by regular wind speed measurements performed by the office workers of the Latvian Center for Environment, Geology and Meteorology at the meteorological station located near the international airport of Riga [11], Fig.1.

More accurate wind speed values in Riga can be obtained from the results of automated measurements performed continuously at a weather station based in Botanical Garden of the University of Latvia [8], Fig.2, 3. These data were obtained using a measuring apparatus Laboratory for Mathematical Modelling of Environmental and Technological Processes of University of Latvia.

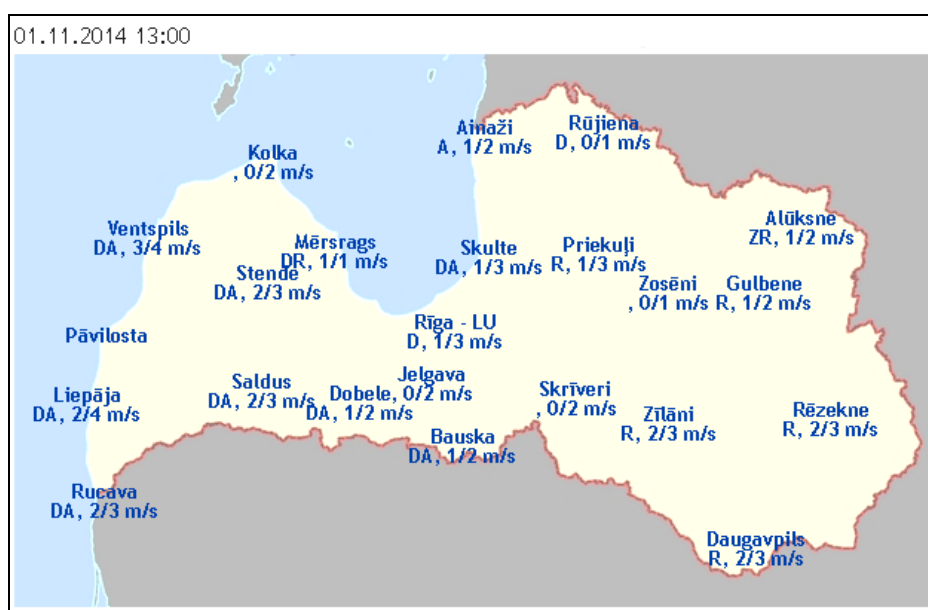


Fig.1. Example of on-line data on wind speed in Latvia

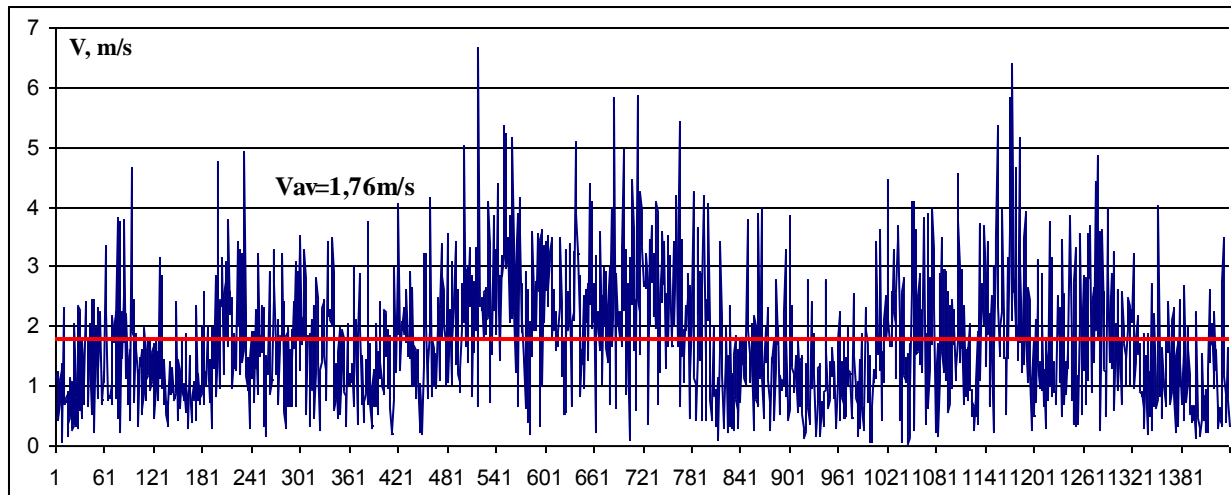


Fig.2. Every minute wind speed change during the day (07.01.2014) in Riga.

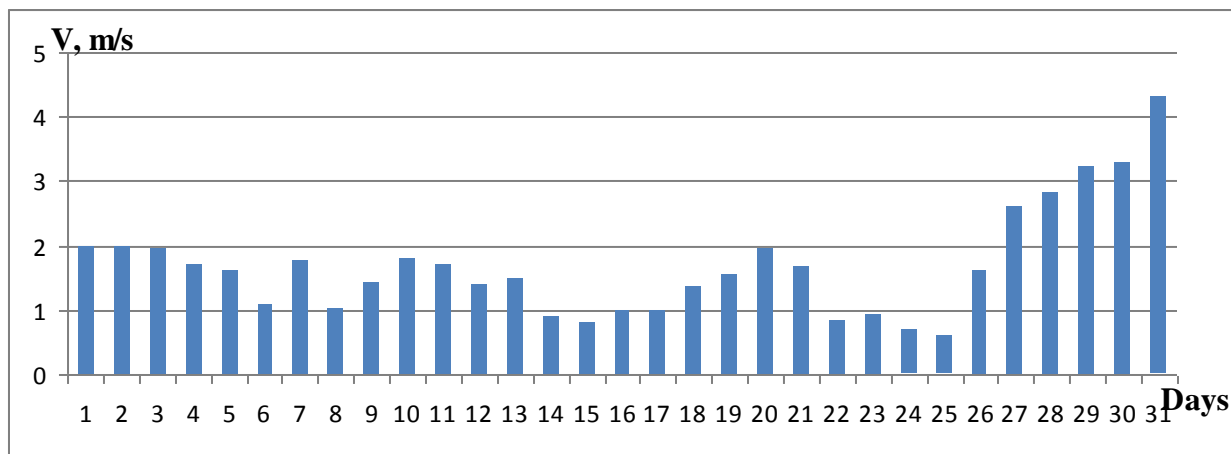


Fig.3. Wind speed change during January 2014 in Riga.

According data analysis in 2013-2014 an average annual wind speed is $V=1.12$ m/s in Latvia. Measurements show that in the central part of Latvia, an average wind speed is (3-4) m/s; in Riga the wind speed is even smaller and varies from 1.09 m/s to 2.8 m/s.

A similar picture of the wind potential can also be seen on the map of winds in Kazakhstan [10]. Fig.4 shows wind map of Karaganda region, wind speed was measured at a height of 80 meters in 2014 [12]. Due to its geographical position, the Republic of Kazakhstan is in a wind zone of the northern hemisphere and in some regions of Kazakhstan there are sufficiently strong air currents.

For example, according to the data of weather stations in Karaganda region in 2014, in the central part of Kazakhstan the average annual wind speed measured at a height of 80m, and in Karaganda city wind speed is less, Fig. 5.

Use of manufactured in production scale small or medium power WDPP are economically unprofitable, since at these wind speeds, they do not work. For this purpose, it is necessary to take into account specific features of the climate in the area, in this case, the wind speed and its direction.

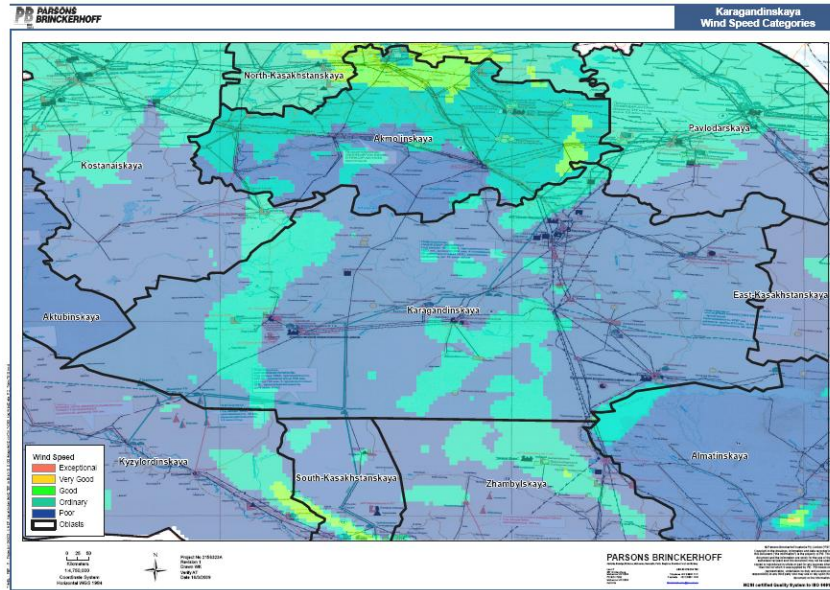


Fig.4. Wind map of Karaganda region, 2014.

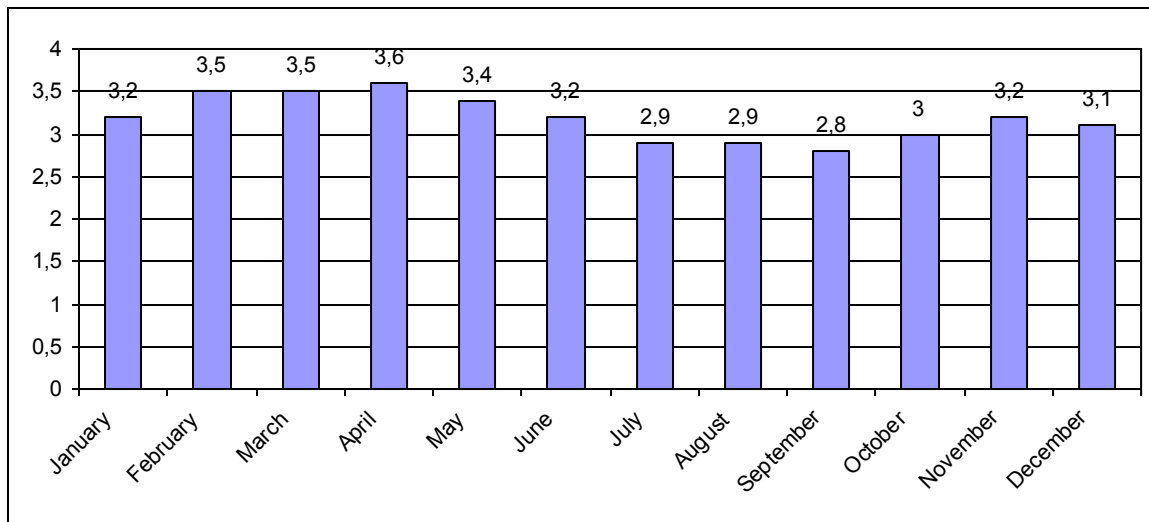


Fig.5. Monthly change of average wind speed in Karaganda city, 2014.

EXPERIMENTAL TECHNIQUE

Wind turbine or wind power unit (WPU) is a device for converting the kinetic energy of wind flow into mechanical energy of rotation of the rotor and its further conversion into electric energy. Its main difference from the conventional thermal electric and atomic power plants, as well as its advantage, is the complete absence of both raw materials and waste. Practice shows that the correctly selected wind turbine during its operation produces energy, which costs almost 80 times more than it is spent on its production [1-3]. In fact, the owner of an autonomous power plant becomes quite independent of traditional energy producers. When choosing a wind turbine for energy supplying autonomous system, priorities are determined by many factors that depend on the demands of a particular customer, the quality and price of products [13].

Characteristics analysis of various WDPP showed that sail type wind turbines are suitable for low wind speeds [14-16]. The advantage of sail type wind turbines is that they can generate electrical energy at low wind, less than 3 m/s. For sample studies model of sail type wind turbine with dynamically changeable sail shape was designed. The model consists of a wind wheel made of

metal frame rods with six flexible sails of triangular shape fixed on them. The soft sail was made of lightweight and durable materials. One end of the sail is attached to the top of the frame by strong thread. The diameter of the sail wheel is 0.4 m.

The model is fixedly attached to the mount by support rods. This model of wind turbine differs from known analogues in that as load bearing elements, triangular soft sails with dynamically variable surface shape and movable ends are used. It provides continuous rotation of the wind wheel during a rapid change in the direction of airflow. To supply with electrical power, the model of sail wind turbine is coupled to a low power generator through a sheave and a belt drive. Initial tests of the model of a sail type wind turbine were carried out at T-I-M wind tunnel with an open test section in laboratory of E.A. Buketov KarSU, Fig.6.

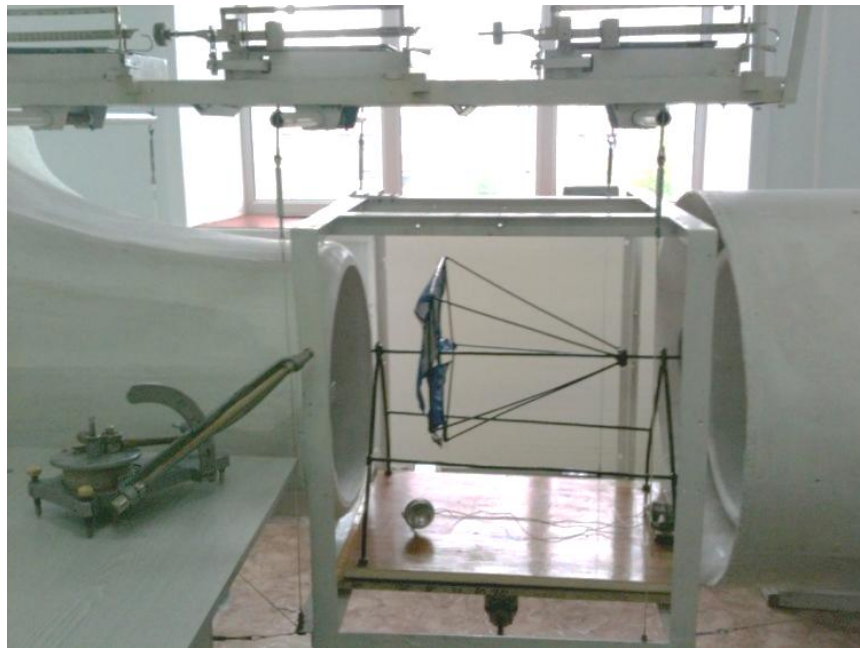


Fig.6. T-I-M wind tunnel working section with sail type wind turbine model.

Main characteristics of the wind tunnel open working section are follows: the diameter is 0.5 m; the length is 0.8 m; the range of air flow speed changes is between 2 m/s up to 25 m/s and turbulence level is 3%. Rotational speed of the sail type wind turbine is 50-100 rev/min, the minimum threshold of airflow operating speed is 3 m/s. Measurement errors of airflow speed in working section using a built-in sensor do not exceed 3-5%. The traction force was measured using a spring dynamometer, which was rigidly attached to the sheave of the wind turbine model. The model of the wind turbine in the test section is fixed to the cubic frame of an aerodynamic balance using thin metal braces to minimize the resistance of auxiliary elements. Aerodynamic characteristics of the wind turbine model at various speeds and directions of airflow were measured using a three-component aerodynamic balance.

DISCUSSION OF THE EXPERIMENTAL RESULTS

Aerodynamic characteristics of the wind turbine model at various speeds and directions of the airflow were measured. As a result of the experiments dependence of drag force, lifting force and traction force at various flow conditions were obtained. For definition the dimensionless drag coefficient C_D , traction force coefficient C_M and Reynolds number were used following formulas:

$$C_D = \frac{2F_D}{\rho u^2 \cdot S}, \tag{1}$$

$$C_M = \frac{2M_{tr}}{\rho u^2 \cdot S \cdot l}, \tag{2}$$

$$Re = \frac{u \cdot L}{\nu}. \tag{3}$$

Here F_D is the drag force, M_{tr} is the traction moment coefficient, ρ, ν are the air density and viscosity, u is the air flow speed, S is the characteristic area of midship section, l is the length of the lever arm that equals to the radius of the pulley $l = 0.06$ m, Fig.7a. L is the characteristic size of the wind turbine model, in our case it equals to diameter of the sail wheel $L = 0.4$ m. We use all values for air parameters at experiment conditions: $\rho = 1.21$ kg/m³, $\nu = 1.49 \times 10^{-5}$ m²/s. When wind wheel is perpendicular to the air flow then there is maximal streamlined cross-sectional area (midsection) which equals to the sum of all six sails squares $S = 0.0825$ m², Fig.7b. If the wind wheel axis is installed at an angle α to the direction of airflow, its streamlined area we can be defined as $S_\alpha = S \times \sin \alpha$.

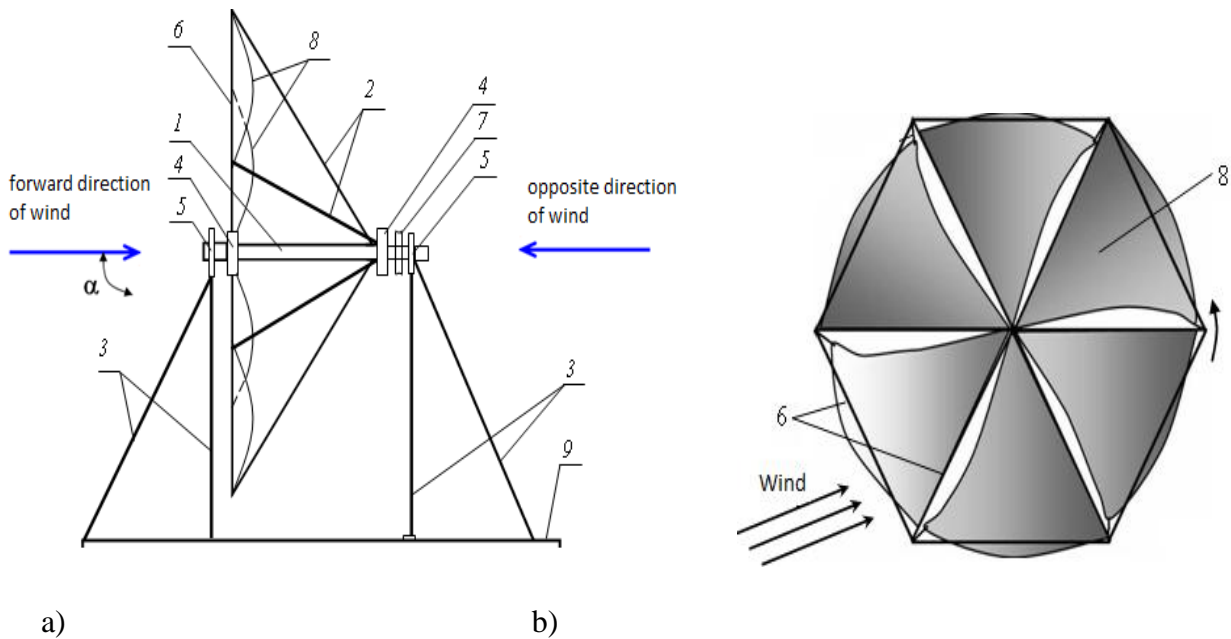


Fig. 7. Scheme of the sail type wind turbine model: a) a side view; b) a front view:

1 – shaft; 2 - support rods of wind wheel; 3 - binders; 4 - rotating disk; 5 – bearing; 6 - frame rods; 7 – pulley; 8 – sails; 9 – foundation.

Fig.8 shows the dependence of the drag coefficient on the Reynolds number which values are between $Re = 5.37 \times 10^4$ and $Re = 21.48 \times 10^4$ that correspond to air flow speed values between $u = 2.0$ m/s up to $u = 8.0$ m/s.

Decrease of the drag coefficient is observed up to $Re = 8 \times 10^4$, at further increase in the flow rate this decrease becomes less intense, and then virtually remains constant. Fig.9 shows the variation of the drag coefficient C_D by changing the dimensionless attack angle β of flow at two different airflow rates, here $\beta = \alpha / (\pi / 2)$, where α is angle of attack.

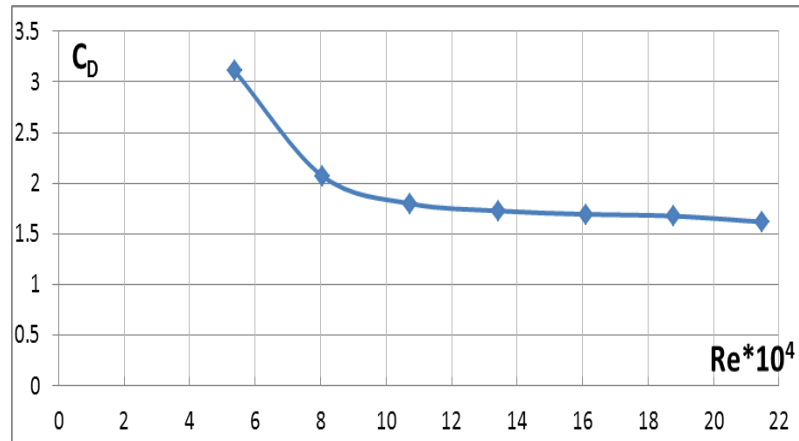


Fig. 8. Dependence of the drag coefficient of the wind turbine model on the Reynolds number

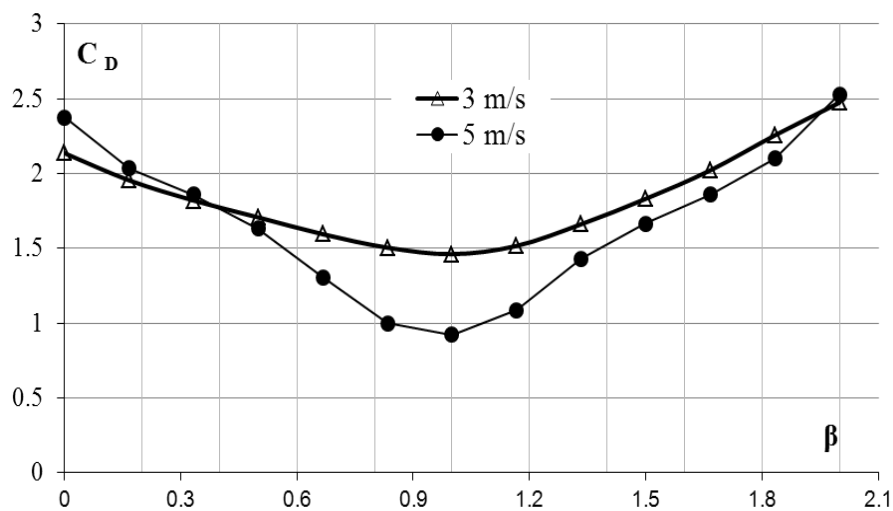


Fig. 9. Dependence of the drag coefficient of the wind turbine model on the dimensionless angle of attack

Attack angle $\alpha(\beta)$ changes from $\alpha = \beta = 0$, when air flow is directed along rotation axes of wind turbine wheel, up to $\alpha = 180^\circ (\beta = 2)$ in opposite direction. When air flow direction is perpendicular to rotation axes of wind turbine wheel (along to plane of the wind wheel rotation) there is $\alpha = 90^\circ (\beta = 1)$.

It is evident that the types of dependences of drag force on the dimensionless angle of attack for these rates are practically the same. It can be seen when the attack angle of airflow increases up to $\alpha = 90^\circ$, the drag force coefficient diminishes and then rises. This is due to the fact that when the attack angle increases, the square of midship section of the wind wheel decreases, and at further increase in angle of attack up to $180^\circ (\beta = 2)$ it grows.

Fig.10 shows the dependencies of the traction moment coefficient C_M of the wind turbine model on the Reynolds number at various attack angles of air flow.

The highest values of the traction moment coefficient are observed in the forward direction of the wind flow at $\alpha = \beta = 0$, since in this case there is the maximum streamlined surface. For other angles of attack of the flow when Reynolds number increases, the traction moment coefficient C_M gradually rises.

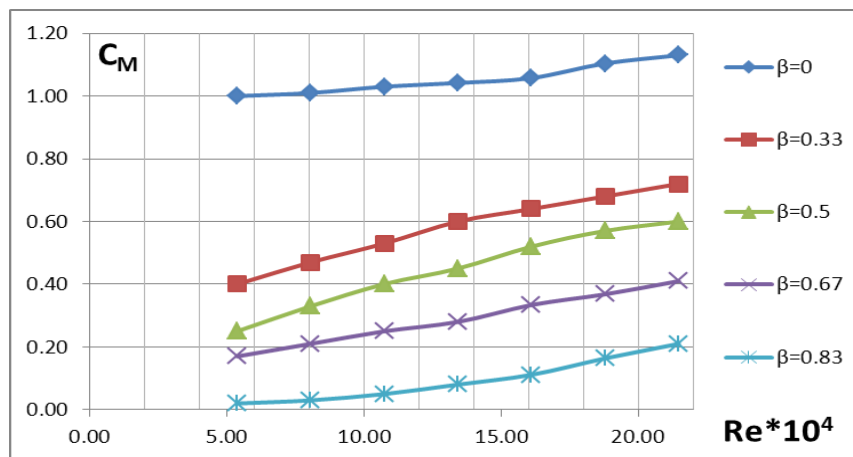


Fig. 10. Dependence of traction moment coefficient on Reynolds number at various dimensionless angles of attack of air flow.

CONCLUSION

Unlike fossil fuels, wind energy is inexhaustible, widely available everywhere and more environmentally friendly. The investment amount in wind energy engineering will increase thanks to important social and economic benefits, such as: environmental safety and reduction of emissions into the environment, reducing the dependence of the state on imported oil and gas, providing employment, gains in tax revenues, the development of new technologies [5-7, 17]. However, currently generated by WDPP energy provides only 2.5% of global electricity consumption in the world.

We tried to study the wind energy potential in Latvia and Kazakhstan. Data analysis shows that average wind speed is less than 3 m/s on the main territory of both countries.

Based on the qualitative assessment of the wind turbine capacity a sail-type wind turbine was selected. A pilot model of a sail type wind turbine with dynamically changeable surface shape of sails was developed. The paper describes characteristics of given wind turbine model which were obtained at tests on the wind tunnel. The obtained results will be used for engineering calculations in the development of sail type WDPP adapted to specific climatic conditions. This model will be designed for small buildings remote from the centralized power lines. But for a more stable and complete electricity supply of individual buildings it is need to use the combined systems based on renewable energy.

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