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ON THE CREATION OF SMALL WIND POWER PLANTS IN KAZAKHSTAN

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The article deals with the data on renewable energy sources in the Republic of Kazakhstan, in particular, on the creation of wind power plants. Here with, there are noted design features of the created small wind power plants. There are identified three stages that arise when creating small wind power plants, as well as a brief description of the corresponding types of work. The role of composite materials in creating new products in mechanical engineering is shown. There are described design features of a composite wind power plant with a diffuser in details. Results of analytical studies and graphs of the air velocity changes inside the diffuser are presented. There are described main points of the manufacturing technology of fiberglass fairings.

Keywords: wind power plant, composite material, fairing, diffuser, construction, generator.

Introduction

In recent years, there are actual the issues of using clean and sustainable energy, that is the sphere of mass application of high technology, a catalyst for "wide" social and economic development. It also provides a higher life quality and the transition of the whole society to a new technological structure, which is the subject of fundamental conceptual research [1]. This approach provides for the coordinated implementation of the national initiatives «Green Bridge», «Green Growth», and the Global Energy and Environmental Strategy. It considers the decisions of the UN Conference on Sustainable Development in the fields of energy, ecology, and economy, when national interests and characteristics are taken into account.

In Kazakhstan there is a Concept for the country's transition to a green economy that was approved by the President of Kazakhstan6 years ago. Herewith, there are given the desired indicators of the share of electricity from renewable energy sources. (RES): 3% in 2020, 10% – 2030, 50% – 2050. Wind power is an essential factor in achieving these goals. According to the Ministry of Energy of the Republic of Kazakhstan, the operation of wind power plants (WPP) with a total capacity of less than 230 MW began in 2010.This year there are already 15 functioning objects of wind power plants, and by the end of the year it is planned to put into operation three more objects [2].

In September 2019, there were announced the results of the tender for the selection of wind power plants projects [3], where the winners were the firms with an auction price of 19.27 − 19.33tg / kW (excluding VAT). This is a breakthrough step forward for our country, because these figures are already comparable to coal energy tariffs. However, these parameters are related to the energy sector as a whole, including large wind power plants. This article deals with the creation of small wind power plants (SWPP), for them the development indicators have not been determined in the country yet.

1. Small wind power plants of Kazakhstan

Nowadays, the use of electricity in agriculture of the Republic of Kazakhstan remains at an insufficient level in comparison with the developed countries − it is 7-10 times less in our country. This represents approximately 1% of total energy consumption. All this is due to the fact that centralized energy supply does not cover a large number of individual consumers and therefore does not meet modern requirements. The reason for this situation is that the transmission of power lines by traditional methods is not economically attractive in remote and inaccessible places with a low population density. To improve the situation here, one can use autonomous sources of electricity. These include energy machines developed at the initiative of domestic specialists, in accordance with the goals and objectives of “Green Energy”.

The scientists of the Republic of Kazakhstan have designed several types of SWPP with both vertical and horizontal axes of rotation. The first group includes the inventions of academician of NAS RK Yershin Sh.A., the academician of NEA RK Bolotov A.V., doctor of technical sciences Buktukov S.N., the academician of NAS RK Otelbayev M.O. and candidate of Physics and Mathematics Kunakbayev T.O. The second group includes the prototypes of doctor of technical sciences Kambarov M.N., doctor of technical sciences Baishagirov Kh.Zh., candidate of Physics and Mathematics Zhilkashinova E.M., and others. Standing apart, there is a model of the WPP, by doctor of technical sciences Kussaiynov K.K. and his students that works on the basis of the Magnus effect. Here the axis of rotation may not have a fixed direction [4, 5].

Thus, there are created a number of original SWPP in our country that differ from foreign plants both in terms of design and technical parameters. For instance, Bidarrieus wind turbine by academician Sh.A. Yershin combines two modes: Darrieus and Bidarrieus. It has a vertically axial rotor with two coaxial shafts that rotate independently in different directions [6]. Vertical-axis wind turbine by academician A. Bolotov (VWT) generates energy thanks to modules rotating in opposite directions. Thus, achieves a synergistic effect in combination with solar panels [7]. Original and sufficiently equipped with devices wind power plants by N. Buktukov can be as a light house in steppe remote areas. With increasing wind velocity, the rotor can change its shape due to the compression of the rotating blades [8].

Compact multistory model of a wind power station (CMWS) is being developed in al Farabi KazNU under the guidance of doctor of Physics and Mathematics T.O. Kunakbayev and academician of NAS RK M. Otelbayev. CMWS – a multistory construction, where there are situated various types of wind turbines on its floors. It has several advantages over conventional wind power plants located at the height of one floor on the ground. The advantages of CMWS – it is the stable use of wind energy, which has an increased velocity in the air passages between floors. There is also realized land saving of the territory given for the SWPP [9].

In National scientific laboratory at S. Amanzholov East Kazakhstan State University candidate of Physics and Mathematics A.M. Zhilkashinova put into operation the sail SWPP. This plant’s wind wheel quickly adjusts to the direction of the air flow and has a low breaking moment [10]. Among compact SWPP one cannot emobile composite wind power plant with diffuser (WPPD), created under the guidance of doctor of technical sciences Kh.Zh. Baishagirov in the laboratory of Sh. Ualikhanov Kokshetau State University.

2. Stages of SWPP creating and composite materials.

To assess the completeness of plans and work on the creation of SWPP in the country, one should mind the "laws" of modern engineering. According to them, the whole process of creating machines consists of three large stages: 1 – obtaining the first prototype with the implementation of a new theoretical idea («know-how»); 2 – creation of prototypes of machines and drive into a competitive level; 3 – mass production. Such stages are usually implemented by various relevant organizations and specialists.

For instance, stage 1 is usually conducted in universities and research institutes of an academic or applied orientation. Here dominate the specialists in physics, mechanics, mathematics, etc. For the implementation of stage 2, there work design and industry research institutes, various design bureaus(DB), enterprises and R&D institutions involved in the implementation of the results of fundamental and applied science. The main backbone of such organizations is made up of scientists, designers - planners, engineer - technologists, etc.

The tasks of stage 3 are solved at factories and engineering enterprises. The work is carried out in various kinds of DB, experimental and other workshops of enterprises by engineers, technologists, adjusters, production innovators, etc. For instance, in the early 80s in Karaganda there were more than 20 research institutes serving industry enterprises (stage 2). In the same years "Vetroen" plant produced SWPP and the wind pumps “Romashka” for rural workers (stage 3).

Most of the domestic SWPP designers practically did not move beyond the first stage. The reason for this, apparently, is that in the country there are practically no enterprises where is implemented the entire chain of work from the idea to the serial production of modern high-tech products. Indeed, it is difficult to indicate the enterprises of machine, aircraft or shipbuilding, where the specialists in hydromechanics, strength, energy, design, technology of modern materials, electronics work together. But to create SWPP one need just such a team of specialists.

Among SWPP of the country only the wind power plant with diffuser (WPPD) is created from composites, moreover, the development moved to the second stage. Therefore, at present, after the model prototype, there is being created a technical prototype of the energy machine. It will serve as the basis for the creation of a pilot industrial prototype with the goal of moving to the third stage of small-scale or mass production. Here the fundamental issue is the development of the technology of composite materials and their products.

The rapid growth of global wind energy is directly related to the development of composite materials technologies, the most common one is fiberglass. In recent decades, composite materials (CM) are widely used in other areas of modern technology, where their high specific strength and stiffness are favorably used in constructions. In the science and practice of CM, there are developed new trends and approaches [11], caused by the desire to create multifunctional structures and expand the sphere of their application by using components with lower cost.

Composites arose as a natural reaction to the needs of modern technology. Composites, strictly speaking, are not materials in the classical sense, i.e. ready product, for example, in metallurgy, with predetermined and practically unchanged properties during processing. They constitute an extensive group of materials created from semi-finished products together with design, i.e. as a whole the properties of composites and the structure are technologically formed simultaneously during its manufacture. Therefore, when creating structures from CM, design issues (in the traditional sense), rational reinforcement and process development are three sides of a single problem and cannot be considered in isolation that is allowed when creating a construction from metals. Thus, the effective use of CM requires from the developers to solve the three-pronged problem at a time: problems of the mechanics of a composite body, micromechanics, and manufacturing technology.

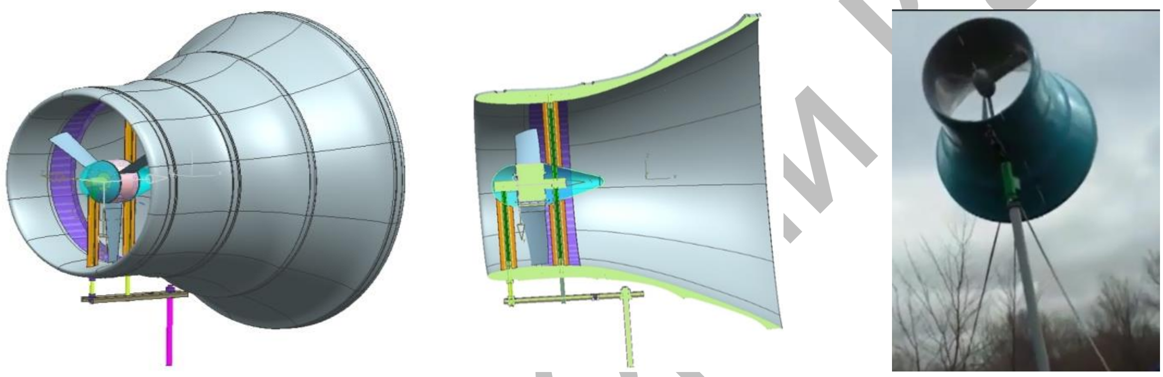
Chronologically, the mechanics of CM first dealt with models of a homogeneous (quasi - homogeneous) anisotropic body, then CM were presented as anisotropic bodies with homogeneous layers, and a higher level of modeling are, for example, options when each layer itself has heterogeneity at the structural level. It is quite consistent that such a sequential staging of the research is observed in the development and creation of such essential products from CM as the working blade of an aircraft engine compressor or the blade of a wind power plant.

3. Wind power plant with diffuser

In view of the foregoing, for the model prototype of the WPPD, there was used the technology of layer-by-layer manufacturing of composite parts, its stress-strain state was studied earlier. This technology can significantly increase the service life of the products, the cost of maintaining the plant and generally increases the efficiency of using the wind engine. There are various wind power plants with a diffuser (USA, Japan, etc.), but, as a rule, they are stationary. In contrast, our WPPD is portable. Its mobility is ensured by the fact that it has got light weight. Here with, installation and dismantling of the WPPD can be carried out by 2-3 workers in a couple of hours without lifting devices. During the IUE “Astana EXPO - 2017. Future Energy” there was hosted the international forum“ Integration of Science and Business ”, organized by the National Center for State Scientific and Technical Expertise (NSSTE) together with the Ministry of Education and Science of the Republic of Kazakhstan. In the report “Energy of Kazakhstan: Yesterday, Today, and Tomorrow”, the President of the Scientific Center for Scientific and Technical Information singled out the project on the development of a model prototype of composite WPPD among the four best achievements of Kazakhstan innovators in the field of green technologies [12].

In this energy machine, the nodes are created from composite materials using appropriate technologies. A distinctive feature of the design is the use of a diffuser, as indicated in Figure 1.It turns with its narrow part in the wind and increases the velocity of the air flow in the wind wheel area. Also, the diffuser protects the generator from external undesirable effects (moisture, birds, sun rays, dust, etc.) [13].

WPPD consists of the following parts: a wind wheel with three-blades, generator, fairings of the generator; diffuser – wind direction indicator with sectors in the amount of 12 pieces, 4 stainless steel hoops; spars (pylons);strong ring; support tower with extensions; rotary device (at the top of the tower) with rectifier; channel support beam.



a) b) c)

Fig.1. Wind power plant with diffuser (ВЭУД): a – 3D model of a wind wheel and a diffuser, b – longitudinal section of a 3D model of a wind wheel and a diffuser, c – WPPD – 4 (4th prototype).

WPPD parameters: weight - 95 kg, tower height - 4 m, project capacity– 1kWt, temperature regime from minus 50 ° C to plus 80 ° C, 20 years of operating life, generates current at a wind velocity of 4-25 m/s. Using resource-saving technology for processing composite materials, the main components and diffuser were made of fiberglass, due to which there is increased the operating mode of the plant and the geography of its location [14; 99]. One can distinguish the high mobility of WPPD, ease of maintenance, increased serviceability, resistance to the effects of various manifestations of the climate, safety at the widest range of use, silent-running operation, low metal consumption, attractive design, lack of radio interference, etc. WPPD pays off in 4-5 months when used together with the "Vodoley-3" pump to supply drinking water from a well.

4. Modeling of the longitudinal velocity of the air flow inside the diffuser

The output characteristics obtained during field tests of the WPPD based on the PMGV3 electric generator prove its effectiveness. Therefore, there is carried out a cycle of work to create the corresponding nodes from composites for a technical prototype. This requires a preliminary mathematical justification of the effectiveness of the shapes of the diffuser and fairings. To obtain the simplest analytical dependence of the flow velocity distribution along the axis of the diffuser, we use the mass conservation equation. It is based on the equation of continuity of the one-dimensional motion of an ideal compressible gas in a pipe of variable cross section, which has the form [15]:

$$\rho VS = const, \qquad (1)$$

where ρ – gas density, kg/m^3; V – gas velocity, m/s; S – cross-sectional area, m^2 .

Differentiating equation (1) with respect to x, we divide it by ρVS. If we take into account that we are considering the one-dimensional motion of an incompressible fluid, i.e. our conditions are close to normal ($\rho = 1$), then the equation will take the form:

$$\frac{1}{S} * \frac{dS}{dx} + \frac{1}{V} * \frac{dV}{dx} = 0 \qquad (2)$$

The functions V and S vary with x, therefore, setting one of them based on empirical considerations, the other can be calculated from the differential equation (2). It is advisable to set the distribution $S= S(x)$, that is, the dependence of the cross-sectional area of the diffuser on the longitudinal coordinate along its axis. Since the inner surface of the diffuser is obtained by rotation of the curve forming $y= y(x)$, in sections we get circles with a radius equal to the ordinate of the points of this curve. Therefore, the area of the current section will be

$$S(x) = \pi y^2(x)$$

If we consider the longitudinal section of the WPPD, then we can describe the generating line of the diffuser through the function$y=a + bx^2$. Transforming and substituting in relation (2) we obtain a differential equation with separable variables. Integrating it and using the well-known experimental relation, we obtain:

$$V = \frac{1{,}27a^2V_\infty}{(a + bx^2)^2}$$

For the real sizes of our WPPD we use the numbers a= 0.5 and $b=0.35$. Then we get the values $V_{in} = 1.12\ V_\infty$, $V_{max} = 1.27\ V_\infty$ и $V_{out} = 0.32\ V_\infty$, corresponding to the distribution of air velocity inside the diffuser as shown in Figure 2.These calculations are made for the diffuser without considering the area of the wind wheel.

Figure 2 was obtained for the first prototype and is presented here for a qualitative comparison with the new calculated parameters. Since the above mentioned calculations were carried out without considering the wind wheel, it is necessary to divide the WPPD into 4 zones, as shown in Figure 3.Each zone has its own formula for calculating the air flow velocity.

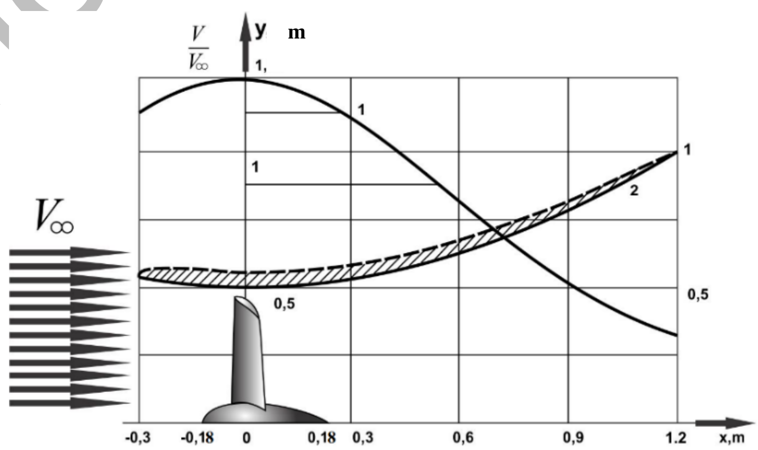


Fig.2. Velocity distribution and the profile of a diffuser with a quadratic generating line.

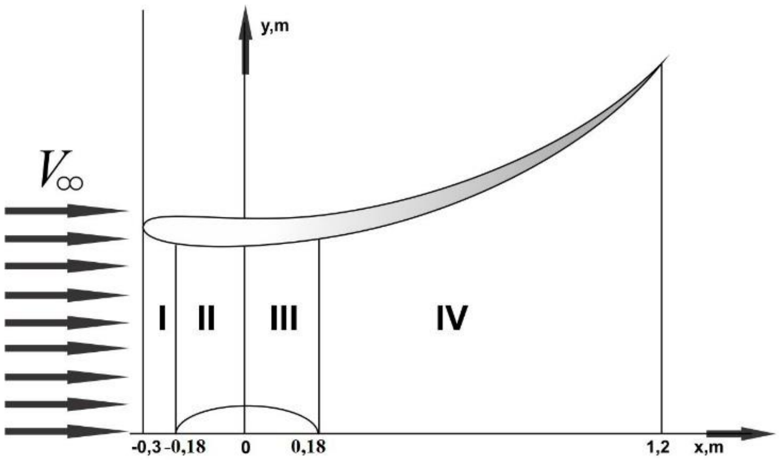


Fig.3. Dividing of the WPPD cross-section into zones.

In zones II and III the airflow is influenced by the shapes of the surfaces of the fairings and the diffuser, and in zones I and IV – only the diffuser. Generating lines of fairings can be described through the functions $y^2 = 2px+x_0$ and $y^2 = -2\,px+x_0$. As a result of solving the problem by dividing into zones, we obtain the following expressions for the air velocity:

for zone I and IV: $V = \frac{0,32V_\infty}{(a+bx^2)^2}$;

for zone II: $V = \frac{0,32V_\infty}{(a+bx^2)^2-(2px+x_0)^2}$;

for zone III: $V = \frac{0,32V_\infty}{(a+bx^2)^2-(-2px+x_0)^2}$.

As a result of the calculations, we obtain:

$V_{in}= 1.1V_\infty$, $V_{max}= 1.27V_\infty$, $V_{out}= 0.32V_\infty$.

Using the previously obtained theoretical results on the shapes of the diffuser and fairings, one should begin the technological part of the work with the manufacture of a new fairing.

5. Manufacturing technique of the fairings

To determine the amount of structural material - fiberglass, there has been solved the problem of calculating the surface area of fairings rotation. There were obtained numerical values of the volumes of the material considering the differences in shapes, sizes, and also the thickness of the layers in the structure of the product. The manufacturing technology of nodes also depends on the strength requirements for the product being created. For instance, when manufacturing the blades, there is required the use of a thermal press, which will give the material a high density, and hence appropriate strength. It is possible to use a simple press - without heating then the formed fiberglass structure will be less durable. Since the rear fairing does not carry a significant load, here one can do without the press and other expensive equipment. For this reason, on its example, we consider the entire process of manufacturing such a node. First, a series of preliminary works is carried out to determine the shape of the master models. Then, using hand-made patterns, there was created a series of components on a lathe with a copier. Further processing of components consists of grinding and varnishing processes in several layers manually. The obtained products are shown in Figure 4. Layers of fairings are made with the hand lay-up method: the lower layers are made of isotropic glass mat, and the upper layers are made of fiberglass T-23 and T-11 with ordered fiber orientation. These surface layers of fiberglass will be subjected to directional effects of external force factors; therefore, the material with anisotropic strength properties was selected as the upper layer.

Fig.4. The components and corresponding fiberglass fairings.

The creation of such structural elements as reinforced layers will enable to compose convenient algorithms for digitalization of calculations based on their regularity. This enables to provide the strength and rigidity of the fairings in the subsequent stages of creating experimental prototypes. Besides, such algorithms and programs are created to automate production in the future.

Conclusion

All types of SWPP developed in Kazakhstan are eligible for implementation, as each of them has its own consumer sector or region of effective use. Thus, sail SWPP and WPPD may be of interest to individual consumers who need an easy-to-use 1-2 kW power sources. For consumers of energy of 3-15 kW there are created Bidarrieus SWPP, VWT. If one need a more powerful power station, then you can choose CMWS. Here we note that all 4 types of the latest SWPPs work regardless of the wind direction. This is their advantage; the disadvantages include the relatively large material consumption of these energy machines in comparison with the WPPD or a sail wind power turbine. The advantage of domestic developments is that they are applicable almost anywhere in the country territory. This cannot be said about any single foreign wind power plant.

The existing scientific potential of the country is a significant reserve in order to speed up the creation of domestic SWWP. Here one can make a breakthrough in attracting investment and developing technology both in the country and in the regions. For the SWPP production in the Republic of Kazakhstan there are elements of a legal framework and other opportunities that require investment of resources and efforts.

Our experience enables to identify those difficulties and problems that hinder the quick bringing of theoretical development (ideas) to the release of final products at the factory:

1. Lack of motives for manufacturers to support R&D.
2. The lack of the SWPP market and the lack of qualified specialists.
3. Undeveloped scientific, technical and technological base for the creation of wind power plants.

Most recently, there has been appeared serious progress in this direction in the country. To realize the Concept for the country's transition to the Green Economy and achieve the relevant indicators for the development of small wind energy, we recommend the following:

1. In the regions of our country, one should create R&D laboratories, technological areas and technology parks connected with the creation of nodes for SWPP, including from perspective composite materials (fiberglass).
2. To work out issues of personnel training and technology transfer.

3. To organize activities on the formation of market elements in the field of renewable energy.
4. To create in Kazakhstan a coordinating structure for the development of SWPP.

Thus, in our country there has been created a wide range of the most diverse designs and types of prototypes and models of SWPP - thanks to the enthusiasm and long-term efforts of physicists, mechanics and other scientists. Now it is necessary to complete the final stage of these samples to a high competitive level in order to enter their production.

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