Increasing the level of the metrological supply of large-sized windows blades (from 60m) at the production stages

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Abstract. The development of the field of renewable energy sources today is happening at a fairly rapid rate, especially in the field of wind energy. In the last year alone, several large wind farms have been built in Russia. The fast pace of development of wind energy in Russia leads to the fact that in the near future there will be a need to produce our own wind turbines, according to the projects of Russian developers. Also, the development of technologies, the rapid introduction of new production systems, an increase in the share of autonomy of industrial enterprises requires the introduction of new modern approaches in the field of energy, energy efficiency and energy conservation. Against this background, the need for innovative solutions in the field of metrological support and measuring technologies in the energy sector is sharply increasing. The paper presents a complex for carrying out control and measuring procedures, which will improve the quality of metrological support in the production process in Russia. Also, the metrological and economic parameters of the described stand have been calculated.

1. Introduction
The development of the field of renewable energy sources today is happening at a rapid pace. According to data from the website for statistics on world energy in 2019, the share of wind and solar energy in the global energy balance increased (+ 12% for wind and + 24% of solar energy), while the generation of electricity from thermal energy decreased.

Renewable energy currently accounts for 35% of the energy balance in the EU, 27% in China, 21% in India and about 18% in the USA, Russia and Japan. Electricity generation from offshore wind turbines increased by 20%, thanks to the commissioning of 5.5 GW of plants in countries such as Belgium, Germany and the United Kingdom.

The use of renewable energy sources influenced the accelerated growth of capacities in wind and solar energy, which led to a sharp increase in electricity generation by wind and solar power plants in China (an increase of +10% and 31%, respectively, almost 9% of the total energy balance), USA (+9% and 15%, respectively, almost 10% of the total energy balance), the EU, Japan, India, Australia and Latin America (strong growth in Chile, Brazil, Mexico and Argentina) [1].

Wind energy, given its low environmental impact and internal energy source, is by far the most demanded resource. Despite the high initial cost, wind energy leads to an increase in the profitability of the economy.
By Decree of the Government of the Russian Federation No. 335 of March 28, 2019, the state program “Energy efficiency and energy development” was renamed “Energy development”, and the implementation period was extended until 2024.

The goal of the program is two-fold:

- maximum assistance to the socio-economic development of the country, which plays a significant role in the formation of budget revenues of the Russian Federation;
- strengthening and maintaining the position of the Russian Federation in the world energy sector.

Achieving this goal requires an accelerated transition to more efficient, flexible and sustainable energy. To achieve the best results, it is necessary to introduce new modern technologies into production.

Already today, the world’s leading companies are introducing modern energy management technologies. It should be noted that the modern level of automation has reached such a scale that it is impossible to control technological processes without the introduction of measurement, control and management systems. Today, instrumentation is not just a set of sensors, but measuring complexes combined with modern measurement and control methods, as well as advanced measurement techniques.

The development of technologies, the rapid introduction of new production systems, an increase in the share of autonomy of industrial enterprises require the introduction of new modern approaches in the field of energy, energy efficiency and energy saving.

Against this background, the need for innovative solutions in the field of metrological support and measuring technologies in the field of energy is sharply increasing.

Research of the last decades is largely devoted to the issues of increasing the reliability and diagnostics of industrial facilities. The operational reliability of power generating capacities distributed throughout the territory of Russia for thousands of kilometers must be guaranteed by means of monitoring their technical condition.

2. The blades

Today, on the eve of innovative technologies in the field of renewable energy, especially in the wind energy of the Russian Federation, a special place is occupied by metrological support of the entire structure of a wind turbine. Since the production of its own wind turbines in Russia began relatively recently, control problems occupy important positions in the life cycle of wind turbines.

Carrying out control and measuring operations of the large-sized products are widely used all over the world today. So, in the work "Coupled system of 3D laser scanning and correlation of digital images for obtaining geometry and monitoring deformations of a railway tunnel" results of research and measurement using 3D scanning of a section of a railway rock tunnel in Brazil are presented.

In the authors' study "Monitoring the alignment of the wind turbine shaft in real time using laser measurement", an example of the use of laser measurements to determine and control the fixation of positional changes in wind turbines during operation and alignment of the drive lines of the shafting in wind turbines is given. The measuring system is a set of lasers of the installation; based on the results of the control, the average and periodic amplitudes are determined from the ensemble of the averaged signal.

Thus, the problem of measuring control of large objects, including blades, is of great importance, and many modern solutions are based on the use of non-contact measuring systems, including scanning and lasers.

2.1. The features of the blades

For the structural design of wind turbine blades, a compromise must first be found between aerodynamic and structural efficiency. The choice of materials and manufacturing process will also affect how thin (aerodynamically perfect) the blade can be made and the price point. Consequently,
the structural design process plays a critical role in bringing together all design and manufacturing disciplines to create the optimal solution in terms of performance and cost.

When manufacturing a blade, the following criteria must be considered:

1. The blade must be strong at the base. This is necessary to create sufficient lift to accommodate the lower wind speed near the hub. Unfortunately, the thickness required to provide blade rigidity and strength is greater than that required for aerodynamic efficiency, so a trade-off must be found between the weight of the structure and the loss of aerodynamic efficiency.

2. Towards the end of the entire piece, the blade should be tapered. The narrowest part of the blade is needed at the apex where drag is most critical, also for power regulation in strong winds, the thinner part breaks off more easily, therefore useful at the tip.

Thus, the shape of the blade itself, its thickness directly affects the efficiency of the wind turbine. If the blade is made thinner, its aerodynamic performance is improved, but stronger spars will be required, which will increase the cost of the blade. Optimal geometry is achieved iteratively, taking into account turbine design, loads, design and manufacturing costs. As mentioned earlier, different product thicknesses are required to create lift on the blade, which in turn drives the turbine and is distributed along the blade approximately in proportion to the local radius, that is, the tip has more lift than the hub. The lifting force acts on the blade, bending it. This effect is called bending moment. At the base, the bending moment is most significant, but at the tip, the bending moment drops to zero. [6]

Today, statistical tests are carried out on wind turbine blades. This is done to confirm the required load profiles and to check the blade design. Typically subjecting the blades to 150% of their rated load power. Accurate blade failure testing requires high strength, high precision and reliability. Impact Resistant Test Equipment. Checking the profile of the blade section, its shaping, plays an important role in the quality and efficiency of the wind turbine. We need innovative technical solutions based on a scientific and modern technological base. Our country already has accumulated potential, scientific groundwork and staffing [7-14].

3. Control and measuring operations of wind turbine blades using the test board

Today, when the production process is automated, when it is equipped with modern progressive technologies, production is being improved, which means that the role of metrology is increasing. It becomes relevant to carry out measurements in dynamics with a significant influence of external factors. With the introduction of new technologies in the production process, today measurements are more often carried out at all stages of the product life cycle, while the share of measurement procedures often exceeds the share of production.

Therefore, a promising direction in control and measurement operations in metrology is considered to be such measurements using the methods of non-contact measuring procedures based on the use of modern laser and optical measuring systems.

Since most of the generated electricity from the wind turbine depends on the quality of the manufactured blade, the increase in such parameters as reliability, accuracy of mold manufacturing, namely, compliance with the specified aerodynamic parameters, largely depends on the quality of the control performed.

3.1. The stand

Wind farms are actively being built in Russia; on May 1, 2020, the Kamenskaya wind farm with an installed capacity of 100 MW was commissioned. Until the end of the first half of the year, it is planned to launch another wind farm, Gukovskaya with a capacity of 100 MW. Also, by the end of 2023, it is planned to build a wind farm with a capacity of 1.8 GW. And what is remarkable, Russian companies are engaged in the construction of wind farms. But, unfortunately, the wind turbines themselves are not manufactured on the basis of Russian developments, but on the basis of joint ventures with foreign firms. Rusnano and Rosatom are actively localizing production from towers to gondolas, and in May this year, supplies of wind turbine blades to Denmark began.
The rapid pace of development of wind energy in Russia leads to the fact that in the near future there will be a need to produce own wind turbines, according to the projects of Russian developers. This is not only a cost-effective strategy, but it will also allow for the creation of wind farms, depending on our climatic and landscape conditions.

That is why, when producing our own wind turbines, the presented test bench will be the solution to many problems in measuring and controlling blades.

The test bench is a simple structure equipped with an electric drive for automatic movement of the control device. Thus, an example of a design is shown in figure 1. The stand consists of:

1. the base, which is also used for painting the blade;
2. a mechanism equipped with an electric drive for moving the carriage with a scanning device;
3. carriage on which the measuring device is installed;
4. measurement tool - 3D scanner;
5. computer for receiving and processing the information received.

![Figure 1. Design of the stand.](image)

The device is moved along the slats. The rail serves to adjust the position of the device attached to the bracket. The measuring instrument is selected taking into account the design features, the shape and dimensions of the measured part, the required measurement accuracy, the metrological characteristics of the instrument, the control performance, etc.

3.2. Means of measurement used in control

The device under development must perform various measurements on the surface of the object in the process of scanning an object. These measurements must then be transferred to a microcontroller to process and prepare the data in the required format. Consequently, the main requirement for a laser meter is the availability of a data interface, through which information about each measurement can be obtained and stored. This interface must be supported by the controller.

The second important requirement for the measuring device is the ability to control the operation through the data interface. This function will allow transmitting data in the form of a command from the controller to the laser device and thereby completely control the process of scanning the object. The microprocessor must at least be able to send a command for one measurement. Therefore, the laser must support the “measure” command transmitted to it via a specific data interface.

For the purposes of our work, the scanner 3D scanner Creaform HandySCAN 307 is suitable. The blade will be scanned in two sections simultaneously, i.e. to scan the upper and lower parts of the blade, two scanners will be used, which will subsequently carry out the measurement process synchronously.

After scanning and processing digital images, the system receives data from a part of the object's surface in the form of an array ("cloud") of points. For each point, its three-dimensional coordinates are known.

To perform one scan, the time and speed of the carriage is set by the operator sitting at the computer and monitoring the progress of the process.

To automatically combine data, a system of markers is used that are glued to the surface of an object or next to it. During scanning, the coordinates of the center of the markers are calculated automatically.
After the scanning of the entire object is completed, the system processes the received array of points, after which you can start analyzing the results.

### 3.3. Metrological characteristics

For correct processing of the results of measurements carried out at the stand, it is necessary to take into account the error created by the installation itself. Without taking into account this error, the data obtained should be considered fictitious.

To calculate the total error, we will use formula 1, obtained by the stand, and summarize the errors that affect the measurement result.

\[
\Delta = (\Delta_{\text{instr}}^2 + \Delta_{\text{meth}}^2 + \Delta_{\text{rand}}^2 + \Delta_{\text{sub}}^2 + \Delta_{\text{stand}}^2 + \Delta_{\text{fact}}^2 + \Delta_{\text{design}}^2)^{1/2} \quad (1)
\]

The formula shows that the error consists of the following components:

1. \(\Delta_{\text{instr}}\) - instrumental error. In our case, when using a 3D scanner Creaform HandySCAN 307
2. \(\Delta_{\text{meth}}\) - a methodical error. Methodological error arises from the deviation \(\Delta t_1\) and temperature fluctuations \(\Delta t_2\). It is due to the difference in the coefficients of linear expansion of materials and parts.

\[
\Delta t = d \cdot \theta \cdot 11,6 \cdot 10^{-6}, \text{mm} \quad (2)
\]

Where \(\theta\) is the temperature regime.

3. \(\Delta_{\text{rand}}\) - Random error - a component of the measurement error that changes randomly during repeated measurements of a given value. Calculated as follows:

\[
\Delta_{\text{rand}} = tS \quad (3)
\]

4. \(\Delta_{\text{sub}}\) - the subjective error in this design due to the use of an automated device with a non-contact measurement method is negligible, so we do not take it into account.

5. \(\Delta_{\text{fact}}\) - the error due to external factors. External error occurs due to non-compliance with normal conditions when measuring in the room GOST 15150-69. In the room where the experiment will take place, it is necessary that the room meets the requirements prescribed in GOST (temperature, humidity, air cleanliness, lighting, sound and vibration isolation, radiation protection, electricity, water, air, heat, refrigerant, etc.).

6. \(\Delta_{\text{stand}}\) - the error of the workpiece. Deviations from the geometric shape and dimensions that occur during the processing of the workpiece must be within the tolerances that determine the maximum permissible values of errors in the size and shape of the part. When machining, ensuring the specified accuracy depends on the choice of technological bases and the installation scheme of workpieces.

The blank error can be written as follows:

\[
\Delta_{\text{stand}} = (\Delta_{\text{basing}}^2 + \Delta_{\text{work piece}}^2)^{1/2} \quad (4)
\]

\(\Delta_{\text{basing}}\) - the basing error. The error of basing occurs as a result of basing the workpiece in the device on technological bases that are not related to measurement bases. When basing on the design base, which is also the technological base, the basing error does not occur.

\(\Delta_{\text{work piece}}\) - the accuracy of fixing, the accuracy of the result directly depends on the installation of the part on the base. The fixing error is formed from the surfaces that occur before the application of the clamping force and during clamping.

7. \(\Delta_{\text{design}}\) - the error structure. This error directly affects the measurement results. The error of movement of the carriage. An important component of the test stand design is the carriage, which is used to move the scanning device. This error must be taken into account, as it has a direct impact on the accuracy of the measurement result.

The design error is calculated using the formula (5).

\[
\Delta_{\text{design}} = (\Delta_{\text{moving thr carriage}}^2 + \Delta_{\text{linear movement}}^2)^{1/2} \quad (5)
\]
Thus, with more detailed calculations, the error that may occur when using a test bench varies depending on the conditions of external factors from 40-45 microns, which is relatively small in a large-scale production process [16-20].

3.4. The economic benefit

General industrial economic requirements are based on the conditions of competitiveness and economic feasibility in industrial production. The main indicator that determines the economic feasibility of costs for the creation and implementation of the test bench is the annual economic effect.

When calculating technical and economic indicators, the following results were obtained:

- Cost of 3 939 322 rubles.
- The profitability index is equal to 2 (more than 1) at a given discount rate \( E_n = 10\% \).
- The payback period of the project is 1.5 years with a productivity of 240 units per year.

As a result of the two main calculations, the calculation of the error and economic indicators, it follows that the proposed solution for monitoring blades over 60 meters using a test bench is not only economically profitable, but also effectively used in the manufacturing process of the blade itself [21-22].

4. Conclusion

As a result of the two main calculations, the calculation of the error and economic indicators, it follows that the proposed solution for monitoring blades over 60 meters using a test bench is not only economically profitable, but also effectively used in the manufacturing process of the blade itself.

The results obtained can be used online at the enterprise. The test bench and the program for processing the results are able to analyze the state of the object in real time, measure and control the required geometric parameters.

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