Development of a control system for large-sized products to improve product quality in mechanical engineering

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Abstract. The paper considers the problems of monitoring the metrological support of overall parts in mechanical engineering. The decision to implement the control of large products such as ship’s shaft. In addition, an algorithm for analyzing control results using the Matlab program to assess the state of the object of study is proposing.

1. Introduction

According to the forecasts of The Boston Consulting Group, by 2025 up to 10% of vehicles will operate autonomously, move without driver’s participation, said Nicholas Lang, the company’s managing director, by 2025 all new cars, buses and even tractors will switch to electric traction, the expert believes Clean Energy Founder, RethinkX Founder and Stanford University Lecturer Tony Ceba. At the same time - manned space flights to the moon since 2030, rail transport will speed up to 600 km / h, and means of levitation can already perform some movements. One cannot but mention the use of drones in the form of drones, and autonomous sea vessels. [1] According to the “Strategy for the Development of the Shipbuilding Industry until 2035” dated October 28, 2019 No. 2553-r, several key indicators established, such as

- Construction of 653 vessels of various types under the target scenario, including sea transport vessels, fishing fleet vessels, vessels and orders for the development of offshore fields, etc.;
- ensuring full and timely financing of measures for the development of unknown technologies critical for creating promising marine equipment;
- ensuring the loading of at least 80% of the bench test base;
- Introduction of at least 60% of the developed technologies and optimization of the structure of research centers;
- It should double the number of new and updated ship repair facilities.

It should be note that according to JSC TsNIIMF1 (Central Scientific Research and Design Institute of the Marine Fleet) as of February 1, 2019, the Russian marine transport fleet totalled 1394 vessels with a total deadweight of 21.8 million tons, including:

- 1,143 vessels under the flag of the Russian Federation with a total deadweight of 7.1 million tons;
- 1,108 vessels providing the fleet;

1Data from the Central research Institute of the Sea Fleet
- 1080 vessels of the fishing fleet;
- 77 vessels of the research fleet.

The Russian Federation developed and approved by Government Decree No. 1756-r of August 17, 2017, “The Strategy for the Development of Transport Engineering of the Russian Federation for the Period until 2030”, “The Strategy for the Development of Railway Transport in the Russian Federation until 2030”, approved by order of the Government of the Russian Federation dated June 17, 2008 No. 877-r. Based on the analysis of these documents, the tasks of the domestic industry for the next 10-15 years are more than serious.

It needs Innovative technical solutions based on a scientific and modern technological base. Our country already has accumulated potential scientific backlog and staffing. [2-7] [19-20]

2. Metrological support for parts control in mechanical engineering

A serious production problem is the operation of controlling the parameters of dimensional objects, mainly rotation bodies, with high accuracy. The large dimensions of the measured products and the enormous volume of measuring operations explain this. Therefore, the most rational is the use of control systems with non-contact measuring instruments. [8]

To ensure the required accuracy, increase reliability and simplify the control process itself, a test bench has developed that allows you to control products at the last stage of the life cycle, which will not only reduce time but also increase the life of the object, since the likelihood of a marriage will increase. Using non-contact measuring instruments in the developed stand not only simplifies the control procedure but also reduces the subjective and systematic error.

It should be noted that measurements of large-sized products widely used. Therefore, in [9], it presents the results of research and measurement using 3D scanning of a section of a railway rock tunnel in Brazil.

The work [10] presents the results of studies when aligning the line of a heavily loaded shaft with geometry control. It presents a numerical analysis; it tests the proposed method on the example of measurements on actual ships.

A study of the authors of [11] gives an example of the use of laser measurements to determine and control the fixation of positional changes of wind turbines during operation and alignment of drivelines of the shaft line in wind turbines. The measuring system is a complex of lasers of the installation, according to the results of the control, the average and periodic amplitudes determined from the ensemble of the averaged signal. [11]

Thus, it shown that the problem of measuring control of large-sized objects, including shafts, is important and it base many modern solutions on the use of non-contact measurement systems, including scanning and lasers.

2.1. The stand

The stand presented in the work is a reliable design. The purpose of the design is to improve the ability to detect inaccuracies in the finished product, and to increase monitoring production. To describe the operation of the stand, it selected the object of the study ship shaft with a length of 11860 mm and a diameter of 60 mm. The current situation with metrological support at shipbuilding enterprises does not fully meet the requirements. For example, the required accuracy of large-sized structures not ensured, and with high-precision measuring instruments not introduced into practice, there are no certified measurement procedures, etc.

Since the subject of the study is the ship’s shaft, which is the most important part of the SEU, the quality of manufacture of this product depends on the course and performance of the vessel. Therefore, an important measure in the shaft's manufacture is to control its parameters. One of the key problems of controlling the ship’s shaft today is that different parts of the shaft are controlling separately, and then the shaft connected and installed directly on the ship. The operation takes a long time and the metrological characteristics may violate during Assembly [12].
The relevance of the developed stand is that controlled supposed to carry out at the last stage of production. Such objects as the ship’s shaft provided with high accuracy of manufacture, so the last stage of control is important, since the quality will depend on performing the entire product where the object will installed.

The stand designed in such a way that the structure does not take up much space and is easy to operate and assemble. Figure 1.

![Figure 1. Test bench](image)

The test stand comprises:
- 2 frames equipped with a mechanism for driving the rotation of the studied shaft and a device for fixing its support element;
- Base design. Mobile platform with a device for fixing the shaft support element and its centering mechanism;
- The platform moved along 2 rails using an electric drive;
- Carriage for placing a non-contact coordinate measuring device, which moved along the guides using an electric drive;
- Electric motor 4A250M2 U3 with a speed of up to 3000 RPM. Designed for rotating the test shaft.
- COMPUTER. Stand control panel.

The measuring instrument selected for monitoring attached to a specialized mount. It mounts this mount on the bracket plate (in place); the bracket mounted on the mount and calibrated.

The device moves along the rails. The rail used to adjust the position of the device attached to the bracket.

The measuring tool selected taking into account the design features, shape and size of the measured part, the required measurement accuracy, metrological characteristics of the device, monitoring performance, etc.

Since there is a task to improve accuracy, a laser micrometer from Mitutoyo SJ-506S chosen, with an error of 4 microns. The selected device is suitable for measuring the parameters of rotation bodies with a high accuracy.

Correctly, to get the results of measurements carried out on the stand, it is necessary to take into account the error created by the installation itself. Without taking into account this error, we should consider the received data fictitious.

To calculate the total error got by the stand, it is necessary to sum up the errors that affect the measurement result, Formula 1.

\[
\Delta_{общ} = \Delta_{инст} + \Delta_{метод} + \Delta_{случ} + \Delta_{суб} + \Delta_{уст} + \Delta_{окр.,ср} + \Delta_{конст} \quad (1)
\]

- \( \Delta_{инст} \) - Instrumental error. In our case, when using a Mitutoyo laser micrometer, the value will be 4 microns;
- \( \Delta_{метод} \) – Methodical error;
- \( \Delta_{случ} \) - Random error;
- \( \Delta_{суб} \) - The subjective error in this design due to the use of an automated device non-contact method of measurement is negligible, so we do not consider it;
\( \Delta_{\text{окр.,ср.}} \) – Error due to external factors;
\( \Delta_{\text{уст.}} \) - Error in the installation of the workpiece in the stand;
The error of the workpiece written in the following form:
\[
\Delta_{\text{уст.,заг.}} = \sqrt{\Delta_{\text{баз.}}^2 + \Delta_{\text{заг.}}^2 + \Delta_{\text{п.з.}}^2}
\] (2)
\( \Delta_{\text{баз.}} \) – Base error;
\( \Delta_{\text{заг.}} \) - Fixing error, the accuracy of the result depends directly on the setting of the part on the base;
\( \Delta_{\text{п.з.}} \) - Error in the position of the workpiece;
\( \Delta_{\text{констр.}} \) - Design error.

After calculating and summing the errors, we get that the error of the entire installation will be only 40 microns, which for dimensional products (longer than 10 m) has a relatively slight error.

Thus, the use of the stand will improve the quality of product control. Identification of discrepancies in the specified shaft parameters, violation of metrological characteristics during assembly of the finished product detected and corrected.

During the control operation, took readings from the measuring instrument and entered the computer, the report generated in xlsx format. After receiving the measurement results, displays the data analyzed and a general characteristic about the state of the object.

3. Analysis of measurement results. Detection and elimination of errors. Evaluating the adequacy of the model

The accuracy and correctness of the values got during the control largely depends on the results got during the procedure. The conclusion of data analysis gives a complete picture of the state of the object under control. The occurrence of errors in the results is not uncommon. Sudden or short-term changes in the measurement conditions or unnoticed failures in the equipment at work, errors made by the operator during the measurement process, the incorrect recording of the observation result, etc. Can cause gross errors. The elimination of such errors becomes a primary task in the analysis of the results of measurements.

The Bauman Moscow State Technical University has developed a method for detecting and excluding errors from measurement results. The program wrote on the Matlab platform. To identify and exclude gross errors, we used the following criteria: the Grubbs, Chauvenet, Romanovsky, Charlier, and 3-Sigma criteria. We applied each criterion for a different number of measurements [13-17].

3.1. A description of the criteria
1. The Chauvenet criterion applied if the number of measurements is small \( n < 10 \). Here, we consider the result \( x_i \) a miss if the difference \( |\bar{x} - x_i| \) exceeds the value \( \sigma \) given below, depending on the number of measurements.
2. The Romanovsky (R.C.) Criterion applied when \( n < 20 \). The formula determines the theoretical value of the RC: the Condition is that the theoretical value must be greater than or equal to the critical value taken from the table. If we meet the condition, consider the element a miss.
3. Charlier Criterion. This criterion used for samples where the number of observations \( n \) exceeds 20. We consider the \( x_c \) a flagrant error, if inequality \( |x_c - x_{ср.}| > K_w S > X \) , where \( x_{ср.} \) is the mean value of the sample, \( K_w \) - is the tabulated value of the criterion Charlier, \( S \) - is the sample standard deviation.
4. The 3-Sigma criterion. Values of a normally distributed random variable that deviate from the mathematical expectation \( M(x) \) greater than three Sigma are unlikely and therefore are gross errors. I.e., the value of \( x_i \) is a gross error.
5. The Grubbs test described in GOST R ISO 5725-2-2002 and GOST R 8-736-2011 and used to test for gross errors (misses) doubtful sample values from a random variable with a normal distribution. The program works as follows: measurement results data about the process filled in excel format. We upload the file to the Matlab system in the program body. The downloaded file analyzed, and the
results are output as three graphs for each criterion. After displaying values that differ from the main dataset and identified as errors by the criteria, the program excludes them from the file and tests the adequacy of the measured object. Thus, at the end of calculations, we get a ready-made image of the state of the measured object.

3.2. Experimental part of the program
To verify the correct operation of the algorithm for identifying and eliminating misses, we carried the following experiments on.

The experimental conditions were suppose a quantity measured whose actual value is 2. In this case, the device gives an error of 5%. Thus, values deviating from 2 by over 5% should consider a gross error.

To test the operation of the program, we generated data series that deviated from the value of 2 by only 5%. Then, several deliberately erroneous values added to each row, deviating from the actual value by over 10%.

For each criterion, it generated 2 graphs Figure 2: The generated values were within the 5% interval.

- A histogram showing the quantitative distribution of the generated values and detected errors
- A figure showing which values the algorithm threw back (in red) and the rest of the values (in green).

For example, for the Chauvin criterion in Excel, we randomly generated the data shown in Table 1 were randomly.

Table 1. Generated values for checking the Chauvin criterion for finding and eliminating misses.

|                | First experiment |               |               |               | Second experiment |               |               |
|----------------|------------------|---------------|---------------|---------------|------------------|---------------|---------------|
| Measurement number | 1  | 2  | 3  | 4  | 5  | 6  | 7  |               | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
| Value          | 2  | 1.97 | 2.03 | 2  | 1.96 | 2.23 | 1.95 |               | 2.2 | 2.03 | 2.01 | 1.95 | 2.04 | 1.99 | 2.02 |

The measurement results from table 1 saved in xlsx format and loaded into the program. After the analysis carried out and shows the result in Figure 2.

Figure 2. Analysis of the measurement results by the Chauvenet criterion.

The same algorithm is used to check for other criteria Figures 3-4.
The conclusion of the work of the program: for some measurements, the Chovine and Romanovsky criteria work relatively efficiently. When using Charlier criteria and 3 sigma for more measurements, problems arise with many errors. It can not always output the correct results, skips errors. The Grubbs criterion described in GOST R ISO 5725-2-2002 and GOST R 8-736-2011 works in comparison with the Charlier criterion more efficiently and is comparatively simpler than the 3-sigma criterion.

In addition, for the second part of the program, it supposed to assess the adequacy of the model and the measurement object. To write the algorithm, we used the methodological material of NT Polaris “To assess the adequacy of the model and the measurement object” [18]. In the method, the Fisher criterion used to assess the adequacy of the model and gives a monosyllabic answer “YES” or “NO”.

**Figure 3.** Analysis of measurement results by criteria:

a) The Romanovsky criterion  
b) The Charlier criterion

**Figure 4.** Analysis of measurement results by criteria:

a) The 3-Sigma criterion  
b) The Grubbs criterion
Thus, the written program allows you to analyze enormous amounts of data, find and eliminate misses using different criteria and choose the result. The program also tests the adequacy of the model and the measurement object, which is necessary for further deeper analysis of the got results.

According to the data got at the end, it is possible to accurately and fully analyze and conclude on the state of the investigated object.

4. Conclusion
The problems of metrological support in the control of large-sized parts are considered. The analysis of control systems using contactless measuring systems is carried out.

The developed stand for control of rotation details on the example of large-sized shafts is presented. The stand is an automated measurement system, including a Mitutoyo LSM-506S laser micrometer and an automated system for collecting measurement information. An algorithm for analyzing control results using the Matlab complex is proposed.

The total value of the error in the control of large-size shafts of more than 1000 mm is $\Delta=\pm 40$ microns.

In this paper, a study was conducted to verify the criteria for analyzing measurement information. The analysis was performed using the following criteria: Grubbs, Chauvinet, Charlier, Romanovsky, and 3 Sigma.

Research results show that the Grubbs criterion works better in comparison with the Charlier criterion. The Charlier criterion and 3-Sigma work worse, and they miss a lot of data.

For a small number of measurement criteria Sovine and Romanowski the most effective and preferred. When using them, gross errors are detected and excluded from the measurement results.

An algorithm, research methodology, and data analysis program were developed. The presented algorithm provides a high probability of detecting defects in production. This approach can be used as an additional tool for product quality management.

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

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