Selection of effective criteria for determining the volume of measurements

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Abstract. The cost of carrying out control measures increases significantly if they are not effectively controlled, in particular when the consumer gets low-quality products. The increase in cost is due to the completion of products or return of marriage. Therefore, the main task of this article is to develop effective control methods that can provide both a certain output level of quality and its improvement. Active control devices are often used to create an effective control system for the accuracy of part processing. They work using different algorithms. Recently, active control is increasingly used to control the current value. Based on the measurement results of each processed part, an adjustment equal in magnitude to the resulting deviation is entered. Similar control methods are used in the ISO 8258-91 standards. Modern software allows you to effectively manage the processing process, so the choice of a rational control algorithm plays an important role.

The development of information processing methods has a significant impact on measurement technologies. In general, the concept of "measurement" implies actions for planning an experiment, obtaining the required information with sufficient accuracy, and then processing it [1-6]. The physical direction in measurement theory considers measurement as a process based on a comparison with a unit and inevitably with an error. This comparison depends on the sensitivity of the process to disturbing factors. It turns out that the better we want to make a comparison, the more sensitive the measurement process is to perturbations.

The use of mathematical methods for processing the results of observations allows in some cases to select the necessary measurement information. However, this is almost always impossible with scheduling errors [7].

In physical experiments, in technical control, when the random component of the measurement is significant, it becomes necessary to take multiple measurements in order to take the average as a measurement result. This raises the problem of choosing the number of dimensions.

Planning a measurement is a stage of managing it with incomplete knowledge of the mechanism of the phenomenon or otherwise-under conditions of uncertainty [8]. Various recommendations and tutorials suggest determining the number of measurements before they are performed using various reference tables. Such planning requires a fairly accurate assumption about the distribution law and, at best, an assumption about the ratio of the mean and standard error [9]. In addition, the planning methodology does not involve evaluating the correctness of the choice and does not provide for the use of current information. Automation of control measures allows to improve the approach to
planning and processing of the measurement process. But these activities are directly related to the development of algorithms.

With multiple measurements, the random component of the measurement error is large enough and the measurement result can lead to erroneous conclusions. In such cases, the task is to select effective criteria for determining the volume of observations [10]. If the measured value retains sufficient stability during the measurement process, it is usually assumed that, in the absence of a systematic error, the mathematical expectation is the actual value of the measured value. Then the arithmetic mean is taken as an estimate and the accuracy of this estimate will depend on the volume of measurements. Similar problems arise when evaluating other statistics [11-13].

There are two approaches to determining the scope of measurements in planning.

1. The first one is based on the assumption that the model of the law of distribution of random deviations of the mean is known, and at least the ratio of the square mean to the limit for a given probability of error of the arithmetic mean for the calculated volume of measurements is known.

2. The second is based on seemingly less stringent requirements for the source data. This is a volume determination using the Neumann-Pearson optimality criterion. This also requires a model of the distribution law. In contrast to the first approach, two simple hypotheses about the mean value and the corresponding error probabilities must be set for the calculation. Since in this case, instead of the values of two averages, you can use their difference, it is enough to set a limit on the difference of two neighboring averages to determine. Using sequential analysis based on the Wald test also requires knowledge of the distribution law.

In practice, the type and parameters of the distribution law of conducting control measures cannot be determined before the measurements are made, so it seems appropriate in most cases to switch to non-parametric methods using the idea of sequential analysis.

As evaluation criteria, selection constraints are used to: variance in average $T_1$ (1); increment the fluctuations in the average $T_2$ (2); the oscillation of the mean square $T_3$ (3); increment fluctuations of the mean square $T_4$ (4). These criteria can be used separately or in combination. This approach is methodically more convenient when there are sufficient reasons to choose a model of distribution laws. In particular, you can use restrictions on the confidence interval as a criterion.

$$T_1 = \frac{x_{n-1} - x_n}{x_{n-1}}$$  \hspace{1cm} (1)

$$T_2 = T_{n-1} - T_n$$  \hspace{1cm} (2)

$$T_3 = \sqrt{\frac{n-2}{n-1}} \left( x - \frac{x_{n-1}}{n-2} \right)$$  \hspace{1cm} (3)

$$T_4 = \sqrt{\frac{n-2}{n-1}} \cdot \frac{t(0.95; n-2)}{\sqrt{n-1}}$$  \hspace{1cm} (4)

Research on models of the stability of these criteria and their comparative effectiveness has shown that their use leads to a decrease in the probability of errors. The measurements are sequentially entered into the program that performs calculations based on the $T_1 - T_4$ criteria. When the
fluctuations in the criteria no longer exceed the set range, depending on the requirements for measurement accuracy, the algorithm gives the command to stop the process and calculates the average value of the performed measurements. If necessary, you can use either one of the criteria or a set of several criteria at the same time.

![Figure 1. Fluctuations in criteria values depending on the number of measurements.](image)

By performing multiple measurements a systematic error may occur, especially at the time of checking parts in production. The operation of machines and other equipment creates unwanted vibrations that have a significant impact on the results of high-precision measurements. In some cases, there is a poor calibration of measuring equipment (example - failure to return the sensor to zero and so on). Therefore, it is necessary to take into account and, if possible, exclude systematic errors from the measurement results.

We studied random sequences of numbers that change according to the normal distribution law. The described algorithm was used to calculate a sufficient number of measurements with the specified control accuracy requirements. Thus, both the average values of the criteria for which the requirements are met and the range of possible values that the criteria accept were established.

Then a systematic error of the form \( y = kx \) was added to the random sequences and a similar calculation was performed. It was found, that in the presence of a linear systematic error, the criterion T2 begins to decrease, and T3, on the contrary, increases. Then if, when processing the measurement results, the criterion T2 is less than the average value, and T3 is greater, then we can assume that there is a systematic error. To eliminate it, the function \( y = kx \) is subtracted from the resulting sequence of measurement results, where \( k \) is iterated until the values of the criteria are close to the average.

For a sinusoidal error of the form \( y = a \sin(x) \), the T4 criterion increases. Although the determination of the error of the sinusoidal type is complicated, due to the fact that for such an error, both the period and the amplitude of the oscillations are not initially known. For small amplitude values, it is more difficult to recognize the sinusoid added to the sequence than to identify the error that changes according to the linear law.

The proposed algorithm was tested on mathematical models, where the systematic error was set artificially, and confirmed its effectiveness. To confirm the results of research in practice, the shaft was selected, processed on a CNC machine. Rolling bearings are placed on the two shaft necks, which imposes special requirements for size and shape accuracy on the diameter Ø54.
Measurements were made using an inductive transducer. During data analysis, a small systematic error was detected using the software.

To evaluate the effectiveness of the algorithm, the part under study was additionally measured in the laboratory using a high-precision MarShaft device for measuring rotation bodies. The results confirmed the effectiveness of the active control method in performing multiple measurements.

With a small volume of measurements, random variables do not show their properties completely, so due to a limited number of data, we translate the random component into a pseudo-system component [14-19].

The sequential analysis method for multiple measurements allows you to improve the accuracy of the result, as well as to identify possible systematic errors. In some cases, the use of a systematic error detection algorithm even allows you to formulate certain recommendations for control operations and helps to identify the causes of errors. When receiving results with a small variance of values, the number of measurements will be reduced, which reduces the control time. If the variance of the results is significant, the calculation method will allow you to get the required value with higher accuracy and thereby reduce the number of defective products.

This algorithm can be used effectively when automating the measurement process in CNC machines or coordinate measuring machines.

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