Assessment of the Suitability of the Measurement Process for the Implementation of an Effective Statistical Management System of the Enterprise

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Keywords: Verification of the suitability of the measurement process, Innovative metrological equipment, Statistical process control system, Statistical process control.

Abstract. A necessary control element of automated production systems is an assessment of the functioning of the technological environment, including verification of the suitability of the measurement process. The values of the process characteristics obtained in the measurement process are the basis for the evaluation of the process and should be sufficiently reliable. The article proposes a method for assessing the suitability of the measurement process for the implementation of an effective system of statistical control of technological processes at the enterprise. An algorithm for process control is presented, which provides verification of the linearity and stability of measurement processes in production activities. A software module is proposed to provide a methodology for calculating the suitability index and obtaining a result when automating the measuring process.

1 INTRODUCTION

Metrological equipment plays an important role in various types of production, because it is with its help that control is carried out in the production process and the time for modernization and development of new products is significantly reduced. The process of operation of metrological equipment begins from the moment it is included in the technological process. In order to assess the rationality of the use of metrological equipment in the production process and to ensure its high productivity, it is subjected to a suitability test procedure. With the help of non-destructive technologies, it is possible to identify inaccuracies in the operation of components without overloading them and without subjecting them to excessive loads.

The measurement management system ensures compliance with the established metrological requirements. The established metrological requirements for measuring equipment and measurement processes are related to the requirements for products. Requirements may include the maximum allowable errors and uncertainties, the range of changes in characteristics, requirements for stability, resolution, environmental conditions, and the qualifications and experience of operators.

2 FUNCTIONAL MODEL OF THE VARIABILITY OF THE PRODUCTION PROCESS

With the development of modern industry, control objects are becoming more and more complex, which creates many new problems associated, for example, with a large number of time-varying parameters, large time delays, high nonlinearity of processes and a complex relationship between input and output parameters.

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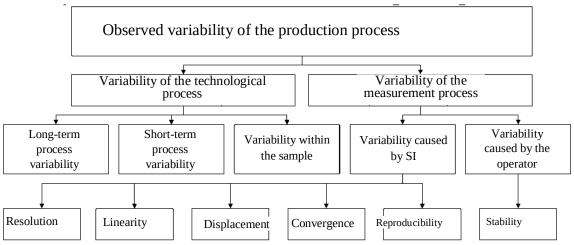

Figure 1: Functional model of the variability of the production process.

The revealed features of the production system made it possible to form a functional model, which is characterized by its variability (Figures 1,2).

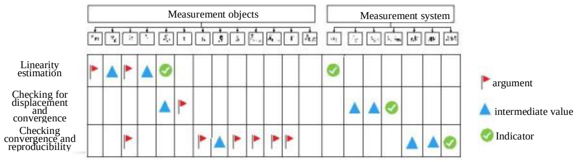

Figure 2: Graphical form of the model of the variability of the production process.

Based on the dependencies identified above, methods for assessing the suitability of the production process based on measurement data using a digital information processing system are proposed (Table 1).

Table 1: Methods (algorithms) for verifying the suitability of the measurement process.

Method	**Indicators**
Method 1. Method for displacement and convergence	C_g, C_{gk}, t-test, confidence interval
Method 2. Method for convergence and reproducibility (with the influence of the controller)	%R&R, confidence interval
Method 3. Method for convergence and reproducibility (without the influence of the controller)	

where $C_g$is the index of reproducibility of the process, C_{gk} is the minimum index of reproducibility of the process, $R\&R$is the indicator of convergence and reproducibility (repeatability and reproducibility).

3 METHODS (ALGORITHMS) FOR VERIFYING THE SUITABILITY OF THE MEASUREMENT PROCESS

Before applying any of the methods, the suitability of the resolution of the measurement system is checked (Figure 3). In addition to these methods, the linearity and stability of the measurement process is checked, as well as the uncertainty of the normal or reference part is estimated.

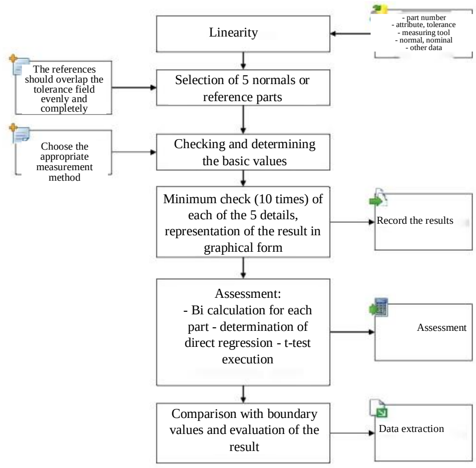

Figure 3: Linearity estimation scheme.

The calculation method verification of the suitability of the resolution of the measurement system can be presented as follows:

$$|B_i| = x_m - \bar{x}_g;$$
$$\bar{x}_g = \frac{1}{n}\sum_{i=1}^{n} x_i;$$
$$S_g = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x}_g)^2. \quad (1)$$

where $B_i$is the displacement, $S_g$is the standard uncertainty of the displacement, $x_m$is the nominal value of the reference (the reference value of the value), $\bar{x}_g$is the average value of the measurements obtained, $n$is the number of repeated measurements.

Method 1. The method for checking the displacement and convergence (Figure 4) involves checking the suitability under sufficient conditions. Its main use is when purchasing measuring instruments. It allows you to make sure that this measurement process (more precisely, the measuring tool) is sufficiently suitable for this feature.

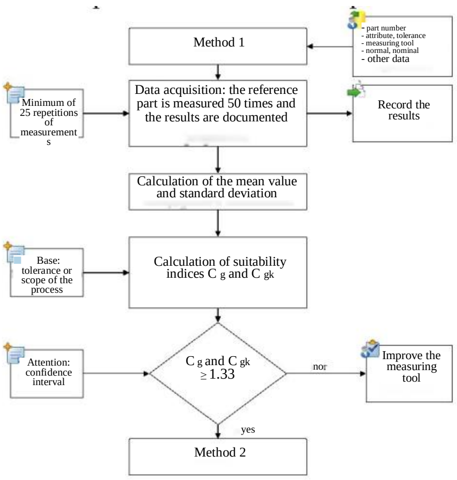

Figure 4: Diagram of method 1. A method for checking displacement and convergence.

Calculation method according to method 1:

$$C_g = \frac{t}{20S_g};$$

$$C_{gk} = 0{,}05\frac{t}{S_g} - \frac{|B_i|}{2S_g}; \quad (2)$$

$$C_g, C_{gk} \geq 1{,}33.$$

where C_g is the process reproducibility index, C_{gk} is the minimum process reproducibility index.

In most cases, the minimum reproducibility value of the process is taken to be greater than one, often it is equal to 1.33; which is due to GOST R ISO 22514-1-2015 "Statistical methods. Process management. Part 1. General principles".

The use of this method avoids the time and money spent on the use of the laborious method 2 for convergence and reproducibility, the algorithm of which is shown in Figure 5. It is applied if method 1 shows the unsuitability of the measurement process.

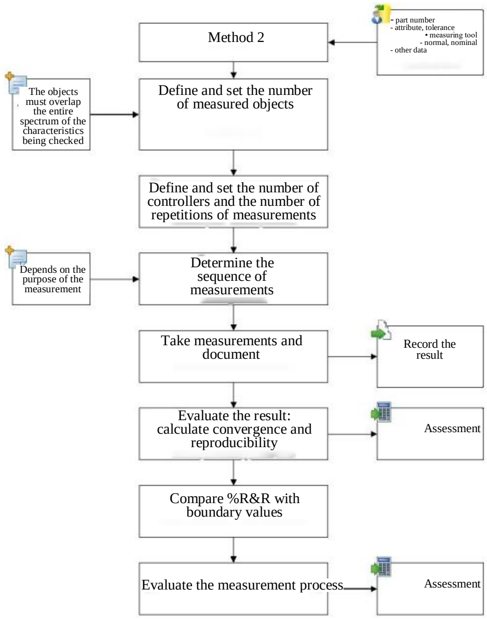

Figure 5: Diagram of method 2. Method for checking convergence and reproducibility (with the influence of the controller).

Method of calculation of method 2:

$$EV = \bar{R}K_1;$$

$$\bar{R} = \frac{\sum_{i=1}^{n}\bar{R}_i}{k}; \quad (3)$$

where EV is the convergence index, the standard uncertainty of the maximum reproducibility value, $\bar{R}$ is the limit of repeatability (convergence), K_1 is the constant corresponding to the volume subgroup n, n is the number of measured objects, k is the number of subgroups.

$$AV = \sqrt{\left(\bar{X}_{Diff}K_2\right)^2 - \left[\frac{EV^2}{nr}\right]}; \quad (4)$$

$$\bar{X}_{Diff} = \bar{X}_{i_{max}} - \bar{X}_{i_{min}};$$

where AV is the reproducibility index, the standard uncertainty of reproducibility of measurements by the operator, $\bar{X}_{Diff}$ is the total average value for all subgroups of data, $\bar{X}_{i_{max}}$ $\bar{X}_{i_{min}}$ is the minimum and maximum value for all subgroups of observed values, r is the reproducibility limit, K_2 is the constant corresponding to the volume subgroup n, n is the number of measured objects.

Method 3 for convergence and reproducibility (without the influence of the controller), which is shown in Figure 6, is a special case of method 2, in which the operator cannot influence the measurement process, for example, when automatically loading into the measuring tool.

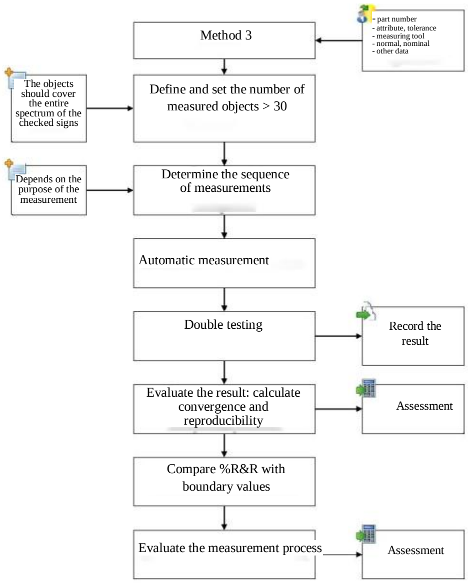

Figure 6: Diagram of method 3. Method for checking convergence and reproducibility (without the influence of the controller).

In this case, a larger number of parts are measured on an automatic measuring instrument during double testing. As a result, AV is always equal to zero, and $\%R\&R$coincides with EV.

4 ASSESSMENT OF THE SUITABILITY OF THE MEASUREMENT PROCESS

After checking the suitability of the processing equipment and the suitability of the measuring instruments used, you can proceed directly to the implementation of process control. The controllability of the process depends on the stability of the state and how stable this stable state is.

$$R\&R = \sqrt{EV^2 - AV^2} \quad (5)$$

where $R\&R$is the indicator of convergence and reproducibility (repeatability and reproducibility).

Evaluation of the result:

$$\%EV = \frac{EV}{RF}100\%;$$
$$\%AV = \frac{AV}{RF}100\%; \quad (6)$$
$$\%R\&R = \frac{R\&R}{RF}100\%.$$

The base RFin most directives corresponds to the part tolerance field.

Table 2: Assessment of the suitability of the measurement process.

Typical boundaries	
$0 \leq \%R\&R \leq 10\%$	The process is suitable
$10 \leq \%R\&R \leq 30\%$	The process is conditionally suitable
$\%R\&R > 30\%$	The process is unsuitable
Expanded boundaries	
$0 \leq \%R\&R \leq 20\%$	The process is suitable
$20 \leq \%R\&R \leq 30\%$	The process is conditionally suitable
$\%R\&R > 30\%$	The process is unsuitable

The general algorithm for verifying the suitability of the measurement process is shown in Figure 7-8.

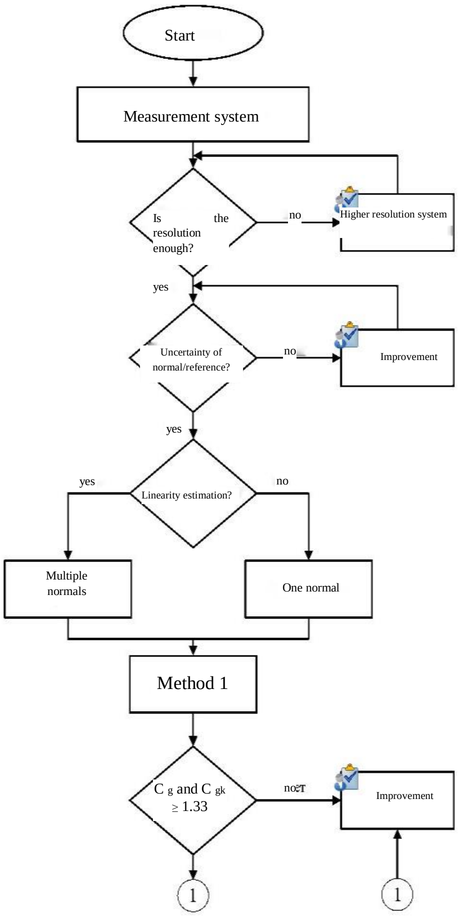

Figure 7: Algorithm for checking the suitability of the measurement process (beginning).

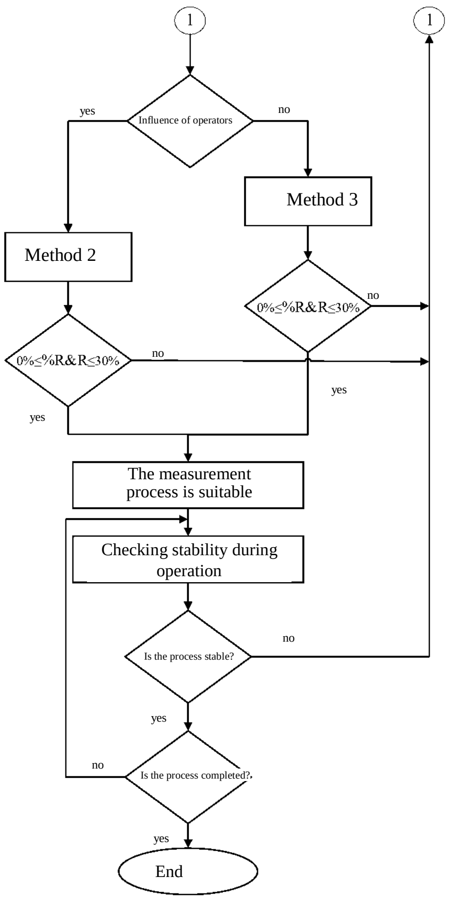

Figure 8: Algorithm for checking the suitability of the measurement process (continued)

This algorithm was presented in the form of software "A software module evaluating the suitability of the technological process of an experimental sample of the software package SPC StatPRO.

Thus, having checked the suitability of the processing equipment and the suitability of the measuring instruments used, it is possible to proceed directly to the implementation of process control. The controllability of the process depends on the stability of the state and how stable this stable state is. In other words, whether the process, after appropriate adjustment, can produce suitable products and how reliably it can do this.

Stability is studied for at least one day. During this time, about 25 samples are taken. For verification, you can use the reference used for method 1.

Case 1: if the measured values are in the range of +/- 5% of the nominal normal, then the process is monitored further once a day.

Case 2: if there is a trend in the measured values, then the calibration interval must be set so that the values do not exceed the range of +/- 5% of the nominal normal.

Case 3: if, nevertheless, it is not possible not to go beyond the specified limits, it is necessary to improve the measuring tool.

Case 4: for very narrow tolerances, it may be necessary to calibrate before each measurement.

To assess the stability of the process and identify the presence of special reasons, control cards are used.

4 ASSESSMENT OF THE SUITABILITY OF THE MEASUREMENT PROCESS

Let's consider an example of intermediate control of rear car windows of an automated system of residual stresses of predicted quality.

According to GOST 32565-2013 "Safety glass for ground vehicles. General specifications" measurement is carried out along the entire contour of the product to determine the maximum value of the tensile stress at 12 points along the perimeter of the glass with a polaroscope.

The control card before identifying and eliminating special causes of variability is shown in Figure 9.

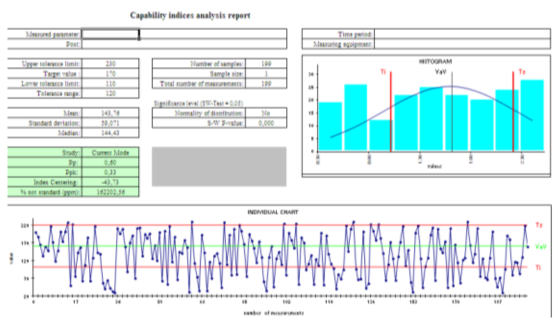

Figure 9: Control card before identifying and eliminating specific causes of variability.

In the case under consideration, the main sign of unstable behavior of the process is the values going beyond the control boundaries. Other signs that occur (trend, frequency) are due to the technological process of hardening and cannot be considered signs of unstable behavior of the process.

A control card of individual values and sliding swings, constructed after excluding special causes of variability, is shown in Figure 10.

Figure 10: Control card of individual values and sliding swings after identifying and eliminating special causes of variability.

Thus, it can be concluded that a special role in the construction of automated quality management systems is played by controls that allow not only to establish the suitability of the part (i.e. its compliance with design documentation), but also provide information about the real state of certain parameters.

5 CONCLUSIONS

This article contains a solution to the problem of increasing the efficiency of the production process of technical control of products using an analytical approach using a digital data processing system by developing a method for identifying the suitability of measuring equipment in the management of automated production systems, which is essential for the transformation of the existing production system in order to adapt it to modern information technologies and innovative technical solutions.

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