Assessment of the influence of measurement error on the quality of selective assembly

Pavel Golintsiky and Uliana Antonova*

Department of Metrology, Standardization and Quality Management, Russian State Agrarian University – Moscow State Agrarian University named after K A Timiryazev, Moscow, 127550, Russia

*E-mail: uantonova@rgau-msha.ru

Abstract. The article considers the influence of measurement error on the quality of selective assembly using the example of a piston-cylinder liner connection. The quality of repaired parts, assemblies and assemblies depends on a rational choice of measuring and control instruments in order to reduce the number of incorrectly received and incorrectly defective parts, and, in turn, internal and external losses, especially with regard to ensuring quality and accuracy of control of parts during selective assembly.

1. Introduction

The issues of ensuring the quality of single and small-scale machine-building production, including machine repair, are currently relevant due to a number of objective and subjective factors that are associated with the culture of design and production of machines. The level of quality provided by mass and large-scale production is much higher than the quality level of single and small-scale production and repair of machines [1]. This is due to a number of objective factors [2, 3], the main of which are economic indicators of profitability: small enterprises cannot upgrade their machinery stock for profit, and use original materials and spare parts and have highly qualified workers for working capital [4]. The required dimensional accuracy in the nodes and assemblies of machines, which is reflected in the technical documentation by class of accuracy and tolerances [5], is poorly formed by old and worn-out technological equipment used in the manufacture and repair of equipment in small-scale production [6].

Metrological provision of control in mechanical engineering is one of the main barriers that really does not allow to miss marriage to assembly. It includes two essential elements - the unity of measurements and ensuring the required accuracy of control. Improving the accuracy of control leads to a decrease in the components of the cost of quality [7], namely the costs of internal and external marriage [8]. The nomenclature of universal measuring instruments, which are widely used in small-scale production and in the repair of machines, most often includes several instruments that can satisfy the requirements of the choice of measuring instruments. In this paper, we consider the feasibility of choosing one or another means of control, including the responsible process of sorting into the selective group of cylinder liners, both received in the form of spare parts and processed for repair size. Emphasize that this is important precisely in breeding, where control is carried out not on the edges of the product size scattering zone, but on its sectors, and errors of the first and second kind are quite large here.
2. **Main part**

The purpose of the research is to study the degree of influence of measurement error on the scattering area of the dimensions of cylinder liners during processing and control during group interchangeability, the formation of the number of incorrectly received and incorrectly rejected parts, as well as determining the probabilistic value of the output for each tolerance border for incorrectly accepted sizes liners.

3. **Existing techniques**

Currently, the choice of linear measuring instruments for tolerance control is considered by technologists as a simple task, during which it is necessary to be guided by the requirements of GOST 8.051-81 and RD 50-98-86.

Measuring instruments are selected taking into account the accuracy and metrological characteristics of the control object. The production program also influences the choice of measuring instruments. In mass production, usually use original high-performance measuring instruments or calibers with elements of robotization and automation, and in small-scale and single-unit production, universal measuring instruments are used.

The measurement error, having a certain scattering, is superimposed on the scattering zone of controlled sizes, as a result, the probability of error is formed when deciding on the suitability of the product. Controlled product dimensions that are closer to the limits of the tolerance fields fall under the influence of scattering overlay. Consider the scheme of such an overlay (figure 1), where tolerance T is shown, the parameters characterizing the scattering of the controlled product dimensions are the scattering zone \(\omega_{\text{tech}}\) and root-mean-square deviation \(\sigma_{\text{tech}}\), as well as the scattering of the measurement error \(\Delta\), provided that these scatterings are distributed according to the normal law distribution.

![Figure 1. The control scheme.](image)

A specific measuring instrument during tolerance control is chosen so that the limiting measurement error \(\Delta_{\text{lim}}\) is no more than the permissible standardized measurement error \(\Delta\), i.e. \(\Delta_{\text{lim}} \leq \Delta\).

The influence of scattering of the measurement error on the formation of the results of sorting is evaluated by the following parameters (figure 1):

- \(m (m_1)\) - number of incorrectly received parts as a percentage of the total number of measured (number of received);
- \(n (n_1)\) - number incorrectly rejected parts as a percentage of the total number measured (suitable numbers)
- \(c (c_1)\) - the probability value of the measured parameter going beyond each tolerance limit for incorrectly received products (from the number of received parts).

When determining the above parameters, it is most rational to use a relative value:

\[
A_{\text{met}}(\sigma) = \left(\frac{\sigma_{\text{met}}}{T}\right) \cdot 100\% \tag{1}
\]
where $A_{\text{met}}(\sigma)$ - relative measurement error (measurement accuracy coefficient);

$\sigma_{\text{met}}$ - root-mean-square deviation measurement errors $\sigma_{\text{met}}=\Delta\text{lim}/2$;

$T$ - controlled size tolerance.

4. Object, means and research methods
As an object of research, cylinder liners of MMZ diesel engines were selected. In the technical requirements for maintenance and overhaul when monitoring the diameters of cylinder liners, it is recommended to use an internal dial with a division value of the reading device of 0.01 mm. When tuning along the mounting rings, the error of such a device $\Delta\text{lim} = \pm 10 \mu m$, and according stack of gage blocks $\Delta\text{lim} = \pm 15 \mu m$. The use of this device is unacceptable, since at such error values the number of incorrectly received parts and incorrectly left from the group or rejected will increase at least twice. Therefore, the main metrological principle is not maintained that the measuring instrument should be three or more times more accurate than the tolerance of the measured parameter.

For our case, the group tolerance $T_{\text{gr}}$ is 20 $\mu m$, and it can only be controlled by measuring instruments with an error $\Delta\text{lim} \leq 6.5 \mu m$.

To analyze the formation of scattering of the diameters of the sleeves in the control process in order to ensure group interchangeability of sleeves with pistons, the following measuring instruments were selected:

- internal dial with a division value of the reading device of 0.001 mm when configured according stack of gage blocks $\Delta\text{lim}1 = \pm 6.5 \mu m$ (denoted by MI1);
- internal dial with a division value of the reading device 0.001 mm when setting on mounting rings $\Delta\text{lim}2 = \pm 4 \mu m$ (denoted by MI2).

The diameters of the cylinder liners were controlled in two mutually perpendicular planes and in cross-section and longitudinal section. The average size was determined, which can be taken as the actual diameter.

The determination of the number of incorrectly rejected parts from the number of suitable, the number of incorrectly received parts from the number of accepted, the maximum size over the border of the tolerance field was carried out according to the standard method.

![Figure 2. Scattering of diameters of the bore of the cylinder liners of the engine MMZ.](image)
5. Results and discussion
To assess the scattering, a batch of cylinder liners was controlled in an amount of 50 pieces. The control results are reflected in the form of a histogram, a polygon and a theoretical distribution curve (figure 2).

An initial analysis of the quality of cylinder liners will be carried out using the coefficient of accuracy and mood of the technological process.

The accuracy factor of processing is determined by the formula:

$$ K_T = \frac{T}{6S}, $$

where $S$ is the standard deviation scattering of the size.

At $K_T = 0.7 \ldots 0.9$, the process has low accuracy and does not meet the requirements.

The coefficient of mood of the process is determined by the formula:

$$ K_C = \frac{D_{cp}-\bar{X}}{2T}, $$

where $D_{cp}$ is the average size;

$\bar{X}$ is the arithmetic mean value of the sample.

At $|K_C| \leq 0.05$, the tune process is considered good.

Data on the analysis of scattering are summarized in table 1, from which it can be seen that the technological process of processing the cylinder liners can be considered unsatisfactory, since the accuracy coefficient $K_T = 0.76$. There is also a rework material of 4% and waste of 2%.

The scattering zone of sizes has an offset towards rework material $K_C = -0.027$, which indicates an acceptable qualification of workers who perform this operation.

| Table 1. Scattering of cylinder liners by selection groups. |
|-----------------------------------------------------------|
| Selection group | Size, mm | Number of details | Theoretical probability |
|-----------------|----------|-------------------|------------------------|
| Rework material | Less 110.00 | 2 | 0.046 |
| Group M | 110$^{+0.02}$ | 16 | 0.278 |
| Group C | 110$^{+0.04}$ | 19 | 0.445 |
| Group B | 110$^{+0.06}$ | 12 | 0.201 |
| Waste | More 110.06 | 1 | 0.027 |

Determine the number of incorrectly rejected parts (n,%) of the number of suitable parts, the number of incorrectly accepted parts (m,%) of the number of received parts and the limit values for the size to go beyond the tolerance field (c, μm) according to the procedure (table 2).

| Table 2. Parameters for sorting cylinder liners when using an internal dial with different measurement errors. |
|-----------------------------------------------------------|
| The distance from the middle of the tolerance field to the border of the corresponding group 2t, mm | Number of incorrectly rejected parts, n,% | Number of incorrectly accepted parts, m,% | The value of the output of the measured parameter beyond the tolerance limit, c, μm |
|-----------------------------------------------------------|
| MI1 | MI2 | MI1 | MI2 | MI1 | MI2 |
|-----------------------------------------------------------|
| 0.0152 | 7.6 | 5.2 | 7.7 | 4.9 | 2.28 | 1.75 |
| 0.0248 | 4.7 | 2.8 | 4.1 | 2.9 | 2.85 | 1.49 |
| 0.0552 | 1.9 | 1.2 | 1.3 | 0.4 | 2.07 | 1.93 |
| 0.0648 | 0.4 | 0.4 | 0.2 | 0.2 | 1.56 | 1.36 |
| Amount | 14.6 | 9.6 | 13.2 | 8.4 | - | - |
Thus, when using an inaccurate internal dial with an error $\Delta \text{lim}_1 = \pm 6.5 \, \mu \text{m}$, the number of parts that are incorrectly out of the group or rejected is 5% larger. The number of incorrectly received parts is 4.8% higher than when using a more accurate internal dial with an error of $\Delta \text{lim}_2 = \pm 4 \, \mu \text{m}$.

6. Conclusion
When choosing measuring instruments for monitoring the quality of processing cylinder liners in a single, small-scale and repair production, the most accurate should be used from the proposed range of universal linear measuring instruments. In this example, this is an internal dial with a division value of the reading device of 0.001 mm when tuning by the installation rings, while the measurement error will be the smallest: $\Delta \text{lim}_2 = \pm 4 \, \mu \text{m}$. If it will be possible to replace this measuring instrument with a more accurate one from the category of universal ones, then this must be done. Reducing the error of measuring instruments leads to a significant reduction in the number of incorrectly admitted to the group and incorrectly left the group or rejected parts. This, in turn, affects not only the quality of the subsequent assembly of the connection, but also the economy of the enterprise.

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