Assessment of the influence of deviations in the shape of the surface of the part on the measurement error

N Zh Shkaruba¹, O A Leonov and L A Grinchenko

Department of Metrology, standardization and quality management, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Timiryazevskaya, 49, Moscow, 127550, Russia

¹E-mail: metr@rgau-msha.ru

Abstract. The analysis of the factors influencing the occurrence of errors when measuring linear dimensions by universal measuring instruments have carried out. It has shown that for linear measurements, the errors of measuring instruments are in most cases the main components that have a dominant effect on the total measurement error. The specific components of the measurement error at the stage of defective detection of parts during machine repair have considered. For the analytical representation of the current size, a polar coordinate system has introduced and an equation for the contour of the cross section of the measured part has drawn up. To quantify the error caused by not detecting the smallest diameter of the part, an error formula has derived for the oval profile of the part. The estimation of the influence of the number of measurement directions during fault detection on the value of the measurement error has been carried out. Recommendations have presented to reduce the measurement error associated with the deviation of the geometric shape.

1. Introduction

The quality of car repair depends on many factors [1, 2]. Mechanical engineers manufacture and assemble parts into connections, connections into assembly units, assembly units into assemblies from new elements. During operation, there is a change in the initial clearances [3], structural tightness [4, 5], specified values of accuracy in seals [6, 7] according to complex laws of wear in time. The originally adjusted tolerances in fits have also been changed [8]. In order to form a larger wear margin, methods of incomplete interchangeability are used [9, 10]. When one of the critical connections calls, the unit goes for repair. A defect, as a type of incoming inspection, is the most important operation that is carried out before the repair of parts and assemblies of modern technology [11]. The quality assurance of input and other types of control is carried out by the metrological service at the repair enterprise [12, 13]. Improving the accuracy of processing new and repaired parts, the issue of rational justification, including an increase in the cost of control [14] and the likelihood of displaying losses from the error of funds [15, 16].

The measurement error is a consequence of the manifestation of factors that create the total effect. There may be a lot of such reasons, depending on the method used, the object of measurement and conditions, but not all of them equally affect the overall measurement error [17].

Proceeding only from the dominant factors for many types of measurement, in some works [18, 19] it is indicated that the measurement error consists of the instrument error, the error from temperature...
deformations and the error of the setting measures; sometimes an error from the measuring force is added. However, there are a number of very important components, which sometimes significantly more affect the total measurement error than those listed, for example, the error of the applied measurement scheme, the error from the difference in the measuring force, the subjectivity of the controller, the error from the deviations of the geometric shape and surface roughness of the tested part, the error basing and others (in technical and educational literature, sometimes a slightly larger number of components of errors are given, and sometimes even less). The lack of unity in the number of components of the measurement error among different authors is mainly due to the conventionality of the very principle of separating individual components. The assignment of some components of the error to a separate type or their inclusion in the main, dominant components to a large extent depends on the authors of such a classification.

For linear measurements, the errors of measuring instruments are in most cases the main components that have a dominant effect on the total measurement error. Usually it is this error that is taken for the measurement error as a whole. It should be borne in mind that, firstly, the value of the error of the device indicated in its technical documentation, i.e. normalized permissible error should be considered as the measurement error for one of the possible options for using this measuring tool. Secondly, the error of the measuring instrument, in all cases, is taken on the assumption that the device is serviceable and meets the requirements of the technical documentation.

Errors depending on gauge blocks arise due to an error in their manufacture or inaccuracy of certification (discharges), as well as due to an error due to grinding.

Errors arising from thermal deformations. Fluctuations in temperature, as well as its deviation from normal (20 °C), lead to measurement errors. The cause of errors is temperature deformations due to the difference in heating of the measuring instrument and the object of measurement, as well as the difference in their coefficients of linear expansion.

Along with the considered components of the measurement error for measurements carried out at the stage of flaw detection during the repair of machines, there are a number of specific components due to both the object of measurements (worn parts) and measurement methods (micrometer). Fault detection during repair of cars is an integral part of the technological process and is a kind of entrance king of refurbished products. The purpose of the fault detection is to determine the size wear and deviations of parts.

In this regard, the issue of calculating and assessing the components of the error associated with the distortion of the geometric shape of the part and determining the optimal combinations of the choice of the number of planes and sections when carrying out micrometering of worn parts is urgent.

The purpose and objectives of the research. To develop recommendations for improving the metrological support of measurements of parts during repair of machines at the stage of fault detection. To achieve this goal, it is necessary to determine the components of the measurement error during fault detection of machine parts, draw up an analytical formula describing the measured size and derive a formula for calculating the error for the oval section of the part profile.

2. Analysis of the measurement error of internal dimensions

When controlling dimensions, the distortion of the geometric shape of the part introduces a systematic error with a plus sign in the measurement result and, therefore, can be taken as suitable parts with dimensions smaller than permissible. Shape error in cross and longitudinal sections is defined as the difference between the largest and smallest diameters or radii and is presented as a random variable for a batch of parts. The polar coordinate system was introduced to analytically represent the current measurement. The equation of the cross-sectional contour of a part having an elementary form of form errors was written

\[ \xi_{(\phi)} = r + \sum_{k=2}^{P} x_k \cos(k\phi + \Psi_k), \]  

(1)
where \( r \) – the radius of the middle circle, defined as the average value of the function; \( x_k, \psi_k \) – the amplitude and phase of the harmonic characterizing the shape error.

For \( k = 2 \), the second term expresses tolerance circle. The random variable expresses the error of its own size, the elementary random function determines the error of the shape in the cross section. When detecting such errors, the method will consist of three types of errors:

the error caused by the failure to identify the smallest diameter of the part \( \Delta_1 \) in a given section;
instrumental error of the device \( \Delta_2 \);
errors when checking along the neck length \( \Delta_3 \).

To quantify the error \( \Delta_1 \), consider the equation of the neck contour in polar coordinates relative to the angle \( \alpha \). The equation of the curve in polar coordinates in general form has \( r = f(t) \). Let us expand the function \( r = f(t) \) in a Fourier series with a period of \( 2\pi \) corresponding to the closed contour of the neck cross section and consider the difference between the actual radius of the permissible circle \( \Delta r = r - r_0 \). Then the deviation of the actual profile from the permissible one has the form:

\[
\Delta_1 = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos(k\alpha + A_k). \tag{2}
\]

The geometric meaning of this formula: the zero expansion term is the deviation of the worn surface from the permissible profile (deviation of the mean diameter). The first term of the expansion \( \alpha_1 \cdot \cos(\alpha + A_1) \) depends only on the choice of the polar coordinate system of the given section and will be equal to zero when the rotation pole is aligned with the geometric center. Therefore, proceeding from the oval shape of the working surface of the checked part, the equation of the shape error will be the second term of the decomposition \( \alpha_2 \cdot \cos(\alpha + A_2) \). The scheme for measuring an oval worn part has shown in figure 1. Obviously, if the measurement of the part in the cross-section is carried out in the direction of the angle \( \alpha \), then the error arising from the fact that the smallest diameter was not detected will be equal to the difference between the diameter measured in the direction of angle \( \alpha \) and the smallest diameter of the checked part.

\[
\Delta_1 = D_\alpha - D_{\min}, \tag{3}
\]

where \( D_\alpha \) – the diameter measured in the direction of the angle \( \alpha \); \( D_{\min} \) – the smallest cross-sectional diameter of the worn part.

![Figure 1. Schematic representation of a worn part with a tolerance circle measured in an arbitrary direction.](image)

The formula for calculating the error for an oval profile is as follows.
\[ \Delta_1 = \overline{X}_{sp} \cdot \sin \alpha; \quad \overline{X} = D_{\text{max}} - D_{\text{min}}, \]  
(4)

where \( \overline{X}_{sp} \) – the tolerance circle of the worn part in a given section; \( \alpha \) – the angle in the direction of which the measurement was made.

Let us consider the influence of the direction of measurement on the errors \( \Delta_1 \). In the case of a defect in one direction, the margin of error is equal to the value of the tolerance circle, since the largest diameter can be measured by checking the smallest size. To reduce the error \( \Delta_1 \), it is necessary to make measurements in several directions, evenly around the circumference. When measuring (controlling) along two mutually perpendicular planes (\( n = 2 \)), the measurement error decreased by 2 times. In the general case of detection of defects in the surfaces of the tolerance circle in several directions, the maximum error \( \Delta_{1\text{lim}} \) has found by the formula:

\[ \Delta_{1\text{lim}} = \overline{X}_{sp} \cdot \sin \frac{\pi}{2n}. \]  
(5)

where \( n \) – number of measuring directions.

This formula should be used when determining the effect of tolerance circle on the results of fault detection when choosing the number of measurement directions. It should be borne in mind that an increase in the number of measurement directions over 4 is impractical, since it does not give a significant effect. Thus, an increase in the number of measurement directions from 4 to 5 reduces the limiting error by only 5%, while an increase in them from 1 to 2 gives a 50 % decrease in tolerance circle.

3. Conclusions

Thus, it has been established that the error of the surface shape has a significant effect on the accuracy of measurements in the repair industry, because when measured, the object is replaced by a model. Deviations of the geometric shape of the tested parts during a single measurement have an effect on the error in determining the actual size, which is a random component of the measurement error and manifests itself depending on the measurement scheme and the nature of the geometric shape deviation. The formula for calculating the error for the oval profile of the part is presented. It has been proven that in order to reduce the measurement error, it is necessary to use measurements in several directions, evenly around the circumference. The results of the research can be used to compile micrometer maps of various parts at the stage of fault detection during machine repair.

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