Selection criteria for universal measuring instruments for internal dimensions of parts

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Abstract. The urgency of research on the issues of substantiating the requirements for the accuracy of measurements of linear dimensions has substantiated. The main differences between the means for measuring external and internal dimensions have formulated. The factors influencing the choice of measuring instruments have considered. Specific additional measurement errors associated with the alignment of the measurement line with the hole diameter have described. A comparative analysis of the possibility of using various types of bore gauge to control the internal dimensions of holes during machine repair has carried out. The results of an experimental evaluation of the components of the measurement error of a two-point bore gauge have presented.

The criterion for the selection of measuring instruments for measuring the holes of objects of maintenance of machinery and equipment has been substantiated. Recommendations have given aimed at improving the accuracy of measuring the holes of parts during the repair of machinery and equipment.

1. Introduction

The quality of the final product of an engineering and repair enterprise depends on many different factors, the most important of which are: the level of quality of technological processes; manufacturability of the design; quality of technological equipment; quality of purchased materials and components; methods and means of measurement, testing and control; professional level of the company's personnel.

Among the factors considered, a special place is occupied by methods and means of measurement, testing and control at machine-building and repair enterprises. It is on the reliability of the measurement information that the adequacy of the management decisions taken on the regulation of the technological process and the conclusion on the suitability of the controlled parts and the final product depends. The system of metrological support is responsible for the quality and reliability of measuring information at enterprises [1].

The main objectives of metrological support at enterprises are:

- providing conditions for obtaining reliable measurement information;
- maintenance of measuring, testing and control instruments in constant suitability for use;
- metrological support for monitoring working conditions and environmental protection.
Strong competition among machine-building enterprises and enterprises providing services for the repair of machinery and equipment leads to stricter requirements for the accuracy of machines and equipment in order to ensure the durability of critical joints both with a gap [2] and with an interference fit [3, 4]. To improve the accuracy, methods of incomplete interchangeability are also used [5]. Increasing the accuracy of manufacturing and assembly of joints leads to the need to ensure the accuracy of the means and methods of their control [6, 7]. Separately, it is possible to single out technologies for controlling the diameters of holes in rubber reinforced cuffs to ensure the absence of the beginning of leaks [8, 9].

Particularly acute is the issue of ensuring the accuracy of measurements of the holes of the basic resource-determining parts, such as engine blocks, gearbox housings, transmissions, as well as holes of typical parts: cylinder liners, connecting rods and many others. The diameters of the holes in the listed products are different and are in the range from 50 to 260 mm, they are made according to 5–7 accuracy grades, they have standardized accuracy requirements for the mold surface. Cylinder blocks, gearbox housings, transmissions have a large mass, therefore, the measurement of the dimensions of the holes during maintenance and repair can only be performed with portable universal devices. Metrological requirements for the selection of universal measuring instruments for linear dimensions according to the criterion of the permissible measurement error are established in GOST 8.051-81 and RD50-98-86. The margin of error (for 5–7 accuracy grades) is taken equal to 30 ... 35 % of the tolerance for manufacturing the size of the part. This metrological requirement was substantiated in the 80s of the last century.

The purpose and objectives of the research. To develop recommendations for improving the metrological support for controlling the internal dimensions of parts during engine repair. To achieve this goal, it is necessary to determine the criteria for choosing measuring instruments for controlling the internal dimensions of parts, taking into account the peculiarities of using universal measuring instruments and the formation of a total error in measuring internal dimensions.

2. Analysis of the measurement error of internal dimensions

Instruments for measuring internal dimensions are included in a special group and have the following differences from instruments for measuring external dimensions:

- when measuring internal dimensions, the device must be inserted into the part, and when measuring external dimensions, it is outside the part.
- the contact conditions of the surfaces are different. When measuring internal surfaces, the concave cylindrical surface is in contact with spherical or linear measuring tips. When measuring external surfaces, a convex cylindrical or flat surface contacts the flat or spherical measuring tips of the measuring instruments.
- when measuring inner cylindrical surfaces, the device does not self-align with respect to the axis of the measured diameter. The alignment of the measurement line with the diameter is solved by complicating the design of measuring instruments and measurement techniques.
- instruments for measuring internal cylindrical surfaces are characterized by a greater complexity of design and measurement method.

The choice of measuring instruments is influenced not only by the technical requirements related to the object of measurement, but also by the economic criteria associated with the costs of measurements and losses from the measurement error [10, 11]. During the technical service of machines, the actual size and wear are determined, which, as a rule, are not uniform along the length of the surface, and the suitability of the part for operation is established. During the repair and control of spare parts, their suitability is determined [12,13]. All these factors affect the quality of repair [14], and the effectiveness of such an operation as incoming inspection is proved during the repair of machines [15], and non-contact special control devices are being developed [16].

Easy to use, economical and do not require adjustment, digital and dial calipers with a reading accuracy of 0.01 mm from different manufacturers and world brands have a measurement error of ± 30 μm
or more in a measurement range of up to 200 mm, and should not be used for measuring the objects under consideration. may, due to low accuracy. In addition, the depth of measurement of the holes with calipers is limited.

Specially produced calipers with extended jaws, point and other types, increase the measurement depth up to 30 mm, but this reduces the measurement accuracy. An additional error appears from the deformation of the main rod, since the reference contact points of the measuring jaws are at the greatest distance from the main rod and from the applied measuring force, a skew error occurs, the Abbe principle is violated, especially when used at the full measurement limit. Thus, measurements of holes with a caliper with regular and elongated jaws can be considered unreliable. Therefore, they can only be used to roughly estimate the size of the hole.

When measuring the hole diameter with hole-gauge using the differential method, the following errors occur: instrument error, instrument adjustment error for size, error from alignment of the measurement line with the hole diameter (centering and skew error), temperature error, subjective errors, error from hole surface roughness, errors from the measuring force, errors caused by contamination of the inner surfaces of the measured parts, etc.

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.

To reduce the risk of accepting results containing gross errors and misses, as well as to reduce the random component of the error, it is advisable to perform four measurements. The frequency of measurements over four is impractical, since the efficiency of their influence decreases, due to the increase in the complexity of measurements.

3. Practical implementation of the research

Firms in different countries produce two-point, three-point, precision bore gauges of various types and measurements in the range from 0.5 to 1150 mm. Each type has its own advantages and disadvantages. Three-point bore gauges are available both vernier and digital. In vernier bore gauges, a direct method of direct assessment is used, in electronic differential methods of comparison with a measure.

Three-rod bore gauges are set to size only according to the setting rings or according to the sample. They cannot control the geometric shape of the part, therefore, in practice, they are not used for technical service and machine operation. These instruments can be used to inspect remanufactured and spare parts.

In the technical service of machinery and equipment, two-point bore gauges are mainly used. Let us consider the components of the measurement error by instruments in more detail to substantiate the requirements for measurement accuracy.

Two-point bore gauges can be set to a size according to a certified micrometer, a block of gauge blocks with sidewalls assembled in a clamp, a calibrated ring, according to a special adjusting device and according to a sample.

Installation by a micrometer is not recommended due to the large error in the installation process itself. When set to the size of the block of gauge blocks with sidewalls, errors arise from lapping the measures (the smaller the size of the measures, the larger the lapping errors) and errors from deformation of the clamp in the clamp.

It is recommended to install bore gauges to the size according to the setting rings and adjusting device. Can be customized and sampled. The calculated and experimental components of the measurement error of a two-point bore gauge are presented in table 1.
Table 1. The components of the measurement error with two-point indicator bore gauges with reading devices 0.01 mm / 0.001 mm.

| Error type                                                                 | Hole diameter intervals, mm |
|---------------------------------------------------------------------------|----------------------------|
| Instrument errors when measuring under ideal conditions within 0.8 of the movement of the measuring rod, μm | 18-50 | 50-120 | 120-260 | 260-500 |
| Installation error per size, μm:                                        |                             |
| by block of gauge blocks                                                 | 2               | 3.5       | 5         | 7         |
| on the certified ring                                                     | 1               | 1.5       | 2         | 3         |
| by special device                                                         | 1.5             | 2.0       | 3         | 4         |
| Error from alignment of the measurement line with the hole diameter (centering error), μm | 3 / 1.5 | 4 / 2.5 | 6 / 4 | 8 / 6 |
| Temperature error at a drop of 3 °C, μm                                   | 3 / 2           | 5 / 3     | 8 / 4     | 10 / 6    |
| Subjective errors, μm                                                     | 3 / 1.5         | 3 / 2     | 4 / 2.5   | 5 / 3     |
| Errors from the influence of surface roughness and operational pollution, μm | 3               | 3         | 4         | 4         |
| Total measurement errors, μm:                                            | 12.7           | 16.4      | 20.3      | 25.6      |
| when installed on a block of gauge blocks and reading device 0.01 mm       |                 |           |           |           |
| when installed by tool and reading device 0.001 mm                        | 6               | 7         | 9.4       | 12.7      |

The total impact of all risk factors is random and increases the total measurement error, calculated by quadratic addition, 1.3 - 1.8 times of the instrumental error. Moreover, for micron heads, the coefficient of influence is greater.

Thus, to ensure the uniformity and quality of measurements of holes made according to 5 - 7 accuracy grades, the criterion for the selection of measuring instruments should take into account the entire total error and is tightened. The permissible error of measurement with internal gauges must correspond to less than a fifth of the tolerance ($\Delta_{iper} \leq 0.2T$).

4. Conclusions

When measuring the hole diameter with bore gauges, additional measurement errors appear, associated with the alignment of the measurement line with the hole diameter. The dominant components of the errors when measuring the hole with bore gauges are in the order of their weight: temperature errors, centering, setting to size, subjective errors and errors of operational pollution, which increase with increasing size.

Three-rod bore gauges are not suitable for assessing the suitability of worn parts. They can be used to measure the diameters of holes after their restoration to size or to check spare parts, while fitting to size is performed only according to the certified ring or sample.

When measuring the diameter of the holes with indicator two-point bore gauges, the total measurement error increases by approximately 1.3-1.4 times, which grows with increasing size. The device can be set to size by different methods, optimally according to the device or certified sample and ring. The criterion for the selection of indicator bore gauges for measuring the holes of objects of technical service of machines and equipment has been substantiated: their error should not exceed the allowable one, equal to a fifth of the tolerance.

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