Measurement of machine parts dimensions positional deviation with regard to their geometric accuracy

D B Martemyanov¹, V V Pshenichnikova¹, V A Penner¹, and A E Zemtsov¹
¹Omsk State Technical University, 11, Mira av., Omsk, 644050, Russia
E-mail: den-79-03@yandex.ru

Abstract. Real surfaces of the parts, obtained with the help of technological processes, are always characterized by deviations from a nominal (regular) form. When analyzing a nominal cylindrical surface or a prismatic component element, the interrelation between current dimensions in various sections and a surface form, as well as surfaces position, can be found.

Key words. tolerance, positional deviation, form deviation, geometric model, qualified tolerance, element dimensions.

1. Introduction
Qualitative indicators, reliability and durability of hydraulic units depend to a large extent on the correctness of the normalization, the accuracy of manufacturing and the accuracy of each geometric element, each part of the unit arrangement tolerances control.

It is very difficult to ensure the given tolerances of channel dimensions and their positional deviations in the machine parts, because making accurate measurements of the through holes and their numerous positional deviations actual dimensions with respect to the set of bases in each mating part is necessary.

As practice shows, the measurement of holes and ports in the parts of hydraulic units is very laborious. Besides, it is not always possible to detect deviations in the arrangement of all the holes in the parts of hydraulic units with an error not exceeding the permissible value (30% of the position tolerance). The values of the hydraulic units channels axes positional deviations influence the area of the flow sections for the part-to-part passage of liquid, which in turn affects the intensity of increasing or decreasing the liquid pressure along its flow through a spool valve or a sleeve. In accordance with this, the characteristics of the sleeve ports opening by the spool valve ports influence the hydraulic drive accuracy and sensitivity. The tolerances of the channel axes position are among the most important indicators of the parts quality by geometric accuracy [1].

2. Statement Of The Problem
The analysis of the form deviations of standard surfaces presupposes the following statements:

1. As the form deviations are automatically limited by the pre-set fields of the dimensions tolerances, they should be intentionally normalized only in cases when they have to be made more rigorous compared with values which were pre-set during dimensions tolerancing.

2. The form tolerances system should include tolerances for the most frequent standard cases. Above all, form tolerances of nominally flat surfaces and the surfaces of a rotary body type should be normalized [3].

3. The element complex dimensions include the dimensions of the adjoined element, the deviations of the element surface form and the deviations of the considered element position towards the bases.
As the measurement of the position deviations are carried out by the subtraction, element size and form deviations do not influence the accuracy of the position qualified tolerances measurement results.

Position deviations are geometric values, so the two-dimensionality principle should also be applied to them. The application of the two-dimensionality principle makes it possible to implement a systematic approach to the classification of position deviations, to the account of the elements service purpose, to establishing the optimal composition of deviations, to shortening the extent of the dimensional chains of elements and, as a consequence, to increasing the geometric accuracy of the elements arrangement with respect to the parts' bases [4].

4. In order that the two boundary values of the elemental dimensions do not exceed the limits of the tolerance field, they should be understood as the dimensions of two regular elements nominally located with respect to the set bases and covering the real element surfaces, touching them: one - outside the material of the part (determines the size of the element material maximum), the second - from the element material (determines the size of the element material minimum). These definitions determine the dimensions of the element dimension field, i.e. the zone in the part area, which occupies the real surfaces of the element due to the deviations in form and position with respect to the coordinate system of the elements set [2].

Thus, the reason for the two-dimensionality of elemental dimensions are the form deviations of the elements surfaces and the elements position deviation in the reference frame of the elemental dimensions – in the coordinate system materialized by the set of elements bases. If one of the set elements shows its maximum informativeness, it will not have any position deviations with respect to the bases of other elements, since it determines the position of the reference frame coordinate axis or coordinate plane itself. In this case, the reasons for the two-dimensionality of its dimensions are only the form deviations of the element surfaces.

3. Methods

The basis for analyzing and measuring position deviations of the machine part is a geometric model that is a graphic representation of all the part components together with the deviations of the working surfaces in the generalized coordinate system of the part as a whole (Figure 1). The reference system of the deviations in the position of the normalized spool valve elements is the generalized OXYZ coordinate system, which is materialized by a set of three bases: by the Z4 axis of the cylindrical base A4 double guide, which deprives the object of 4 degrees of freedom measurement, by the end datum base B1, which deprives the part of the translation along the Z4 axis, and by the datum base B1 symmetry plane of the prismatic spool, which deprives the part of the rotation about the Z4 axis.

Figure 1. The spool valve geometric model.

In the Cartesian coordinate system, the dependent tolerance of the base B1 symmetry tolerance to the base A4 is normalized, while in the polar coordinate system, the dependent positional tolerances for the twelve cylindrical holes Ø D and for twelve prismatic slots of width H fulfilling the service purpose of the hydraulic channels are given, since in the first case the base B1 has spent only one
degree of freedom (from the maximum possible 2) on the materialization of the Cartesian frame of reference, while the channels, being the execution surfaces, - none [4].

4. Implementation
Full dependent position deviation of the channel axis (DPOhole or DPOport) is determined as the half-difference of the maximum and the minimum complex channel dimensions, while their half-sum is equal to the element dimensions (Del or Hel). Geometric models of the parts (sleeve and spool) channels interaction prove, that minimum Dmin.ch. and maximum Dmax.ch. channel complex dimensions include adjoined element dimensions Del and the double value of the position deviation DPO of the considered element with respect to the bases (Fig. 2):

\[ D_{\text{min.ch.}} = \text{Del} - 2\text{DPO}, \quad D_{\text{max.ch.}} = \text{Del} + 2\text{DPO}. \]

Qualified tolerance of the position depends not only on the normalized minimum position deviation value, but also on the deviations of the actual dimensions of the base and analyzed elements from the maximum material sizes, or maximum material limits:

\[ T_{\text{qual}} = T_{\text{min}} + T_{\text{add}}, \]

where \( T_{\text{min}} \) is the tolerance, specified in the draft; \( T_{\text{add}} \) is the additional variable tolerance constituent, which value depends on the actual dimensions of the analyzed elements:

\[ T_{\text{add}} = T_{\text{i}} + T_{\text{t}}, \]

where: \( T_{\text{i}} \) is the intrinsic tolerance of the channel size; \( T_{\text{t}} \) is the base tolerance [5].

![Figure 2. Geometric models of sleeve and spool channels interaction.](image1)

Additional constituent of the qualified tolerance can be found only after measuring the actual dimensions Dmin.ch. and Dmax.ch. of the basic and normalized elements (figure 3). The tolerance field of the coordinated channel complex dimensions widens into the two full dependent position tolerances in terms of diameter, which spikes the machine parts processability.

![Figure 3. Position of the dependent dimensions and position tolerances fields.](image2)

5. Conclusion
The principle of the proposed method for measuring position deviations of the channel axes is to measure the half-difference of the maximum and minimum complex dimensions of the element in question, that is, the dimensions of two regular elements nominally located with respect to the parts' bases and the tangential real surfaces of the elements outside and from the material of the parts. Since
measurements of position deviations are made using the difference method, the intrinsic deviations of
the form and dimensions of the element do not influence the accuracy of the arrangement dependent
tolerances measurements results. When measuring, the minimum Dmin.ch., Hmin.ch. and the
maximum Dmax.ch., Hmax.ch. values of the complex channel dimensions, in fact, only the minimum
complex dimensions (Dmax.ch., Hmin.ch.) will determine the area of the channel cross-sections. In
order to increase the accuracy and performance of the channel position dependent deviations
measurements it is proposed, instead of six differentiated measurements (three position deviations
and three influencing dimensions of normalized base elements), to determine two values of one normalized
element complex dimensions, taking into account its position with respect to the set of base elements
(figure 1).

In conclusion, when conducting the technological processes metrological examination, special
attention should be paid to the choice of measuring techniques (MT) of the units geometric values.
The MT must provide control in accordance with the requirements to the permissible measurement
errors.
The proposed method of reliable complex measurements of the pass channels effective dimensions
will increase the reliability and durability of the hydraulic units’ details. Knowing the actual position
of the channels deviations, it is possible to ensure the adjustment of the machine program, which will
allow obtaining a higher precision of manufacturing hydraulic components, their quality and reliability
in operation.

References
[1] Henke R P, Summerhays K D, Baldwin J M, Cassou R M and Brown C W 1999 Precision
Engineering 23 (4) p 273-292
[2] Summerhays K D, Henke R P, Baldwin J M, Cassou R M, and Brown C W 2002. Precision
Engineering vol 26 (1) p 105-121
[3] Qingzhen Bi, Nuodi Huang, Chao Sun, Yuhan Wang, Limin Zhu, and Han Ding 2015 Journal
of Machine Tools and Manufacture 89 p 182-191
[4] Glukhov V I and Martemyanov D B 2013 The world of measurement 7 (149) p 7-13
[5] Russian State Standard 28187-89 Basic norms of interchangeability. Deviations of the form and
arrangement of surfaces. General requirements for measurement methods p 19