RESEARCH OF THE PROBLEMS OF AUTOMATION ASSEMBLY OF HIGH-PRECISION DETAILS

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Abstract: *In this article are described the component parts of technological maintenance of assembly of the precision pairs, which have an influence on the assembly quality of pairs and possibility of realization of assembly process. For achieve this goal authors suggest solving two tasks: research the influence of form deviations and the influence of camber of axis of the parts on the technological process of assembly of precision pairs. In the result in given article it is shown that at the automated precision assembly it is possible not to measure a form deviation of the details, but sort them, using inexpensive means of certification of the details size.*

Keywords: AUTOMATION ASSEMBLY, FORM DEVIATION, HIGH PRECISION, GROUP TOLERANCE, CAMBER OF AXIS

1. Introduction

The precision pairs or units there are the units and products during the assembly of which the complete interchangeability can not be to achieve in the case, when these units are produced with the standard precision according to adopted system of tolerances and fits. As the examples of precision pairs can be mentioned the bearings, ball screw pairs (Fig.1), plungers pairs.

Fig. 1 *Precision ball-screw pairs*

The main task of precision assembly is to guarantee of goods performance. Production characteristics of engineering products are defined, as a rule, by accuracy of assembly, which main part of cases depends on deviation of dimensions and form of collected details. Result of violation of assembly accuracy requirements, particularly of no allowable deviation of geometrical form of work surfaces of collected details, is loss of lubricant of fuel through out precision surfaces, seizure of moving parts and other undesirable consequences.

In this case conditions of stocking and assembling of details have the special role in maintenance of quality and reliability of precision equipment [1]. In the course of details assembly:

1) have to be removed adverse combinations of constructive-technology factors, which have an influence of final parameters;

2) has to be ensured maximally possibly not changeable parameters of equipment;

3) and has to be ensured defined character of connection.

At assembly of precision connections for achievement of the required accuracy of the closing dimension mainly apply a method of group interchangeability (selective assembly). At this method high requirements to the geometrical form of details should be ensured.

2. Selective assembly of precision parts

In many enterprises precision components and products are manufactured in mass quantities. Typical is the production of precision pairs of diesel fuel injection equipment, production of which reaches tens of millions of pairs a year. Similar precision pairs are, for example, plunger pairs (Fig.2) of high pressure sections of diesel fuel pumps for tractor and combine engines.

At selective assembly of precision parts the precision measurement of actual size and its labelling to the appropriate group has decisive importance, because these determine the deviation value of the closing link (for example, clearance) and, thus, the quality of the product. Processes of measurements and sorting at assembly consist in following: the details manufactured of set tolerance have to be divided into groups.

Fig. 2 *Plunger pairs*

Metrological tools allow realizing the automatic measuring of geometrical parameters of details with precision 0,1 - 0,2 μm in the mass production's conditions.

Decisive importance has the problem of determination of the details parameters, which have to be measured. This is due to the fact that in the real process of assembly the possibility of connection of details and product's quality does not be guaranteed even in the case, when measured parameters are in tolerance group zone [2]. This indeterminacy is the result of

1) form deviations of connected details from the ideal;
2) measuring errors, and
3) instability of assembly process, which is determined by the errors of positioning , by influence of vibrations, pollutions and by others reasons.

So, after carrying out of finishing operations high-precision details of plunger pair go at a position of the form deviations control. We can do the conclusion, that the high precision of details' production is replaced by the high precision of measuring of geometrical parameters [3].

Technical requirements for the precision details of fuel injection equipments envisage the completely definitive of form deviations in the longitudinal section, which ensure the occurrence of the minimum gap.

3. Measuring of form deviations of precision pair

For experimental measurements two batch of complete sets of details of plunger pairs - on 10 complete sets in everyone have been selected. Bushings in these batches had diameters ($Ø8^{+0,015}$mm) close to most often occur during assembly.

At the assembly during the processes of measuring and sorting, the details are divided into groups, which are produced within a specified tolerance. Used for sorting of the details means have the certain measuring error, which limiting values Δ_{lim} must be 20…40% from the group tolerance T_{gr}, that is the relative error of measuring

$$\Delta_{rel}=\Delta_{lim}/T_{gr}=0,2\ldots0,4. \qquad (1)$$

Form deviations (roundness, cylindricity) depending on the relative geometric accuracy are 20 ... 60% from the T_{gr} , ie, the relative form deviation

$$\delta_{rel} = \Delta_{lim} / T_{gr} = 0.2 \ldots 0.6. \qquad (2)$$

During the details sorting because there are form and measuring deviations details from others groups will be mixing, ie part of the details from group i will be placed in the groups i-1 and i+1, bet part of the details from groups i-1 and i+1 will be placed in the group i and that can lead to the defect at the assembly. Therefore, the important problem at the assembly of precision pairs is the ensuring of geometrical precision of details and choosing the measuring means, which guarantee the specified precision.

Reduction of limited error of measuring Δ_{lim} leads to the rise in price of means of sorting. For determination of rational precision of sorting it is necessary to estimate the influence of form and measuring errors on the part of defect at the assembly of precision pairs.

At the experiment was examined the assembly of 100 bushings with holes $Ø8^{+0,015}$ and 100 plungers $Ø8^{+0,0045}_{-0,0045}$ (fit *8H7/js6*) with clearance *0,0045...0,009* mm, at the using of attestation means with $\Delta_{rel}=0,2\ldots0,4$ and relative camber of axis $\delta_{rel}=0,2...0,6$, with specified group tolerance $T_{gr}=0,002$ mm, which is equal to the half of tolerance gap.

At the Figure 3 are shown the form deviations [4]: a) roundness; b) flexion. Form deviation can be determined as difference of diameters $D_F=d_1-d_2$; c) tapering; d) barrel; e) bow.

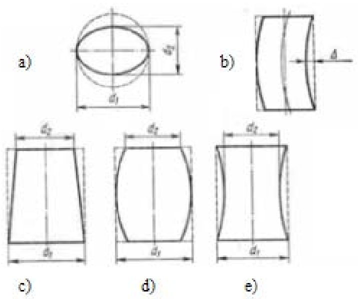

Fig. 3 *Form deviations*

The analysis of geometry of a precision cylindrical surface of bushings has shown, that the most typical form deviations for this surface are a deviation of axes straightness, deviation of roundness in various cross-section sections, bow of the top part of inner surface of the bushing (between sections I and III, Figure 4), taper (sections II-IV). For plunger axes straightness is provided with finishing technology, but it has deviations of roundness (lobbing), basically, in section I and taper. For metering device characteristic form deviations are deviations of roundness in cross-section sections, taper, barrel and bow. All these form deviations to a greater or lesser extent influence both mobility, and on hydrodensity of connection.

In order to determine the basic dimensions (diameter in the middle section) and to identify mentioned in this article form deviations of details of selected batches [5], carrying out a minimum number of different measurements, the following geometric dimensions have been measured:

- Diameters of bushings in sections I ÷ IV, and the deviations of the axis straightness. In each section diameters were measured in two perpendicular directions - A and B (Figure 4);

- Diameters of plungers in sections I ÷ III and quantities of lobbing in section I;

- Diameters of metering device in sections I ÷ III in two directions A and B in each section.

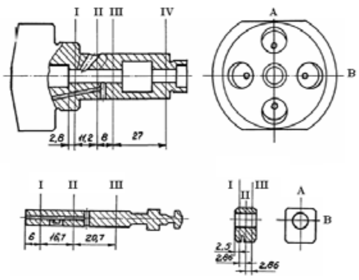

Fig. 4 *The sketch of details of plunger pair of diesel fuel pump*

For determination of form deviations in the cross section (roundness) and it's influence on the defect at the assembly, the measurements were making in the one and two perpendicular sections of the detail (Fig.4), in the longitudinal – in the middle and across the edges of the detail. In Tables 1 and 2 are shown the data of the measurements.

Table 1: *Shafts' measurements:* $d=Ø8^{+0,0045}_{-0,0045}$, $\delta_{rel}=0,003$

Nr.	Δd, μm	Roundness	Barrel/bow	Defect
1	0,0	0,0	2,0	
2	3,0	4,0	2,0	
3	4,0	5,0	3,0	
4	6,0	2,0	3,0	√
5	-3,0	0,0	3,0	
…	…	…	…	…
99	-3,0	7,0	3,0	√
100	4,0	5,0	5,0	

Table 2: *Bushings' measurements:* $D= Ø8^{+0,015}$, $\delta_{rel}=0,003$

Nr.	ΔD, μm	Roundness	Barrel/bow	Defect
1	15,0	1,0	1,0	
2	6,0	2,0	2,0	
3	0,0	0,0	4,0	
4	5,0	3,0	2,0	
5	8,0	1,0	3,0	
…	…	…	…	…
99	7,0	5,0	1,0	
100	14,0	6,0	4,0	√

At the beginning the details were separated on 3 dimension groups, with the group tolerance n=1. Details' dimension limits for each group are shown in Table 3.

Table 3: *The division into dimensions' groups for n = 1*

Group	Bushing's dimension (n=1)	Shaft's dimension (n=1)
I	$D=8\ldots8^{+0,005}$	$d=8_{-0,0045}\ldots8_{-0,0015}$
II	$D=8^{+0,005}\ldots8^{+0,01}$	$d=8_{-0,0015}\ldots8^{+0,0015}$
III	$D=8^{+0,01}\ldots8^{+0,015}$	$d=8^{+0,0015}\ldots8^{+0,0045}$

At the sorting details with defects were separated, if the measured dimension was out of the fit of production.

Table 4: *The division into dimensions' groups for n = 1,5*

Group	Bushing's dimension (n=1,5)	Shaft's dimension (n=1,5)
I	$D=8\ldots8^{+0,035}$	$d=8_{-0,0045}\ldots8_{-0,002}$
II	$D=8^{+0,035}\ldots8^{+0,007}$	$d=8_{-0,002}\ldots8$
III	$D=8^{+0,007}\ldots8^{+0,105}$	$d=8\ldots8^{+0,002}$
IV	$D=8^{+0,011}\ldots8^{+0,015}$	$d=8^{+0,002}\ldots8^{+0,0045}$

At the analyse of data the possibility of decreasing of group tolerance T_{gr} in n times for permanent values of form and measuring deviations was examined and determined the part of defective connections P_d. In the Tables 4, 5, 6 are shown the divisions into dimensions' groups depending on group tolerance n: for n = 1,5; n=2; n=2,5.

***Table 5:** The division into dimensions' groups for n = 2*

Group	Bushing's dimension (n=2)	Shaft's dimension (n=2)
I	$D=8\ldots8^{+0,0025}$	$d=8_{-0,0045}\ldots8_{-0,003}$
II	$D=8^{+0,0025}\ldots8^{+0,005}$	$d=8_{-0,003}\ldots8_{-0,0015}$
III	$D=8^{+0,005}\ldots8^{+0,0075}$	$d=8_{-0,0015}\ldots8$
IV	$D=8^{+0,0075}\ldots8^{+0,01}$	$d=8\ldots8^{+0,0015}$
V	$D=8^{+0,01}\ldots8^{+0,0125}$	$d=8^{+0,0015}\ldots8^{+0,003}$
VI	$D=8^{+0,0125}\ldots8^{+0,015}$	$d=8^{+0,003}\ldots8^{+0,0045}$

***Table 6:** The division into dimensions' groups for n = 2,5*

Group	Bushing's dimension (n=2,5)	Shaft's dimension (n=2,5)
I	$D=8\ldots8^{+0,0025}$	$d=8_{-0,0045}\ldots8_{-0,003}$
II	$D=8^{+0,0025}\ldots8^{+0,005}$	$d=8_{-0,003}\ldots8_{-0,0015}$
III	$D=8^{+0,05}\ldots8^{+0,0075}$	$d=8_{-0,0015}\ldots8$
IV	$D=8^{+0,0075}\ldots8^{+0,01}$	$d=8\ldots8^{+0,0015}$
V	$D=8^{+0,01}\ldots8^{+0,012}$	$d=8^{+0,0015}\ldots8^{+0,002}$
VI	$D=8^{+0,012}\ldots8^{+0,0135}$	$d=8^{+0,002}\ldots8^{+0,003}$
VII	$D=8^{+0,0135}\ldots8^{+0,015}$	$d=8^{+0,003}\ldots8^{+0,0045}$

δrel=0...0,6

δrel=0,2=0,009 x 0,2 = 0,0018 µm

δrel=0,4=0,009 x 0,4 = 0,0036 µm

δrel=0,6=0,009 x 0,6 = 0,0054 µm

Obtained at the result of analyse of data the experimental data have been processed statistically and the results are shown on the Figures 5, 6, 7, 8.

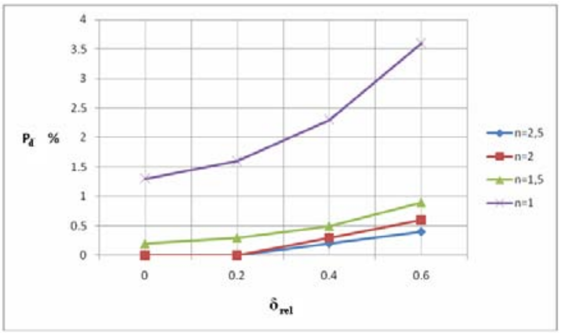

***Fig. 5** Dependence of the assembly probability P_d from the relative form deviation δ_{rel} in the cross section*

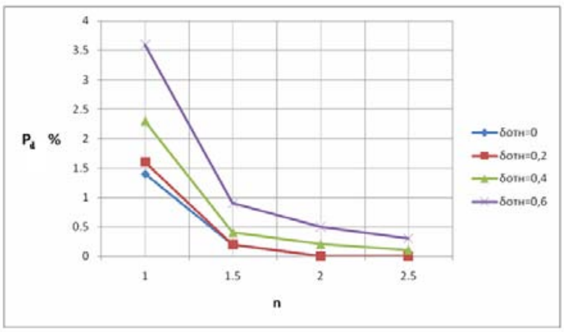

***Fig. 6** Dependence of the assembly probability P_d from the decreasing degree of group tolerance n at change of δ_{rel} in the cross section*

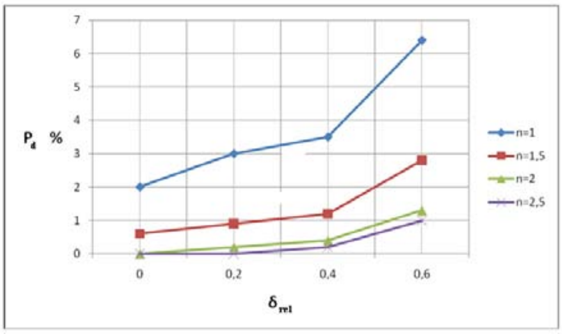

***Fig. 7** Dependence of the assembly probability P_d from the relative form deviation δ_{rel} in the longitudinal section*

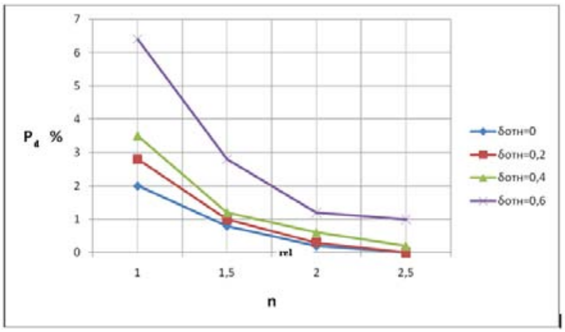

***Fig. 8** Dependence of the assembly probability P_d from the decreasing degree of group tolerance n at change of δ_{rel} in the longitudinal section*

On graphics (Figure 5-8) that are shown above - the relative measurement deviation was equal to 0,4 and this conform to precision workmanships, which are used at the production of precision details.

4. Determination the clearance in precision pairs

Technical requirements for the precision details of fuel injection equipments envisage the completely definitive of form deviations in the longitudinal section, which ensure the occurrence of the minimum gap [6]. As a result, it was stated that the presence of such form deviations in longitudinal section leads to a redistribution of the diametrical clearance size along the length of the pair and arouse appearance of the so-called "jamming." In this case, the shaft does not have free movement under its own weight. Therefore, the main parameters determining the possibility of an assembly of precision parts are camber of shaft and hole axis and the size of diametral clearance. There are the next condition of the assembly of plunger pair: the diametrical clearance has to be greater than the sum of the camber of shaft and hole axis.

$$S_d > \delta_{sh} + \delta_h, \qquad (3)$$

where S_d - diametrical clearance of the connection; δ_{sh} – camber of shaft axis; δ_h – camber of hole axis

After measuring the detail size details are sorted by the measured dimension, and then is determined the group number for details. During sorting provides rejection of parts, which measured size goes beyond the manufacturing tolerance. According to the results sort of details is done the complication of pairs by method of group interchangeability. Then for ready connections is defined clearance, taking into account the deviations of the correct geometric form. The size of the hole is evaluated equal to the minimum value (taking into account the camber of its axis), but the shaft size – to the maximum value. Consequently, the diametrical clearance in the precision pair is equal to the difference between the diameters of the holes and the shaft and is a minimum clearance of the connection in longitudinal section. If the clearance in the pairs goes beyond tolerance, the pair is considered to be defective.

Influence of camber of axis on the precision of assembly of precision details let's examine on the bushings connection example.

Bushings were with holes $Ø8^{+0,015}$ and shafts - $Ø8^{+0,0045}_{-0,0045}$ (fit *8H7/js6*) with clearance *0,0045...0,009* mm, at the using of attestation means with $\Delta_{rel}=0,2…0,4$ and relative camber of axis $\delta_{rel}=0,2...0,6$, with specified group tolerance $T_{gr}=0,002$ mm, which is equal to the half of tolerance gap.

According to the specified was determined the dimension of the details and also camber of axis of the detail. Measuring of the dimension of the detail we did in one section – in the middle of the detail. Next we did the sorting by the measured dimension and determined the number of the dimension's group. When, during the sorting, the measured dimension was out of the limits of manufacturing tolerance was happened the rejection of the details as defective.

During the experiment we measured 100 examples of the connected details – shafts and bushings for determine the real dimension (in one section). Also was measured the camber of axis in the longitudinal section. In the Tables 7, 8 are shown the results of measuring.

Table 7: *Shafts' measurements:* $d=Ø8^{+0,0045}_{-0,0045}$, $\delta_{rel}=0,005$

Nr.	Δd, µm	Camber	Defect
1	2,0	2,0	
2	1,0	4,0	
3	0,0	1,0	
4	3,0	4,0	
5	1,0	1,0	
…	…	…	…
99	0,0	7,0	√
100	-2,0	2,0	

Table 8: *Bushings' measurements:* $D= Ø8^{+0,015}$, $\delta_{rel}=0,005$

Nr.	ΔD, µm	Camber	Defect
1	15,0	0,0	
2	10,0	2,0	
3	1,0	2,0	
4	3,0	5,0	
5	4,0	3,0	
…	…	…	…
99	14,0	4,0	√
100	5,0	3,0	

Similar to the determination of influence of form deviations on the precision of assembly, the details were separated on 3 dimension groups, with the group tolerance n=1; n=1,5; n=2; n=2,5.

Obtained at the result of analyse of data the experimental data have been processed statistically and the results are shown on the Figures 9, 10.

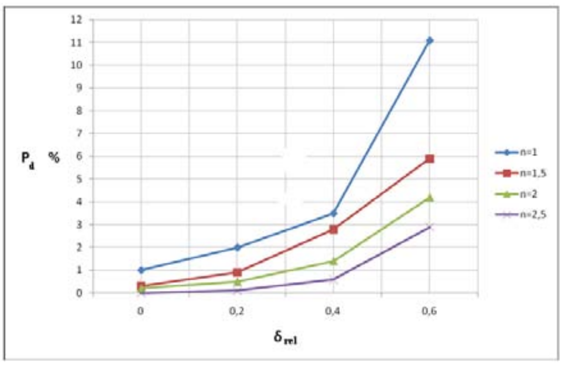

Fig. 9 *Dependence of the assembly probability P_d from the relative value of camber of details axis δrel. at change of group tolerance in n times*

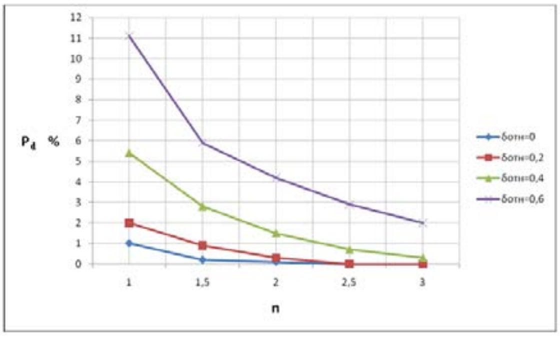

Fig. 10 *Dependence of the assembly probability P_d from the decreasing degree of group tolerance n at change of δ_{rel}*

At testing clearance in connection is determined for two cases of operating conditions:

1) minimum clearance at turning of the shaft relative to the bushing;

2) random clearance at forward motion of the shaft relative to bushing.

Conclusions:

The data analysis shows that

1) with increasing of camber of details axis the number of defective connections increases;

2) form deviation in the longitudinal section has a more influence on the size of defective connections as a deviation of the details in the cross-section;

3) measuring of the details in the several sections allows to decrease a part of defective connections on the 60...80%;

4) decreasing the group tolerance in the 2 ... 2.5 times can reduce the proportion of defective connections at 70 ... 80%;

5) camber of axis of details has a more influence on the size of defective connections at the precision assembly as a form deviation of the details in the longitudinal and cross-sections and deviations of measuring.

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