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DETERMINATION OF ALLOWABLE DEVIATION OF AXES OF ASSEMBLED DETAILS WITH CYLINDRICAL SURFACES AT ASSEMBLY WITH VIBRATIONS

Natalija Mozga
Riga Technical University, Institute of Mechanical Engineering
Riga
Latvia

Ilmars Brensons
Riga Technical University, Institute of Mechanical Engineering
Riga
Latvia

ABSRACT
In article are considered conditions, which are necessary for realization the automatic connection of parts in assembly with using vibrations. To confirm the calculated dependences were conducted experiments on three groups of parts.

Keywords: deviation of axes, automation, assembly

1. CONDITIONS OF AUTOMATIC CONNECTION OF PARTS

Typical process of automatic assembly consists of many steps, such as loading of components, their feeding, orientation, fitting, control, transportation etc. But the most difficult and responsible step in the all-assembling processes is to make sure of interaction between components relative to each other on the assembling position with demanded accuracy, because the possibility of assembly depends on accuracy of this step.

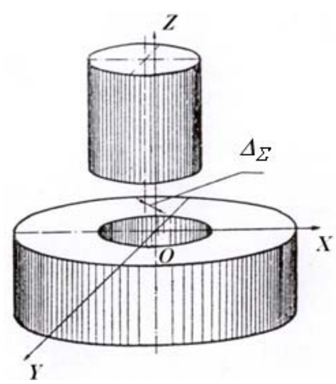

Figure 1. Scheme of relative orientation of details during assembly.

There are few methods allowing to increase accuracy of relative interaction in assembly:
1. application on the parts chamfers and force for connection;
2. reporting one of the parts rotational movement;
3. the method of relative misalignment of connecting parts axes;
4. shaking of the part, which is coming on;
5. orientation with using ultrasound devices etc.

But the method with application of vibrations is the most reliable to achieve this goal [1]. During automatic assembly with using vibrations assembled parts oscillate relative to each other in a plane perpendicular to their axes (Figure 1). For this purpose vibratory device is included in assembly machine but for drive of movable part are usually used electromagnetic vibrators. On the assembly' position the vibrating device has displaced one or two assembling parts by the certain trajectory in a plane, which is perpendicular to the direction of the connection of parts. In result there is taken place the "search" of mated surfaces of parts and is provided the assembly process. For the connection parts is required:
1. that at a certain time - axis of the parts were at a distance less than the tolerance value;
2. to take into account the speed of their relative movement.

For the standard join such as shaft and bush the condition of ensuring of connection can be written as

$$\Delta_{\Sigma \max} \leq \delta_q , \qquad (1)$$

where $\Delta_{\Sigma max}$ - maximum total error of the relative orientation of the assembled parts;
δ_q – minimal radial clearance.

Allowable error of the relative orientation of the assembled parts is determined by the type of assembly and precision manufacture of the mating surfaces.

In the case of assembly without using of vibrations the allowable deviation is determined by the geometrical sizes of connected parts (size of clearance in the connection, chamfers' sizes of the details etc.).

At the assembly with using of vibrations the allowable deviation is determined by the size of relative movement in the plane of vibrations, which still allows the connection of parts. Character of further connection is depends on trajectory of movement, amplitude of oscillations and the speed of relative movement of parts in plane of vibrations.

The speed of relative (transport) movement of parts in the direction, that cross the vibrations, is determined in the straight dependence from the value of allowable deviation δ and frequency of the vibrator ν (2).

$$v_y = 2\delta\nu = \frac{2\delta}{T} , \qquad (2)$$

where T – period of oscillations.

Depending on the speed of relative movement of the parts, as so as the forces working on assembled details in a point of their contact - three different cases of assembly are possible:
1. The shaft will discontinue the oscillatory movements and the assembly of parts will be executed;
2. The shaft will discontinue the oscillatory movements and will press with rounded edge on the edge of the hole. During to the second half period the assembly of parts will be executed;
3. The contact by the rounded edges will not change the character of oscillations. Shaft missed the hole of the bush.

The automatic assembly with application of vibrations is provided even then when edges of parts at initial contact a little cover each other.

For confirmation conclusions mentioned above were conducted experiments on three groups of cylindrical parts:

I group – shaft and bush with diameter of connection - ∅6H7/f7;

II group – bush and benched shaft with diameter of connection - ∅4H9/e8;

III group – roller and bush of bush-roller chain of motorcycle with guarantee clearance.

Parts from the first and second groups are made with sharp edges (r≅0,01mm) of connected surfaces.

Let's define allowable deviation for above mentioned parts taking in account geometrical parameters, influence of vibrations and value of overlapping of edges.

2. CALCULATION OF THE ALLOWABLE DEVIATION ACCORDING TO THE GEOMETRIC DIMENSIONS

For definition of actual values of clearances were measured diametral dimensions of connected surfaces of the parts and calculated the actual deviations. Measurement results are summarized in Table 1.

Table 1. Theoretical clearances in connections

Group of parts	Value of clearance, mm			Clearance tolerance, mm
	smallest	largest	average	
I	0,010	0,035	0,023	0,025
II	0,011	0,069	0,040	0,058
III	0,080	0,180	0,130	0,100

For each group of parts the coordinate of the grouping centre of deviations has been calculated as a expectation value of measured value [2].

Distributions of dimensions' deviations of researched parts were similar to normal (Gaussian) distributions. Therefore during the calculating of average values of clearances were not taken account the coefficients of relative asymmetry of closed and component links.

The average value of actual clearance in the connection, calculated according to the values of coordinates of the grouping centre of deviations of the shafts' and bushes' diameters, are summarized in Table 2.

Table 2. Actual clearances in the connections

Group of parts	Coordinates of the grouping centre of deviations, mm		The average value of diametral clearance, mm
	For bush	For shaft	
I	0,007	-0,016	0,023
II	0,013	-0,028	0,041
III	0,039	-0,010	0,129

The values of maximal and minimal allowable deviation in the case when as a allowable deviation was taken the clearance in the connection were determined by the following Formula [3]:

$$\delta_{\substack{\max \\ \min}} = \frac{1}{2}\left[2\Delta_q \pm \sqrt{\delta_b^2 + \delta_s^2} \right], \qquad (3)$$

where Δ_q – radial clearance in the connection;

δ_b – the half of tolerance zone of the bush;

δ_s – the half of tolerance zone of the shaft.

Measurement results are summarized in Table 3.

Table 3. Allowable deviation

Group of parts	Δ_q , mm	δ_b , mm	δ_s , mm	Allowable deviation δ_0 , mm	
I	0,0115	0,0065	0,0060	0,016	0,007
II	0,0205	0,0125	0,0165	0,031	0,010
III	0,0645	0,0400	0,0100	0,085	0,044

3. CALCULATION OF THE ALLOWABLE DEVIATION WITH AN ALLOWANCE FOR VIBRATIONS

In the presence of vibrations, which are imparted to the connected parts, the value of allowable deviation is differed from the calculated value, which was calculated according to the diametral dimensions of connected surfaces and is determined with an allowance for scheme of crossing of the zone of allowable deviation δ_0 by the trajectory of relative movement.

The value of allowable deviation δ_v in the presence of vibrations is changed in the wide range (from the maximal value, which is equal to δ_0, till the minimal value, which is equal to the zero), that is

$$\delta_0 \geq \delta_v \geq 0 . \qquad (4)$$

During the experimental inspection of assembly possibility of the parts their relative movement across the position of assembly was realized similar to the sinusoidal trajectory.

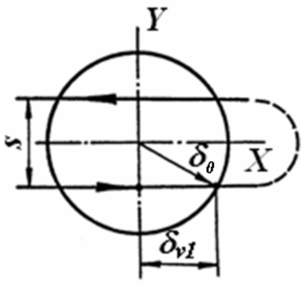

Figure 2. Calculated schemes to determine the tolerance δ_{v1} during the vibration assembly.

To the calculated case, when the trajectory of oscillated part crosses the zone of allowable deviation twice along the lines, which are on the equal distances from the edges and from the centre of zone δ_0 (Figure 2), the value of allowable deviation with an allowance for vibrations is determined by the following formula:

$$\delta_v = \frac{\delta_0}{2}\sqrt{3} . \qquad (5)$$

Measurement results are summarized in Table 4.

Table 4. Allowable deviation δ_v

Group of parts	Minimal allowable deviation $\delta_{0\,min}$, mm	Allowable deviation δ_v , mm
I	0,007	0,006
II	0,010	0,009
III	0,044	0,038

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Allowable deviation δ_v of the parts with rounded or other type of edges in the presence of vibrations increase on the value of overlapping of edges C, which is related by the geometrical dependence with angle α of incline of the normal in the connection point of the parts' edges (Figure 3).

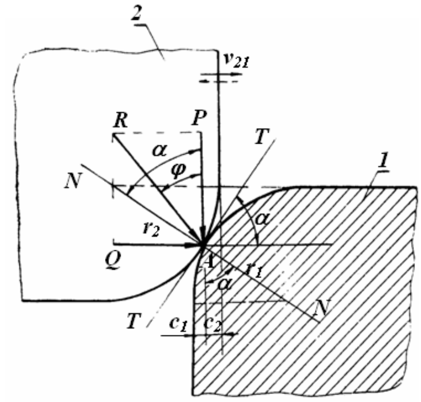

Figure3. Scheme of the contact of details with rounded edges.

The minimal value of the angle α is limited by the ratio of the angle φ of incline of the resultant forces in the contact point and the angle of friction, which is determined by the friction coefficient f.

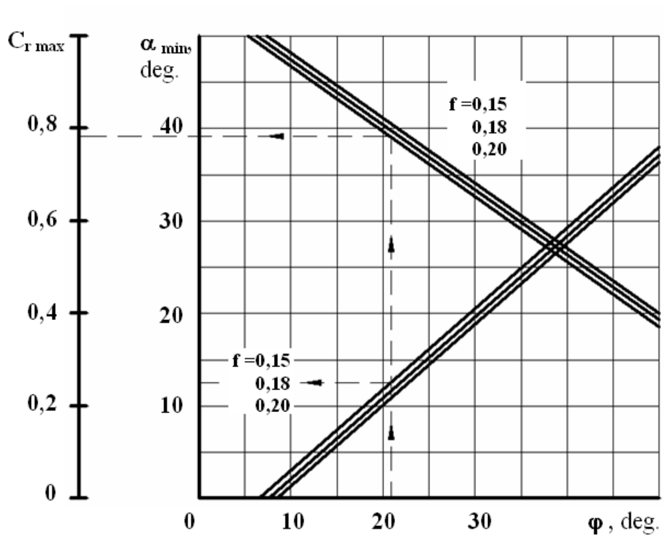

Figure 4. For determination α_{min} and $C_{r\,max}$. .

On the Figure 4 in the form of graphs are shown the dependence of angle α_{min} for different materials (f=0,15; 0,18; 0,20) at the changing of direction of resultant's action.
For parts with rounded edges, the value of possible overlapping of edges is determined by the next formula:

$$C = (r_1 + r_2)(1 - \sin\alpha_{min}), \quad (6)$$

where r_1, r_2 – radiuses of parts' edges,
α_{min} – is determined by the second case of assembly [1].
In practical calculations is convenient to use relative value of edges' overlapping (7). Values are calculated and shown on the Figure 4 – by the arrows is shown the order of the graphical determination of the value.

$$C_{r\max} = \frac{C}{r_1 + r_2} = 1 - \sin\alpha_{min}, \quad (7)$$

The values of overlapping of parts' edges and the allowable deviation δ_v at the vibrations are summarized in Table 5. The values C and δ_v are calculated at the tgφ=0,4.

Table 5. The values C and δ_v.

Group of parts	Coefficient of friction	r_1, mm	r_2, mm	Overlapping C, mm	allowable deviation δ_v, mm	Ratio δ_v / δ_{0min}
I	0,18	0,01	0,01	0,016	0,022	3015
II	0,20	0,01	0,01	0,017	0,026	2,60
III	0,15	0,20	0,01	0,065	0,103	2,70

For three groups of the parts the experimental assembly was realized at the given conditions of weighting. The step of sinusoidal trajectory of relative movement of the parts is controlled by the speed of the transport movement. In the result the assembly of all parts was ensured even when the step of trajectory exceeds the calculated step at 2,5-3 times.

4. CONCLUSIONS

In given article experimentally is shown, that the allowable deviation is determined by the value of relative movement of parts in the plane of vibrations. And the automatic assembly with application of vibrations is provided even then when edges of parts at initial contact a little cover each other.

5. REFERENCES

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