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ANALYSIS OF METHODS FOR COMPENSATION OF DIFFERENCES OF INTER-AXIAL DISTANCE IN A CONE TRANSMISSION

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Annotation.*The article reviewed analysis of methods for compensating deviations of the axle distance in a bevel gear. A comparative assessment of methods for achieving the accuracy of the center distance in a traditional and fully adjustable bevel gear is presented. As a result of the analysis, it was concluded that it is advisable to directly regulate the interaxal distance in spur bevel gears of the compensating link in the form of a pair of rotary oblique washers.*

Keywords: *bevel gear, interchangeabilitygear wheel, center distance, axial displacement, tooth contact, axial errors,fully adjustable bevel gear, compensator, swivel washers.*

In the generally accepted design of a bevel gear design, the accuracy of the center distance (MPD) should be ensured by the interchangeability method. However, studies [1] found that in the absence of regulation of the interaxal distance in the spur bevel gear, the lateral clearance in the engagement exceeds the limiting one according to GOST 1758 by 4 ... 7 times. Contact stresses due to their concentration increase 1,3 ... 1,5 times. Actual radial errors are not compensated by the axial displacements of both gears, therefore, the required indicators of completeness of contact of the teeth are not achieved, despite the complexity of the assembly process. This is explained by the relatively low sensitivity of the tapered gear to axial errors of wheel mounting compared to the sensitivity to radial errors (2,75 times).

The obvious feasibility of direct compensation of MPA deviations is implemented in a fully adjustable bevel gear [2]. Since axial and radial errors in the conic meshing are interconnected, axial errors are easily compensated by the radial displacements of the conical wheels. In this case, the limit values of axial errors can be easily ensured by one of the known methods, for example, using technological devices during assembly.

For a comparative assessment of the methods for achieving MPA accuracy in a traditional (Fig. 1) and fully-adjustable (Fig. 2) bevel gear, we use the work [3].

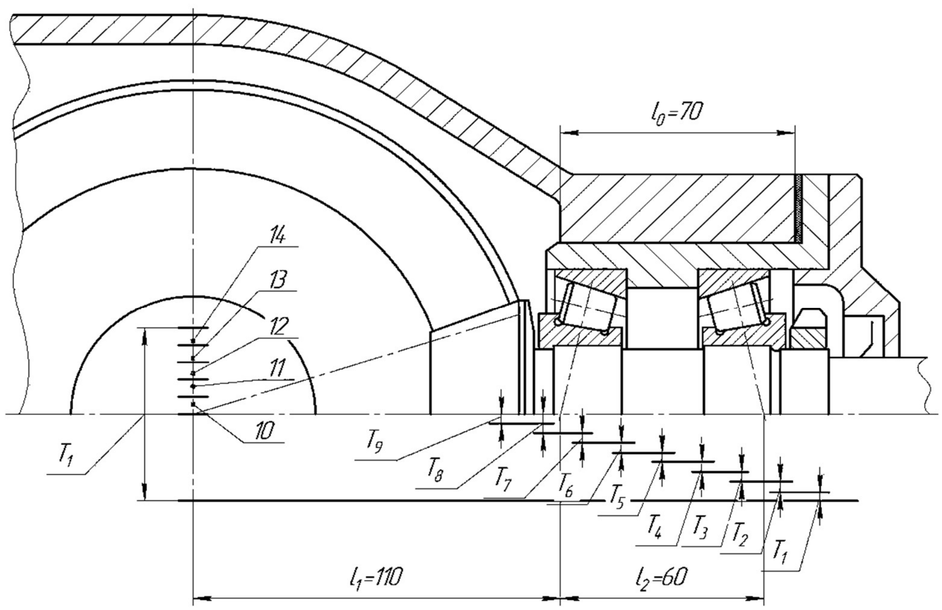

Fig. 1. Design dimension chain of a traditional bevel gear [3]

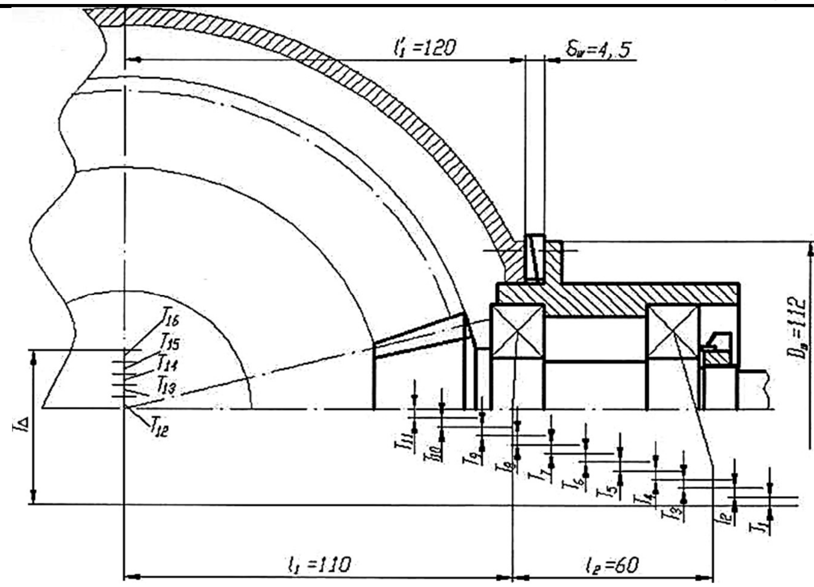

Fig. 2. Design dimension chain of fully adjustable bevel gear

Fig. 1 shows a structural diagram of a traditional bevel gear and a dimensional chain diagram of deviations of the axle distance of the bevel gear with the following parameters: mean cone distance $R_m \leq 100$ mm, degree of accuracy 7, limit deviation $f_a = \pm$ 0,020 mm, the middle of the field allows $em_{\sum} = 0$, deviation tolerance $t_{\sum} = 2|f_a| = 0{,}040$ mm.

The power circuit and the basic geometric and accuracy parameters of a fully adjustable bevel gear (Fig. 2) will be accepted coinciding with the traditional gear. This will ensure the equality of the reduction coefficients of the corresponding component sizes and angles between the directions of the forces in the supports from external load.

The transition to a new scheme of basing the shaft-gear set and the introduction of an adjustable design compensator caused the following differences in the dimensional chains characterizing the deviation of the center distance:

the cup of the bearing assembly was eliminated from the set of the shaft-gear and, therefore, deviations of dimensions and conjugations with the clearance of the outer cylinder of the cup to the accuracy of MPA were excluded from the dimensional chain;

deviations from the perpendicularity of the end face of the main body and the end face of the housing of the pinion shaft assembly to the corresponding rotation axes are included in the number of component dimensions;

a deviation from the parallelism of the outer planes of the set of oblique washers of the compensator is introduced into the dimensional chain.

All three sizes are vector quantities.

The constituent dimensions of the dimensional chain T (Fig. 2): T_1 and T_2 - deviations from the alignment of the raceways of the outer rings of the left and right bearings of the pinion shaft, T_3 and T_4 - gaps in the mates of the outer rings of the left and right bearings with holes in the housing of the shaft kit - gears, T_5 - radial clearance in the bearing of the pinion shaft not loaded by external axial force, T_6 - deviation from the alignment of the centering belt of the housing of the pinion shaft assembly relative to the common axis of the holes for the bearings, T_7 - deviation from the perpendicularity of the base end body of common axis bearing hole, T_8 - deviation from perpendicularity based end of the main body (shelfplasty) axis of the centering holes, T_9 - deviation from parallelism of the planes of the outer pair of rotation oblique shims (compensator), T_{10} - clearance in the interface between the centering belt of the housing of the pinion shaft assembly and the hole of the gear housing, T_{11} - center distance in the main gear housing, T_{12}, T_{13} - deviations from the alignment of the outer rings of the wheel shaft bearings, T_{14}, T_{15} - clearances in the joints of the outer rings wheel shaft bearings with holes of the main body, T_{16} - radial clearance in the wheel shaft bearing not loaded with external axial force.

Coefficients of reduction of newly introduced dimension components that follow from the design scheme of the dimensional chain (Fig. 2):

$$C_7 = (l_1'/D_{ш}) = 120/112 = 1{,}07;\ C_8 = (l_1' + \delta_{ш})/D_{ш} = (120 + 4{,}5)/112 = 1{,}11; C_9 = C_8 = 1{,}11.$$

The characteristics of the constituent dimensions (deviations from perpendicularity and parallelism) will be taken according to the 12 accuracy class: $T_7 = T_8 = T_9 = 0 \pm 0{,}125$; $t_7 = t_8 = t_9 = 0{,}25$; $\alpha = 0$; $K_v = 0{,}75$

Let us express the above tolerances of the MPD deviations through the sums of the dispersion characteristics of scalar quantities, gap mates, and vector quantities:

for a traditional bevel gear

$$t\sum = (1/K_{\Sigma})(K_{\Sigma S}^2 t_{\Sigma S}^2 + K_{\Sigma Z}^2 t_{\Sigma Z}^2 + K_{\Sigma V}^2 t_{\Sigma V}^2)^{1/2}; \quad (1)$$

for fully adjustable bevel gear

$$i_{\Sigma}' = (1/K_{\Sigma})(K_{\Sigma S}^2 t_{\Sigma S}^2 + K_{\Sigma Z}^2 t_{\Sigma Z}^2 + K_{\Sigma V}^2 t_{\Sigma V}^2 + K_{\Sigma V}'^2 t_{\Sigma V}'^2)^{1/2}; \quad (2)$$

where is the $K_{\Sigma V}'^2 t_{\Sigma V}'^2$ — sum of the dispersion characteristics of the vector values of the component dimensions of the circuit T of a fully adjustable transmission (Fig. 2)

$$K_{\Sigma V}'^2 t_{\Sigma V}'^2 = K_V^2 (C_7^2 t_7^2 + C_8^2 t_8^2 + C_9^2 t_9^2). \quad (3)$$

The admitted deviation tolerance of the MPA of a fully adjustable transmission follows from the joint solution of equations (1) and (2)

$$i_{\Sigma}' = \left[t_{\Sigma}^2 + (1/K_{\Delta}^2) K_{\Sigma V}'^2 t_{\Sigma V}'^2\right]^{1/2}. \quad (4)$$

According to the calculation of the dimensional chain of the bevel gear, made according to the traditional structural scheme [3], t_{Σ} = 0,4 mm. The sum of the dispersion characteristics according to the formula (3), mm^2,

$$K_{\Sigma V}'^2 t_{\Sigma V}'^2 = 0.752\ (l{,}072\ 0.252 + 1.112\ 0.252 + 1.112\ 0.252) = 0.1269.$$

Substituting the numerical values in (4), we obtain the reduced tolerance - the total error of the component sizes, mm,

$$i_{\Sigma}' = (0{,}4^2 + (1/1) \cdot 0{,}1269)^{1/2} = 0{,}536.$$

The compensator introduced into the design scheme - a pair of rotary oblique washers - should completely eliminate the total error i_{Σ}', which is taken equal to the value of the necessary compensation. Studies [4] established the limit values of the total deviations of the top of the gear pitch cone for degrees of accuracy from 7 to 10 and cone distances R = 50 ... 400 mm, for which standardized bevel angles are recommended $\gamma_0 = 0.005;\ 0.003;\ 0.002$ rad, and the total thickness of the pair of washers δ_{sh} = 4.5 mm.

In this case, the value of the necessary compensation is determined by the reduced tolerance of the MPA deviation, mm,

$$t_{\Sigma}'' = i_{\Sigma}' + 2 \cdot [t_{\Sigma}] = 0.536 + 20.04 = 0.616.$$

Compensation for the deviation of the axle distance in a fully adjustable bevel gear is carried out by two turns (rotations) of the washers: mutual rotation by an angle ψ and joint by an angle φ [4].

The angle of mutual rotation at $\gamma_0 = 0.005$ rad:

$$\psi = 2\arcsin t''_{\Sigma}/2R_0\gamma_0 = 2\arcsin 0{,}616/(2\cdot 122{,}25\cdot 0.005) = 60^{0}\,40',$$

where $R_0 = l'_1 + 0{,}5\delta_{ш} = 120 + 0{,}5\cdot 4{,}5 = 122{,}25$ мм is the radius of rotation of the vertex of the gear pitch cone.

Joint rotation angle

$$\varphi = \pi\,'. - \psi/2 = 180^{0} - 60^{0}\,40'/2 = 149^{0}40$$

The direction of rotations (rotations) is determined by the position of the top of the cone relative to the axis of rotation of the wheel shaft, which can be determined by calculation [3] or the instrument control method [4]. The above calculations show that the compensating ability of a pair of washers at $\gamma_0 = 0{,}005$ rad is only partially used and it is possible to reduce the requirements for dimensional accuracy.

Taking into account the fact that elastic deformations in the gearbox cause additional MPD deviations of 1,6 ... 4,6 times exceeding the permissible ones [4], we take, *mm*,

$$t^{*}_{\Sigma} = 1{,}6\cdot 0{,}536 = 0{,}858\ mm$$

$$t'^{*}_{\Sigma} = t^{*}_{\Delta} + 2\cdot[t_{\Sigma}\quad] = 0{,}858 + 2\cdot 0.04 = 0{,}9376$$

$$\psi = 2\arcsin t^{*\prime}_{\Sigma}/2R_0\gamma_0 = 2\arcsin 0{,}858/2\cdot 122{,}25\cdot 0.005 = 100^{\circ},$$

$$\varphi = \pi. - \psi/2 = 180^{\circ} - 100/2 = 130^{\circ}$$

If, for example, characteristics of additional dimensions (tolerances of perpendicularity and parallelism) are accepted for 14 qualifications, i.e. $T_7 = T_8 = T_9 = 0 \pm 0{,}3$ *mm*, $t_7 = t_8 = t_9 = 0{,}6$ *mm*, $\alpha_0 = 0$, $K_v = 0{,}75$, then the calculated tolerances will have values $i'_{\Sigma} = 0{,}94\ mm$, $t''_{\Sigma} = 1.02\ mm$. In this regard, the angles of mutual and joint rotations of the oblique washers will be ψ = 113 °, $\varphi = 123°$, i.e. and in this case, the compensating ability of the adjusting device is not fully used.

From the above analysis, it follows that it is advisable to introduce direct adjustment of the interaxal distance in spur bevel gears of the compensating link in the form of a pair of rotary oblique washers. Fully adjustable bevel gears can significantly reduce the requirements for precision manufacturing of gearbox body parts and, accordingly, the cost of their manufacture.

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