Technique for monitoring the indicators of the total contact spot of spur gears of the truck's differential gear

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Abstract. The article contains the main provisions of the technique, which allows to control the area of the total contact patch and its position relative to the tooth edges. Graphical schemes for finding indicators are given. An example of the calculation of the indicators established by the methodology, as well as the results of its application for assessing the quality of the setup performance, is considered on the example of processing a differential satellite in the operation of circular gearing.

1. Introduction
Straight bevel gears are part of various differential gears to ensure the independence of the rotation of the driving wheels of the car.

The accuracy of the processing of the teeth of conical wheels largely determines their resource and noise level in the transmission. One of the main indicators determining the reliability of the conical transmission in the differential is the total contact spot. Inconsistencies in the location of the contact spot in the conical gear lead to serious consequences during the operation of the vehicle.

For example, the local output of the contact patch to the spherical end face of the satellite leads to the appearance of a significant moment directed along the axis of the satellite. Chamfering at the ends of the teeth can not fully compensate for the exit of the contact patch on the edge [1, 2]. As a consequence, the pressure in the area of the hole close to the flat end of the satellite increases. There is an extrusion of the oil film, heating and wear of the antifriction coating and adhesion of the satellite to the reference axis. After that there is jamming of the gear drive, gear transmission, breakage of the teeth, destruction of the mated parts and failure of the differential.

2. Statement of the problem
The normalization of the total contact spot is carried out according to the requirements of the standards. So the requirements of the standard [3] for bevel gears, the relative dimensions of the total contact patch in percent are determined: the length of the tooth is the ratio of the distance between the extreme points of the traces of adherence to the length of the tooth; on the height of the tooth - the ratio of the average height of the traces of adherence to the average tooth height of the corresponding active lateral surface (Figure 1).

An estimate of the contact spot size is performed according to the standardized procedure given in [5]. The standard defines the concept of an instantaneous contact spot as one of the indicators of the accuracy of tooth contact. An instantaneous contact spot means "a part of the active side surface of the gear wheel tooth on which traces of its attachment to the gear teeth coated with the dye are located after turning the wheel of the assembled gear to full turn with slight braking ensuring continuous contact of the teeth of both gears" [5].
Relative dimensions of the contact spot in percent:
- by the length of the tooth - the ratio of the distance between the extreme points of the traces of adherence to the length of the tooth ($\frac{d}{b} \times 100$);
- by the tooth height - the ratio of the average height of the traces of adherence to the average tooth height of the corresponding active side surface ($\frac{h}{h_a} \times 100$).

Currently, many machine-building enterprises, as well as assembly enterprises, assess the shape and dimensions of the total contact spot visually. In this form, the method is used for the initial assessment of the correspondence of a single tooth of the wheel toothed wheel, as well as the adjustments of the machine nodes to achieve the location of the spot, was approximately at the center of the lateral surface of the tooth. In rare cases, the dimensions of the contact spots along the length and height are determined for one or two teeth of the wheel by measurements using universal measuring instruments.

**Figure 1.**

- **a)** Normalizing the size of the contact patch in a bevel gear. I is the largest limiting size of the contact spot; II - nominal size of the contact spot; III - the smallest limiting size of the contact spot [1];
- **b)** the standard scheme for estimating the dimensions of the total contact spot [4].

It should be noted that the standard method is based on the assumption of the location of the contact spot near the calculated point of the gear train. Its calculated data can not be used to assess the compliance of the total contact spot with significant deviations from the calculated point of transmission, for example, in the adjustment processes or the deviations that occur when the bevel gears are chiseled.

### 3. Theoretical part

Because the tapered differential gears of the truck are not adjustable, it is not possible to change their axial position during installation during the assembly of the differential and thus affect the position of the total contact spot. It is important to obtain a contact patch not only approximately in the central part of the gear tooth, but to ensure the stability of its location along all the teeth of the ring gear after the operation of the gear.

The developed procedure for normalizing the total contact patch takes into account the requirements of the standard (allows quantifying the dimensions of the contact patch along the axis and tooth height), and additionally normalizes its relative position on the side surface of the gear wheel (Figure 2). Let us consider the main provisions of the methodology for finding separate indicators of the quality of the total contact spot.

Based on the data of the conical transmission tests under load, it is established that the optimal form of the total contact spot is an ellipse located at a distance of two to four mm from the flat end of
the conical transmission satellite (Figure 2a). The minimum width of the contact patch in its middle part (or the small axis of the ellipse) should be ½ the active height of the tooth. Along the axis of the tooth, the total contact spot (or major axis of the ellipse) should occupy from ½ to ¾ its length along the generatrix of the fission cone. These data are taken into account when determining the minimum and maximum allowable form of the total contact spot (Figure 2b).

Figure 2. Normalization of the shape and relative location of the total contact patch a) nominal location, b) permissible sizes of the total contact spot, c) the maximum permissible detection limits, d) the minimum permissible detection limits.

The normalization of the boundaries of the location of the total contact spot is to establish the minimum and maximum boundaries for finding the total contact spot (Figure 2c, d). The boundaries of the zone are located in the form of lines that equidistantly repeat the contours of the tooth at a given distance from the edges of the tooth. Depending on the gear module and the magnitude of the moment transmitted by the gear, it is 1–3 mm.

As a result, the form of the actual contact patch should be between ellipses and should not go beyond the inner and outer boundaries of the location area. The obtained generalized values of the indicators allow us to calculate the limiting values of the boundaries of the tolerance fields and are suitable for calculating the values of the gears of any conical spur gear.

4. Practical implementation
The contact spots are formed as a result of the rolling of the teeth on a special gear-rolling machine (Figure 3).
Figure 3. Formation of the total contact spot: a) the rolling mill, b) the result of rolling the teeth of the gears.

Quantitative determination of indicators is possible only on the basis of photographing the lateral surfaces of the gear teeth with further processing of the image (Figure 4a). The image processing consists of the outline of the tooth contours and contact spots, which resulted from abrasion of the special pigment. To estimate the dimensions of the total contact patch, schemes have been developed for finding the parameters of the total contact spot in accordance with the requirements of the provisions of the technique of simultaneous normalization and the shape and location of the total contact spot (Figure 4a, b).

Figure 4. Graphical schemes for finding the parameters of the total contact spot: a) photograph of the side surface of the gear wheel with the contours of the active zone of the lateral surface and the contact spot, b) the scheme for finding the dimensions of the total contact patch, c) the scheme for finding the parameters of the location of the total contact spot.

Calculation of the area and relative location of the total contact spot for the calculation schemes shown in Figure 4 is performed by the following formulas:

1. The size of the total contact patch along the length of the tooth.
2. The size of the total contact patch along the height of the tooth.

\[
\%L = \frac{a}{b} \times 100 = \frac{13.74}{34.76} \times 100 = 39.53\% 
\]

3. Calculation of the linear dimensions of the location of the total contact patch along the length of the tooth:

\[
L2 = \frac{L2}{b} = \frac{3.29}{34.81} \times 26.44 = 2.45\, mm \\
L4 = \frac{L2}{b} = \frac{18.92}{34.81} \times 26.44 = 14.37\, mm 
\]

4. Calculation of the linear dimensions of the location of the total contact spot over tooth height:

\[
L1 = \frac{L2}{h_a} = \frac{2.91}{12.91} \times 8.18 = 1.84\, mm \\
L3 = \frac{L2}{h_a} = \frac{8.97}{12.91} \times 8.18 = 5.68\, mm 
\]

The results of the simultaneous calculation of the area of the contact patch serve for the construction of control charts for controlling the progress of the adjustment of gear machines with the change of circular broaches.

5. Conclusions and results

An example of control charts for \%L for rolling clockwise and counterclockwise is shown in Figure 5. The control map field indicates the outlets of the graph points beyond the limits of the tolerance zone USL and LSL (the red line on the control field is shown), which indicates the presence of special reasons. In addition, the estimation of the intrinsic variability of the parameter (on the field of the control map indicated by dashed lines) is performed. In the process of adjusting by radial, axial and angular displacements, broaches seek to eliminate on the charts the presence of special causes and hit the control boundaries of the graphs for the remaining set of indicators - \%H , L2 , L4 , L1 , L3 .

In addition to ensuring control over the implementation of adjustment, the developed methodology has shown its effectiveness and effectiveness in the certification audit of process equipment in the workplace of circular tooth gearing of differential gears. The approach presented in the methodology can be successfully used for the purpose of improving the quality of products in a manner similar to those described in [6–8].
Figure 5. Example of control charts of individual values and sliding ranges of the% L and% H indices on the side surfaces of the satellites crown during the adjustment stage. a, b) when the satellite is turned in a counterclockwise direction, c, d) while rotating clockwise.

Thus, the quantitative data characterizing the area and the relative location of the contact spot make it possible:
- The use of control charts to eliminate special causes in gear tooth gear cutting, the preparation of a new product and the adjustment of the machine.
- Calculate the indices of stability and tuning of the gear cutting processes for the purpose of attestation of the technological process.
- To provide more effective control over the adjustment of the machine already in the adjusted process of gear cutting.

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