Determination of the parameters of adjusting the gear broaching machine, according to the measurements of the spur bevel gears

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Abstract. The process of adjusting a gear broaching machine is considered, according to the angle of the cone of the depressions and the symmetry of the side profiles of the gear wheel. Standard adjustment methods do not allow measuring the values of the taper angle of the valleys and deviations from the symmetry of the profiles. The article proposes a method for finding the main setting parameters of gear broaching machine, according to the measurement data of spur bevel gears. The measurement method is implemented in the form of a measuring system, including a special control device equipped with inductive probes, and algorithms for processing their readings. The use of the measuring system makes it possible to increase the accuracy of setting up the gear traction machine and to improve the quality of manufacturing of spur bevel gears.

1. Introduction

The most productive way of processing gears is the circular gear pulling method. This method is used to process bevel spur gears for truck differentials [1-3]. To form a gear rim, the bevel gear is sequentially indexed during processing in angular positions corresponding to the number of cavities of the gear wheel, the main movement is set by rotating a circular broach, the feed movement is performed in the direction of the angle of the cavity of the gear wheel (Figure 1) [4].

The adjustment of the machine consists in setting a given location of the movable units (Figure 1 b), each of which affects the parameters of the gear wheel [5]. Adjustment of the gear broaching machine is carried out according to the angle of the cone of the cavities and the symmetry of the side profiles of the gear wheel. The angular direction along the trough is provided by installing the tool head along the vernier angular limb of the machine and its value after processing is not checked on the part.

Determination of the symmetry of the side profiles is carried out indirectly by assessing the displacement of the pointed rollers nested in opposite wheel cavities (Figure 2). Thus, the accepted methods of finding the setting parameters do not allow checking their actual set value and, as a consequence, ensuring the control of the setting parameters. Measurement of machined parts in order to assess their suitability often does not provide a hint for setting up equipment [6]. In a number of works [7,8], the possibilities of diagnosing equipment and tooling based on the results of measuring the processed parts are considered; these developments can be used to improve equipment setup.
2. Theoretical part

To find the actual values of the setup parameters, it is necessary to provide measurements of bevel gears, for example, on a coordinate measuring machine. The use of a coordinate measuring machine in a shop environment is difficult due to the need to ensure that it operates clean and environmentally friendly.
At the workplaces there is a control and measuring device for measuring the radial runout of the cavities of the teeth of the gear wheel (Figure 3 a), equipped with a dial indicator. A control device in this design does not allow measuring the desired parameters of the gear wheel, however, such a gear wheel positioning scheme can be used to develop a special control device equipped with inductive probes and featuring a mechanism for angular division of a bevel gear. (Figure 3 b).

Eight inductive probes are required to measure the angle of inclination along the bottom of the cavity and deviations from the symmetry of the right and left profiles of the gear teeth. Three styli are in contact with the left flank, two styli with the root surface, three other styli with the right side flank of the teeth. Measurement of deviations is carried out at different satellite depressions, which must be taken into account when combining measurement data along the satellite depressions after measurements are taken. Deviations of measuring points along the left and right lateral surfaces of the satellite are performed through one depression.

The initial data are the readings of the measuring probes of deviations from the reference bevel wheel:

\[ \Delta_{1at} \ldots \Delta_{2at}, \Delta_{1bt} \ldots \Delta_{2bt}, \Delta_{1ct} \ldots \Delta_{2ct} \] – indications inductive measuring probe in the lower, middle and upper part of the left side surface of the bevel gear.

\[ \Delta_{1ar} \ldots \Delta_{2ar}, \Delta_{1br} \ldots \Delta_{2br}, \Delta_{1cr} \ldots \Delta_{2cr} \] – indications inductive measuring probe in the lower, middle and upper part of the right side surface of the bevel gear.

\[ \Delta_{1af} \ldots \Delta_{2af}, \Delta_{1cf} \ldots \Delta_{2cf} \] – readings of measuring inductive probes in the lower and upper part of the bevel wheel cavity.
Figure 4. Scheme for calculating the angle along the trough of the bevel wheel adjustment displacements to ensure the direction of the trough line

Figure 4 shows a graphical diagram of finding the angle along the troughs of the bevel wheel. The angle value can be found using the following formula:

\[
\alpha_f = \arctg\left(\frac{Y_{af} - Y_{cf} - \Delta_{cf} + \Delta_{af}}{Z_{cf} - Z_{af}}\right)
\]

where \(Y_{af}, Y_{cf}\) – coordinate of the center of the spherical tip of the stylus when it touches the surface of the cavity of the differential satellite along the Y axis;

\(Z_{cf}, Z_{af}\) – the coordinate of the center of the spherical stylus tip when it touches the surface of the satellite cavity.

\(\Delta_{cf}, \Delta_{af}\) – indications of the measuring inductive probes in the lower and upper parts of the cavity of the differential satellite.

The trough line adjustment offset is calculated using the following formula:

\[
\Delta\Sigma_f = \frac{\Delta_{cf} + \Delta_{af}}{2}.
\]

For each trough, the angle of its slope is calculated using the following formula:

\[
\alpha_{fi} = \arctg\left(\frac{Y_{af} - Y_{cf} - \Delta_{cfi} + \Delta_{afi}}{Z_{cf} - Z_{af}}\right),
\]

where \(\Delta_{cfi}, \Delta_{afi}\) – indications of measuring inductive probes in the lower and upper part of the cavity.

Based on the angles found for each trough, the arithmetic mean is calculated, then, if necessary, the angular correction of the tool head installation is determined. In the same way, deviations of the right
and left profiles from symmetry are found, their correction is performed by vertical movement of the circular broach.

3. Practical part
The developed scheme for measuring the differential satellite of a truck is implemented in the designed 3D model of the control device shown in Figure 5. To perform measurements, it is necessary to install the reference satellite on an expanding mandrel. Orient the rotary indexing mechanism by installing the lock in the adjusting corner slot of the rotary disc. Then insert the Orientation head into the satellite slot. Secure the differential pinion by tightening the screw and pressing the conical washer against the collet lugs. After completing the adjustment of the initial angular position, it is necessary to turn the rotary indexing mechanism to any setting angular position.

Next, you need to bring the carriage with the rotary device to the stop. Turn off the vacuum in the supply and return system of the measuring inductive probes, which makes it possible to automatically bring the tips of the probes to the lateral surfaces of the reference cavity of the differential satellite. Then reset the readings of all sensors. Performing the adjustment of the styli on the valleys of the reference gear must be performed when calibrating the measuring diagnostic device in accordance with the schedule for their implementation.

After adjusting the diagnostic test fixture, it is possible to measure the differential pinions. The manufactured differential satellite is installed on the mandrel, its initial angular position is adjusted, and then the mandrel is rotated to the working angular position, the carriage is brought up to the stop and the probes are brought in, and the deviations of their readings relative to the adjusted zero values are recorded. If necessary, perform sequential measurements for each valley of the differential pinion.

Figure 5. 3D model of the control device for measuring the differential satellite
After taking measurements, the carriage and the measuring probes are retracted to the initial position. Data from the probes are transferred through the measuring unit and interface cables to the database of the software product for recording and processing measurement data.

Table 1 shows the form of the measurement protocol of the differential satellite with the found values of the adjustment parameters and the correction value. The protocol contains the data of the angle values along the bottom of the groove, the arithmetic mean value is the initial value for calculating the correction of the angular position of the tool head of the machine, Adjustment correction for the angle \( \alpha_f = 0.03^\circ \).

### Table 1. Tabular form of differential satellite measurements.

| № of toothspace | Angle along the bottom of the groove, deg | Deviation, along the left profile, mm | Deviation, according to the right profile, mm | Deviation from symmetry, mm |
|-----------------|-----------------------------------------|--------------------------------------|-----------------------------------------------|------------------------------|
| 1               | 20.93                                   | 0.05                                 | -0.12                                         | -0.07                        |
| 2               | 20.90                                   | 0.05                                 | -0.10                                         | -0.05                        |
| 3               | 20.84                                   | 0.04                                 | -0.02                                         | 0.02                         |
| 4               | 20.90                                   | 0.07                                 | -0.08                                         | -0.01                        |
| 5               | 20.93                                   | 0.01                                 | -0.08                                         | -0.07                        |
| 6               | 20.95                                   | 0.04                                 | -0.06                                         | -0.02                        |
| 7               | 20.80                                   | 0.02                                 | -0.10                                         | -0.08                        |
| 8               | 20.83                                   | 0.09                                 | -0.15                                         | -0.06                        |
| 9               | 20.90                                   | 0.08                                 | -0.12                                         | -0.04                        |
| 10              | 20.80                                   | 0.04                                 | -0.11                                         | -0.07                        |
| 11              | 20.84                                   | 0.04                                 | -0.12                                         | -0.08                        |
| \( \alpha_{\text{mid}} \) | 20.87 | \( \Delta_{\text{mid}} \) | | |

Adjustment correction for the angle of the valley (feed direction of the broach) \( \alpha_f = 0.03^\circ \)  
Symmetry Correction (Vertical Feed Offset) \( \Delta = 0.048 \) mm.

The deviation from symmetry is calculated from the deviation data for the right and left profile, the arithmetic mean of the deviations is also the starting point for calculating the vertical correction of the circular broach position. For the example shown in Table 1, symmetry correction \( \Delta = 0.048 \) mm.

### 4. Conclusion

The use of the designed control device makes it possible to increase the accuracy of the adjustment of the gear-traveling machine and improve the quality of manufacturing of spur bevel gears.

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