Finish machining of gear wheels in a progressive manner

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Abstract. The article describes the method of finishing, combined, cutting-deformation machining of gear wheels, which has a high correcting ability in terms of kinematic accuracy, smoothness of operation, contact of the teeth side surfaces and side clearance.

1. Introduction
The main objective of engineering technology is the manufacture of parts with the lowest labor costs, with the highest productivity and metal utilization. As a rule, parts with the specified drawing dimensions and the required surface roughness are obtained by machining. A great future in metal processing belongs to plastic deformation methods. These are the most advanced and progressive methods for manufacturing parts that provide a sharp increase in labor productivity, a significant reduction in technological metal waste, a decrease in the complexity of processes and the cost of production.

Consider the diagram of the progressive machining method presented in figure 1.

![Figure 1](image)

**Figure 1.** Scheme of machining of spur gear wheels with tools, the involute profile of which is performed by the electroerosive method: 1 - tool; 2 - work piece; 3 - involute profile; 4 - crater; 5 - mandrel; \(d_w, d_{w0}\) - the diameters of the initial circles of the work piece and the tool teeth [1].

The teeth of the tool have an involute profile formed by the EDM method. The edges of craters 4 after EDM are located on the involute side surface of the teeth, as a result of which producing surface 3 of tool 1 is intermittent. The tool works as follows.
Machined gear wheel 2 is mounted on the machine spindle and introduced into the clearance-free engagement with the gear ring of tool 1. Then the tool is radially fed until the required center distance is reached. Machined gear wheel 2 begins to rotate and drives the tool. When the work piece reaches the number of revolutions equal to the number of the teeth of the tool, the rotation is reversed. A number of the tool teeth should not have common factors with the number of teeth of the work piece. To improve the quality of the machined surface, the engagement of the work piece with the tool should be extrapolar, that is, the pole of the engagement $P$ should be extended beyond the working height of the tooth. In the places where the surfaces of the gear wheel and the tool come in contact with the microrelief of the working surfaces of the teeth, the microprotrusions of the tool are introduced into the tooth body, the sliding of the surfaces provides cutting.

2. Analysis of the cutting process by the working surface of an instrument with artificial microrelief

With extrapole engagement of the tool and the machined wheel, the contacting points of the surfaces slip, and thus, the cutting of the teeth of the tool with artificial microrelief during micro-cutting is performed by the working surface. A similar artificial microrelief can be formed using EDM. It is known that after such processing holes remain on the surface with sufficiently sharp annular edges, which can have cutting properties. In addition, in areas where the holes overlap one another, pointed protrusions appear, which also have certain cutting properties. It should also be borne in mind that when metal is ejected from the hole, annular protrusions are formed at its edges, in which metal can be hardened. These protrusions also participate in the cutting process with this surface. An example of such a tool is shown in figure 2.

![Figure 2](image)

**Figure 2.** A tool for finish machining of spur gears with an artificial micro-relief of the working surfaces of the teeth obtained by the electroerosive method.

![Figure 3](image)

**Figure 3.** Samples of cutting surfaces after electric discharge machining (scale 50: 1): a - experimental tool - plate, b - tool shown in Figure 2.
As it can be seen from the photographs in figure 3, the cutting surface is formed from a plurality of overlapped holes. In this case, only the holes from the last pulses corresponding to the departure of the electrode wire from a given area of the treated surface can be represented in the form of a circular segment of the sphere, and the previous holes will be distorted by subsequent discharges.

To analyze the features of cutting by the edges of the holes formed on the surface after EDM, microphotography of the chips formed after finish machining was carried out (figure 4).

Figure 4. The shape of the chips after finish machining with a tool with an artificial micro-relief of the working surfaces of the teeth, processed by the EDM method.

From the presented image, one can judge the shape of the shavings, and it is quite clearly noticeable that this shape is diverse. There is a short chip, almost without curling, and elongated, twisted into a spiral chip. From this we can conclude that various surface elements after EDM are involved in cutting.

To detail and analyze the process of cutting an artificial micro-relief of the working surfaces of the teeth of the tool after EDM, a three-dimensional surface model with holes was developed (figures 5 and 6).

Figure 5. A fragment of a three-dimensional surface model after EDM.

Figure 6. Three-dimensional model of a pyramidal cutting surface element after EDM.

It can be seen from the surface photograph (figure 3) and the three-dimensional model that the surface is cut primarily by protruding pyramidal elements that are formed at the boundaries of overlapping holes. For these elements, a cutting pattern can be formed, shown in figure 7. It should be noted that both the three-dimensional model and some subsequent cutting patterns are simplified, since they do not show the rounding of the vertices of the cutting elements and the influx at the boundaries of the holes. This rounding is formed as a result of fusion of the boundaries of the holes. However, the radius of such a rounding does not exceed several microns, so it does not significantly affect the cutting process. It should also be noted that, since in this case processing with a cutting depth $t$, exceeding the height of the
artificial surface microrelief $h$, is not possible, when analyzing cutting with an individual element, the cutting depth coincides with the thickness of cut layer $a$.

![Diagram of cutting by elements with artificial microrelief of the surface after EDM.](image)

**Figure 7.** Diagram of cutting by elements with artificial microrelief of the surface after EDM.

### 3. The methodology of the experiment

An experiment was performed to study the cutting properties and wear resistance of a tool with an artificial microrelief of the working surfaces of the teeth and the combined displacement of the producing rack contour. Gear wheels module = 2 mm, number of teeth = 16, displacement coefficient $= + 0.5$ manufactured on a 5K301 gear cutting machine made of 40X steel with hardness HPC 28...32, in the amount of 50 pcs. were chosen as the objects of study.

The gear wheels are made at the upper tolerance limit, which limits the removal of metal by the lower tolerance limit.

The gear wheel under study is mounted on a mandrel in commissioning and is fixed using a clamping sleeve by a rotating center. The needle bearing tool is mounted in the blade holder of the machine.

The tool is brought into engagement with the machined gear wheel until touchdown, while the gear wheel rotated should not jam. The machine is turned on and running in the selected modes.

The chips formed during the run-in are small-size - 0.05-0.1 mm.
All gear wheels were measured on the instruments according to 4 parameters before and after processing (radial runout, oscillation of the length of the general normal, step error, accumulated profile error).

Studies were carried out to reduce tooth roughness after gear milling and after finishing by tools, with an artificial micro-relief of the working surfaces of the teeth, which are formed by the electro erosive method.

To measure the roughness parameters, a stationary HOMMEL-WERKE roughness measuring device (Germany) was used.

The measurement results are summarized in table 1.

Table 1. The measurement results.

| Parameter value in microns | Parameter | gear milling | machining by artificial micro-relief of the working surfaces of the teeth |
|----------------------------|-----------|-------------|---------------------------------------------------------------|
| $R_a$                      | 4.82      | 1.17        |
| $R_z$                      | 29.54     | 9.45        |
| $R_{\text{max}}$           | 34.25     | 12.55       |
| $t_p$                      | 0.8       | 0.8         |
| $F\text{r}$                | 54-136    | 26-50       |
| $F_{\text{VW}}$            | 16-49     | 9-27        |

4. Conclusion
According to the experimental studies of the quality of finish machining of spur wheels after preliminary gear milling, it was found:

- correction of the error of preliminary machining according to parameters Fr, Fvw at 1...2 degrees GOST 1643-82
- decrease in the roughness of the machined surface with $Ra = 4.8 \mu m$ after pre-machining to $Ra = 1.2 \mu m$ after finish machining.

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