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# Disc Shaping Cutters and Their Features When Cutting Tooth Wheels

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**ABSTRACT:** The article covers the analysis of calculation data for tooth wheels of various sizes and their influence on the service life of disk shaping cutters, and provides algorithm for constructing the line of features of the absence of gear interference.

**KEYWORDS:** shaping cutter, displacement of the initial section, indexing height of the tooth head, rake angle, interference of tooth gear, engagement, involute profile, line of features.

## 1. INTRODUCTION

The shaping cutter is an enhanced tooth gear that generally has both positive and negative correction, provided with appropriate cutting angles. To create a clearance angle at the top of the tooth  $\alpha_a$  (the value of the angle  $\alpha_a$  is assigned depending on the value of the profile angle of the original contour  $\alpha$ ) and on its lateral sides, the teeth of the shaping cutter are formed by displacing the original contour of the rack and have their own contour displacement value in each section perpendicular to the axis  $x_0m$ . The end section *II-II* of the shaping cutter (Fig. 1) is called the initial (calculated) section; when gearing with tooth gear it forms a zero drive. The distance *A* from the front *I-I* of the new shaping cutter to the initial section is called the displacement of the initial section (contour) and is generally considered a positive displacement. A variable shift of the initial contour of the rack, gradually decreasing from the front surface to the base surface, creates a clearance angle at the tooth apex  $\alpha_a$  and on the lateral sides. [1].

Thus, the shaping cutter can be considered as a set of infinitely large number of elementary tooth gear with an infinitely small rim width, having, respectively, positive, zero and negative contour displacement and fixed on one axis in the order of decrease of displacement values  $x_0m$ . Therefore, gears cut with different sections of the shaping cutter will have the same involute profile.

In the initial section of the shaping cutter, the initial circle coincides with the dividing circle, and the thickness of the tooth  $s_0$  along the dividing circle arc, the dimensions of the dividing height of the tooth head  $h_{a0}$  and the flank of the tooth  $h_{f0}$  will be equal to the dimensions of the original contour of the rack of the shaping cutter [2].

The dividing of the tooth head  $h_{a0}$  is determined by the formula:

$$h_{a0} = (h_{a0}^* + c^*)m \quad (1)$$

Where:  $h_{a0}^*$  - coefficient of the tooth head height;

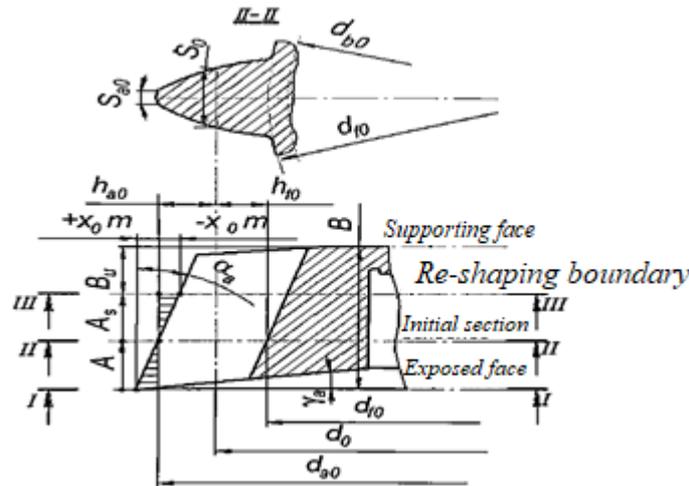
$c^*$  - coefficient of the radial clearance;

$m$  - module of the cut pair of tooth gear.

Dividing height of the tooth flank  $h_{f0} = h_{a0}$ .

The shaping cutter is also supplied with a rake angle  $\gamma_a$  (the value of the angle  $\gamma_a$  is assigned depending on the type of machining: rough machining or finishing). The re-sharpening of the shaping cutter is performed along the front surface,

which will lead to a decrease in dimension  $A$  with each re-sharpening. In this regard, in order to increase the service life of the shaping cutter, they tend to choose the value of the  $A$  dimension as large as possible. However, at the same time, the danger of sharpening of the teeth increases, which leads to a decrease in the durability of the shaping cutter, and also the danger of interference between the gear teeth and the wheel, cut by this shaping cutter.



**Fig. 1. Cut of the disc shaping cutter**

The distance  $A_s$  from the initial section to section III-III is the boundary of the permissible re-shaping of the shaping cutter (Fig 1). Since with each re-shaping the diametrical dimensions of the shaping cutter decrease, the risk of cutting off the lateral sides at the top of the teeth and the risk of cutting the flanks of the teeth of the gear and wheel being cut increases.

## II. DESIGN METHODOLOGY

The design of shaping cutters with different parameters of the tooth gears being cut will be carried out in the “CAD RI” engineering program.

Characteristic feature of the shaping cutter design task is the need to check seven conditions: check for sharpening of the shaping cutter teeth, interference and undercutting the gear and wheel flanks, cutting off the tops of the gear and wheel teeth. In a normal calculation, if any of these checks are not performed, the re-assign the displacement of the original contour and perform these checks again must be performed, which requires a lot of computational work, since you have to repeatedly solve the transcendental equations to find the angles from their involutes. Below is an example of solving this problem, which presents the results of the calculation, including in the form of a graphical picture of checking for interference, which allows not only to choose rational values of design parameters, but also allows to visually assess the proximity or remoteness of design parameters from their unacceptable values.

The first main task in the design of the shaping cutters is to select an acceptable displacement  $A$ . The second task is to select the distance  $A_s$  from the initial section to section III-III, which is the boundary of the permissible re-shaping of the shaping cutter (Fig 1). Since the diametrical dimensions of the shaping cutter decrease with each re-shaping, the risk of cutting off the lateral sides at the top of the teeth and the risk of undercutting flanks of the teeth of the gear and wheel being cut increases, i.e., conditions must be checked.

In most methodologies, the solution to these problems is carried out as follows: the displacement  $A$  of the initial section is assigned (or calculated using empirical formulas) and the compliance with the first three conditions for the sharpening of the teeth of the shaping cutter and for the absence of interference between the teeth of the gear and the wheel is checked. If at least one of these conditions is not met, then the value of  $A$  is adjusted and checks of all three conditions are performed again, and so on until all of them are met. The same is repeated when assigning the distance  $A_s$ , but now when checking four conditions. Not only is this rather tiresome and uninteresting, the main thing is that as a result of such a selection of  $A$  and  $A_s$ , we will not know how far we are from the boundaries of violation of already seven conditions. Knowing these boundaries will allow us to choose rational values for  $A$  and  $A_s$ , which ultimately will

increase the overall life of the shaping cutter. Below are the algorithms, the description of the calculation of straight-toothed disc shaping cutter for cutting wheels with external engagement with the module  $m$  1÷12 in automatic mode, which greatly simplifies the solution of these problems.

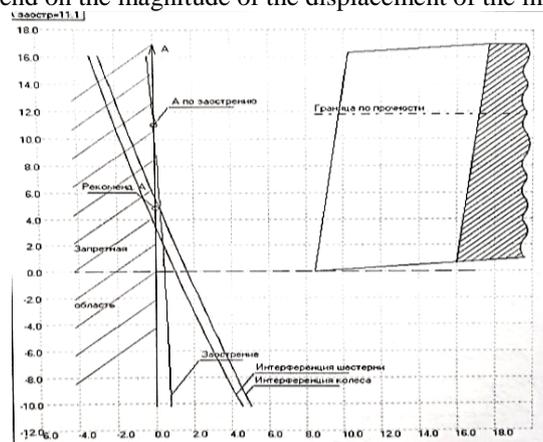
The values of the shaping cutter parameters are presented in accordance with GOST 9323-79. The initial data are:  $m$  is the module of the being cut gear pair;  $\alpha$  is the profile angle of the initial contour;  $h_{a0}$  is the coefficient of the height of the tooth head;  $c^*$  is coefficient of radial clearance;  $Z_1$  is the number of gear teeth;  $Z_2$  is the number of teeth of the wheel;  $D_{o\text{ ном}}$  is the nominal diameter of the dividing circle of the shaping cutter;  $x_1$  is coefficient of displacement of the original contour of the gear  $x_2$  is coefficient of displacement of the original wheel contour;  $\Delta R_{a1}$  is permissible cutting of the lateral sides at the top of the gear tooth;  $\Delta R_{a2}$  is permissible cutting of the lateral sides at the top of the wheel tooth; WO is the type of machining (roughing WO = 0, finishing WO = 1).

The program will automatically select from GOST the value of the sharpening cutter height  $B$ , which will be required in further calculations, depending on the entered nominal dividing diameter  $D_{o\text{ ном}}$  and the entered modulus  $m$ . In addition, the program will remember the thickness of the  $B_1$  hub and the hole diameter  $d_{0\text{ ТВ}}$ , which will be displayed at the end of the calculation to print and will be required to build a drawing of the shaping cutter. Then the program will calculate the following parameters: number of teeth of the shaping cutter: actual diameter of the dividing circle of the shaping cutter; vertex back angle depending on the profile angle; rake angle depending on the type of processing WO; profile angle of the shaping cutter on the indexing cylinder (with an accuracy of 1''); the diameter of the main circle of the shaping cutter.

Then the dimensions of the teeth of the shaping cutter in the initial section will be calculated: separating height of the tooth head; separating height of the tooth flank; separating thickness of the tooth (along the arc) depending on the type of processing WO: the diameter of the circle of the tops of the teeth; pressure angle at the apex of the tooth: the thickness of the tooth on the circumference of the protrusions (along the arc); the angles of inclination of the helical lines on the lateral surface of the shaping cutter tooth (lateral rear angles) (with an accuracy of 1'') on the indexing cylinder.

These data are already enough to construct on a scale the axial section of the shaping cutter tooth with the already known rear  $\alpha_a$  and face  $\gamma_a$  angles and height  $B$  for the initial data (Fig 2). To the left of the shaping cutter at a distance of, for example, 0,5-  $B$ , we place the coordinate syflank, along the ordinate of which we will plot the displacement  $A$  of the original section from the front end (section  $I-I$ ) of the shaping cutter (Fig 1), that is, the zero point along the  $A$  axis will be coincide with the front end of the shaping cutter.

On the abscissa axis, we will plot the values of the checked features, which, as will be shown later, must be greater than zero and not enter the area of negative values, which is shaded and marked with the inscription "Forbidden area" (Fig 2). In this coordinate syflank, let us first construct three graphs for the initial data to check for the sharpening of the teeth of the shaping cutter and the absence of interference between the gear and wheel cut by this shaping cutter, since all these three indicators depend on the magnitude of the displacement of the initial section  $A$ .



**Fig. 2. Axial section of the shaping cutter tooth**

To determine the sharpening, it is necessary to calculate the following dimensions of the sharpening cutter in the plane  $I-I$  of the front end (Fig. 1): the height of the tooth head; the height of the tooth flank; the thickness of the tooth along the arc of the dividing circle; diameter of the circle of the tops of the teeth; pressure angle of the involute on the tooth head; the thickness of the tooth along the circumference of the protrusions; the minimum permissible thickness of the tooth along the circumference of the protrusions of the new sharpening cutter.

Then the feature of the absence of tooth sharpening  $P_{za0}$  can be written as:

$$P_{za0} = S_{ta0} - S_{a0} \geq 0 \quad (2)$$

To plot the line of the  $P_{za0}$  feature on the graph, it is sufficient to vary the distance  $A$  in the range, for example, from  $A_{min} = -0,6B$  to  $A_{max} = B$  with a pitch  $\Delta A = 0,05B$ , where  $B$  is the height of the sharpening cutter. A line of the  $P_{za0}$  feature will be drawn (Fig 2), which is indicated by the “Sharpening” leader. The transition point of this line to the area of negative values (“Forbidden area”) will determine the maximum possible displacement  $A$  for this sharpening cutter. The program, using linear interpolation between two nearest  $P_{za0}$  values with different features relative to the border of the forbidden area, will find this point, mark it with a circle with a radius of 4 pixels and a leader “ $A$  by sharpness”. The numerical value of this point will even be displayed in the upper left corner of the screen in the transparency “ $A$  sharpen = ...”

The literature provides several ways to determine the initial value of the displacement  $A$ , from different empirical formulas to using different graphical dependencies. The most common of them is the calculation of the coefficient of displacement of the original contour  $x_0$  (Fig 1) using the empirical formula:

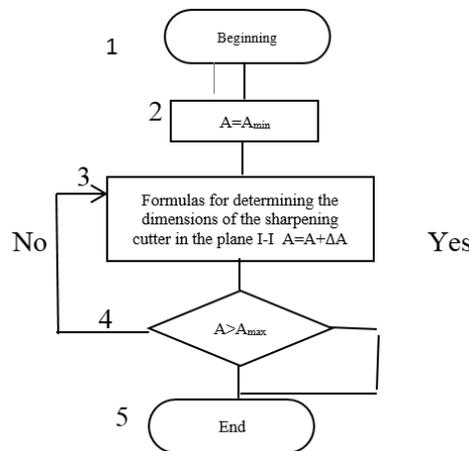
$$x_0 = 0,01(z_0 - 10), (3)$$

which allows you to calculate the initial values of the displacement  $A$  as:

$$A = \frac{x_0 m}{\text{tg} \alpha_a}$$

For comparison, this value is also plotted on the graph as a circle with a radius of 4 pixels with a leader “Recommend.  $A$ ”. As we will see later, formula (3) is too “empirical”, since it does not take into account the whole variety of possible combinations of the parameters of the sharpening cutters, and even more so the parameters of the being cut pair of gears.

Final algorithm for constructing the line of the  $P_{za0}$  feature by sharpening is shown in Fig 3.



**Fig. 3. Algorithm for constructing feature line  $P_{za0}$**

Next, a check for the absence of interference of the gears, which also depends on the displacement  $A$  is made. To do this, the first needed to calculate the constants for this tooth gear value:

tooth gear engagement angle  $a_{12}$ :

$$\text{inv} a_{12} = \frac{2(x_1 + x_2)}{z_1 + z_2} \text{tg} \alpha + \text{inv} \alpha; (4)$$

axle distance at grip of wheels  $Z_1$  and  $Z_2$ : 
$$a_{w12} = \frac{m(z_1 + z_2)}{2} * \frac{\cos \alpha}{\cos a_{12}}; (5)$$

diameter of the main circle of the gear:  $d_{b1} = m z_1 \cos \alpha; (6)$

diameter of the main circle of the wheel:  $d_{b2} = m z_2 \cos \alpha; (7)$

the diameters of the circle of the gear lugs:  $d_{a1} = m(z_1 + 2h_a + 2x_1); (8)$

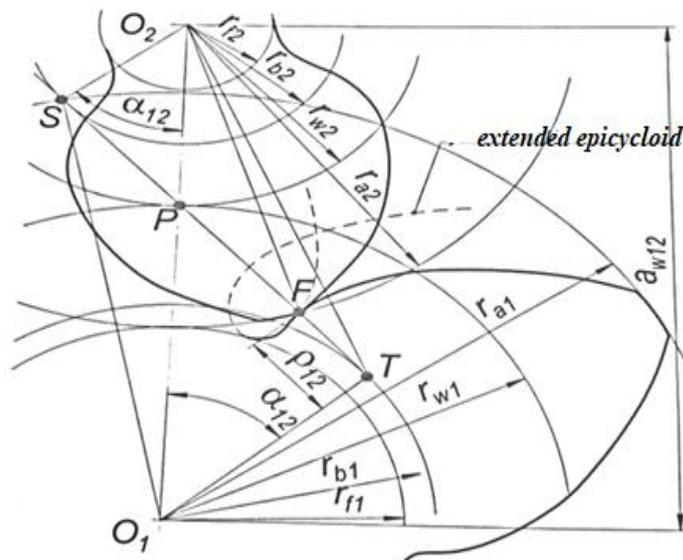
diameters of the circle of the wheel lugs:  $d_{a2} = m(z_2 + 2h_a + 2x_2); (9)$

Interference is the superposition of involute tooth profiles of cut wheels with transition curves. The engagement of the mating gears will be correct if there is no contact of the involute section of the gear tooth profile with the transition curve of the gear tooth, and vice versa. Various methods of checking for interference have been

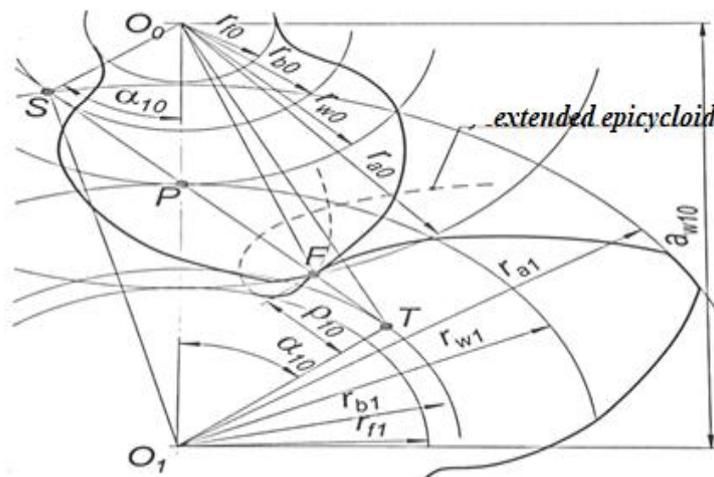
developed, but more often the check of the new sharpening cutter for the absence of interference of the gears cut by the sharpening cutter is performed by checking whether the following two inequalities are observed:

- for gear  $p_{12} \geq p_{10}$ ; for wheel  $p_{21} \geq p_{20}$ ;

where  $p_{12}$  is the radius of curvature of the boundary point of the tooth profile of the gear  $Z_1$  required for normal engagement with the wheel  $Z_2$ ;  $p_{21}$  is the radius of curvature of the boundary point of the tooth profile of the  $Z_2$  wheel, required for normal engagement with the gear  $Z_1$  (Fig 4, if all the indices «2» of the wheel are changed to indices «1» for the gear, and all indices «1» of the gear - to the indices «2» wheels);  $p_{10}$  - radius of curvature of the boundary point of the tooth profile of the gear  $Z_1$  when cutting with a sharpening cutter;  $p_{20}$  - radius of curvature of the boundary point of the tooth profile of the  $Z_2$  wheel when cutting with a sharpening cutter (Fig 5, if to change all indices «1» of the gear on it to indices «2» for the wheel).



**Fig.4. Interference of transition curves with involute profiles of wheel teeth**



**Fig. 5. Cutting a flank of gear or wheel with a sharpening cutter**

Then the features of the absence of interference can be written as:

-for a gear:  $P_{u1} = p_{12} - p_{10} \geq 0$ ; (10)

-for a wheel:  $P_{u2} = p_{21} - p_{20} \geq 0$ ; (11)

To construct the lines of features  $P_{u1}$  and  $P_{u2}$ , we will also vary the displacement  $A$ , but since each value of  $A$  corresponds to its own displacement coefficient of the original contour  $x_0$ , then for each value of  $A$  it must be recalculated. From (4) we get:

$$x_0 = \frac{A \cdot \operatorname{tg} \alpha}{m} \quad (12)$$

Then we will calculate:

- angle of engagement when cutting gear with a sharpening cutter:  $\operatorname{inv} \alpha_{10} = \frac{2(x_1+x_0)}{z_1+z_0} \operatorname{tg} \alpha + \operatorname{inv} \alpha; \quad (13)$

- angle of engagement when cutting wheel with a sharpening cutter:  $\operatorname{inv} \alpha_{20} = \frac{2(x_2+x_0)}{z_2+z_0} \operatorname{tg} \alpha + \operatorname{inv} \alpha; \quad (14)$

- center-to-center distance when cutting a gear with a sharpening cutter:  $a_{w10} = \frac{m(z_1+z_0)}{2} * \frac{\cos \alpha}{\cos \alpha_{10}}; \quad (15)$

- center-to-center distance when cutting a wheel with a sharpening cutter:  $a_{w20} = \frac{m(z_2+z_0)}{2} * \frac{\cos \alpha}{\cos \alpha_{20}}; \quad (16)$

The radii of curvature in formulas (10) and (11) are calculated as follows:

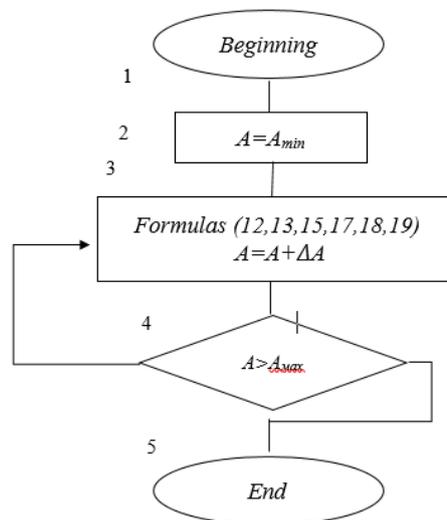
$$p_{12} = a_{w12} * \sin \alpha_{12} - 0,5 \sqrt{a_{a2}^2 - d_{b2}^2} \quad (17)$$

$$p_{10} = a_{w10} * \sin \alpha_{10} - 0,5 \sqrt{a_{a0}^2 - d_{b0}^2} \quad (18)$$

$$p_{21} = a_{w12} * \sin \alpha_{12} - 0,5 \sqrt{a_{a1}^2 - d_{b1}^2} \quad (19)$$

$$p_{20} = a_{w20} * \sin \alpha_{20} - 0,5 \sqrt{a_{a0}^2 - d_{b0}^2} \quad (20)$$

Final algorithm for constructing the line of the feature of the absence of interference of the gear  $P_{u1}$  is shown in Fig 6. The algorithm for constructing the line of the feature of the absence of interference of the wheel  $P_{u2}$  will be similar, only in block 3 the numbers of the formulas will be different, i.e. formulas (12,14,16,19,20). Naturally, for both algorithms the constants must first be calculated



**Fig 6. Algorithm for constructing the line of feature of absence of interference of the gear  $P_{u1}$**

The leaders “Gear interference” and “Wheel interference” (Fig 6) indicate the lines of these features on the screen. In our example, of the three points of intersection of the  $A$  axis by the feature lines, the interference line of the gear  $P_{u1}$  has the smallest value. Therefore, the smallest of these three values must be entered into the “Enter the offset of the original contour  $A = \dots$ ” dialog box, and, if necessary, even with some guaranteed margin for this characteristic.



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**III. CONCLUSION**

Based on analysis the calculation data for gears of various sizes, it can be concluded that such parameters of the being cut tooth wheels, such as the number of teeth of the gear and wheel, the profile angle, have a serious impact on the service life of the disk sharpening cutters.

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