# Gear Grinding With Dish Wheels

Dr. Evgueni I. Podzharov

THIS ARTICLE ANALYZES THE POSSIBILITIES FOR THE SELECTION OF TOOL ADJUSTMENTS TO REDUCE TOOTH PROFILE ERRORS AND RUNNING DISTANCE AND TIME DURING GRINDING OF GEARS WITH DISH WHEELS. THE SELECTION OF PARAMETERS WAS BASED ON THE ANALYSIS OF A GRID DIAGRAM OF A GEAR AND A RACK. SOME FORMULAS AND GRAPHS ARE PRESENTED FOR THE SELECTION OF THE PRESSURE ANGLE. GRINDING OF EXPERIMENTAL GEARS CONFIRM THE THEORETICAL ANALYSIS.

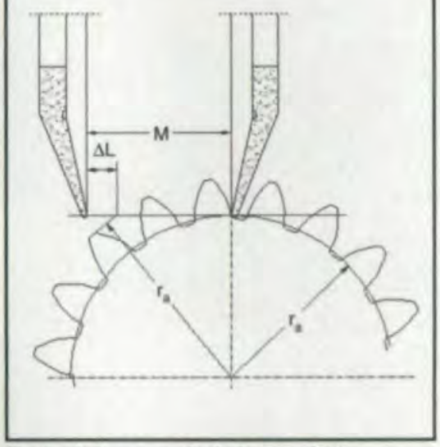


**Fig. 1—0-degree method of gear grinding.**

### Introduction

The grinding of gears with dish wheels (Maag type grinding machines) is widely viewed as the most precise method of gear grinding because of the very short and simple kinematic links between the gear and the tool, and also because the cutting edges of the wheels represent planar surfaces. However, in this grinding method, depending on the parameters of the gears and one of the adjustments (such as the number of teeth encompassed by the grinding wheels), so-called overtravel at the tip or at the root of the teeth being ground generally occurs. When this happens, machining with only one wheel takes place. As a result, the profile error and the length of the generating path increases while productivity decreases.

### Analysis of Grinding Gears With Dish Wheels

The 20-degree method of gear grinding with dish wheels was examined in a previous article (Ref. 1). In that method, the blades of the dish wheels represent part of a 20-degree rack.

Here we shall consider the process of grinding gears with dish wheels using the 0-degree method (Fig. 1). This is more productive than the 20-degree method because of the shorter running distances involved. However, because of the overtravel, the formation of a step form profile error is possible. In Figure 1, $\Delta L$ is the overtravel at the tooth tip, which enlarges the running distance. During this overtravel, a step is formed near the tooth root.

Consider this problem using the grid diagram of gear-tool engagement (Fig. 2a). The grid diagram is constructed for a spur gear with the following parameters: pressure angle $\phi = 20°$, module m = 3.5 mm, number of teeth N = 19, addendum modification coefficient x = +0.5, outside diameter $d_a$=76.78 mm, distance between grinding wheels M = 28.0 mm, which is equal to the span measurement. The coordinates of the grid diagram are described as follows: The ordinate axis represents the actual radius of curvature ρ of the tooth profile; the abscissa axis represents the corresponding length $S=\varphi r_b$ of the arc along the base circle of radius $r_b$, $\varphi$ – arc angle. The inclined lines on the diagram denote the motion of the points of contact of the grinding wheels with the right and left profiles. Here, $\rho_a$, $\rho_m$ and $\rho_l$ are the radii of curvature on the outside diameter, at the points of contact with the wheels during symmetric positioning relative to the

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axis of the centers and at the boundary point of the tooth profile respectively.

Figure 2b shows plots of the normal components of the cutting forces for the right and left profiles, which, as in a previous article (Ref. 2), were proportional to the width of the contact area of the wheel with the tooth being machined. As a result of the effect of normal cutting forces and the deformation of the elastic system, the gear rotates, causing a deviation in the profile. Figure 2c shows this deviation of tooth profile by the addition of the lines in Figure 2b.

As we can see in the diagram of the tooth profile (Fig. 3), which was obtained after grinding such a gear in a Maag-type grinding machine, a step was formed at the root of the teeth. We can see from the diagrams in Figure 2c and Figure 3 that the experimental and theoretical curves are very similar to each other and that the step at the tooth root is caused by the overtravel.

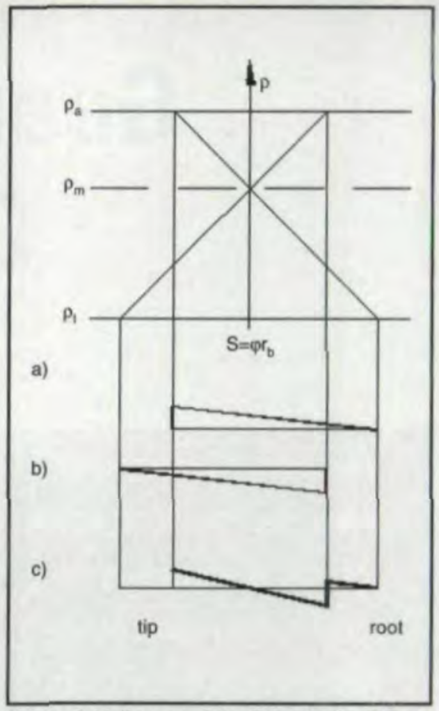


Fig. 2—Grid diagram of the dish wheels. a) Gear teeth engagement, b) Construction of the profile error, c) Theoretical tooth profile error.

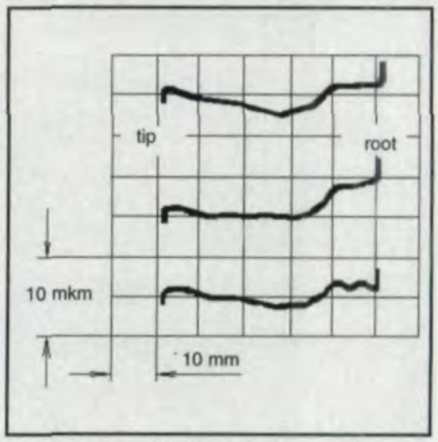


Fig. 3—Tooth profile diagram after grinding by 0-degree method.

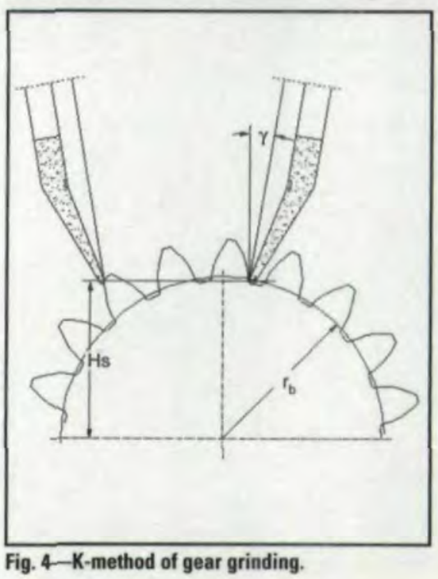


Fig. 4—K-method of gear grinding.

In order to eliminate the problem overtravel during grinding, the Maag Co. (Switzerland) developed the K-method of grinding (Ref. 3). Using the K-method, during overtravel of the tips, the lower edge of the wheels is placed above the axis of the centers at height $H_S < r_b$. During overtravel of the roots, the lower edge of the wheels is placed at height $H_S > r_b$. Quantity $H_S$ was chosen so that at the end of the generating stroke both wheels simultaneously complete grinding on the tips and roots of the teeth. In the first case, the wheels also rotate by a certain angle $\gamma$ in order to complete the grinding of the root section of the tooth.

A shortcoming of this method is that the obtained profile (either a lengthened or shortened involute) differs from the theoretical. Therefore, a mechanism is needed to correct the profile (Ref. 4).

The mentioned shortcomings of the K-method can be eliminated if grinding is carried out using a generating roller with a corrected diameter and an angle of machine tool engagement $\alpha_{0t}$ in the transverse plane. The angle $\alpha_{0t}$ must be determined from the condition of evenness of the number of contacts during gear grinding or a symmetry of the grid diagram (Ref. 5). From the symmetry of this diagram (Fig. 2a) with respect to the line corresponding to the radius of curvature $\rho_m$ of tooth profile we have

$$\rho_a + \rho_l = 2\rho_m \quad (1)$$

From Figure 5 we can find the quantity of $\rho_m$ as

$$\rho_m = 0.5\,(M / \cos\psi_b - d_b\,\alpha_{0t}) \quad (2)$$

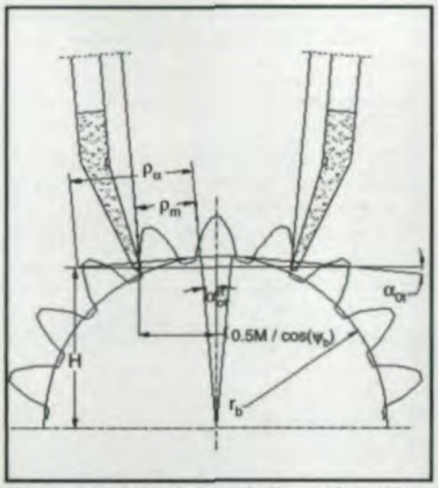


**Fig. 5—$\alpha$-method of gear grinding with positive angle of engagement.**

where $M$ = span measurement of the teeth encompassed between grinding wheels. $\psi_b$ = base helix angle and $d_b$ = base diameter.

Substituting equation (2) in equation (1) we can get

$$\alpha_{0t} = [M / \cos\psi_b - (\rho_a + \rho_l)] / d_b \quad (3)$$

Figure 5 shows a diagram of grinding according to the proposed method. Let us call it the $\alpha$-method when $\alpha_{0t} > 0$. Figure 6 shows the $\alpha$-method when $\alpha_{0t} < 0$. The axes of the grinding wheels are also inclined at an angle $\alpha_{0t}$ to the horizontal axis, and diameter $D$ of the generating roller is determined from the condition of equality of the meshing intervals of the part being machined and the imaginary tool rod according to the known formula

$$D_r = 2r_b / \cos\alpha_{0t} - \delta \quad (4)$$

where $\delta$ is the thickness of the generating strip in mm.

The points of contact of the wheels with the teeth move in the planes of meshing tangent to the base cylinder and inclined at angle $\alpha_{0t}$. For this reason, the length of longitudinal travel of the part during machining by this method is somewhat greater than during machining by the K-method.

It is apparent from Figure 5 that when $\alpha_{0t} > 0$ the wheels must be lowered in comparison with their position during grinding according to the 0-degree method. The setting height of the lower points of the grinding wheels above the axis of the centers is found by considering the diagram in Figure 5

$$H = r_b \cos \alpha_{0t} - \rho_a \sin \alpha_{0t}$$

In similar fashion, when $\alpha_{0t} < 0$ we can find from Figure 6

$$H = r_b \cos \alpha_{0t} + \rho_l \sin \alpha_{0t}$$

We must note that during grinding with positive $\alpha_{0t}$ (Fig. 5), in order to ensure the emergence of the edge of the wheel at the tooth root, it is desirable to carry out undercutting at the tooth roots (filleting), since deeper cutting of the tooth root is required. However, in many cases machining is possible without filleting, since the radial clearance is adequate for emergence of the edge of the grinding wheel.

The proposed method of tooth grinding was checked on the same model

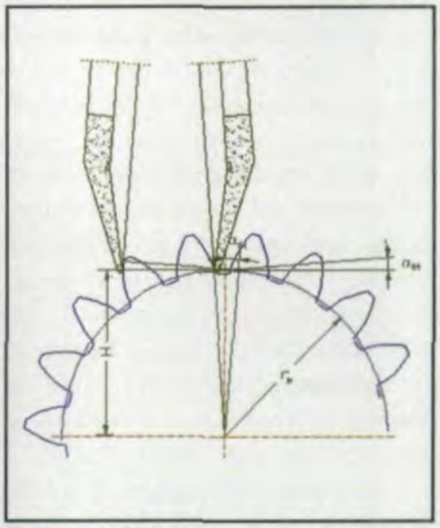


**Fig. 6—$\alpha$-method of gear grinding with negative angle of engagement.**

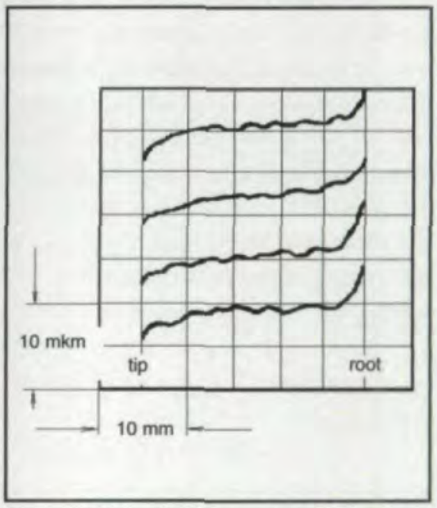


**Fig. 7—Tooth profile diagram after grinding by $\alpha$-method.**

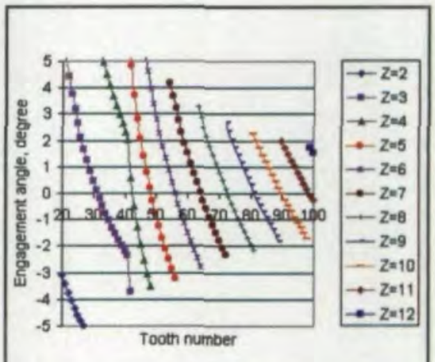


**Fig. 8—Charts for selecting the engagement angle between gear and dish wheels.**

machine tool as the 0-degree method. A gear with the same parameters as above was ground. The calculated parameters were: angle of engagement $\alpha_{0t} = -4.29°$; span measurement $M = 17.6$ mm for the number of teeth $Z = 2$, encompassed between the grinding wheels; generating path $L = (\rho_a - \rho_l) \cos \alpha_{0t} = 22.3$ mm. This was 4.7 mm less than in the 0-degree method of gear grinding in which $L = 2\rho_a - M = 27.0$ mm (in case of 2 teeth between the wheels) and $L = M - 2\rho_l = 28.0$ mm (in the case of 3 teeth between the wheels).

Figure 7 shows diagrams of tooth profiles of the indicated gear, ground according to the proposed method. In this case, the profile error does not have a step at the tooth root.

To determine the angles $\alpha_{0t}$, the charts shown in Figure 8 can be used. Here the values of $\alpha_{0t}$ are plotted as a function of the number of teeth of the gear being ground and the number of teeth Z, encompassed between the grinding wheels. The calculation was made using Equation 3 for standard gears of 20-degree pressure angle, full tooth height and without addendum modification and rounding at the tooth root. From these charts one must select the smallest angle possible, either positive or negative, because of limitations of angle in some models of machine tools with dish wheels and also for shorter length of longitudinal travel. A smaller number of teeth encompassed between grinding wheels gives negative angle and larger number gives positive angle of engagement between gear and grinding wheels. ○

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