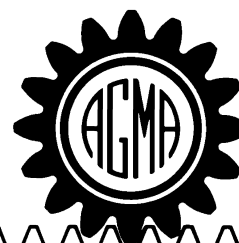


Determining the Shaper Cut Helical Gear Fillet Profile

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American Gear Manufacturers Association



TECHNICAL PAPER

Determining the Shaper Cut Helical Gear Fillet Profile

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

This paper describes a root fillet form calculating method for a helical gear generated with a shaper cutter. The shaper cutter considered has an involute main profile and elliptical cutter edge in the transverse plane. Since the fillet profile cannot be determined with closed form equations, a Newton's approximation method was used in the calculation procedure. The paper will also explore the feasibility of using a shaper tool algorithm for approximating a hobbled fillet form. Finally, the paper will also discuss some of the applications of fillet form calculation procedures such as form diameter (start of involute) calculation and finishing stock analysis.

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1 Introduction

Analytical methods for determining the gear fillet profile (trochoid) have been well documented. Khiralla [1] described methods for calculating fillet profile of hobbed and shaped spur gears. Colbourne [2] provided equations for calculating the trochoid of both involute and non-involute gears generated by rack or shaper tools. The MAAG Gear Handbook [3] also provided equations for calculating trochoid generated with rack type tools that have circular tool tips. Vijayakar, et al. [4] presented a method of determining spur gear tooth profile using an arbitrary rack. The above mentioned are only samples of many published works. However, the method for determining the trochoid of a helical gear generated with a shaper tool is not widely published. This paper presents an intuitive algorithm where the fillet profile of a shaper tool generated external or internal helical gear can be calculated.

A shaper tool generating a gear can be visualized as a gear set meshing with zero backlash. The algorithm in this paper is based on a shaper tool in tight mesh with a semi-finished helical gear. The semi-finished gear geometry was used for calculation because the shaper tool, used as the semi-finishing tool, is usually the one that generates the trochoid. However, if the shaper cutter is the finishing tool, the algorithm presented will also work by letting the finishing stock equal zero. The trochoid of a spur gear can also be calculated by letting the helix angle equal zero.

The shaper tool used in this algorithm may have a different reference normal pressure angle than that of the gear. A necessary condition for a shaper tool to generate the correct involute profile on a gear is that both the tool and the gear must have equal normal base pitch. This paper stipulates that the axis of the shaper tool and the gear are parallel, which is often true for gear shaping. Consequently, the shaper tool and the gear must also have an equal base helix angle.

Although, the algorithm is based on the shaper cutter as a generating tool, the presented method

can also be used to calculate a trochoid generated with a hob or a rack type tool if the number of the shaper teeth is large (e.g. 10000).

2 Symbols and Convention

The symbols are defined where first used. This paper tries to adhere to the following rules in subscript usage:

- Symbols related to tool geometry have subscript "0";
- No subscript is used for symbols related to the gear;
- Subscript "n" is used for measurements in the normal plane;
- Subscript "r" is used for symbols related to the semi-finished gear
- Subscript "g" is used for symbols related to the generating pitch circle

When dual signs are used in an equation (e.g. $\pm$), the upper sign is for external gears and the lower one for internal gears.

Non-italicized upper case symbols are used to designate points on the shaper tool, the gear, or other points of interest. Points are also represented as the coordinates (x, y). The length of a vector (e.g. R) is represented as $\|R\|$.

3 Coordinate System

The reference position of a shaper tool generating a gear is depicted in Fig. 1, for external gear shaping, and Fig. 2, for internal.

The following coordinate system and sign conventions are followed:

- Standard Cartesian coordinate system is used. The center of the shaper tool O_0 is (0, 0).
- The reference position of the shaper tool is with one of its teeth aligned with the y-axis. The end of the shaper tooth points in the $-y$ direction.

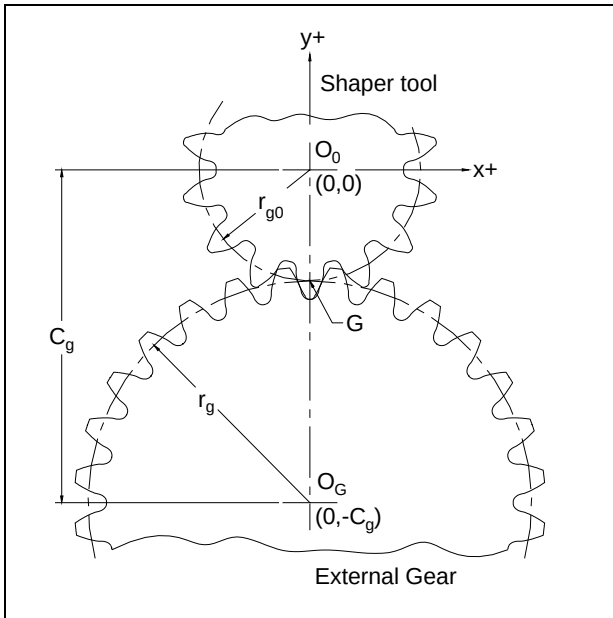


Fig. 1 Shaping an external gear

- The center of the gear, O_G , is also on the y -axis with one of the tooth spaces aligned with the y -axis. The opening of the tooth space is in the $+y$ direction.
- Angular measures, related to tool or gear rotation or location of a point, are signed. CCW rotation from the reference line is positive, and CW, negative.

4 Shaper Tool and Gear Geometry

The following are required tool and gear data for calculating the trochoid:

Shaper tool data:

- P_{nd0} is the ref. normal diametral pitch, tool (in^{-1})
- n_0 is the number of teeth, tool
- ϕ_{n0} is the ref. normal pressure angle, tool
- ψ_0 is the ref. helix angle, tool
- s_{n0} is the ref. normal circular thickness, tool (in)
- d_{a0} is the outside diameter, tool (in)
- ρ_0 is the tool tip radius (in)
- δ_0 is the protuberance (in)

Gear data:

- P_{nd} is the ref. normal diametral pitch, gear (in^{-1})
- n is the number of teeth, gear
- ϕ_n is the ref. normal pressure angle, gear

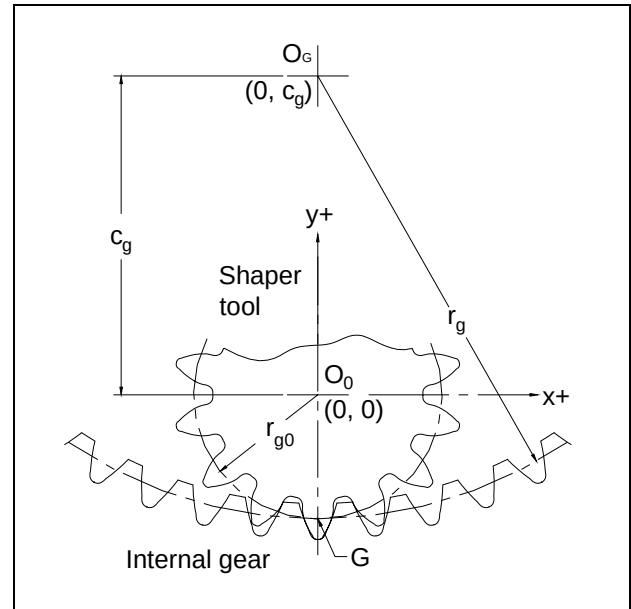


Fig. 2 Shaping an internal gear

- ψ is the ref. helix angle, gear
- s_n is the ref. normal circular thickness, gear (in)
- μ_s is the stock allowance per flank, gear (in), defined on the reference pitch circle (not along the base tangent).

4.1 Basic Shaper Tool and Gear Geometry

The following equations calculate the basic tool and gear geometry:

Standard transverse pressure angle of tool, ϕ_0

$$\phi_0 = \arctan\left(\frac{\tan \phi_{n0}}{\cos \psi_0}\right) \quad (1)$$

Standard reference pitch radius of tool, r_0 (in)

$$r_0 = \frac{n_0}{2P_{nd0} \cos \psi_0} \quad (2)$$

Base radius of tool, r_{b0} (in)

$$r_{b0} = r_0 \cos \phi_0 \quad (3)$$

Ref. transverse circular thickness of tool, s_0 (in)

$$s_0 = \frac{s_{n0}}{\cos \psi_0} \quad (4)$$

Transverse base pitch of tool, p_{b0} (in)

$$p_{b0} = \frac{2\pi r_{b0}}{n_0} \quad (5)$$

Normal base pitch of tool, p_{nb0} (in)

$$p_{nb0} = \frac{\pi \cos \phi_{n0}}{P_{nd0}} \quad (6)$$

Base helix angle of tool, ψ_{b0}

$$\psi_{b0} = \arccos\left(\frac{p_{nb0}}{p_{b0}}\right) \quad (7)$$

Base circular thickness of tool, s_{b0} (in)

$$s_{b0} = 2r_{b0} \left(\frac{s_0}{2r_0} + \text{inv} \phi_0 \right) \quad (8)$$

where

inv is the involute function of an angle

$$\text{inv} \alpha = \tan \alpha - \alpha$$

Standard reference pitch radius of gear, r (in)

$$r = \frac{n}{2P_{nd} \cos \psi} \quad (9)$$

Base radius of semi-finished gear, r_{br} (in)

$$r_{br} = r_{b0} \frac{n}{n_0} \quad (10)$$

The helix angle at standard pitch radius of semi-finished gear, ψ_r

$$\psi_r = \arctan\left(\frac{r \tan \psi_{b0}}{r_{br}}\right) \quad (11)$$

Transverse pressure angle at reference pitch radius of semi-finished gear, ϕ_r

$$\phi_r = \arccos\left(\frac{r_{br}}{r}\right) \quad (12)$$

Transverse circular thickness of semi-finished gear, s_r (in)

$$s_r = \frac{s_n + 2\mu_s}{\cos \psi_r} \quad (13)$$

Base circular thickness of semi-finished gear, s_{br} (in)

$$s_{br} = 2r_{br} \left(\frac{s_r}{2r} \pm \text{inv} \phi_r \right) \quad (14)$$

4.2 Center of Tool Tip on a Shaper Tool

A shaper tool for gear semi-finishing usually has protuberance. It generates undercut on a gear, so that the finishing tool only needs to machine the involute profile of the gear. To obtain the designed amount of protuberance on a shaper tool, the tool tip is made tangent to the involute profile that is temporarily formed by increasing the shaper tooth thickness to include the protuberance (Fig. 3). The tangent point, common to the tool tip and the involute profile, will be referred to as the profile tangent point, P_0 . When the temporarily formed involute profile is removed, the shaper tool will have the designed amount of protuberance.

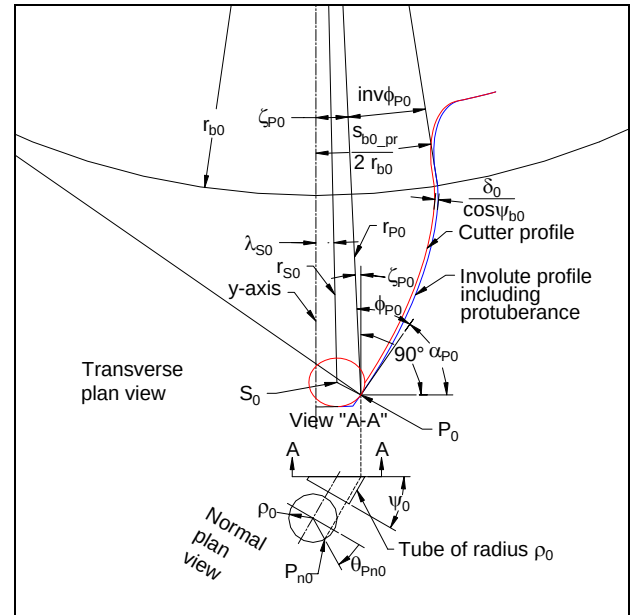


Fig. 3 Tool tip of a shaper tool

The shaper tool tip is also made tangent to the outside diameter of the tool (Fig. 4) so that the transition from the outside diameter to the tool tip will be smooth. The common tangent point on the

