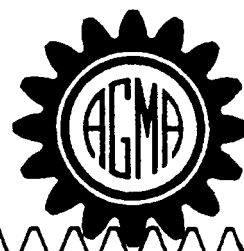


# Study of Effect of Machining Parameters on Performance of Worm Gears

by: Anand Narayan, Xerox Corporation, Donald Houser  
and Sandeep Vijayakar, Ohio State University

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American Gear Manufacturers Association



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## TECHNICAL PAPER

# Study of Effect of Machining Parameters on Performance of Worm Gears

**Anand Narayan, Xerox Corporation, Donald Houser and Sandeep Vijayakar,  
Ohio State University**

[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 studies the effect of machining parameters on the performance of worm gears using a special purpose finite element technique. Algorithms are presented to determine the worm and gear geometries by simulating the grinding action of the grinding wheel and the cutting action of the hob. Results are presented delineating the effect of machining parameter such as the hob oversize, hob swivel angle, profile modification etc., on performance parameters such as the size and location of contact zone on the gear tooth, contact stresses, root stresses, load distribution and transmission error. Results are also presented on the effect of load on transmission error of worm gears.

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## Effect of Machining Parameters on Performance of Worm Gears

Anand Narayan  
Xerox Corporation  
800 Phillips Road, 147-54A, Webster, NY 14580

Sandeep M. Vijayakar  
Advanced Numerical Solutions  
2085 Pine Grove Lane, Columbus, OH 43232

Donald R. Houser  
Professor, Dept. of Mechanical Engineering  
The Ohio State University, Columbus, OH 43210

### Introduction

Some of the earliest work on worm gears was done by Dudley & Poritsky[1,2]. They showed how the shape of a worm produced by a given cutter could be computed and conversely how to determine the cutter shape to produce a desired worm shape. Buckingham[3,4] categorized worms on the basis of the cutting process. Janninck[5] used a simplistic model to determine the separation contours between the worm and gear surfaces. studied the effect of hob oversize and swivel angles on the separation contours and compared two different hob design concepts viz. axial pitch design concept and normal pitch design concept. Colbourne[6] used a different model for predicting the separation contours and studied the effect of hob oversize and hob swivel angle on the separation contours and proposed a new method for hob design viz. base pitch design concept. Octrue[7] determined the line of contact by simulating the cutting process and used a simple extension of the two dimensional beam model to determine the stiffness along the line of contact. Assuming equal deformation at all points along the line of contact and using the Hertzian theory of cylindrical contact he determined the load distribution and contact pressure without taking into consideration the frictional effects. Advances in three-dimensional contact analysis made it possible to consider the frictional forces in the analysis. However conventional finite element techniques require a very highly refined mesh. due to the fact that the contact zone is extremely small as compared to the other dimensions of the gear. Vijayakar et al[8,9,10] overcame this problem by developing a special type of element called

finite quasi prismatic element which uses a combination of the finite element model and the Bousinessq-Cerruti surface integral solution to compute the compliance matrix and makes it possible to accurately define the worm and gear geometries with fewer elements. This method has been implemented in the Contact Analysis Program Package (CAPP). This technique has been used by Singh[11] to study spur and helical gears. Vaidyanathan[12] to study bevel and hypoid gears and by Singh et al[13] to study off-line of action at the tips of helical gear teeth. The finite quasi prismatic element technique has been used in this study to determine the effect machining parameters on the performance of worm gears.

### Generating Worm and Gear Geometry

The different types of worms are classified on the basis of the cutting process. A screw-helicoid worm is cut by a straight sided tool on a lathe with the cutting edges of the tool lying in the axial plane of the worm. A chased-helicoid worm is produced if the cutting edges lie in the normal plane of the worm. A thread-milled helicoid worm is produced by a double conical vee shaped grinding wheel. Involute-helicoid worms are produced by using a special dressing on the grinding wheel. Hobbing and roll forming are mass production methods of producing involute-helicoid worms. Thread-milled and involute worms are the more common types. The procedure to generate the geometry of thread-milled worms from the grinding wheel geometry is described below. A similar procedure can be used for the other types of worms.

The grinding wheel can be described as two truncated cones stuck end to end with a cylindrical portion in between the cones. Fig. 1 shows the

enlarged view of the grinding wheel cutting section. There are three cutting regions on the grinding wheel as indicated in Fig. 1. The regions AB and CD cut the profile of the worm whereas the region BC cuts the root of the worm. Let  $r_o$  be the outer radius of the grinding wheel,  $f_o$  be the thickness at the tip and  $p_a$  be the pressure angle of the grinding wheel. Let "s" be a variable which varies along the surface of the grinding wheel in the direction of the arrows in Fig. 1. "s" has a value of zero at point C and a value of  $-f_o$  at point B. Then the position vectors and normal vectors for the three regions can be defined in terms of "s" as follows:

Region AB:

$$\begin{aligned}x_t &= r_o + (s + f_o) \cos(p_a) \\y_t &= 0 \\z_t &= -f_o/2 + (s + f_o) \sin(p_a) \\x_{nt} &= \sin(p_a) \\y_{nt} &= 0 \\z_{nt} &= -\cos(p_a)\end{aligned}\quad (1)$$

Region BC:

$$\begin{aligned}x_t &= r_o \\y_t &= 0 \\z_t &= s + f_o/2 \\x_{nt} &= 1 \\y_{nt} &= 0 \\z_{nt} &= 0\end{aligned}\quad (2)$$

Region CD:

$$\begin{aligned}x_t &= r_o - s \cos(p_a) \\y_t &= 0 \\z_t &= f_o/2 + s \sin(p_a) \\x_{nt} &= \sin(p_a) \\y_{nt} &= 0 \\z_{nt} &= \cos(p_a)\end{aligned}\quad (3)$$

where  $x_t$ ,  $y_t$  and  $z_t$  represent the position vectors of any point in the grinding wheel reference frame and  $x_{nt}$ ,  $y_{nt}$  and  $z_{nt}$  represent the normal vectors.

To convert a point on the grinding wheel to a point on the worm a series of transformations is applied to account for the following machine motions.

1. Rotation of grinding wheel about its axis
2. Tilt of grinding wheel to account for the lead angle of worm
3. Center distance transformation

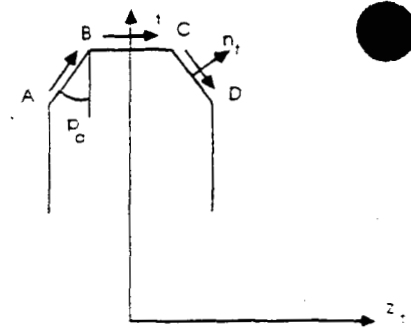


Figure 1 : Grinding Wheel Cutting Section

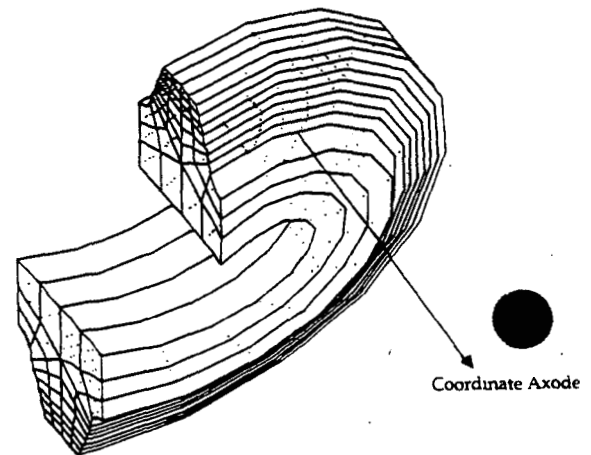


Figure 2 : Worm Tooth Generated

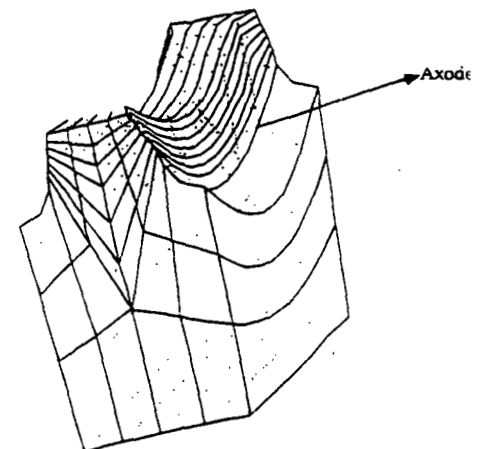


Figure 3 : Gear Tooth Generated