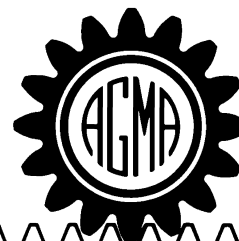


Bevel Gear Model

by: T. Krenzer

American Gear Manufacturers Association



TECHNICAL PAPER

Bevel Gear Model

Ted Krenzer

[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

The paper presents a method for developing an accurate generic bevel gear model including both the face milling and face hobbing processes. Starting with gear blank geometry, gear and pinion basic generator machine settings are calculated. The contact pattern and rolling quality are specified and held to the second order in terms of pattern length, contact bias and motion error. Based on the setup, a grid of tooth points are found including the tooth flank, fillet and, if it exists, the undercut area. It is proposed as the model for the next generation of bevel gear strength calculations in that the procedure produces true bevel gear geometry, uses blank design parameters as input and is vendor independent except for cutter diameter.

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American Gear Manufacturers Association
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Alexandria, Virginia, 22314

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Ted Krenzer

For over a hundred years bevel gear tooth strength has been approximated using virtual spur gears. The calculation has adequately served the gear industry. However with new high speed computers, strength estimates should be based on a more realistic model. Recognizing the need for improved bevel and hypoid strength calculations, finite element and boundary element strength programs based on bevel gear geometry have been developed. Most notable is Dr. Lowell Wilcox's finite elements stress TCA (tooth contact analysis). Input to these programs is the actual machine settings and cutter specifications as defined by vender calculations. This is an excellent check on the strength of designed sets. However the engineer must complete the entire design process and depend on vender software for input data before a true strength analysis can be made.

In this paper a generic bevel gear tooth model that can be the next generation gear tooth strength model is developed. Input is basic gear design parameters. Therefore calculations can be made at the beginning of design process. Output is basic generator machine settings that can be used to calculate a grid of pinion and gear points including fillet and undercut points so that finite element or boundary element as well as conventional analysis can be applied. The only vender input required is cutter diameter, blade edge radius and number of blade groups. Either the face milling (FM) or face hobbing (FH) generating method can be used.

The settings produce specified tooth surfaces to the second order. Procedures for calculating tooth surface points as well as fillet points are included. Separate pinion setups for the drive and coast sides, rather than completing setups, are calculated. This is partly done so as not to provide generation methods that compete with vender calculations. Due to length constraints not all formulas can be included. A complete set of formulas can be found in the author's book titled 'The Bevel Gear'.

Basic generator

The basic generator is configured with a machine base that carries a generating head and a work

head mounted on its horizontal face with the offset perpendicular to the horizontal face.

The generating head has a cradle that carries the face mill cutter whose axis is offset from the cradle axis by an adjustable radial distance, S , set at an angle, q , from the horizontal direction. The cutter, which has a radius, r_{cP} , and a pressure angle, ϕ_b , can have its axis tilted by an angle, i , relative to the cradle axis. The direction of the cutter tilt angle is referenced relative to a perpendicular to the radial distance by the swivel angle, j . The cutter phase angle, θ_G , about the cutter axis (not shown) is from the direction of tilt to the contact point.

The work head holds the work in a spindle with its axis the in horizontal plane. The work head is rotated by the angle, γ_m , about the offset line that intersects the cradle axis. The work is adjusted a distance, X_p , along its axis and a distance, E_m , in the offset direction. The work head also is adjusted a distance, X_B , along the cradle axis.

A timed roll relationship between the cradle and work, R_a , is set. For face hobbing an additional timed roll relationship between the cutter and the work is added. The basic generator configuration is shown in Figure 1.

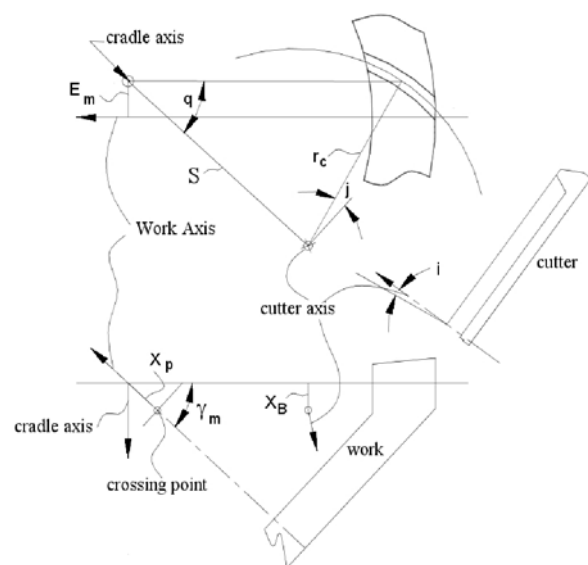


Figure 1. Basic generator configuration

Generating processes

With face milling, the generator is setup so that the cutter produces the desired spiral and pressure angles and the cutter blade tips follow the root line. Cutter blades rotate through the work piece, producing a slot as the generator and work rotate together to generate the tooth surface. The cutter is withdrawn, the work piece is indexed and cycle is repeated. See Figure 2.

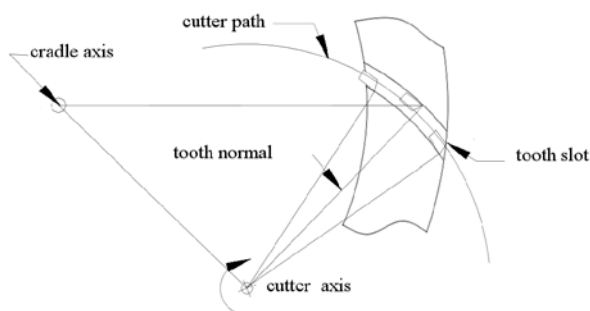


Figure 2. Face milling cradle/cutter setup

With face hobbing, the generator is setup to follow the root line and produce the desired spiral and pressure angles taking into account the continuous indexing motion. Cutter blades are arranged in groups with the work indexing one tooth as each blade group passes through the cut. The indexing motion is superimposed on the generating process. All teeth are formed in a continuous cycle. The lengthwise tooth form is a kinematic curve. See Figure 3.

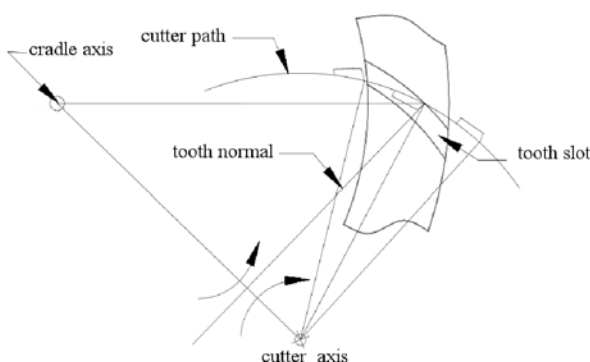


Figure 3. Face hobbing cradle/cutter setup

Generator vector model

The coordinate system is defined with the $\mathbf{i}$ vector in the machine horizontal plane pointing to the right. The $\mathbf{j}$ vector is along the machine vertical axis point-

ing up. The $\mathbf{k}$ vector points out in the direction of the cradle axis. Figures 4 and 5 show a vector setup of the generating machine as defined below.

Unit vector along the cradle axis

$$\mathbf{g} = (0, 0, 1)$$

Unit vector in the offset direction

$$\mathbf{e} = (0, 1, 0)$$

Unit vector along the pinion axis

$$\mathbf{p} = (-\cos \gamma_m, 0, -\sin \gamma_m)$$

Vector from machine center to cutter center

$$\mathbf{S} = S (\cos q, -\sin q, 0)$$

Unit vector along the cutter axis

$$\mathbf{c} = (-\sin i \sin j, \sin i \cos j, \cos i)$$

Cutter radial unit vector

$$\mathbf{r} = (-\cos i \sin j, \cos i \cos j, -\sin i)$$

Unit vector along the cutting element

$$\mathbf{t} = [\sin(\phi_b - i) \sin j, -\sin(\phi_b - i) \cos j, \cos(\phi_b - i)]$$

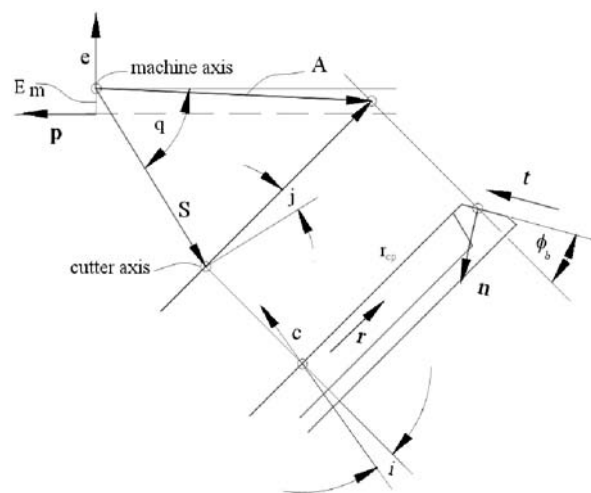


Figure 4. View looking along cradle axis

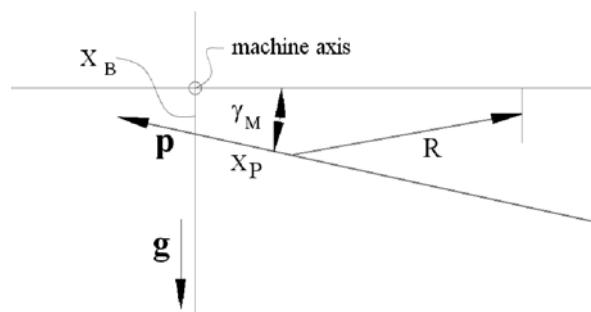


Figure 5. View looking down on generator