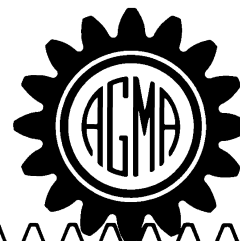


Straight Bevel Gear Cutting and Grinding on CNC Free Form Machines

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American Gear Manufacturers Association



TECHNICAL PAPER

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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

Manufacturing of straight bevel gears was in the past only possible on specially dedicated machines. One type of straight bevel gears are the gears cut with a circular cutter with a circumferential blade arrangement. The Machines and the gears they manufacture have the Gleason trade name Coniflex®. The cutters are arranged in the machine under an angle in an interlocking arrangement which allows a completing cutting process. The two interlocking cutters have to be adjusted independently during setup which is complicated and time consuming.

The outdated mechanical machines have never been replaced by full CNC machines but there is still a considerable demand in an high variety of low quantities of straight bevel ears. Just recently it was discovered that it is possible to connect one of the interlocking straight bevel gear cutter disks to a free form bevel gear generator and cut straight bevel gears of identical geometry compared to the dedicated mechanical straight bevel gear generator. A conversion based on a vector approach delivers basic settings as they are used in modern free form machines. The cutter is mounted to a shaft which is connected to the cutter spindle. Additional features like reverse cutter mounting, vector feed and root limited roll finally enabled the straight bevel cutting process on modern free form machines.

The advantages are quick setup, high accuracy, easy corrections and high repeatability. Because of the use of a single cutter disk, it will be possible to grind Coniflex bevel gears on standard free form grinding machines. The grinding technology of straight bevel gears whose geometry bases on an interlocking cutter system is being developed in the next development step.

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Introduction

Manufacturing of straight bevel gears was in the past only possible on specially dedicated mechanical machines. Such machines are by nature difficult to set up with limited ability to precisely repeat the setup. Mechanical machine setup has been historically slow and time consuming. New developments allow the use of the straight bevel gear cutting system known as Coniflex® on the Phoenix free form machine. This patent pending methodology takes advantage of the Phoenix free form flexibility and reduces setup time to a minimum while applying the Coniflex cutting system used previously on mechanical machines.

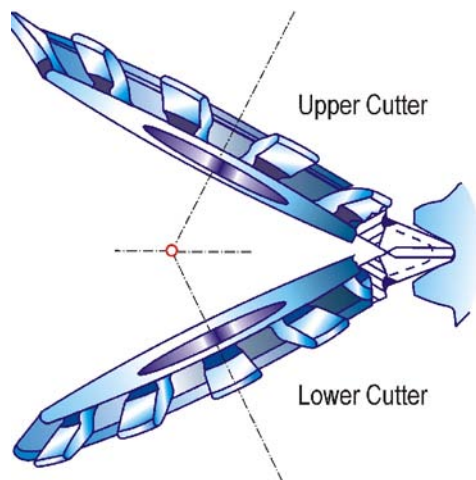


Figure 1. Interlocking Coniflex® cutters

Coniflex straight bevel gears are cut with a circular cutter with a circumferential blade arrangement. The Coniflex cutters are arranged in the machine under an angle of e.g. 24° to a plane which is perpendicular to the generating plane or cradle plane. The upper cutter disc is inclined to point down with the cutting zone of the blades and the lower cutter is inclined to point up (**Figure 1**). The blades of the lower cutter move through the gaps between the blades of the upper cutter while rotating (and vice versa). This pair of cutter disks and the arrangement in the cutting machine is called interlocking cutter system.

The upper cutter cuts the upper flank only and therefore is equipped with blades that have their cutting edges towards the top of the figure. The lower cutter in turn cuts the lower flank and is equipped with blades that have their cutting edges towards the bottom of the figure. The two cutters generate a combination of profile and length crowning in the flank surfaces. A side effect of the cutter arrangement is a curved root line, depending on the cutter diameter.

The two cutters represent one tooth of a generating gear which subsequently requires the setup possibilities for a variety of job designs. The cutters can be moved away from the center of the cradle to achieve a certain mean cone distance. Since the Coniflex flank line tangents point to the pitch apex, it is necessary to adjust the angle of the flank line tangent with the so called space angle. To control the slot width using existing cutters the cutters can independently be shifted apart or towards each other. Some Coniflex machines allow an additional freedom to adjust both cutters in order to modify the length crowning (swing angle). Coniflex is a completing process which, compared to spiral bevel gear wet cutting is considered a rather fast process. **Figure 2** shows a Gleason No. 2A Coniflex generator with the interlocking cutters engaged in a slot of a ring gear.

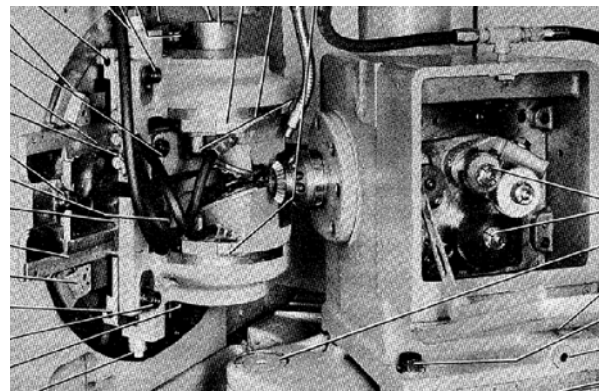


Figure 2. View into the work chamber of a Gleason No. 2A Coniflex® Machine

In case of a 20° pressure angle system and a tilt angle of 20° for each cutter the planes of the cutter disks would generate flank surfaces which consist of precise spherical involutes. However, also in straight bevel gears a located flank contact is desired which lead to a modified cutter and cutter tilt design. If in the case of a 20° pressure angle system the tilt angle of the cutter disks is 24° and the cutting edge, rather than being part of the cutter disk plane, form an internal cone of 86° cone angle ($90^\circ - 4^\circ$), then the internal cone generates a certain length crowning. This effect in connection with curved cutter blades is used to produce the crowning in straight bevel gears. As mentioned before, it is always a pair of cutters, one left hand and one right hand cutter, required to realize the interlocking arrangement in the cutting machine in order to cut both flanks of a slot at the same time.

There is still a considerable demand for straight bevel gears and machines for their manufacturing. However, there was never a full CNC machine developed to satisfy the present demand. Manufacturers of straight bevel gears were relying on remanufactured mechanical machines, some of which are equipped with partial CNC functions like cradle roll, sliding base, ratio of roll and indexing. The reason why no Coniflex CNC free form machine was designed becomes evident after studying the geometrical concept in Figure 2. It is not possible to utilize a 6-axis machine because of the double tilted cutter spindles and the interlocking cutter arrangement. To configure a regular 6-axis free form machine with the Coniflex double spindle head including an automated head setup would have introduced 6 additional axes with complicated setup actuators. The cost to build such a machine is between 150 and 200% of a regular today's Phoenix® II free form generator.

Motivation of Coniflex cutting on free form machines

Manufacturers of straight bevel gears are processing mostly low quantities and a high variety of different designs. The applications are differential gears for special equipment, electrodes for forging dies and powder metal dies, machine tool applications etc. The demand for higher quality straight bevel gears has been raised together with the desire to apply a defined hard finishing method such as grinding.

Manufacturers with a high job variety and many changeovers between jobs would invest in a modern machine tool for their straight bevel gear needs if it was also possible to put the machine to different uses e.g. to cut spiral bevel gears. A six axis free form machine can present a tool in every desired position and angular inclination to a work. This is the basis for the ideas that realized Coniflex cutting on Phoenix free form machines. It is only possible to use one cutter which makes the completing process "semi completing". The cycle time is still acceptable since the free form machine with direct spindle motors indexes extremely fast and since the higher stiffness of a Phoenix machine allows a cycle of rapid plunge and limited roll.

There are additional features like independent correction of upper and lower flank (even using different ratio of roll, root angle, tilt angle and more), summary storage and fast setups and the possibility to implement cutter disks with carbide tips, that would allow a high speed dry cutting of Coniflex gear sets.

Conversion of Coniflex® summaries to Phoenix®II machines

Coniflex summaries which have been calculated for the Gleason machine Nos. 2A, 102, 104 and 114 can be converted to general basic settings in order to perform Coniflex cutting on Phoenix II free form machines. The procedure that has been developed follows the list of steps below:

- ◆ Conversion of Coniflex summary into general basic settings
- ◆ Conversion of upper and lower Coniflex cutter separately
- ◆ Transformation of basic settings into free form motions
- ◆ Reverse mount Coniflex cutter on the free form machine to avoid too negative machine root angles
- ◆ Rolling of root only to the bottom of the involute (avoids undercut and reduces negative machine root angle), rolling face like on Coniflex machine
- ◆ Calculate work phase angle set over between upper and lower cutting in order to manufacture correct slot width
- ◆ Use vector feed to allow cutting slot from solid with outside blades only (no alternating blades)