Conclusions

The computational model allows to determine basic dimensions of both nuts and return elements, and also dimensions of the screw thread, with according to determined designing criteria.

Thanks to integrating of the three applications - data are passed to SOLIDWORKS without conversion, and pictures that are received can be immediately verified, edit or – by running the program again with changed entrance parameters – make now.

The above integrated application makes designing and making a specification sheet out of ball screw much faster.

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VIRTUAL MODEL OF 6-AXIS CNC SPIRAL BEVEL AND HYPOID MILLING MACHINE

CNC машина механізму похилої поверхні спіралі, керована в 6-осях, була проаналізована в цій статті. CNC машини дозволяють вирізувати спіраль і гіпоїдні косі механізми незалежно від різальної системи, з індексацією або без індексації. Віртуальну модель 6-осної CNC машини було створено.

Ключові слова – CNC машина, мпіральний механізм, віртуальна модель

The CNC spiral bevel gear machine controlled in 6-axis has been analyzed in this paper. The CNC machines allow to cut spiral and hypoid bevel gears independently of the cutting system, with indexing or without indexing. Virtual model of 6-axis CNC machine was created.

Keywords – CNC machine, spiral gear, virtual model

Introduction

Conventional bevel gears machine include two main components: a cradle, which hold a milling cutter head and carries it along a circular path and work support, which orients the work-piece relative to the cradle and rotates it at a specified ratio to the cradle rotation.

Conventional machine are usually equipped with a series of linear and angular scales which assist the operator in accurately locating the various machine components in their proper position. The eight settings is useful to measure the rotational position of the work about its own axis from some reference. Also, in the case of face-hobbing, the rotary position of the hob about own its axis may be of interest (two settings). Combined together, these ten parameters totally describe the relative positioning between tool and work at any instant. Three of them (cradle angle, work rotation, cutter head rotation) change in the process of generation, while the other seven settings are usually remain fixed.

CNC machine, the universal bevel gear generator is guided by a controller which continuously issues positioning commands to the various machine axes. The six independent orthogonal coordinates (X, Y, Z, A, B and C) provide direct method for positioning the tool (cutter head) and work-piece. There are six mechanical freedoms, as opposed to the ten freedoms found on conventional machine. The model is defining by vectors along the work-piece and tool (cutter heard) axes and the vector from the tool seat to the point on the work axis which lies directly above the swinging base point and are translated by a series of equations.

Conventional machine

A conventional machine for spiral and hypoid bevel gears has two units: cradle unit and work unit mounted on the machine frame. The cradle unit is equipped with a tool spindle, and depending on machine construction, the cutter axis is fixed parallel to cradle axis. The cradle unit includes the modified roll mechanism or the special mechanism allowing to tilt it. The schematic of conventional machine with tilted cutter axis is shown on figure 1. The machines with cutter tilt unit are very often equipped with modified roll mechanism. It means, that such machine allows using all technological methods for generating gears and format gears.

The eight settings determine relative position of the cradle and work-piece in the machine space and these settings do not change during the cutting process. The remaining settings determine the kinematics of generating process. It is necessary during a generation process to change the following settings: cradle angle as a result of rolling motion and accordingly to this ratio of roll, pinion rotation. If it is done under continuous cutting (face hobbing), than the index ratio controls this relation between number of group of cutter blades and number of teeth in opposite to single indexing cutting. The index ratio independently of face hobbing or face milling has no influence on the generating motion (tooth profile).

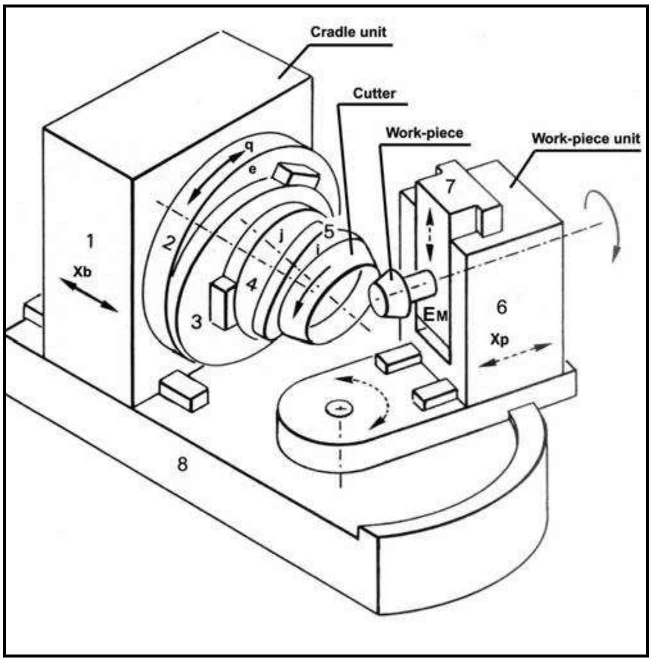

Figure 1. Conventional machine [4]: 1- cradle units, 2 – cradle, 3 – eccentricity, 4 swivel angle, 5 - cutter spindle rotation angle, 6 – work-piece unit, 7 – blank offset, 8 – frame

Basic technological settings

Based on the analysis of basic technological setup for machines with cutter axis tilt as a general solution (Figures 2), it is necessary to define at the beginning some important points. Point OM is the machine center. Point OG is on the cutter axis at the plane tangent to the top of blades. Point OP is located on the pinion (gear) axis and is the top point of pitch cone. These three points allow to define the following settings:

- cradle angle ***q*** in the XY plane (cradle plane) defined by radial setting ***U*** and X axis,
- radial setting ***U*** as a distance in the cradle plane (XY plane) from machine center O_M to cutter center O_G,
- swivel angle ***j*** which defines the direction of cutter axis tilt. This angle is determined as a projection angle on the cradle plane and lies between perpendicular plane to the radial setting O_MO_G and the plane λ in which the cutter axis is tilted.
- cutter spindle rotation angle, tilt angle ***I*** formed by cutter axis which lies on the λ plane and cradle axis.
- root angle δ_M in the horizontal (XZ) plane formed by work axis and cradle plane XY.
- work offset a_M as the distance between the cradle axis and work-piece axis. This distance is measured up or down to machine center O_M.
- head setting X_P the distance in the XZ plane measured along work axis between O_P point and O_{PM}. Point O_{PM} is the crossing point of work axis and parallel line to the Z axis in a_M distance and perpendicular to Y axis.
- sliding base X_b as a distance between machine center O_M and point O_{PM} in perpendicular direction to the cradle plane.

These values determine the virtual machine settings as linear and angular parameters and describe the relative geometric positioning between cutter head and work-piece. The virtual machine settings should be completed in the kinematic relations between cutter and work-piece for the hobbing and milling methods, first: as the rotational position which complies the ratio of roll motion, second: as the rotational relation between number of blade groups of cutter and number of teeth for continuous indexing (hobbing method). For the methods when the cradle motion is fixed (Formate), the virtual machine settings are described only by eight geometric parameters.

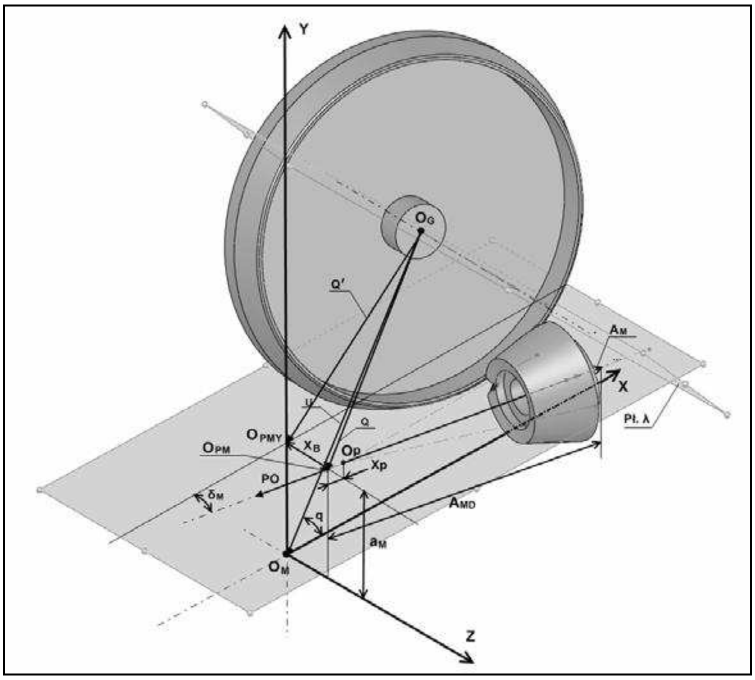

Figure 2: Isometric view of basic technological setup

Virtual model of 6-axis CNC machine

Generally, the work space of CNC cutting machines is determined by the Cartesian coordinates. The number of coordinates depends on number of axes which are necessary to note the relation between tool and work-piece. For the CNC bevel gear machine six independent coordinates describe the relative position between the cutter head and work-piece. The schematic drawing of the 6-axis CNC bevel gear machine is shown on Figure 3.

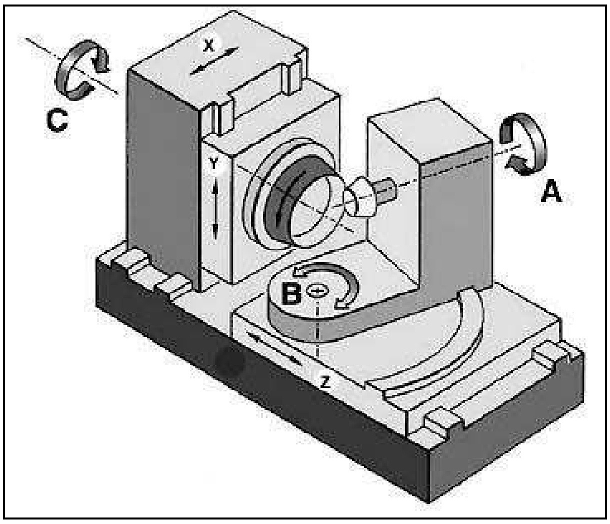

Figure 3. Idea of 6-axis CNC bevel gear machine

CNC machine uses 6 axis: three linear and three rotational axis which are as following:

- X - horizontal movement perpendicular to cutter head axis,
- Y – vertical movement perpendicular to cutter head axis,
- Z – horizontal movement parallel to cutter head axis,
- A – rotation of work-piece about its axis,
- B – rotation of the work head about vertical axis parallel to the Y axis,
- C – rotation of the cutter head about its axis.

According to Figure 2, point OM is the beginning (zero point) of the machine coordinates. These machine coordinates are the global coordinates in the machine work space. The CNC machine does not have a work-piece offset as mechanical displacement of work-piece unit (Figure 3). It means that the work-piece unit is more rigid than the same unit in the conventional machine. In the CNC solution, work-piece offset is realized by the movement of the local coordinates. Typical cradle for the conventional machine is replaced with the special unit, which elements move in perpendicular direction as X and Y axes (Figure 3) and give effect of the cradle rotation.

The Z axis is perpendicular to the XY plane and parallel to the cutter axis and it controls the movements of the work-piece unit (table unit) towards the XY plane (the cradle plane). The CNC machine does not have a cutter tilt unit but it is possible to realize the technological methods with cutter tilt as SFT (Spiral Formate Tilt), HFT (Hypoid Formate Tilt), and other similar approaches. Because of the continuous transformation of coordinates by a controller during generating motion it is possible to hold the cutter axis and the work axis at the same relative orientation, like in the conventional machine. The B axis of the CNC machine is the rotation about Y and it corresponds to root angle from the basic technological setup. Axes A and C require an additional explanation. For single indexing (Gleason technology) the rotational position of work-piece depends on generating motion connected with the XY cradle position and does not depend on the rotational cutter position. Continuous indexing requires, independently of generating motion (Oerlikon/Klingelnberg technology), a very close relation between angular position of number blade groups of cutter and number of cutting teeth. In both cases, the C axis is controlled as cutting speed. A mathematical model of CNC machine is supported on the basic technological settings for the conventional machine which have been listed above (10 settings), but determined in 6 - axis (6 mechanical freedoms) of the Cartesian coordinates.

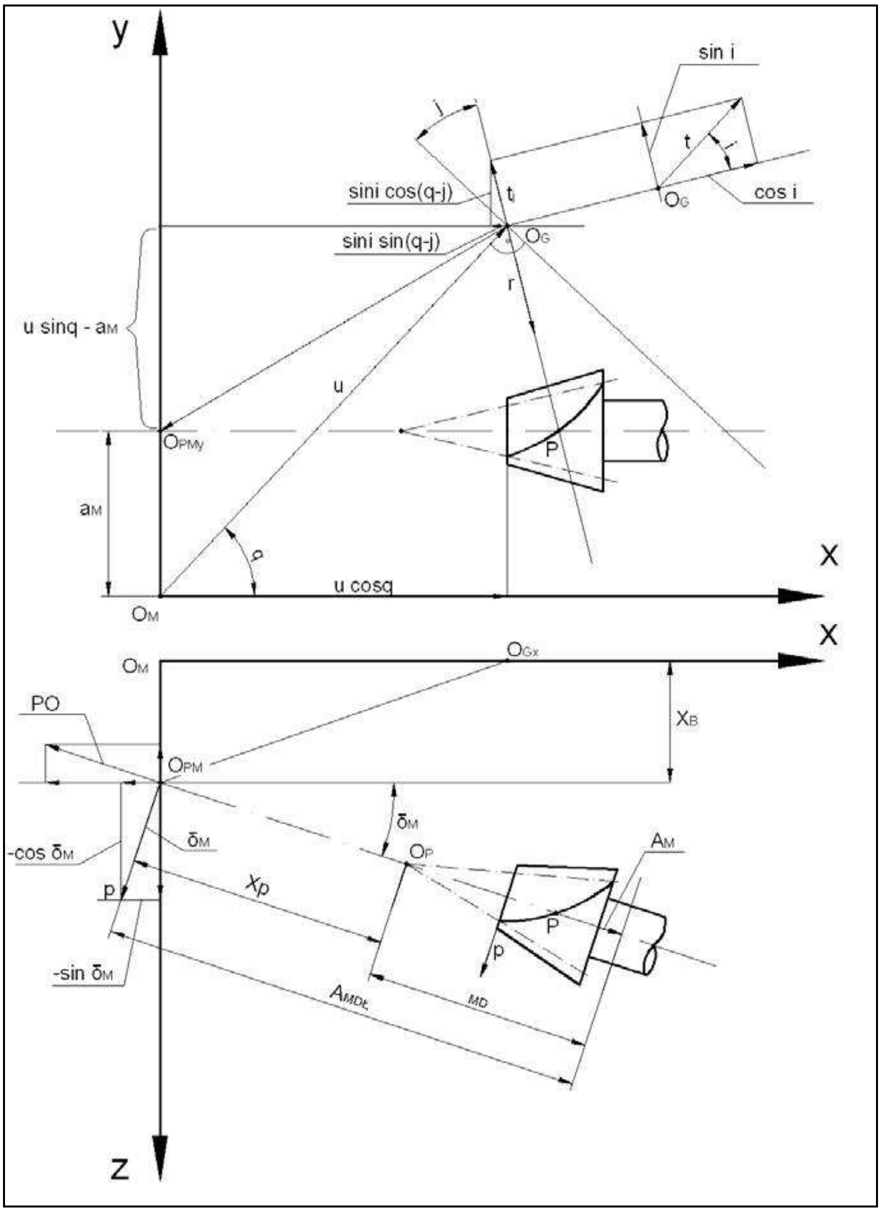

Figure 4. Coordinates system for 6-axis CNC machine

Vector $\overline{PO}$ along work-piece axis is defined:

$$\overline{PO} = [-\mathrm{Cos}\delta_M, 0, -\mathrm{Sin}\delta_M] \tag{1}$$

Vector $\overline{t}$ along tool axis:

$$\overline{t} = \left[-\mathrm{Sin}(i)\ \mathrm{Sin}(q-j),\ \mathrm{Sin}(i)\ \mathrm{Cos}(q-j),\ \mathrm{Cos}(i)\right] \tag{2}$$

The unit vector $\overline{p}$ and $\overline{t}$ of work-piece and cutter position:

$$\overline{p} = [-\ \mathrm{Sin}\delta_M,\ 0,\ \mathrm{Cos}\delta_M\ ] \tag{3}$$

$$\overline{r} = \left[\ -\mathrm{Sin}(q-j),\ \mathrm{Cos}(q-j),\ 0\ \right] \tag{4}$$

Vector from point O_G to point O_{PM} :

$$\overline{Q} = \left[-\ \mathrm{U\,Cosq},\ (\mathrm{U\,Sinq}\ -\ a_M\ ),\ x_B\right]\ -\ A_{MDt}\ \overline{PO}\ +\ H\,\overline{t} \tag{5}$$

where: U – radial setting, q –cradle angle, i – tilt angle, j – swivel angle, δ_M – root angle, a_M – hypopid offset, x_B – sliding base, A_{MDt} – mounting distance, H – height of cutter.

Unit vectors of orthogonal axes are determined:

$$\hat{W}_Y = \frac{P\bar{O} \times \bar{t}}{\left|P\bar{O} \times \bar{t}\right|} \tag{6}$$

$$\hat{W}_Z = \bar{t} \tag{7}$$

$$\hat{W}_X = \hat{W}_Y \times \bar{t} \tag{8}$$

Than, the linear coordinates X, Y and Z are equal:

$$X = -\bar{Q} \cdot \hat{W}_X \tag{9}$$

$$Y = \bar{Q} \cdot \hat{W}_Y \tag{10}$$

$$Z = \bar{Q} \cdot \hat{W}_Z \tag{11}$$

The angular coordinate B means rotation about Y axis and corresponds to root angle δ_M and is given by:

$$B = \mathrm{Sin}^{-1}(-P\bar{O} \cdot \hat{W}_X) \tag{12}$$

For the Gleason system, the C axis means the cutting velocity and the rotational angle does not depend on rotational position of the work-piece. The C axis is very important for Oerlikon/Klingelnberg system, where the relation between rotational position of cutter and work-piece exists. Thus, the reciprocal rotational position of cutter and work-piece is determined by the functions:

- for cutter head angular position:

$$\omega_C = \mathrm{Sin}^{-1}(-\bar{r} \cdot \hat{W}_Z) \tag{13}$$

- for work-piece angular position:

$$\omega_{PO} = \mathrm{Sin}^{-1}(-\bar{p} \cdot \hat{W}_Y) \tag{14}$$

It means that rotation of the cutter head with number of blade groups should be synchronous with number of work-piece teeth. The rotational velocity of the cutter and work-piece does not have any relation and it is the cutting speed only.

Conclusions

The CNC spiral bevel gear machine controlled in 6-axis has the common basic technological parameters with the conventional machine. It is very important, because computer calculations for the conventional machines and particularly the basic technological settings are the grounds to determine relations in all 6-axis. The basic technological settings are the input data to CNC controller. Even though the cutter axis is parallel to the Z axis and perpendicular to the XY plane, because of continuous transformation of the coordinates it is possible to use the technological methods with cutter tilt. The CNC machines allow to cut spiral and hypoid bevel gears independently of the cutting system, with indexing or without indexing.

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MODELLING OF FRICTIONAL TAPERED CONNECTIONS IN MACHINE DESIGN

Стаття присвячена моделюванню фрикційних конічних зв'язків у проектуванні машин. Проектні завдання для пристроїв і механічних елементів потребують підвищення якості на виробництві. Важлива річ – правильне проектування і точне копіювання геометричної форми та структури поверхонь, що з'єднуються. Показано як потрібно отримати об'єктивніші проектні умови для геометричних параметрів конічних з'єднувальних елементів, які задовольняють вищі ступені статичного і динамічного навантаження.

Ключові слова – проектування механізмів, якість виробництва, конічне з'єднання

This paper is devoted to the modelling of frictional tapered connections in machine design. Designing tasks for devices and mechanical units need manufacturing quality increasing. Important thing is correct design and accurate reproduction of geometrical shape and structure of mating surfaces. The article shows how to obtaining more objective design conditions of geometrical features of tapered connection elements, which satisfy in higher degree than before the conditions of state of static and dynamic load.

Keywords - machine design, manufacturing quality, tapered connection

Introduction

Shaped separable and nonseparable axialsymmetrical connections such as: tapered connections, splined connections, fitted bolts are used as one of basic method of connecting mechanical parts. Designer in complex design process determines their nominal form and size limits using his ideas, experience and knowledge about function of considered unit. Reliability and safety features of tapered connections depends fundamentally on accurate reproduction of designed geometry and stereometry of surface. Their real geometrical form is connected with frictional contact of connected elements (journal and seat). Real contact surface of mated pairs is smaller than surface, which is applied during calculations according to current ideal model.

During manufacturing real elements are produced, their geometrical profile is distorted, dimensions are not equal to assumed ones, and surface is rough [3].