Improving the process efficiency of helical gears’ toothed rims at the stage of pre-production

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Abstract. The article reveals modes of increasing the efficiency of preproduction process for manufacturing nodes with helical gears. The increased efficiency is ensured by processing toothed rims of helical gears with end tools on multi-axis CNC machines. The advantage of the proposed processing method is the minimum deviation of actual and theoretical profiles of gear tooth side surfaces.

Introduction

The development and production of new products that include cylindrical spur gears and helical gears (speed reducing gears, transfer boxes, gearboxes) is impossible without working out several options for their design with various test cycles and the selection of the most optimum design. The product design includes some options for its designing and experimental production of its parts. Parts production with simple structural flat, cylindrical, conical elements does not cause significant technological difficulties, but high-quality production of gear rims is impossible without designing and manufacturing a special cutting tool - rams or worm milling cutters [1-3]. Their additional design and manufacture significantly lengthens the process of pre-production and manufacturing pilot runs.

Research objective

Processing gear rims on multi-axis CNC machines without manufacturing special cutting tools can be taken as an alternative solution. Currently, there is a wide range of CAM systems integrated with CAD systems that allow you to generate control program texts for a CNC machine [4-8]. The most famous of them are NX CAM, PowerMill, MasterCam, SprutCam, Adem, etc.

All these software products implement a single sequence of work preceding processing toothed rims, designing the 3D model either in the same integrated CAD software environment or in another, reading 3D model in CAM system. CAM system generates various movement patterns of the selected tool according to universal algorithms incorporated in calculating path-planning module of these programs. The process ends with the formation of a control program code for CNC machine.

As a rule, these universal algorithms implement an equidistant traversal of structural elements’ processed surfaces according to previously worked out rules (for example, layer-by-layer removal of the allowance from the periphery to the central point or from the central point to the periphery). The more developed the CAM system is, the greater the number of options for setting the working paths it allows you to perform. Let’s consider the most likely ways to handle toothed gear roots. Coordinates of work points can be calculated by all the listed software products in the basic version.
The first is the transfer of rough milling which should eliminate the main allowance from the root, leaving it on the sides. The allowance is sampled by a spherical end or a keyway cutter (Figure 1a). Then comes the fine milling. It can be made with a modular end mill. This variant of processing assumes the shortest possible processing time of the wheel root, but the modular milling machine must be specially manufactured for parameters of the gear, its manufacturing cost may be comparable to the cost of manufacturing the worm gear-cutting milling machine. Another optional variant is the traversal by a spherical end mill (Figure 1b). Unlike a modular disk or end mill, a spherical end mill is an inexpensive and affordable tool. The smaller the depth of cut, the better the surface of the side gears, but the longer the process is. In any case, to achieve an acceptable quality of the lateral surface of gears the processing time of toothed rims will be significant. In some cases it can reach 4-5 hours or more.

Figure 1. The movement patterns of the end mill: a) rough milling of the root, b) fine milling, c) processing the root of the gear wheel.

The intermediate option among milling options discussed above (modular milling and spherical end milling) is, for example, Sandvik Coromant's offer in the form of “patented InvoMilling process” [9] (figure 2).

This process by the duration of its processing can compete with the milling of gear rims of modular milling cutters. It should be noted that although this solution is ready-made and universal, the cost of the mill body and quick-change milling grades exceeds the cost of manufacturing not only a worm, but also a modular cutter. Its high price is compensated by the versatility of processing gear wheels of a different module with the same tool. In addition to the need to purchase special tools and plates, an enterprise implementing this method should purchase a specialized software product from this company. In addition, the implementation of this processing method requires a 5-axis CNC milling machine, the cost of which is maximum among CNC machining center line. Thus, such a solution can be acceptable for enterprises that process gears in small batches only on condition of their work with significant profitability.

Figure 2. Processing cylindrical gear teeth with special cutters of Sandwik CoroMill 161 and CoroMill 162 [9].
The work with the above CAD, CAM systems is implemented by various production services of the enterprise. The mathematical model is created by the designer on gears in the CAD system, then he sends it to the control design department of CNC machines in which another expert decides how to process the rim and adjusts one or another variant of equidistant processing of the mathematical model in CAM system. Then, depending on the model of the machining center, he generates the text of the control program and sends it to the workshop for processing. When changing design parameters of wheel rims during the development of the product design or arising deviations in the process of manufacturing gears, the transfer of information from one department to another can lead to errors in design, increasing the duration of getting information.

Results and problem solution

To reduce the number of errors and speed up the process of transferring information from one service to another is possible by transferring the program development functions for CNC machine to the designer on gears. This requires a software product that allows you to generate a control program from a single side, which indicates the necessary structural data of the gear rim of the wheel and data processing wheel on a CNC machine.

For many enterprises the most acceptable option is processing gear rims on the 4-axis machining center. Only the end milling cutter can be the cutting tool for a stack with 4 controlled coordinates for machining helical gears. To reduce the complexity of processing, the main allowance from the root is removed with a mill of the maximum possible diameter. Since the gear profile is formed by an involute called the engagement line rolling along the main circumference, the side surface can be machined with an end mill, the axis of rotation of which is perpendicular to the engagement line and the forming edge is on the side surface of the tooth (Figure 3 b, c).

There has been developed the software product, the input data of which are gear wheel, tool, transition parameters — cutting-in and an overtravel of a tool, safe tool lifting as well as machining process parameters — cutting speed and tool feed amount. The software product calculates coordinates of points of tool’s working strokes; the sequence of individual steps of the algorithm is performed taking into account the methodology described [10]. The output of the product is the control programming text with CNC. The program is designed for experts on gears. Approbation of the technique was performed on a 4-axis CNC milling machine when processing a cylindrical helical gear from an aluminum alloy (Figure 3). The results of measuring the machined gear showed acceptable deviations of the actual profile of gear’s side surface from the theoretical one.

![Figure 3. Processing the gear rim of a horizontal wheel: a) a semi-fine milling, b) milling the left side of the root, c) milling the right side of the root.](image)

Currently, the software product and processing technology by the end tool of gear wheels are being implemented at the experimental site for manufacturing gear shafts and wheels of “KamAZ”.

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