Innovative Methods for Efficient Processing of Gear Wheels

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ABSTRACT

The article considers the technology of producing and processing gear wheels. It provides some requirements for gear units, directly for gear wheels and their production. The paper analyzes the effectiveness of various techniques for cutting the gear teeth, as well as the effectiveness of various modern tools used for gear-tooth milling. The article mentions that it is possible to increase the effectiveness of the tool due to simultaneous processing of two or three tooth spaces. It requires the use of full-duplex (tandem) and triplex interlocking disk milling cutters. The results of these studies are confirmed by the description of a number of practical examples implementing these reporting provisions when using the equipment described in the paper.

INTRODUCTION

Gear wheels are and will remain one of the basic elements of machines and mechanisms. They cover a very broad range of applications. They are used in motor industry, tractor construction, machine-tool and aircraft industry, space-based technology and other engineering industries.
The technology of gear-wheel production is one of the most difficult and challenging processes that require special expensive equipment, production tools and highly skilled specialists. The improvement of technological processes in terms of challenging issues of improving quality and productivity, durability of cutting and deformation tools means not only the analysis and collation of the world experience, but also the need for continuous theoretical and experimental studies, taking into account different conditions of gear wheel production. Therefore, this paper is aimed at solving a relevant scientific problem of national economic significance.

Nowadays, there are many essential requirements for gear units (gearboxes, transmission gear boxes). Besides, gear wheels are the main element of any gearboxes, so the majority of these requirements for gearboxes directly relates to gear wheels. Some of these requirements should be implemented through the appropriate design of gear wheels, and some of them – through the manufacturing technology. However, the production technology should in any case enable the implementation of design parameters with required engineering accuracy.

**PROBLEM STATEMENT**

The last decades have seen significant changes in the processing technology of cylindrical gear wheels. As a result, there appeared a possibility to increase the efficiency of processing cylindrical wheel teeth several times (and in some cases several tens of times).

The above-mentioned requirements for gearboxes and gear wheels specify even more strict requirements for the accuracy of gear wheels.

The aim of this study was to determine:
- the effectiveness of various techniques for cutting of gear teeth;
- the effectiveness of various modern tools used for gear-tooth milling.

The main methods of gear-tooth milling are profile milling (form-copying method with a single division) and generating gear hobbing. In the former case, the tool is an interlocking disk milling cutter (less frequently end-mill type gear cutters), in the latter case – a hob cutter.

Prior to the application of the generating gear hobbing, the gear teeth were processed only by profile milling. In this case, the tool – an interlocking disk milling cutter or an end-mill type gear cutter – has in section a profile that matches the profile of a given tooth space. The tooth is processed by feeding a part along an axis for full length of one space, then the part is rotated to the angle corresponding to the tooth spacing angle and the next space is processed. This process is repeated as many times as many teeth require processing. The need to turn (“divide”) the part on a spacing angle when machining the next tooth gave another name to this method – a unit division method (Fig. 1). The paper contains detailed study of this method [3].
Gear generating hobbing provides for continuous kinematic connection between the machine table, on which the workpiece is fixed, and the main spindle on which a hob cutter is fixed. The tooth cutter has a profile of a square-sided spline. As a result, the involute profile of the part is developed in the form of straight envelope lines that are formed at different angular positions of the tooth cutter (Fig. 2).

**Relevance and scholarly importance of the study**

Unlike standard constructions of interlocking disk milling cutters, the modern processing technology considers entirely different cutter constructions. Cutters with indexable inserts are used almost everywhere when applying modern technologies of tooth cutting.

The principle of using form gear cutters means that the profile of a cutter is fully consistent with the tooth profile of a workpiece. However, if we use separate cutters for roughing and finishing operations, then the profile of roughing cutters does not necessarily have to match the profile of the component tooth with appropriate allowance. Roughing cutters can cut through a preparative pre-sided (non-involute) profile, make a tooth top, or roughly generate involute profiles and form a tooth with cutting-edges (cutter profile with clearance lug) to avoid processing bottom land during subsequent finishing operations. The tooth surface of large cutter modules is formed by several cutting inserts (Fig. 3), the process is described in detail in the paper [4].
A carbide finishing cutter has an involute profile fully corresponding to the profile of the processed tooth. A finishing cutter can also form a tooth top, if required (Fig. 4). Cutters with indexable inserts have higher economic efficiency compared to cutters with brazed cutting tips due to the following factors:
• No need to resharpen knives with brazed tips, as a result resharpening expenses are excluded;
• A cutter construction has no knives so it makes the construction simpler and cheaper;
• Indexable inserts are fixed mechanically, so there is no need to braze and then to rebraze them at the end of their efficient life;
• Indexable inserts may have wear-resistant coating, which allows increasing the cutting speed when processing as well as increasing productivity during simultaneous improvement of their durability. The brazed cutting tips can be hardly coated due to brazed joints whose properties can be changed when heated to the temperature of the coating.

As scholarly importance and practical significance of the research within the framework of this paper, it should be noted that it is possible to increase the effectiveness of the tool due to simultaneous processing two or three tooth spaces. It requires the use of full-duplex (tandem) and triplex interlocking disk milling cutters. Full-duplex cutters allow processing two tooth spaces all at once and triplex cutters simultaneously process three tooth spaces (Fig. 5).
Interlocking disk milling cutters with indexable carbide inserts operate at speeds up to 170 m/min (depending on the modulus and strength of the workpiece material) and feed rates up to 0.7 mm/tooth.

**Research methods.** The study is based on a complex research method, including system analysis, experimental investigations conducted on original stands with the use of close control modern equipment.

The main theoretical results were obtained by using approaches based on classical methods of calculating machine parts, theory of machines and mechanisms, tribology and truboengineering, kinetic theory of fracture of materials. Methods of mathematical statistics were used for processing experimental data.

**Practical significance, results obtained in experimental studies.** The results obtained in these studies are confirmed by a number of practical examples when using the equipment described in the paper [2].

**Example 1** (Fig. 6). A work-piece is a gear wheel of 20 mm module, material - 40ХM. A tool is a finishing cutter (second-pass machining), cutter diameter - 290 mm, max cutting depth - 2 mm. Processing conditions: cutting speed - 132 m/min, feed per tooth - 0.4 mm/tooth, feeding speed - 520 mm/min.
Example 2 (Fig. 7). A work-piece is a gear wheel of 10 mm module, material - 40XM. A tool is a finishing cutter (single-pass machining), cutter diameter - 380 mm, max cutting depth – 22.5 mm. Processing conditions: cutting speed - 140 m/min, feed per tooth - 0.45 mm/tooth, feeding speed - 785 mm/min.

The same situation with inadequacy of technological level takes place in generating gear hobbing as well.

Modern technology corresponding to the world level also implies a solid-on-shaft hob as a basic tool, but made of powdered metal high-speed steel and with obligatory modern wear-resistant coating.

Powdered metal high-speed steel has higher hardness and higher toughness compared to standard high-speed steel. This is due to the metal structure – the powdered metal high-speed steel consists of small evenly distributed carbides, therefore, has no carbide inhomogeneity and practically is free from impurities and inclusions. As a result, a hob cutter made of powdered metal high-speed steel with an appropriate wear-resistant coating can process gear wheels at a cutting speed up to 180 m/min. This provides at least twofold performance improvements. It can also significantly increase feeding speed due to higher strength of the powdered metal high-speed steel. Thus, the use of modern tool materials allows implementing a fundamentally new technology for gear wheels milling by using a form-generating method.

Simultaneously with the change of tool materials and application of wear-resistant coatings, the design of modern hob cutters was also changed, so they had an extended working section length compared to standard cutters.

Besides, the paper considers the choice of the best available technology for processing teeth parts of mining machines. The main criterion for choosing this or that tooling method is economic efficiency. In this case (as particularly always when estimating the efficiency of cutting operations) it is determined by the machining time (and related cost) and the tool cost.

As a practical result of the research, let us consider, as an example, a gear wheel of 12 mm module with 190 teeth. The time and cost results are provided in Fig. 8 and 9.
SUMMARY

As can be seen from the above results, profile milling is no longer the most productive and efficient method of machining. The highest efficiency is achieved by hob cutters with indexable carbide inserts. As for machining cost, the most profitable method is the use of high-speed cutters with a progressive cutting pattern. A particular optimization of a cutter and a carbide material may increase the resistance of carbide inserts, and then this method could be the most economic.

The above examples show that interlocking disk milling cutters with indexable carbide inserts are more efficient when machining parts with a small number of teeth. The majority of producers of this tool determine the limits of effective application of this method with respect to hob cutter to 35-40 teeth of the product. When processing gear wheels with a greater number of teeth, it affects the increase of auxiliary time for profile-cutting, but at the same time it becomes possible to increase feed per revolution for generating gear hobbing.

It should be noted that this limit is rather conditional and when choosing a process method, a detailed calculation should be made for each particular case.
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