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Production of non-standard gears

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Abstract Among the most used transmission mechanisms are gear transmissions. Various requirements are placed on these gears, such as requirements for performance, durability, weight, and the like. The production of gearing also has an impact on achieving these results. The correct manufacturing process is particularly important for the production of non-standard and atypical gear wheels. This article discusses the factors that influence the optimal choice of the method of production of non-standard gearing wheels.

Keywords non-standard gearing wheels, production, optimalization.

1. INTRODUCTION

Gears have become a symbol of engineering and gears are the basic element for the transmission and transformation of mechanical energy and movement from one place to another. Due to their specific shape, gears are one of the most complex and technologically demanding machine parts. The specific shape of a gear wheel can be referred to as gearing, which is made up of teeth. The teeth have precisely defined dimensions, shape, properties, distribution around the circumference of the wheel and very high demands are placed on their manufacture [1, 2]. Be it in terms of accuracy, performance, noise, durability and most importantly the speed of their manufacture [3-6]. These constantly increasing demands can be influenced by finishing methods, primarily by grinding.

The field of gear manufacturing is advancing at a rapid pace and has undergone many changes in its existence. It is a relatively challenging technological process because the shape of the gearing is complex and is precisely defined by its size and function [7, 8]. A few years ago, the production of gearing was only possible by basic - conventional methods. The production of gearing is most often carried out by machining. The gears are formed by removing the tooth gap between the individual teeth. Gearing is obtained by milling, hobbling, broaching, or forming [9]. Finishing machining methods such as grinding, shaving, burnishing, honing, and lapping are used to achieve the best possible degrees of surface accuracy.

In practice, non-standard - atypical shapes of gearing, for the production of which it is not possible to use these conventional methods of gearing production, are also more and more often used [10-12]. That is why unconventional methods of gearing production are also coming into awareness nowadays, of which it is possible to mention, for example, plasma arc cutting, laser removal, water jet or five-axis machining centre.

The main goal of the article is the production of non-standard gears, where the use of conventional methods of gear production is not suitable and it is necessary to use another, non-conventional method of production.

2. ELLIPTICAL GEAR TRANSMISSION

The most commonly used gears in practice are "standard" gears, which can be characterized by a constant gear ratio. This means that when the driving wheel rotates, the driven wheel also rotates uniformly, i.e., the gear ratio must be constant during one revolution. The teeth of these "standard" gears on one gear have the same shape and are teeth with a symmetrical profile (in exceptional cases also with an asymmetrical profile).

In practice, gearing whose gear ratio is not constant during one revolution also finds its application. Based on practical requirements, a geometric model of a gear with a continuously variable gear ratio was created so that the gear meets the conditions of correct meshing. The gearing was designed for the following specific parameters:

- a pair of gears consisting of two identical gears,
- a harmonically repeating gear ratio in the range u = from 0.5 through 1.0 to 2.0 and back per revolution of the gears together,
- the number of teeth of the gears $z_1 = z_2 = 24$,
- normalised value of the gearing modulus $m_n = 3.75$ mm,
- axial distance a = 90 mm,
- designed for one direction of rotation.

The continuously variable gear pair consists of two identical elliptical wheels with an eccentrically mounted centre of rotation. The resulting AutoCAD model of this wheel is shown in Figure 1.

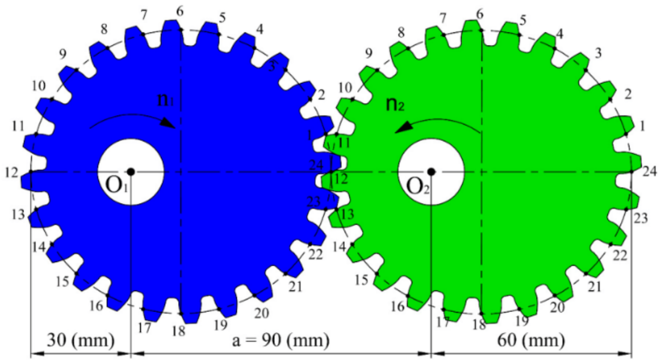

Fig. 1. Model of non-standard elliptical gears

The gear pair is formed by a pair of identical elliptical gears, with the centre of rotation in one of the centres of the pitch ellipse, i.e., they are eccentrically mounted gears. The active curve of the tooth profile is the involute, where unlike the involute of the tooth flank in "standard" circular gears, where the evolute of the involute is the base circle, and in this case the evolute of the involute is the ellipse. Each of the twelve teeth of a gear is different, the other twelve teeth of the same gear are the same. The flank curve is the involute and is different for the active and passive sides of the tooth. These are gears with an asymmetrical tooth profile, so the manufacture of such gearing is not possible with standard manufacturing processes developed for spur gears.

3. UNCONVENTIONAL PRODUCTION METHODS OF GEAR WHEELS

Spur gear, where each tooth is different and the tooth profile is asymmetrical, is impossible to produce by standard manufacturing processes. This is where gear manufacturing comes in, where a CAD model of the designed gearing is used [13, 14].

3.1 Electrical discharge machining

Electrical discharge machining (EDM) is a method of electrically erosive machining of electrically conductive material. The removal of the material occurs by the action of an electric spark. In this method, the tool (electrode) is brought close to the workpiece at such a distance that a spark jumps between the electrode and the workpiece. The spark removes a small particle of molten metal from the surface of the workpiece. To increase the effect, to prevent arcing, and for local cooling, the whole process takes place in a liquid (dielectric). The size and speed of material removal depends on the size of the gap, and also on the material properties of the workpiece and electrode. Any conductive material can be machined with this method.

EDM processes include ED die sinking, ED wire cutting, anodomechanical cutting and ED hole drilling.

Electrical discharge wire cutting is a progressive modification of electro discharge machining. The first machine for wire cutting was developed by the Swiss company AGIE, which was the first to use NC control, thus speeding up the process and achieving more precise results. Nowadays, a CNC control system is used. This method allows control of direction, speed of movement, wire unwinding speed, monitoring of physical properties and control of the ongoing electroerosion.

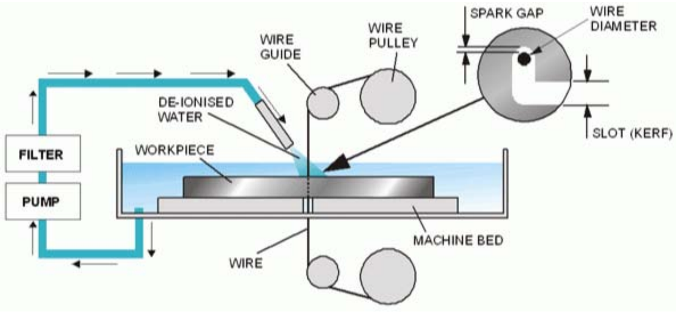

Fig. 2. Principle of Electrical Discharge Wire Cutting

The tool of the wire cutter is a thin wire, which is continuously unwound from the spool in the tray during cutting with the help of a special feeding device, which also has a wire sponging function to avoid wire tearing. To avoid inaccuracies, the wire is constantly tensioned with a constant tensile force by means of pulleys. The wire moves slowly, between 2.5 and 300 $mm.s^{-1}$, and is controlled by the machine system (Fig. 2.). The wire as a tool can only be used once during the cutting process, then after use it ends up in the collection point.

3.2 Production by plasma arc

This method is nowadays one of the most widespread methods of thermal separation of metallic materials. A plasma with a density of 5.105 Wm^{-2} is used and the plasma temperature reaches temperatures up to 30.103 ºK. Plasma cutting has been used to cut stainless steels using inert gas. It has been used for cutting structural steels with the addition of oxygen as a protective gas.

The plasma is formed by an electrical discharge between the anode and cathode, thus the necessary condition is an ionized medium. This can be a gas, which is in the form of hydrogen, argon, etc.

This energy is transferred to the surface of the material to be split by the plasma and gas flow in the torch nozzle. The plasma drives into the material and local melting and partial evaporation of the molten metal from the surface of the material occurs resulting in a cut mark. Plasma cutting is very fast.

The production of gearing by plasma arc (Fig. 3.) has positive feedback in mechanical engineering practice. Different types of construction materials can be used for cutting. It is important to note that after the production of gearing by plasma arc, a thermally affected region is formed on the surface of the gearing, which is changed by the action of the plasma beam from top to bottom. At the beginning of the cutting thickness, the thermal effect is more intense than at the end, where the heat effect is lower.

Fig. 3. Part of gearing produced by plasma arc at different thickness of gearing

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The advantages of this method include high cutting speed, the ability to cut all materials and high precision in repeated cuts. Disadvantages include the limitation of the thickness of the material to be cut, the sloping of the cutting surface and the high cost of parts when the torch is gas cooled.

3.3 Production by laser beam

The principle of this material separation technology relies on the energy that is delivered by the light beam. At the point of impact on the opaque material, this energy is converted into thermal energy, which melts the material in the cutting plane. The cutting energy intensity is about 105 kW.cm^{-2} and the laser cutting beam diameter is 1μm.

When used for the production of gearing (Fig. 4.), the interaction of the laser energy and the material of the workpiece to be cut is important. Energy absorption occurs due to the partial reflection of the beam from the material which is being cut. The deposition of absorbed energy is in about 0.1μm layer, which later penetrates the workpiece material due to thermal conductivity. Propagation of the liquid interface into the material begins when the absorbed energy is high enough to melt the material.

Fig. 4. Production of gear wheel by laser beam gear

3.4 Production by water jet

This method of manufacturing is also known as Water Jet (WJ), Water Jet Machining (WJM) and Abrasive Water Jet Machining (AWJM) as water jet machining with abrasive particles.

In the WJM and AWJM process, the mechanical energy of both water and abrasive particles is used for machining. The typical pressure range for waterjet application is 205 - 600 MPa. When water is delivered at this pressure through the nozzles, the potential energy is transformed into kinetic energy and the water velocity increases up to 100m/s and the water behaves as a solid body.

Fig. 5. Use of waterjet gear production

If pure water is used, the water jet tends to pick up atmospheric air and this reduces the cutting ability. Therefore, chemical stabilisers are added to the water. The technology is mainly used in cutting soft materials such as small thickness sheets, plastics, foils [15, 16]. To eliminate this deficiency, abrasive particles, most often aluminium oxide grains, sand or glass microspheres, are added to the water. Therefore, AWJM is designed to machine harder materials (Fig. 5.). When the strength of the material is exceeded by the pressure of the beam head, the beam induces an erosive process in the workpiece material.

The advantage of its use is high energy efficiency - up to 85 %, the possibility of use in explosive environments, the material only needs to be clamped lightly, no cracks occur in the material due to the small number of cutting edges. There is no dust formation, so it is classified as an environmentally friendly technology. It is possible to change production in a very short time, high reliability in operation and accuracy of the given dimension (0.13 mm, repeatable 0.025 mm). The biggest advantage is the absence of temperature influence on the cut material.

The shortcomings of this technology include variations in the quality of the cut along the cutting surface and at the exit of the cutting water jet. It is necessary to ensure the protection of steel semi-finished products against corrosion.

4. PRODUCTION OF NON-STANDARD GEARING GEAR WHEELS

For the technical preparation of production, it is necessary that it is provided by a company that specializes in the development and distribution of CAM systems and systems for the automation of programming of NC and CNC machines. The choice of the optimal production method is limited by conditions such as the number of pieces produced (only one pair of gears was produced), the production had to be ensured by a technology commonly available in the vicinity and without the use of any costly fixtures, and the costs for the technical preparation of the production and for the production of the functional model had to be as low as possible.

On the basis of the mentioned conditions, the NC machine for electrical discharge cutting EIR 005 B with RS-ER5 control was selected. Although it is an older machine of the production facility, the machine in question allows the creation of the designed shape of the gears with the required precision of 0.01mm and roughness Ra 1.6μm.

The main problem was the generation of NC code for a complex gear shape, which did not allow to use the usual approach for creating NC programs for gears, when the shape of one tooth is described and this is repeated according to the required number of teeth. There were three ways of preparing the NC code.

The first method is programming in the NC code of the machine. Due to the complexity of the shape requiring as many as 300 blocks, this method is complicated and messy, and for the machine in question this option was practically out of the question.

The second method was based on the use of existing software support for the machine. The description of the produced elliptical wheel contains 48 linear parts and 192 circular arcs, which would have to be tediously defined in this method (centre of the circle, radius, start and end point of the circular arc, etc.), therefore this method is time-consuming to prepare.

The last method is based on creating a postprocessor (translator) for the machine in the CAM2000 system, which is designed for automation of NC machine programming. This option has proven to be clearly the most effective and technically by far the most efficient. A postprocessor for ED wire cutting EIR 005 B with RS-ER5 control system was created. Its task was to automatically generate the NC code for the designed gear shape. In this way, an NC program for any desired profile shape can be created in a very user-friendly way within a few minutes.

As the cutting length of each gear was approximately 532 mm, each piece took 8 hours to produce with a recommended cutting wire thickness of 0.02 mm and test wheel thickness of 3 mm. This time could be increased up to 40 hours if the thickness of the gears is expected to increase to 15 mm. This method of repeated production (whether bespoke production or mass production) is obviously not sufficiently productive, and a more appropriate production technology will have to be chosen if the expected number of required gears is defined.

A powder metallurgy method may be used in the manufacture of the elliptical gear in question. Powder metallurgy products are currently among the so-called "economically efficient" products because their price can be up to 25-50 % lower compared to components produced by, for example, machining by material removal. Powder metallurgy is characterised by up to 95 % material utilisation due to the production of the part "to-finish" without machining costs. Powder metallurgy is one of the waste-free technologies, it is a closed-loop process, and the output is a finished product ready for assembly. It is characterised by energy savings of up to 50% and labour savings of up to 75%. This method is suitable for huge batches, mass production.

5. CONCLUSION

The gears themselves have undergone tremendous development since their invention. There have been changes in their shapes, the type of materials used and so on. Both standard and non-standard gears find their application in the automotive, shipbuilding, aerospace and food industries, as well as in other branches of the machine industry. This versatile use of gears in everyday life has led to the development of a large number of different processes and methods for their production. Each technology and production method used corresponds to the requirements and demands on the accuracy of the gearing and is dependent on the parameters and shape of the gearing.

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