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STRENGTHENING THE GEAR TEETH WITH SURFACE WORK

WZMOCNIENIE PRZEKŁADNI KÓŁ ZĘBATYCH OBRÓBKĄ POWIERZCHNIOWĄ

***Summary**: The present paper considers the beneficial effects that can be obtained by cold work type of machining performed as the final technological treatment in the process of gears manufacturing. Limitations in the use of shot blasting as a method of surface cold work of gears were pointed out and the concepts of two devices for carrying out the cold work with much greater efficiency than in the case of shot blasting were presented. The discussed devices use pressure burnishing of the critical zones of the gears.*

***Keywords**: cold machining, surface cold treatment, shot blasting, gear*

***Streszczenie**: W artykule rozważono korzystne efekty, jakie można uzyskać stosując obróbkę nagniataniem na zimno, wykonywaną jako końcowa obróbka technologiczna w procesie wytwarzania kół zębatych. Wskazano ograniczenia w stosowaniu śrutowania jako metody powierzchniowej obróbki na zimno przekładni oraz przedstawiono koncepcje dwóch urządzeń do prowadzenia obróbki na zimno ze znacznie większą wydajnością niż w przypadku śrutowania. Urządzenia te wykorzystują nagniatanie naporowe krytycznych stref zębów kół zębatych.*

***Słowa kluczowe**: obróbkę skrawaniem na zimno, powierzchniowa obróbka na zimno, śrutowanie, przekładnia*

Introduction

In many fields of drive technology, especially in mining, construction, road and agricultural machines and in vehicles, it is necessary to use mechanical gears to obtain high torque, often at moderate speeds. Gears with involute tooth profiles are most often used, which is mainly due to the ease of obtaining involute profiles using envelope methods.

The development of toothed gears has resulted in the development of many methods

to improve the operational properties of gears by design, material, selection of manufacturing technology and proper operation to increase both service life and safety [1, 2].

The basic processes that generate the wear and failures of the gears meshing, such as fatigue breakage of the teeth, abrasive and erosive wear, fatigue chipping of the surface layer of working surfaces of the teeth (pitting) and sometimes the phenomenon of tooth seizing, cause premature loss of the gear's usability, causing large technical and economic losses, and even resulting in an increased risk [3].

Technological treatments in the form of special types of heat treatment of gears made of steel, and especially thermo-chemical treatments, make it possible to achieve a significant improvement in resistance to the aforementioned destructive processes [6]. To a small extent, however, the additional large possibilities created by the use of cold work of the toothing of the gears are used [4].

Surface deformation as a method of improving the usable properties of gears

Cold work, i.e. operation below the recrystallization temperature of the material, has been known for a long time [4]. It was used to obtain favourable features, e.g. in the production of white weapons (swords), when the essence of the processes that then take place in the surface layer of the strengthened element was not yet known. Many technologies used in the practice of manufacturing elements from metal alloys, especially iron (Fe) alloys, have been developed to improve selected functional properties [4-6]. In the case of gears, shot preening is used, which consists in the action of a stream of, most often, steel balls falling at high speed on the treated surfaces. The kinetic energy of individual balls causes overlapping plastic deformations of the surface layer, which positively changes the usable properties. As a result of shot preening, the hardness of the strengthened surface layer increases, the surface roughness pattern changes, and, above all, residual compressive stresses are formed to a depth depending on the initial hardness of the work piece and the kinetic energy of the falling balls [4]. A jet of balls is ejected with compressed air or by rotor mechanical ejectors.

When machining elements with greater hardness, shot blasting encounters a number of technical limitations.

Pneumatic ball jet ejection has a physically limited airflow velocity through the jet nozzles. With the increase in the rotational speed of the mechanical rotor ejectors, the abrasive wear of the device elements increases strongly, and the fine-dispersion metallic dust formed at that time poses a danger of explosion [4].

Sometimes the use of carrier liquid for the stream of balls eliminates some of the aforementioned phenomena, but by wetting the surface of the strengthened elements, the contact pressure of the falling balls is limited, which must "breakthrough" the layer of liquid, which significantly reduces the efficiency of shot blasting.

In the case of shot preening of gear teeth, additional difficulties arise. The most stressed zones of the teeth at their base have definitely more difficult access of the ball stream due to the increased distance from the nozzle outlet, which results in a partial loss of kinetic energy of the stream. In addition, the transition radius zone at the base of the teeth cannot be crushed to the required depth.

In the described situation, the best way to generate deformation of a sufficiently large depth is pressure burnishing, which allows obtaining good strengthening effects at the full height of the teeth, with particular emphasis on the zone of the transition radius of the tooth outline. Reinforcement of the bottom of notches is of particular importance from the point of view of the tooth resistance to fatigue fracture. In this zone, the initiation and then the development of tooth fatigue cracks, the most critical form of operational damage to the gears, usually takes place [3].

Irrespective of the method of obtaining the surface deformation of orking zones of the teeth, the most important effect of this type of machining is the formation of a state characterized by constant internal stresses in the surface layer of the teeth of a compressive nature. These stresses in a very favourable way change the resultant state of variable stresses occurring during the operation of the gears. There is a reduction of the resultant stresses in the stretching zone, especially at the base of the teeth that is caused by the bending moment of the teeth. The summation of stresses on the compression side does not matter, because the compressive strength, especially fatigue strength, of the materials for gears is many times higher than the tensile strength due to the concave curvature.

The favourable compressive stresses generated by the surface work treatment, which balance the favourable compressive stresses, cause that the appropriate tensile stresses occur in the core of the material with a much larger load-bearing cross-section and in the section of the tooth cross-section where the bending stresses are lower. They are, therefore, of little importance for the resultant state of tooth material effort and do not affect the reduction of the service life of the gears. The increase in the hardness of the surface layer obtained in the process of deformation treatment serves improving the resistance to abrasive and erosive wear of the teeth. The transformation of retained austenite, which occurs as a result of heat treatment of steel wheels, is also beneficial. It is important to eliminate machining scratches that occur with typical methods of machining gears. The very unfavourable system of roughness's parallel to the axis of the gears as a result of cold work, regardless of the method, results in a more favourable non-directional character of the roughness, which has a beneficial effect on the incubation and development of tooth fatigue cracks. In the layer subjected to crushing in terms of microstructure, grain fragmentation is favourable and the dislocation density increases [8, 9]. The tribological properties of the working surface of the teeth are improved as a result of surface deformation treatment, because the adhesion of lubricants to the tooth surfaces treated in this way is improved. The relief of the tooth surface created as a result of machining, especially by shot preening, creates numerous "lubricating pockets" that facilitate the formation of a lubricating film. It also increases the resistance of the teeth to sudden overloads and scuffing.

Together, the described effects result in a significant increase in the service life of the gears after cold work.

The concept of devices used for surface cold work of gears by pressure burnishing

In the Department of Mechanization and Robotization of Mining at the Silesian University of Technology, a number of devices concepts for the implementation of strengthening of gears by surface work through pressure burnishing have been developed. In this way, the previously described numerous limitations that occur in shot blasting are eliminated, and the parameters of the treatment process can be easily adjusted within wide limits [12÷15].

A device for pressure burnishing of the transition radius zone at the base of the gear teeth

The transition zone at the base of the teeth is burnished using a universal device, the design of which is shown in Fig. 1.

The gear wheel 4 to be machined is mounted on the end of the piston rod 8 of the double-acting hydraulic cylinder 18. It is secured by a quick-release nut 21. The 6 transition radius zones of the workpiece gear are burnished simultaneously with burnishing rollers 2 loosely mounted on the axles 3. Pressing rollers are pressed against the gear being machined by marked disc springs 5. The amount of burnishing force is controlled by the position of the nut 6. The burnishing head holders 10 are fixed to the base of the device 11. It is advantageous to use three holders 10 evenly distributed around the circumference of the base at an angle close to 120°.

When the number of teeth of the burnished wheel 4 is divisible by three, the aforementioned angle of the housings distribution is exactly 120°. This configuration serves to fully balance the forces acting on the gear wheel being machined, eliminating the side forces acting on the piston rod 8. A single burnishing cycle

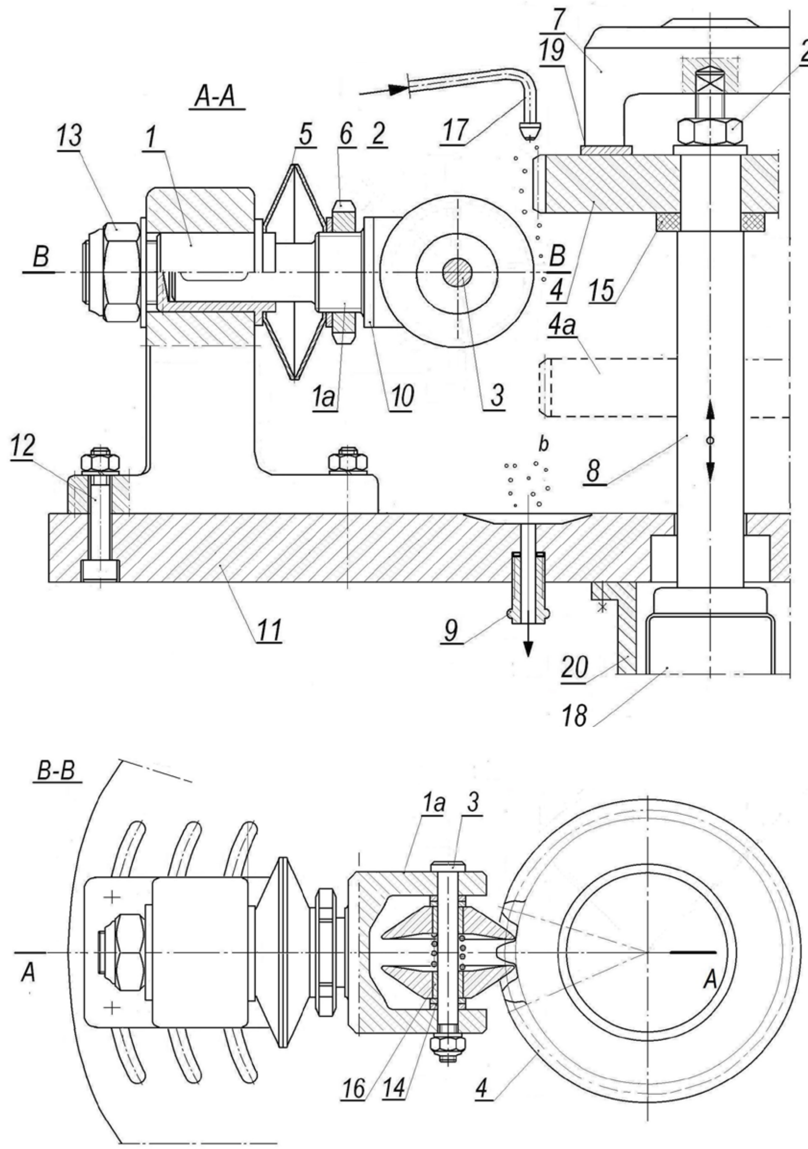

Fig. 1. Device for pressure burnishing of the bottom of gear grooves

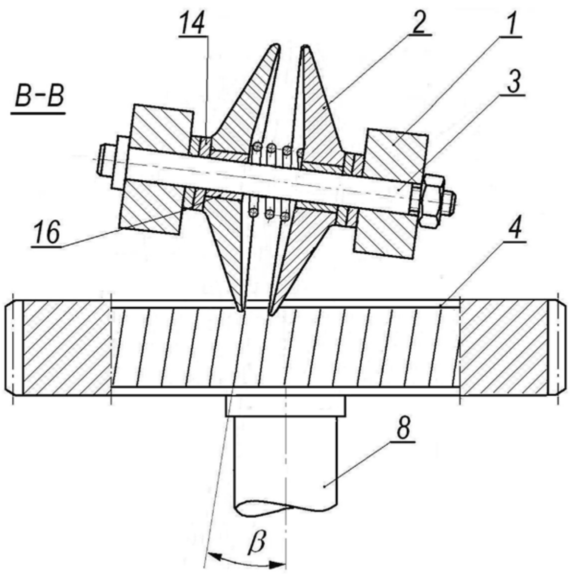

Fig. 2. Adaptation of the device from Fig. 1 for burnishing of helical gears

consists in moving the machined wheel in the up-down system from the initial position 4 to the final position 4a and back. During burnishing, the cooling and lubricating liquid is automatically sprayed through nozzles 17. This ensures high smoothness of the gear surface being machined and eliminates the occurrence of unfavourable phenomena of recrystallization of the burnished surface layer as a result of temperature increase.

After the simultaneous burnishing of six transition radii, the turntable 7 rotates the wheel 4 by the angular pitch of the teeth. It is advisable to repeat the burnishing procedure several times with possibly increasing pressure of the burnishing rollers 2. The burnishing rollers should be made of steel subjected to heat and chemical treatment to high hardness, and the roller radii should be polished. Alternatively, carbide rollers can be used.

When there is a need to machine gears with helical teeth, the burnishing heads should be turned by the angle β corresponding to the angle of the inclination of helical teeth (Fig. 2). During the burnishing of the oblique teeth, the machined wheel rotates automatically on the end of the piston rod 8.

As a result of pressure burnishing with the described device, a significant increase in the resistance of the teeth to fatigue breakage is achieved due to the formation of compressive residual stresses in the surface layer of the transition radius zone; it provides obtaining high surface smoothness and elimination of tooth machining scratches, too.

The burnishing device is characterized by great versatility. It enables the machining of gears with different number of teeth, corrected and non-corrected wheels, modified and unmodified teeth, and after replacing the burnishing rollers, it is possible to machine gears with a wide range of modules. It is also characterized by high treatment efficiency with low energy consumption.

The concept of devices used for surface cold work of gears by pressure burnishing

The basic tool of the device for the implementation of deformation treatment by burnishing the working surfaces of the gear teeth is a toothed wheel equipped with movable burnishing rollers. A single tooth of such a tool is shown in Fig. 3.

Burnishing rollers 2 are located on the whole tooth profile of the tool-wheel 1, held by covers 6 that are connected with bolts 4 and 5. Rolling rollers of needle roller bearings can be used as burnishing rollers after appropriate adaptation of their ends.

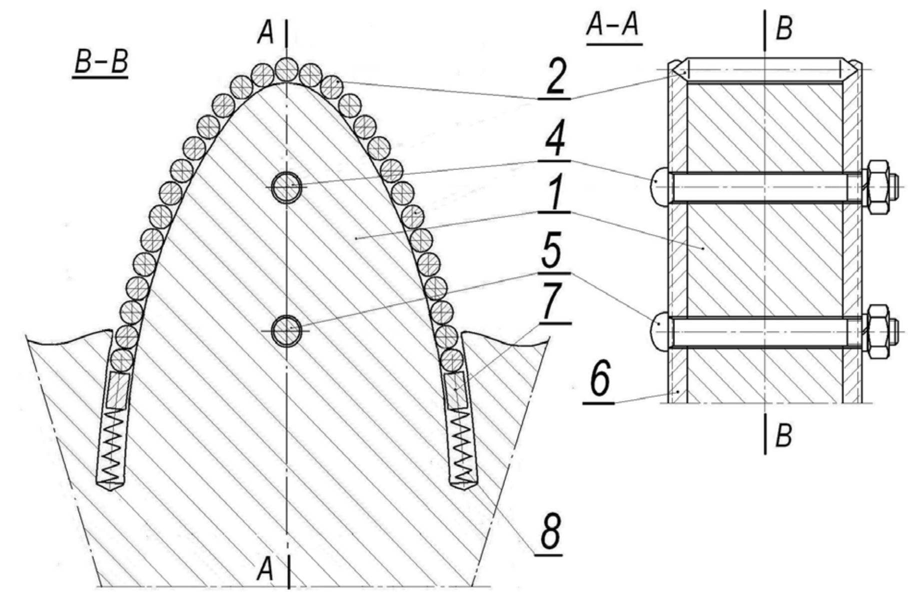

Fig. 3. Tool for pressure burnishing of working surfaces of gears

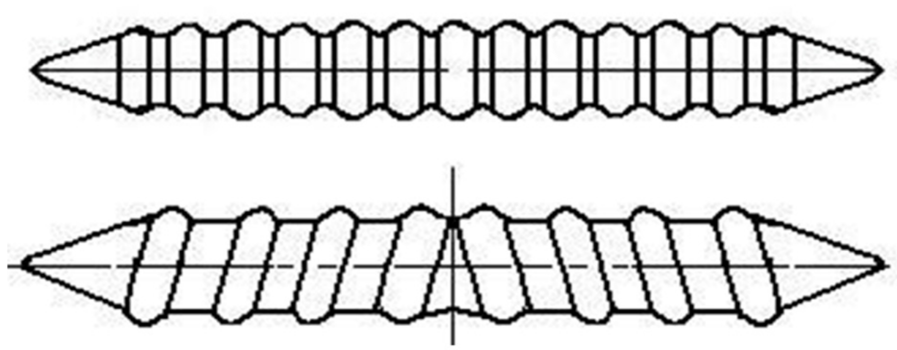

Fig. 4. Exemplary shapes of burnishing rollers with increased contact pressures for use in the burnishing tool from Fig. 3

Burnishing rolls may have cylindrical working surfaces or have humps, as shown in Fig. 6. These humps are used to increase the contact pressures of the rollers when burnishing the working surface of the teeth of gear being machined. Forming rolls like 2a requires additional longitudinal feed during burnishing.

The spiral formation of burnishing humps as shown in pos. 2b can be make without of the longitudinal feed of tool or burnished gearl. The opposite shape of the spiral humps along the length of the burnishing rollers limits the generation of longitudinal forces during machining. The burnishing treatment consists in the cooperation of the wheel-tool with the machined gear under appropriately selected pressure. Additional braking of the machined gear is desirable.

The tooth profiles of the tool wheel should be made so that the envelope of the burnishing rollers corresponds to the involute profile of the teeth of the mating gear, intended to work in tandem with the currently burnished gear. The correction of the shift of the outline of the teeth of the wheel-tool can be selected in such a way as to increase the slip (actually rolling) during burnishing in the area of the tooth base. This serves to intensify the burnishing process in the more critical part of the tooth height.

Supporting the set of burnishing rollers 2 on beams 7 and springs 8 allows them to freely roll over the burnished tooth profiles and then return to the starting position.

During the burnishing procedure, an intensive spray of cooling and lubricating liquid should be used to eliminate unfavourable excessive heating of the elements. It is also possible to perform burnishing in full immersion in a cooling and lubricating liquid.

Depending on the needs, one-sided or double-sided tooth machining can be used, especially for gears operating in reversing systems or intermediate gears. When machining on two sides, the gear must be turned over to the other side. Also, the gear-tool is purposeful to be turned over periodically for even wear of the tool.

After appropriate adaptation of the device, it is possible to process helical gears and roof gears. Noteworthy is the low energy consumption and high efficiency of wheel machining. Gears made of various materials can be machined, with particular emphasis on wheels made of steel after thermal improvement and carburized wheels. However, machining of wheels after nitriding or nitrosulphurization should be avoided due to the possibility of exfoliation of the thin layer of tooth material strengthened by nitriding.

A water-oil emulsion commonly used for cooling during machining can be used as a cooling and lubricating liquid.

Final remarks

The selection of the optimal burnishing treatment parameters for both described devices can only be made by the trial method because of the huge number of gears sizes, their modules, types of materials, applied tooth treatment methods, parameters of heat treatment and thermo-chemical treatment. The purpose of the reinforced gears should also be taken into account.

It is advisable to use both devices described for burnishing in any order. In order to enhance the improvement of the tribological properties of reinforced wheel teeth, it is additionally recommended, after performing the pressure burnishing with both devices, to apply short-term shot peening to obtain a particularly favourable relief of the operating surface of the teeth of the reinforced gears.

The application of the described surface work hardening treatments in practice allows for a significant improvement in the durability of the gears in terms of increasing the tooth breakage resistance, improving the resistance to abrasive wear and fatigue pitting.

The improvement of the tribological properties of the working surface of teeth increases the effectiveness of lubrication and increases the resistance to temporary overloads of the gears during operation and to scuffing, too.

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