RECOVERY THROUGH SURFACE-WELDING OF TOOTHED GEARS OF DRUM MILLS

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ABSTRACT. The majority of the drum mills used in the mining industry have peripheral drive of the drum. This determines the presence of large-sized toothed gears with considerable size, weight and cost. After 8 to 10 years of service, the cog-wheels wear out on the one side of the teeth (depending on the direction of drum rotation), which results in deterioration of the teeth pair operational mode and risk of fracture and failure of the mill unit. Therefore, after expiration of the term of service, they are scrapped or recovered. This article shows a technology for recovery of worn out toothed gears through welding. The method for determining the electrical parameters of the electric arc welding is also explained, as an example it is applied to a gear of a mill type МШЦ 4,5 x 6. All other concomitant technological operations related to the restoration of toothed gears with parameters similar to a new one are also shown here.

Keywords: toothed gear, mill, surface-welding, electric arc

ВЪЗСТАНОВЯВАНЕ НА ЗЪБНИ ВЕНЦИ НА БАРАБАННИ МЕЛНИЦИ ЧРЕЗ НАВАРЯВАНЕ

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РЕЗЮМЕ. Голяма част от барабанните мелници, използвани в миннодобивната промишленост, са с периферно задвижване на барабана. Това обуславя наличие на едрогабаритни зъбни венци със значителни размери, тегло и цена. След 8-10 години служба зъбните венци се износват от едната страна на зъбите - в зависимост от посоката на въртене на барабана, което води до влошаване режима на работа на зъбната двойка и до опасност от счупване и отказ на мелничния агрегат. Поради това, след изтичане на срока им на служба, те биват бракувани или възстановявани. В настоящата статия е показана технологията за възстановяване на износени зъбни венци чрез наваряване. Обяснена е и методиката за определяне на електрическите параметри на електродъговото наваряване, като за пример тя е приложена на зъбен венец от мелница тип МШЦ 4,5 х 6. Показани са също и всички други съпътстващи технологични операции до получаването на възстановен зъбен венец със сходните параметри на нов.

Ключови думи: зъбен венец, мелница, наваряване, електродъгово.

Introduction

The toothed gears of the mills wear out one-sidedly by reducing the thickness of the tooth. Three methods are used for the gear`s restoration:

- replacement with a new one;
- recovery of the gear through surface-welding;
- correction of the toothed gear via the method of "Negative height correction".

The following has to be summarized about the recovery of toothed gears:

- it is advisable to create a stand with automatic surface-welding devices for worn teeth;
- an electrode or wire consumption is necessary, e.g.its quantity for a toothed gear of drum mill МШЦ 4,5x6 exceeds 1000kg;
- high electricity consumption, associated with the surface-welding of teeth;
- undetermined mechanical properties of the teeth, different from those of the main metal;
- difficulty in the mechanicl treatment (lathing and teeth-cutting) of the welded teeth, leading to further operation, namely temperature recovery in a furnace after the welding;
- thermal tensions between the weld layer and the base metal of the gear, resulting in a decrease of the teeth mechanical properties, variation in their geometric shapes, microcracks and lower reliability and term of service of the toothed gear.

To apply the "Negative Height Correction" method, we need to have the following prerequisites:

- the presence of a residual thick bandage of the toothed gear, allowing a negative height correction (pitting of the cutting contour at the teeth-cutting) without affecting the solidity and deformation characteristics of the gear;
- the possibility of displacement of the center-to-center distance of the gear.

The technology of toothed gear recovery through a "Negative height correction" has the following advantages:

- the geometrical and kinematic characteristics of the reconstructed gear are equivalent to the normal features of a new one;
- the teeth are made entirely of the gear's main metal;
- the mechanical treatment (lathing and teeth-cutting) is several times smaller in volume, than when making a new toothed gear;
- the exact calculation of the height correction allows very rapid and good recovery of the gear;
- the installation works, when replacing a repaired gear, are with lower labor costs than during the installation of a new toothed gear;

- the technology including a height correction can not be used in mills, where it is not possible to displace the center-to-center distance or there is a thin bandage.

The main question that may be set in the present study is about the possibility to recover a toothed gear through the surface-welding method and its economical justification.

Summary

The aim of the present study is to describe the activities of a vast recovery of large-scale toothed gears through surface-welding and to prove the quality of this technology.

Technology and equipment for toothed gears recovery through surface-welding. On the basis of what has been mentioned above and having in mind that the technology includng a height correction can not be used in all mills, a technology for recovery through surface-welding is proposed. This repairing technology covers a number of activities carried out in the following order:

Identification of the toothed gear. After removing it from the mill, the gear is stored in two or four parts (Fig. 1). The next step is testing after thoroughly cleaning of all contact surfaces (A_1, A_2) and the gear parts. The cleaning is performed with a metal brush and sandpaper in order to remove all mechanical contaminants and metal oxides on the co-mounting surfaces.

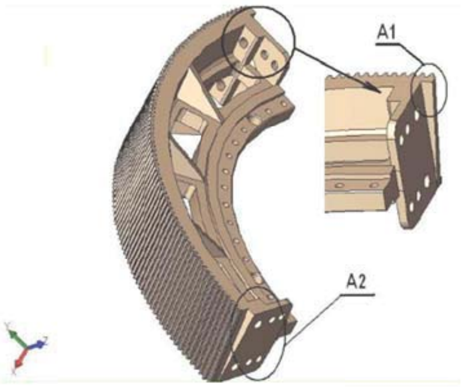

Fig. 1. One fourth of a toothed gear

The trial installation aims to establish the compliance and the affiliation of the separate parts of the gear. After that, the gear is separated and transported to the machine factories for a mechanical processing.

Preparation of a gear for surface-welding. When worn out parts are recovered, the place to be welded (the worn out part of the tooth) must be cleaned to a metallic gloss. This is done by sandblasting, technical brushes attached to a mechanized hand tool or by grinding with a DASH disk driven by an angle grinder. Regardless of the chosen mode, the cleaning should cover the welding area and in addition, 10-15mm around it.

During the recovering of the worn out part of the gear it is necessary to remove the top layer of metal from the working surface due to the danger of old cracks and other defects that can develop in depth of the part or in the welded layer. For this reason, these areas with defects are taken off in depth until they completely disappear. The area of the gear that is meant to be welded should not have sharp edges, so there should be made roundings with a radius over 3-4mm. Occasionally, when welding details with more complex shapes, a special bending (bed) for the welded metal is made, which takes into account the required thickness of the layer and the addition for the mechanical treatment, as well as the conditions for more convenient surface-welding.

When welding the toothed gear, the basic metal must be in inversely heated condition to have sufficiently high plasticity to absorb stresses and deformations.

The cleaning is done with metal brushes, sandpapers and sandblasting apparatus in order to remove all mechanical contaminants and metal oxides on the main metal onto which the surface-welded layer will be placed (Fig. 2).

In order to achieve a better quality of the coated layer and fewer defects, it is recommended the sectors of the toothed gear to be heated up to 150 degrees prior to the teeth welding.

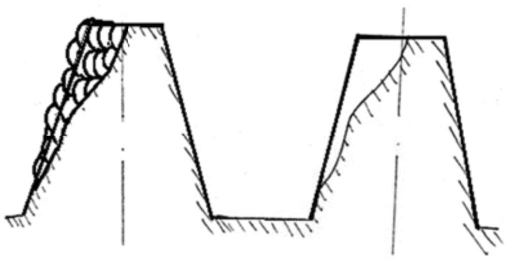

Fig. 2. A layer intended for surface-welding

Technological parameters of welding. The main parameters, determining the technological mode of welding are: the type of grease coating and the thickness of the electrode or electrode wire; the amperage, voltage and polarity; the length of the arc and the speed of movement of the electrode or the handle. These parameters determine the size and quality of the surface - welded layer as well as the character of the heat influenced area.

The welding should be done with a minimal arc length and without any interruptions. In order to avoid defects, the excitation as well as the break of the arc are as far away as possible from the welded layer. The surface-welding should be performed insuch a way that each subsequent transition overlaps from 1/3 to 1/2 of the previous one. The toothed sectors of the gear are placed in such a manner that the manual arc welding to be horizontal and comfortable for the welder (Fig. 3).

Fig. 3. A method of placing the gear at the welding

Selection of electrodes or wire for welding. Generally, the electrodes are selected with a basic thick grease coating, and the choice of electrodes and wire is determined by the chemical composition of the main material. In this case the rule is that the chemical composition of the electrode or wire corresponds as much as possible to the basic material. However, when it is necessary to increase the wear resistance of the parts, it is recommended to use alloyed materials, for example with a high content of manganese or chromium. Generally, the welding technology must be pursuant to the features of the basic material so that no structural changes occur in the part under the influence of the thermal welding mode.

At the manual welding, the electrode quality is of a great importance.

When there is a large difference in the compositions and properties of the base and the welded material, defects (cracks or flakes of the coated layer) may occur, so it is necessary to use the so-called intermediate layers.

Once an electrode or a wire is selected for welding according to their mechanical properties and chemical composition, the next step is the selection of the diameter of the electrode rod or the wire. This choice is determined by the required thickness of the welding layer and for this purpose the information presented in Table 1 is recommended.

Table 1.

Diameter of the electrode, mm	3	4-5	5-6
Thickness of the welded layer, mm	Up to 1.5	Up to 5	over 5
Number of welded layers	1	2	2 and more

When determining the overall thickness of the surface-welded layer, it is also necessary to provide an addition (2-3 mm), because subsequent mechanical processing is required.

Determination of the electrical parameters of the welding. The selection of amperages depending on the diameter of the electrode is based on the constant current loading of the electrode rod cross-section. The approximate amperage for electrodes with a diameter of 3 to 5 mm is determined by the formula:

$$I = k.d, A \qquad (1)$$

where: d is the diameter of the electrode;

k - coefficient varying in the ranges from 30 to 50, proportional to the diameter of the electrode.

More precisely, the amperage, depending on the diameter of the electrode, is determined by the empirical formulas:

$$I = (20 + 6.d).d, A \qquad (2)$$

$$I = (20 - 25).d^{1,5}, A \qquad (3)$$

Based on the formulas 2 and 3, the indicative values of the current are calculated, depending on the standard diameters of the electrodes (Table 2).

Table 2.

Diameter of the electrode, mm	2.5	3.25	4	5	6
Current amperage, A	60	100	150	200	340

The data from Table 2 is indicative because the optimum values of the current depends, althought to a lesser extent, on the chemical composition of the electrode, the type of grease coating, the length of the arc, the welding rate and other factors. When using wire feeders, only the diameter of the wire is set and the current is automatically determined by the welding machine.

A selection of the welding mode. It is recommended to be performed at a short arc, without interruptions and with minimal melting of the base material. The arc must be excited and interrupted, if possible, outside the working part of the welded layer. Table 3 shows the mode procedure at the surface-welding of a toothed gear of a mill type МШЦ 4,5 x 6.

Table 3.

El. d, mm	Pol.	I, A	U, V	t, s	L, mm	V, $mm.s^{-1}$
5	+ riverse	200	22	4-6	500	3.2-4.2

Technique of manual arc welding of the toothed gear. It differs from the welding mainly by the movement and inclination of the electrode or handle of the wire-feeding apparatus. The welding begins by tapping the electrode (vertically) onto the gear, causing the arc to ignite, then the electrode quickly retracts at a distance of 2-3mm and inclines at an angle of 20-30° to the vertical direction towards the direction of motion. With such an inclination, the drops of molten metal from the electrode fall into the melted area of the part.

In vertical position of the electrode (which should not be allowed) or if it is inclined to the vertical, but moves in the opposite direction of the above-described situation, it is possible the molten metal drops to fall on the surface of the detail, that is not yet melted, which is a prerequisite for weak bonding of the welded layer with the main metal of the part.

When welding, it is considered that the optimal depth of the molten area of the part should be about 30% of the total thickness of the welded layer. In the case of a larger molten area, carbon and other alloying elements of the part are burned, thereby reducing the mechanical properties of the base of the welded layer with the basic metal.

Welding should be performed in such a manner that each subsequent welding layer (transition) should overlap from 1/3 to 1/2 the previous one (Fig. 4a). Otherwise, slag inclusions may remain between the passages (Fig. 4b) and in case of multi-layer welding the quality of the welding may be coarsed. Fig. 5 shows a planar suface as the large-scaled toothed gear could be accepted for, because of its enormous radius. The welding often occurs without the oscillating movement of the electrode, which is characteristic of the joint-welding.

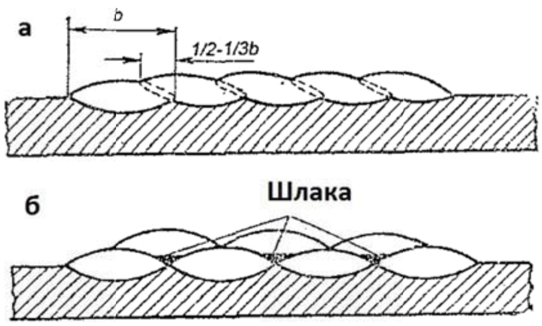

Fig. 4. Technique of surface-welding, used for recovery of a toothed gear

Apart from the above-described, the welding of planar surfaces can be done by a combined method, known as alternation of narrow and wide strips as shown at Figure 5. In this method, narrow strips without the oscillating movement of the electrode (3-5 times the diameter of the electrode) are initially welded, and then the intermediate distances are filled with oscillating motions of the electrode. The wide inter-layers should overlap from 1/3 to 1/2 of the narrow strips.

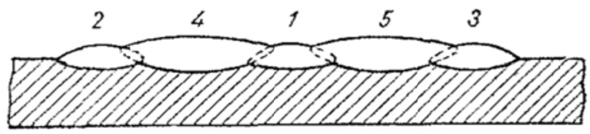

Fig. 5. Welding with narrow and wide strips

In the multi-strip welding of the surfaces of the gear, the welding of the next (upper) layers should be done after the surfaces of the lower ones are cleaned from the slag to a metallic gloss. In addition, each next (upper layer) is placed perpendicular to the lower one.

Assembly and annealing of the gear. The assembling is carried out in the company in which the thermal and mechanical processing of the toothed gear will be done.

The annealing is necessary due to the high hardness of the welded layer, that would result from the self-hardening, caused by the large mass of the bandage, leading to therapid cooling of the welded layer. This is done after the gear is assembled in a gas furnace. An exmplary thermal characteristic is shown on Figure 6.

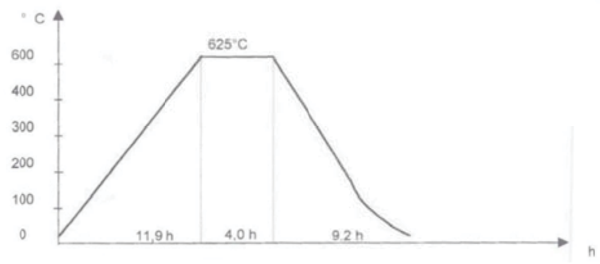

Fig. 6. Annealing characterisctics

Lathing of the toothed gear. The gear is placed on the planner rigger of the carousel lathe. In order to ensure a good result of the teeth-cutting, the lathing operation must be performed under conditions which ensure reliable setting and measurement bases. These bases are the internal diameter D_B, mm of the gear (setting) and the outer diameter D, mm (measuring). Thus, the accurate operation of the front and cylindrical surfaces is ensured and minimal radial and front beatings are guaranteed on them.

As the surface of the processed diameter serves as the basis for the alignment, this is done through an indicator clock with a sensitivity of $\delta = 0{,}01 mm$. In the case of available ellepticity on the centering (setting) diameter, the center of the planner rigger has to coincide with the geometric center of the gear. This is achieved if the measuring clock nozzle, attached to the spindle of the carousel lathe, describes a circle with a radius where *a* and *b* are relatively the both half-axes of the ellipse in the diameter hole.

The centering on the toothed gear front surface is also done with an indicator clock with a sensitivity of $\delta = 0{,}01 mm$. This centering follows the front beating, measured on the surface at both ends of two mutually perpendicular diameters of the toothed gear, and divides symmetrically (as divided into two) with respect to the horizontal plane.

The accuracy at the lathering of the outer diameter shall be of the seventh rate, where the tollerance for this diameter does not exceed 0.8 mm, and the beating of this diameter and the forehead with respect to the setting - not more than 0.08 mm.

All the base surfaces are processed to a roughness class not exceeding $R_Z = 20 \mu m (\Delta 5)$.

The obtaining of the new diameter of the repaired gear is achieved with a radial feed of the knife equal to l (Fig. 7).

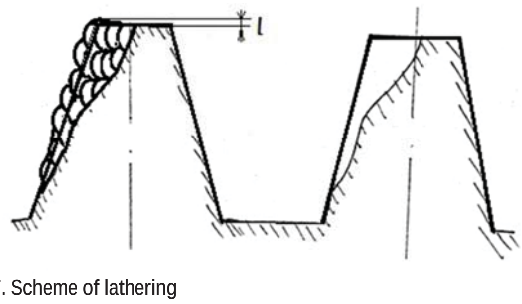

Fig. 7. Scheme of lathering

It is appropriate for the removal of the addition to happen in one transition at a rate of submission $v = 0{,}8 mm / \min$.

The recommended speed for this typical continuous cut-off mode is from 30 to 90 m/min. It is assumed for it to be about $v_P = 60 m/\min$.

Teeth-cutting of the gear. The teeth-cutting of the gear can be performed on a worm gear hob by the touring method. The axial profile of the cutting section of the worm hob practically does not differ from the toothed gear, and therefore the cutting of the teeth with a worm gear hob can be represented as a splitting of an edge with a toothed wheel.

The working motion is ensured by the rotation of the hob 4 (Fig. 8). To ensure touring, the rotary movement of the worm hob and the toothed gear 3 must be coordinated in the same way, as the splitting of the worm 1 and worm gear 2. The rotation rate of the table with the gear must be less than the rotation rate of the hob, as the number of teeth of the toothed gear is greater than the number of hob cuts (in a single-cut hob the table rotates *z* times slowly than the hob).

When setting up the machine, the following operations are used: tuning of the machine's kinematic chains – gears lyra, feeding, dividing, differential; the toothed gear is put into place and centered, the hob is set to a specified cutting depth and the automatic cut-off or switching stops are set.

The machine has a differential mechanism that provides additional rotation of the gear when cutting the teeth because they are inclined.

Before the teeth-cutting, the toothed gear is adjusted to the front surface and the outer diameter.

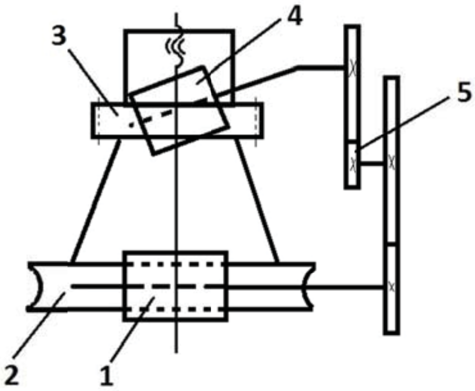

Fig. 7. Principle of operation of teeth-cutting hobs

The following rules must be observed when operating:

1. When attaching the toothed gear, gently clean all the centring and supporting surfaces from raspings and dirt.
2. Periodically check the radial beating of the work (centering) mandrel on the table.
3. Periodically check the front beating of the supporting bases of the setting device.
4. Place and screw up the toothed gear not to deform at the strongest tightenings, the screws are evenly tightened.
5. Check the radial and front beating of the gear before and after the machine is attached.
6. Due to the large sizes of the toothed gear, in order to reduce the internal stresses it is recommended to loosen the clamping screws after the rough machining process, re-tighten them prior to the clean processing and check the beating.

The outer surface of the gear ring serves as the base for adjusting the depth of hobbing. After switching on, the hob approaches the gear until its touching. In this position of the table and the stands, the linear or circular scale is reset to zero. The cutting-machine support is then lifted while the hob is over the toothed gear and then an additional radial alignment of the hob and the gear is performed to obtain the required cutting depth. The movement is detected with a ruler, a circle scale, or a measuring clock.

The sensitivity is checked with an indicator measuring clock with a sensitivity of $\delta = 0,01 mm$, in the same way as at the lathing operation.

Full tooth processing should be done for no more than 2-3 passes. Toothed gears of 7^{th} rate of precision are cut into a slot-shaped modular hob and two clean passes with a worm gear hob.

The gear of 8^{th} rate of precision are cut into a slot-shaped modular milling cutter and a single worm gear pass.

The cutting rate depends on the hardness of the material and it is selected as follows:

$v = 18 m/\min$ at HB = 160;

$v = 15 m/\min$ at HB = 190;

$v = 12 m/\min$ at HB = 220.

Due to the fact that a large part of the intermediate space is formed during the initial cutting of the gear, the removal of the basic amount of metal takes place through a drafting pass. Its depth should be determined in such a way so as to ensure that the worm hob is operated at the cleaning pass only with the side cutting edges. Therefore, it will only shape the evolvent profile of the working surfaces of the teeth, with minimal wear on the back surface of the teeth of the hob.

The control of the final phase of teeth-cutting can be done by measuring the total norm or by measuring the thickness of the tooth in different sections.

After the cutting, the gear is also controlled. This includes a profile error measurement. Deviations of the profile from the theoretical ones are recorded with a measuring clock or footprint. The universal evolvent-meter allows the profile of the tooth to be checked in different sections along its right and left sides without changing the position of the gear.

In addition, the basic step is also controlled, for example by a stationary universal tooth measuring device БВ-5060.

Conclusions

In conclusion, it can be stated that the chosen technology in this report is suitable for the recovery of the toothed gears of drum mills for ore grinding.

A new toothed gear is priced and available in the market at costs from 300 000 to 450 000 EUR, while the cost of the surface-welding recovery operations is no more than 50 000

EUR, which proves the great economic effect of the implementation of this technology. In addition, the material of the old restored gear is well trained and has better exploitational properties and fewer internal defects than these of a new one.

The qualitative performance of this technology can be increased considerably if a mechanical stand for automatic surface-welding of worn out teeth is designed and manufactured.

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