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RESTORATION OF LARGE MODULAR TEETH OF BALL MILL GEARS BY ELECTRO-SLAG SURFACE

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This article is devoted to researching the possibility of restoring straight-toothed large-module gears by electro-slag surfacing of individual defective teeth. During the work, an installation was designed and manufactured to restore gears that do not require further machining. A comparative analysis of the proposed technology with the traditional surfacing technique was carried out, paying attention to variables such as the composition of the surfacing material used, process parameters, stabilization of the electro-slag process, and ensuring the geometric dimensions and profile of the tooth. The study results demonstrate that the proposed technology provides higher hardness and wear resistance of remanufactured parts compared to traditional methods.

Keywords: large-module gears, tooth wear, electro-slag surfacing, ball drum mills, crystallizer

1 INTRODUCTION

Drum ball mills (DBM) (Fig. 1) [1] are designed for grinding anthracite, hard and brown coals, shale, etc. to a powder state, and are designed for continuous operation in dust preparation systems of thermal power plants. Mills are installed in the dust preparation systems of thermal power plants and are selected following the standards to calculate and design dust preparation installations for boiler units.

Coal grinding is carried out by the impact and rubbing action of steel balls loaded into a drum. The mill is unloaded by continuous suction of finished dust through a pipe using a gas-air network.

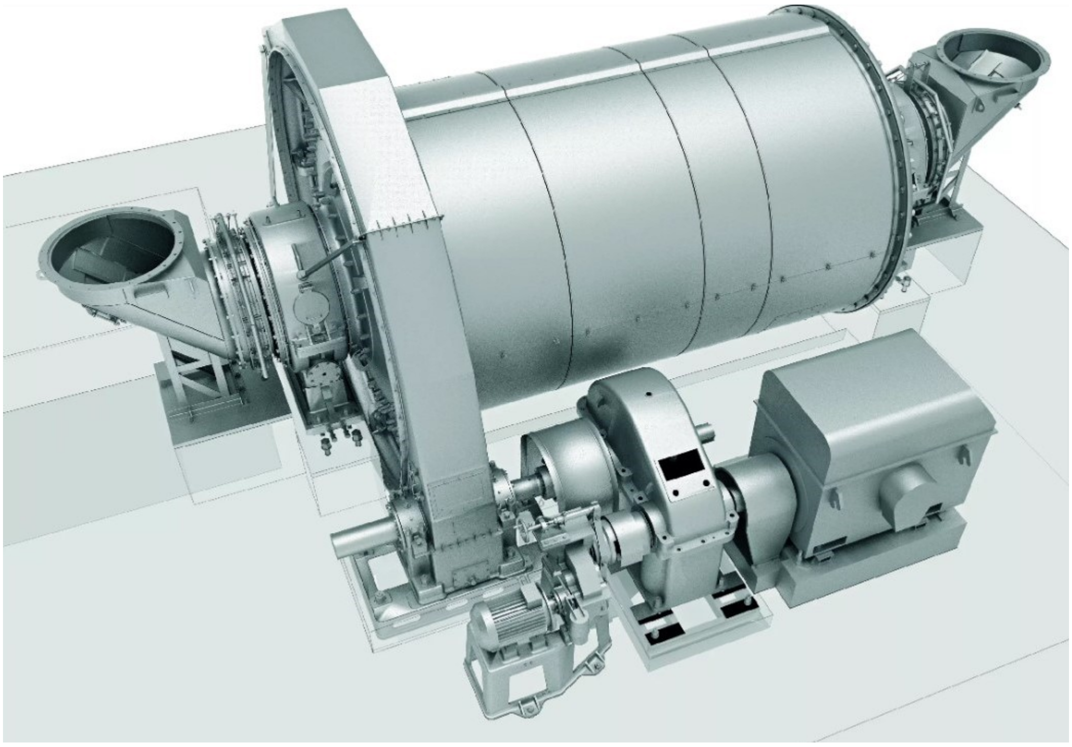


Fig. 1. Ball drum mills (scale 1:1000) [1]

Ball drum mills (Fig. 2) consist of bearings 1, 6; 2 – sealing pipe, two pipes – coal supply and dust discharge with seals 3, 7; 4 - gear, 5-drum and 8 - drive. The drum rotates from the main electric motor through couplings, gearboxes and drive gears (Fig. 3). The drive system consists of a ring gear and a drive gear.

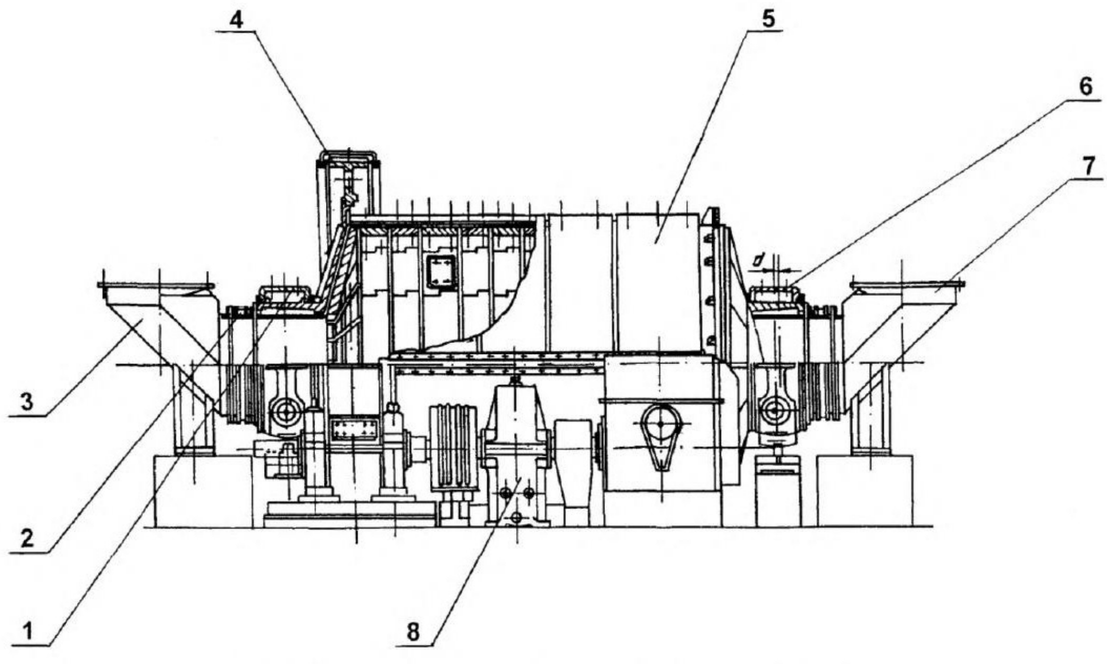


Fig. 2. Sketch of a ball drum mill (Author's contribution):1, 6 – bearings, 2 – pipe seal, 3, 7 – pipe, 4 – gear ring, 5-drum, 8-drive

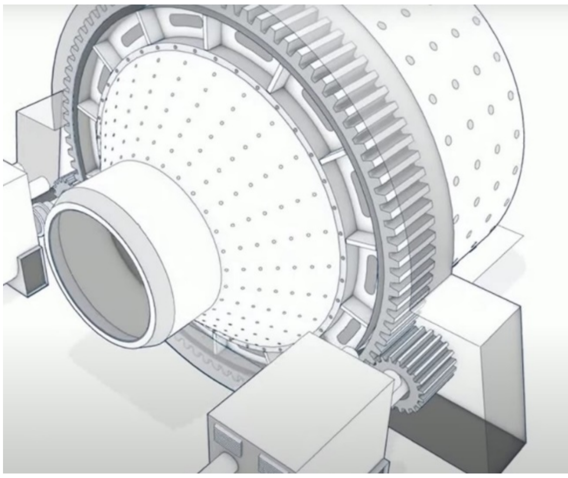


Fig. 3. Ball drum mill drive (scale 1:1000) [1]

The advantages of drum ball mills compared to other devices for grinding hard rocks are high productivity, the ability to adjust the grind size, and versatility, i.e. possibility of processing a variety of materials [1]. A characteristic feature of the operation of the grinding machines of the dust preparation system of thermal power plants is the flow of a continuous technological process (Fig. 4).

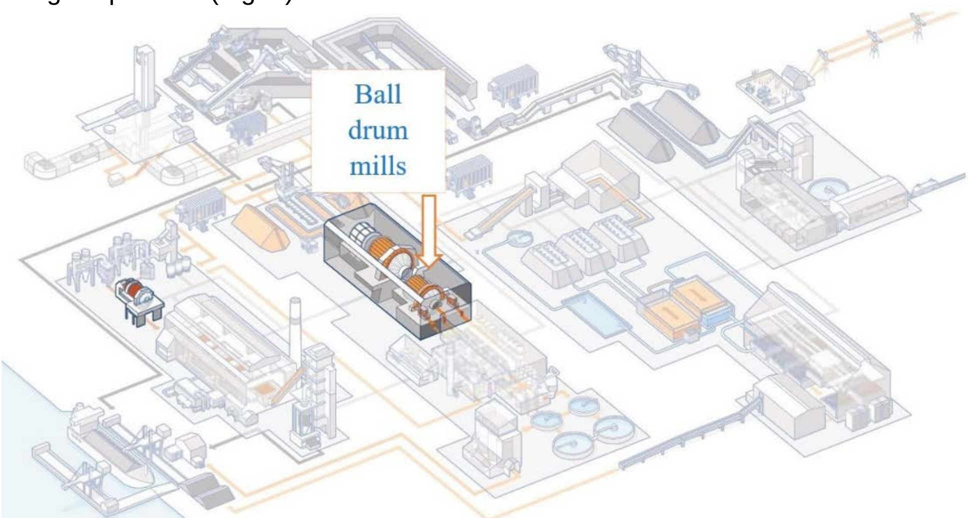


Fig. 4. Power plant process flow [1]

All equipment is connected into a single technological chain, thus, stopping or failure of any machine or unit that makes up this chain leads to a stop of the entire chain. Increasing the service life of a part is especially important if the operation of high-performance equipment or a technological chain depends on it, and the replacement of such a part is associated with long downtime. In connection with this, the restoration of worn parts of the technological chain is relevant.

During operation, grinding units are most intensively subjected to abrasive wear [2]. Wear disrupts the interaction of parts and assemblies and can cause significant additional loads, shocks in joints and vibrations, and cause sudden destruction [3]. During operation, parts of the DBM drive, for example, the drive gear, are subject to prolonged exposure to variable loads. Under the action of variable loads, the destruction of parts occurs with noticeable plastic deformations. As a result of wear, abrasion, and fracture of the teeth, the initial dimensions (Fig. 5, a) and shapes (Fig. 5, b) change.

a) change in tooth size

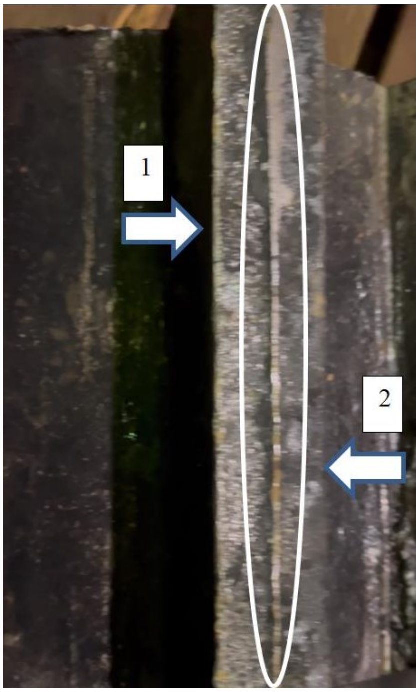
b) change in tooth shape

Fig.5. Worn DBM drive gears (Author's contribution)

Restoring the performance of gears is an important and complex process that can be performed using various methods depending on the condition and nature of the damage to the gear [4]. It is more expedient to restore large steel gears by completely cutting off worn teeth on lathes, automatically surfacing under a layer of flux along the outer surface to the full height of the teeth, processing the deposited layer on lathes, and cutting teeth on a gear hobbing machine [5]. Metal of the same chemical composition as the gear being deposited is used as a filler material.

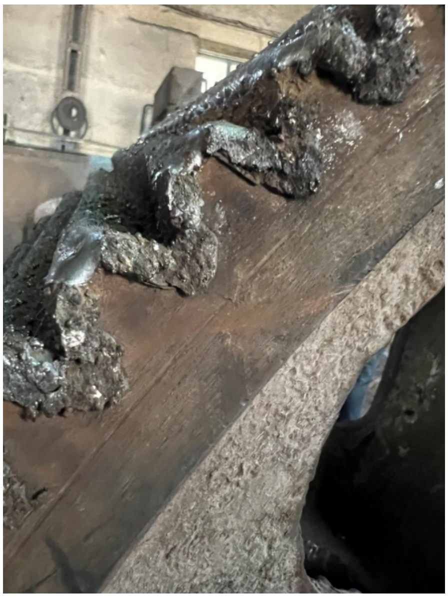
In the conditions of the enterprise, the worn teeth are restored by surfacing the gear element on the wheel body (Fig.5, a), in this case, involute tooth shape is not observed, and some teeth consist of two parts (Fig.5, b), then they are joined by welding (the welding place is marked with a circle), or surfaced along the whole contour (Fig.5, d), then cleaned manually. The gears restored by such methods are not durable, do not withstand dynamic loads, and after the short-term operation (about 5h.) they are again partially destroyed (Fig.5, e), after several attempts worn-out wheels are sent for remelting. The problem of research is the creation of effective technology and design of the unit for surfacing of worn large-modular teeth, providing high workability and minimization of post-fusion machining.

a) factory remanufactured gear



b) restored gear tooth, m=20mm: 1-part, 2-part

c) restored gear tooth, m=20mm



d) welded tooth, m=20mm

d) welded tooth, m=14mm

Fig. 6. Reconditioned gear teeth under factory conditions (Author's contribution)

The purpose of the study is to develop the technology and design unit for surfacing worn large-modular teeth that eliminates the need for subsequent machining.

2 METHODS AND METHODOLOGY

In the course of the study the following methods were applied: the existing literature was analyzed to familiarize with the methods of restoration of gear teeth. An experimental approach was applied, including the use of an electro-slag surfacing method for gear teeth restoration. Testing of the developed device for electro-slag surfacing and verification of compliance of the restored gear teeth with the requirements of the working drawings.

The research methodology includes the following main stages: identification of mechanism parts with a high degree of wear; development of equipment for electro-slag surfacing, including the development of working drawings, manufacturing of parts and assemblies, as well as their subsequent assembly and testing; development of the crystallizer design, ensuring compliance of the part dimensions with the drawings; surfacing of teeth on the electro-slag surfacing unit; verification of compliance of the surfaced tooth dimensions with the requirements of the drawings; assembly of the restored drive pinion.

Surfacing is used as a process designed to restore worn parts and create surface layers that differ from the base metal in specific properties [6, 7]. For these purposes, many technological methods have been developed, which have led to a variety of types of surfacing [8]. When restoring non-cylindrical surfaces, such as gear elements, there are two main layout options: horizontal and vertical [9, 10]. The horizontal surface is most often restored using arc surfacing processes, while the vertical arrangement is more competitive with non-arc processes. Among non-arc vertical welding processes, electroslag surfacing is the most common [11, 12].

One of the key problems encountered in vertical electroslag surfacing is ensuring the initial process of guiding the slag pool and the stability of the electroslag process itself [13, 14]. In order to facilitate the creation of a slag bath, special fluxes are mainly used [15, 16]. Stabilization of the electroslag process itself is achieved in various ways: by using special current sources [17], increasing the diameter of the electrode wire [17], and intermittently supplying electrical power to the welding zone with a continuous supply of electrode wire [18].

The length of the gear teeth of ball mills reaches 450 mm. Increased requirements for the cleanliness of tooth surfaces exclude the use of sliders that move during welding and dictate the use of a stationary die. In this case, a melting nozzle becomes inevitable, designed primarily to guide the welding wire into the melting zone [19].

An analysis of the current state of technology for restoring worn parts [20] showed that several types of welding can be used for these purposes. A distinctive feature of gears as objects of surfacing was the large volume of surfacing and the absence of its solidity. In addition, when developing the technology for restoration work, it was necessary to take into account the following factors:

1. The large mass of the gear when using arc processes will cause rapid heat removal, which can lead to the formation of hardening structures in the thermally affected zone.
2. When arc surfacing, it is necessary to provide for the initiation and termination of the arc process outside the gear body, which can significantly complicate the design of the equipment.
3. To ensure a constant value of the heat input and the same dimensions of the deposited teeth, it is necessary to abandon the formation with a free surface and choose forced formation.

Taking into account the above conditions, electroslag surfacing was chosen to restore gear teeth. Analysis of electroslag surfacing showed a significant advantage of this method in comparison with arc surfacing.

To ensure the dimensions according to the drawing of the part, the crystallizer design was developed (Fig.8, a) [21]. The crystallizer is made of annealed copper and is a metal cauldron, which provides for obtaining the clad metal of a given shape. In the lower part of the crystallizer is attached an introductory pocket in which the metal and slag baths are necessary for heating the base metal and providing the necessary depth of penetration of the root of the tooth. Fastening the crystallizer - rigid, the screw provides radial movement relative to the gear. To ensure the constancy of the heating temperature of the mold during cladding in its body milled channel 1 for cooling water (Fig. 7), which is closed with a cover with fittings (Fig. 8, a). The unit is equipped with a system of forced water cooling of the crystallizer, providing heating of its external parts not exceeding the temperature of 50-60 ° C. There is also a place for fixing the grounding wire. Fixing of welding cables is carried out directly on the cladding gear and fusion mouthpiece fixing unit.

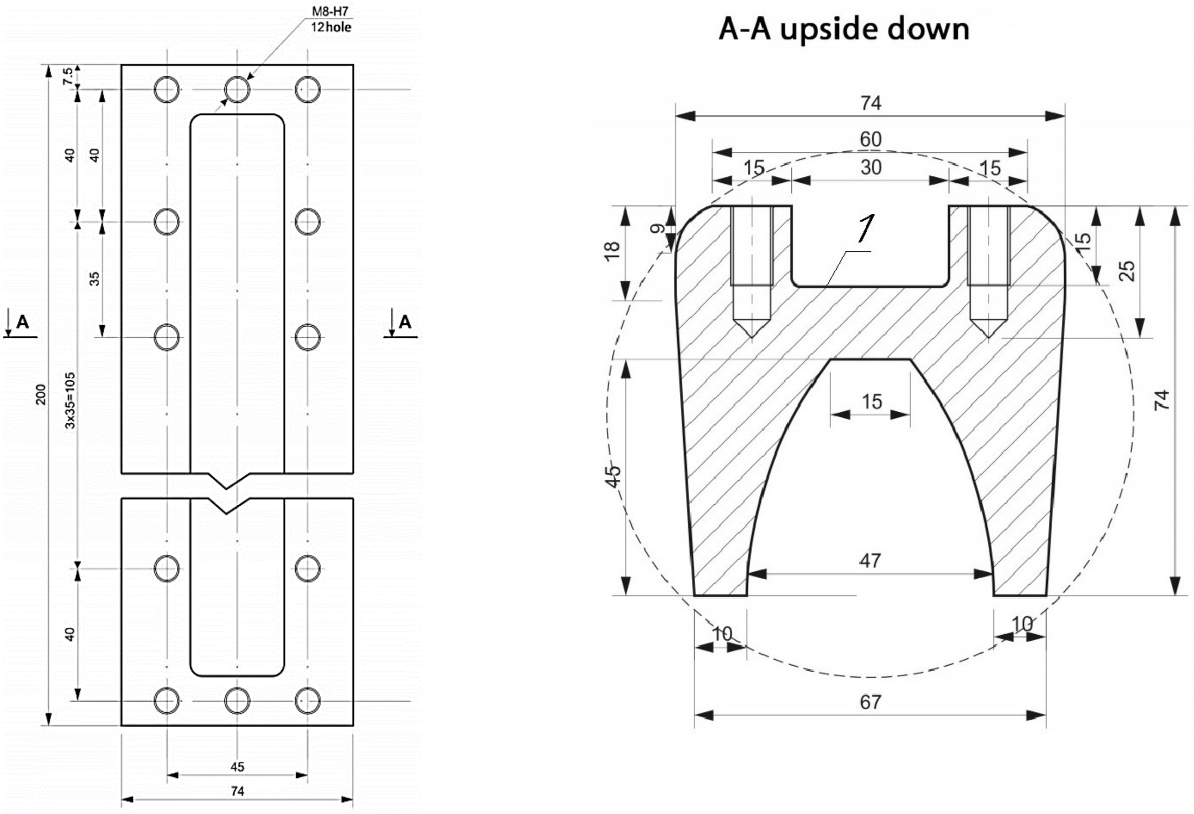
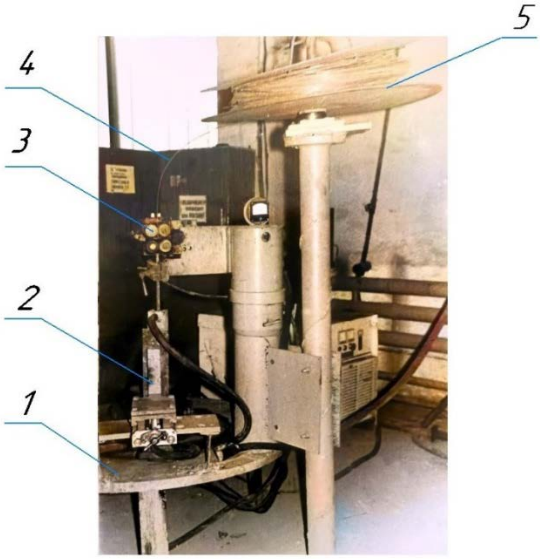


Fig. 7. Crystallizer (Author's contribution)

Varying technological parameters, using different materials, methods, and techniques of use make it possible to obtain in this case a deposited metal with the desired properties. Forced forming makes it possible to deposit metal over an almost unlimited cross-sectional area in one pass. The vertical arrangement of the teeth during electro-slag surfacing made it possible to solve the problem of excitation and termination of the process outside the gear body. Flux 10.71 flux was used to direct the slag bath, and forced formation was used for stability. To excite the initial arc process, a source with a sufficiently high open-circuit voltage was selected: the VDU-1250 Ural transformer. The feed mechanism must ensure a constant wire feed speed. In our case, an ADF-1005 Ural assault rifle was used.

The developed technology for surfacing coarse-grained gear teeth allows surfacing of several worn teeth according to thickness and profile. The principle of operation of the installation (Fig. 8, b) is as follows: a worn gear is installed on the 1st table of devices. In a gear, pre-worn teeth are cut off at the base. A 2-copper crystallizer with a shape corresponding to the tooth profile is brought to the gear and pressed. Flux is poured into the cavity between the gear and the crystallizer and through the 3rd feed mechanism the 4th welding wire is fed from the 5th wire cassette. The process of surfacing a new tooth begins with placing an electro-slag bath at the bottom of the mold.

a) crystallizer



b) general view

Fig.8. Installation for surfacing spur gears using a mold (Author's contribution)

The temperature of the slag bath reaches 2000°C. Maintaining the depth of the slag bath within 40-50mm (controlled by voltmeter readings -50-52W) is carried out by periodically (every 4-5 minutes) pouring flux into the forming cavity in doses not exceeding 15g. A large dosage leads to disruption of the stability of the process and can cause non-fusion of the metal with the base metal.

3 RESULTS AND DISSCUSIONMETHODOLOGY

As a result of electro-slag surfacing, a sample of a drive gear tooth was obtained, shown in Figure 9. In this figure, numbers 1 indicate the prepared surface of the gear before surfacing (base metal of the gear), 2 – the area exposed to electr-slag surfacing (slag), 3 – the deposited tooth. Welded teeth are the main element in the restoration of worn parts, and their quality and compliance with standards play an important role in ensuring the reliable operation of mechanisms. This sample was subjected to quality assessment and checking for compliance with the drawings.

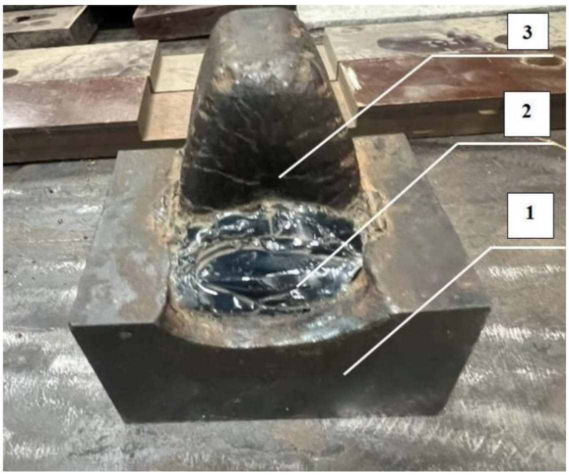


Fig. 9. A sample of a surfaced tooth: 1 - the main metal of the gear, 2 – the area exposed to electro-slag surfacing (slag), 3 – the surfaced tooth (Author's contribution)

During the process of surfacing the teeth, the bath melts the filler wire and heats and melts the surface of the gear in contact with it. As the crystallizer cavity is filled with liquid metal and the metal solidifies, a new tooth profile is formed. In this case, guaranteed fusion of the tooth with the gear body is achieved. After the slag bath exits into the upper part of the mold, the tooth surfacing process is completed, and the mold is removed from the gear. Then the gear rotates, the mold is brought in and the next worn tooth is deposited. The use of this surfacing technology makes it possible to obtain a deposited layer of optimal chemical composition with the required performance properties by selecting the composition of the surfacing wire, consumable nozzle and surfacing modes. The arrangement of elements during surfacing is shown in Figure 10. Equipment for electro-slag surfacing of large-module teeth is installed in the International Welding Laboratory of the Karaganda Technical University named after Abylkas Saginov.

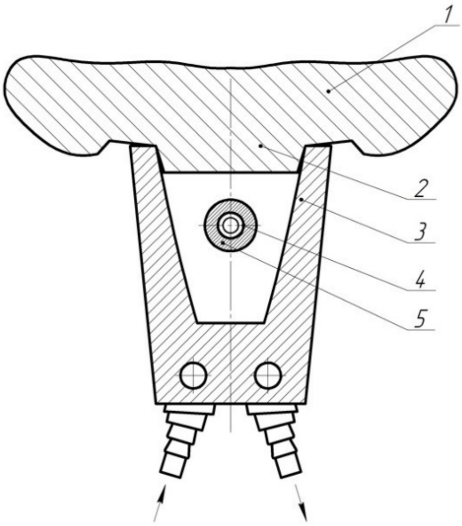
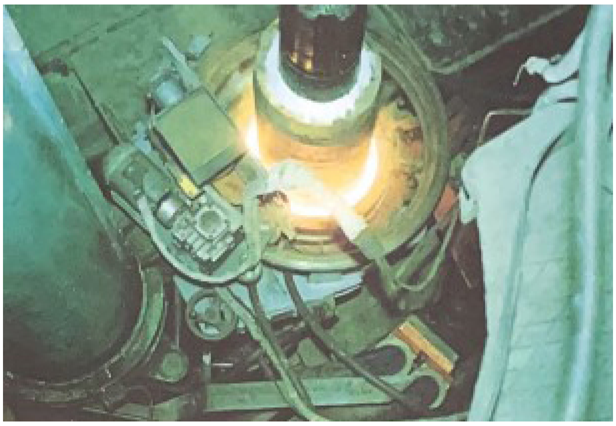


Fig. 10. A sample of a surfaced tooth: 1 - the main metal of the gear, 2 – the area exposed to electro-slag surfacing (slag), 3 – the surfaced tooth (Author's contribution)

a) from the side

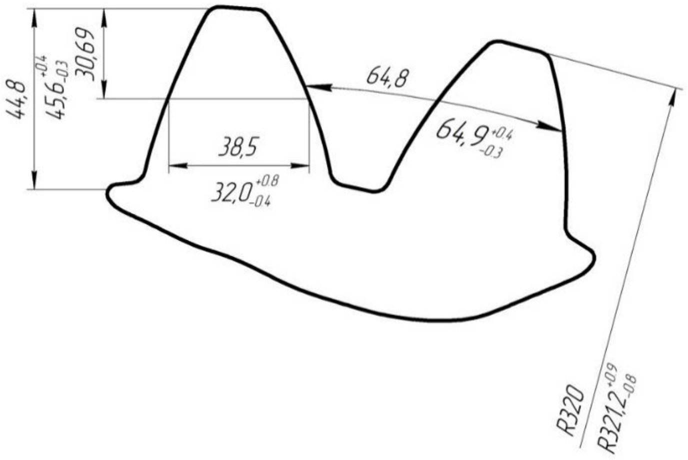


b) from above

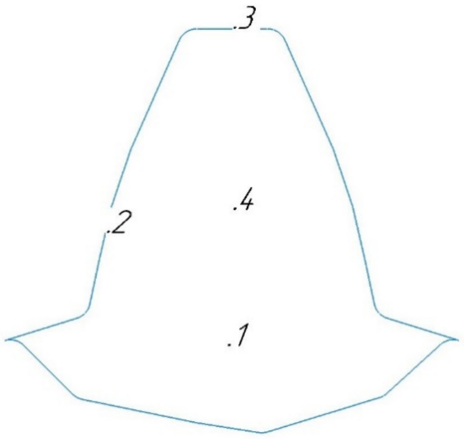
Fig. 11. Teeth surfacing process (Author's contribution)

After surfacing, the deposited teeth were subjected to control (visual inspection) and verification of geometric parameters (Fig.12, a), and hardness measurement (Fig.12, b). Visual inspection did not reveal any surface defects: pores, cracks, shrinkage shells, non-melting, etc.

Hardness measurement was carried out using a dynamic hardness tester TU-I1, the hardness of the deposited metal is on average HB 176.



a)



1-210, 2-176, 3-176, 4-176
b)

Fig. 12. Control of surfaced tooth parameters (Author's contribution)

The restored gear is installed in a ball mill (Fig. 13). After 2.5 months of continuous 24/7 operation, the mill was stopped to inspect the gears. Upon inspection, there was slight wear of the teeth within 1.5-2 mm and a satisfactory condition of their working surfaces. As a result of hardening during operation, the hardness of the working surfaces reached HB210.

Fig. 13. On-site assembly of a remanufactured wheel (Author's contribution)

4 CONCLUSIONS

The problems with gear restoration under factory conditions were identified, which do not ensure the complete restoration of the involute tooth profile, leading to premature gear failure.

The developed equipment for electroslag surfacing ensures compliance of the deposited tooth with the drawing requirements and enables complete restoration of the tooth's involute profile due to the use of the developed crystallizer. A utility model patent of the Republic of Kazakhstan has been issued for the developed crystallizer.

During the research, the peculiarities of gears as surfacing objects were taken into account, such as their large volume, lack of monolithicity, and the need to maintain consistent dimensions of the surfacing teeth.

The developed equipment for electro-slag surfacing, including the crystallizer design, ensures compliance with the drawing requirements for the surfacing tooth.

The conducted testing showed satisfactory conditions of the gear's working surfaces after continuous operation for 2.5 months.

Thus, the developed electro-slag surfacing technique enables successful restoration of worn gears, ensuring their durability and reliability in operation.

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