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ELECTROSLAG SURFACING OF ROTATING KILN GEAR SHAFT TEETH*

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Described is the experience of application of electroslag surfacing for repair of manufacturing defects in teeth of sub-rim gear shaft of a rotating kiln.

Keywords: *electroslag surfacing, gear shaft, teeth defects, recovery, involute profile, consumable nozzle, heating temperature, thermal cycle, residual stresses and deformations*

Reconditioning of large-sized expensive machine components with application of electroslag welding and surfacing allows a considerable extension of their operating life, as well as decreasing the load on foundry and press shops by reducing the quantity of manufactured spare parts [1]. Repair of defects of parts and units developing during their manufacturing, is the less studied category of repair varieties known in practice.

Defects that were not repairable in accordance with the technology of such items manufacturing existing at the enterprise (Figure 1) were found in two teeth at the final stage of manufacturing the sub-rim gear shaft of a rotating kiln of 3.6 × 110 m at PA «Volgotsemmash». Gear shaft (tooth module $m = 40$, number of teeth $z = 21$, teeth length — 700 mm, diameter of protrusions — 920 mm, gear shaft mass — 4150 kg) was manufactured from a solid forged piece of 34KhN1MA [2] steel and designed for delivery to Nikolaev Industrial Complex of Building Products for mounting into kiln unit.

After teeth cutting an inadmissible lowering of the slot and involute profile was found along the entire tooth length on one of the teeth, on the other tooth a part of the profile was cut away. As a result, the expensive part that passed practically all the stages of machining was found to be a definite reject by the plant Department of Quality Control.

However, the specialists of PWI of the NAS of Ukraine and the Department of the Chief Welder of «Volgotsemmash» decided to recondition the rejected gear shaft by applying electroslag surfacing (ESS). ESS technology and special technological fixtures were developed for this purpose. It was necessary not only to only to ensure the quality of teeth reconditioning, but to also to preserve the geometrical dimensions of the gear shaft. The main objective was to avoid formation of longitudinal residual stresses in the gear shaft body in the process of ESS that exceed the area of elastic deformations for the given structural material.

Considering that the gear shaft was manufactured from structural alloyed steel with a high content of carbon (0.3–0.4 %) [3], preheating and post-weld treatment is required at teeth reconditioning. Preheating temperatures were determined by well-known procedure described in study [4]. Calculation showed that the metal section of the gear shaft should be heated up to the temperature of 320 °C in surfacing zone. As it is impossible to apply general normalization of the item after surfacing in this case, it was decided to carry out only high tempering as an experiment.

Defective gear shaft was mounted on reusable bases in a strictly vertical position in one of the electroslag welding sections at PA «Volgotsemmash». A special device was manufactured for monitoring the shaft bending deformation, where two pointer indicators

b

Figure 1. Gear shaft of kiln rotating drive with teeth defects formed in their manufacturing (*a*) and scheme of defects in the teeth (*b*): *1* — tooth with lowered slot and cut away part of involute profile; *2* — tooth with cut away part of involute profile

*Employees of PA «Volgotsemmash» A.P. Syatishev, engineer, D.I. Filchenkov and L.F. Bashev, Cands. of Sci. (Eng.), participated in gear shaft reconditioning.

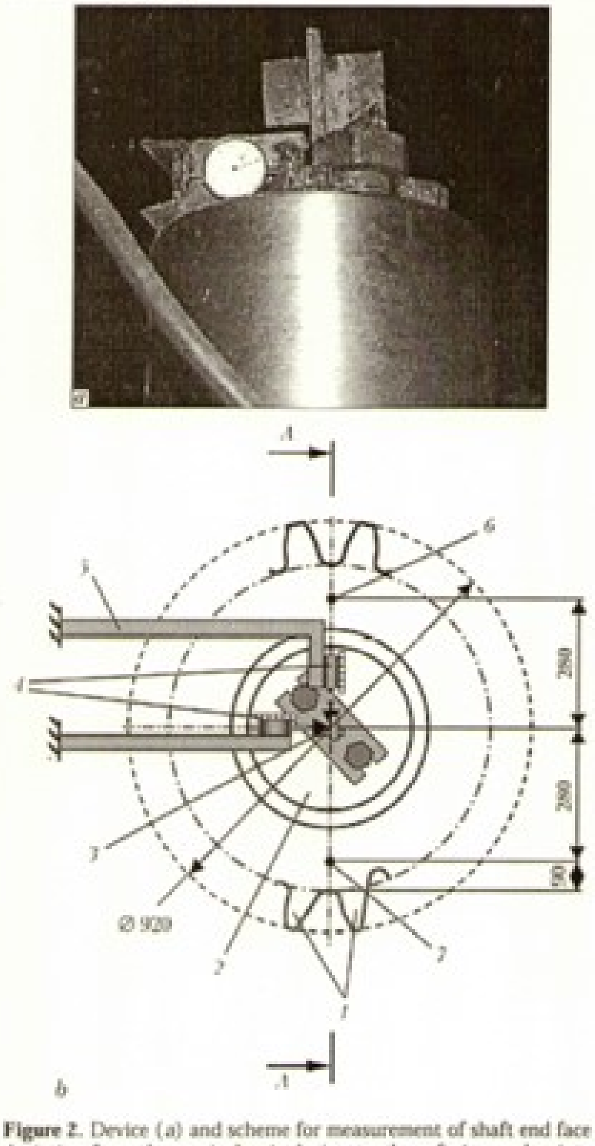

Figure 2. Device (*a*) and scheme for measurement of shaft end face deviation from the vertical axis during teeth surfacing and points of thermocouple mounting (*b*): *1* — defective teeth; *2* — shaft end surface; *3* — supporting straps; *4* — clock-type indicators; *5* — indicators fastening arm; *6, 7* — spot of placing thermocouples # 2 and 1, respectively

with measuring sensibility 0.01 mm were mounted. It was intended to measure the shaft axis deviations in horizontal plane on the level of the upper shaft end (Figure 2). One indicator fixed deviations in the plane passing in the middle of the slot located between the defective teeth, the second — the deviations in the perpendicular plane. Chromel-alumel thermocouples (Figure 2) were calked in the diametrically located sections on the end surface in the area of slot diameter to control the degree of gear body overall heating, as well as for temperature differences supervision. Automatic KSP-4 recorder performed temperature recording.

Considering that the tooth defects were located only on one side of the involute profile, it was decided not to remove the defective tooth body as it was usually done [1], but to perform one-sided surfacing of each tooth with subsequent reconditioning of the working profiles using a modular milling cutter in a gear milling machine. Special technological fixture was manufactured for conducting the reconditioning work: a post with an outer support for holding the clock-type point indicators, plate with supporting straps, copper water-cooled coverplates of a special configuration, graphite crucible, graphite electrode with an electric holder, bottom trough and other.

Figure 3. Fragment of sub-rim gear shaft teeth recovery ($m = 40$, $z = 21$) with ESS application

In order to form the cavities for surfacing, water-cooled coverplates were mounted in parallel to the planes of the cut-off teeth profiles and changeable water-cooled coverplates were mounted at definite angle to them from the side of the tooth tops. The forming fixture was attached to the inlet and outlet pockets located on the tooth end parts to preserve the working surfaces of the teeth located next to the defective teeth. The beginning of electroslag process was performed by the «liquid» start technique for providing a guaranteed fusion in the lower (end) sections of the teeth, as well as required depth of the slag pool. For this purpose a bottom trough was mounted in the inlet pockets, through which strictly dosed portions of the liquid flux were poured in. The flux was melted in a graphite crucible using a graphite electrode. Surfacing was performed by a consumable nozzle using A-645 machine and TShS-3000-3 transformer (Figure 3). Consumable nozzle plates were manufactured of 34KhN1MA steel, using Sv-10G2 welding wire and AN8M flux. ESS conditions were calculated taking into account the recommendations given in study [1]. Preheating of the gear shaft was performed by a powerful flame torch of plant design using natural gas. Shaft neck surfaces accommodating the bearings were covered by asbestos cloth for preserving them from damage during tooth reconditioning. Experimental data of residual deformation measuring obtained at ESS of medium-carbon steels [5] were used, in view of the absence of a practical calculation method of anticipated deformations of items as a result of trans-

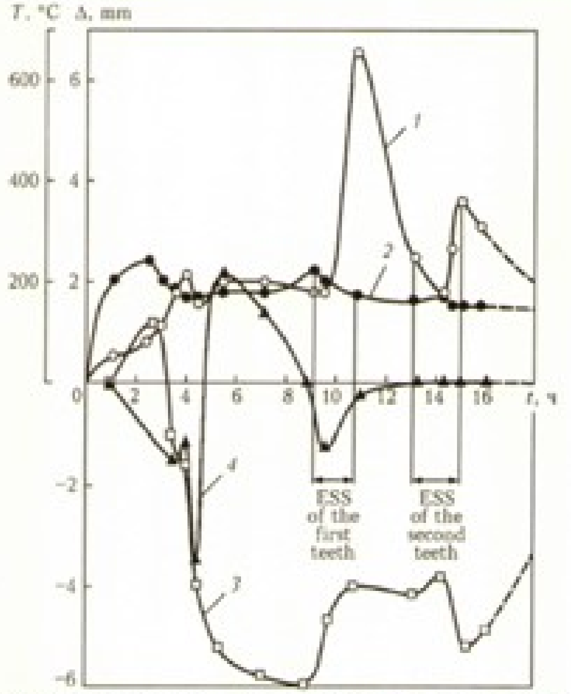

Figure 4. Thermal cycles of gear shaft heating in the spots of thermocouple placing and deviation of the shaft cantilever part from the vertical axis during preheating of gear shaft and repair of defects in teeth (see Figure 2): *1, 2* — metal heating in the spot of placing thermocouple # 1 and 2, accordingly; *3* — deviation in plane *A–A* passing between the repaired teeth; *4* — deviations in perpendicular plane *A–A*

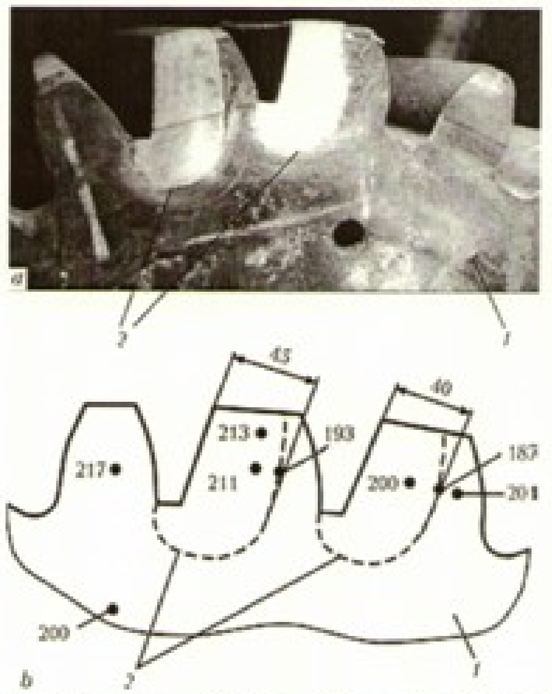

Figure 5. Appearance of end parts of the teeth after ESS and machining of top sections (*a*) and scheme of the shape and depth of teeth penetration (*b*): *1* — gear shaft end; *2* — penetration shape; spots and values of *HB* hardness are shown by dots

verse and longitudinal shrinkage of the deposited metal.

Overall preheating of the gear shaft was done before tooth surfacing. Heating temperature and deformations values were controlled by thermocouples and clock-type indicators (see Figure 2). Flame torch was placed from the side of the defective teeth before surfacing for compensation of longitudinal shrinkage influence on geometrical sizes of the item, and local heating of treated surfaces up to the specified temperature was performed, the upper shaft end surface deviating to the side opposite to surfacing zone by 6 mm. The nature of thermal cycles of metal heating in the spots of thermocouples placing in combination with gear shaft vertical axis deformations caused by preheating and directly by ESS is given in Figure 4.

To eliminate the possibility of partial quenching of the end surfaces of the surfaced teeth, cutting off of the top sections by oxy-gas cutting was performed immediately after ESS. Top sections were cut off not completely, leaving the protruding sections of 15–20 mm high for their further machining. Then, the gear shaft was placed for not more than 30 min into the electric furnace heated up to 350 °C with drawout bottom for conducting high-temperature tempering. In the furnace, the gear shaft was placed on steel bases in the vertical position. Tempering was carried out in the following mode: heating up to 650 °C with the speed not higher than 50 °C/h, soaking during 8 h, cooling with the kiln up to the temperature of 80 °C.

After complete cooling of the gear shaft, machining of deposited end faces of the teeth was carried out in lathe DIP-500 to the sizes shown in the drawing. Appearance of end faces of the surfaced teeth, penetration shape and results of hardness measurement performed with Poldy device, are shown in Figure 5. The results of ultrasonic testing of the surfaced teeth showed absence of defects in the deposited metal of the teeth and in the HAZ metal of gear shaft. Deposited metal hardness differed from the hardness of soft sections by not more than 8 %, that confirmed the correct choice of welding consumables.

Reconditioning of involute teeth profiles was performed by the standard modular milling tool in the gear-milling machine. Then the gear shaft was placed into the lathe. Control measurements of flange diameters and shaft journals for bearings, as well as radial run-outs of shaft sections were done with the clock-

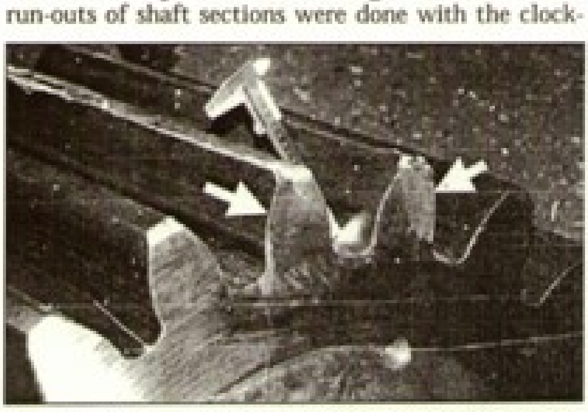

Figure 6. Appearance of teeth deposited by ESS after their machining in the gear-milling machine

type indicator and measuring clamps. Measurements showed that run-out of the teeth top surfaces (except for the recovered ones) do not exceed 0.1 mm along the entire length (admissible run-out is 0.15 mm), shaft journals run-out — 0.05 mm (admissible value is 0.05 mm). Shaft diameters are also within the limits of admissible values [2]. Thus, shaft bending after ESS of two teeth turned to be minor. The height of the surfaced teeth and two adjacent ones decreased by 0.9–1.0 and 0.4–0.5 mm, respectively, compared with the drawing dimension. However, specialists from the Department of Quality Control of plant-manufacturer decided that such a minor decrease of teeth height will not impair their performance.

After hardening of the working surfaces, the gear shaft was recognized to be fit-for-service (Figure 6) and sent to Nikolaev Industrial Complex of Building Products, where it successfully operated for the specified service life.

CONCLUSIONS

1. Technology and technique were designed and successfully realized for repairing manufacturing defects of major module teeth ($m = 40$, $z = 21$) of sub-rim gear shaft by ESS method without subsequent high temperature treatment.

2. The results of performed work confirm that ESS is an effective method for repairing practically any defects formed in manufacturing or operation of major module gear shafts.

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