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SELECTION OF TECHNOLOGY FOR REPAIR WELDING OF PARTS OF TURBINE UNITS

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The peculiarities of disassembly-free repair of steel grade 15Kh1M1FL body of the control valve of the medium pressure cylinder of the turbine PT-200-130 of the heat power plant, in which a crack was formed after a long-term service, are given. The repair without disassembly of the valve is possible due to the use of technology of repair arc welding by pearlite electrodes with preheating and thermal recovery. 12 Ref, 1 Table, 7 Figures.

Keywords: *crack, case, steel 15Kh1M1FL, repair welding, thermal metal recovery*

During long-term operation of power equipment under the conditions of high-temperature heating and stressed state, the degradation of structure, decrease in properties and crack resistance of metal occur [1]. The cast case parts of turbines are the most vulnerable to this phenomenon, especially such as bodies of high- and medium-pressure cylinders, stop and control valves, whose metal has a significant heterogeneity of control properties, cast defects and increased contamination of metal with non-metallic inclusions. The formation and propagation of cracks are caused both by thermomechanical loads, as well as additional combined action of processes of corrosion fatigue and hydrogen embrittlement of steel [2].

The main method to eliminate defects in the case parts of power equipment is the manual arc welding using pearlite electrodes with local preheating and postweld high-temperature tempering. The purpose of heat treatment is the increase in reliability of welded joint due to bringing the metal structure to equilibrium state, reducing the level of welding stresses and diffusion hydrogen. The local heat treatment of large-sized case parts is characterized by a non-uniform heating, appearance of additional temperature stresses, deterioration of structure and properties of welded joint. It is quite possible to prevent that in a certain degree having applied the high-tech thermal equipment, which allows performing all the operations of heating and cooling completely in automatic mode. However, the difficulty in selecting the optimal parameters of local heat treatment mode, especially of large-sized equipment having a different wall thickness, significantly complicates its performance [3]. In addition, the use of heat treatment turns to be impossible, for example, during repair without disassembly of parts when a high-temperature heating can lead to deformation and damage of the power plant entire unit.

For repair of cast case parts of steam turbines and fitting valves, the technologies for rewelding defects without heat treatment were also developed.

One of such technologies is welding by austenitic high-nickel electrodes [4]. It allows preventing the formation of cold cracks in welded joints of hardened steels without preheating and postweld heat treatment. This predetermined its high efficiency during elimination of defects in the parts of power equipment of heat-resistant chromium-molybdenum and chromium-molybdenum-vanadium steels, including also during disassembly-free repair. The disadvantage of such welding technology is the formation and subsequent development of chemical and structural heterogeneity in the fusion zone of austenitic weld metal with pearlite steel, caused by diffusion of carbon. An increase in the nickel content in the austenitic weld is the main method to reduce structural heterogeneity in this zone, however it does not completely eliminate it [5]. This leads to delamination of austenitic metal with the chemical composition based on iron after 4–8 years of service, and with the chemical composition on the base of nickel — after 15–20 years of service. During repair of parts, whose metal worked out more than 150 thou h, the reliability of their service with austenitic high-nickel deposition can be reduced to 3–4 years [3]. The technology of repair welding using austenitic electrodes is successfully used at the present time [3, 4]. However, according to the requirements of modern standard documents, the admissible operation temperature of dissimilar joints is limited to 480 °C [6].

The relatively new technologies of welding by pearlite electrodes applying technological procedures for control of thermodeformational welding cycle offered an alternative to the technology of rewelding defects by austenitic electrodes without heat treatment. One of them is transverse multilayer hill welding technology. The high resistance of metal against crack formation is achieved not only without heat treatment, but also without preheating. The effect is achieved due to an efficient use of welding heating and reducing the rate of metal cooling to prevent the formation of brittle hardening structures. This method is widely used in welding of thick-sheet metal and being improved at present as-applied to welding during elimination of casting defects in the power equipment of heat-resistant steels [7, 8]. The disadvantage of this method is, obviously, an increase in metal overheating and grain growth in the near-weld zone. This is particularly undesirable for metal with a degraded structure. The possibility of applying this method for parts with such a metal requires additional investigations.

The technology of welding by pearlite electrodes with preheating and low-temperature tempering (recovery) [3, 4, 8, 9] has found a wide application for repair welding of castings of power equipment. The principle of the technological operation of tempering consists in the fact that after the end of welding the preheating temperature of welded joint is maintained for some time. The recovery belongs to recrystallization process, which is accompanied by removal of lattice distortions, ordering of atomic structure and increase in the ductility of metal. The positive influence of recovery on increase in crack resistance of welded joints is explained also by decrease in diffusion hydrogen content in the deposited metal [9, 10]. The obligatory component of this technology is the preliminary application of lining, consisting of two layers of deposited metal, on the surface of area of removed metal. Their surfacing is performed at a minimal input energy by narrow annealing beads [6] which are deposited in a certain sequence. Such a technological method of surfacing allows efficiently reducing the hardness and increase in the ductility of heat-affected zone (HAZ) metal due to tempering of hardening structures without a significant grain growth in the near-weld zone [11]. In addition, at the same time, the level of welding stresses is reduced by 21–32 % [12]. This is especially important for metal which worked out its life, has an unfavourable structure and an increased tendency to crack formation. The further decrease in the level of welding stresses occurs during high-temperature operation [9]. Depending on the level and type of alloying of base metal and wall thickness, the recovery temperature is relatively low (120–300 °C) as compared to the temperature of high-temperature tempering (560–750 °C). In this regard, the danger of possible distortion of complex-shaped parts, the formation of cracks and scale, as well as undesirable structural transformations is eliminated. This makes it possible to use such technology for disassembly-free repair. The crack resistance of welded joints is determined by sizes of the defect, by the technique and parameters of the surfacing mode, which are the features of the welding technology.

The aim of this work was the selection of welding technology in disassembly-free repair of cast body of control valve of the medium pressure cylinder (MPC) of a 130 MW power steam turbine (Figure 1) made of steel 15Kh1M1FL.

The valve body represents a large-sized casting of a complex configuration (Figure 2), which is welded-on to the case of MPC (Figure 3). The valve worked out about 300 thou h at the temperature of 545 °C and at the vapor pressure of 3.0 MPa. The damage in the form of a small (30–40 mm) crack in the fusion zone of austenitic deposit on its outer surface was detected during preparation of the turbine for major repairs. The deposit was located on the area of variable cross-section, in which the wall thickness varied from 60 to 140 mm. This deposit worked out without remarks about 200 thou hours. It was made by high-nickel electrodes TsT-28 (type 08Kh14N65M15V4G2) during rewelding of removed metal area of 420×155 mm section and 45 mm depth, formed during removal of the delaminated metal deposited by austenitic electrodes of

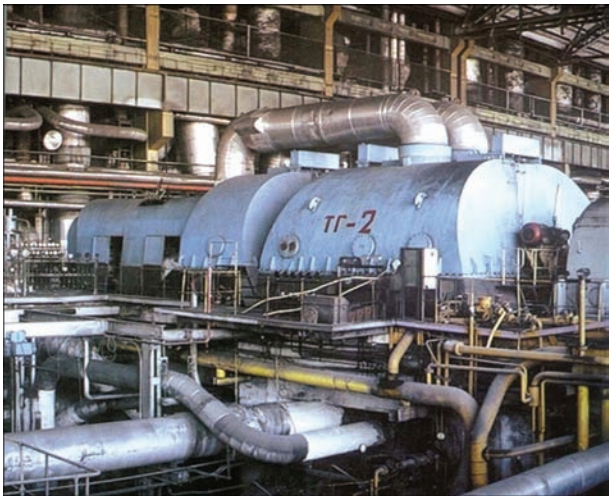

Figure 1. General appearance of turbine PT-200-130

Figure 2. MPC cover with stop valves during preparation for repair

Figure 4. Fragment of austenitic deposit (×3). Appearance on the side of delamination surface

grade EA-395/9 (of type Kh16N25M6). The cause for carrying out initial surfacing was detection of a casting defect in this area in the form of a shrinkage crack of 10–35 mm depth and up to 120 mm length.

During removal of a defect applying layer-by-layer grinding, the propagation of delamination and separation of austenite metal in small pieces were observed (Figure 4). Moreover, the delamination surface had a relief, typical for deposited metal, and the hardness of its areas had high (*HV* 480–520) and low (*HV* 110–150) values. It indicates that the fracture occurred in the fusion zone both in the carburized as well as in the decarburized area. The completeness of removal of austenitic metal was controlled by a magnetic powder method and by metallographic etching of surface with 20 % nitric acid. Except of austenitic metal, a layer of base metal of 8–10 mm thickness was also grinded. This made it possible to remove the HAZ metal having a high degree of defectiveness caused by coarse grains, embrittlement of grain boundaries, phase and structural transformations which reduce the mechanical properties. As a result, a removed metal area with dimensions in the plan of 590×185 mm and the depth within 30–65 mm was obtained. Moreover, in its middle part a through slot of 10–18 mm width and 120 mm length was formed, in which the surface of the saddle was uncovered (Figures 3 and 5).

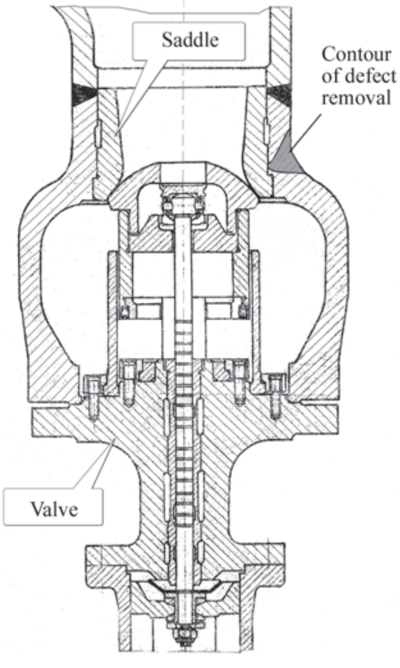

Figure 3. As-assembled control valve

The disassembly of the saddle from the valve body turned to be impossible because of the «overgrowing» of the gap with the inner surface of the valve body by strong precipitations in the process of a long service. This predetermined the selection of technology of welding for repair of the body of the MCP valve with preheating and postweld thermal recovery.

To diagnose the metal state on the repair area, to determine the possibility of further operation and its suitability for producing of welded joint, its microstructure and hardness were investigated and the evaluation of microfracture was carried out. For metallographic examination, a fragment of base metal with the size of 20×30×8 mm was selected at the area to be repaired. The hardness of base metal was measured by the portable durometer of Poldi type, and its microhardness was measured by the device PMT-3A.

The microstructure of base metal represents a fine grained bainite with carbide particles of up to 12 μm size and single isolated micropores of up to 2 μm size. The ferrite component amounts to not more than 5 %. The microfracture of base metal corresponds to point 2 of the scale of the Appendix Zh OST 34-70-690–96 at the admissible one being not higher than point 4 [1]. The microhardness of structural components is given in Table and the microstructure of base metal is given in Figure 6.

The results of investigations of base metal prove its repairability with application of arc welding and its possible further operation.

The preheating of the defect zone to the temperature of 280 ^{o}C, maintaining the recovery temperature of 6 h duration, was performed using the thermal automatic

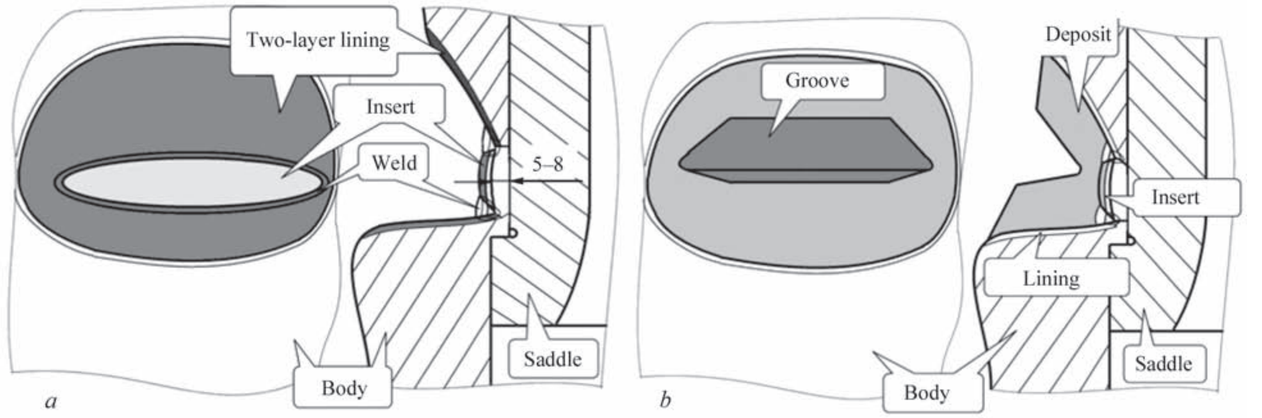

Figure 5. Preparation of a crack in the body of the MCP control valve for welding and the stages of its rewelding

installation «Weldoterm». The adjustment of temperature was performed at 12 controlled points to provide the uniformity of its distribution not only in the repair area but also in the area of 150 mm adjacent to it.

To eliminate the damage of saddle during rewelding of through slot, a special insert was welded-in to it at the distance of 5–8 mm from its surface (Figure 5, *a*). The insert was cut out of the section of pipe (steel 15Kh1M1F) deposited by the electrodes TML-5 (06Kh1M) and subjected to heat treatment: normalization and high-temperature tempering. The profiling of the insert was performed strictly according to the size of slot with the edge bevel for welding at the angle of 45° on the side of deposit. It was located by 1–2 mm higher than the lower edge of the slot with the formation of gap of 1.0–1.5 mm size between the edges to be welded. To prevent a possible welding-on to the saddle, its surface was protected with anti-burning coating. The root layer of the weld of the insert was made by argon-arc welding using W-electrode with the filler wire of grade Sv-08KhGSMFA of 1.6–2.0 mm diameter. The value of welding current was 220–240 A and the presence of a gap provided a complete penetration of edges welded. The subsequent weld layers of the insert were made by electrodes TML-5 (06Kh1M). The surface of welded joint of the insert was dressed up to a metallic glittering and controlled for absence of cracks by a visual method.

The surfacing of lening metal on the surface of removed metal area was carried out in two layers by electrodes of grade TML-5. The scheme of crack metal removing for welding and stages of its rewelding are shown in Figure 5. The annealing beads during surfacing of the first layer were produced by 3 mm electrodes and a width of not more than 5–8 mm. They were applied with overlapping by 40–50 % of the width of previous bead. The second layer was made by 4 mm electrodes. When the base metal was heated to the temperature exceeding 280 °C, the welding was stopped to reduce and equalize the temperature to the preheating level. After surfacing of the second layer, the surface was subjected to peening by 0.5 kg hammer with a rounded striker. This technological method is an effective way to reduce welding stresses [4]. After dressing the surface of the as-peened metal, its control for absence of defects was carried out. The subsequent filling of the removed metal area was performed in two stages: the first one is a layer-by-layer surfacing on the side and bottom regions of the removed metal area in the direction from edges of the removed area to the centre up to the formation of a longitudinal V-shape groove of 15–20 mm width and the common slot angle of 40–45° in the middle part of the removed area (Figure 6, *b*). The second stage is filling the groove by surfacing using longitudinal

Microhardness of structural components of base metal

Structural component	Value of hardness *HV* 0.2[*]
Ferrite grains	114–123 118.5
Grains with bainite substructure	143–155 151

[*] The denominator indicates the arithmetic mean of hardness from six measurements.

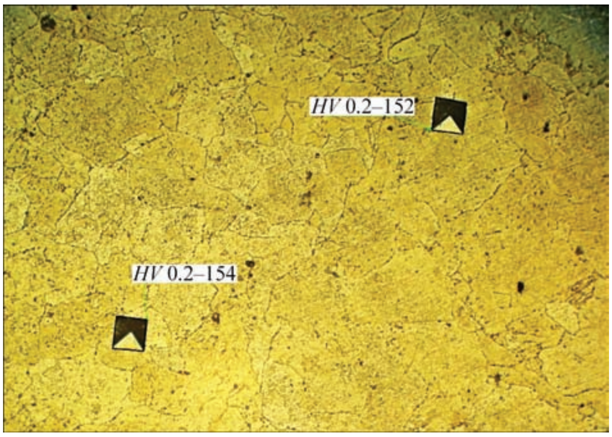

Figure 6. Microstructure (×200) of steel 15Kh1M1F at the area of repair

Figure 7. Performing repair welding of a crack in the body of the MCP control valve

beads. The moment of performing repair welding is shown in Figure 7. After end of surfacing, the thermal recovery of metal was carried out by maintaining the temperature of 280 °C durating 24 h with the help of the installation «Weldoterm». The cooling of surfacing area was carried out under the layer of thermal insulation at the rate of not more than 25 °C/h to the temperature of 70 °C, and at a lower temperature — in a calm air with the removed thermal insulation. As a result, the hardness of the deposited metal was obtained within the limits of HB 150–175 and of the base metal in the heat-affected-zone *HB* 140–240.

The quality control of metal was carried out before, during and after surfacing throughout the whole surface of the deposited metal and beyond its 150 mm width by visual-measuring, magnetic-powder and ultrasonic methods. The cracks were not revealed. Based on the results of ultrasonic testing, the metal of repair rewelding met the requirements according to the quality level 2 in accordance with EN 12680-1:2003 and SOU VEA.200.1.1/01-2016.

Due to a low temperature thermal recovery as compared to high-temperature tempering, the widening of the area of application of this repair technology is possible with accumulation of the results of inspection of repair welded joints not only of the parts of power equipment, but also of petrochemical one.

Conclusions

1. In case when high-temperature tempering is impossible for repair of damages of assemblies and parts of turbine units from heat-resistant steels of operating TPPs, the technology of arc welding using pearlite electrodes with preheating and postweld thermal recovery can be used.

2. The technology of arc welding by pearlite electrodes with preheating and postweld thermal recovery allows:

- increasing the resistance of repair welded joints against crack formation due to improvement of the structure, increase in the ductile properties of metal of the heat-affected-zone and reduction of welding stresses under the influence of the effect of «annealing» beads during two-layer lining, as well as decrease in the content of diffusion hydrogen in the metal under the influence of thermal recovery;
- prolonging the service life of power equipment units;
- reducing the power losses and improvement of operating conditions during repair due to refuse from high-temperature postweld heat treatment.

3. The widening of application of this repair technology is rational while accumulating the results of investigations of properties and reliability of repair welded joints not only of parts of the power equipment, but also of the petrochemical one.

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