Improvement of performance properties of products by surface treatment of materials with cathode spots of vacuum arc discharge

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Abstract. It is shown that the impact of cathode spot of vacuum-arc discharge on the plastically deformed surface may be partially or fully recovered her form. This effect was detected during vacuum-arc cleaning of the inner surface of the cylinder. Mathematical and experimental modeling of the process of restoring the inside diameter of the cylinder confirmed the effect of shape recovery upon exposure of the cathode spots of a vacuum arc on the surface.

Fundamental and applied research in the field of mechanics and physics of interaction of plasma jets from the cathode spots of a vacuum arc with a solid surface in recent years greatly intensified in connection with the development of new applications of vacuum-arc discharge. In addition to the widely used direction of vacuum-arc coatings deposition [1], this type of discharge is mastered for hardening of the surface of metals [2], for vacuum arc cleaning [3] of the surface from scale, rust, oil film and other contaminants in mechanical engineering, metallurgy and other fields, for defectoscopy of surface layers of metal products [4], for protect the metal from corrosion by passivation of the surface [5] and in other directions.

When developing cleaning technologies of plastically deformation of inner surface of the cylinder by the cathode spots of vacuum arc discharge was discovered the effect of reducing of the internal diameter. By removing of dirt and minor sputtering surface of the metal layer the diameter of the cylinder must be increased. As the cylinder was used the housing case of axle box of railway wagon. Housing case of the axle box perceives and transmits to wheelset gravity of the loaded wagon, as well as dynamic loads that occur when driving. In the process of operation the axle box is subjected to heavy loads, causing the appearance of plastic deformations in the areas of contact of the housing with the bearing bushing [6]. As these loads are distributed unevenly on the inner surface of the cylinder inner radius of surface due to plastic deformation changes non-uniformly, this creates ovality of the inner surface.

In figure 1 are presented experimental data of changes of the internal diameter of the 190 cylinders when vacuum-arc cleaning.

To develop methods for the measurement of thermal fields and deformations during vacuum-arc treatment of the inner surface of the cylinder was created the experimental apparatus. Figure 2 shows a photograph (figure 2(a)) and scheme of the experimental equipment and the measurement procedure (figure 2(b)).
Figure 1. The change in the internal diameter of the 190 cylinders after vacuum-arc cleaning the surface (D – diameter, # – identification number).

![Graph showing the change in internal diameter of cylinders before and after cleaning.]

Figure 2. Photograph (a) and diagram (b) measurement of temperature and displacement of the external surface of the cylinder by vacuum-arc heating (1 – cylinder-cathode, 2 – electrode-anode, 3 – thermal imaging camera, 4 – semiconductor laser, 5 – photo detector, 6 – interferometer).

Cylinder is installed on the vacuum post and is closed by a lid with a viewing window. Temperature measurement was carried out by thermal imaging camera (3) ThermaCAM™ SC 3000 (figure 2(b)). For studies of the movements of the outer wall of the cylinder in the process of vacuum-arc heating was used a laser interferometer with a sensitivity of better than 5 nm. In the interferometer implements the classical scheme of the Michelson. One of the mirrors of the interferometer was placed on an elastic membrane with a central steel probe Ø1×5 mm, which was in contact with the wall of the cylinder. In the measurement counted the number of photoelectron bands. Synchronization of the measurements with the movement of the rotating electrode was carried out by the signal from the photodetector (5), arising in the penetration of the laser radiation (4), reflected from a mirror, rigidly connected to the axis of rotation of the anode (figure 2(b)).

Vacuum arc discharge was ignited between the axle box housing (cathode) 1 and rotating along the surface the electrode 2 (anode). The cathode spots of a vacuum arc, followed by the anode, carried out the surface cleaning and at the same time heated surface layer of the cylinder.

Obtained the combined in time dependencies (figure 3) of temperature change (T) and displacement (U) of the outer wall of the cylinder in one pass of the electrode by heating on 2 °C. Shows a qualitative coincidence time dependencies corresponding to the classical model of thermoplasticity.

Developed experimental methods of measuring the temperature and movement of the outer surface of the cylinder possible to obtain data for verification of boundary conditions for solving nonstationary problems of thermoplasticity by finite element method. Conducted finite-element analysis of transient
heating of a cylindrical pipe with an initial ovality generated by the uneven pressure on the inner surface of the cylinder.

Consider the finite element model. Owing to the symmetrical geometry of the problem consider one quarter of the cylinder. Thereby neglecting the asymmetry due to local heating by a heat source moving on a circle with angular velocity of 2 revolutions per minute. After processing of the inner surface by means of uneven pressure occurs ovality.

Figures 4 and 5 shows the picture of radial displacements after the removal of the internal pressure and a graph of radial displacement.

Figure 3. Combined time dependencies of temperature change (1) and moving of the outer wall of the cylinder (2) for one pass of the electrode.

Figure 4. Picture of radial displacements after the removal of the internal pressure.

Figure 5. Radial displacements after the removal of the internal pressure at the circumference.

In the presence of initial ovality of the inner surface, that is, the difference of the values of the radii is equal to 77 µm after two passes of the electrode is reduced ovality, and the difference of the values of the radiuses decreased to 40 microns.

In the result of experimental and theoretical studies on the effect of vacuum-arc exposure on the inner surface of the housing case axle-box of railway wagon has been shown the reducing of out-of-roundness acquired during a maintenance period.

When the load is removed on the inner surface arise the compressive circumferential stress, the intensity of which depends on the magnitude of applied normal pressure. Intense local heating of the surface compression zone creates a thermal expansion and, as a consequence, plastic deformation, depending on the pre-compression: the more pre-compression, the greater the deformation, which explain the effect of reducing the internal diameter and ovality.

Heating of the surface and restoring its shape was carried out by the discharge from the surface of the cylinder to the rotating electrode. Pattern of radial displacements after the removal of the internal pressure and graph of radial displacement was obtained.
Comparison of radial displacements of the inner surface after removing the pressure and after final cooling to room temperature shows the real effect of reducing the induced ovality during the operating period. It is shown that in addition to reducing of ovality due to non-stationary localized heating of the inner surface of the cylinder decreases and her inner diameter. With the help of experimental studies and mathematical calculations on the developed models confirmed the possibility to recover the plastically deformed surface by means of the cathode spots of a vacuum arc at currents of 100-200 A up to 70 µm. When increasing the current of the vacuum arc discharge and adjusting the speed of movement of cathode spots can significantly reduce the ovality.

References
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