TECHNOLOGY FOR WIDE-LAYER HARD-FACING OF CRANKSHAFTS

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Results of experimental investigations of the effect of wide-layer hard-facing parameters on characteristics of the deposited layer are presented. Optimal ranges of variations of the process parameters in hard-facing of cylindrical parts 180–300 mm in diameter were determined. Application of the investigation results to development of the technology for repair of large-size diesel generator crankshafts is shown.

Keywords: *wide-layer arc hard-facing, large-size crankshafts, self-shielding flux-cored wire, optimisation of hard-facing parameters, hard-facing technology*

Large-size crankshafts (crankshafts of main gas pipeline compressors, diesel generators, marine and diesel locomotive engines, etc.) are metal-consuming parts with weight of up to 6 t and length of about 6 m. Average price of such a crankshaft is US $ 70,000. Physically, a crankshaft is a crank made from medium-carbon steel and consisting of two groups of cylindrical journals, i.e. rod and main ones. The rod group consists of up to eight journals, and the main group — up to ten journals, their diameter being 180–280 mm.

Key parameters of the loads that determine service life of a crankshaft are high contact pressure at interfaces between the journal and bushing in friction, and quantity of alternating loading cycles. They lead to wear out of working surfaces and decrease in nominal diameters of the rod and main journals. In turn, a change in geometric parameters of the interfaces in friction leads to occurrence of an emergency situation: violation of lubrication of the friction interfaces, creation of «dry» friction conditions, «seizure» and burning out of bushings that interface the journals. Therefore, a crankshaft that spent about 30 % of its design safety factor for strength may fail because of an insignificant wear ranging from 1.5 to 2.5 mm, depending upon its operational conditions and real service life.

Hard-facing on a helical line by the submerged- or open-arc welding method is used to repair large-diameter cylindrical parts with a substantial wear (over 5 mm). If wear is less than 3 mm, it is recommended to apply wide-layer hard-facing by using a self-shielding flux-cored wire, the productivity of which is 1.8–2 times higher than that of the helical hard-facing process. Moreover, wide-layer hard-facing is characterised by a favourable thermal cycle (self-heating of a workpiece treated)*, which is very important for improving crack resistance of hardening steels in hard-facing.

Figure 1 shows the flow diagram of wide-layer hard-facing of a cylindrical surface by using a self-shielding flux-cored wire. In hard-facing, rotation of a workpiece with diameter D occurs at welding speed v_w. The flux-cored wire (electrode) is fed to the melting zone at speed $v_{w.f}$, and, at the same time, it makes reciprocal movements (oscillations) to width B of the surface treated (oscillation amplitude or range) at preset radius r and oscillation speed v_o. A deposited layer forms on the workpiece surface during welding and gradual solidification of the weld pool. Welding cycle time t_w corresponds to the time of one revolution of the workpiece. Apparently, parameters of wide-layer hard-facing affect thickness of the deposited layer, δ, and quality of its formation. In this case, optimisation of the wide-layer hard-facing process is often hampered by a big quantity of the process parameters and the probability of their variations over wide ranges.

The purpose of this study was to experimentally investigate the effect of individual parameters of the wide-layer hard-facing process on characteristics of the deposited layer, as well as determine the optimal ranges of their variations in hard-facing of cylindrical parts 180–300 mm in diameter.

Experimental welding runs were performed at a direct current of reversed polarity on samples of steel St3, the geometric dimensions of which corresponded to those of the rod and main journals of large-size crankshafts. 2 mm diameter self-shielding flux-cored wire PP-Np-30Kh4G2SM, which gave good results in hard-facing of steel crankshafts, was used as an electrode material.

Average thickness δ of the deposited layer and quality of its formation are the key characteristics used as a basis to choose such wide-layer welding process parameters as I_w, U_a, v_w, $v_{w.f}$, v_o, electrode extension l_e, and electrode displacement from zenith, e. The following formula can be used to set the δ value (with machining allowance taken into account):

$$\delta = (1.0 - 1.2)(W + 0.5A),$$

where W is the wear or thickness of the deposited layer, mm; A is the machining allowance for diameter, mm; and 1.0–1.2 is the coefficient that accounts for

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* Krivchikov, S.Yu., Zhudra, A.P., Petrov, V.V. (1998) Thermal cycle in wide-layer hard-facing of cylindrical cast iron parts. *Avtomaticheskaya Svarka*, **4**, 49–50.

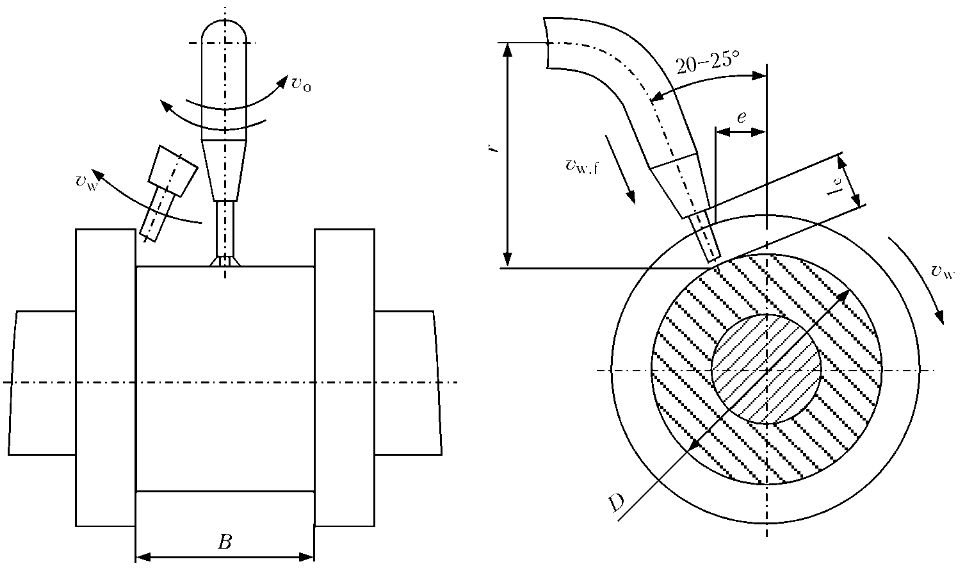

Figure 1. Flow diagram of the method of wide-layer hard-facing of cylindrical parts using oscillating electrode (self-shielding flux-cored wire) (see designations in the text)

surface roughness of the deposited layer. As noted above, W = 1.5–3.0 mm for large-size crankshafts. Wide-layer deposition of this thickness of the metal layer on a large-diameter cylindrical surface can be performed over a wide range of welding currents. However, for the flux-cored wire employed, the technologically efficient ranges of the welding current and arc voltage are I_w = 200–400 A and U_a = 26–28 V, respectively, at l_e = 20–25 mm. It should be noted that for such values of the welding current the maximal width of the deposited layer should not exceed 70 mm in order to provide the acceptable quality of its formation and productivity of the process. Also, the absolute values of I_w (A) and $v_{w.f}$ (m/h) were found to be almost identical (Figure 2) in the case of wide-layer welding using the 2 mm diameter medium-alloyed flux-cored wire. This makes it possible to use the $v_{w.f}$ parameter as a more general characteristic of the process and exclude the welding current from the range of the process optimisation parameters.

Surface roughness of the deposited layer taking place in wide-layer hard-facing, was evaluated on the basis of the coefficient of variations of real thickness of the layer, CV_δ. The maximal value of CV_δ = 30 % was assumed for the investigations, by accounting for the value of allowance for subsequent machining of the deposited surface. It was established that a welding speed of 3–8 m/h corresponds to the range of variations in the real layer thickness equal to 15–30 %. In this case, the displacement of electrode from zenith providing good formation of the deposited layer also varies within a rather narrow range. For example, at a welding speed of 5.5 m/h and current of 200–400 A, the optimal quality of formation of the deposited layer was provided at a displacement of electrode from zenith equal to 8–12 mm (dashed region in Figure 3). Outside this range, formation of the deposited layer is disturbed, this leading to the risk of flow of part of the weld pool down from the surface being treated. It should be taken into account that the higher the values of v_w and I_w, the higher should be the value of e. The effect of the v_w and I_w values on average thickness of the deposited layer is shown in Figure 4.

Electrode oscillation speed v_o affects the process of formation of the weld pool, the length of which in wide-layer hard-facing is approximately equal to the electrode oscillation amplitude (or range). If the v_o value is low, the deposited metal has the form of isolated transverse beads. And if this value is too high, then regions of the lack of fusion form between the base and deposited metal, and stability of the arc and uniformity of melting of the flux-cored wire deteriorate. In both cases the quality of formation of the deposited layer is unsatisfactory. In this connection, the optimal value of v_o in terms of ensuring the good quality of formation is such at which the common liquid weld pool with a length equal to the electrode oscillation amplitude forms at the beginning of the welding process. It was experimentally proved that in deposition of layers with width of 40–70 mm and

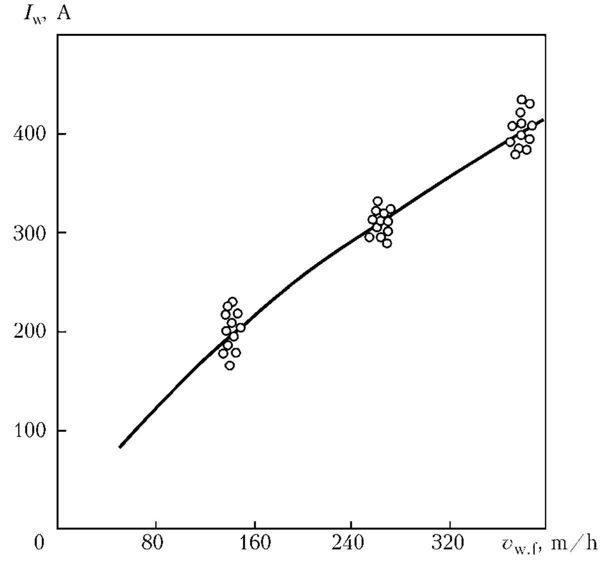

Figure 2. Current I_w versus wire (2 mm diameter flux-cored wire PP-Np-30Kh4G2SM) feed speed $v_{w.f}$ in wide-layer hard-facing (U_a = 26–28 V, l_e = 20–25 mm, v_o = 155–215 m/h)

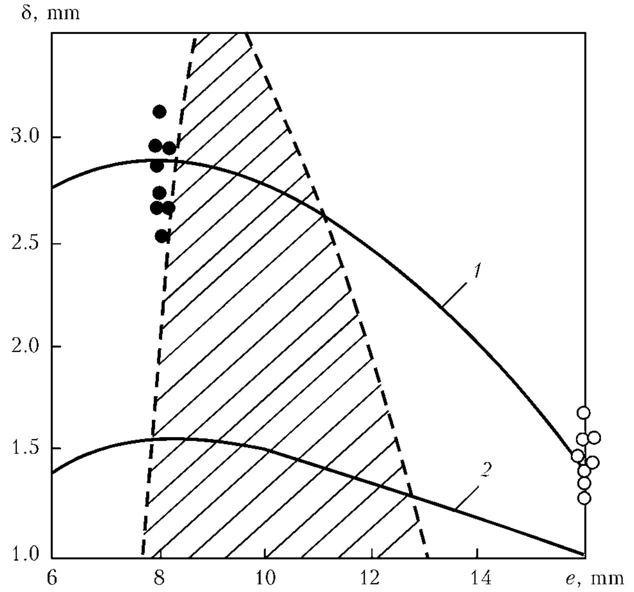

Figure 3. Average thickness δ of deposited layer versus displacement e of electrode from zenith at v_w = 5.5 m/h, CV_δ = 30 % and I_w = = 400 (*1*) and 200 (*2*) A: ●, ○ — forward and backward flow of liquid metal

at I_w = 200–400 A, the optimal values of v_o may vary from 120 to 250 m/h, and that it depends upon the welding current and width of the deposited layer. It should be noted that the oscillation speed exerts the substantial effect only on the time of formation of the common weld pool at the beginning of the welding process. After its formation the v_o value can be varied over a wide range without any loss in the quality of formation of the deposited layer.

However, adjustment of the v_o parameter is time-consuming. To exclude this operation, it is enough to determine the time required for formation of the common weld pool and use it as a constant parameter of the welding process. It was established that within the investigated ranges of the welding currents (200–400 A) and width of the deposited layer (30–70 mm), this time is 2–3 s, which corresponds to electrode oscillation frequency $n_o = 60$ min^{-1}. This oscillation frequency provides a good quality of formation of the deposited layer. Therefore, it can be used as a universal value. It should be taken in consideration in this case that for a welding process beginning lag time of 2–3 s the welding speed should be equal to zero. When this time expires, v_w grows to the preset value. The use of the n_o parameter instead of v_o permitted the electrode oscillation mechanism to be substantially simplified.

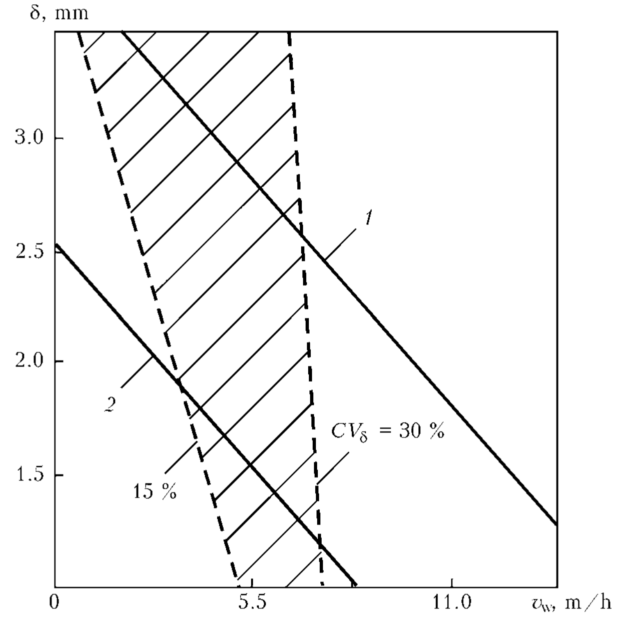

Figure 4. Average thickness δ of deposited layer versus welding speed v_w at l_e = 8 mm: *1*, *2* — see Figure 3

One of the requirements imposed on the technology for wide-layer hard-facing of crankshaft journals is compulsory welding of fillets, i.e. regions of transition from a cylindrical surface of a journal to normal surfaces of webs. As experimentally found, if an electrode during the welding process makes oscillatory movements at a constant speed, at the moments of its approaching the fillets (at extreme positions) the arc and electrode metal heat is not enough for their reliable fusion. This results in formation of a defect in the form of a region of lack of fusion between the deposited layer and near-fillet region of the crankshaft journal web. To eliminate this drawback, one more characteristic, i.e. the time of dwelling of the electrode at the extreme positions, should be added to the set of the wide-layer welding parameters. The quality of the deposited near-fillet regions varies depending upon τ: the longer the lag time and the lower the welding speed, the higher is the quality of formation of the deposited metal. Other conditions being equal, τ also depends upon the heat removal conditions: the heavier the weight of the webs adjoining the journal, the higher is the τ value. The character of the oscillatory movement of the electrode is set by a shaped cam, which is kinematically connected to the flux-cored wire feed nozzle. The shape of the cam is set such that the total cycle of one oscillatory movement of the electrode consists of three regions: regions 1 and 2 — dwelling of the electrode near the fillets for time t, and region 3 — movement of the electrode at a preset constant speed. For the studied ranges of the wide-layer hard-facing parameters, the maximal value of τ is not in excess of 0.26 s.

Including radius r of oscillations of the electrode into the range of the optimisation parameters is attributed to the fact that surfaces of the fillet regions are more convenient to deposit at a curvilinear path of movement of the electrode tip. This eliminates the probability of short circuits between the nozzle and webs. According to the calculations, a change in extension of the electrode at its oscillations to a width of 30–70 mm is 0.6–4.8 mm. However, as shown by the experiments, such a change in the extension at a flux-cored wire feed speed of over 180 m/h does not have a marked effect on length of the arc, its electrical parameters and quality of formation of the deposited layer. A change in the oscillation radius exerts a considerable effect on the process of welding of the fillet regions and losses of the electrode metal. As follows from the data obtained, the quality of formation of metal deposited on the fillet regions deteriorates, and losses of the electrode metal grow from 8.1 to 15.8 %

Optimal parameters of wide-layer hard-facing of rod and main journals of diesel generator crankshafts

Process parameter	Type of crankshaft journal	
	Main journal	Rod journal
I_w, A	320–340	340–360
U_a, V	27–28	27–28
v_w, m/h	4.5	5.0
Electrode oscillation amplitude, mm	50	65
e, mm	8–10	8–10
n_o, min^{-1}	60	60
Quantity of adjacent layers, pcs	2	2
t_w, min	6.0	4.0
l_e, mm	25–28	25–28

with increase in the r values from 81 to 145 mm. This is associated with decrease in the electrode inclination angle to the plane of a web of the journal being welded, which, in turn, leads to incidental contacts of the web with the side surface of the flux-cored wire sheath, formation of short circuits that shunt the arc, and spattering of the electrode metal. Therefore, to deposit layers no more than 70 mm wide, the optimal value of r should be 80–90 mm.

The investigations conducted served as a basis for the technology developed by the E.O. Paton Electric Welding Institute for hard-facing of large-size diesel generator crankshafts. The technology consists of three successively performed stages: preparation of a crankshaft, wide-layer welding of rod and main journals, and machining of the hard-faced crankshaft. If defects (e.g. regions with large pores or voids, etc.) are detected in the deposited layer after hard-facing or during machining, method for removing them is added to the technology.

Preparation of the crankshaft for hard-facing includes inspection of the shaft surfaces subject to hard-facing in order to detect cracks. In the case of cracks escaping to the journal surfaces and having a length of more than 20 mm, they are subjected to machining and repair welding.

Equipment for hard-facing of crankshafts includes a rotation mechanism and welding device (e.g. welding head A-580) fitted with the electrode oscillation mechanism. The rotation mechanism is a specialised screw-cutting lathe intended for machining of billets of diesel generator crankshafts. Wide-layer hard-facing is performed by using the 2 mm diameter self-shielding flux-cored wire, the journal to be welded being preheated to a temperature of 220–240 °C. The optimal hard-facing parameters are given in the Table.

With wide-layer hard-facing by the open-arc welding method using flux-cored wire PP-Np-30Kh4G2SM, the deposited metal has the following chemical composition, wt.%: 0.3 C, 4.0 Cr, 2.0 Mn, 0.8 Si, 0.8 Mo, and 0.45 Ti.

Figure 5, *a* shows appearance of the 65 mm wide crankshaft journal after hard-facing. Width of the diesel generator shaft journal is 135 mm, which is much in excess of the maximum permissible width of the layer deposited with the above grade of the flux-cored wire. Therefore, the process of hard-facing of the journal consists of two stages: first the wide-layer hard-facing process is performed on one part of the journal at the electrode oscillation amplitude equal to its half-width, and then the other half of the journal is subjected to hard-facing. As a result of performing hard-facing in two stages, two adjacent layers are formed on the journal, thus fully covering its worn-out working surface (Figure 5, *b*).

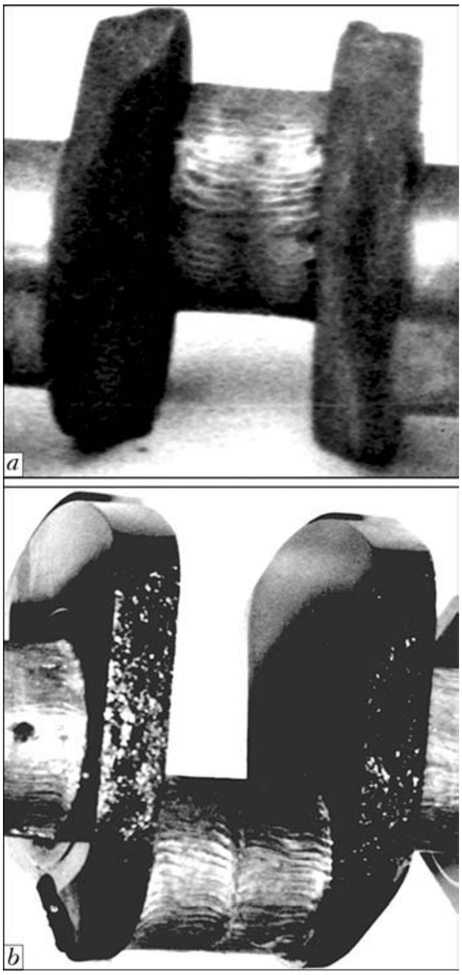

Figure 5. Appearance of crankshaft journals after wide-layer hard-facing using self-shielding flux-cored wire PP-Np-30Kh4G2SM under optimal conditions with one layer (*a*) and two adjacent layers (*b*)

The developed technology for wide-layer hard-facing passed the experimental-industrial verification at Company «Pervomajskdizelmash» (Pervomajsk, Ukraine). A batch of crankshafts was hard-faced and machined, after which the crankshafts successfully passed the bench tests. At present, these crankshafts are commercially applied. No data are available on the effect of wide-layer hard-facing on fatigue strength of the repaired large-size crankshafts. However, a long-time experience of application of wide-layer hard-facing to different types of crankshafts proves that it exerts no significant effect on this characteristic.

Application of the technology for wide-layer hard-facing of diesel generator crankshafts showed that the hard-facing costs constituted 22 % of the price of a new crankshaft.