THEORETICAL BACKGROUND OF THE RESTORING OF THE CRANKSHAFT NECKS BY FERROMAGNETIC MATERIALS WELDING

When developing the technological process of cast iron crankshaft restoring, it is necessary to obtain a martensitic structure in the pad weld in order to ensure the wear resistance needed. To form the martensitic structure the cooling rate after padding must be at least 80 - 90 ^{0}C / s. The helical surface welding does not lead to such a result, so in our research we use the welding according to the width of the shaft neck. We also examined the heat release from the pad weld and its cooling rate. For its implementation, the necessary calculations were made according to a compiled program in the QBASIC language. On the basis of these provisions, the theoretic background is proposed for the possibility of the wide-ringed welding of crankshaft necks, which ensures a minimal change in the structure and geometry of the crankshafts.

Key words: crankshaft, welding, restoring, numerical method, structure.

INTRODUCTION

One of the most expensive parts of the motors for cars, tractors and combine harvesters is the crankshaft [1]. The technology of steel crankshafts remanufacturing was developed quite well and does not cause major problems [2]. The restoring of cast-iron- crankshafts causes certain difficulties due to the special properties of high-strength cast-iron, that is why the development of the remanufacturing technology for cast-iron crankshafts is a critical task given that cast-iron crankshafts are being used more and more [3]. When developing the remanufacturing technology for cast-iron crankshafts, it is necessary to obtain a martensitic structure in the pad weld in order to ensure the wear resistance needed.

MATERIALS AND METHODS

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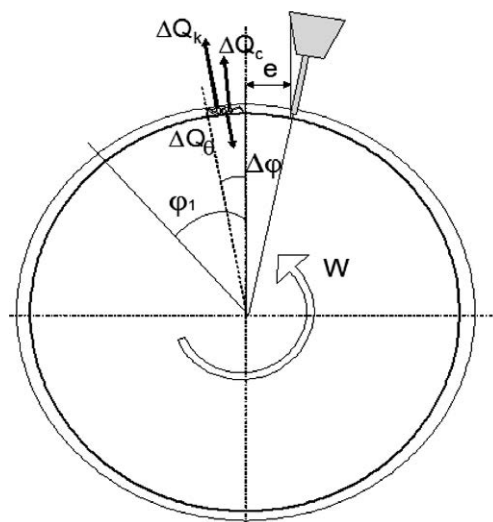
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Figure 1 Calculation model of the natural heat release from the neck pad weld

The heat content in the part of the pad weld in the first sector is [3]:

$$\Delta Q_1 = \delta \cdot R \cdot \Delta \phi \cdot l \cdot \rho \cdot C(t_1 - t_0) \qquad (1)$$

where, $\square$ is the thickness of the neck pad weld / m; R is the neck radius / m; $\Delta 3$ - is the central angle of the sector / rad; l - is the length of the pad weld / m; $\smile$ – is the density of the pad weld / kg / m^3; K– is the heat capacity coefficient of the pad weld / J / kg×^{0}C; t_1 - is the temperature of the pad weld in the first sector / ^{0}C; t_0 - is the temperature of the environment / ^{0}C.

The temperature of the pad weld in the first sector in relation to its onset of solidification is equal to the temperature of the cast-iron fusion t_1=$t_{melting}$=1 150 ^{0}C.

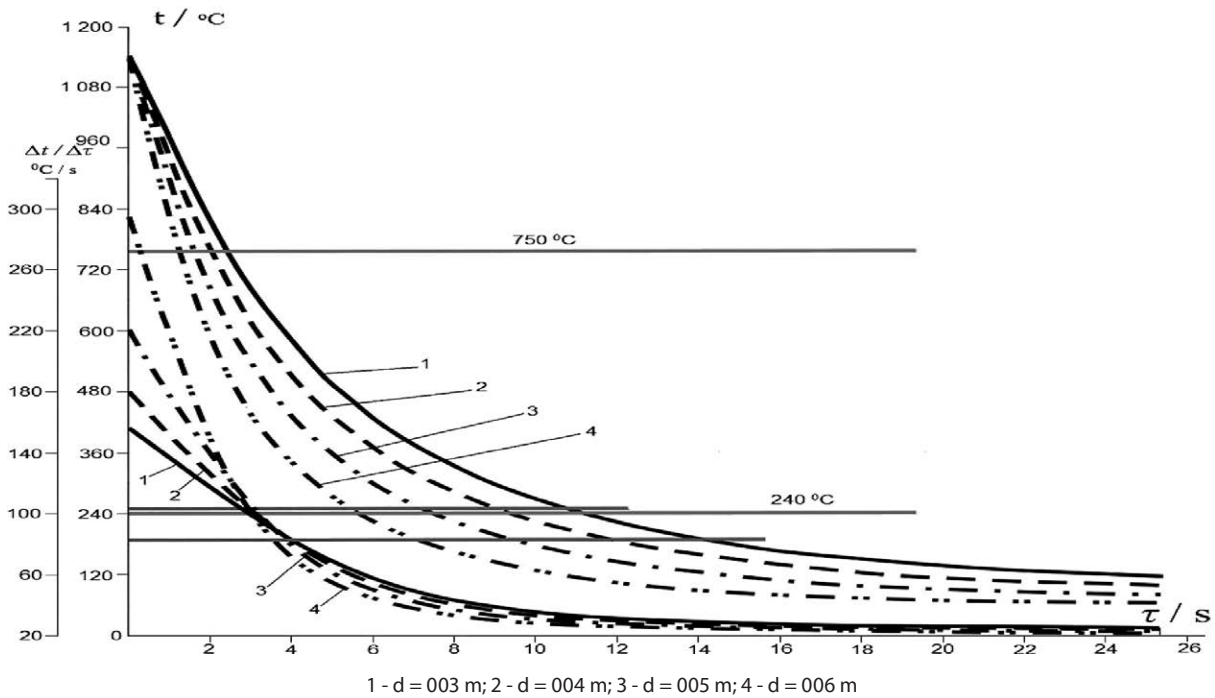1 - d = 003 m; 2 - d = 004 m; 3 - d = 005 m; 4 - d = 006 m

Figure 2 Diagrams of temperature change and temperature descent rate of the neck pad weld under the natural cooling and different thickness of the pad weld through time

In the first sector the part of heat is released by above mentioned means. A principal one is the heat release by the convection [4]:

$$\Delta Q_k = \alpha \cdot A_s \left(t_1 - t_0\right) \cdot \Delta \tau \cdot \overline{\varepsilon}_p \qquad (2)$$

where, α – is the heat-transfer coefficient / W / m^2 ^{0}C; $A = R \cdot \Delta 3 \cdot l$ - is the external surface area of the pad weld in the sector / m^2; $\Delta \tau = \dfrac{\Delta \phi}{\omega}$ - is the time of the heat release in the sector / s; $\check{}$- angular rate of the neck / rad / s; ε_p - coefficient, taking into account the ratio of the neck length to its diameter. In the present case $l / = 50 / 60 = 0,833$.

From literary sources it is known, if $l \cong 1$, then $\overline{\varepsilon}_p = 1,9$. The value of the heat generated by radiating [4]:

$$\Delta Q_c = q \cdot A_p \cdot \Delta \tau \qquad (3)$$

where, $q = C_p \left(\dfrac{t_1 + 273}{100}\right)^4$ - is the heat flux rate by Ste-aBa la / W / m ^{2}; $C_{po} = \varepsilon \cdot C$ - is the coefficient of the heat radiation from the pad weld; 0– is the emissivity factor of the pad weld. It is recommended to accept 0± 0,81 for the pad weld by the electric arc. $C_o = 5,67$ W / (m$^2_*$^{o}K) – is the heat radiation coefficient of the blackbody radiator.

Heat value, transferred by the heat conductivity in the base metal of the neck:

$$\Delta Q_\Theta = \lambda \cdot A_p \cdot \dfrac{\Delta T}{\Delta R} \Delta \tau \qquad (4)$$

where, ⊡is the heat conduction coefficient of the base metal / W / m×^{0}C; A - contact area of the pad weld with the base metal / m^2; $\dfrac{\Delta T}{\Delta R}$ - average temperature gradient in aлдаerce e / ^{0}C / m.

Due to the heat release in the first sector, the heat content of pad weld decreases and when passing to the second sector it is equal [5]:

$$\Delta Q_2 = \Delta Q_1 - \Delta Q_{K_1} - \Delta Q_{C_1} - \Delta Q_{O_1} \qquad (5)$$

Naturally, due to the decrease of the heat content, the temperature of the pad weld will also decrease.

Its value is determined [5]:

$$t_2 = t_0 + \dfrac{\Delta Q_2}{\delta \cdot R \cdot \Delta \phi \cdot \ell \cdot \rho \cdot C} \qquad (6)$$

In following sectors the temperature of the pad weld was calculated according to the same procedure, and the temperature variation rate of pad welds were determined in every sector [5]:

$$\dfrac{t_1 - t_2}{\Delta \tau}, \ \dfrac{t_2 - t_3}{\Delta \tau}, \ \dfrac{t_3 - t_4}{\Delta \tau}, \ .... \ \dfrac{t_{n-1} - t_n}{\Delta \tau} \qquad (7)$$

Naturally, to obtain martensite structure in the temperature range of the pad weld $750 - 240\,^oC$ its cooling rate must be at least $\dfrac{\Delta t}{\Delta \tau} \min \rangle 80\,^0C / s$.

RESULTS AND DISCUSSION

Based on the above mentioned procedure, a numerical method was used to predict the temperature of the pad weld and its cooling rate [4]. The results of these calculations with the different thickness of the pad weld (= 0,003…0,006 m) are shown in Figure 2.
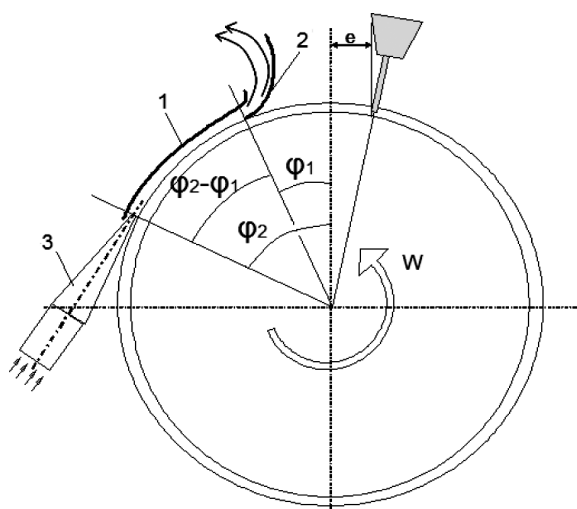
1 – *guide casing*, 2 – *air deflector*, 3 – *nozzle*

Figure 3 Structure diagram for the cooling of the pad weld by the forced convection

The main conclusion of calculation results is the following - for all examined thicknesses of the pad weld at the end of the temperature range (750...240 ^{0}C), where the fine-grained martensite is formed, the cooling rate of the pad weld does not correspond to the condition $\frac{\Delta t}{\Delta \tau}$ min$\rangle$80 ^{0}C / s Consequently, in the mentioned temperature range, not all conditions were observed for the formation of fine-grained martensite. To create all conditions for the formation of martensite in the pad weld, it is necessary to intensify the heat release at the final stage of cooling at least of one way of heat release. This task can be solved by increasing the intensity of the convective heat release from the pad weld into the environment. Compared to other methods this way of heat release has low heat retention, so it is possible to intensify the heat release in the required time interval. The intense heat release comes from the outer surface of the pad weld and does not have a significant effect on the temperature regime of other parts of the neck. The pad weld at the descent rate of its temperature below 100 ^{0}C / s will be found in zone of action of the high-speed non-ramming air directed against its flow by the casing 1 (see Figure 3). Within the range of central angles j_2-j_1, the cooling rate of the pad weld is achieved not lower than 80 ^{0}C / s by changing the speed of the directed air flow and its flow regime. To eliminate the influence of the flow directed to the neck weld zone, a reflector 2 is installed. To increase the intensity of the convective heat transfer from the pad weld in the range of central angles j_2 - j_1 according to the above mentioned program QBASIC, an average heat transfer coefficient a was predicted by the approximation method. The results of these research calculations are shown in Figure 4.

The duration of self-cooling j_1, the duration of forcible convective heat transfer j_2 - j_1, the necessary average heat transfer coefficients of forcible convective heat transfer α_a were determined depending on the pad thickness and are presented in Table 1.
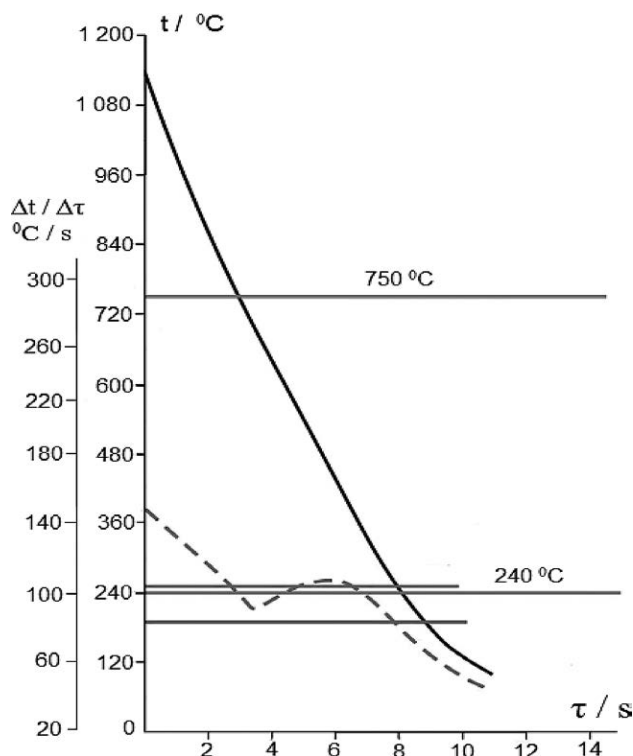

Figure 4 Diagrams of temperature change and temperature descent rate of the neck pad weld under the forcible convective heat transfer (the thickness of the pad weld d = 005 m) through time

Table 1 **Duration of self-cooling and forcible convective cooling, necessary average heat transfer coefficients under the forcible convective pad cooling according to the pad thickness**

d / m	0,003	0,004	0,005	0,006
j_1 / deg	39,58	32,38	29,68	23,39
j_2 - j_1 / deg	17,09	33,29	43,18	53,07
α_a / W / m²×^{0}C	34,34	40,73	46,84	55,02

In the range of angles j_2 - j_1, a well-known combined nozzle was used to provide the forcible convective cooling of the pad weld (see Figure 3). On the divergent section of the combined nozzle, the air **ex aà-btall** to the ambient pressure and goes at high speed to the pad weld. The quantity of heat ΔQ_{air} that is taken out by the air flow should correspond to the quantity of heat generated from the pad weld during its forced convection (see Figure 4):

$$\Delta Q_{air} = \Delta Q_\kappa = \alpha_a \cdot A_p (t_{1a.p} - t_{a.air}) \cdot \Delta \tau \cdot \overline{\varepsilon}_p \qquad (8)$$

The required average heat transfer coefficient a_a $(\overline{\alpha})$ for the cross flow of gases of a cylindrical surface according to the results of well-known studies in the range of the Reynolds criterion Re = 1...4×10^5 is characterized by the following criteria equation [5]:

$$\bar{N}u = \left(0,43 + C_R \, \mathrm{Re}^m \, \mathrm{Pr}^{0.38}\right) \qquad (9)$$

where, $\bar{N}u = \overline{\alpha} \cdot d / \lambda$ - is the average Nusselt number; $\mathrm{Re} = c_2 \cdot d / \overline{v}$ - is the average Reynolds number; $\mathrm{Pr} = \overline{v} / a$ - is the average Prandtl number, for the air with atmosphere pressure (p$_2$ = 98 066,5 N / m²) and in the

temperature range - 50...+300 ^{0}C; Pr = 0,71; d = 0,06 m – diameter of the pad weld of the neck; $\bar{v}$ - is the kinematic viscosity of air at its average temperature, m^2 / s; $\overline{\lambda}$ is the t̶e̶r̶m̶a̶l̶ ̶ coefficient of air / m ^{2} / s.

This equation determines a required air flow rate c_2, blasting the pad weld [5]:

$$c_2 = \left(\frac{\frac{\bar{\alpha} d}{\bar{\lambda}} - 0,43}{C_R \cdot \mathrm{Pr}^{0,38}} \right)^{\frac{1}{m}} \cdot \frac{\bar{v}}{d} \qquad (10)$$

Along with that, the air flow rate c_2 at the combined nozzle exit [5]:

$$c_2 = \sqrt{ 2 \frac{k}{k-1} R T_1 \left[1 - \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \right] } \qquad (11)$$

where, $\approx 1,4$ – is the adiabatic index of air; R – is the gas constant of air / J / (kg×^{0}C); T_1 – is the air temperature before passing through the combined nozzle / ^{0}K; p_1 – is the air pressure before passing through the combined nozzle / N / m^2; $p_2 = 98\,066,5$ N / m^2 – is the air pressure after passing through the combined nozzle.

By equating the two expressions Eq. (10) and Eq. (11) a required air pressure at the entrance to the combined nozzle is determined [7]:

$$p_1 = p_2 \cdot \left[1 - \frac{k-1}{k} \cdot \frac{1}{2 R T_1} \left(\frac{\frac{\bar{\alpha} d}{\bar{\lambda}} - 0,43}{C_R \cdot \mathrm{Pr}^{0,38}} \right)^{\frac{2}{m}} \cdot \frac{\bar{v}^2}{d^2} \right]^{\frac{-k}{k-1}} \qquad (12)$$

Using well-known heat engineering methods and taking the average heat conduction coefficient $\overline{\lambda}$ and average kinematic viscosity of air $\overline{v}$ according to its

average temperature, the dependence of the required initial pressure of air on the thickness of the pad weld at the entrance to the combined nozzle is determined in Table 2.

The air under such pressure at the final stage of pad weld cooling enhances the convective heat transfer from it.

CONCLUSIONS

1) The temperature variation rate not lower than 80...100 ^{0}C / s at the end of the martensite under the temperature range 750 – 240 ^{0}C of the pad weld can be achieved by the forcible convective heat transfer with low heat retention and impact only on the pad weld.

2) To ensure the formation of fine-grained martensite in the neck pad weld by the forcible convective heat transfer, the air pressure at the combined nozzle entrance should be within $p_1 = 314\,793,5$ Pa under the pad thickness d = 0,005 m and within $p_1 = 408\,937,3$ Pa under the pad thickness d = 0,006 m.

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Table 2 **The dependence of the required initial pressure of air on the thickness of the pad weld at the entrance to the combined nozzle**

d / m	0,003	0,004	0,005	0,006
p_1 / Pa	207 901	261 837,6	314 793,5	408 937,3