MACHINE BUILDING AND MACHINE SCIENCE

UDC 621 https://doi.org/10.23947/2687-1653-2020-20-4-390-396

Technological features of crankshaft hardening by vibration shock method

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Introduction. The technological features of the processing crankshafts by the vibration shock method of surface plastic deformation (SPD), which is widely used in the technology of manufacturing machine parts, are considered. The research objective is to justify the efficiency of the influence of vibration shock hardening treatment on improving the quality and performance of crankshafts (CS).
Materials and Methods. The methodological studies included the validation of the vibration shock processing flowchart and the development of an analytic model for assessing the effect of processing on the change in the macrogeometry (warpage) of the CS.
Results. Flowcharts have been developed for volumetric vibration shock finishing and hardening treatment of CS using a vibratory machine with a U-shaped work chamber. Its overall dimensions measure alike or exceed the overall dimensions of the CS being processed, and ensure the location of the shaft in such a way that its main axis, coinciding with the axis of the main bearing journals, is in the zone of the conditional axis of working mass rotation. The surface quality parameters were investigated during their processing on the UVG 4X10 vibratory unit according to the proven techniques using the dedicated tooling. It has been established that the vibration shock hardening treatment (ViHT) enables, due to plastic deformation of microroughness, to obtain a qualitatively new surface microrelief and to reduce its initial roughness, to drastically increase the surface microhardness of the CS main and rod journals; at that, it changes the stressed state of their surface layer. A calculated dependence is proposed to assess the total warpage of the CS strengthened under the ViHT, and its adequacy is confirmed. It is shown that the warpage of the shaft after the ViHT is due to the different tension of the rod and main journals of the CS at the level of $K_{\text{н}} \approx 0.6$.
Discussion and Conclusions. Vibration shock treatment of CS provides an improvement in the geometric and physicomechanical parameters of surfaces of the rod and main journals. As a result of processing all surfaces of the shaft, warpage does not exceed the permissible values established by the technical requirements. So, we can conclude on the efficiency of the considered method of hardening CS with the aim of increasing their operational properties.

Keywords: crankshaft, surface plastic deformation, vibration shock method, hardening, surface quality, warpage.

For citation: V. A. Lebedev, F. A. Pastukhov, M. M. Chaava, et al. Technological features of crankshaft hardening by vibration shock method. Advanced Engineering Research, 2020, vol. 20, no. 4, pp. 390–396. https://doi.org/10.23947/2687-1653-2020-20-4-390-396

Introduction. A set of measures to preserve the accuracy of the CS achieved through forming includes improving the methods for obtaining blanks, mechanical processing, as well as the introduction of strengthening treatment operations into the general process designed to enhance the service properties of these products. One of the most common SPD methods that strengthen chamfers and increase the fatigue resistance of CS is running-in and caulking [1–7]. However, the CS strengthening through methods of running-in and caulking chamfers is accompanied by their warpage, which causes an increase in the main journal runout, the violation of the initial geometric shape that requires additional adjustment. In this regard, the development of new processing techniques of finishing and strengthening by SPD methods, which increase the reliability and durability of CS under difficult operating conditions, is urgent. Of particular interest in this area is vibration shock treatment, which has received wide practical application in the technology of manufacturing machine parts [8–15]. In this regard, the research objective is to validate the effectiveness of the vibration-shock hardening impact on the quality and performance of CS.

Materials and Methods. To achieve this goal, the following tasks are set:

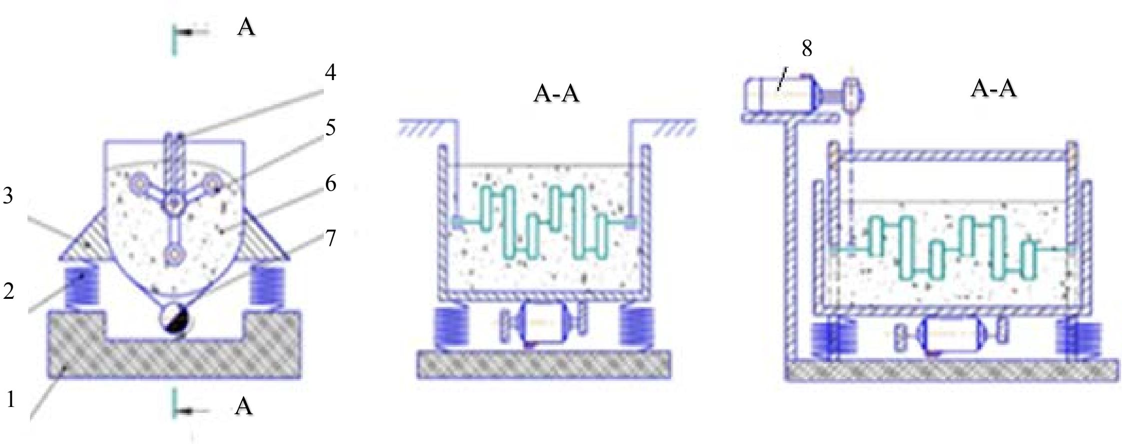
— to develop flowcharts for vibration shock hardening of all components of CS;

— to study the impact of vibration shock treatment on the geometric and physicomechanical parameters of the surface of rod and main journals;

— to propose a computational model for assessing changes in the macrogeometry (warpage) of CS under vibration shock treatment and validate it.

The research was carried out on the UVG 4X10 vibratory unit according to the proven techniques. A special device simulating a crankshaft was used to determine the quality parameters of the hardened surface. The measurement results were processed using mathematical statistics. The warpage of the studied shafts was determined through measuring the radial runout of the journals before and after hardening by an indicator reading in 0.01 mm. At the same time, the CS was installed with its main journals on prismatic supports and rotated by hand.

Research Results. Fig. 1 shows flowcharts for volumetric vibration shock finishing and hardening treatment of CS using a vibratory machine with a U-shaped work chamber, whose overall dimensions measure alike or exceed the overall dimensions of the CS being processed. During processing, the shaft is installed in such a way that its main axis coinciding with the axis of the main bearing journals, is in the zone of the conditional axis of working mass rotation. As a result of this arrangement of the shaft, the central zone of low activity is excluded, and the cylindrical surfaces of the main and rod journals displaced relative to the main axis of the shaft are processed in the zones of medium and maximum pressure. CS is installed in the bed along the guiding groves and is held on the supports attached to it. The bed with the shaft is immersed in the chamber with the working medium and fixed on racks attached to the frame. Supports allow the shaft to scroll around its axis and evenly strengthen under the dynamic impact of the working environment (Fig. 1. *a, b*) or through imparting an oncoming or passing rotation to it using an independent drive (Fig. 1 *c*).



a) *b*) *c*)

Fig. 1. Flowcharts for processing CS with rotation under the action of the working medium (*a, b*) and using an additional drive (*c*): 1 — frame; 2 — springs; 3 — working chamber; 4 — bed; 5 — crankshaft; 6 — working medium; 7 — vibrator, 8 — auxiliary drive

To determine the preferred modes of processing CS, geometric and physicomechanical parameters of the surface of rod and main journals were studied using cylindrical and annular samples made of 45 and 40X steels with initial roughness R_a=0.16-0.42 µm. Processing was carried out by a working medium consisting of steel balls with a diameter of 3–6 mm, according to the basic technological scheme shown in Fig. 1. *a, b*, using a special mandrel (Fig. 2) with different amplitude-frequency characteristics and the process time.

a) *b*)

Fig. 2. Experimental mandrel simulating the crankshaft: *a)* general view; *b)* installation in the working chamber of the vibration unit

It is established that under ViHT, a qualitatively new microrelief is formed on the surface of the samples, whose arithmetic mean deviation of the profile is less than on the initial surface. The change in the arithmetic mean deviation of the profile is critically affected by the amplitude of the working chamber vibrations and the processing time. So, for the same processing time period t = 20 min, at frequency f = 25 Hz, under increasing the amplitude from 2 to 3 mm, mean arithmetic deviation of surface profile is decreased by 1.7 times, and a change in the oscillation frequency from 20 to 30 Hz at the amplitude A = 3 mm has reduced arithmetic mean deviation of the surface profile by 1.1 times.

Taking into account the capabilities of vibratory machines, the established regularities made it possible to validate the amplitude-frequency parameters that provide the most effective power impact on the part under the ViHT process at the level of A = 3 mm and f = 25 Hz. Processing samples in these modes for 20 min, as shown in Fig. 3, reduces the arithmetic mean deviation of the initial surface profile by 2.6 times or 60 %. Increasing the processing time to 40 minutes does not cause a significant change in the parameter under consideration.

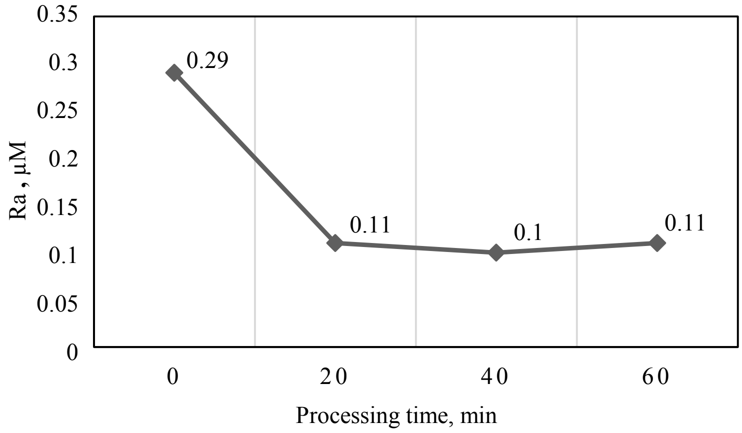


Fig. 3. Dependence of arithmetic mean deviation of the surface profile
on duration of vibration shock treatment

The efficiency of the selected modes is validated by the study results of physicomechanical characteristics of the surface layer after processing with steel balls in the mode: A = 3 mm, f = 25 Hz (Fig. 4, 5). Microhardness was evaluated on hardness tester PMT3, the stress state was estimated by the value of residual compressive stresses determined by the Davidenkov method through cutting ring samples.

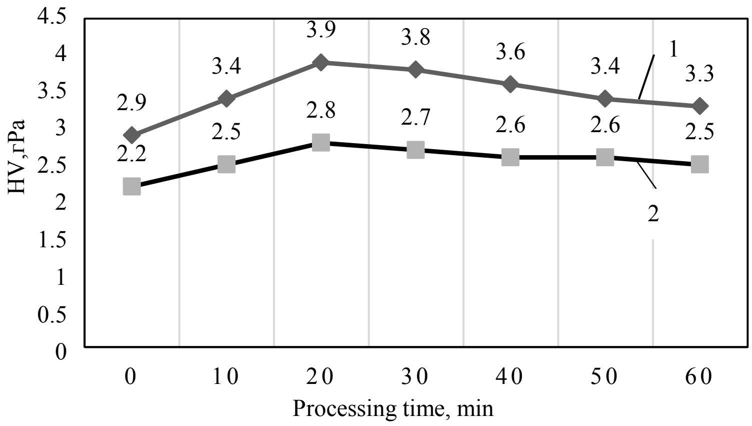


Fig. 4. Effect of processing time on microhardness of the surface layer for the ball material:
1 — steel 40X; 2 — steel 45

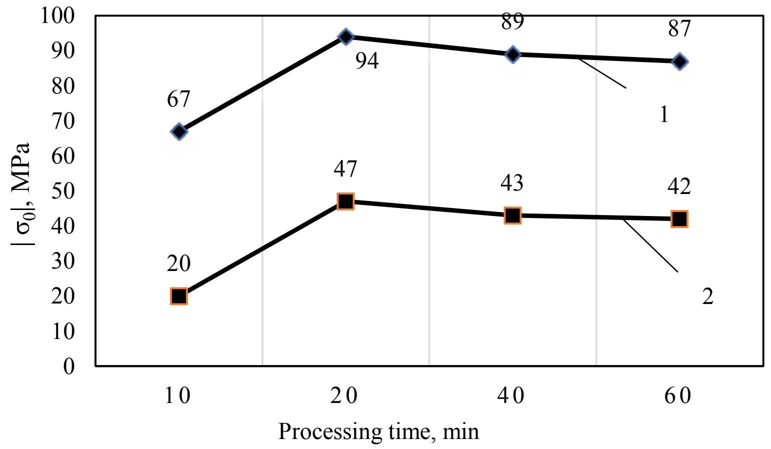


Fig. 5. Dependence of residual compressive stresses σ_0 on ViHT duration of samples installed on the bushings (1) and on the shaft (2)

Analysis of the stress state of samples hardened under ViHT (Fig. 5) has shown that the residual compressive stresses of samples fixed on bushings and simulating CS rod journals are 35% higher than those of samples fixed on the shaft and simulating main journals. This is due to the difference in the intensity of exposure to the processing medium in various areas of the working chamber.

The next stage of research provided for the development of a computational model for estimating the macrogeometry (warpage) variation of CS under vibration shock treatment, and its experimental validation. V. N. Emelyanov [1] proposed a graphoanalytical method for analyzing the macro deformation of CS after hardening treatment by the SPD method (Fig. 6).

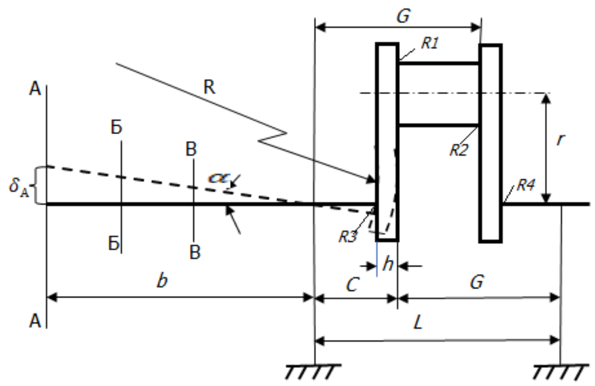


Fig. 6. Scheme of CS warpage after SPD of chamfers of main and rod journals

The method consists in determining the displacement of the shaft end δ_A in section A–A depending on its geometric dimensions: r — the distance from the axis of the main journal (MJ) to the axis of the rod journal (RJ); h — the thickness of the crank web; b — the distance from the MJ axis to the end of the CS; L — the distance between the MJ axes of one crank; C — the distance from the crank web from the RJ to the MJ axis.

The offset δ_A corresponds to the angle of deviation of the shaft axis from the horizontal whose value depends on the angular position of the crank web α, which is rigidly connected to the main and rod journals. The interrelated parameters δ_A and α depend on the average value of the residual compression stresses σ_o in the surface layer after the SPD and the depth of their occurrence δ_σ. In addition, it is shown in [1] that the value of warpage of a multicrank CS is mainly determined by the degree of hardening of the MJ and RJ chamfers attached to the end web of the end crank.

Using the considered method, an expression is obtained for calculating the total warpage of CS reinforced through ViHT:

$$\delta_A = \frac{6\,(1-\nu)}{E} \cdot \frac{r}{h^2} \cdot \frac{b}{L} \cdot K_у \cdot \sigma_{дт} \cdot K_{ко2}[-K_н(L+h-C)+(L-C)], \quad (1)$$

where E — elasticity modulus of the first kind; ν — Poisson's ratio; $\sigma_{дт}$ — dynamic yield strength; $K_{ко2}$ — coefficient of adjustment of the value of the RJ residual compressive stresses depending on their diametrical dimensions and deformation parameters of the power impact of a part of the working medium; $K_у$ = 1.1–1.5 — coefficient of correction of the depth of residual compressive stresses; $K_н$ — coefficient that takes into account the difference between the stress state of the MJ and the stress state of the RJ. According to the results of these studies, this coefficient depends on the distance from the walls of the working chamber and is $K_{\text{н}} \approx 0.6$.

To validate the model (1), experimental studies were carried out on 5 full-scale CS that underwent complete mechanical processing. The crankshaft material was as follows: steel 45, hardness after annealing 180 – 228 HB, rod journals of 25 mm diameter subjected to the HFC hardening to a depth of 2–4 mm to hardness of 52–65 HRC, while the chamfers of 2–3.2 mm radius with roughness R_a = 1.6 µm remain without heat treatment. Mechanical characteristics of the CS material are: $\nu = 0.25$; $E = 2{\cdot}10^5$MPa; $\sigma_{\text{т}} = 360$ MPa. The CS dimensions are: $r = 37.5$ mm, $h = 27$ mm, $L = 254$ mm, $C = 60$ mm.

CS hardening was carried out according to the basic technological scheme (Fig. 1, *a, b*) on 2×50 UVG vibratory unit with a working chamber volume of 50 dm^3. The working environment was a mix of hardened polished balls of 3 – 6 mm diameter from steel ShKh15 of 60–62 HRC hardness. The processing parameters were: vibration amplitude — 3 mm; vibration frequency — 25 Hz; processing time — 20 min.

Warpage of the shafts was determined through measuring the radial runout of the main journals before and after hardening by an indicator reading in 0.01 mm. The CS was installed by its main journals on prismatic supports and rotated by hand. Fig. 7 shows the experimental and calculated values of the CS radial runout after ViHT in sections of the shaft end removed from the end crank web of the end crank at the distances: A–A = 123 mm, B–B = 77 mm, C–C = 17 mm. From these data, it follows that the deviation of the actual values of CS warpage from the calculated values is on average no more than 15–20 %, which allows us to recommend the dependence (1) for calculating CS warpage under vibration shock treatment.

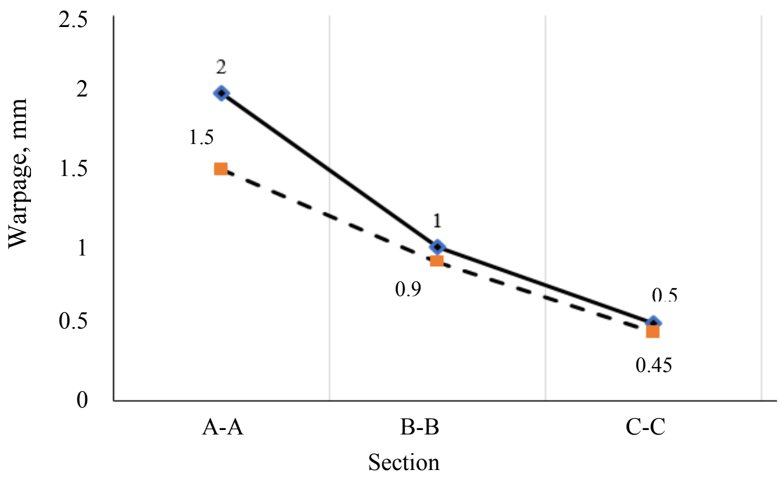


Fig. 7. Dependence of CS radial runout on the location of the controlled section:
solid line — experimental values, dotted line — calculated values

Discussion and Conclusions. Vibration shock treatment improves the geometric and physicomechanical parameters of the surfaces of rod and main journals of CS. As a result of processing all surfaces of the crankshaft by this method, the amount of warpage does not exceed the permissible values established by the technical requirements. This allows us to draw a conclusion about the efficiency of the considered method of strengthening CS to increase their operational properties.

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Submitted 08.09.2020
Scheduled in the issue 07.10.2020

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Claimed contributorship

V. A. Lebedev: basic concept formulation; research objectives and tasks setting; academic advising. F. A. Pastukhov: analysis of the research results; text preparation; formulation of conclusions. M. M. Chaava: computational analysis; text preparation; formulation of conclusions. G. V. Serga: correction of the conclusions.

All authors have read and approved the final manuscript.