Research of crankshaft with three crankpins warping due to fillets stamping

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Abstract. The paper presents the results of the experimental study of the process of warping of dimensioned crankshafts with three crankpins during hardening their fillets by stamping

Introduction
Crankshafts (CS) are widely used in modern engineering. However, despite the extensive experience gained by specialists in the design, manufacture and operation of CS, they are often destroyed in operation due to insufficient supply of fatigue resistance. According to Prof. V. P. Uskov, such destruction is observed in 2-8% of engines coming for repair [1]. Destruction occurs mainly along fillets. The most effective and simply implemented in terms of increasing the resistance to fatigue of CS is the operation of hardening their fillets by surface plastic deformation (SPD): roller burnishing, hammering, etc. [2]. However, as practice shows and numerous experiments, processing fillets of CS by SPD leads to warping of CS [3]. Moreover, the more effective way in terms of increasing the resistance to fatigue, the more it leads to CS warping. With intensification of hardening mode resistance to CS fatigue, increases but at the same time increases the size of its warping.

At the department of engineering technology of Yaroslav-the-Wise Novgorod State University the basic provisions of the theory of CS warping have been developed when hardening their fillets by SPD [4]. In particular, the experimental and computer simulation was carried out of the process of warping of spatial crankshafts with six crankpins (CP), which are in pairs located at angles of 120 ° [5] and with five CPs, located at angle of 72 ° [6, 7]. The purpose of this work is to study the regularities of the spatial CS warping process with three CPs, located at angle of 120 ° relative to each other, which has not been previously studied.

Results of the experiment
As the object of the research the CS of SMD-60 engine was selected, the sketch of which is presented in Figure 1. This CS has three CPs, located at an angle of 120 ° to each other. The diameter of the crankshaft necks (CN) is 90.5 mm, the diameter of the CP equals to 84.5 mm. The radius of the crank is 57.9 mm. One cheek-piece (to the left in Figure 1) of CS has the thickness of 34 mm, other cheeks of the shaft have the same thickness of 26.5 mm. The radius of fillets of the CN, and crankpin equal to 4.5 mm. The distance between supports is L = 551 mm.
Experiments were conducted at the consistent hammering of the fillets. Fillets were processed manually with the help of striker with spherical head and hammer in such sequence: fillet No 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 (fillet 1 and 12 were not processed). The energy of impact $E_I$ was approximately 38 J. The magnitude and direction of the CS wobbles vector was measured after the processing of each fillet with the help of indicator, the measuring rod of which was entered in contact with the third on the left (in Figure 1) $CN$, between fillet 8 and 9. The direction of the wobbles vector was characterized by an angle of $\alpha_i$ that is the angle between the $y$ axis and the wobbles vector. The size and direction of the wobbles vector of CS from the processing of each fillet counted as the difference of the wobbles vectors after and before the processing of given fillet. The direction of the wobbles vector was characterized by an angle of $\alpha_j$ that is the angle between $y$ axis and the wobbles vector.

![Figure 1. Sketch of SMD-60 engine CS.](image)

Before the beginning of the experiment the initial wobble of CS $\delta_i$ was 0.21 mm and the vector of wobbles was directed at an angle $\alpha_i = 190 ^\circ$. After hammering fillets 2-11 the final wobble of CS $\delta_f$ was 0.18 mm, and the vector of wobbles is directed at angle $\alpha_f = 220 ^\circ$. The total value of warping $\delta_s$ after hammering fillets 2-11 was 0.115 mm. By results of experiment the epure of CS warping vector was plotted which is shown in Figure 2.

The analysis of the given plot has shown, that the majority of CS warping vectors from hardening of separate fillets lie in the plane of cranks with an error not exceeding 10 – 15% (except for vectors from hammering fillet 2, 5, 6).

On the basis of the received data the curve of dependence of CS warping value from distance from fillets to supports, i.e. from fillet number (Figure 3) has been constructed.
During the experimental study of the CS warping process with five CPs also was obtained undulating graph of the dependence of CS warping from the distance from fillets to the supports (from the fillet number) (Figure 4) [6, 7].

The authors explain the undulating nature of the curves in the following way. In publication [8] formula (1) for calculation of CS warping value at hammering the fillets is given:

$$\delta = K \left( \frac{HB^{0.75}(1540 - HB)(1 - \nu)}{E} \right) \frac{R}{h^2} \frac{c}{2} \sqrt{\frac{E}{D}} \Psi,$$

where $K$ is the coefficient determined by experiment; $HB$ is Brinell hardness; $\nu$ is the Poisson coefficient; $E$ is the modulus of elasticity of I-type, MPA; $R$ is the radius of the CS crank, mm; $h$ is thickness of the cheek, mm;
C is the distance from the left support (at processing fillets 2 – 6) or from the right support (at processing fillets 7 – 11) up to the processed fillet;

$E_i$ is the energy of striker impact, J;

$D_1$ is diameter of the spherical head of the striker, mm;

$\Psi$ is the coefficient that takes into account the incomplete processing of the cheek by hammering; It is counted according to formula (2) [8-11]:

$$\Psi = \frac{F_i}{F_R} \leq 1,$$

where $F_i$ is the area of the cheek of the crankshaft, where the cheek bend occurs (this changes the macrogeometry of the crankshaft);

$F_R$ is the total area of spherical prints of striker on the surface of fillet (and partially cheeks), which in turn depends on the diameter of the neck and the radius of the fillet.

Thus, "$\Psi$" value of each fillet also depends on the diameter of the neck and the radius of the fillet. At transition from processing one fillet to processing the next fillet at the same time value "C" and value "$\Psi$" are changing simultaneously. With the increase of "C", value "$\Psi$" gradually increases up to the middle of the shaft. And value "$\Psi$" increases, then decreases, because CN and CP for the given CS alternate. This circumstance leads to the appearance of wave graph of CS warping dependence on the fillet number.

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