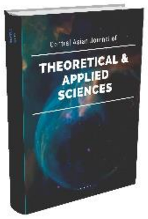

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Improvement of Operational Characteristics Crankshafts Made of High-Strength Cast Iron

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Abstract: *Based on the results of experimental studies and operational tests, the effectiveness of using combined hardening to improve the performance of cast-iron crankshafts of transport diesel engines has been established.*

Keywords: *crankshafts, combined hardening, fatigue resistance, wear resistance.*

Introduction.

Improving the operational reliability and service life of transport diesel engines is closely related to improving the technology of manufacturing crankshafts – the most responsible, heavily loaded and expensive engine parts. The crankshafts of diesel engines of types D100 and D80 up to 4.5 m long and weighing up to 1.7 tons are cast from high-strength cast iron with a spherical graphite shape [1].

The technology currently used in industry for manufacturing cast crankshafts is usually based on on the application of casting operations with subsequent early knocking out of castings, which significantly reduces the cost of their production.

This technology provides a given level of strength properties of the material, however, during operation, there is a gradual wear of the necks, causing an uneven distribution of loads along the length of the shaft, the emergence of fatigue cracks and the destruction of parts. Thus, the main indicators characterizing the operability of the shafts are the wear resistance of the neck surface and fatigue resistance under the action of cyclic loads [2].

Analysis of publications.

The study of literature sources indicates that there are a large number of hardening technologies aimed at improving the operational reliability of parts, including crankshafts, the most effective of which are HDPE hardening, laser beam hardening, electroplating, detonation, gas-thermal coatings on the surface of the shafts, vibro-arc surfacing, ion-plasma treatment, electric spark alloying, treatment with a highly concentrated plasma jet, mechanical hardening by rolling in rollers, riveting shot, hammering, etc. The noted methods of hardening are well researched and implemented for products made of steels and light alloys and are significantly less used for hardening cast iron parts, especially high-strength, and, in particular, such critical parts as crankshafts. In addition, known processing methods often do not provide a comprehensive increase in the characteristics of wear resistance and fatigue resistance of parts [3]. In this case, it is advisable to use combined hardening methods, including surface plastic deformation (PPD) in combination with hardening methods that increase the wear resistance of the surface. However, the material science aspects of the application of such methods for strengthening parts made of high-strength cast iron, in particular the crankshafts of powerful transport diesel engines, have not been sufficiently developed.

Purpose and task statement.

Proceeding from the above, the purpose of this work was to study the effect of combined hardening methods based on a combination of one of the types of heat treatment (quenching with heating HDPE, laser heat treatment (LTO), electric spark alloying (EIL) of the surface) and subsequent surface plastic deformation, on the performance characteristics of cast-iron crankshafts (wear resistance of the neck surface and fatigue resistance).

Research methodology.

High-strength cast iron, modified Mg, of the following chemical composition, mass %, was used as a material for research: 3.4...3.9 C; 1.9...2.5 Si; 0.8...1.25 Mn; 0.5...1.0 Ni; 0.2...0.5 Mo; 0.05...0.1 Mg; ≤ 0.1 Cr; ≤ 0.05 P; ≤ 0,02 S. The basis is Fe.

The implementation of a complex of experimental studies allowed us to establish the dependence of the operational characteristics (wear resistance and fatigue resistance) of samples and full-scale crankshafts from high-strength cast iron with spherical graphite from the structure of the material formed as a result of thermal treatments and its strength properties. According to the results of wear and fatigue tests , the following are determined optimal parameters of the hardening processes by hardening HDPE, LTO, EIL, providing the depth of hardening and surface hardness in accordance with the technical requirements for crankshafts. It has been established, however, that practically all the studied variants of thermal hardening lead to a decrease in the limits of limited endurance by 15-25% compared with the values of this characteristic for cast iron released after early knocking out of castings (the variant adopted as the initial one) [4-6]. Optimization of parameters of subsequent hardening of crankshafts rolling in rollers led to an increase in fatigue characteristics due to the creation of a high level of residual compression stresses and a more uniform distribution of them along the length of the hardened surface [7, 8]. Based on the positive research results, experimental batches of crankshafts hardened by quenching were made HDTV, LTO and EIL with subsequent PPD run-in rollers. In the manufacture of crankshafts, cast iron was smelted in an electric arc furnace of the DS-6N1 type with a capacity of up to 6 tons. During the melting process, cast iron was modified with ferrosilicon FS-75 (L). Processing of cast iron metallic magnesium was carried out in a converter-type LO-16 hermetic bucket. The casting of the crankshafts was carried out in double flasks at the temperature of the beginning of pouring 1360 – 1340 ° C. 7 hours after casting, the molds were opened and intensive cooling of the castings was carried out by aerators. After knocking out of the mold, the castings were released at a temperature of 680 ± 20 ° C for 6 hours. The castings subjected to stumping and cleaning were sent for gamma-grading at the Gammarid-192 installation in order to detect internal defects, the structure and level of mechanical properties, after which they were mechanically processed. Hardening of the HDPE surfaces of the main and connecting rod necks of the crankshafts of diesel engines of the type 10D100 was carried out according to the technological scheme, including preheating of the surface layer of metal to a temperature of 350 – 400 ° C (for 40 seconds with a generator power of 40 kW), heating with high–frequency currents up to 955 – 990 ° C (generator power 500 – 700 kW, time 5 - 6 s) and air cooling for the account of the heat sink into the mass of the part and the environment. Quenching was performed using detachable copper inductors of the appropriate size with side screens. Permanent gap (3 mm) between the inductor and the neck surface was provided through the use of refractory inserts. To protect the edges of the oil supply holes from cracking and melting during quenching, shaped copper inserts were used, tightly installed in each hole. In order to reduce residual stresses in the hardened HDPE layer, the crankshafts were subjected to tempering at 370 ± 10 ° C for 12 hours. Such processing ensured the receipt of the specified CD parameters. The depth of the hardened layer was 4.5 – 5 mm, surface hardness: after hardening HDPE 48...52 HRCe, after vacation 42...49 HRCe. A hardened zone of martensitic-perlite structure was formed in the near-surface volumes.

Laser heat treatment of crankshafts was carried out on a special stand with a laser radiation source in the form of a CO2 laser (LT1-2M installation). The radiation power is 2.6...2.9 kW, the axial displacement speed is 15 mm min–1, the rotation speed is 1.5 min–1. The roughness of the surface of the shaft necks before the LTO was 2.0 microns, to improve the absorption of laser radiation, all necks were treated ammonium persulfate. The hardening was carried out without melting the surface along a single-pass helical line with the closure of the rings at the beginning and end of the spiral at a distance of 4 ... 6 mm from the galtels. The width of the laser hardening track was 5 mm, the distance between the tracks was 5 mm. At the same time, 50 – 70% of the neck surface is strengthened. After LTO , the shafts were released at a temperature of 350±10°C for 2 hours.

The hardening depth is ~ 1.1 mm, the hardness of the hardened sections is 691...698 HV, non–hardened - 233...229 HV, a martensitic-austenitic structure is formed in the quenching zone. The implementation of the process of hardening of the EIL was carried out using an installation in which the gap between the disk electrode and the part is kept constant during processing, and the electric discharge is provided by the formation of current pulses in the circuit generated by the generator. An electrode made of steel was used for electric spark treatment of the surface of the crankshaft necks 12X18H10T, made in the form of a disk with a diameter of 450 mm. The discharge power was 1.5 kW. Shaft rotation speed 5.5 min–1, the longitudinal feed is 0.4 mm · about-1. After performing the EIL operation, the surfaces of the root and connecting rod necks were polished to a roughness of 0.63 microns. This processing scheme ensured the appearance of secondary hardening structures and "white" layers up to 0.3 mm deep. Hardness HV ≥ 500 and the hardening density within 75 – 80% of the cylindrical surface of each neck. Hardening by rolling in the rollers of the galtel transition along the R8 of the main and connecting rod necks was performed using a universal hydraulic device with three pairs of rollers, which made it possible to strengthen at the same time both galteli. The working force was communicated to one pair of rollers in the radial direction to the center of the shaft being processed. The rollers used differ from each other in the geometry of the working profile and strengthen various sections of the galtel (multi-profile rollers). The diameter of the rollers is 75 mm, the angle of inclination of the plane of the rollers to the shaft axis is 75 °. The running–in force is 16 kN per roller.

The shaft rotation speed is 15-20 min–1. The hardening of this section of the galtel is carried out in 8-9 revolutions of the shaft. The run-in along the radius of the galtel interface with the neck forming (R2,5) was carried out paired rollers with an inclined profile with a force of 13 kN for each roller. The profile radius of the rollers used is 1.5 mm, the diameter is 75 mm. For 12 – 15 revolutions of the shaft, the hardening of this surface is performed. To harden the surface of the necks due to the fact that the generally accepted axial feed running-in scheme is practically difficult to implement in this case, cylindrical rollers with a working profile in the form of a spiral protrusion were used. The running–in force was in the range of 42 ... 48 kN, the shaft rotation speed was 10 – 15 min–1. One of the rollers had the left direction of the spiral, the other – the right. The third video was supportive. The run-in was performed by simultaneously creating a series of hardened strips along the entire length of the cylindrical part of the neck in the form of turns shifting with partial overlap at each subsequent rotation of the shaft, while the width of the hardened strip was specially calculated [9]. After running-in, all the crankshaft necks were subjected to superfine treatment to the final size with the removal of a surface layer of at least 0.03 + 0.01 mm per side.

Research results.

In the manufacture of crankshafts, reinforced with HDPE with subsequent PPD, on single-cylinder compartments and deployed products, a negative effect on the quality of the shafts of casting defects in the form of pores and looseness located in the near-surface layer was found. This led to a high percentage of hardened shaft defects: 13.6% for casting defects, 18.2% for the presence of quenching and grinding cracks, the order of 5% on gamma-grading, linear dimensions and neck beating. The roll-in of the shafts and shaft necks by rollers did not allow to completely neutralize the negative influence of the foundry defects, although significantly increased the fatigue resistance of hardened shafts.

High-quality shafts installed on diesel engines operated on railways have no complaints. As a result of the work carried out, it was found that the industrial use of HDPE hardening for local heat treatment of the necks of cast-iron crankshafts of transport diesel engines largely depends on the quality of castings.

Crankshafts, hardened by a laser beam and run-in rollers, have a higher efficiency, since the influence of permissible casting defects is practically does not affect. Positive results of operational tests of shafts installed on products with combined hardening based on LTO followed by PPD, despite the long service life, emergency failures of the crankshafts of the experimental batch were not recorded. However, it should be taken into account that the industrial development of LTOs for strengthening the crankshafts of transport diesel engines made of high-strength cast iron is associated with the need to create an expensive laser technological complex. Introduction into the production of electric spark alloying the surface of the crankshaft necks requires significantly lower costs and is implemented in serial production in the manufacture of diesel locomotives of the D80 type. However, despite the satisfactory wear resistance characteristics, the small depth of the hardened layers makes it necessary to re-harden the surface of the crankshaft necks during major repairs. The work carried out shows the effectiveness of the use of thermal treatments (HDPE, LTO, EIL) followed by PPD run-in rollers according to optimal modes to improve the performance of crankshafts of transport diesel engines made of high-strength cast iron with spherical graphite. The industrial implementation of the developed methods for strengthening crankshafts made of high-strength cast iron with spherical graphite allows to increase the service life of the diesel engine up to the first bulkhead by 2 times, the service life up to overhaul by more than 1.5 times (Table 1). Maintenance of diesel engines with hardened crankshafts at the depot revealed that the cost of repair work during the service life of diesel engines has been reduced by more than 2 times.

Table 1 Results of operational tests of shafts on deployed diesel engines

№	Manufacturing technology of crankshafts	Material from the sliding beari	Resource (mileage of the locomotive) up to	
			first bulkhead, thousand km	Capital repairs, thousand km
1	Early knockout, vacation	Bronze babbit B2	200	**800**
2	According to claim 1, HDTV, PPD	**AO20-1**	400	1200
3	According to claim 1, LTO, PPD	**AO20-1**	400	1500
4	**According to claim 1, ETHYL, PPD**	**AMO1-20**	400	1200

The use of combined hardening made it possible to exclude cases of destruction of crankshafts in operation and to install more wear-resistant steel-aluminum plain bearings with an anti-friction layer of the alloy type on the engines AMO 1-20.

Conclusions.

The analysis of the obtained results indicates the high efficiency of the use of combined hardening methods for crankshafts made of high-strength cast iron with spherical graphite. The obtained patterns are confirmed by operational tests.

The most effective way of processing, providing high wear resistance of the surface of the parts while increasing fatigue resistance, is the hardening of the shaft necks of the SUMMER, followed by the PPD of the shaft transitions and the surface of the necks. The results of the work carried out show the expediency of widespread implementation in production of the studied methods of combined hardening in the manufacture of large diesel engines with cast-iron crankshafts.

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