Improving the Quality of Friction Surface by Applying Antifriction Materials to Them

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Abstract. The article investigated the process of applying antifriction coatings to the surface of hardened cast iron gear wheels. The diffusion coating of cast iron wheels with vanadium greatly strengthened the surface and increased its wear resistance. Aluminium, tin bronze and copper were used as antifriction materials. The coating was applied with metal brushes. The brushes tore off individual fragments of anti-friction metal particles and smeared them over the surface of the coated product. Research results have confirmed the acceptability of this method instead of expensive finishing operations that cannot be applied to diffusion-hardened gears due to the shallow depth of the vanadium coating. The proposed method is universal for all types of metal products operating under sliding friction conditions. Results are presented as spatial histograms.

1. Introduction
The President of the Russian Federation pointed out the need to develop domestic production of products to ensure the country's food independence [1-2]. The volume of supplies of foreign agricultural machinery is not sufficient. Import of agricultural machinery is only 80% of the required number of tractors and 50% of the demand for combines [3]. The Russian tractor industry is experiencing another crisis.

Agricultural producers are forced to use old equipment. The service life of machines exceeds the standard by 2-3 times [4]. The reliability indicators of such equipment are quite low. Improving the efficiency of using agricultural machines in such harsh operating conditions is possible due to the restoration of worn parts [5].

The reliability of agricultural machines is often determined by the durability of the rubbing surfaces of the kinematic pairs. Refusal from such surfaces occurs already with wear of 0.1-0.3 mm according to the All-Russian Scientific Research Technological Institute for the Repair and Operation of the Machine and Tractor Park of the Russian Academy of Agricultural Sciences. A promising way to restore and harden failed parts is the use of thermal diffusion wear-resistant coatings. The cost of this technology is only 25-30% of the cost of the workpiece. This increases the durability of parts by 2-4 times [6-10].

The highest adhesion strength to the base metal is possessed by coatings with a thickness of no more than 1.0-1.2 mm [7]. However, the surfaces of rubbing parts after restoration of diffusion coatings have increased roughness. This contributes to the development of cavitation pitting [11-16].
2. Materials and methods

The object of research was a spur gear pair made entirely of high-strength cast iron VCh 60 (Figure 1).

The investigated cast iron gear pair: (a) is gear; (b) is wheel.

The diffusion saturation method is an affordable and effective way to restore parts of agricultural machinery. Thermal diffusion vanadium coating was applied to the surface of gear wheels after quenching and low tempering. The coating consisted of the following components:

- Ferrovanadium with a vanadium content of at least 50% by weight (GOST 27130-94);
- Ferromanganese with an average manganese content of 88% by weight (GOST 4755-91);
- High-carbon ferrochrome with a chromium content of more than 65%, carbon 8-8.5% and silicon not more than 2% (GOST 4757-91);
- Aluminum oxide (GOST 8136-76);
- Ammonium chloride (GOST 2210-73).

The components of the mixture were mixed until smooth. Subsequent quenching in oil at a temperature of 675°C and low tempering ensure the hardness of the cast iron matrix 50–55 on the Rockwell hardness scale.

External antifriction coatings were mechanically applied to the working surfaces of the teeth over the vanadium coating. The purpose of applying such coatings was to increase the contact of the working surfaces of hardened gears and improve the running-in processes [9].

The tests involved three contact pairs with the same internal thermal diffusion vanadium coating and a different type of surface coating. All gear pairs were hardened at the same time. The following materials were used as antifriction materials: Aluminum (Al), Bronze (B 555) or Copper (Cu). The donor metal was pressed with a force sufficient to remove small inclusions from it. The coating was applied from the donor metal using metal brushes, which in the form of individual fragments strip off the particles from the anti-friction metal and smear them on the surface of the coated product (Figure 2).

Figure 2. Scheme of applying antifriction coatings with metal brushes: 1 is donor metal; 2 is metal brush; 3 is working surface.
The purpose of the research was to select an anti-friction coating. The selection criteria were:
- ensuring the smallest roughness after running-in wheels in pairs;
- no chips and chipping of the diffusion layer under the anti-friction coating.

Running-in was carried out without load at idle speed on a special test bench for 0.5 hour (Figure 3). An asynchronous electric motor with a rotation speed of 3000 rpm was used as a traction device. The speed of rotation of the gear, taking into account the gear ratio, was 1925 rpm, the speed of rotation of the wheel was 1600 rpm.

![Figure 3. Installation for testing cast iron gear wheels](image)

The condition of the working surfaces of the teeth was assessed after the running-in of the gear wheels in a pair. The roughness was measured using a profilometer with an electronic reading scale. The measurement results were compared with the roughness of the gears after the fine grinding operation.

### 3. Results and discussion

The results of measurements of the surface roughness of the gear pair before and after running-in are presented in the form of bar diagrams (Figure 4).

![Figure 4. Surface roughness diagram of with anti-friction coating (a) for gear and (b) for wheel:](image)
- initial roughness (after vanadium treatment);
- after coating with anti-friction material;
- after running-in in a pair.
The initial roughness of the gear surface after vanadium treatment was 1.495 µm, and for the wheel it was 1.226 µm. Antifriction aluminum (Al) coating evens out the initial roughness after thermal diffusion vanadium. This was due to the soft properties of aluminum, which was easily "smeared" on the surface of the gears and wheel. The roughness of the gear after applying the aluminum coating decreased to 1.22 µm, and on the wheel to 0.998 µm.

Tin bronze is less ductile than aluminum. This leads to a lesser effect of "healing" the initial roughness after thermal diffusion saturation with vanadium. The roughness of the gear with a bronze coating (B555) is 1.297 µm while the original is 1.361 µm. For a cogwheel, these data are 1.702 µm before bronze application and 1.548 µm after bronze treatment.

Copper (Cu) coatings was characterized by the smallest changes in roughness. This was because copper had a high melting point and high toughness. It was poorly "smeared" over the surface and remained in the form of separate fragments. Mechanical copper plating even slightly increased the original roughness. The roughness of the gear after copper plating increased from 1.548 µm to 1.624 µm. The roughness of the gear wheel after mechanical deposition of copper coating changed from 1.368 µm to 1.402 µm.

After running-in, the roughness of the mechanically coated surfaces of the teeth decreased relative to the initial state: 2.3 - 2.8 times when coated with aluminum (Al), 1.4 - 1.9 times when coated with bronze (B555) and 1.2 - 1.4 times when coated with copper (Cu).

4. Conclusion

Comparison of various mechanical coatings on the surfaces of the gear teeth and wheels showed that the aluminum coating is the best. The roughness value of the cast iron wheels with aluminum coating after running-in was 0.527 µm for the gear and 0.641 µm for the wheel.

The quality of the working surfaces was assessed by comparing its roughness with the steel wheels traditionally used in this box after fine grinding. The roughness of steel wheels is 0.522-0.680 µm. Mechanical application of softly plastic materials to gears with their subsequent running-in in pairs allows achieving results similar in quality to the surface of the teeth in comparison with finely ground steel wheels. The proposed surface preparation of vanadium-coated cast iron gears using and aluminum coating is fully consistent with the quality of a steel gear tooth.

The use of a mechanical coating of tin bronze (B555) or copper (Cu) does not provide the required quality of rubbing surfaces. The final roughness after running-in is 1.7 - 1.9 times higher than the roughness of steel teeth after fine grinding in the case of coating with tin bronze (B555) and 2.2 - 2.3 times when coating with copper (Cu).

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