Research on the impact of various coating types on parts wear of certain injection pump elements

Badania wpływu różnych typów powłok na zużycie elementów pompy wtryskowej

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The geometric structure of mating surfaces has a crucial influence on the friction and resulting wear processes. This is particularly important in the case of injection pumps, where ensuring appropriate surface quality and tightness in a long-term operation process is extremely important in order to maintain nominal operating parameters. It is extremely important during variable pump operation conditions, start-up and shutdown, when there is a significant deterioration of cooperative conditions resulting from insufficient lubrication of the mating surfaces. The contact pressures on the mating surfaces are increasing and they are in contact with each, causing significant wear and high movement resistance. The technology of the application of special coatings is used in industrial scenarios for the deposition of thin layers to modify the surface layer in order to improve tribological properties, increase abrasive wear resistance, and improve the visual quality of the surface. The authors compared the current possibilities of the technique (ceramic coatings) with the commonly known methods for strengthening the cooperative surface (phosphating). As part of the work, several potentially applicable types of protective coatings were tested.

KEYWORDS: pump shaft, diesel engine, analysis, pump drive shaft, experimental verification, covering

Struktura geometryczna powierzchni współpracujących wywiera kluczowy wpływ na procesy tarcia i zużycia. Jest to istotne w przypadku pomp wtryskowych, w których zapewnienie odpowiedniej jakości powierzchni oraz szczelności w długotrwałym procesie eksploatacji jest niezwykle ważne dla utrzymania nominalnych parametrów pracy. Ma to ogromne znaczenie podczas zmiennych warunków pracy pompy, rozruchu i zatrzymania, gdy występuje znaczne pogorszenie warunków współpracy wynikające z niedostatecznego smarowania powierzchni współpracujących. Zwiększają się naciski kontaktowe na powierzchnie współpracujące, które stykają się ze sobą, powodując znaczne zużycie i duże opory ruchu. Jednym ze sposobów zmniejszenia zużycia współpracujących elementów jest nałożenie powłok. Technologia nakładania specjalnych powłok jest stosowana w warunkach przemysłowych do osadzania cienkich warstw w celu modyfikacji warstwy wierzchniej, aby poprawić właściwości tribologiczne, zwiększyć odporność na zużycie cierne i polepszyć wizualnie jakość powierzchni. Autorzy porównali obecne możliwości techniki (powłoki ceramiczne) z powszechnie stosowanymi metodami wzmacniania powierzchni współpracy (fosforanowanie). Przetestowano kilka możliwych do aplikacji rodzajów powłok ochronnych.

SŁOWA KLUCZOWE: pompa wtryskowa, silnik diesla, analiza, pompa łopatkowa, eksperymentalna weryfikacja, pokrycie

Introduction

Wear is the damage to the surface of individual parts or the entire assembly, resulting in the loss of material from the surface layer. It is caused by the movement of one surface with respect to another in contact with it. When wear occurs, there is a gradual reduction in the parts' dimensions over a period of time. The main symptom of adhesive wear is the occurrence of „sticking" (build-up) on the deformed second part, increased surface roughness, formation of deep holes. This causes defects such as dents and scratches (fig. 1). The process of creating and destroying adhesive joints

Fig. 1. Enlarged view of material sticking to the surface of the injection pump part

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Fig. 2. Pump assembly with components subject to high wear

is random. The „local sticking" formed on injection pump parts as a result of repeated cyclical deformations becomes hardened and is then destroyed pump parts (fig. 2).

The damage in the form of tears and craters on the elements proves that the failure of the frictional connection occurred not at the „built-up-part" boundary, but in the surface layer of the part. In addition to adhesive wear, abrasive wear may also occur, caused by the impact of impurities on the surface of other elements and broken „build-ups". A symptom of abrasive wear is a change in the dimensions and macro- and microgeometry of the part. Figure 1 shows an enlarged view of a layer of another material stuck to some parts [1, 2, 5].

The use of protective coatings

Continual efforts to improve the efficiency of machines and devices, *inter alia*, by reducing losses due to friction, forces manufacturers to pay special attention to the technology of shaping a specific part's surface topography. The geometric structure of the rubbing surfaces has a significant impact on the processes of friction and wear. In the area of cooperation of two solids (with the participation of a thin layer of liquid), the most favorable conditions occur when the friction surfaces create smooth sliding surfaces and cavities that can generate hydrodynamic force and accumulate wear products and block their direct entry into the friction zone.

During boot and stopping the work of various mechanisms, the terms of cooperation significantly deteriorate. The pressures increase and the mating surfaces are in contact with each other, causing significant wear and high movement resistance. Protective coatings can limit these unfavorable phenomena.

The first method used to protect the surface layer was phosphating, which is the process of creating a protective layer of phosphates on the metal surface. During this process, the metal chemically reacts with phosphoric acid to form a phosphate layer. This coating has a low coefficient of friction and high porosity, which ensures good adhesion. Slip (manganese) phosphating is typically applied to iron alloys (bearings, gearboxes, and engine components) to improve galling resistance. In the process of producing the coating, the parts are immersed in a water mixture with a suspension of fine manganese phosphate crystallites, and then into a liquid phosphatizing solution. The process was carried out at a temperature of 95÷100°C within 10÷15 min, and the thickness of the created coating is approximately 5 μm. An example of a phosphated ring of an injection pump is shown in fig. 3.

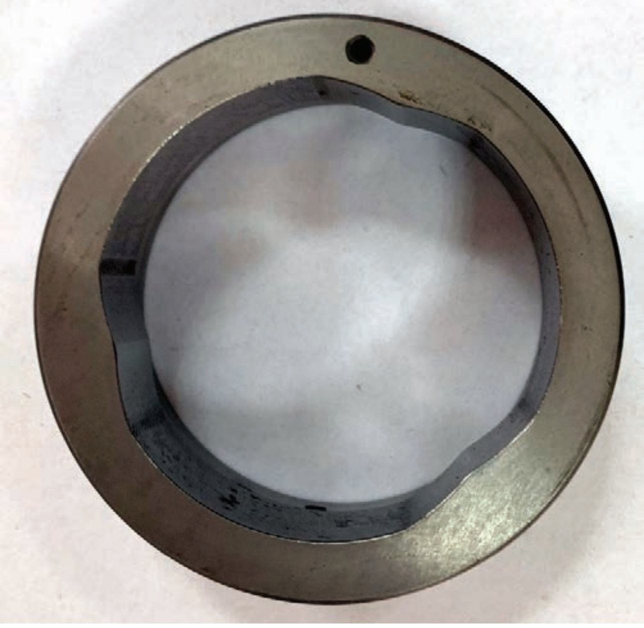

Fig. 3. Injection pump cam ring subjected to manganese phosphating (slip)

The tribological properties of the various layers are given in the table. Two vapor deposition processes are used:

- a physical PVD process where atoms or molecules are deposited from the vapor phase and deposited on the substrate;
- a chemical CVD process where the vapor phase produces a coating of the products of the chemical reaction taking place in the gas phase.

PVD coatings require a high vacuum to allow the atoms that make up the coating to travel long distances without colliding. CVD coatings are realized under atmospheric pressure. The layers produced in the CVD process are homogeneous despite the complex shape and geometry of the parts. The application temperature of the titanium layer for physical deposition is approx. 500°C, and for the chemical layer approx. 1000°C.

There are major stages in chemical vapor deposition (CVD) processes:

- creating a chemical compound of the applied element,
- gas transport of the compound,
- a chemical reaction to form a coating.

The CVD process produces layers of materials, e.g. carbides, nitrides, borides, and oxides.

The layer application process can be carried out under conditions of atmospheric pressure (100 kPa) or reduced pressure of 0.1÷6.6 kPa. In this way, a coating thickness of 5 to 15 μm can be obtained in about 4÷6 hours. The deposition rate depends on the temperature (usually 500÷1100°C), therefore high temperatures are preferred, but this may have an adverse effect on the substrate, i.e., it may cause changes in the microstructure and mechanical properties. Therefore, after the application process, heat treatment of the

TABLE. Tribological properties of layers of applied coating materials

Material	Hardness [HV]	Tribological properties
Carbide	3140	High wear resistance, low coefficient of friction
Titanium nitride	2060	Stable and inert, high lubricity
Titanium carbonitride	2450÷2940	Permanent grease
Chromium carbide	2210	Oxidation resistant up to 900°C
Silicon carbide	2740	High heat resistance, resistance to heat shock
Titanium diborium	3300	High hardness, high wear resistance
Aluminum oxide	1880	Resistant to oxidation, very low solubility in iron
Diamond-like	2900÷4900	Very hard, high thermal conductivity
Diamond	9800	Extremely hard, high conductivity, thermal

parts is required to ensure the required parameters [4, 6, 8]. An example of a PVD coated article is shown in fig. 4 (fuel injection pump cam ring).

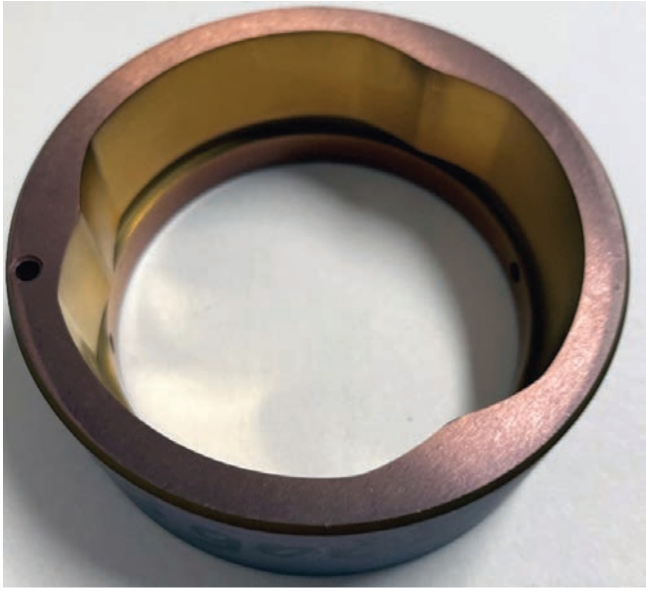

Fig. 4. Ring with a PVD coating based on titanium nitride TiN (gold colour)

Fig. 5. Ring with a DLC coating (anthracite colour)

A great advantage of the CVD process is the ability to apply a coating to selected areas of the part by covering undesirable areas, e.g., the surface of the inner holes' small diameter. An important issue is the preparation of the surface:

- sandblasting, brushing, polishing (used to smooth the surface and remove oxides);
- degreasing: in an aqueous solution of ultrasonically activated detergent, with rinsing in deionized water, in isopropyl alcohol activated by ultrasound, ultrasonically activated pea/acetone;
- finishing polishing (used to smooth the surface).

Due to their low application temperatures, DLC (diamond-like carbon) coatings have recently become very popular. The coating application temperature is below 250°C. This protects the heat treated object from losing its strength properties and hardness on machined surfaces. The selected protective coating of the Bainit C type (with DLC) belongs to the group of tribological coatings used to reduce adhesive wear associated with scuffing or the resulting build-up. The low Coulomb friction coefficient for this coating is $\mu = 0.09$, the obtained high hardness of approx. 1100 HV and good sliding properties make this coating perfect for applications with reduced lubrication and even dry running. The thickness of the applied coating was 5÷6 μm.

Microstructure

The microstructure of PVD and CVD coatings consists of columnar grains and equiaxial grains on the products' surface. The type of microstructure and grain size depend to a large extent on the process conditions. The best microstructure usually forms during rapid cooling. The grain growth velocity is much faster in the direction parallel to the surface of the substrate than in the perpendicular direction. This leads to the formation of a thin coating layer. The microstructure of the shell and its topography depend on:

- process temperature (mobility of atoms),
- supersaturation,

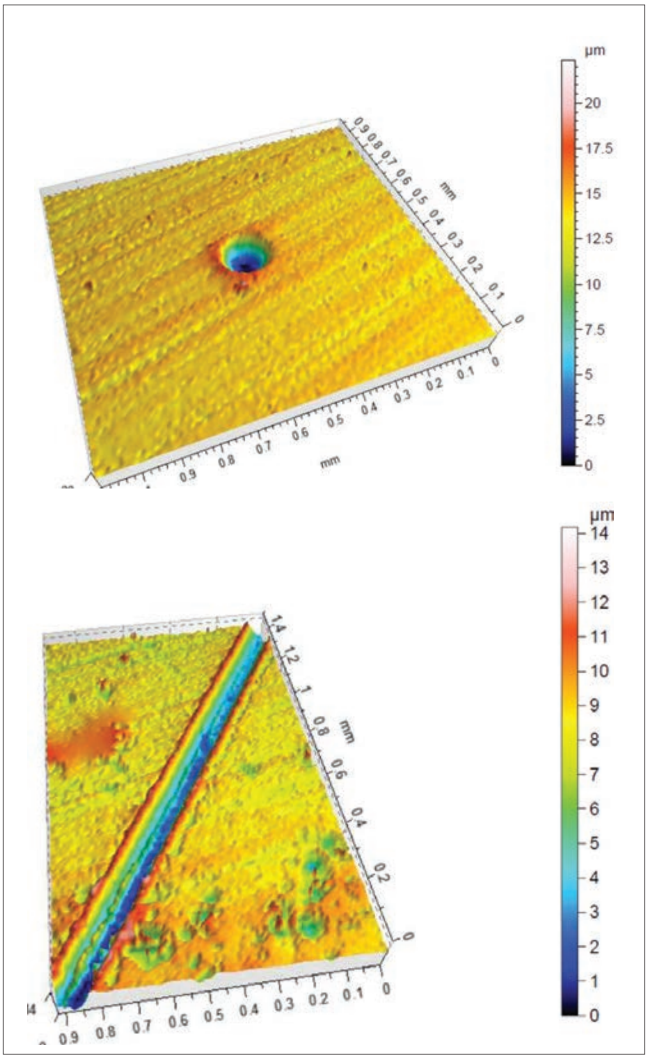

Fig. 6. Roughness measurement of scuffing marks on the surface of injection pump parts without coating

- time of applying the layer,
- pressure in the chamber,
- gas flow rates,
- preparation of the substrate.

Increasing the process temperature changes the topography of the outer surface of the coating. A relatively low temperature and short deposition times lead to the formation of a coating roughness of approx. 1 µm with characteristic spherical protrusions (fig. 6). Increasing the temperature causes grains in the shape of needles to dominate on the surface.

Due to the need to maintain the parameters of the native material, the use of a DLC coating based on diamond-like carbon is the most appropriate, because the temperature of the layer application process is below 250°C. Such a temperature of the coating application process does not change the microstructure of the material, which is important when considering applications for diesel engine injection pump parts [3, 7].

Conclusions

The test results clearly show that due to the different nature of tribological cooperation, the elements of the injection pump cannot remain undamaged without additional coating. This is due to the nature of contact cooperation, which is different from standard contact cases, as is the magnitude of the frictional forces, which is neither comparable nor scalable. As shown by the experiment on a laboratory stand, the use of phosphatizing allowed for only a few dozen hours of pump operation, which was not at all satisfactory. In light of our own research and industrial experience, the use of thin ceramic coatings based on TiN titanium nitride and diamond-like coatings allows one to obtain a coating showing very low reactivity with mating surfaces, therefore the wear due to adhesive processes is low. PVD coatings are characterized by high hardness and resistance to oxidation as well as high resistance to abrasive wear and can be used to improve the tribological properties of the surfaces of parts of internal combustion engine assemblies.

The application of a layer of titanium (Ti) provided a low coefficient of friction, galling resistance, and abrasion resistance, which directly translated into durability. As the tests showed, the number of hours was 12,000 work of the injection pump on the bench, which is a much better result (previously it was 10,000).

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