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POSSIBILITIES OF APPLICATION OF HARD THIN COATINGS IN HCR GEARING WORKING IN INTERACTION WITH ECOLOGICAL LUBRICANT

The article describes the possibilities of application of hard thin coatings to a non-standard involute HCR gearing, made from 16MnCr5, working in interaction with ecological transmission oil OMV Biogear S150. Based on an analysis of their geometric characteristics and their differences from non-standard C–C teeth, the possibilities of applying thin hard coatings to the side surface of the teeth are assessed. From the previous results obtained at the research center (UDTK sjF STU in Bratislava), the nitride TiALCN was applied and the article presents the results obtained on the Niemann´s stand for scuffing, from which it follows that due to the higher heights of the tooth addendum (h_a = 1,2m) compared to the standard (h_a = 1,0 m) and hence larger meridians, the greatest damage there was on an addendum of pinion.

Keywords: PVD, TiAlCN hard coating, HCR gearing, C–C gearing, Niemann´s stand, 16MnCr5.

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МОЖЛИВОСТІ ВИКОРИСТАННЯ ТВЕРДИХ ТОНКИХ ПОКРИТТІВ У HCR ЗАЧЕПЛЕННІ, ЯКЕ ПРАЦЮЄ В ЕКОЛОГІЧНО ЧИСТОМУ МАСТИЛІ

У статті описані можливості застосування твердих тонких покриттів до нестандартної евольвентної передачі HCR, яка виготовлення з матеріалу 16MnCr5 і працює в екологічно чистому трансмісійному мастилі OMV Biogear S150. На основі аналізу їх геометричних характеристик і відмінностей від нестандартного зубчастого зачеплення C–C оцінюються можливості нанесення тонких твердих покриттів на бічну поверхню зубів. З попередніх результатів, отриманих в дослідницькому центрі (UDTK sjF STU в Братиславі), застосований нітрид TiALCN і в статті представлені результати, отримані на стенді Ньюмана для зносу, з яких випливає, що через більшу висоту головки зуба (h_a = 1,2m) порівняно зі стандартною (h_a = 1,0m) і, відтак, великими меридіанами, найбільший знос був на голівці зуба шестерні.

Ключові слова: PVD, TiAlCN тверде покриття, HCR зачеплення, C–C зачеплення, стенд Ньюмана, 16MnCr5.

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ВОЗМОЖНОСТИ ПРИМЕНЕНИЯ ТВЕРДЫХ ТОНКИХ ПОКРЫТИЙ В HCR ЗАЦЕПЛЕНИИ, РАБОТАЮЩЕМ В ЭКОЛОГИЧЕСКИ ЧИСТОМ МАСЛЕ

В статье описаны возможности применения твердых тонких покрытий к нестандартной эвольвентной передаче HCR, изготовленной из материала 16MnCr5 и работающей в экологически чистом трансмиссионном масле OMV Biogear S150. На основе анализа их геометрических характеристик и отличий от нестандартного зубчатого зацепления C–C оцениваются возможности нанесения тонких твердых покрытий на боковую поверхность зубьев. Из предыдущих результатов, полученных в исследовательском центре (UDTK sjF STU в Братиславе), применен нитрид TiALCN и в статье представлены результаты, полученные на стенде Ньюмана для износа, из которых следует, что из-за большей высоты головки зуба (h_a = 1,2 m) по сравнению со стандартной (h_a = 1,0 m) и, следовательно, большими меридианами, наибольший износ был на головке зуба шестерни.

Ключевые слова: PVD, TiAlCN твердое покрытие, HCR зацепление, C–C зацепление, стенд Ньюмана, 16MnCr5.

1. Introduction. Gear transmission are among the most stressed mechanical transmissions. They are mainly used in gears with small axial distances. Transmission oils are primarily oils for lubricating gears. Their task is to reduce tooth wear, to lubricate not only the tooth gear, but also the gearbox bearings and to act as an anti-corrosion protection element. They are also involved in cooling the transmission by removing the heat generated by friction in the gearing, as well as the damping of the thread and the impact in the gearing, thereby reducing the noise of the gear. Typically, oils of higher viscosity grades from VG100 to 680 are used. However, their application to lubrication of tribological machines nods also has a risk of leakage into the environment, which is particularly negative for machines working in agriculture, forestry and construction. One option to prevent extensive soil or water contamination is the use of environmentally friendly lubricants and oils. Some countries, such as Germany and Sweden, even require the use of biodegradable oils in all applications operating in ecologically sensitive areas, such as water protection areas [1].

Thus, in addition to the power requirements defined by the machine manufacturer, ecological lubricants must meet the environmental degradability and toxicity requirements of the lubricant. Today's ecotoxicity tests under OECD Directives 201, 202, 203 assess the impact of substances in the aquatic environment by studying their impact on algae, daphnia and fish, standard species representing the aquatic environment. Furthermore, biodegradability tests such as the OECD 301 series or CEC L-33-A-93 are available which are available for assessing biodegradability in water. These various methods make it possible to assess the impact of chemical substances on the aquatic environment [2]. The limiting element of their deployment is a particular transmission mechanism.

2. Gearbox as a tribological system. The gearbox of a working machine can be characterized as a complex tribotechnical system consisting of several basic tribological junction such as bearing, shaft gasket and gearing, fig. 1.

From the point of view of the possibility of increasing the bearing capacity of gears, the key observation of the friction, lubrication and wear indicators in gear engagement in the interaction with used lubricant [3]. With increasing gear loads, contact pressures also increase in gearing, friction and temperature. The size of the contact stresses plays a significant role in the damage to the tooth face such as pitting – fig. 2 or scuffing – fig. 3. Factors such as operating (load size, operating temperature, lubricant), geometry, gearing material, surface hardness of the tooth side, or the accuracy of the engaging wheels are involved in the development of individual malfunctions.

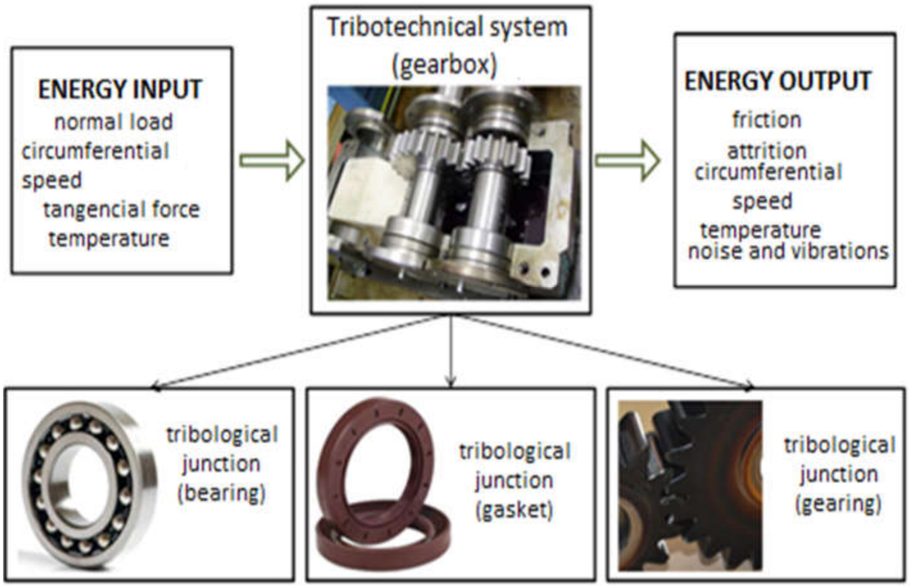

Fig. 1 – Gearbox as a tribological system

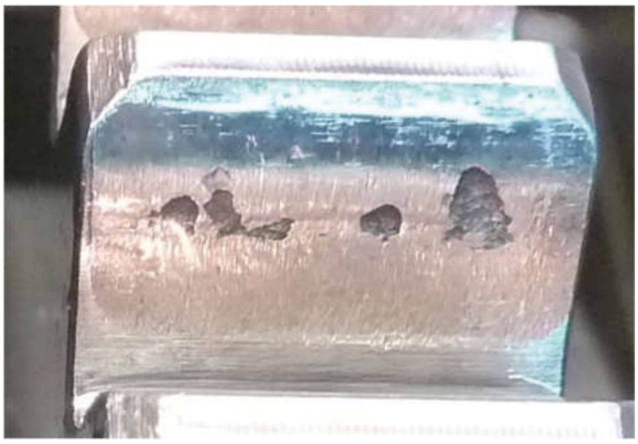

Fig. 2 – Pitting to the tooth flank

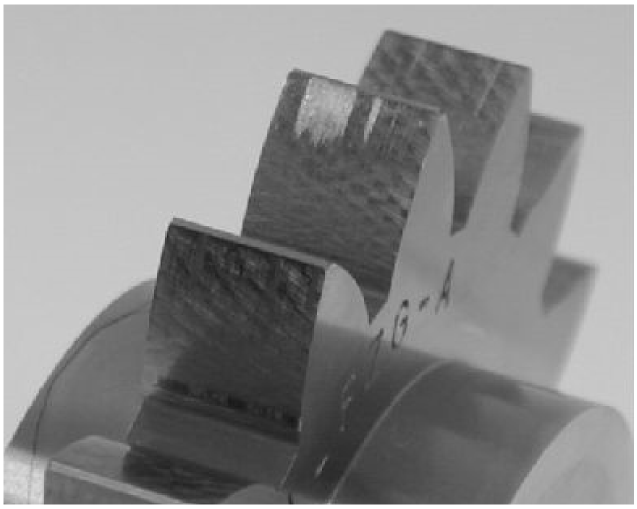

Fig. 3 – Scufing to the tooth flank

Scuffing primarily on the addendum and dedendum of the teeth, that is, in areas with higher slip rates and high heat development. This breakdown occurs especially in high-speed and heavy-duty toothed gears, due to a considerable amount of work on the area of the working teeth of the teeth [4].

An analysis of the malfunctions on the tooth face [5] shows that the main role in the problem of tooth damage in toothed gear is the magnitude of contact pressures. Higher resistance to failure can be ensured by increasing the surface load-bearing capacity of the tooth side, which can be achieved in the following ways:

– changing geometric dimensions of gearing; however, the disadvantage of this solution is an necessary increase in the total weight of the gear;

– using better oils; however, higher oil quality is usually achieved by adding higher concentrations of suitable additives, which are often characterized by considerable ecotoxicity;

– using better materials; this results in higher material costs;

– increasing the resistance of the surface of the tooth face;

– changing the shape of the tooth flanks.

From the point of view preventing operating tooth side damages, it is best to increase the resistance of the tooth side in the contact or to change the geometry of the tooth. One option to increase the surface bear ability on the tooth face is also the technology of applying different coating layers. As most of the degradation processes begin with surface component defects, coating coatings can be an appropriate solution for increasing surface bear ability and hence the life of sprockets. Surface layer formation is possible in a wide range of thicknesses (from several millimetres to several μm). By applying the surface layers, it is possible to achieve improved abrasion resistance, corrosion resistance, fatigue life, and so on. Coating adhesion to the substrate has a very important role because it determines the allowable stresses of the coated part. HCR gear – fig. 4, in which, compared to the standard involute gear, respectively. convex-concave gear engage higher meridian slots [5], but with respect to the two-part engagement in the gear, lower load forces, and thus lower contact pressures – fig. 4. Today, this type of gearing is wider in the automotive industry, and it is therefore interesting to explore also the possibility of applying thin coatings.

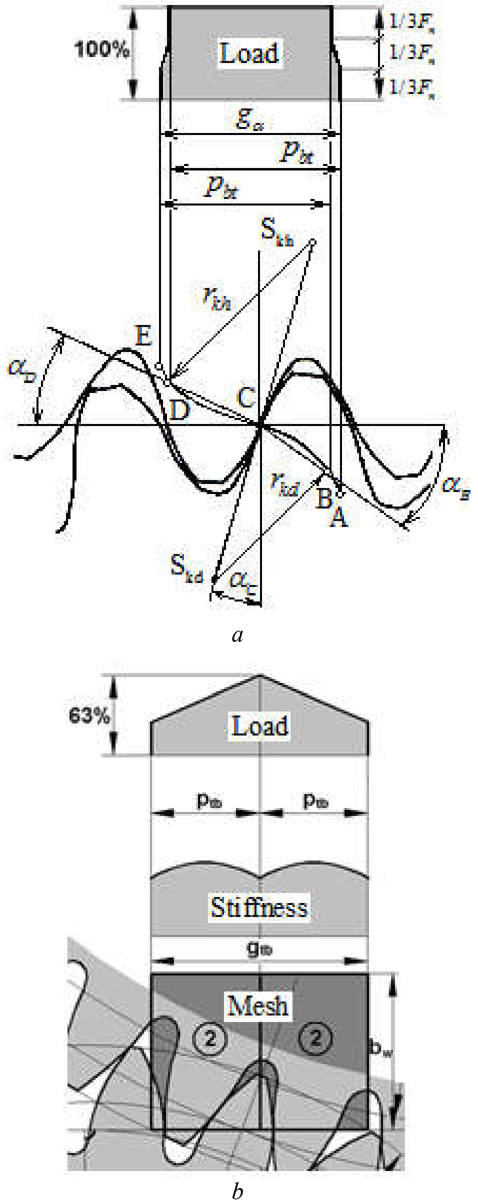

Fig. 4 – The course of load – bearing forces in the teeth engagement:
a – Allocation F_n along mesh in C-C gearing;
b – Allocation F_n along mesh in HCR gearing

3. Coatings on gearing. The processes of applying additional layers to the surface of the base material can be divided into the following groups:

– electrochemical deposition,
– chemical deposition,
– jet spray,
– physical and chemical coating methods in vacuum (CVD, PVD, ...) [4].

Increasing surface load capacity by coating PVD and CVD coatings began to be used in the 1970s. The titanium carbide coating layer was first used with the CVD method. Among the former, the coated carbide cutting plates began to be coated. Later materials such as TiN or TiCN have begun to be used. However, high deposition temperatures of about 1000°C did not permit the use of CVD method for depositing coatings on high-speed steel tools. Therefore, the PVD method was launched in the early 1980s [4]. PVD (Physical Vapor Deposition) is a method which consists of transferring the deposited material to the gas phase in a vacuum, followed by application to a substrate at low temperatures in the range of 150°C to 500°C. [6] In the case of toothed gears, however, when applying thin hard coatings, it is necessary to consider the specific conditions for engagement of gears and, therefore, when applying them in toothed gears, the following requirements are applied to the potential coatings:

– resistance to high pressures in meshing gearing;
– sufficient adhesion of the coating on the gear surface for selected gearing materials;
– resistance to temperatures arising in meshing gearing up to 450°C;
– max roughness of tooth flank of gear Ra 0,6 μm;
– min surface hardness of the tooth flank 60 HRC;
– low friction value of 0,4;
– coating resistance to mineral, synthetic, ecological lubricants.

Increasing resistance to seizure and pitting is also reported by Michalczewski [8], who also deals with the replacement of commonly used oils with additives to prevent wear – AW and for extreme pressures – EP, ecological lubricants and their interaction with coatings applied to the surface of gears made of material. 20MnCr5 (14,221).

The results of his research show, among other things, that under extreme load conditions the DLC coating can take on the role of AW and EP additives, thereby minimizing the application of these toxic additives to lubricants to achieve the so-called "Ecological lubrication". At the same time, gears with amorphous C:H:W coating lubricated with ecological oil had 20°C lower oil temperature during operation and also 20% lower friction coefficient compared to uncoated gear wheels and lubricated with high performance GL-5 gear oil.

Based on previous research at the UDTK SjF STU in Bratislava in the coated C–C and involute gearing we also used on HCR gearing on the Niemann's test the biodegradable gear oil OMV Biogear S150 and TiAlCN coating application. It is nitride gradient coating for universal use with high toughness and hardness (30 GPa) with low friction coefficient (0,5) with max. application temperature (450°C) suitable for milling. Test results to scuffing on Niemann's stand are shown in fig. 5 for the wheel and fig. 6 for pinion.

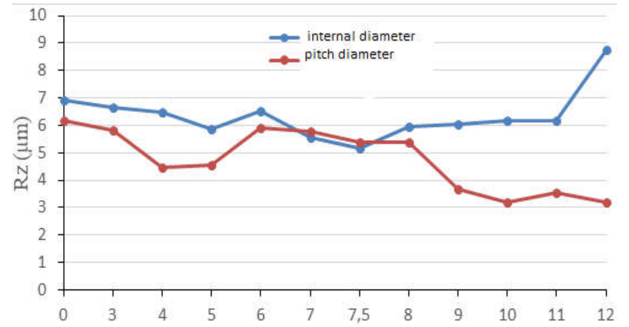

Fig. 5 – The wheel roughness changes from Rz to HCR

4. Conclusion. From the results obtained, it can be stated that due to the specific operating conditions in HCR gearing (large sliding on the addendum and dedendum of the teeth) and vice versa, due to the lower contact pressures resulting from the permanent meshing of two teeth, it can be stated that they have been achieved in interaction with the ecological OMV Biogear S150 transmission oil in the Niemann stand test results better than that of the standard involute and non-standard C–C gearing [4, 5, 9, 10, 11, 12]. The scuffing occurred only on the pinion to the 11 load stage as shown in fig. 6.

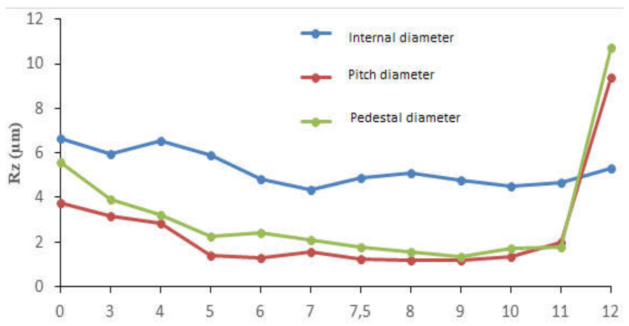

Fig. 6 – Pinion roughness changes from Rz to HCR

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