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Hard Thin Layers as a Contribution to Increase the Surface Bearing Capacity of C-C Gearing

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Abstract

The contribution is focused on the possibilities of applying hard thin coatings in non-standard gears. Based on the analysis of individual methods of their application, it appears that the most suitable method is the PVD (Physical Vapor Deposition) method. From the point of view of possible application, non-standard C-C gearing was chosen, which shows lower contact pressures compared to standard involute gearing and especially lower values of specific slips, the size of which has a negative effect on the wear of hard thin coatings. A TiN coating was chosen and for comparison TiNC in the Niemann stand scuffing experiment. The tested gear was lubricated with Biogear S 150 ecological lubricant.

Keywords: Hard Thin Coating, C-C Gearing, PVD Technology, Scuffing, Ecological Lubricant Biogear S 150, Niemann Stend

Introduction

The application of hard thin coatings is currently a technology that is often used to increase the service life of machine parts and thus entire machine devices. The aim of the coating is mainly to increase the resistance against corrosion and surface wear, i.e., to increase the surface carrying capacity. However, gear transmissions are characterized by certain specific operating conditions compared to other structural nodes. Large specific slips, especially on the faces and flanks, high contact pressures and temperatures in the gear contact exceeding temperatures of 400°C create increased demands on the properties of the coatings used in gear transmissions. When applying them in gears, it is important what type of gearing they will be applied to, what type of coating to choose and what coating technology to apply.

We chose already proven layers used in the coating of machining tools, namely the TiN layer (hardness 2300 HV, coefficient of friction μ=0.6) and, for comparison, the TiNC layer (hardness 3500 HV, coefficient of friction μ=0.25).

Materials and methods

Constantly increasing requirements for the wear resistance of the parts, as well as increasing the carrying capacity of the contact pair, have contributed to the development in the field of the theory of surface layers, which, among other things, is also applied to the surface of the parts.

In practice, in addition to purposefully applied coatings, spontaneous coatings (caused by the external environment) can also occur.

According to the nature and method of creation, coatings can be divided as follows [1,2]:

1. inorganic
    - metallic (electrolytic, thermal spraying, welding)
    - ceramic (oxide, non-oxide)
    - metal-ceramic (homogeneous, heterogeneous)
    - other inorganic compounds (phosphate, glass enamels)
2. organic
    - coating materials (polyester, powder)
    - plastics (plastomer, duromer, elastomer)
    - preservation coatings (oil, vaseline)

The use of coatings in gear turns out to be a very specific task, unlike other friction nodes (sliding and rolling bearings, machining processes, etc.) mainly because of the size of the contact pressures, which change depending on the selected type of gearing and sliding conditions, which arise during operation. The type of gear itself (cylindrical, bevel, worm, etc.), as well as its type (involute, convex-concave (C-C), cycloid, etc.) plays an important role here. The applied coating therefore requires sufficient hardness, resistance to high temperatures in contact, in shear, and its uniform thickness on the tooth flank, as well as the smallest possible coefficient of friction. It is obvious that these requirements in the application on gear transmissions are quite specific compared to the commonly used coatings applied in other tribological systems today.

CVD, PVD and PACVD technology can be included among the most used coating application technologies [2]. In tab. 1 shows their basic parameters.

Tab. 1 Basic Parameters of Selected Coating Technologies

	Temperature (°C)	Pressure (Pa)	Rotation
CVD	800 - 1000	atmospheric	No
PVD	200 - 450	~ 1	Yes
PACVD	~ 500	~ 200	No

As can be seen from tab. 1, the CVD method works at a temperature of 800 - 1000°C, and therefore this method is not suitable for use when applying a coating to the surface of a gear, because due to the application temperature, the geometry of the gear wheel may decrease by up to two degrees of its accuracy. Such a deformation would require the finishing operation of grinding, which is not possible due to the coating thickness of 2 to 4 μm. The PACVD method is based on the CVD method, but a lower temperature is used during deposition, which is due to the plasma effect. The use of this method is mainly when creating multilayers and non-layers. In addition, this method is also financially demanding.

Based on the analysis of the individual methods used to deposit the coating on the surface of the base material - the substrate, we chose the PVD (Physical Vapor Deposition) method based on the analysis performed and the above-mentioned requirements. This method meets the requirements in terms of possible application in gear transmissions, i.e.: - it works below the temperature of phase-structural transformations (i.e. from 200 to 500°C), it is affordable and there are several companies with high-quality technical and technological equipment available.

Applying hard layers using the above method requires the use of a specific technology to improve the parameters (mainly hardness) of the base material under the applied layer (coating). In general, it can be said that the application of hard layers requires the surface of the base material to be hard (around 550 HV), in the case of application of soft layers (coatings), the surface of the base material can also be soft (around 350 HV). This is related to the fact that if a hard layer (coating) is applied to a soft, unrefined surface, the applied layer (coating) would break through or peel off.

As part of the project solution, we applied TiN coating and, for comparison, TiNC coating on the convex-concave gearing (C-C) and verified its load-bearing capacity on the Niemann stand from the point of view of the occurrence of scuffing.

Convex - concave (C-C) gearing as one of the non-evolved types of gearing is, among other types of gearing, the subject of research at the Institute of Transport Technology and Engineering Design [3,4,5]. In general, it can be characterized as a gear whose side of the tooth is a curve composed of two curves with a convex and a concave part with an inflection point at the rolling point C. Such a gearing occurs when it has an S-shaped path of contact -fig.1.

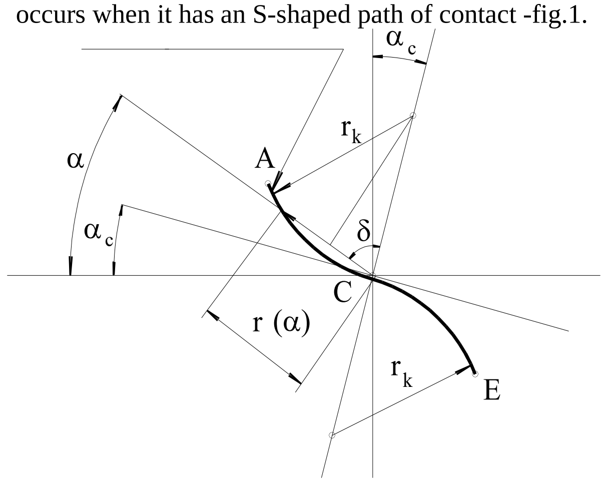

Fig. 1 Convex-Concave Gearing

Depending on whether the arcs of the engagement line are symmetrical or asymmetrical, we distinguish symmetrical convex-concave gearing or non-symmetrical convex-concave gearing. The case of a symmetrical convex-concave gear is shown in Fig. 2.

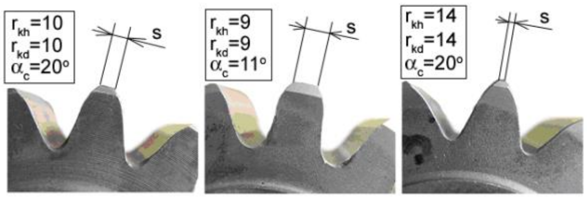

Fig. 2 Symmetric Convex-Concave Gearing

Previous investigations of convex-concave gearing have concluded that, compared to involute gearing, there are smaller contact pressures in convex-concave gearing [3,4,5,6] and at the same time, as can be seen from fig. 3, in the case of convex-concave gearing, significantly more favorable specific slip values are achieved than in the case of involute gearing [5].

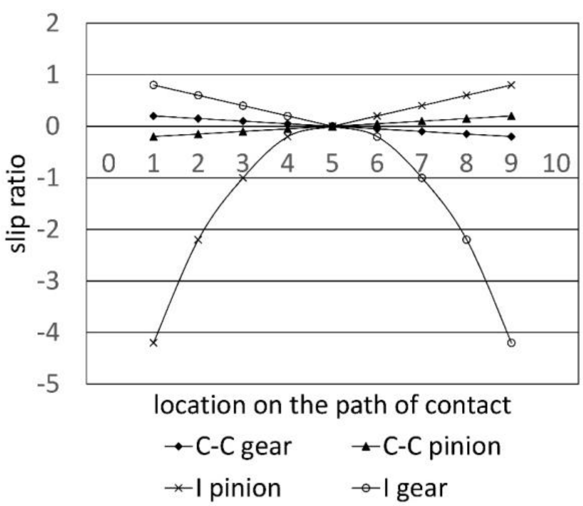

Fig. 3. Slip Ratios in Involute and Convex-Concave Gearing

From the mentioned facts, in the case of C-C gearing, it is possible to use ecological lubricants with a lower viscosity when lubricating the gearing, or lubricants without EP. In the tests, we used the ecological oil OMV Biogear S 150 [6]. Its basic properties are listed in tab. 2.

Tab. 2 Basic Properties of Selected Ecological Oils

Type of Oil	OMV Biogear S 150
Viscosity at 40°C [mm2/s]	150
Viscosity 40°C [mm2/s]	24,45
Flash Point	224
Freezing Point [°C]	-27
Density at 15°C [g/ml]	0,945

Biogear S is a biodegradable transmission oil for mechanically and thermally heavily loaded transmissions of various structures, for lubricating bearings in agriculture, forestry, the construction industry, shipping and protected natural areas.

Experimental methods

It is possible to experimentally test the load-bearing capacity of the gearing, either for scuffing or for pitting, on the Niemann stand - fig. 4 [6].

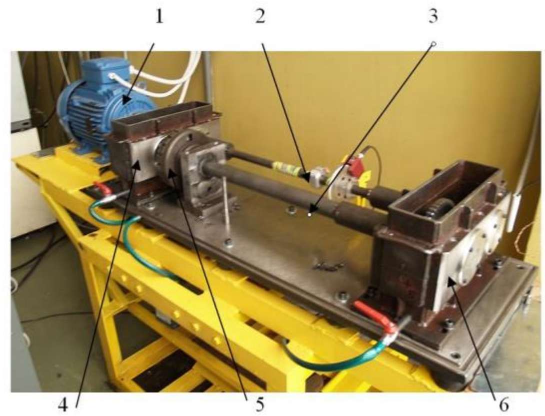

Fig. 4 Test Equipment with Closed Power Flow Loop 1- Drive electric motor, 2-Torsion shaft, 3-Shaft, 4,6-Gearbox, 5-Dual disc clutch

During the experiment, the parameters of the oil itself were also checked, especially the temperature and contamination of the oil. The results of the tested gear pair from the point of view of scuffing are shown in fig. 5. and fig. 6.

Results and discussion

Fig. 5 shows the results achieved for the Convex-Concave gears (C-C), to which a TiN hard coating was applied by the PVD method and for which the scuffing test was performed on the Niemann stand. From fig. 5, the tested Convex-Concave gear has reached the set condition for the occurrence of scuffing for the 7th load level.

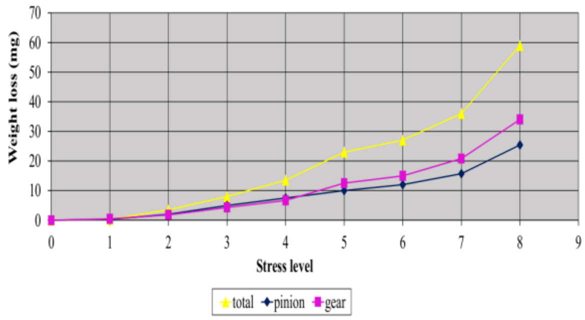

Fig.5. Weight loss of a TiN-coated gear pair in the scuffing test

In fig. 6 shows the results achieved for the Convex-concave gears (C-C), which were applied with a TiCN hard coating by the PVD method and for which the scuffing test was performed on the Niemann stand using the same experimental methodology.

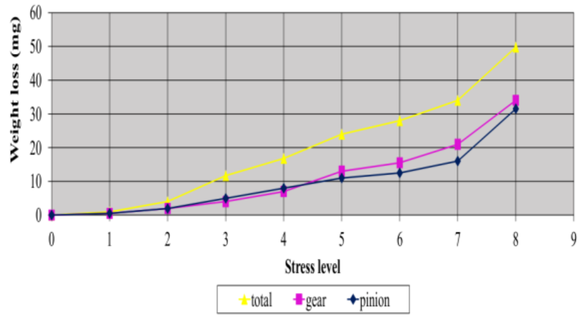

Fig. 6. Weight loss of a TiCN-coated gear pair in the scuffing test

Conclusion

The results of the scuffing tests on the Niemann stand show that the convex-concave gear working in interaction with the ecological oil OMV Biogear 150 achieved comparable results both for the TiN coating and the TiCN coating. However, the achieved 7th load level in connection with lubrication with ecological lubricant Biogear S 150 can be considered as a good basis in the field of application of hard thin coatings on gears lubricated with ecological lubricants. The results of the presented tests, other experiments carried out at the Institute of Transport Technology and Engineering Design as well as in the world show that in the case of further research in the field of application of hard coatings in gear transmissions, the assumption is to achieve an increase in the bearing capacity of coated gear transmissions lubricated with ecological grease to the standard level as in the case of lubricants based on petroleum products.

Acknowledgements

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