малой технологически достижимой толщиной. Во многих случаях (особенно в зубчатых передачах с зацеплением Новикова) область локализации максимальных критериальных напряжений приходилась не на эффективную зону, а на сердцевину. Наибольший процент контактных разрушений при азотировании связан с «отрывом» упрочненного слоя. Поэтому особое значение приобретает прочность сердцевины, что отражено, например, в методике оценки глубинной контактной прочности Р.Р. Гальпера [7]. В этих случаях применение критерия Писаренко-Лебедева смысла не имеет.

Разумеется, полученные результаты носят предварительный характер. Вследствие отсутствия согласованной методики определения напряжения отказа при сжатии, значения параметра χ, полученные разными авторами, сильно разнятся (сводка известных экспериментальных данных приведена в [5]). Зависимость параметра пластичности от твердости принята линейной и подлежит уточнению.

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PVD COATING AS A POSSIBILITY TO INCREASE THE LOAD CAPACITY OF GEARINGS TO SCUFFING

Стаття знайомить з можливостями підвищення контактної несучої здатності незагартованого опукло-ввігнутого зубчастого зачеплення. Однією з можливостей є використання металевих покрить. На підставі порівнювання окремих методів нанесення покриття підхожим виявляється у випадку зубчастих передач технологія PVD (physical vapor deposition). Ця технологія використовується для нанесення твердого покриття. TiN покрита С – С зубчаста передача у взаємодії з обраними екологічними мастилами була експериментально провірена проти заїдання на стенді Німанна /Niemann/ та порівнювалася з загартованою евольвентою зубчастою передачею.

In the article we describe the possibilities of increase of the contact load capacity of unhardened C-C toothed gear. The use of metal coatings proves to be one way. On the basis of a comparison of the individual methods of depositing the coating technology of PVD (physical vapour deposition) proves to be suitable application for the case of gearings. This technology is used for depositing the hard coatings. C-C toothed gear, coated with TiN, in interaction with ecological lubricant was experimentally verified with respect to scuffing on test stand by Niemann and compared to the hardened involvent gearing.

Key words: TiN coating, C-C tooth gear, PVD technology, scuffing, ecological lubricant, test stand by Niemann

Introduction.

The toothed gears are mechanisms, whereat the material of toothed gears is exposed to high contact pressures, wear, corrosion, thermal fatigue etc. From viewpoint of its lifetime, therefore the improvement of properties of wheel materials plays an important role. The depositing of thin coatings on surfaces of material proves to be one way. These coatings, which are called also as thin layers, thanks to its extraordinary properties like high hardness, great adhesion, chemical stability, have a widespread use in various industrial fields. The coatings can be prepared as monolayer, multilayer with more or less the abrupt boundary transitions between individual layers (for example TiC, TiN, ZrN, Al_2O_3 etc.) [1,6].

There is many methods of preparation of the thin layers depending on the kind of deposited material, a substrate type, properties of the resultant layers and its applications. The most use methods are like this: widespread spectrum of methods of chemical vapour deposition (CVD) and physical vapour deposition (PVD) and also plasma sprayed coatings.

Material and methodology.

The use of coatings in gearings turns out as very specific task in comparison with present applied coatings in other tribological systems (slide bearings, journals and etc.), namely in particular for the reason of magnitude of the contact pressures and sliding conditions which are created at operation of gearings. Own kind of gearing (cylindrical, bevel, worm gearing etc.) but also its type (involute tooth system, convex-concave, cycloidal etc.) plays also an important role at its evaluation. The gearing, contrary to another commonly occurring tribological systems, thereafter is to have, after depositing the coating, sufficiently hardness, resistance to high temperatures in contact and at shear with its regular thickness and required roughness. At present there is many methods which enable to deposit various metal coatings on any components. In principle we can divide the methods into three groups [5]:

- chemical methods – referred to as CVD (Chemical Vapour Deposition). Technology of CVD belongs to the oldest methods of creation of a thin layers and it is based on principle of chemical synthesis of layers from gaseous phase at temperature approximately 1000°C. It is used mainly in deposition of coatings on the cutting blades made of hard metals.
- physical methods – referred to as PVD (Physical Vapour Deposition). This process (magnetron sputtering) produces the coating by evaporation of metal from metal target as a consequence of bombardment of its surface by ions. Almost all metals, which are nonreactive, can be deposited by this technology. Multilayer coatings can be produced by exchange of targets. Technology of PVD enables production of quality layers at temperature approximately 500°C and less.
- physico-chemical methods – referred to as PACVD (Plasma Assisted CVD), or PECVD (Plasma Enhanced CVD). Deposition of thin hard layers by PACVD method is performed using the activation of the working mixture in arc surrounding the substrate surface. In plasma of this arc the individual constituents of the working mixture are molecularly excited thereby a synthesis of layers by new out-of-balance process is induced without necessity of heating the substrate above 650°C.

An individual types of coatings differ each other considerably in its properties and wherefore its use cannot be universal. The layers having higher hardness resist better to abrasive wear whereas more ductile layers resist better dynamic stress. Some layers but decrease coefficient of friction and so resistance to mechanical wear will be improved. Thickness and the surface properties of layers play an important role too. It is necessary to take into consideration also resistance of layers to oxidation and also but low thermal conductivity and the ability to retain the hardness of some layers at higher temperatures too. Development of technologies is particularly focused on decreasing the temperature and a shortening of deposition time, optimization of thickness of individual layers of coatings and improvement of adhesion of coating to the substrate.

Within the solution of grant projects VEGA 1/3184/06 inter alia we deal with lubrication, application of coatings mainly on contact surfaces of an not involute types of gearings and also the questions of the strength and lifetime characteristics of drive at minimization of negative influence on the human environment. The convex-concave gearing as one of the not involute types of gearings is, apart from other types of gearings, the object of research on Institute of transport technology and engineering design [3, 4, 7, 9, 11, 12]. In principle the gearing can be characterized by the tooting of which flank is created curvature which consists of two curvatures with convex and concave part with inflexion point on pitch point C. This gearing is created when the line of contact has the shape of letter S (Figure 1).

Accordingly whether the arcs of the line of contact are symmetrical, or not symmetrical we distinguish the symmetrical convex-concave gearing, or the not symmetrical convex-concave gearing. The present researches of convex-concave gearing proved that in comparison with a involute type of convex-concave gearing the contact pressures are reached lower [2]. It is possible to state also that as well at the comparison of course of slippage circumstances in case of convex-concave gearing, more favourable values in comparison with a involute type of gearing are reached, Figure 2 [8]. It follows on from this also the possibility of the use of ecological lubricants at its lubrication with lower viscosity, or lubricants without additives EP. In case of surface treatment of teeth by hardening, the required roughness, or deviation of geometric parameters from theoretical parameters after heat treatment in case of involvent gearing, will be achieved using the grinding. The grinding technology of convex-concave gearing is economically more difficult. Wherefore we was seeking the method where the shaping deformation of tooth flank would not occur contrary to hardening and wheel would not be needful to be grinded. The best method is PVD which meets these requirements. Coatings on basis titanium nitride (TiN) belong to the most commonly used types coatings with regard to its stable properties. TiN coating belongs to universal types of coatings with high performance and wide exploitation for various purposes with regard to its versatility, high chemical stability combined with abrasive resistance. We used TiN with regard to above mentioned reasons and industrially good availability of its deposition on gearings for experimental verification the convex-concave gearing with tooth number of z_1=16, z_2=24, m_n=4.5mm, a_w=91.5 mm, see Figure 3, from viewpoint of resistance to scuffing.

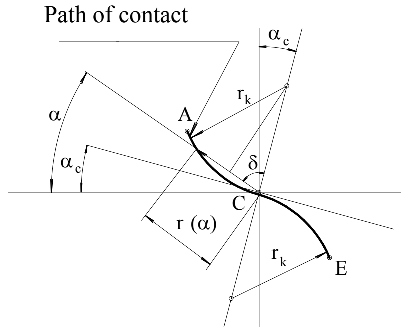

Figure 1. S form path of contact
Convex-concave gearing

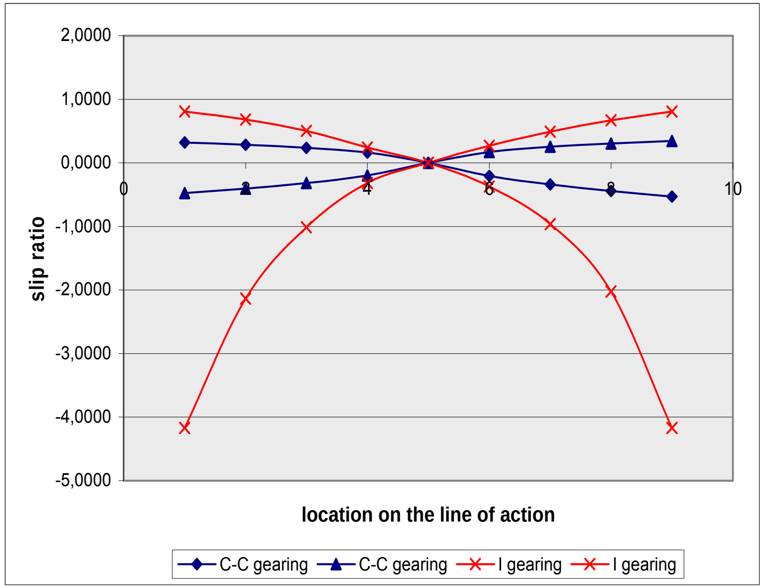

Figure 2. Shape of the curve of the slip ratio Convex concave and Involute gearing

Figure 3. Convex-concave gearing for deposition TiN coating

In experiment the K-K gearing was lubricated with two kinds of hydraulic oils (Biohyd M – biologically fully degradable hydraulic oil on basis of rapeseed oils, Biohyd MS – biologically fast degradable multirange hydraulic oil) and one kind of gear ecological oil (Biogear S – fully synthetic biologically degradable gear oil for mechanically and thermally excessively loaded gearings of varied constructions). Lubrication with hydraulic oil was chosen for verification of case provided that hydraulic converter together gearbox is situated in common box.

Experimental methods.

We chose the test apparatus with closed flow of performance, which we built on our workplace, see Figure 4. At tests of convex-concave gearing with TiN coating, we used ecological lubricants with low viscosity. These lubricants can not be heated on required temperature like at standard test of wear and wherefore we designed own methodology of tests [10].

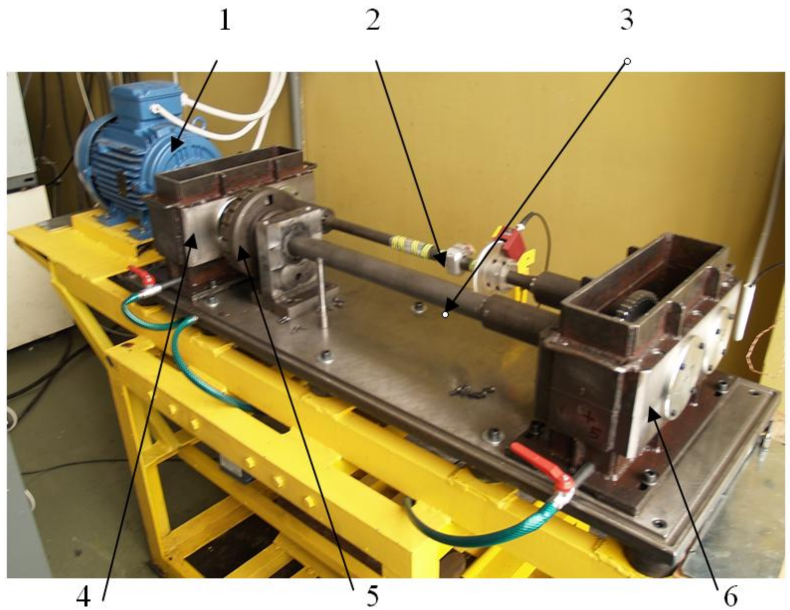

Figure 4. Equipment for measuring of the gearing strength in scoring
1-eletric motor, 2-torsial shaft, 3-shaft, 4,6-gearboxes, 5-strain coupling

The basis parameters of mentioned oil are given in Table 1, while in experiment was used the accented oil. During the experiment the parameters of own oil were checked in particular temperature and contamination of oil. The results of tested gearing from viewpoint of scuffing are shown in Figures 5, 6, 7.

Tab. 1.

Parameters of oil OMV

Product	Viscosity at 40°C [mm²/s]	Viscosity at 100°C [mm²/s]	Burning Point of [°C]	Solidfication point [°C]	Density at 15°C [g/ml]
OMV Biogear S					
100	100	14,84	220	-30	0,940
150	150	24,45	224	-27	0,945
220	220	28,82	226	-27	0,951
320	320	38,02	228	-21	0,959
OMV Biohyd M					
32	32	8,10	265	-33	0,920
46	46	10,24	265	-33	0,921
68	68	13,20	270	-33	0,922
OMV Biohyd MS					
32	32	6,90	230	-42	0,938
46	46	9,68	232	-36	0,943
68	68	12,78	244	-30	0,946

Results and discussion.

Figures 5, 6 and 7 shows the reached stages of loading for the convex-concave gearing according to the used oil. The hard coating of TiN by method PVD was applied on the gearing. The curvature P represents loss of weight of pinion, the curvature K of wheel and S is total value of loss on both wheels which within the test had to be below the value of 10 mg. Similarly as for the convex-concave gearing, shows the reached stages of loading for the comparable hardened involvent gearing which is lubricated with the mentioned oils Biohyd M, Biohyd MS and Biogear S [8]. From results of tests it is obvious that the TiN convex-concave gearing, in comparison with the involvent hardened gearing, reached with oil Biogear S 150 the same 7th stage of loading, with oil MS 46 the same 5th stage of loading and with oil M 46 by one stage greater stage of loading (5th K-K gearing, 4th E gearing).

Conclusion

The use of the hard thin layers in field of tools is at the present time very wide and multilateral. The layers are mainly used on deposition of cutting tools, made of hard metal, tool steel and cutting ceramics. Together the development of deposition technologies, the hard layers are applied, also in many another fields of mechanical engineering. Properties of layers are nowadays exploited on tools for the volume

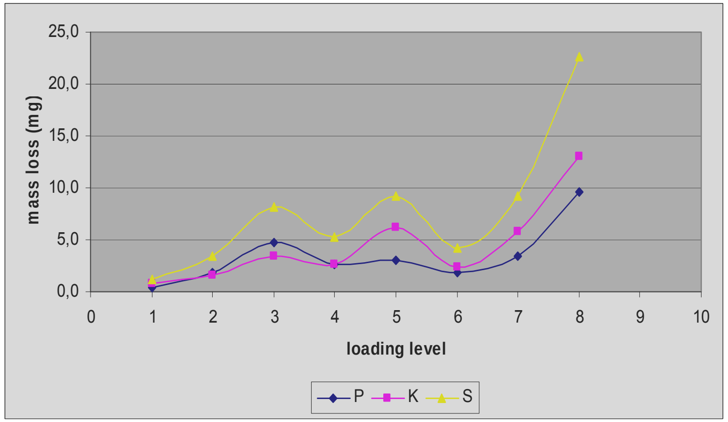

Figure 5. Test on scoring of hardened C-Cgearing lubricateted of oil Biogear S 150

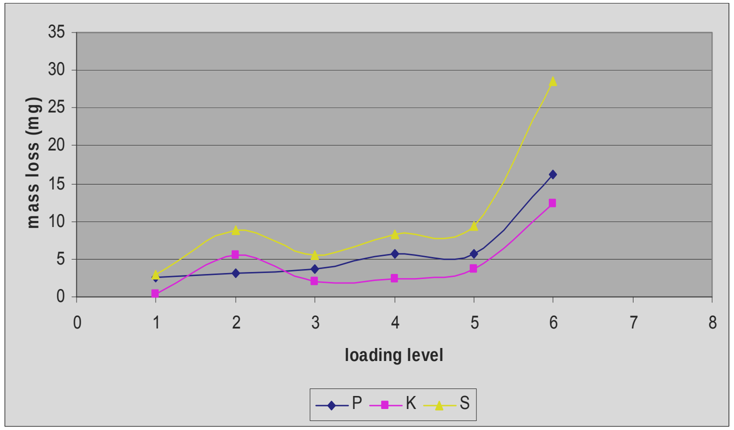

Figure 6. Test on scoring of hardened C-Cgearing lubricateted of oil Biohyd MS46

and surface forming (punches, matrixes, ...), construction elements such as turbine blades, journals, pistons, valves etc., but also in elements exploiting the rolling friction without the use of lubricants, in dies, in compression and injection moulds for plastics and light metals. Development and application of the hard layers are not until now finished far from it ones have considerable tendency of subsequent very perspective development. The results of tests on test stand by Niemann show that in case of subsequent research in a field of application of the hard coatings in the gearings the presumption is that even better results will be reached and so method of deposition could be common used for surface treatment of the gearings.

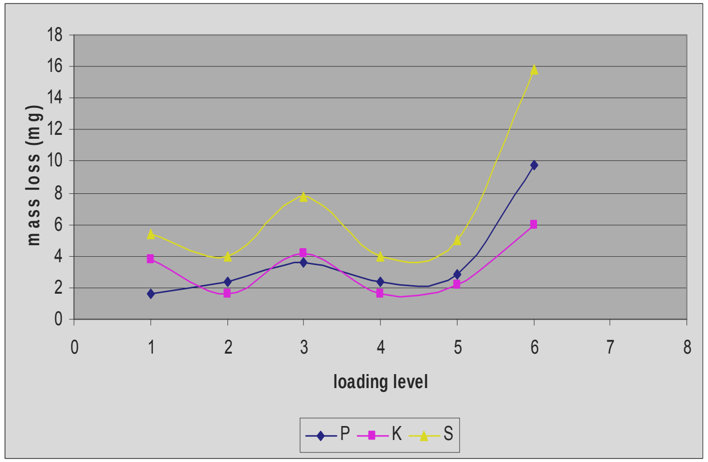

Figure 7. Test on scoring of hardened C-Cgearing lubricateted
of oil Biohyd M46

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ПРОГНОЗУВАННЯ НАДІЙНОСТІ РЕДУКТОРІВ З ВИКОРИСТАННЯМ МЕТОДУ СТАТИСТИЧНОГО МОДЕЛЮВАННЯ

Розглянуто методологію визначення основних показників надійності редукторів, а саме імовірності безвідмовної роботи та комплексного показника, до якого відносять коефіцієнт готовності.

Methodology of determination of basic reliability of reducing gears indexes is considered, namely probabilities of faultless work and complex index to which take the coefficient of readiness.

Сучасний стан проблеми. Однією з найголовніших проблем сучасних технічних систем і, зокрема, редукторів є проблема надійності. Неперервне ускладнення машин та посилення вимог до їх якості вимагає відповідного забезпечення надійності та довговічності сучасної техніки. Проблемами надійності та довговічності різних конструкцій машин займалися відомі вчені О.С. Проніков, Б.І. Костецький, Д.М. Решетов, І.Г. Косовський, Т.І. Рибак, Б. Ділонг, Ч. Синг та багато інших. Результати їх робіт дозволили впровадити в машинобудівну галузь промисловості різні методи забезпечення та підвищення надійності технічних систем і машинобудівних конструкцій.

Стосовно редукторів і, зокрема, зубчастих передач, питаннями надійності в цьому напрямку займалися К.І. Заблонський [1], А.Ф. Кіріченко [2], В.П. Шишов [3, 4], Г.П. Гриневич [5] та інші. Але розроблені методи забезпечення або підвищення надійності стосувалися лише окремих елементів зубчастих передач за рахунок удосконалення та синтезу їх конструктивних елементів і покращення роботи. Тому була поставлена задача розробити таку методологію, яка б дозволила визначати показники надійності не тільки окремих елементів, а і редуктора загалом.

Мета роботи. На підставі результатів теоретичних і експериментальних досліджень розробити методологію визначення основних показників надійності редукторів з використанням методу статистичного моделювання для прогнозування надійності.

Постановка задачі та її розв'язання. В довідковій літературі [6] вказується, що гамма-відсоткове напрацювання редуктора на відмову складає $T_\gamma = 3600$ год, тобто це є напрацювання, протягом якого відмова об’єкта не виникне з імовірністю 90% при довготривалій роботі з постійним навантаженням. Інших даних по надійності редукторів в науково-технічній та довідковій літературі не було виявлено. Тому ставиться задача розробити методологію визначення основних показників надійності редукторів. За основу для