Protecting surfaces of parts with wear-resistant vibration damping coatings

E S Ankuda¹, V V Kalmykov¹, M V Musokhranov¹, I K Ustinov¹

¹The Kaluga branch of Bauman Moscow Student Technical University, 2 Bazhenovastreet, Kaluga, 248000, Russia

e.ankuda@mail.ru

Abstract. The article is a review describing and justifying the necessity creation and using wear-resistant anti-vibration coatings in tool-making and machine-building industry. The basic methods of applying wear-resistant and anti-vibration coatings were presented and analysed, a search and study of the closest analogues of the studied coatings were carried out, and appropriate conclusions were drawn on the acceptability of using certain methods of applying such coatings.

1. The need for applying wear-resistant vibration damping coatings

Tear and wear of tribosystems is one of the most pressing problems in the vast majority of manufacturing industries. Development and production of new equipment is necessary to increase the power, productivity and bearing capacity of machines, which is inevitably accompanied by an increase in loads and internal stresses leading to fatigue damage, cracking and deformation of the structure of materials. These factors entail instability of the processes occurring during operation of the system and the probability of failures, which can cause equipment failure or adverse effects on the health of workers.

Vibrations, in turn, contribute to reducing fatigue strength of machines and structures, which leads to premature failures, and reduces the service life of the system. The harmful effects of vibrations followed by an increase in the rate of wear must be suppressed, and this can be done by using coatings with both wear-resistant and anti-vibration properties.

In production structures of various purposes, there is often a joint effect of fretting and tribological wear, that is, wear under conditions of small vibrational relative displacements of the contacting bodies, while the effect of vibrations inevitably leads to tribological wear. As a result, there is intensive wear of working surfaces, even in the presence of special wear-resistant lubricants.

The presence of surface energy preconditions interaction of the surface with substances in the environment surrounding the working surface (including lubrication) [1]. This phenomenon is called adsorption. The modern lubricants used contain surface-active substances producing the wedging effect of molecules, which inevitably leads to the growth of microcracks and their subsequent transformation into cracks. This phenomenon is described by the Rehbinder effect (Figure 1), which consists in formation of a thin plastic layer in the process of friction due to the adhesion activity of surfaces [2]. Adhesion is the cause of the formation of boundary layers, it leads to the mandatory appearance of elements of neighbouring phases on the surface. A thin plastic layer has low resistance to shear deformation causing adhesive joints to break.
The adsorption activity leads to the formation of a thin boundary layer on them, differing from the main material of the part body in structure and properties. Upon contact interaction of the deformed bodies during their relative movement, the state of such a boundary layer changes. The unlubricated tribological contact of working surfaces 1 and 2 for new parts (Figure 2, a) is replaced by lubricated contact in the process of running in. This process is characterized by formation of a boundary layer with a structure different from the base material (Figure 2, b). The phenomenon described above enables an adhesion breakdown which leads to wear.

2. Major and most common methods of applying wear-resistant coatings

2.1. Gas-thermal coating
A gas or plasma stream heats, crushes and transfers the condensed particles to the substrate. This forms a layer of the required material with the specified properties [3]. It is possible to apply any meltable material and several layers with different properties. The substrate may have almost any shape, and its dimensions may vary in a wide range. During the process, there is no mixing of the sprayed material and the substrate material. Besides, there are no errors, defects and beads. The method features relatively low heating of the treated surface (about 150°C) and relatively high environmental friendliness. Due to the high feed rate, strong adhesion of the sprayed material to the surface occurs [4, 5].

2.2. Chemical deposition of coatings
Deposition occurs when chemical reactions take place on the substrate surface. Continuous layers of material on the substrate are formed as a result of deposition of substances from the gas phase, plasma or colloidal solution. The structure of the coatings obtained can be different: it can be single-crystal, epitaxial, amorphous, polycrystalline, etc. The method allows for applying coatings on parts of various sizes and shapes, however, the accuracy of the coating is achieved by a high accuracy control of the flow of the substances deposited. It is possible to obtain high-density homogeneous clean coatings with good adhesion. The main drawback of the method is the probability of chemical and fire hazard, caused in some cases by toxicity, corrosion activity, flammability and explosiveness of the precursor. Relative difficulty is posed by deposition of multicomponent materials, which is associated with the difference in the evaporation rates of the precursors used. The method is also limited by the ability to conduct separate chemical reactions taking into account deposition of the required components on a given substrate. The method is widely used in the tool-making industry [6, 7, 8].

2.3. Physical deposition of coatings from the gas phase
Deposition takes place in vacuum from the vapor (gas) phase by direct condensation of the vapor of the material applied on the substrate [9]. In the process of deposition, the sprayed material is heated to
high temperatures to transfer enough energy to atoms or molecules to break chemical bonds and leave the substance, thereby the liquid phase evaporates and the solids sublime. The process takes place in a vacuum environment, since the pressure of the gas medium is relatively low, but it reduces the pollution of the gas phase to a rather low level and produces a clean film on the substrate surface, but at the same time it complicates the method and increases its cost. Just like with chemical deposition, the synthesis of multicomponent surfaces is hindered, since many materials, when in the form of chemical compounds, partially dissociate during thermal evaporation, which leads to the formation of non-stoichiometric precipitation [10]. It is difficult to obtain coatings on surfaces of complex shape, since the method is a version of one-sided directional deposition [11].

2.4. Electrospark doping with electrodes from EDM powders
They resist abrasive and corrosive wear and consist in powders obtained by recycling wastes from solid alloys [12]. They found application in mechanical engineering, agricultural, food processing and many other industries. During operation of an element with this coating, there is no direct wear of the material of the element body; however, such a coating must be periodically reapplied. When applying such coating for a cutting tool, the resistance of the latter increases by 3.8-4.8 times [13].

2.5. Electrochemical deposition of electroplated coatings
It allows you to restore the performance of worn parts, as well as to prevent further loss of material during their operation. The method allows you to adjust the thickness of the coating at the stage of its formation and to form it on surfaces of complex geometric shape [14]. The major disadvantages of the method include non-ecological vapors of the electrolyte and the duration of the process [15].

2.6. Cathode ion bombardment
The surface is generated in vapors of the evaporating electrode using an arc discharge. Condensation of applied coatings of carbides or nitrides is carried out by means of chemical reactions in the plasma under the effect of ion bombardment in vacuum. The method is highly efficient because the ion flux can be accelerated by setting the sprayed product to a negative potential or by increasing the density of the ion flux [16]. This process is environmentally friendly, efficient, it provides the possibility of automation and high adhesion of the sprayed surface [17].

2.7. Magnetron deposition method
The method consists in vacuum application of thin films by magnetron spraying of the target and allows you to adjust the thickness of the films applied [18]. The main advantages of the method are ease of use, high quality of the coatings applied and a large supply of the material sprayed [19]. The films feature high quality and record-breaking physical characteristics: thickness, porosity, adhesion, etc., and are created at the level of atomic planes. However, the method allows you to apply coatings on very small areas, which is a significant disadvantage for the engineering industry. The method is mainly used in the instrument-making industry, namely in microelectronics [20].

3. Anti-vibration coatings
Vibrations entail fatigue damage to working surfaces; therefore, anti-vibration coatings must protect the part from the appearance and development of fatigue stresses. Two types of anti-vibration coatings can be used to protect parts of machine-building and instrument-making products. There are coatings with a high coefficient of elasticity, and coatings with a low coefficient of friction. In the first case, the reduction of the vibration load occurs due to the absorption of vibrations, and in the second case, the vibration waves are damped in the direction of the tribocoupling movement.

4. Coatings with wear-resistant and vibration-damping properties
Thus, the use of standard wear-resistant lubricants, coatings and vibration protection means does not fully meet the needs of modern machine building and instrument making. This raises the issue whether
it is relevant to create and use competitive coatings. Such coatings must feature acceptable adhesive resistance, low impact on the surface of the material and combined properties. Anti- vibration and wear-resistant properties must be combined. Such coatings will help reduce the harmful effects of vibrations on the operation of the mechanism and increase its service life without reducing the operational accuracy and without running in the working surfaces of parts which would lead to a change in configuration, and, consequently, to an even greater increase in vibration exposure and wear.

The life cycle of equipment must be increased by coating the loaded parts with anti-vibration and wear-resistant material due to the high adhesion of the material to the metal, and the adhesion strength is achieved by controlling the surface energy of the substrate. There are no complete analogues of the products offered, and partial ones do not fully meet the needs of the engineering industry, or feature a narrow focus.

In order to choose the right wear-resistant coating, it is necessary to take into account a number of factors, including the hardness ratio of the materials of the response parts, the temperature of the working contact, the rate and angle of attack of the abrasive material, anti-friction properties, brittleness, adhesion and cohesion of the surface and many others. The correct choice of the coating can significantly extend the service life of the product.

References
[1] Geguzin Ya E and Ovcharenko N N 1962 Sov. Phys. Usp. 76 283-328
[2] Myshkin N K, Petrokovets M I 2007 Friction, Lubrication, Wear. Physical Foundations and Technical Applications of Tribology (Moscow: FIZMATLIT) p 368
[3] Khan A N, Lu J 2007 Surface and Coatings Technology vol 2018 4653-8
[4] Lyudagovsky A V 2006 Gas-Thermal Dusting of Coatings (Moscow: Russian State Open Technical University of Communication Ways) p 43
[5] Puzryakov A F 2008 Theoretical Foundations of Plasma Spraying Technology (Moscow: BMSTU) p 360
[6] Syrkin V G 2000 CVD-Method. Chemical Vapor Deposition (Moscow: Science) p 482
[7] Danilin B S 1989 The Use of Low-Tempeature Plasma for Deposition of Thin Films (Moscow: Energoatomizdat) p 328
[8] Ivanovsky G F and Petrov V I 1986 Ion-Plasma Processing of Materials (Moscow: Radio and Communication) p 232
[9] Oura K, Lifshits V G, Sararin A A et al 2006 Introduction to Surface Physics ed V I Sergienko (Moscow: Science) p 490
[10] Gurin V N, Korsukova M M, Nikanorov S P, Nechitaylov A P, Derkachenko L I, Uspenskaya Z I and Zimkin I N 2003 Letters to the Journal of Technical Physics 29 51-5
[11] Mattox D M 1998 Handbook of Physical Vapor Deposition (PVD) Processing: Film Formation, Adhesion, Surface Preparation and Contamination Control (Westwood, N.J.: Noyes Publications) p 917
[12] Sidorov A I 1987 Restoration of Machine Parts by Spraying and Surfacing (Moscow: Mashinostroenie) p 192
[13] Ageev E V, Davydov A A, Ageeva E V, Bondarev A S and Novikov E P 2013 News of South-West University. Series: Technique and Technology 1 32-8
[14] Panteleenko F I, Sarantsev V, Panteleenko EF, Borovik DI and Khina BB 2009 Strengthening Technologies and Coatings 4 (52) 27-33
[15] Vityaz P A 2004 Friction and Wear vol 256 593–601
[16] Shaparev A V, Aymurzina A D and Savina AI 2017 Scientific Herald 1 (11) 165-179
[17] Savin I A 2012 Procurement Production in Mechanical Engineering 9 41-4
[18] Richter F, Welzel T, Kleinhempel R, Dunger T, Knoth T, Dimer M and Milde F 2009 Surface and Coatings Technology vol 2046-7 845-9
[19] Sagatelyan G R, Shishlov A V 2014 Science and education: a scientific publication MSTU. N.E.
[20] Berlin E V. Seidman L A 2010 *Ion-plasma processes in thin-film technology* (Moscow: Tekhnosfera Publishing House) p 457