https://doi.org/10.21122/2227-1031-2019-18-3-195-199

UDC 621.833; 669.056.9:629.118.6

Some Specific Features of Bearing Unit Development Based on Sliding Friction Pairs for Precision Electro-Spindles

A. S. Kalinichenko[1], U. L. Basiniuk[2], E. I. Mardasevich[2]

[1]Belarusian National Technical University (Minsk, Republic of Belarus),
[2]The Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus (Minsk, Republic of Belarus)

Abstract. Various types of bearing units are used for movable connections in mechanical engineering, and sliding pairs (sliding bearings, guides, bushings) are rather widely applied for this purpose. This allows increasing stiffness of units to reduce their dimensions, to improve heat dissipation and ensure reduction in noise and vibration. However in some cases while using a sliding friction pair higher friction losses occur in comparison with ball bearings and probability is increasing for situations when there is a jamming of friction surfaces. These problems have great significance for application of sliding bearings in precision equipment, which typically operates under stabilized temperature and humidity conditions. So an aim of the investigations is to develop methodological approaches for creation and rational design and manufacture of sliding friction pairs based on application of coatings formed of composite antifriction materials which are used in vertical precision program-controlled electro-spindles for high-speed machining. The paper considers issues pertaining to development and creation of friction units for precision electro-spindles of high rigidity with sliding friction pairs on the basis of composite materials. Diameters of sliding bearings can be rather large that makes it possible to obtain the required super-high accuracy in mechanical processing and nano-metric roughness of the machined surface. A cutting speed (750 m/min or more) which is acceptable with regard to quality of machining by a diamond-like tool can be achieved by placing a cutting edge of the tool on diameter of 200 mm. Such approach permits to use lubricated sliding bearings in the spindle design. As a result, two tasks can be solved in an integrated manner. They include the required rigidity of an electro-spindle for ultra-high accuracy of mechanical blade processing and high smoothness of the machined surface providing nano-metric surface roughness with a decrease of macro-deviations up to 1 μm from a middle surface line. It is worth to note that this is extremely important for a number of special applications.

Keywords: bearing unit, electro-spindle, sliding friction pair, nano-metric roughness, coating from composite anti-friction materials

For citation: Kalinichenko A. S., Basiniuk U. L., Mardasevich E. I. (2019) Some Specific Features of Bearing Unit Development Based on Sliding Friction Pairs for Precision Electro-Spindles. *Science and Technique*. 18 (3), 195–199. https://doi.org/10.21122/ 2227-1031-2019-18-3-195-199

Некоторые особенности создания подшипниковых узлов прецизионных электрошпинделей на основе пар трения скольжения

Докт. техн. наук, проф. А. С. Калиниченко[1], докт. техн. наук, доц. В. Л. Басинюк[2], канд. техн. наук Е. И. Мардосевич[2]

[1]Белорусский национальный технический университет (Минск, Республика Беларусь),
[2]Объединенный институт машиностроения Национальной академии наук Беларуси (Минск, Республика Беларусь)

Реферат. В машиностроении в подвижных соединениях используются различные типы подшипниковых узлов, причем достаточно широко – пары скольжения (подшипники скольжения, направляющие, втулки). Это позволяет повысить жесткость узлов, уменьшить их габаритные размеры, улучшить теплоотвод и обеспечить снижение шума и вибраций. Однако в ряде случаев при использовании пар трения скольжения возникают более высокие по сравнению

Адрес для переписки
Калиниченко Александр Сергеевич
Белорусский национальный технический университет
просп. Независимости, 65,
220013, г. Минск, Республика Беларусь
Тел.: +375 29 190-64-90
akalinichenko@bntu.by

Address for correspondence
Kalinichenko Alexander S.
Belarusian National Technical University
65 Nezavisimosty Ave.,
220013, Minsk, Republic of Belarus
Tel.: +375 29 190-64-90
akalinichenko@bntu.by

с подшипниками качения потери на трение, повышается вероятность возникновения ситуаций, когда происходит заедание трущихся поверхностей. Большое значение эти проблемы имеют в случае применения подшипников скольжения в прецизионном оборудовании, которое, как правило, функционирует при стабилизированных по температуре и влажности внешних условиях. Поэтому целью исследований являлась разработка методических подходов к созданию и рациональному конструированию и изготовлению пар трения скольжения на основе применения покрытий из композиционных антифрикционных материалов, используемых в вертикальных прецизионных программно-управляемых электрошпинделях для скоростной механической обработки. Рассмотрены вопросы разработки и создания подшипниковых узлов прецизионных электрошпинделей повышенной жесткости с парами пар трения скольжения на основе композиционных материалов. Диаметры подшипников скольжения могут быть достаточно большими, что позволяет достигнуть требуемой сверхвысокой точности механической обработки и нанометрической шероховатости обрабатываемой поверхности. Приемлемые с позиций качества обработки алмазоподобным инструментом скорости резания (750 м/мин и более) могут быть достигнуты при размещении режущей кромки инструмента на диаметре 200 мм, что позволяет использовать в конструкции шпинделя смазываемые подшипники скольжения. Вследствие этого комплексно решаются две задачи: достигается необходимая для сверхвысокой точности механической лезвийной обработки жесткость электрошпинделя; обеспечивается высокая плавность работы, позволяющая достичь нанометрической шероховатости поверхности при снижении макроотклонений до 1 мкм от средней линии поверхности, что в совокупности чрезвычайно важно для ряда специальных применений.

Ключевые слова: подшипниковый узел, электрошпиндель, пара трения скольжения, нанометрическая шероховатость, покрытие из композиционных антифрикционных материалов

Для цитирования: Калиниченко, А. С. Некоторые особенности создания подшипниковых узлов прецизионных электрошпинделей на основе пар трения скольжения / А. С. Калиниченко, В. Л. Басинюк, Е. И. Мардосевич // *Наука и техника*. 2019. Т. 18, № 3. С. 195–199. https://doi.org/10.21122/2227-1031-2019-18-3-195-199

Introduction

In mechanical engineering various types of bearing units are used in moving connections, the simplest and economically feasible of which include rolling and sliding bearings. Sliding friction pairs (sliding bearings, guides, bushings) are widely used in some units despite the higher complex of service properties of rolling friction pairs in terms of efficiency and resource [1]. This allows increasing the stiffness of units, reducing their dimensions, improving heat dissipation and reducing noise and vibration. But there are higher friction losses, probability in the increases of situations in which there is a jamming of friction surfaces for application of sliding friction pairs compared to the rolling bearings. These problems are even more important for application of sliding bearings in precision equipment, that typically operates under temperature and humidity stabilized conditions. In particular, this is important for vertical high-speed precision electrospindles with high requirements for rigidity due to their use for machining of accurate electronic engineering. In some cases, high rigidity can be achieved by using sliding bearings with composite antifriction coatings [2–4].

The aim of the work is the development of methodological approaches to the creation and rational design and manufacture of sliding friction pairs based on the composite antifriction materials' coatings for the application in vertical precision program-controlled electrospindles for high-speed machining.

Methodical approach and results

Fig. 1 shows the selection of the bearing unit for precision spindles [2]. Let us consider this scheme in more detail from the standpoint of the possibility to achieve high speeds of blade machining.

The speed of mechanical blade processing is determined by two factors – the rotational speed of the electrospindle and the radius of the cutting edge placement. While processing wafer of ∅200 mm with cutting rotating tool, for example, cubic boron nitride with a longitudinal feed table the diameter, on which machining tool is placed can be roughly taken equal to ∅210 mm. Thus, spindle rotating speed equal to 1150 min^{-1} is sufficient to implement high-speed machining (cutting speed for CBN over 750 m/min) (fig. 2a).

In sliding friction pairs based on modern composite materials, including nanostructured ones, sliding speeds and lubrication pressures can reach 20 m/s and 6–8 MPa, respectively, with a friction coefficient equal to 0.004–0.006 [3–14]. With this in mind, the diameters of the sliding bearings can be large enough (fig. 2b), that allows to achieve the required ultra-high precision machining and nanometric roughness of the treated surface. For example, the diameters of the sliding bearings even for traditional composites (bronze-graphite or iron-graphite) for permissible sliding speeds (8–10 m/s) can have quite acceptable value of 140–170 mm with consideration of small specific pressures that are characteristic for finish machining with diamond-like instrument.

The use of aluminum alloys in the manufacture of electrospindles is prominent approach from the standpoint of improvement of their dynamic properties, including the increase of own frequencies of mechanical vibrations to prevent resonances. As well the heat exchange can be increased for electrospindle with forced cooling of its components in this case. All together this allows minimizing the shaft weight and improving the heat exchange during its cooling in comparison with the steel spindle. In this design the working surfaces of the sliding bearings can be made directly on the electrospindle shaft. Composite antifriction coatings can be formed on the shaft to increase the wear resistance of the friction unit.

One of the promising ways of forming such coatings can be considered as the implementation of the following technological scheme:

– formation a coating with thickness of 70–90 microns as a substrate on the working surfaces of sliding friction pairs by anodic-cathode micro-arc treatment (MAT), which will eliminate the "pushing" of the support surface and the occurrence of jamming in contact with abrasive particles;

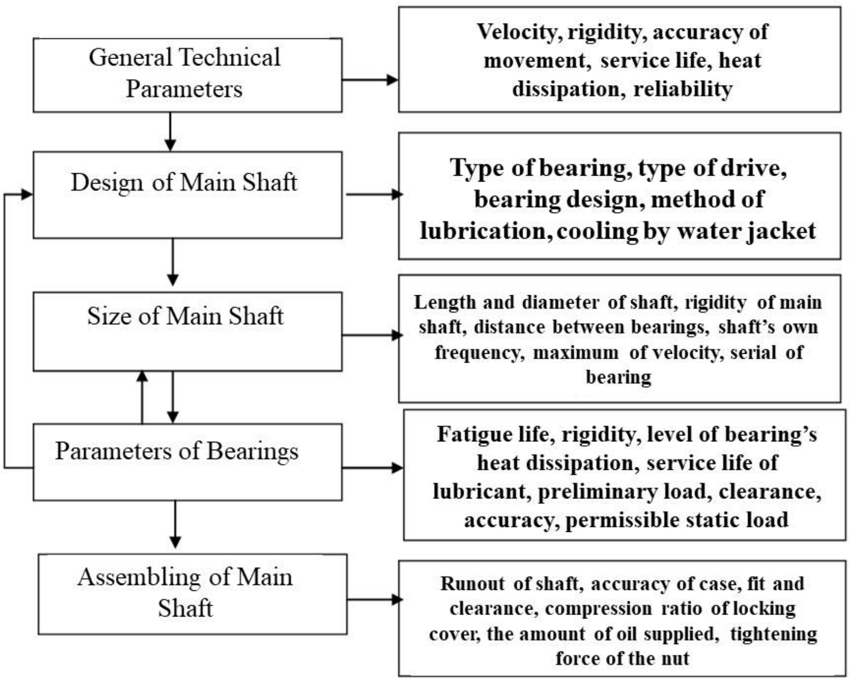

Fig. 1. Diagram of bearing unit selection [2]

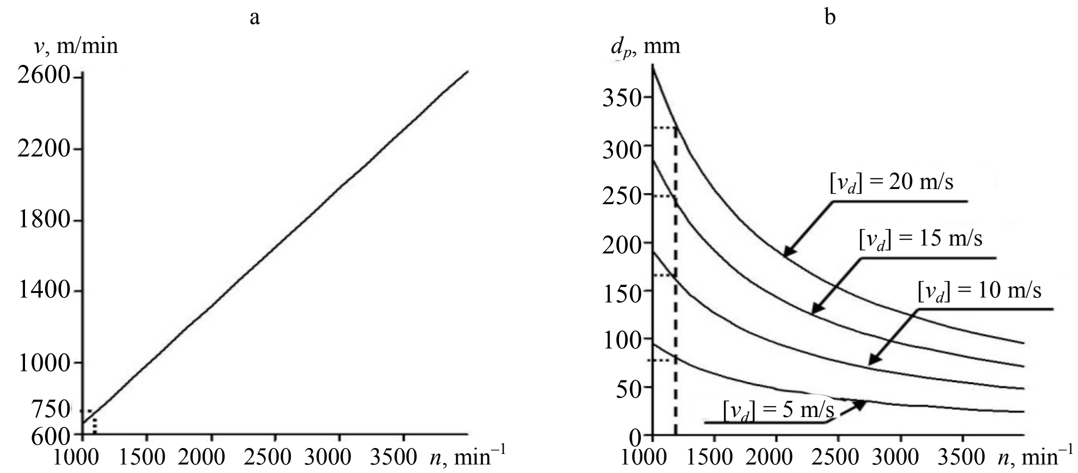

Fig. 2. Dependence of cutting speed v on number n of electro-spindle revolutions (a) and diameter d_p of sliding bearing on permissible sliding speed $[v_d]$ (b)

– preparation of the surface of the MAT-coating for subsequent processing;

– surface cladding of MAT-coating with antifriction material, for example, nanostructured composite based on copper alloy.

In the considered technological scheme the interrelated operations of preparing the surface of the MAT-coating for subsequent cladding and its cladding determine the adhesive strength of the antifriction coating to the MAT-coating.

Research and analysis of the results of the above scheme showed the following features. Even after mechanical superfinish treatment of the MAT-coating's surface (fig. 3a) the topography of this surface remains sufficiently developed (fig. 3b). Analysis of microstructures indicates the presence of a significant number of pores and cracks (fig. 4).

Adhesion of antifriction materials based on copper alloys during their deposition on the surface of the MAT-coating by a mechanical method, such as cladding with a flexible tool without further processing, is relatively small. To ensure high adhesion properties of the antifriction cladding layer on the surface of the MAT-coating it is advisable to use a technological scheme including:

a) mechanical treatment of the surface layer of the MAT-coating aiming the removal of its most defective zone which reduces the adhesive strength of the coating deposited on the surface of the antifriction layer;

b) it is advisable to form on the surface of the MAT-coating a nanoscale layer based on material that fills the cavity, pores and cracks on its surface during its deposition (for example, a copper layer deposited by electron beam or laser treatment) to ensure high adhesive properties of the antifriction coating;

c) after the formation on the surface of sliding friction pair an additional antifriction layer with a thickness of 3–5 μm the subsequent additional processing of the composite coating by plastic deformation is advisable.

Preliminary tests have shown the prospects of the proposed technology for the manufacture of friction units of electrospindles for precision machining.

a b

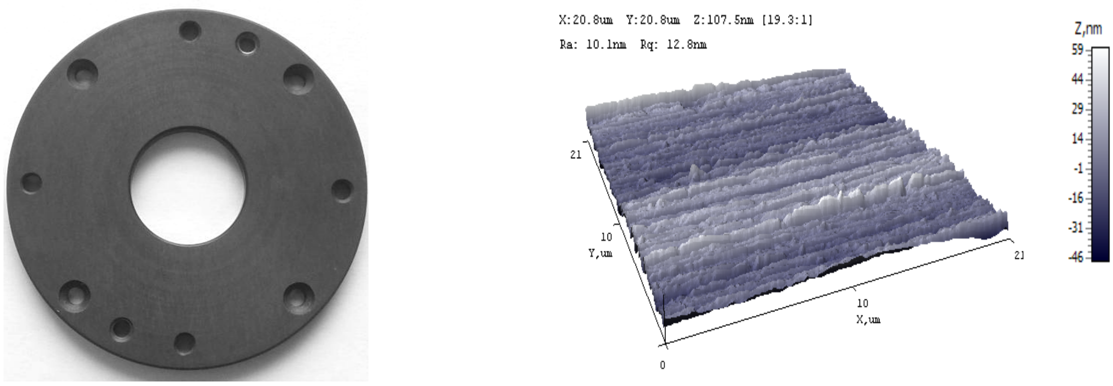

Fig. 3. Sample with machined surface of MAT-coating (a) and topography of this surface (b)

a b

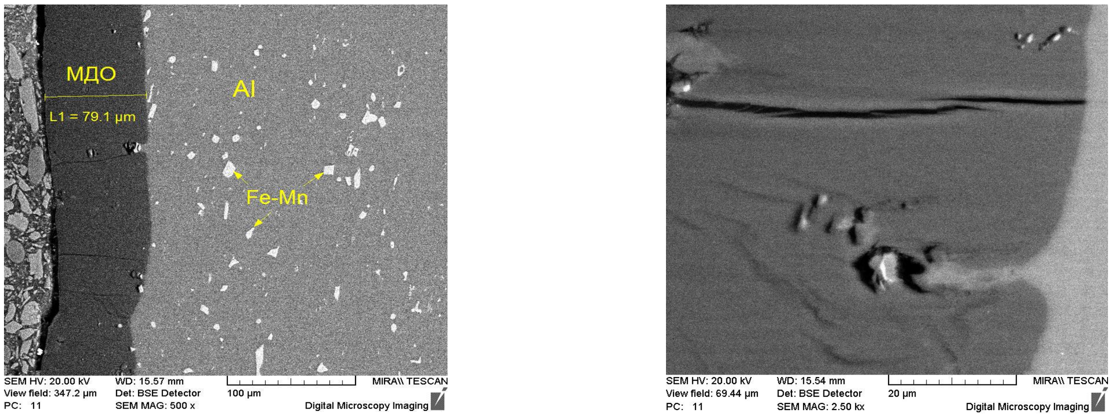

Fig. 4. Microstructure of MAT-coating (a) and view of through-the-thickness crack (b)

CONCLUSIONS

1. While processing wafer of ∅200 mm with cutting rotating tool, for example, cubic boron nitride with a longitudinal feed table the diameter, on which machining tool is placed can be roughly taken equal to ∅210 mm. It allows the use of lubricated sliding bearings in the spindle design. As a result, two tasks are comprehensively solved:

– the necessary rigidity of the electrospindle is achieved for ultra-high accuracy of mechanical blade processing;

– high smoothness of processing is provided allowing to achieve nanometric surface roughness by reducing to 1 μm deviations from the mean line of the surface. This is together extremely important for a number of special applications.

2. To improve the dynamic qualities of the electric spindle its shaft can be made of aluminum alloy and directly sliding bearings on the working surfaces are made. This will reduce at least three times the weight of the shaft in comparison with the steel shaft and significantly improve the heat exchange in the mechanical system. Working surfaces of rolling bearings with a composite structure based on MAT-coating can be created directly on the shaft and cladded with a nanostructured antifriction layer based on copper. Together, this will create a high-speed precision software-controlled electrospindle with a qualitatively new set of service properties, including dynamic and stiffness characteristics.

REFERENCES

1. *Sliding Bearing. Less Friction, Higher Resource*. Available at: http://www.upk1.ru/d/115304/d/podshipniki-skolzheniya-elges.pdf (in Russian).
2. Sigitov E. A., Vinogradov M. V. (2011) Perspectives of Application of Multistage Friction gears for Superprecision Handling. *Vestnik Saratovskogo Gosudarstvennogo Tekhnicheskogo Universiteta = Vestnik Saratov State Technical University,* 2 (2), 144–150 (in Russian).
3. Chernogorov E. (2013) *Sliding Bearings*. Chelyabinsk. 10 (in Russian).
4. Technical reference (*Tekhnichesky Spravochnik*) http://razvitie-pu.ru. Advertising Site of JSC "PROMGLEX-M" / Mode of access: http://www.promgleks-m.tiu.ru. Date of access: 20.01.2019.
5. Petrov N. I., Lavreniev Yu. L. (2015) Ways to Improve the Reliability and Service Life of Rotors' Bearing Supports of Modern Gas Turbine Engines and Reducers. *Vestnik Samarskogo Universiteta. Aerokosmicheskaya Tekhnika, Tekhnologii i Mashinostroenie = Vestnik of Samara University. Aerospace and Mechanical Engineering*, 14 (3), Part 1, 228–236 (in Russian).
6. Karimbaev T. D., Mezentsev M. A., Alferov A. I., Gordeev S. K. (2010) *Ceramic Balls for Ball Bearings: Manufacture, Machining, Calculations, and Tests. Kompozity i Nanostruktury = Composites and Nanostructures*, (2), 12–27 (in Russian).
7. Dotsenko V. N., Nikitin S. V. (2008) Research Questions of Ceramic and Hybrid Rolling Bearings and their Application in Aircraft Engines. *Aviatsionno-Kosmicheskaya Tekhnika i Tekhnologiya = Aerospace Engineering and Technology*, 55 (8), 138–144 (in Russian).
8. Oryshchenko A. S., Zagashvili Yu. V., Kulik V. I. (2007) Products of Modern Composites Modified by Nanosize Components, *Innovatsii = Innovations*, (12), 94–98 (in Russian).
9. Barmanov I. S. (2014) Investigation of Axial Dynamic Characteristics of Bearing No 126126 with Ceramic Balls. *Avtomatizirovannoe Proektirovanie v Mashinostroenii = = Auto-mated Design in Mechanical Engineering,* (2), 194–195 (in Russian).
10. Devoino O. G., Kardapolova M. A., Yatskevich O. K., Nikolayenko V. L. (2015) Optimization of Technology of Thermal Diffusion Processing of Ceramic Powders for Plasma Spraying of the Outer Bearing Rings of Electrical Installations. *Progressivnye Tekhnologii i Sistemy Mashinostroeniya = Progressive Technologies and Systems of Mechanical Engineering,* 51 (1), 48–55 (in Russian).
11. Isayeva E. A., Perevoin S. A., Isayev D. A. (2013) The Creation of the Expansion Joint of Thermal Stresses for Advanced Gas Turbine Engines Using Powder Metallurgy Methods. *Izvestiya Moskovskogo Gosudarstvennogo Tekhnicheskogo Universiteta MAMI = Izvestiya MGTU MAMI,* 2 (2), 331–336 (in Russian).
12. Panov A. D., Panova I. M. (2015) Tribological Features of Structural Ceramic Materials in Sliding Bearings. Naukovedenie [Science Studies], 7 (1). Available at: http://naukovedenie.ru/PDF/78TVN115.pdf (Accessed 22 January 2019) (in Russian).
13. Serdobintsev Yu. P., Kharkov M. Yu., Nazzal Anan Se (2014) Overview and Analysis of the Use of Ceramic Materials in Various Branches of Industry. *Sovremennye Problemy Nauki i Obrazovaniya = Modern Problems of Science and Education,* (1), Fvailable at: http://www.science-education.ru/ru/article/view?id=12085 (Accessed 22 January 2019) (in Russian).
14. Volovil A. P., Kovarsky M. E., Zaytsev V. A. (2014) High-Speed Rolling Bearings of the Generator for Gas Turbine Units. *Voprosy Elektromekhaniki. Trudy VNIIEM = Electromechanical Matters. VNIIEM Studies,* 139, 1–6 (in Russian).

Received: 10.12.2018
Accepted: 12.02.2019
Published online: 30.05.2019