POLISH ACADEMY OF SCIENCES - MATERIALS SCIENCE COMMITTEE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY

Conference Proceedings

AMME'2002

11th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

The influence of the ceramics materials used at the main spindle bearings on the machine-tools performances

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The improvement of the machine-tools performances can be realized in many ways. The 3rd millennium has been imposing the utilization of the new materials, generically named *the second-generation materials*, these being used even in the machine-tools construction industry. Today, there is a new concept in producing more precise, faster and ecological machine-tools. The utilization of the ceramics bearings is one of the most important and modern step in obtaining this kind of machines.

In this paper, there are presented the influences on the lathe performances when the ceramics bearings are utilized. Comparing it with those of the same study, but having like parts classical bearings made in steel, will describe the results.

1. THE UTILIZATION OF THE CERAMICS MATERIALS IN THE BEARINGS CONSTRUCTION

Due to the new technologies in obtaining and processing of the ceramics powders, it was possible to produce high-quality ceramics bearings.

In the ceramics products case, there are some major inconvenient regarding the mechanical properties; next to that, it is to not forget the higher price of the obtaining technologies.

One of the first major disadvantages is the fragility of the ceramics. When a micro- fissure appears due to the stresses concentrations, the micro-fissure rapidly becomes a major crack, and the failure of the material appears. A lot of researchers have tried to establish the equation of the crack propagation speed in the ceramics materials. Today, determining of this speed supposes the utilization of the follow empirical relation /1/:

$v = A \cdot K_I^n$,

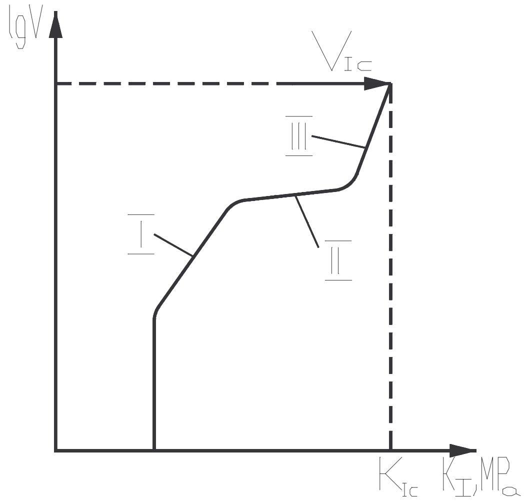

Figure 1. Crack propagation speed evolution function of the K_I factor /1/

for $K_I = \sqrt{a} \cdot R \cdot f$ [mm/sec], where, K_I being the stress intensity factor, in function of the solicitation conditions (traction, bending, compression etc.); a – the fissure length; R – the stress on the ceramic product surface; f – geometrical correctional factor; A, n – coefficients depending on working temperature, environment, the ceramics materials quality etc.

The figure 1 presents the crack propagation speed (v) evolution function of the K_I factor.

In zone I, the strength of the ceramics materials to the mechanical solicitation is depending on the working conditions. In this zone, the speed v increases exponentially function of K_I.

In zone II, the speed v is established function of the corrosive factors that appear in the working environment.

In zone III, an exponentially increase of the speed v appears again, having a slope bigger then that of the zone I. There is an increase of the speed v until the curve $v = f(K_I)$ meets the ordinate of the K_{Ic} factor. This value K_{Ic} of the intensity factor K_I corresponds to the crack propagation critical speed v_{Ic}, when the failure of material appears.

In the last years, the quality of the ceramics powders and that of the all technologies for obtaining the ceramics products has improved. In this way, the pores, the impurities and the density variations disappeared, leading to the decrease of the failures number to the ceramics products. On the other hand, certain advantages like:

- low density (leading to low inertial forces when spindle speed increases)
- an excellent resistance at high temperature
- an excellent resistance at corrosion,

recommend the utilization of the advanced ceramics in the bearings construction.

Certainly, to obtain a ceramics bearings involves new technologies of fabrication and new control methods, meaning some important investments. Also, the design of the machine-tools must be modified function of this kind of bearing utilization.

1.1. Hybrid bearings

Generally, there are three types of ceramics bearings:

- classical bearings having all parts made in steel and just one single ceramics ball (this ball maintains clean the race way of the bearing);
- bearings having all parts made in ceramics (the best for the chemical and corrosion environments);
- hybrid bearings having all the balls made in ceramics and the inners made in steel (recommended for the machine-tools).

In our experiment, we used a pair of hybrid bearings made by SKF, 7015 CD/HC and 7017 CD/HC types. The arrangement with a single pair of bearings, one in the front and the other in the back of the main spindle, is not a very professional one, because of the low rigidity of this kind of assembly. We were interested especially by comparative study of the thermal behavior of the main spindle when it have been used first hybrid bearings and than classical ones (made in steel).

Today, the most utilized ceramics materials for bearings construction are: alumina (Al_2O_3), zirconia (ZrO_2) and, in the most cases the silicon nitride (SiN_4), in two variants, HPSN(hot pressed silicon nitride) and HIPSN (hot isostatic presses silicon nitride). The most important differences between SiN_4 and the classical bearings made in steel (100 Cr 6 - M50) have been presented in the table1 /4/.

The important differences between the silicon nitride and a special steel for bearings

Property	SiN_4	M 50
Density (kg/dm^3)	3,19	7,87
Expansion coefficient 10^{-6} °C^{-1})	3,2	13,3
Longitudinal elasticity module (10^3 MPa)	310	207
Poisson ratio	0,26	0,29
Rockwell hardness	75…80	58…62
Fracture strength (MPa)		
room temperature	850	2400
300 °C	840	2100
600 °C	810	1000
900 °C	750	100
1400 °C	350	--

The low density of the SiN_4 involves proportionally decrease of the inertial forces, this fact leading to an equilibrium between the centrifugal forces and the main spindle load, when the rotational speed is very high.

The very low expansion coefficient of the ceramics materials is important for the observations regarding thermal behavior of the main spindle, especially the thermal extension of this, leading to a lot of precision errors.

The value of 75…80 Rockwell hardness units leads to an extremely reduced wear, and friction, this remaining constant up to 1100°C.

The main disadvantage is the higher elasticity modulus, meaning that the ceramics materials are undistorted ones. In this case, the plastic deformation does not exist. More than that overload appears, in the ceramics bearings a small crack can be observed without a wearing sign, like in the steel bearing case.

2. THE EXPERIMENTAL APPARATUS

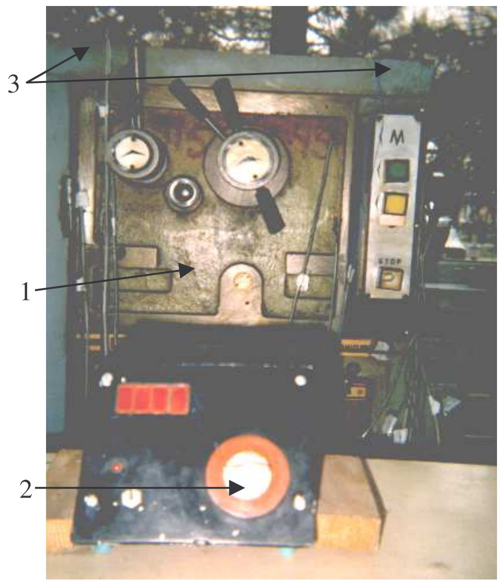

Fig. 2. The experimental stand: 1) a normal lathe; 2) an electronic pyrometer; 3) the zones where exist the thermocouples fixed on the outer ring of the each bearing

Improving the quality of a machine-tool involves also the improvement of a lot of its characteristics.

Heat is one of the most important element that can decide the class of one machine-tool. Inside of one machine-tool there are many heat sources and the spindles bearings are some of them. Especially, the heat field generated by the main spindle bearings is an important accuracy errors generator. Therefore, the specialists propose a lot of solutions against the heat effects. One of them, a simple one, regards the replacement of the steel bearings by the ceramics bearings. This thing means an important decrease of the heat field generator /3/.

The researches from the paper show how much the precise of the machine-tool increases when the steel bearings are replaced by the ceramics ones.

The experiment has been made on a normal lathe (figure 2, 1), having 2 bearings on the main spindle /2/. As it was said before, this kind of montage does not have a good rigidity, but the experiment aim is to demonstrate the difference between heat field generated by the steel bearings, respectively, the ceramics bearings.

In order to measure the temperature, it was used an electronic thermometer (figure 2, 2) having thermocouples with contact and electronic display. The whole number of thermocouples has been 20. Two of them were directly fixed on the outer ring of each bearing (figure 2, 3) through some special holes made in the ceiling of the lathe gearbox. The rest of 18 thermocouples were fixed in another important places of the gearbox and on the rest of the lathe.

To study just the thermal field produced by the bearings, all the heat sources from inside the gearbox have been removed. In this case, the movement of the main spindle has been obtained by external coupling of this one to the electric motor by a belt transmission. The measurements have been realized for two rotational speeds of the main spindle, n_1 = 2600 rpm, respectively, n_2 = 5200 rpm.

An important observation is that in both cases the ceramics bearings worked without lubrication or cooling system. During the experiments, they worked just with a small quantity of grease (LGLT 2 type), fixed on the bearings in the mounting moment /4/.

In the case of the steel bearings, a hydraulic system with 2 l/min flow has been used, especially for the cooling of the bearings. For the front side of the main spindle, it was utilized a hybrid bearing SKF 7015 CD/HC type and steel bearing 7015 type produced in Brasov, Romania. For the backward side, it was utilized a hybrid bearing SKF 7017 CD/HC type and steel bearing 7017 type, also produced in Romania.

3. THE EXPERIMENTAL DETERMINATIONS

In order to arrive at the equilibrium temperature, 3 hours and 20 minute for the hybrid bearings, and 4 hours and 55 minute for the steel bearings were necessary. In this experiment, the equilibrium temperature represents the maximum value of the temperature, this point being a limit after which it does not grow up even if the lathe continue to work /2/.

The difference between the two values of equilibrium temperatures has like basis two important reasons:

- the friction for the steel bearings case is bigger than that for the hybrid bearings case, this thing leading to a greater heating of the steel bearings and of the main spindle,
- in the steel bearings case the hydraulic cooling system works continuously and it obviously grows up the necessary time to touch the equilibrium temperature.

An interesting observation is that the period of necessary time for cooling phase, after the lathe has been stopped, was bigger with 2,5-3 hours in the steel bearings case. This is due to the bigger global heating of the entire gearbox of the lathe.

3.1. The experimental study at *n* = 2600 rpm

In figure 3, *a* (hybrid bearings) and figure 3, *b* (steel bearings), the temperatures obtained in every 20 points of measurement were represented by interpolation.

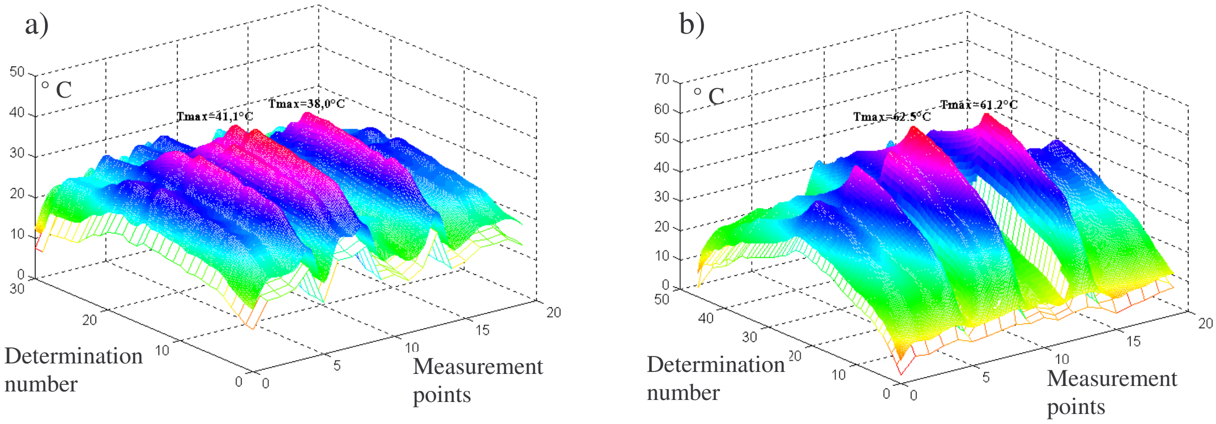

Fig. 3. a) Thermal characteristics obtained by interpolation (n = 2600 rpm, ceramics bearings), b) Thermal characteristics obtained by interpolation (n = 2600 rpm, steel bearings)

That was done with a MATLAB program, which took care about the measurement points order, from the frontal to the backward wall of the gearbox. The indicated temperatures on the figures have been recorded by the thermocouples (T4 and T8) fixed on the outer ring of the each bearing /2/.

In figure 4, it was made a comparatively representation of the temperatures curves recorded on each outer ring of bearings, for both type of bearings.

It can be observed that the growing up of the temperatures measured on both outer rings are very likely, the difference being just of 1…2 °C. This thing can be due to a small different mounting of the bearings and to the ventilation produced by the belt wheel, which rotates the main spindle.

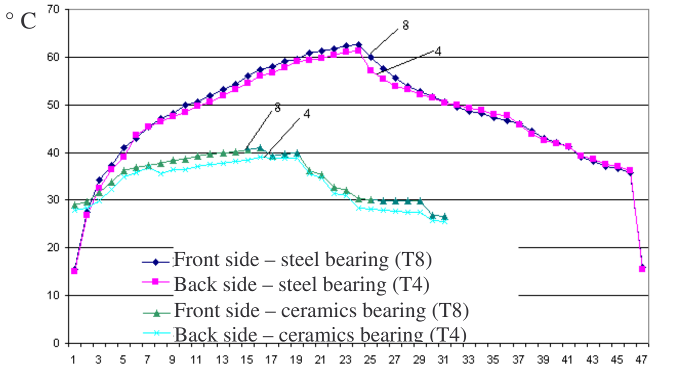

Fig. 4. The comparative representation of the thermal characteristics (n = 2600 rpm, ceramics

3.2. The experimental study at n = 5200 rpm

This experiment was done having a continuously run of the lathe, like in the previous case. The same experiments can be done by simulation of the production process. This thing means that the lathe is not running all the time, short periods of running being inserted with short periods of stopping, which are usually necessary for the fabrication process.

In the figure 5, *a* (hybrid bearings) and figure 5, *b* (steel bearings), the temperatures obtained in every 20 points of measurements were represented by interpolation.

In figure 6 it was made a comparatively representation of the temperatures curves on each outer ring of bearings, for both types of bearings.

In this experimental study case, the influence of the heat quantity on the main spindle and, respectively, on the precision of the lathe is very important. It is also important to observe the influence of this heat quantity on the gearbox and on the entire lathe. In such of great heat quantities case, a lot of angular and linear thermal displacements of the main spindle and the gearbox appear. These affect the entire precision of the lathe in a significant way /2, 3/.

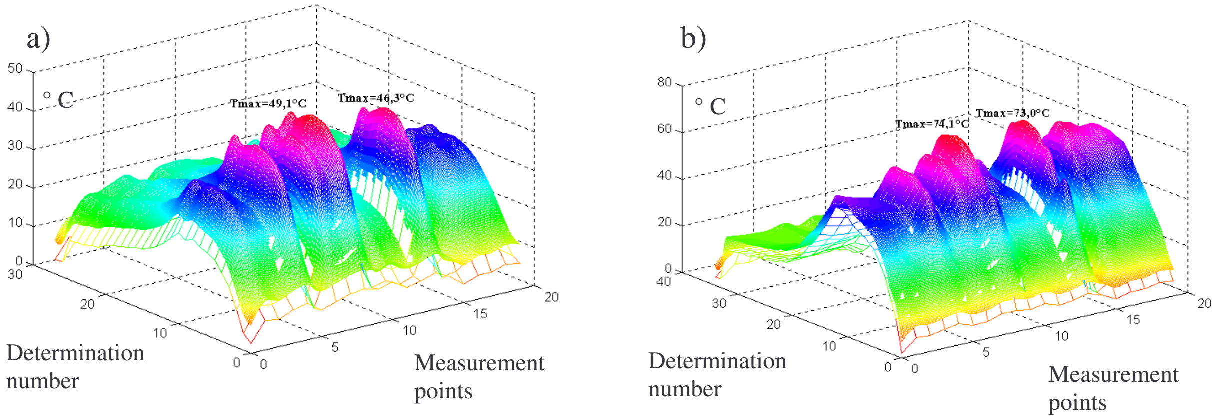

Fig. 5. a) Thermal characteristics obtained by interpolation (n = 5200 rpm, ceramics bearings), b) Thermal characteristics obtained by interpolation (n = 5200 rpm, steel bearings)

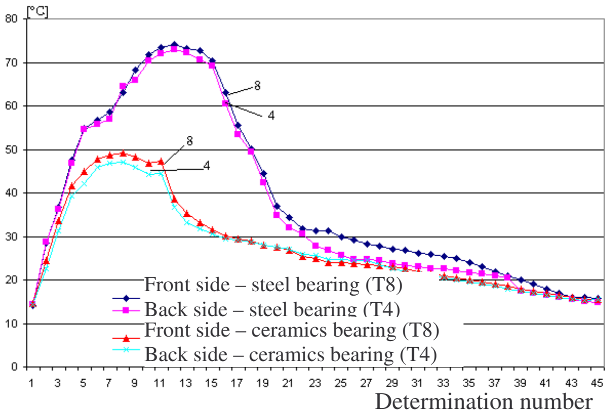

Fig. 6. The comparative representation of the thermal characteristics (n = 5200 rpm, ceramics bearings, steel bearings)

4. CONCLUSIONS

For very high precision machine-tools, the study of the thermal field and its influences are vital. A lot of money is spent for the removing of these influences. The utilization of the ceramics bearings to the modern machine-tools is a safe way in order to minimize these influences of the thermal field.

In the high-speed machine-tools case, it is also compulsory the utilization of the ceramics bearings. In the presented experimental studies for n =5200 rpm case, due to the emission of the great quantity of heat, there was an imminent danger to block the steel bearings.

This paper clearly presents the limits of the steel bearings when they are utilized for the high-speed machine-tools and, also, for the high precision machine-tools.

In order to obtain a machine-tool prepared for to the future requirements, it is necessary to use not only the ceramics bearings, but also, some important parts of machine made in advanced ceramics.

REFERENCES

1. Dumitras, C., Opran, C. The processing of the Composites Materials, Ceramics and Minerals, Technical Publishing House, Bucharest, Romania, 1994.
2. Ghinea, M. Theoretical and Experimental Researches Regarding the Utilization of the Technical Ceramics in the Machine Tools Construction, Ph.D. thesis, University POLITEHNICA from Bucharest, Romania, 1999.
3. Predincea, N. The Study of the Thermal and Elastically Deformations of the Machine Tools and the Influence of These on the Performances Parameters, Ph.D. thesis, Polytechnical Institute from Bucharest, Romania, 1991.
4. High Precision Hybrid Bearings for Increased Spindle Performance, SKF Katalog, 1996.