RELIABILITY ANALYSIS OF BALL BEARING ON THE CRANKSHAFT OF PISTON COMPRESSORS

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ABSTRACT

Technically the system that is the subject of research in this paper is a reciprocating compressor. The goal of the research presented in this paper was to examine the reliability of operation reciprocating compressor with a single cylinder. This study is based on monitoring diagnostic parameters of axial clearance and temperature on tested ball bearings, which are located on the crankshaft of the compressor. The reliability in the work was analyzed observed through monitoring of axial clearance and the temperature of ball bearings and was performed in the laboratory conditions testing. Results of the research on the tested ball bearings show that the size of the axial clearance correspond to the sizes and the temperature before the period of notice that condition and are a good indicator of the reliability of the technical system.

Keywords: reliability, ball bearings, axial clearance, temperature.

AIMS AND BACKGROUND

The most general type of technical system with rotating elements is certainly the compressor that is used in the field of launching of many mechanical installations. Piston compressors use the pistons, which are moving directly by means of the piston mechanism transforming rotary motion into oscillatory motion of the rotor[l]. They sucked the gasses from a reservoir, of penstock or the environment and propulsion still (with a significant increase in of pressure) and the other were

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pipeline, or to the end consumer[2], in other words compressors are machines where power is derived from the gas engine surrender[3]. In the compressors can compress various gases such as air, hydrogen, inert gases and others. In piston compressors that are the subject of research in the work of air compression is performed rectilinear movement of the piston moves in the cylinder depending on the opening and closing of valves[3].

Machine exploitation is impossible without manifestation of moral and physical ageing processes. It results in their technical and economic indicators decrease[4–7]. During operation of the compressor as a technical system leads to irreversible changes within the system induced by the various processes[8]: a friction, wear, the corrosion, deformations[9]. Assessment of diagnosed cases state of such an object is defined limit values corresponding parameters or characteristics[10], the derogation system characteristics of the projected values is considered to be a system failure, and the most common case of such cancellation occurs on the outer bearings[11]. The values of that are characteristic for the normal functioning of the system conditioned by system project, method of production, modes and conditions or by changing environments conditions[12]. It can be assumed that the damage to bearing comes to expensive and unplanned deadlock in production, which is several times exceeding the cost of the bearings themselves[13]. The appearance bearing failures within the system is the result of damage to the rolling elements of bearing assemblies, which can be manifested as a rise in temperature and vibration[14]. The present work deals with problems of reliability of ball bearings through axial clearance diagnostics and temperature on the samples analyzed. On the basis of this approach in the diagnosis enables the operators in maintaining to take appropriate corrective measures, as not to occurred to the cancelation with severe consequences who is arise in case of total system failure. Because justification of the research lies in the fact that the causes that lead to of such phenomena are most often caused by geometrical, the kinematics, and a dynamic occurrences[15].

Many studies were performed in connection with the modeling of the compressor and it is engaged in researching problems of thermodynamics and fluid dynamics. On the other hand, today's research is focused on developing models of tribology bodies in the compressor, whereby it included tribological characteristics of the bearings[16]. The compressor, which is the subject of research in the work includes the main mechanical components which are driven if the motor operates via the of belt gear train. The influence of wear elements of the subsystem bearings on the crankshaft design parameters, such as minimum and maximum clearances, carefully investigated, the model allows to describe such developments. By comparing the established value of the observed parameter (characteristic values for normal functioning) with the limit values, creates a basis for deciding whether the observed part fulfills the function of a projected goal or it needs to perform the appropriate maintenance activity.

Having regard to the aforesaid this research aims to investigate the tribological behavior of rolling bearing 6206 with emphasis on the occurrence of axial clearance, temperature, wear on and deformation, in order to provide new information and knowledge for the future operators of this equipment and the researchers.

WORK METHOD AND MATERIAL

Subject of this study is the piston compressor with one cylinder 'E4 NC' (Fig. 1), the manufacturer of 'Trudbenik' – Doboj. Reliability testing of piston compressor was carried out by monitoring the state of the most sensitive element of working in it – Ball bearing 6206. On examined piston compressor next to the ball bearing are the following operating elements: compressor head, filter, pulleys, shoulder belt, engine, the tank, control command and etc. The research problem that this paper is focused on is that the reviewing the reliability of the piston compressors enhance reliability of the same (century of work), thus influencing the continuity of the production process and the safety of workers in the drive. Reliability of piston compressors in the work are shown by testing of 5 samples ball bearings 6206 which are located at the end of the crankshaft in the vicinity of pulleys and shafts. The goal of the research presented in this paper was to examine the reliability of operations of the piston compressor with a cylinder in laboratory conditions testing.

Reliability of ball bearings was examined by observation dynamic parameters of axial clearance and temperature with one side and analysis of tribological processes and the deformation of the elements of the rolling bearing (outer tracks, internally tracks and balls) on the other side. The actual initial dimensions of the observed ball bearing 6206 are shown in Fig. 2. At the end of the test the reliability of rolling bearings carried out were again measurements of the dimension and visual inspection, and presented to the deformation of rolling bearings elements are connected to with increasing the axial clearance on them.

From the diagnostic the test method reliability during operation following measurements have been used:

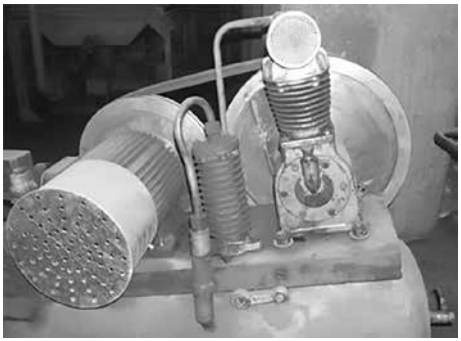

Fig. 1. The piston compressor with one cylinder 'E4NC'

- axial bearing clearance,
- temperatures and
- tribological assessment of defects of the rollers.

Tribological estimate of damage was performed to the damaged exploitation samples of ball bearings.

For the measurement of reliability of rolling bearings of the piston compressor Laboratory test methods were used are as follows:

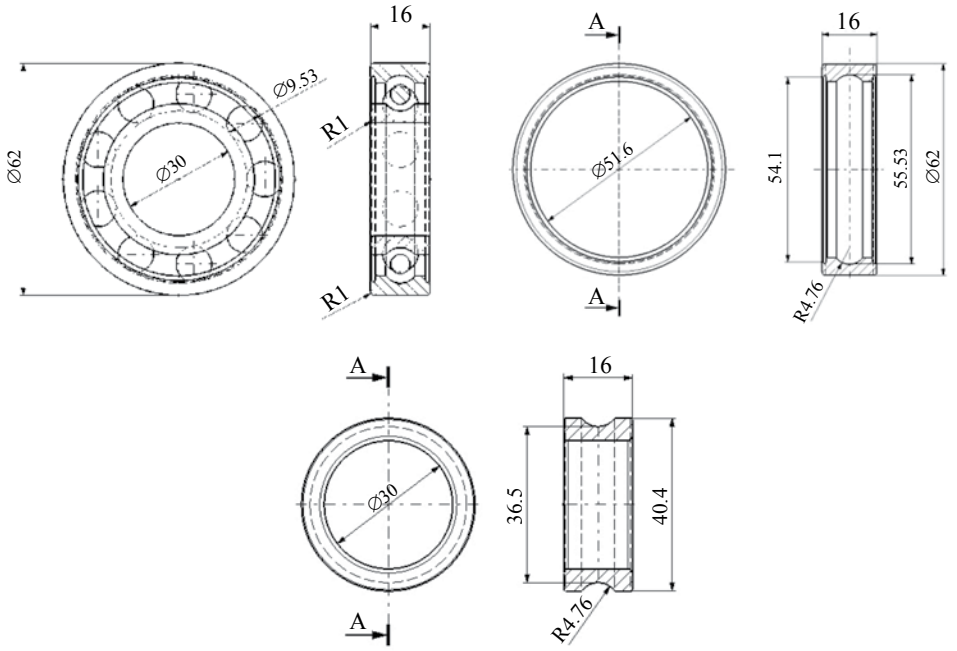

Fig. 2. Dimensions of ball bearing 6206

- laboratory method for testing the reliability of dynamical and
- laboratory method for measuring the clearance.

Measuring equipment for the purposes of the diagnostic measurements was used:

- encoders axial displacements (axial clearance),
- the laser infrared thermometer for temperature monitoring,
- the micrometer for geometrical measurements (0 – 0.025 mm).

LABORATORY TABLES FOR RELIABILITY TESTING

Exploitation tests of reliability bearing would require many years (~12 years), for this reason the laboratory test method is selected how would shorten the test time. For the purposes of the dynamic tests of ball bearing on the compressor was used is an experimental laboratory table (Fig. 3) – FAD AD Gornji Milanovac, which is intended for dynamic testing of the reliability of the bearing the same is suitable for testing the joint dowels in vehicles.

Laboratory table has an option to set a large number of different sizes loads and geometries of movement, as well as measurements of the axial (radial) clearance and temperature.

Dynamic test for the bearing to performed functioning of the alternating variable load (pressure-stretching). Laboratory table by the dynamic test joint clamp

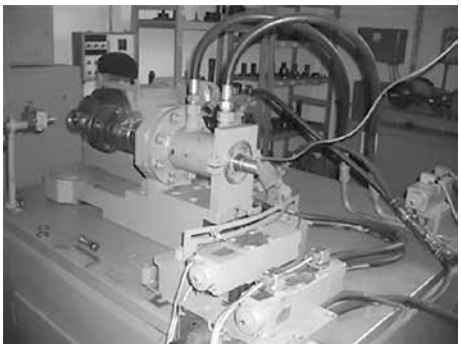

Fig. 3. Laboratory tables for dynamic testing the bearings

is also suitable for testing bearings loaded alternating variable load, the angular oscillation and the angular rotation whereby the parameters vary according to the particular frequency. At the termination of individual phases at specific time moments testing samples are still taken to a laboratory for testing on table the clearance, Fig. 4*a*.

Schematic representation of laboratory table for measuring clearance is given in Fig. 4*b*. Code of this table of laboratory for testing, the load on the test sample transferred via a hydraulic cylinder, a measurement of stiffness (clearance) is accomplished over force transducer with by strain gauges (*10*) and with inductive displacement transducer (I). The base devices (welded construction – *6*) carries the lower bearing plate with superstructure. The upgrade of the pillars (*12*) and the stationary beams which the bearing plate provides in a closed frame. On the lower beam appointed is a force transducer with upper part the tools for examination (*9*). Displacement transducer is placed in a moving the carrier thus that it can be set on any place on the board and finely tune the height by using the scroll wheel. On the bottom side of the carrier plate, in the middle part, is set the

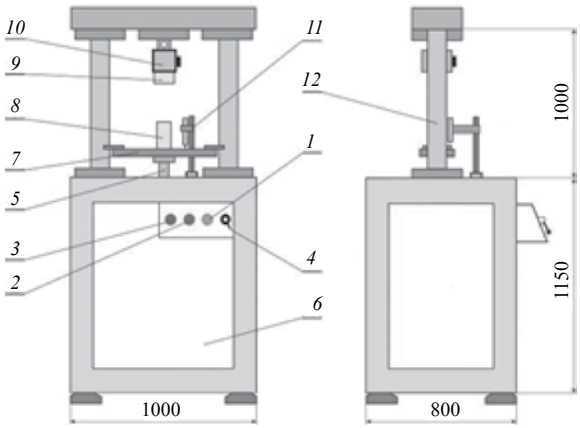

Fig. 4a. Appearance laboratory of the table

Fig. 4b. Schematic representation

1 – stop button, *2* – button down (green), *3* – the button above (red), *4* – manual faucet, *5* – working cylinder the connecting rod, *6* – the support structure, *7* – lower of carrier plate, *8* – the lower part of the tool, *9* – the upper part of the tool, *10* – encoder of force, *11* – the carrier encoder walks (displacement), *12* – supporting pillars

hydraulic working cylinder, which is a related to flange plate. The piston rod of the cylinder (*5*) passes through the circular hole in paneling and coaxially with the fixed encoder forces. The piston rod of the cylinder carries the mobile plate (*7*) that prevents its rotation around its axis and carries lower part of tools for examination (*8*) (Ref. 17).

In exploiting the work of the compressors were working on 2900°/min and crank shafts where they are roller bearings at 900°/min. Checking in exploitation the life of bearing carried out at the total number of cycles load changes of 10^6 cycles, with that the load increased by four times compared to the actual the loads occurring on the a bearing in order to accomplish the process of testing a series of bearings of 5 samples.

With the increased levels workload changes have been made then 250 000 of cycles/sample which corresponds to the total number of cycles of the 10^6 which defines lifetime of the bearing. By analyzing the size of loads bearing on the shaft of the observed compressor was determined the size of the equivalent loads of F = 587 N. This load was increased for 4 times, and the same is applicado on the test bench and is ±2350 N at the frequency of 1 Hz. So that is testing time shortened to 27.5 days for all the 5 samples.

The scheme carrying out the process of measuring the axial clearance is given in Fig. 5: 1 – lower tool, 2 – sample test, 3 – force transducer, 4 – displacement encoder. Examination of axial clearance is performed in such a way that the shaft the bearing set perpendicular to the axis of the joint of the housing in which is embedded bearing. The housing makes the basis of bearing so that there is no deformation of the forging and that the it does not affect the results of testing. The force is inflicted on the shaft via a force sensor reading of a of movement internal ring in relation to the outer ring by means of displacement sensors. Size of force depends

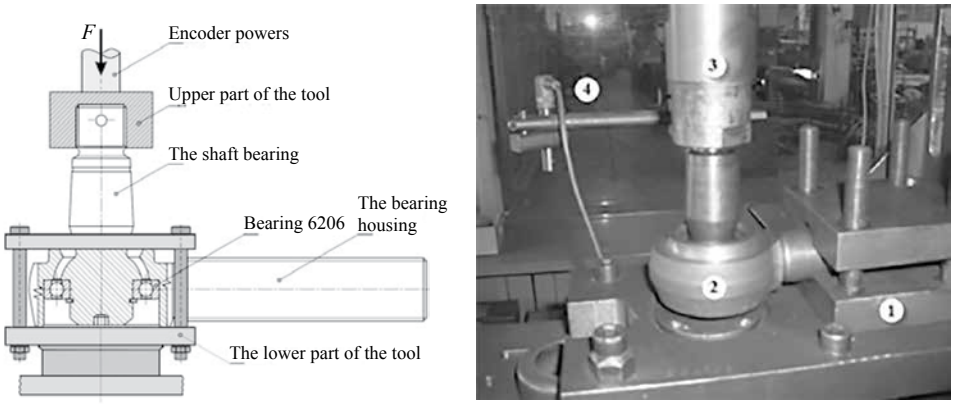

Fig. 5. Measurements of axial clearance: *a*) scheme performing of axial clearance and *b*) measurement procedure of axial clearance

on the inside diameter of the bearing. Total limit value of axial clearance which is defining reliability of ball bearings in operation, is defined by good practices, so that the clearances after the exploitation (testing) must not exceed double values upper limits of constructive clearance 0.09 mm to give bearings[18]. As an end-limit values temperature that defines reliability ball bearings in the paper, was adopted on 73°C (Ref. 19). Also this limit value of the temperature has proven to be the best in testing the reliability of bearing assemblies in joints cardan of agricultural saft[20,21].

EXAMINATION RESULTS AND THE DISCUSSION

Graphical representation of changes, the axial clearance and temperatures, are displayed on Fig. 6 and Fig. 7. Based on test results hereinafter referred to, are explained as the most important results of the research.

The axial clearance generated by movement of the inner the ring in the axial direction up simultaneously stationary the outer ring. On the Fig. 6 is shown the change of axial clearance as the function of time. The values of axial clearance on the diagram correspond to the results obtained in laboratory examinations[22]. The analysis of deformation of the single row ball bearings on the 6206 which is the projected allowed axial clearance would amount from 0.025 to 0.045 mm, which by measuring was observed at the end of the examination that it is clearance on the only one sample – bearing No 5 (0.091 mm) was above the defined limit. This upper limit clearance is a critical value because then it creates the conditions of a nonlinear movement. According to measuring and comparison of the deviations

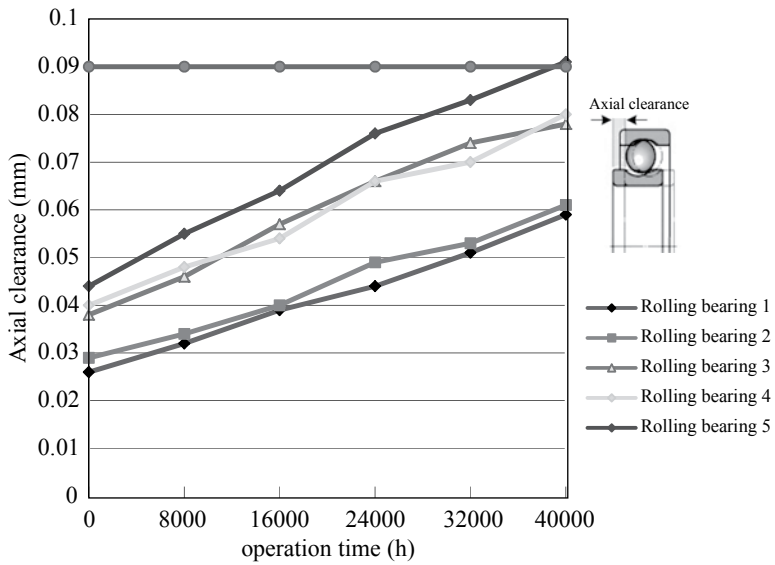

Fig. 6. Diagram of axial clearance

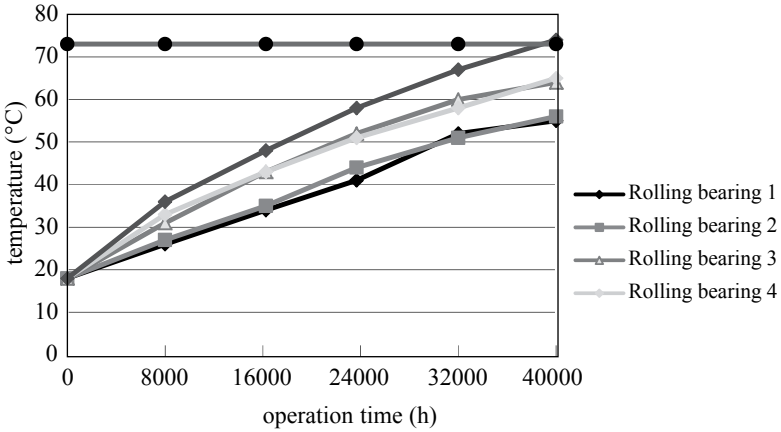

Fig. 7. Diagram the temperature

of dimensions deformed in the bearing – the sample No 5 (Fig. 8) with his initial catalogue values, it can be concluded that there has been significant difference. Axial clearance before testing amounted to 0.044 mm and 0.091 mm after investigation. On all the other samples tested ultimate axial clearance is approximately doubled its value at the end of the examination.

Ball bearings which are designed to test the increased axial clearance, decreasing their working life, as a consequence of growth of excessive temperature is caused by the emergence of vibration in the system.

If we observe the bearing in a state of satisfied clients – No 5, it can be concluded that temperature at the end of the examination on the 40 000 hours

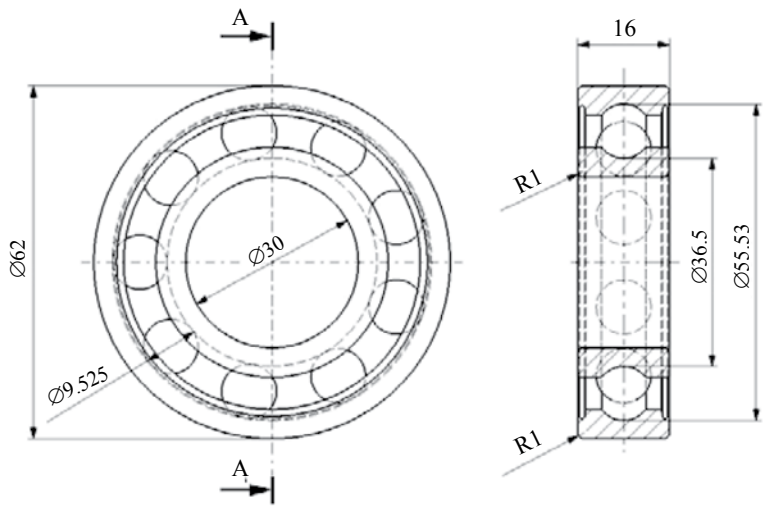

Fig. 8. The geometric sizes of damaged ball bearing 6206

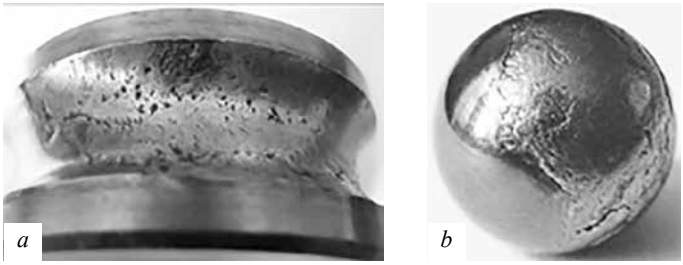

Fig. 9. Pitting wear
(*a*) pitting on the inner ring; **(***b***)** pitting on the ball

amounted to 74°C and to bearing already could not withdraw from the exploitation that comes to actual working conditions (Fig. 7). This bearing is already on the ~28 000 hours of work entered into the warning zone because the temperature amounted to 62°C. The samples bearing Nos 3 and 4 are only on the ~40 000 hours of work entered the warning zone while the other samples the bearing in terms of temperatures as a diagnostic parameter in good condition.

By analyzing the results of tribological researches on the tested samples exploitation ball bearing can also be seen different kinds of scuffing and damage. On a single bearing can arise at the same time more types of wear and tear, caused one of the dominant species and it will essentially determine the further direction of the development of tribological processes and finally lifetime of the bearing[22].

One of the forms of appearance of bearing wear is tedious wear (pitting) and it is one of the most common and at the same time the most characteristic kind bearing wear. It is characterized by the emergence of buttonhole at the initial stage and the destruction of the contact surfaces in its closing stage of the process. Fatigue to wear and tear are exposed to all the elements of bearings: rings, rolling elements, the holder, firm lateral support of the inner ring. In Fig. 9 is displayed pitting on the inside of rolling track the bearing. It is obvious that pitting was not affecting the whole rolling surface but only a part of it, however, of wear analysis shows that it is a devastating pitting. Damage caused by fatigue of materials there appeared on the surface of the rollers (Fig. 9*b*), as consequence of inadequate of lubrication or dirt, this wear recognized the as spot damage to the material[22].

Fig. 10. Fretting corrosion on the outside of the track ball bearing

Another form of appearance of bearing wear is fretting-corrosion that differs from fretting wear. The main difference is that when fretting occurs in the absence of

oxidizing environments and without the development of chemical reactions materials contact surfaces and products wear with oxygen. In Fig. 10 it is shown in the case of fretting corrosion at the outer track ball bearing.

CONCLUSIONS

Analysis of reliability of ball bearing to the crankshaft of piston of the compressor viewed from the aspect of the influence of parameters of axial clearance and temperatures of down, points to the fact that one can predict their lifetime of, from the aspect of monitoring the above parameters[22]. Under laboratory conditions of testing of the surveyed 5 bearings only one bearing came to a state of failure. The size of the state of the axial bearing of clearance and failure temperatures match the size of bearing assembly, which indicates the status of the cancellation. Under the laboratory conditions of testing on the damaged ball bearing the size of the axial clearance on the bearing of 0.091 mm, have indicated the temperature at the bearing of 74°C. An identical trend of monitoring the state proportional of the axial growth of the temperature was recorded in other bearings that were left still in good condition. Present research exclude the continuous influence of external factors that could affect the reliability of the bearing in the exploitation conditions, such as conditions of cleanliness in bearing and conditions of working environment (dust, of moisture, etc.). All of these should be taken into account when bringing conclusions of this research. On the basis of material presented in the work for future researchers created the space for further research to establish an even more precise a functional dependence between parameters of the axial clearance and temperature, both in the laboratory, thus and exploitation conditions of examination.

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