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INFLUENCE OF DIAGNOSTICS ON BEARING RELIABILITY ON ROBOTIC SYSTEMS

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Abstract:
In this assignment investigates the reliability analysis of robotic systems based on the diagnosis of the condition of roller bearings. Analysis reliability was based on diagnostic testing parameters (temperature, vibration, clearance) on the rolling bearings. For the purposes of the research, a special one was used laboratory equipment intended for testing bearings which have oscillatory movements, or other devices mechanisms that have articular connections. The results of the research are showed that the measured values of diagnostic parameters temperatures describing the operating condition of the tested bearings, very well monitored parameters care vibration, axial radial clearances.

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Reliability, robot, diagnostics, maintenance, ball bearing

1. INTRODUCTION

The subject of research in this paper is a roller bearing which is in the function of the industrial robot Fanuc. This robot has a big one application in various types of industrial and transport the machine [1-3]. The elements of a robot in rotation are loaded by combined stress on bending, twisting, shear and superficial pressure. During exploitation, because of overload, different types of destruction can occur material and fracture of individual parts of the robot such as (bearings, joint connections, etc.) [4].

The service life of bearings in industrial ones is in operation robotic systems that have mechanical transmissions, limits by impairing their working ability in 60-70% of cases [5]. All this is conditioned by the impermissible by increasing vibration as well as axial and radial clearance in joints of articulated joints. Basic types of disturbances the reliability of the articulated joints are certainly bearings [6], due certain anomalies on them such as material fatigue [7], friction and wear [8,9], etc. In practice, any such failure leads to production downtime that brings with it losses, often severe large. Also, in order to eliminate these delays as soon as possible, everyone the plant must have a certain number of spare parts, which, on the other hand, brings additional financial burdens.

To preserve the production process and avoid the minimum failures in the process is necessary, equipment maintenance [10] and critical machine parts [11]. Ball reliability improvements bearings for work in special environments such as corrosive medium, high temperature [12], high speed [13], the presence of dust, or high vacuum environments, have become very important.

In this assignment investigates the correlation between analysis of temperature, vibration and axial and radial clearance on ball bearings of a robotic system. Ball bearings, like all machine elements have a characteristic natural vibration. At the same time, frequencies can be calculated with by which the components vibrate and the outer ring, inner ring or beads. This research aims to examines the tribological behavior of the roller bearing 16006, respectively dependence of temperature

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parameters on speed parameters vibration, axial and radial clearances.

2. RELIABILITY OF ROLLING BEARINGS ON MANIPULATION ROBOTS

The mechanical structure of the manipulation robot consists of a series of rigid segments connected by connectors [14]. The behavior of the manipulator is determined mechanically by the arm that provides mobility, the joint provides which mobility, the tip of the manipulator that performs the operations required by the robot, the control system, the drive system, the measuring systems of the sensor systems [15].

They are used in the manipulation robot industry almost all types of roller bearings, which are sealed and permanent lubricated thus saving space and living environment [16]. These roller bearings have good angularity adaptability bearing tolerances and extremely high load capacity in radial direction. Sealed bearings are possible compact ulezistenja, which is in robots crucial characteristic, because it reduces the weight of the arm and its total width.

The values that are characteristic for the normal functioning of the system are conditioned by the design of the system, the way of construction, the way of functioning [17,18], and the working environment conditions [16]. The occurrence of bearing failure in the system occurs as a consequence of damage to the rolling elements of the bearing assemblies, which can manifest as an increase in temperature, vibration [19], and clearance [20].

The roller bearings observed in this work on these systems achieve oscillatory movement, whereby the body of the robotic device does not perform a complete circle of rotation during the process, but it actually only oscillates in the range of 150°. This has the consequence that it is constantly loaded only on the part of the balls. Also in terms of lubrication, this small angle can cause grease to be carried out of the work area, which after a while can cause dry friction in the work area. Therefore, in the recommendations for the use and maintenance of robotic systems, certain procedures should be planned regarding the occasional replacement of lubricants (if feasible), at least every 6 months even when they are at rest, as well as the occasional non-functional turning of the hull for a full circle, the lubricant used is evenly distributed along the rolling points [21].

In order to properly dimension the roller bearing, the calculation of the equivalent load is based on the correction of the radial and axial force quotient, axial clearance, as well as the load generated by the movement of the inner ring in the axial direction while securing the outer ring, Fig.1.

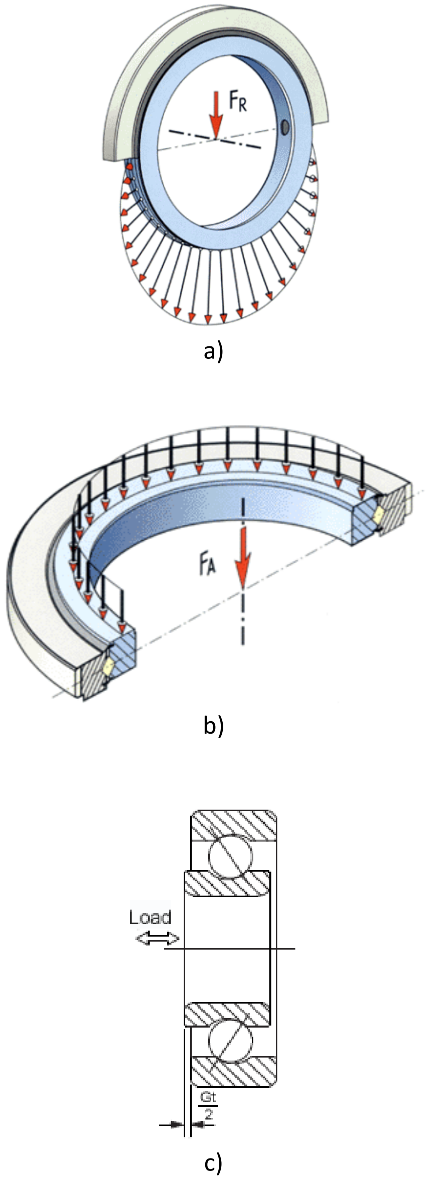
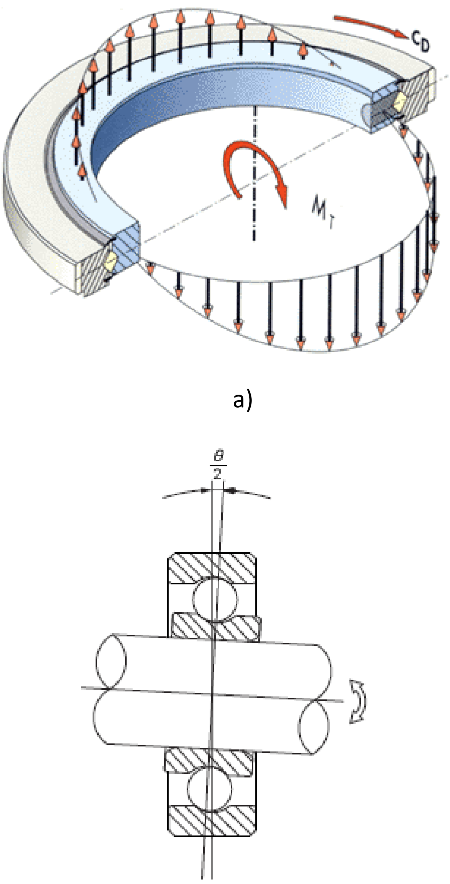


Fig. 1. Loads generated by moving the inner ring in the axial direction while securing the outer ring, (a-axial load, b-radial load, c-axial clearance)

The main feature of these robotic systems are the operational benefits that characterize the work with maximum and minimum labor. At the same time, the requirements placed in front of them, in terms of reliability, are quite high, and the central place in them is occupied by roller bearings both from the aspect of their choice and from the aspect of bearing dimensioning. In Fig.2 shows the torque load and load distribution in bearing oscillations.



a)

b)

Fig. 2. Bearing loads and load distribution during oscillation and angular displacement: a) Instantaneous load and load distribution in oscillation, b) Angular bearings move the inclination of the inner ring in the axial direction while outer ring securing (torque clearance θ)

3. MATERIALS AND METHODS

3.1 Testing methodology

The subject of research in this paper is the industrial manipulation robot Fanuc M-16iB / 10L, which has six rotary joints that give it 6 degrees of freedom, manufactured by "FANUC" Japan. Metalac "AD Gornji Milanovac, Serbia.

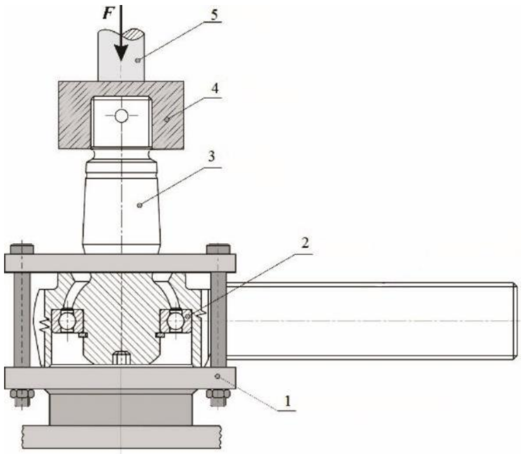
The reliability of the manipulation robot was tested by monitoring the condition of the most sensitive working element on it - the ball bearing SKF 16006. The reliability of the industrial robot in this work was examined by testing 5 ball samples in laboratory conditions. Reliability on ball bearings was tested by observing temperature, vibration, radial and axial clearance parameters. For the purposes of the research, an experimental laboratory table was used - FAD AD Gornji Milanovac, which is intended for dynamic tests of the reliability of roller bearings.

Operational bearing reliability tests would require many years (~ 12 years), for which reason laboratory tests were chosen to determine the test time. The laboratory table has the ability to set a large number of different load sizes and geometry, vibration, as well as measuring the axial (radial) clearance and temperature. Dynamic bearing testing is performed by the action of alternating variable load. In addition to dynamic tests of clamp joints, the laboratory table is also suitable for testing bearings loaded with alternating load, angular oscillation and angular rotation, where the parameters change according to a certain frequency. At the end of individual phases at certain time points of the test, the samples were further taken to the laboratory table for testing the gap.

The axial clearance test was performed by placing the bearing shaft normally on the axis of the joint housing in which the bearing was installed. The housing rested on the bearing so that the forging does not deform and does not affect the test results. The force was applied to the shaft via a force sensor and the movement of the inner ring in relation to the outer ring was read via a displacement sensor. The magnitude of the force depended on the inner diameter of the bearing [4]. The final limit value of the axial clearance, which defined the reliability of ball bearings in operation, is defined by good examples from practice, so that the clearances after operation (testing) must not exceed twice the upper limit of structural gaps of 0.09 mm for a bearing [5]. As a final temperature limit that defines the reliability of ball bearings in operation, a limit temperature of 73 °C was adopted [21,22].

An infrared thermometer TP7 was used to measure the temperature, and a Vibrobalance 5000 BN device was used to measure the vibrations.

The scheme of performing the axial clearance measurement procedure is shown in Fig.3a (1 - lower tool, 2 - test sample, 3 - shaft, 4 upper part of the tool, 5 force transmitter). The values of the axial clearance are defined by the standards for bearings, and the clearances after operation (testing) must not exceed twice the values of the structural clearances. The scheme of performing the procedure of measuring the axial clearance of the bearing is performed by running the program on the computer, according to the instructions for use of the program, then approaching the assembly of the tool, Fig.3b.



a)

b)

Fig. 3. Axial clearance measurements: a) axial clearance execution scheme and b) axial clearance measurement procedure

3.2 Technical test conditions

During the test, a load with a force of 11,242 kN was used, at a frequency of 1 Hz for a total number of cycles of 500,000. The specified force is increased 2 times in relation to the maximum force that occurs during the operation of the robot. This force change adjustment is done in order to reduce the bearing test time, which means that instead of a total number of shaving cycles of 1,000,000 it will be necessary to test 500,000 cycles.

Diagnostic tests were performed every 100,000 work cycles. The total trial time was 60 days.

Table 1 provides data that define the stability of the correlation between the size of the robot shaft diameter and the load, ie the allowed maximum and minimum clearances, both structural and operational.

Table 1. Technical parameters of tested roller bearings

Parameter	Value
Shaft diameter (mm)	30
Torque (Nm)	5-35
Maximum axial clearance for the permissible force value (N)	195
Initial - designed clearance (mm)	0.025 - 0.045
Exploitation clearance (mm)	0.090

4. RESULTS AND DISCUSSION

Based on the measurement results, according to the planned protocol and test program, the research results were obtained, which are shown in Table 2. In the presented laboratory test conditions, out of 5 tested beds, only one bearing reached the failure state. The values of the state of vibration, radial and axial clearances on the tested samples in failure correspond to the values of the temperature of the bearing assemblies, which indicate certain states of the tested bearings. On 5 bearing samples, the bearing temperature of 75° indicates that it is a damaged bearing, these statements are best supported by the measured parameters of vibration velocity of 2.89 mm/s, axial clearance of 0.093 mm and radial clearance of 0.045 mm, Table 2. Identical trend monitoring of operating parameters is also noticeable in the other four tested bearing samples.

Table 2. Test results of ball bearings

Sample No.	RPM $[min^{-1}]$	Number of cycles per hour $\left[\frac{c}{h}\right]$	Hours of work $[h]$	Number of test cycles	Frequency change of load $\left[\frac{\pm kN}{Hz}\right]$	Angular oscillation $\left[\frac{\pm \beta'}{\text{Hz}}\right]$	Angular rotation $\left[\frac{\pm \alpha^{\circ}}{\text{Hz}}\right]$	Temperature [°C]	Vibration speed $\left[\frac{mm}{s}\right]$	Axial clearance $[mm]$	Radial clearance $[mm]$
1	2	3,600	0	0	$\frac{\pm 11.24kN}{1Hz}$	$\frac{\pm 5'}{1Hz}$	$\frac{\pm 20^{\circ}}{0.5Hz}$	18	0.096	0.025	0.006
		3,600	3,731	100,000				21	0.01	0.03	0.008
		3,600	7,433	200,000				27	0.114	0.05	0.015
		3,600	11,194	300,000				30	0.123	0.059	0.017
		3,600	14,933	400,000				33	0.014	0.072	0.019
		3,600	18,665	500,000				35	0.161	0.085	0.02

Table 2. Test results of ball bearings - continuation of the table from the previous page

Sample No.	RPM $[°/min]$	Number of cycles per hour $\left[\frac{c}{h}\right]$	Hours of work $[h]$	Number of test cycles	Frequency change of load $\left[\frac{\pm kN}{Hz}\right]$	Angular oscillation $\left[\frac{\pm \beta'}{\text{Hz}}\right]$	Angular rotation $\left[\frac{\pm \alpha^{\circ}}{\text{Hz}}\right]$	Temperature [°C]	Vibration speed $\left[\frac{mm}{s}\right]$	Axial clearance $[mm]$	Radial clearance $[mm]$
2	2	3,600	0	0	$\frac{\pm 11.24kN}{1Hz}$	$\frac{\pm 5'}{1Hz}$	$\frac{\pm 20^{\circ}}{0.5Hz}$	18	0.084	0.031	0.008
		3,600	3,731	100,000				22	0.089	0.038	0.01
		3,600	7,433	200,000				31	0.098	0.055	0.013
		3,600	11,194	300,000				35	0.101	0.06	0.016
		3,600	14,933	400,000				37	0.139	0.067	0.018
		3,600	18,665	500,000				37	0.171	0.076	0.021
3	2	3,600	0	0	$\frac{\pm 11.24kN}{1Hz}$	$\frac{\pm 5'}{1Hz}$	$\frac{\pm 20^{\circ}}{0.5Hz}$	18	0.107	0.041	0.01
		3,600	3,731	100,000				23	0.114	0.047	0.012
		3,600	7,433	200,000				31	0.013	0.062	0.019
		3,600	11,194	300,000				37	0.147	0.071	0.024
		3,600	14,933	400,000				41	0.179	0.076	0.028
		3,600	18,665	500,000				48	0.210	0.084	0.033
4	2	3,600	0	0	$\frac{\pm 11.24kN}{1Hz}$	$\frac{\pm 5'}{1Hz}$	$\frac{\pm 20^{\circ}}{0.5Hz}$	18	0,115	0.042	0.015
		3,600	3,731	100,000				27	0.136	0.048	0.018
		3,600	7,433	200,000				41	0.206	0.062	0.025
		3,600	11,194	300,000				47	0.243	0.071	0.03
		3,600	14,933	400,000				56	0.284	0.078	0.035
		3,600	18,665	500,000				63	1.890	0.089	0.04
5	2	3,600	0	0	$\frac{\pm 11.24kN}{1Hz}$	$\frac{\pm 5'}{1Hz}$	$\frac{\pm 20^{\circ}}{0.5Hz}$	18	0.159	0.045	0.017
		3,600	3,731	100,000				31	0.238	0.054	0.019
		3,600	7,433	200,000				46	0.179	0.07	0.027
		3,600	11,194	300,000				49	0.306	0.078	0.032
		3,600	14,933	400,000				61	0.346	0.083	0.038
		3,600	18,665	500,000				75	2.890	0.093	0.045

5. CONCLUSION

The presented research aimed to examine the tribological behavior of roller bearings on robotic systems in laboratory test conditions. The conducted research has shown a good dependence of monitoring certain test parameters when testing the reliability of roller bearings. In this paper, the system failure is determined by harmonizing all test parameters of temperature, vibration, axial and radial clearances. The values of the state of vibration, radial and axial clearances on the tested samples in failure correspond to the values of the temperature of the bearing assemblies, which indicate certain states of the tested bearings.

Knowledge of the problems of the functioning of rolling (oscillating) (oscillating) bearings on robotic systems can greatly contribute to the proper dimensioning of the bearing on the example as shown in this paper. Because only an adequate selection of roller bearings and properly dimensioned bearings on robots can provide: high reliability, longer service life, reduction of noise and vibration and reduction of sensitivity to errors when installing roller bearings. tied to the basics

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