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Full Length Research Paper

Development of a multipurpose, efficient and inexpensive bearing test rig

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The basic objective of this research is to develop an inexpensive, multipurpose and efficient test rig for condition monitoring of rolling element bearings. The fundamental philosophy of measurement of lubricant film thickness for monitoring the condition of rolling element bearings has been exploited and transformed in the form of a test rig. The developed test rig is potent enough for performance evaluation and condition monitoring of rolling element bearings which is vital for its prolonged life and enhanced performance. A significantly correct prediction of life of bearing can also be made which in turn gives an idea about possible mode and time of failure. Certain machineries like aircraft, battle tanks, rocket launchers, ships, etc. need impeccable working of the system. Failure of such systems is not acceptable at any cost. In the heart of such system, bearings play a central and key role. Still there is no such standard mechanism available for ascertainment of performance and testing of rolling element bearings with high degree of reliability. In the continuing process of improvement and modification in the existing test rig, a simple, versatile, and inexpensive test rig has been developed and presented through this paper.

Key words: Condition monitoring, low cost, lubricant film thickness, performance evaluation, rolling element bearing, test rig.

INTRODUCTION

Rolling element bearing is a basic component of almost all machinery transmitting power. It finds its applications in land automobiles, aircrafts, ships, space vehicles, large and small industrial installations, defense machinery, etc. The extent of damage or loss can be thought off when the bearing suddenly fails of an automobile overtaking a vehicle, of an aircraft after attaining its maximum height, of a ship in deep sea, of a space vehicle when placed in orbit, of an industrial installation during its peak production run, of a defense vehicle when encircled by enemies, etc.

The testing of rolling element bearings involves various parameters to be considered such as the range of speed and load, type of loading such as radial or axial or both, type of lubricant, etc. A good test rig essentially consists of a prime mover with speed control options, a supporting shaft assembly for test bearing with options to incorporate multiple diameter bearings, arrangement for application of load such as hydraulic or mechanical, measuring instruments related to parameters to be measured, etc. The test rigs (Prashad, 1987, 2006) along with measuring instruments used by researchers mostly are very costly. This limits the bulk of research in the field. Keeping in view the limitation of cost and to promote research in the field, a low cost experimental setup is developed with essential instruments in the Dynamics of Machines Laboratory of National Institute of Technology, Raipur.

The developed test rig have tapping of two electrical points, one connected to inner race of the rolling element bearing and other connected to the outer race. A simple electrical circuit, discussed in methodology, is connected between the tapped points to measure the overall electrical resistance between the inner and outer race of the bearing due to the presence of lubricant between rolling elements and races. The voltage drop across

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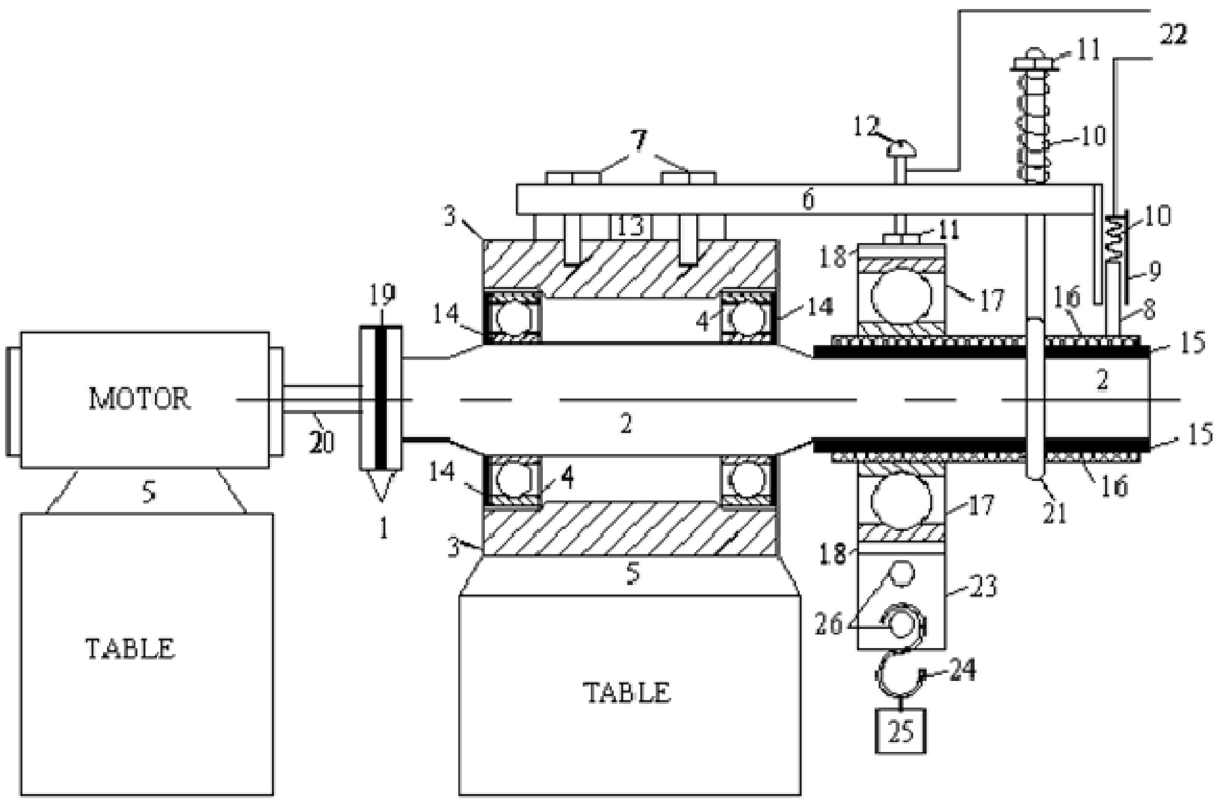

Figure 1. Schematic diagram of rolling element bearing test rig; 1, Coupling; 2, Test rig shaft; 3, Thick mild steel tube; 4, Supporting ball bearings; 5, Supporting stand; 6, Cantilever wooden plate; 7, Bolts; 8, Carbon brush; 9, Brush guide; 10, Helical spring; 11, Nuts; 12, Screw; 13, Spacer washer; 14, Bearing seal; 15, Insulating sleeve; 16, Mild steel sleeve; 17, Test ball bearing; 18, Bearing outer copper sleeve; 19, Rubber pad; 20, Motor shaft; 21, Brass ring; 22, Wires to electrical circuit; 23, Projection on copper sleeve; 24, Steel hook; 25, Suspended weight; 26, Holes for bolts.

bearing inner and outer race is measured by using an Oscilloscope. By using suitable formula, electrical resistance between inner and outer race of bearing is calculated. The value of resistance measured with varying speed and load will directly depict the amount of lubricant present between rolling elements and races. This will lead to convenient, reliable and inexpensive online condition monitoring of rolling element bearings.

EXPERIMENTAL SETUP

Experimental setup has been shown through Figures 1 and 2. Figure 1 depicts the schematics of the setup whereas Figure 2 is the photograph of the setup developed and used in the present study. The test rig essentially consists of a shaft supported at one end by two well placed bearings (press fitted in a steel housing at either ends) and overhung at the other end that supports the test bearing. One end of the shaft is coupled to a DC motor and the other end carries the test bearing. An AC variable transformer is used to vary the input voltage to the motor through the rectifier.

The steel shaft is fitted upon an insulating sleeve on which a steel sleeve of appreciable length is tightly fitted. The outer diameter of steel sleeve is equal to the inner diameter of bearing. Similarly inner diameter of steel sleeve is equal to outer diameter of the insulating sleeve. This steel sleeve accommodates the test bearing and the carbon brush arrangement.

Insulation is needed to eliminate the influence of support bearings in the measurement of resistance and capacitance of the test bearing. The outer diameter of the steel sleeve varied from one end just below 35 mm and at the other end just above 35 mm after considering different tolerances. The steel sleeve was made tapered to facilitate easy fitting and removal of the different test bearing with inner diameter of 35 mm. The test bearings are deep groove ball bearings (6207and 6307) whose inner race is press fitted on one end of the steel sleeve and the carbon brush/brass ring arrangement is accommodated on the other side (free end of sleeve).

A split copper outer sleeve, tightly fitted on the outer race of the ball bearing, acts as the bearing housing. The lower end of the copper sleeve is split end which is tightened with each other by using a nut and bolt. One

Figure 2. Photograph of rolling element bearing test rig; 1, DC motor; 2, Storage oscilloscope; 3, Variable AC transformer; 4, Regulated DC supply; 5, Flexible coupling; 6, Supporting shaft assembly; 7, Wooden cantilever; 8, Carbon brush assembly; 9, Stainless steel sleeve; 10, Copper sleeve over test bearing; 11, Hook for radial loads; 12, Electrical circuit.

more nut and bolt is used just below the previously fit nut and bolt which incorporates hook for application of radial load. A nut on the top is welded on the copper outer sleeve before fitting. Inside the sleeve, some spots of copper are made by using gas welding to ensure good electrical contact with outer race of the bearing when tightened appreciably. The first electrical connection is tapped from this outer copper sleeve.

A longitudinal slit is made in the wooden cantilever beam through which passes a brass rod having a ring at one end, encircling the projected steel sleeve of test bearing, and the other end have threads used to fit a nut with washer after inserting a spring on the cantilever above. The nut is tightened on the washer so as to compress the spring slightly such that the ring always bears against the steel sleeve with some force. The size of the spring is such that its diameter is more than the width of slit in cantilever and the length such that force exerted is just enough to make a good electrical contact of brass ring with the steel sleeve. The second electrical connection is tapped from the threaded portion of the rod with the ring.

As an alternative to brass ring arrangement (which is found later to generate heat due to friction and thus affected the observations taken over a time) the carbon brush arrangement is used to make the electrical circuit. One carbon brush is fitted on the wooden cantilever at the end such that the carbon brush always makes contact with the steel sleeve which is in contact with the inner race of the test bearing. The carbon remains in contact with the steel sleeve by the spring force. The second electrical connection is tapped from the carbon brush in contact with inner race.

Thus two electrical connections are tapped, one in contact with outer race and second in contact with inner race of bearing. These tapped connections are then linked to a standard electrical circuit for measurement of electrical resistance between inner and outer race of bearing which will be due to presence of lubricant in between balls and inner and outer race. The hook fitted to the second bolt at lower end of split copper sleeve is used to hang different radial load on the bearing. The

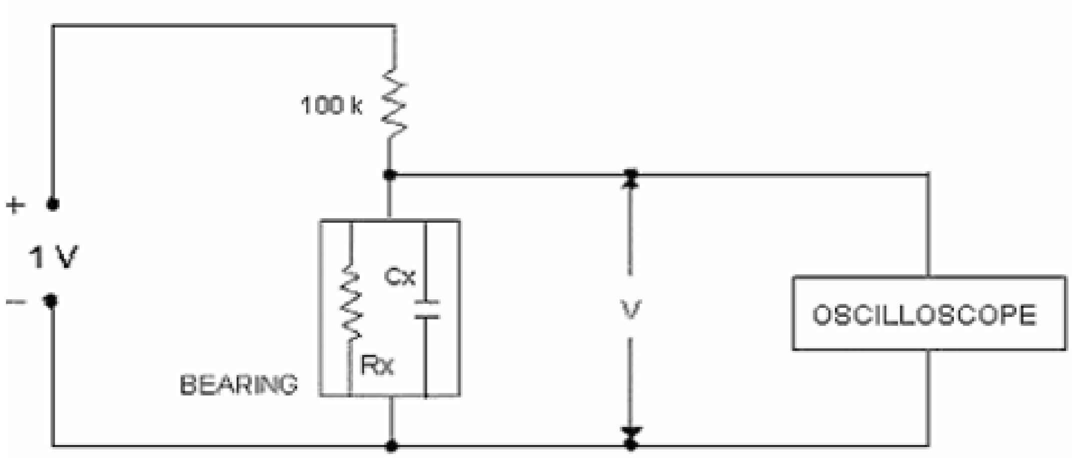

Figure 3. Circuit diagram for measurement of test bearing resistance.

technical specification of various components has been given in Appendix 1.

METHODOLOGY

The tapped points for electrical connections are connected to the electrical circuit shown in Figure 3.

The rolling element bearing is supposed to be a combination of electrical resistance and capacitance in presence of lubricant as shown in electrical circuit of Figure 3. A resistance of known value is connected in series with the bearing. This known resistance is used to determine the current flowing in the circuit. The bearing and a resistance R of known value (here 100 kΩ) is connected in series along with a constant DC voltage supply of 1 V (Vin). A DC voltage is used since the capacitance of bearing being non-polar will be inactive to DC current and hence the voltage drop will be only due to the bearing resistance. The voltage drop (say V) in the bearing can be read from the oscilloscope connected across the bearing terminals. The current flowing in the circuit is given by $I = (V_{in} - V)/R$ and the bearing resistance is given by $R_x = V/I$. This bearing resistance measured is the representative bearing resistance since it is obtained by overall voltage drop between inner and outer race of the bearing.

The bearing resistance thus obtained leads to determination of the lubricant film thickness by using the formula:

$$R_T = \rho h_0\{(1/A_1) + (1/A_2)\}$$

Where:

ρ = resistivity of lubricant in Ω mm,
h_0 = lubricant film thickness in mm,
A_1 = Elastohyrodynamic area of contact of ball with inner race in $mm^2 = \pi a_i^2$,
A_2 = Elastohyrodynamic area of contact of ball with outer race in $mm^2 = \pi a_o^2$,
R_T = Total resistance between inner and outer race of bearing in Ω.
a_i = Elastohyrodynamic radius of contact of ball with inner race in mm,
a_o = Elastohyrodynamic radius of contact of ball with outer race in mm,

Elastohyrodynamic radius can be calculated using the standard formulae

$$a_i = ((3\pi Q(k_1+k_2)r_i r)/(4(r_i+r)))^{1/3}$$

$$a_o = ((3\pi Q(k_1+k_2)r_o r)/(4(r-r_o)))^{1/3}$$

where:

$k1 = (1 - \nu_1^2)/\pi E_1$,
$k_2 = (1 - \nu_2^2)/\pi E_2$,
Q = radial force on ball,
ν_1, ν_2 = Poisson's ratio for the materials of ball and races respectively,
E_1, E_2 = Modulus of Elasticities of the materials of ball and races respectively,
r_i = outer contact radius of inner race,
r_o = inner contact radius of outer race,
r = radius of ball.

DISCUSSION

The formulae are based on the formulae used by Prashad (1966) and Harris (2001). The patterns of results are taken from Dowson et al. (1966). The technique, R-C oscillation was also explored (Peng-shun et al., 1991). The concept of Elastohydrodynamic lubrication was used. The results reported compare fairly well with the earlier available results of Dowson et al. (1966) and Cameron (1981).

The results reported for starved lubrication regime by researchers at laboratory were found to be satisfactory (Damiens et al., 2004). Even the experimental setup was run with no lubricant in the rolling element bearings and the results intimated were very encouraging (Cameron, 1981). The performance on thin lubricant films can also be done (Choo et al., 2004). The set up also tested some worn out bearings, the surface of balls being rough, the results communicated showed that the lubricant film thickness in the rough contacts come out to be less as compared to the smooth contacts (Guangteng et al., 2000).

Also the methodology used in the set up can test variation of lubricant film thickness with asperities making contact in rough bearings as done by Choo et al., 2004; Guangteng et al., 2000.

Experiments on the developed test rig, as informed, were conducted with ball bearings 6207 and 6307. The characteristics of representative film thickness reported agree with the findings of Dowson et al. (1966) and Prashad (2006). Thus the circuit created is adopted after its use is found to be satisfactory as communicated by the researchers.

Conclusion

The developed setup was used at Dynamics of Machines Laboratory of National Institute of Technology, Raipur, to perform experiments with rolling element bearing and it was reported that the results obtained for new (smooth) bearings follow the earlier published results. Similar pragmatic observations with rough (worn out) bearings were communicated which matches the earlier reported results. By changing the diameter of steel sleeve the setup can be used for testing of various rolling element bearings.

On the basis of reported results, it is also concluded that the reduction in quantity of lubricant inside the bearing will be well indicated by drop in voltage across the bearing races. At this stage more lubricant can be fed to the bearing thus maintaining a minimum level of lubricant which leads to better performance and long life of the bearing. Further, it is worth to mention that the setup can be effortlessly modified to incorporate axial loading as well. Journal Bearings can also be tested by suitable changes.

Overall facet of the setup developed was analyzed and thus it can be conveniently concluded that the test rig developed is simple, cheap, versatile, compact and robust. Performance evaluation and continuous condition monitoring of bearing can be achieved successfully by the use of the created test rig. This is imperative for achieving prolonged life and augmentation of the bearing-performance.

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Appendix 1

S.No.	Name of equipment / instrument	Specifications	Current market price (Rs)
1	DC Motor	1 kW	8,000/-
2	Plain oscilloscope	60 MHz	15,000/-
3	Supporting shaft assembly	Robust enough to support radial loads of 1000 kg	5,000/-
4	Mild steel sleeves	As per the inner diameter of the bearing	3,000/-
5	Test bearings and lubricating oils	As per requirements	2,000/-
6	Digital Multimeter	Reputed Make, can measure resistances upto Megha-ohm	4,000/-
7	Weights along with mechanical loading arrangement	In steps of 10 kg	4,000/-
8	Microlab II with -12V to 12V DC supply	Having bread board, function generator, variable voltage supply, etc. of reputed make	18,000/-
9	Wiring and other small requirements	Wires should have low resistance	3,000/-
10	Tachometer	Non contacting type of reputed make	2,000/-
11	Voltage Stabilizer	5 kW, Reputed make with servo motor	12,000/-
12	Regulated DC supply	0 to 30 V DC, 2A, Digital, with separate adjustments of voltage and current, of reputed make	6,000/-
Total in Indian Rupees			82,000/-