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DEVELOPING REGRESSION BASED ANALYTICAL EQUATION BETWEEN SIMULATION AND EXPERIMENTAL RESULTS TO DETERMINE THE STATIC LOAD BEARING CAPACITY OF A ROLLER BEARING

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Abstract: In our present research thesis we tried to reduce the testing cost of the bearing manufacturer by making an effort to modify the destructive testing of the bearing i.e. the static load bearing capacity of the roller bearing to a simulation software and finding out the difference between the simulation and practical laboratory results. We also repeated the same test with increasing bearing size to find out statistical relation between the difference between the simulation and practical results through correlation and regression analysis.

KEYWORDS: Cylindrical roller bearing, finite element analysis, Structure deformations, Multiple objectives, Bearing load

I. INTRODUCTION

The gearbox is continuously being developed for future demands of increased loads, longer lifetime and reductions of noise and weight. A useful FE-analysis requires a good knowledge of the loads that the gearbox will be subjected to during operation Bearings are key components in this aspect as they transmit forces between the components in the gearbox, e.g. gear wheels, shafts and housings.

Using full FE-models of the bearings with contacts and solid rollers is not feasible, from the view of computational cost, when modelling a significant part of the gearbox with several bearings. Thus it is necessary to have simplified bearing models. When the position of the bearing is close to the area of interest, then the detailed deformation and force distribution in the bearing will affect the critical area. This yields different and significantly more complex requirements on the bearing model than for the previous case.

Having bearing models of suitable complexity that is numerically stable and thoroughly tested and verified both decreases the computational time and ensure that the results are adequate. If they can be created automatically from a limited number of parameters then also the time for setting up models of gearboxes can be decreased.

II. THEORY APPLIED TO BEARING DIAGNOSTICS

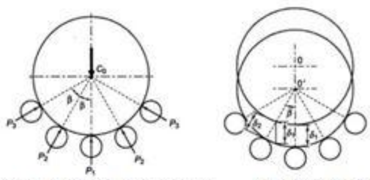
Static load is defined as the load on the bearing when the shaft is stationary. It produces permanent deformation in balls and races, which increases with increasing load. The permissible static load depends upon the permissible magnitude of permanent deformation. From past experience, it has been found that a total permanent deformation of 0.0001 of the ball or roller diameter occurring at the most heavily stressed ball of roller diameter occurring at the most heavily stressed ball and race contact can be tolerated in practice, without any disturbance like noise or vibrations. The static load carrying capacity of a bearing is defined as the static load which corresponds to a total permanent deformation of balls and races, at the most heavily stressed point of contact, equal to 0.0001 of the ball diameter. Stribeck's equation gives the static load capacity of bearing. It is based on the following assumptions:

- The races are rigid and retain their circular shape.
- The balls are equally spaced.
- The balls in the upper half do not support any load.

It is assumed that there is a single row of balls. Considering the equilibrium of forces in the vertical direction,

$$C_o = P_1 + 2P_2\cos\beta + P_3\cos(2\beta) + \dots\dots$$

As the races are rigid, only balls are deformed. Suppose δ1 is the deformation, the inner race is deflected with respect to the outer race through δ1.



(a) Forces acting on inner race, (b) Deflection of inner race

Figure 2.1 load distribution on ball bearing.

As the race of the ball rigid, only balls are deformed. Suppose δ1 is the deformation at the most heavily stressed Ball No.1. due to this deformation, the inner race is deflected with respect to the other race through δ1. The center of the inner ring moves from O to O' through the distance δ1 without changing its shape. Suppose δ1, δ2…… are radial deflections at the respective balls.

Also, δ2 = δ1cos β or

$$\frac{\delta_2}{\delta_1} = \cos\beta \qquad \delta \propto (P)^{2/3}$$

According to Hertz's equation, the relationship between the load and deflection at each ball in given by,

Therefore,

$$\delta_1 = C_1 P_1^{2/3} \text{ and } \delta_2 = C_1 P_2^{2/3}$$

From eq.(b) and (c),

$$\frac{\delta_2}{\delta_1} = \left(\frac{P_2}{P_1}\right)^{2/3}$$

$$\left(\frac{P_2}{P_1}\right)^{2/3} = \cos\beta$$

$$P_2 = P_1(\cos\beta)^{3/2}$$

Or

In the similar way, $P_3 = P_1(\cos 2\beta)^{3/2}$

Substituting these values in eq.(a),

$$C_0 = P_1 + 2[P_1(\cos\beta)^{3/2}]\cos\beta + 2[P_1(\cos 2\beta)^{3/2}\cos 2\beta] + \cdots$$

$$C_o = P_1 M$$

Where

$$(\cos\beta)^{5/2} + 2(\cos 2\beta)^{5/2} + \cdots]$$

$$\beta = \frac{360}{z}$$

If z is the no. of balls,

Nearly all bearing manufacturers' catalogs provide the static radial load capacity for any bearing size.

III. PROBLEM DISCUSSION

In this we carried out experiments on the ball bearings of the size that we drafted in Catia and analyzed practical maximum static load carrying capacity of ball bearing. The specification of the ball bearing of 3 different sizes is following

Make- Svenska Kullagerfabriken AB (Swedish: Swedish ball bearing factory AB)

Bearing No	Bearing Outer Diameter	Roller Diameter
205	52 mm	8 mm
305	62 mm	10 mm
405	80 mm	20 mm

The static load on the bearing was applied gradually on the Universal Testing Machine of the following specification

Make - UTM (Instron 1342)

Type – A servo hydraulic fluid controlled machine

Capacity : load up to 1000 tonne

STEPS OF THE TEST

- The test is to be conducted on the universal testing machine using a fixture to prevent the slipping of the bearing during the test. All the measuring equipment and display units to be used in the test are properly calibrated for its accuracy and effectiveness. It was ensured that the least count of the length measuring instrument is of the order of .0001mm as these are required for the test
- The jaw of the UTM is taken to its extreme position in order to check the hydraulic healthiness of the machine and the bearing was place on the lower jaw in the approximate center and supported by the fixture in order to prevent its dislocation during the test
- The upper jaw was moved to the position that it just touches the bearing surface and the corresponding readings of the display were set to 0 (Zero).
- The compressive load was applied gradually and the corresponding reading were observed in the display and ensure that the reading are being recorded
- Stop the test when the total deformation of the bearing is displayed.
- Repeat the test for the larger size bearing and record the results.

IV. RESULT AND DISCUSSION

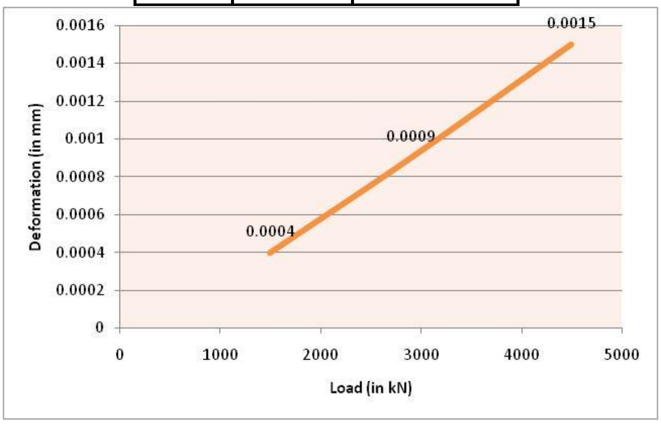
In this section, all the results from both experimental and software (Ansys) implementation will be given with tables and figures of output.

Experimental Vs Laboratory Results

When the original bearing with the material provided in the Ansys were subjected to the laboratory strength analysis following results were obtained. Table and graph depicts the deformation with respect to load for bearing no. 205, 305 and 405.

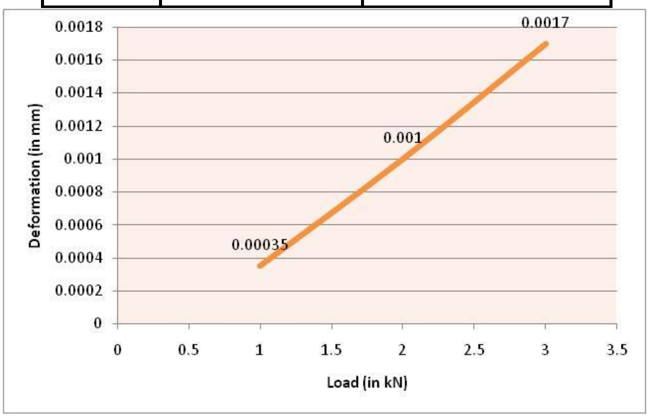
Bearing no.205

S.NO.	Load	Deformation
1	4500kN	.0015mm
2	2900kN	.0009mm
3	1500kN	0.0004mm



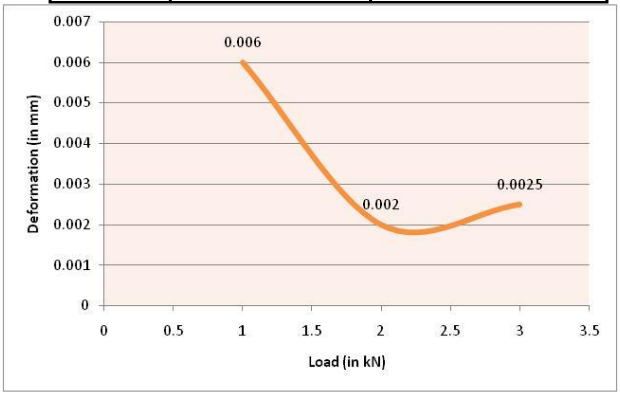
Bearing no.305

S.NO.	Load in Newton	Deformation in MM
1	2300kN	0.0017
2	1500kN	0.001
3	6500kN	0.00035



Bearing no.405

S.NO.	Load in Newton	Deformation in MM
1	1200KN	.006
2	3000kN	.002
3	3200kN	.0025



ANSYS RESULTS

NTN catalogue Bearing no. 205

Bearing Outer dia = 52 mm Shaft Daimeter = 25 mm	$\{(D_o-D_i)/2\}$ X 0001 = 0.00135 mm		
Bearing no. 6205	4555000 N	2555000 N	1000000N
TOTAL DEFORMATION	0.0013002 mm	0.0007293mm	0.00028544 mm
EQUIVALENT STRESS	0.055214 MPa	0.030971 MPa	0.012122 MPa
MAX SHEAR STRESS	0.030371 MPa	0.017036 MPa	0.0066676 MPa

NTN catalogue Bearing no.305

Bearing Outer dia = 62 mm	$\{(D_o-D_i)/2\}$ X 0001 = 0.00185 mm		
Force	21828724 N	12136614 N	4835590 N
TOTAL DEFORMATION	0.0016374 mm	.00910846 mm	.003625666 mm
EQUIVALENT STRESS	0.102428 MPa	0.05695 MPa	0.012122 MPa
MAX SHEAR STRESS	0.05496 MPa	0.03055 MPa	0.012169 MPa

NTN catalogue Bearing no.405

Bearing Outer dia = 80 mm	$\{(D_o-D_i)/2\}$ X 0001 = 0.00275 mm		
Force	31181064.48 N	29809436.8 N	11672274 N
TOTAL DEFORMATION	.2225435 mm	.0020647 mm	.0080785 mm
EQUIVALENT STRESS	0.26729 MPa	0.15568 MPa	0.06092 MPa
MAX SHEAR STRESS	0.14565 MPa	0.0854 MPa	0.03344 MPa

Comparison between Lab Experimental & Ansys results

Bearing No.	Bearing Size (in mm)	Req Deformation (in mm)	Load (in Newton)		Deformation(in mm)		Deviation in Load between Simulation and Experimental
			FEA Software	Lab	FEA Software	Lab	
205	8	0.00135	4555000	4500000	0.00028544	0.0015	55000
305	10	0.00185	21828724	2300000	0.000362567	0.0017	19528724
405	20	0.00275	31181064	3200000	0.00080785	0.0025	27981064.48

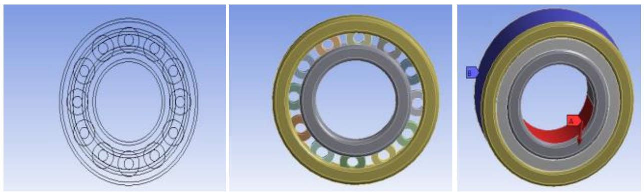


Figure4.1. Model, boundary conditions

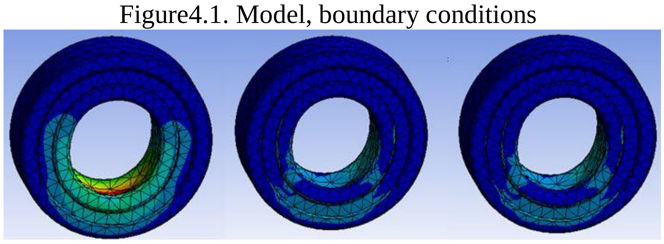


Figure4.2 (205) (a) total deformation (b) von mises stress and (c) max.shear stress

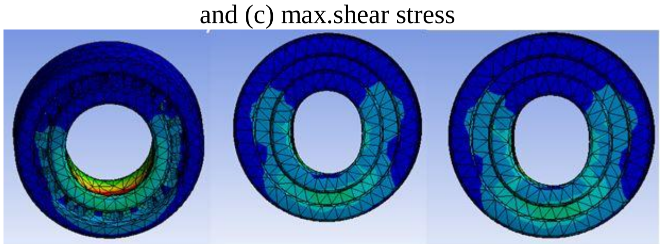


Figure4.3. 305 (a) total deformation (b) von mises stress and (c) max.shear stress

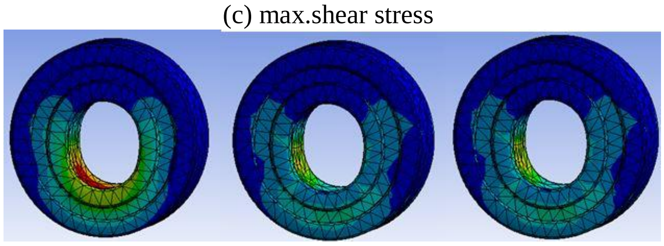


Figure4.4. 405 (a) total deformation (b) Von Mises stress and (c) Max.Shear Stres

The findings of the research were that the deviation between the static load bearing capacity of a roller bearing obtained by finite element software and the result that were obtained by the practical test that was conducted on Universal testing machine in the Laboratory has a linear relation with size of bearing under test. When the statistical relation between this deviation and the bearing size was established using statistical tool of Linear Interpolation the following relation were obtained

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.83013
R Square	0.689116
Adjusted R Square	0.378231
Standard Error	11292379
Observations	3

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	2.83E+14	2.83E+14	2.21663	0.376532
Residual	1	1.28E+14	1.28E+14		
Total	2	4.1E+14			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-7567353	17029392	-0.44437	0.73379	-2.2E+08	2.09E+08	-2.2E+08	2.09E+08
X Variable 1	1849128	1241996	1.488835	0.376532	-1.4E+07	17630184	-1.4E+07	17630184

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*
1	7225668	-7170668
2	10923923	8604801
3	29415198	-1434134

PROBABILITY OUTPUT

Percentile	*Y*
16.66667	55000
50	19528724
83.33333	27981064

The results shows that the relation of deviation between the result obtained by the two method and the bearing size is linearly related with the
Coefficient of Correlation -7567352
Coefficient of Regression 1849127.526
This deviation is of diverging in nature and the significance is of 0.37653239

The results can be interpreted as that if the static load carrying capacity of the bearing is to be determined by the relation developed in this research following equation can be used
Y= 1849127.526X-7567352
Where X= bearing size (in mm)
Y= Deviation in the static load bearing capacity roller bearing by the interpolation method
The effect of the other factors like manufacturing method of bearing and the manufacturing defect are not considered in this bearing analysis.
The Regression analysis tool performs linear regression analysis by using the "least squares" method to fit a line through a set of observations. You can analyze how a single dependent variable is affected by the values of one or more independent variables. For example, you can analyze how an athlete's performance is affected by such factors as age, height, and weight. You can apportion shares in the performance measure to each of these three factors, based on a set of performance data, and then use the results to predict the performance of a new, untested athlete. The Regression tool uses the worksheet function LINEST

V. CONCLUSION

The study was conducted in order to generate a systematic and more accurate system that can be used to determine the static load bearing capacity of the roller bearing without destructive test of the costly bearing which can help to reduce the cost, time and efforts required for determination of static load bearing capacity. Since this method of determining the strength of bearing theoretically, if practically used in industries to do the strength analysis of the bearing will result in saving both in monetary and time front. But before using this analysis the significance and the reliability of the method has to be increased. The divergence we obtained in the analysis is only for the range of the size we selected in the experiment. If more samples are taken in the analysis the relation between the size and the deviation between the practical strength and the strength through Ansys may be converging diverging for different size ranges. This relation can be obtained by increasing the range of the bearing in terms of size and increasing the number of sample so as to increase the regression system analysis reliability

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