Prediction of Stiffness for Angular Contact Ball Bearings

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Abstract - Rotating components in industrial machines are often mounted in antifriction bearings. Typical applications include machine tools, automotive gear boxes, turbine rotors, aerospace engines etc. The rolling elements in the bearings could be spherical or cylindrical in shape. The spherical ones exist in ball bearings whereas the cylindrical shapes are using in roller bearings. Types of Ball bearings are such as deep groove ball bearings, angular contact ball bearings with angularity and self align ball bearings are preferred in machinery where speeds are high and loads are light to moderately high. It is needless to mention that the static deformation or response to vibratory loads of any structure depends upon the stiffness of the rotating components (the shafts), which in turn depends to a considerable extent on the stiffness of the bearings in the machine.

A novel method is proposed now in the research for modeling and computing the stiffness for angular contact ball bearings. This method is proposed to compute the stiffness of bearing using finite element approach. The analysis is proposed to be carried out in two stages – first predict the nonlinear stiffness contact characteristics between the cages and rolling elements, followed by prediction of nonlinear elastic characteristics of the full bearings. The utility of the developed method is illustrated with an application to the prediction of angular contact ball bearings of size Ø110 X Ø70 X 15^{o}. Though the size of the bearings is same at front and rear sides, the computed stiffness is different in view of the change in bearing load at the front and rear sides.

After predicting the stiffness of the angular contact bearings, an application for predicting the deformation of the spindle of a boring machine is discussed. Angular contact ball bearings are supported in spindle shaft.

Key Words: *DESIGN, BALL BEARING, STIFFNESS, FEA, etc…*

1. INTRODUCTION

Angular Contact ball bearings are designed such way that it makes an angle and are placed in inner and outer rings of the bearings, and that are moved with respect to each other in path of axis bearings. In general, a bearing is a machine part whose function is to support a second member, preventing its motion in the direction of an applied load but at the same time allowing motion in another predetermined direction. The rolling contact bearings in which ball bearings, the rolling element is a spherical ball whereas roller bearings, the rolling element is a roller which might be cylindrical, spherical or conical. Angular contact ball berings are design in such manner its undertake a combine loads, Simultan-eouslly stand-in axial and radial loads, the angle of contact is defined as the angle between line joining contact points of ball and races. The use of rolling bearings is known since pre historic times. Fig. 1 shows use rolling elements in transporting huge stones for constructing forts and temples in ancient India.

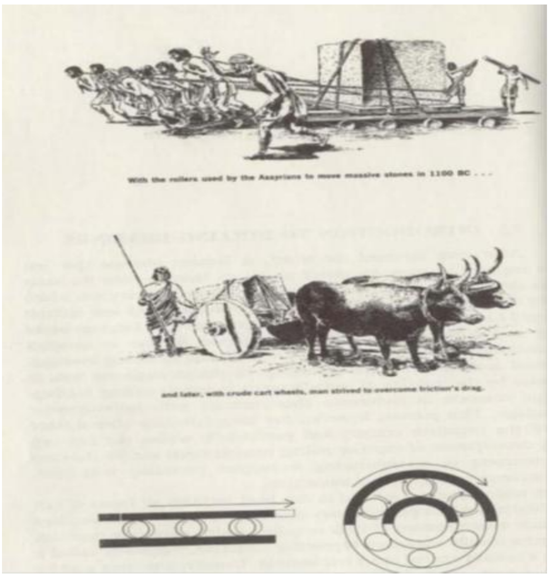

Fig1.1 Transporting huge stones by rolling elements for constructing forts and temples.

Bearings that will be considered are limited to those designed to prevent the radial or axial displacement of a rotating shaft. Rolling contact bearings have greater

capacity for radial loads for a given overall size, due to greater area of contact. and these are more easily adopted to high speed. Most important material used for rolling element bearings is high quality steel. E. g. specially alloy steel with N; and either Cr or Mo, some of the most important disadvantage of the rolling bearings are considerably smaller axial thrust capacity and more sensitive to misalignment and dirt , and these are costlier.
The static behaviour that in its assessment should consider the following aspects:

- Aspects regarding bearing construction,
- The scheme of loading and
- The operating conditions. Aspects regarding bearing construction are:
- Coaxiality of bearings and shaft
- Arrangement of bearings
- Thrust bearings preload-effect. and
- Determination of static radial and axial stiffness of the bearings.

2. PROBLEM DEFINITION AND METHODOLGY

The problem of bearing stiffness computation has arisen while designing a boring machine in which the rotating spindle is mounted in angular contact ball bearings, for which the stiffness values are not provided by the bearing manufacturer. Of late, automotive designers prefer not to use the empirical formulae, but instead prefer to follow a more rigorous approach using Finite Element Approach for bearing analysis.

3. Methodology to meet the objectives

- To develop a method for modeling spherical rolling element located in cylindrical races of the ball bearing and there by predict the nonlinear stiffness characteristics.
- To develop the FEM model of the complete ball bearing.
- To compute the deflection and stiffness characteristics of the full ball bearing.
- To predict the stiffness of a steel shaft mounted in five angular contact ball bearings.
- To verify the results using analytical method.

Material properties

The material properties used for angular contact ball bearing as follows

Table No.1 Material properties for angular contact ball bearings.

No	Young's modulus(Y) (GPA)	Poisson's ratio	Density(D) (gm/cc)	Material used
1	203	0.3	7.8	Martensitic stainless steel

The material used for the steel ball bearings, Young's modulus is 203Gpa, Poisson's ratio 0.3, density of the material is 7.8gm/cc and the type of material used is Martensitic stainless steel.

Design assumption of angular contact ball bearings

The angular contact ball beraings are design such a way that meet the objective of the goal demandinging desires of new tools makers. These bearings require a commerce position therefore that can tolerate major axial loads in one direction together with radial loads.

- High quality steel - excessive fresh steel to extend 10% life of the bearing.
- High rating balls - at high speed operation ball are smooth and quiet
- Super finished raceways - especially improved towards decrease sound and recover lubricant circulation and lifespan.
- Angle of contact - existing popularly 40, 30, 25, 15 angles in degree.
- Untested covers - afford resilient near pollution happening hardest surroundings.
- Enclosures - axial loads fashionable a kind of Polymide, steel brass cage assemblies.
- Quality assured - total product quality ensure by testing is 100%

4. GEOMETRIC MODELLING

4.1 Geometric Modelling Of Angular Contact Ball Bearing

This thesis involves prediction of the deformation characteristic of angular contact ball bearings. Fig4.1 shows the that is outer cage and inner cage and each ball of angular contact of ball bearings is Ø110 X Ø70 X 15° .width of each ball 20mm For predicting the deformation pattern of the model, and the elastic stiffness of angular contact ball bearings should be essential to know.

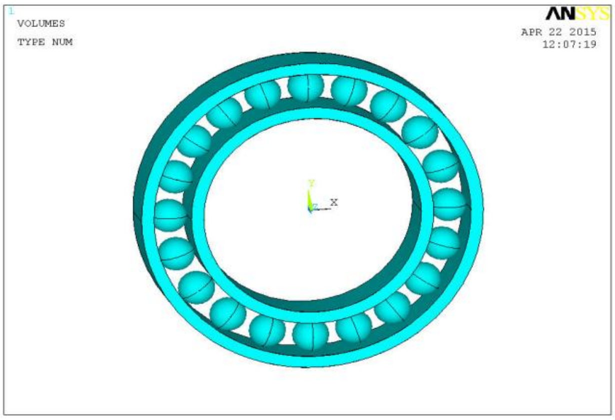

Fig4.1 shows the that is outer cage and inner cage.

In the thesis, first the elastic stiffness of the bearing is computed using finite element method. The stiffness of the bearings is subsequently used in the model for computing the deflection.

Table No.2 Load versus deformation of a single ball of the angular contact ball bearing

No	Load (N)	Deflection (mm)
1	4.8	4.0e-5
2	13.8	1.0e-4
3	34.0	2.6e-4
4	80.0	6.0e-4
5	183.0	1.4e-3
6	412.8	3.1e-3
7	820.4	6.7e-3
8	1200.0	8.7e-3

The table shows that the load versus deflection curve is a nonlinear in nature. This data is later used for analyzing the full bearings, both the front and rear bearings.

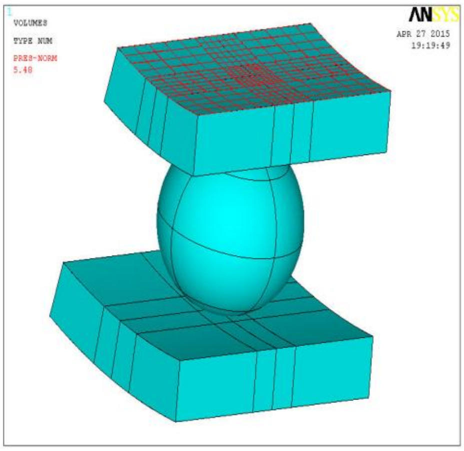

Fig4.2 shows the model with pressure acting on the inner race

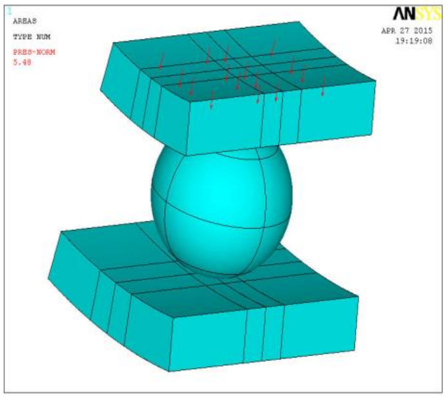

Fig4.3 shows the model with load acting on the inner race

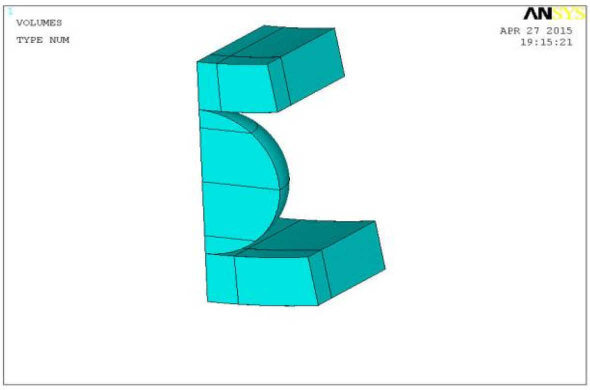

Fig4.4 The quarter symmetric model of the ball in the cages

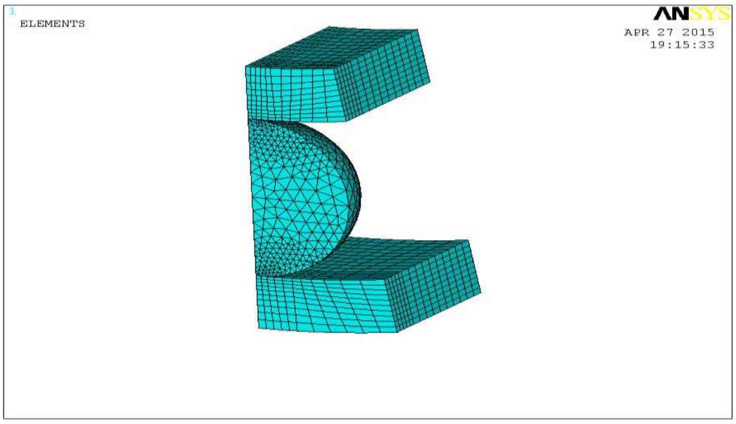

Fig4.5 Meshed FEM model of the cages and the bearing ball

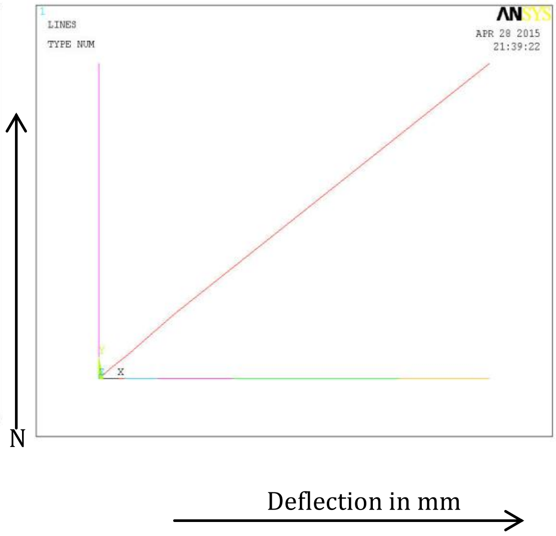

Fig4.7 load versus deflection

The graph shows that the load versus deflection, it gives the similar to straight line but it is something like slant, in the fig4.7

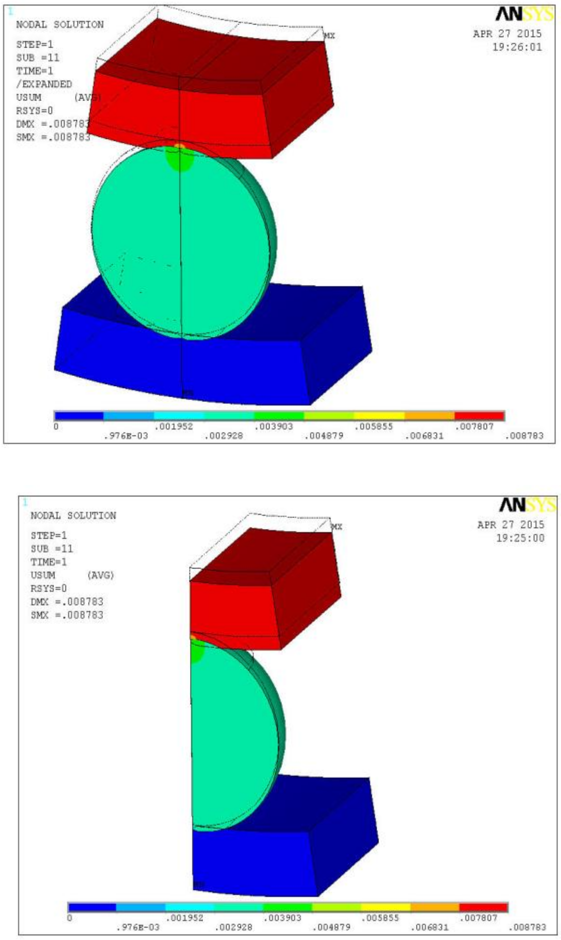

Fig4.6 Deformed mode of the structures

5. Analysis of the Front Bearings

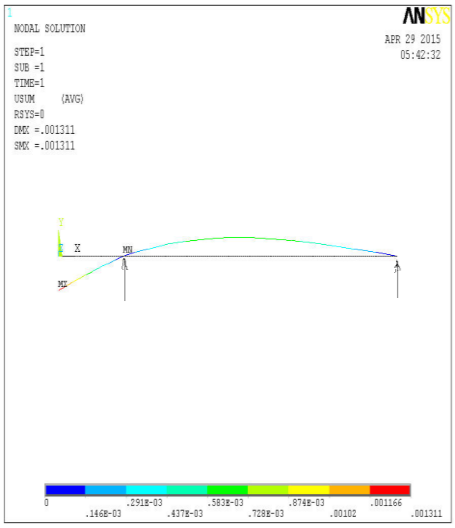

Fig5.1 shows the beam model of the shaft system

Fig5.1 shows the front view of the geometric model of the bearing inner and outer races. The rolling balls angular location can also be seen in the figure. Fig5.2 shows the perspective view of the geometric model. in angular contact ball bearings, since the balls are inclined at the angle of 16.9^{o}, the lines representing the inclined balls are also modeled at the inclination. This inclination can be seen in Fig 5.3 shows the inclined springs that represent the bearing balls. Fig5.4 shows the line diagram of the bearing in which are shown the bearing balls which are shown as lines. These lines actually represent stiffness characteristics of the spring representing the bearing balls. Fig5.5 shows the perspective view of the line diagram.

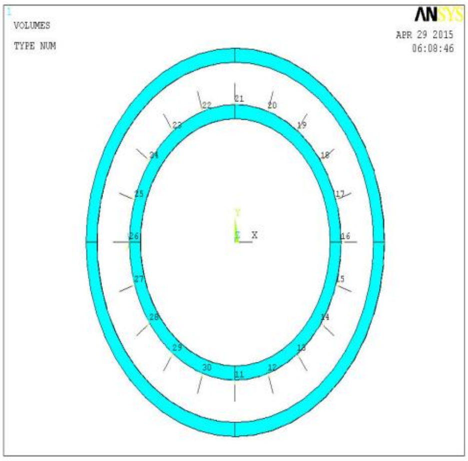

Fig5.1: Front view of the geometric model of the bearing inner and outer races

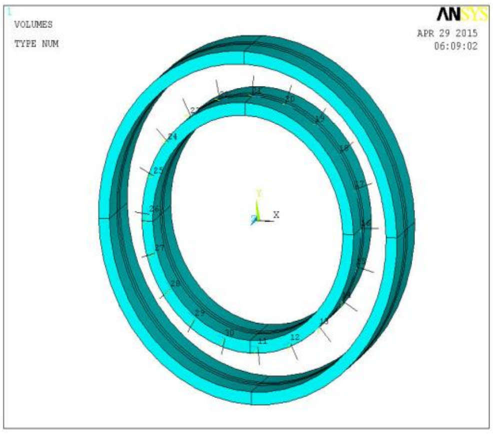

Fig5.2 Perspective view of the geometric model of the bearing inner and outer races.

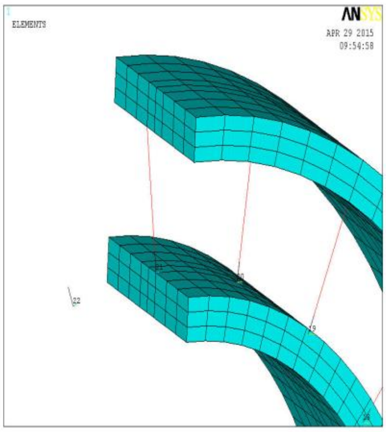

Fig5.3 shows the inclined springs that represent the bearing balls

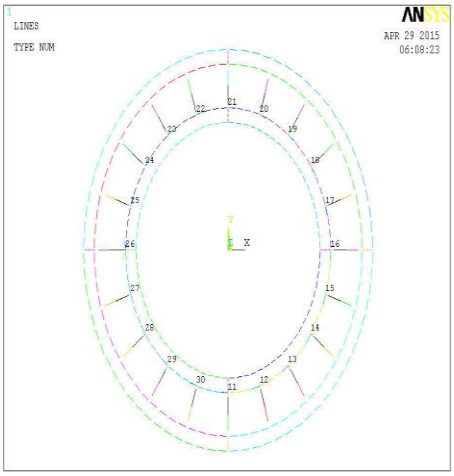

Fig5.4 Line diagram of the bearing

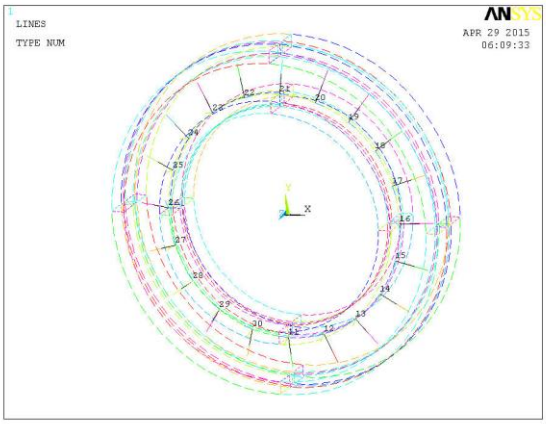

Fig5.5 Perspective view of the line diagram of the full bearing

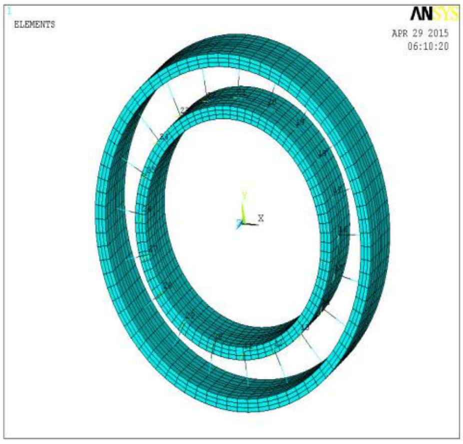

Fig5.6. FEM mesh of the full bearing

Element Types used for meshing: of angular contact ball bearings COMBINATION 39 (Nonlinear 3d Spring element).

Fig5.6 shows the FEM mesh of the full bearing. The elements line representing the bearing balls can be seen in the figure. Appropriate boundary conditions and material properties have been applied in the models. The bearing is subjected to a radial load of 4000N to which it is subjected. The load is applied as equivalent pressure load on bore of the inner race. The pressure load is given as :

Pressure= 4000/ (20 * 70) = 2.86 N/ mm^2.

Fig5.7 show the region of application of the pressure load in the bearing which is shown in red colour.

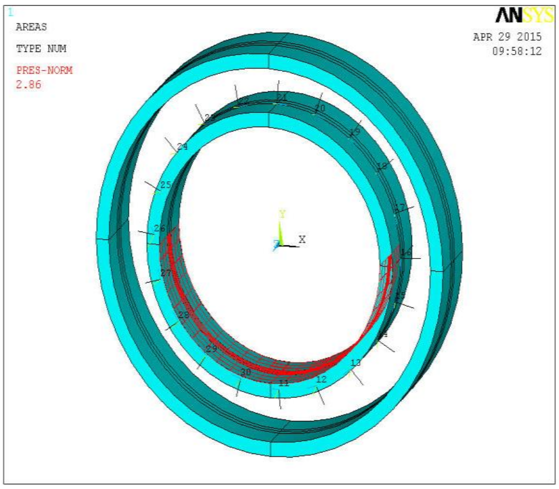

Fig5.7 Region of application of the pressure load in the bearing

Fig7.2.8 Show the deformation pattern of the full bearing. The deformation of the bearing in vertical direction for that load is observed from the FEM model as 0.017mm. The stiffness of the bearing is as such= 4000/ 0.017=2,35,294N/mm.

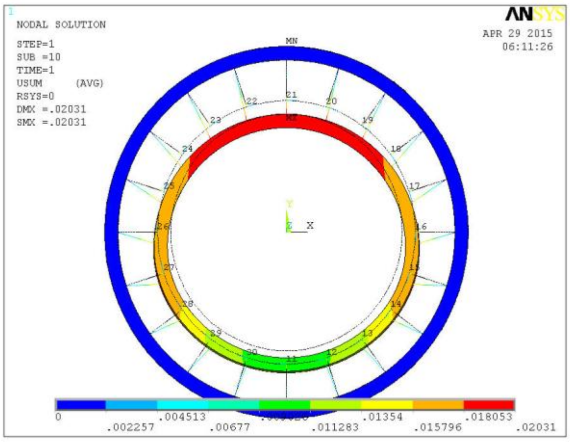

Fig5.8 shows the deformation pattern of the full bearing.

6. Analysis of Rear Bearing

The rear bearing size is also same as that of front bearing, i.e, Ø110 X Ø70 X 15^o, but the load on the bearing is less than that of front bearing. The radial load on the bearing is 1540N, and also the equivalent pressure load on the bearing bore is 1540/ 20/70= 1.1 N/mm^2.

This pressure load is applied on the model. Fig6.1 shows the deformation pattern of the rear bearing. The vertical deflection of the bearing is -0.0083mm.The stiffness of the rear bearing is 1540/ 0.0083= 185542 N/ mm.

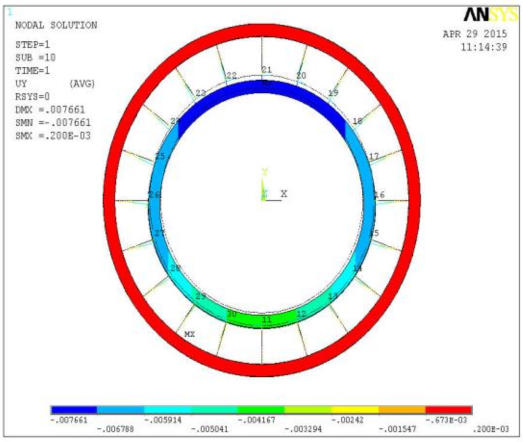

Fig6.1 shows the deformation pattern of the rear bearing

Material Properties for bearings

The material properties used for angular contact ball bearing as follows

TableNo4. Material properties for angular contact steel ball bearing

No	Young's modulus(Y) (GPA)	Poisson's ratio	Density(D) (gm/cc)	Material used
1	203	0.3	7.8	Martensitic stainless steel

The material used for the steel ball bearings, Young's modulus is 203 GPA, Poisson's ratio 0.3 , density of the material is 7.8gm/cc and the type of material used is Martensitic stainless steel.

Material Properties for Spindle System

The material properties used for the spindle as follows

Table No.5 Material properties for spindle shaft system

NO	Young's modulus(Y) (GPA)	Poisson's ratio	Density(D) (gm/cc)	Tool used
1	210	0.3	7.8	Steel

The material properties used for spindle system is young's modulus is 210Gpa Poisson's ratio 0.3, density 7.8gm/cc and type of material used for tool is Steel.

Elements used in the model

a) 2 noded beam element, 'Beam 188'. This is used for modeling the shaft.
b) Spring element, 'Combination 14'. This element is used for modeling the stiffness of the three bearings. The bearing stiffness value is inputted as 'Real Constant'.

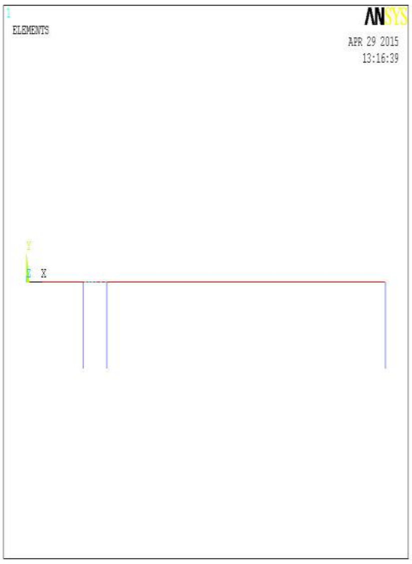

Fig6.2. shows the beam-spring model of the shaft system. The load at the cantilever end is -6500N.

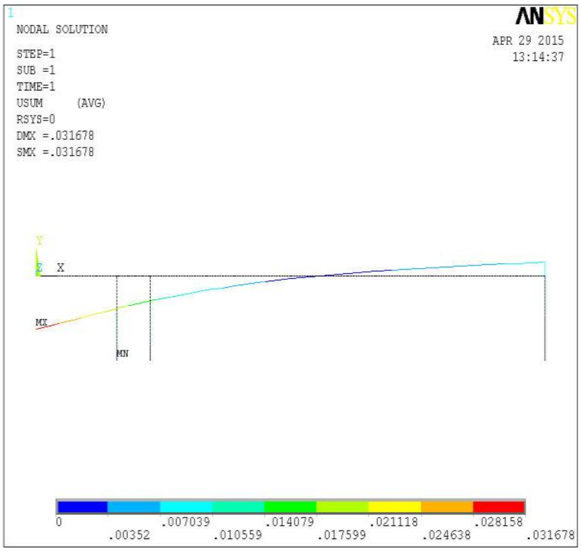

Fig6.3 Show the deformation pattern of the shaft system. The deflection at the loaded point is -0.0317 mm.

7. Conclusions

In the present research, a method has been developed for predicting of angular contact ball bearing stiffness. The rolling elements as the bearing balls make point contact between the mating races and inner and outer rings. This leads to formation of Hertzian contact stresses at the contact points. This leads to nonlinearity in the relationship between the applied load and bearing stiffness.

The developed method is general in nature and it can be applied for any angular contact of the bearings, of any size and any contact angle. The developed method has two stages. In stage 1, only ball is modeled in the races. It is loaded with a load that is slightly higher than load that acts on the bearing. The nonlinear behavior of deflection with load is computed following FEM nonlinear analysis.

The developed method has been applied for computing the deflection of a shaft supported in three angular contact bearings, two bearings are at the front end and one is at the rear end. The size of the bearings are OD 110mm, ID 70mm, width 20mm and contact angle 15^{o}. But the load on the front and rear bearings is different.Using the developed method, stiffness of the front bearings has been computed as 2,35,294 N/mm and stiffness of the rear bearing has been computed as 1,85,542 N/mm. Analytical verification using empirical formulae provided in CMTI, Machine Tool Design Hand Book confirmed these predictions. Application of the method to a machine tool spindle has given a shaft deflection of 0.0317mm at the loaded point.

The developed method is general in nature and it can be applied for any angular contact of ball bearing of any size and any contact angle.

Scope of Future Work

- Experiments can be carried out for estimating the bearing stiffness. For this, the spindle assembly with the bearings can be manufactured and subjected to the load of 6500N at the overhanging end. The spindle deflection at the free end (loaded end) can be measured using micron indicators for comparison with the FEM predicted values.
- Dynamic analysis can also be carried out for the FEM models.
- The effect of speed of the bearing can be considered in the FEM models.

REFERENCES

[1] S. M. Metev and V. P. Veiko, *Laser Assisted Microtechnology*, 2nd ed., R. M. Osgood, Jr., Ed. Berlin, Germany: Springer-Verlag, 1998.

[2] J. Breckling, Ed., *The Analysis of Directional Time Series: Applications to Wind Speed and Direction*, ser. Lecture Notes in Statistics. Berlin, Germany: Springer, 1989, vol. 61.

[3] S. Zhang, C. Zhu, J. K. O. Sin, and P. K. T. Mok, "A novel ultrathin elevated channel low-temperature poly-Si TFT," *IEEE Electron Device Lett.*, vol. 20, pp. 569–571, Nov. 1999.

[4] S. R. Dutta, S. K. Singh, R. Ranjan , ''Analysis of angular contact ball bearings design'International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064 Impact Factor (2012): 3.358, Volume 3 Issue 8, August 2014.

[5] Hermann Golbach, 'Integrated nonlinear FE module for rolling bearing analysis',INA reprint "Proceedings of NAFEMS WORLD CONGRESS '99 on Effective Engineering Analysis", Volume 2, Newport, Rhode Island, USA, 25 –28 April, 1999.

BIOGRAPHIES

RAJANIKANTH obtained his Bachelor's Degree in Mechanical Engineering from Visvesvaraya Technological University. He is presently pursuing Masters Degree in Mechanical Machine Design in Visvesvaraya Technological University.