# Analysis of Transient Thermal Temperature Distribution Over Service Life of Taper Roller Bearing Using FEA

**Rajeev Kumar, Manpreet Singh, Jujhar Singh, and Siddique Khan**

**Abstract** Single row taper roller bearings are basically designed to withstand the radial load, axial load, and torque which results in generation of contact stresses. Generation of contact stresses will take place due to high speeds and heavy loads on bearing that can lead to failure of machine. Bearing life is limited by some of the common phenomena like wearing, smearing, flaking, etc. Bearing life can be enhanced by proper lubrication which separates roller with inner and outer rings. As prediction and validation of contact stresses experimentally is an arduous task, many researchers calculate theoretical method for approximate distribution of contact stresses on bearing race. Some of the methods are numerical method, finite element analysis (FEA) software, traditional method, and Hertz contact stress theory. In this paper, temperature behavior distribution in the bearing, contact stress, deformation of bearing rollers, and heat flux is analyzed by FEA tool. Inner race bearing surface and ball surface contact in bearings can cause an increase in temperature which may result in evaporation of lubricant due to improper heat dissipation and effect the service life of the bearing FEA results is compared with results obtained by Hertz theory to inspect the feasibility of bearing problem and its life. It is found that temperature distribution is 55 °C (maximum) at the inner ring, von Mises stress is 220.23 MPa, and heat flux is 0.61399 W/mm$^2$, whereas result obtained by Hertz theory is 195.2821 MPa. Compariosn of FEA and analytical result, the error is found to be 12.77% analysis of increase in temperature through FEA is a useful tool for estimating the service life of bearings.

**Keywords** Contact stresses · Heat flux · FEA

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# 1 Introduction

A bearing is a machine element to support another moving machine element which allows a relative motion between the contact surfaces during the operation and prevents wear and heat generation at the contact area or point which can be reduced by using the proper lubricant.

The rolling contact bearing is the most crucial component in any rotating machinery. They are supported load during rotary motion. According to surveys, bearing fault is one of the predominant causes for the failure of mechanical drives [1]. Therefore, detection and prognostic of the bearing are important. Taper roller bearings are designed to sustain the axial load and radial load. In this bearing, the rings and the rollers are at an angle (tapered) in the shape of cones to simultaneously support axial and radial loads. The taper roller bearing has the following component: inner ring, outer ring, and roller assembly. Lubrication is a process by which the friction and wear rate between the two moving components or elements can be reduced by using suitable lubricant which also helps in heat dissipation process [2]. Proper lubrication can prevent the corrosion and helps for long service life of bearing.

Desirable properties of lubricants used in the rolling element bearings are:

- Maintain a stable viscosity over a wide-ranging temperature.
- It should have high film strength, and it can support loads.
- The melting point of lubrication is high so that it protects two parts at a high temperature [3].
- It should be non-corrosive.
- It offers a layer against contaminant and moisture.

There are three types of lubrication liquid lubrication, semi-solid lubrication, and solid lubrication, and widely used two lubrications from the 1990s are oil and grease. As bearing contacts can get exploited after continues applications of loads on bearing which results in generation of highly localized pressures and stresses, it needs a good quality of lubrication to avoid contacts from stress concentration and results in improved service life of bearings [4]. Stress concentration can be caused by various reasons like surface roughness, particle denting, etc. and can lead to crack initiation [5] due to developed lubricant film at the dent or other related surfaces. Elasto-hydro-dynamic lubrication (EHL) film [6, 7] plays an important for improving service life of bearings because it is directly connected to lubrication factor which is further connected to micro-EHL pressures and stresses existing in an EHL contact produced by surface roughness and quality of lubrication. Wearing is occurred due to abrasive particles and vibration. It causes due to ineffective seals, improper lubricant, loose fit, and contamination by the foreign particle. Service life of bearing can be increased by using the proper amount of lubrication, maintaining workplace clean, and providing vibration absorb damping base. Smearing means when two deficiently lubricant surfaces slide against each other under load or by the contamination of debris between roller and rings, it causes roughening of surface which can be prevented by improving bearing clearance, sealing, and lubricant film

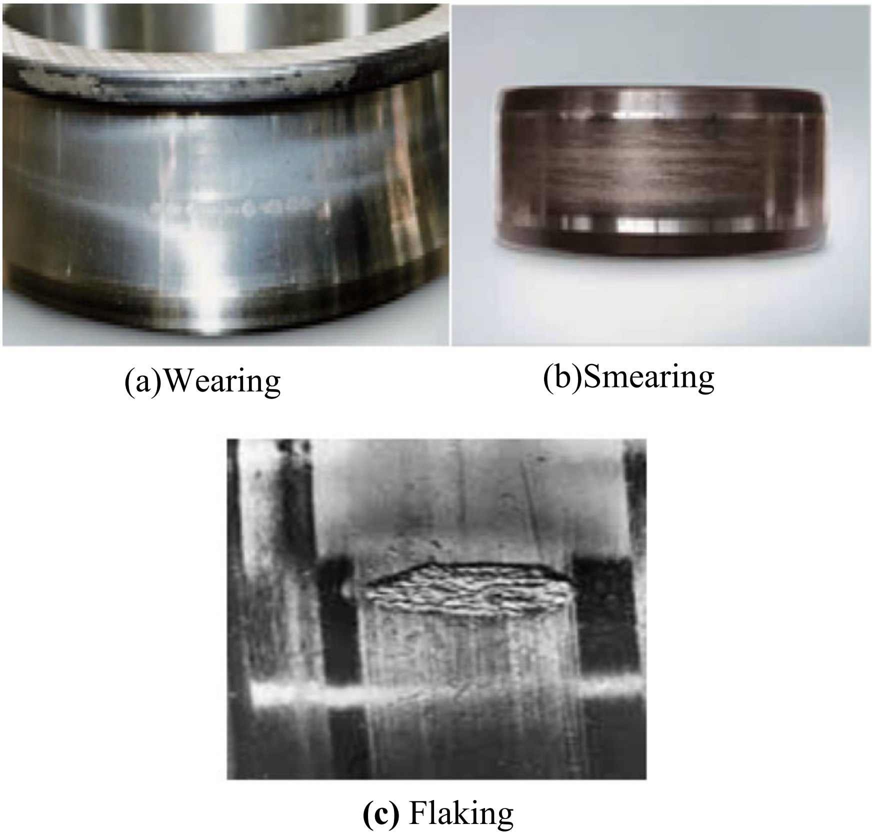


**Fig. 1** Typical photograph of (NBC: 30205 ) defects in bearing [8]

ability. Flaking occurred because of shear stress [3] below the load capacity of the surface. After sometimes, stresses developed cracks which expand gradually up to the end of the surface. Rollers and balls are passing over these cracks, and material removed gradually from the surface are called flaking. Causes of flaking are poor lubrication [7], excessive load, and misalignment in the shaft (Fig. 1).

## 2 Methodology

Research methodology is the organized, theoretic concept of the approaches applied to a field of the study. It involves concept like a theoretical model, phases, and qualitative and quantitative methods. As an alternative, it gives the theoretical concept for the understanding which method is to be used. The flowchart of research methodology is shown in Fig. 2.

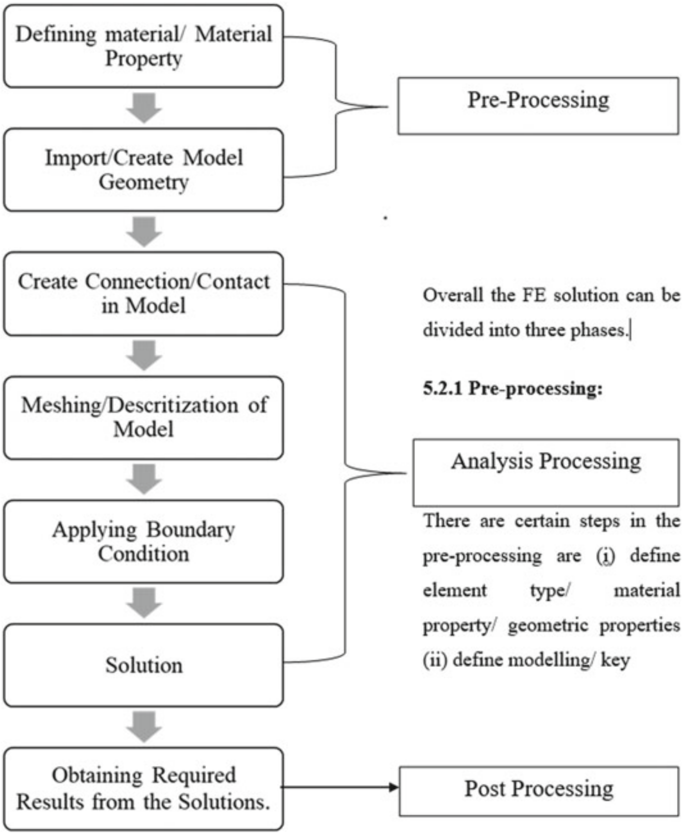


**Fig. 2** Methodology flowchart

## *2.1 Geometry Definition*

Geometry is the main part of any analysis. In geometry data, main focus is on the shape, size, and dimension. With a help of this data, we must create a 3D model. Existing dimensions of single row taper roller bearing 30205 are shown in Fig. 3.

## *2.2 Material Definition*

Bearing model is made from the chromium steel AISI 52100. Meshing is defined as the process of discretization of whole components into small parts or elements so that we can uniformly distribute the load or any other loads [9, 10]. Meshing is one of the most critical features of engineering field. ANSYS provides many options for

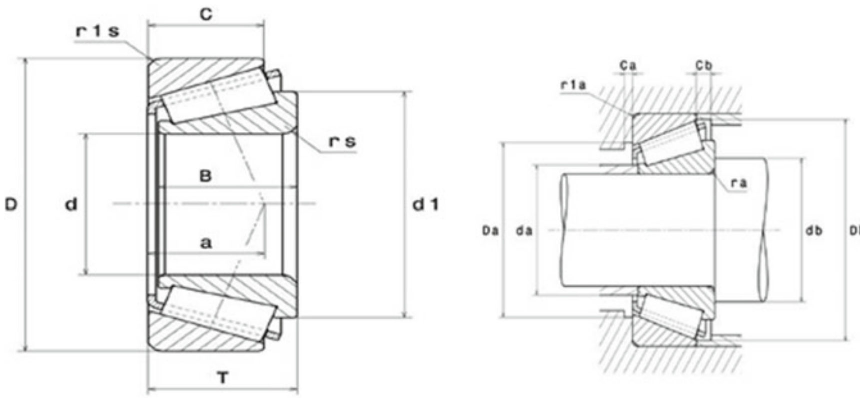


**Fig. 3** Dimensions of bearing 30205

mesh generation according to shape and requirements of accuracy. Meshed model of taper roller bearing is shown in Fig. 4 (Tables 1 and 2).

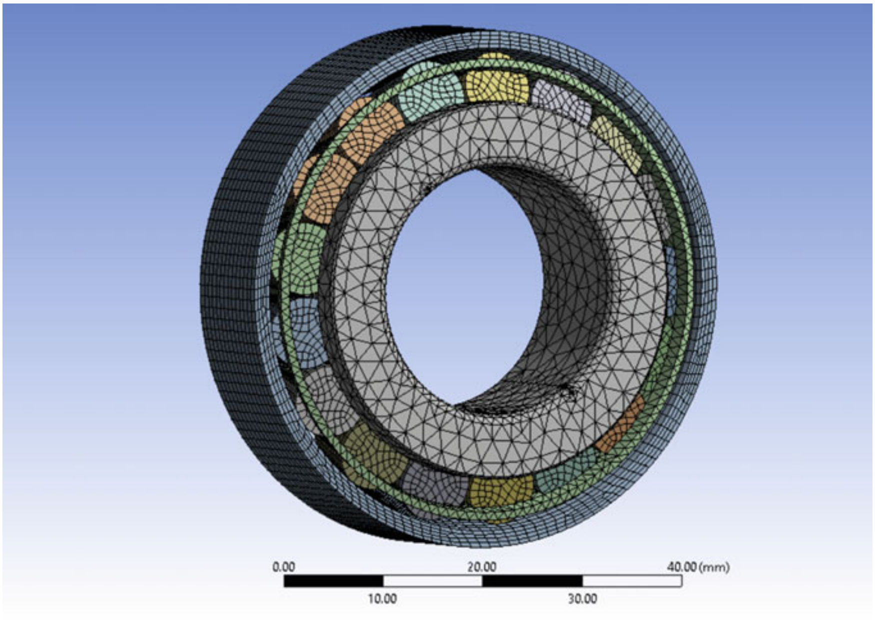


**Fig. 4** Meshed roller bearing

**Table 1** Chromium-steel physical properties of AISI 52100

| Physical Properties | Metric | Imperial |
|---|---|---|
| Density | 7.81 g/c | 0.282 lb/in$^3$ |
| Melting point | 1424 °C | 2595 °F |
| Modulus of elasticity | 210 GPa | 30,500 ksi |
| Bulk modulus | 160 GPa | 23,200 ksi |
| Poisson's ratio | 0.30 | 0.30 |
| Fracture toughness | 15.4–18.7 MPa m½ | 14.0–17.0 ksi m½½ |
| Shear modulus | 80 GPa | 11,600 ksi |

**Table 2** Chromium-steel thermal Properties of AISI 52100

| Thermal Properties | Metric | Imperial |
|---|---|---|
| Specific heat capacity | 0.475 J/g °C | 0.114 BTU/lb °F |
| Thermal conductivity | 46.6 W/m k | 323 BTU in/h ft$^2$ °F |
| CTE, Liner | 11.9 µm/m °C | 6.61 µin/in °F |

## 3 Result and Discussion

FEA solution includes the details of analysis setting; i.e., number of steps, initial time step, and maximum time steps are 20, 20, and 72000 s. After the analysis, results can be interpreted in many ways, results in temperature distribution, total heat flux, thermal error, and behavior for selected bearing material. From the Fig. 5, it can be

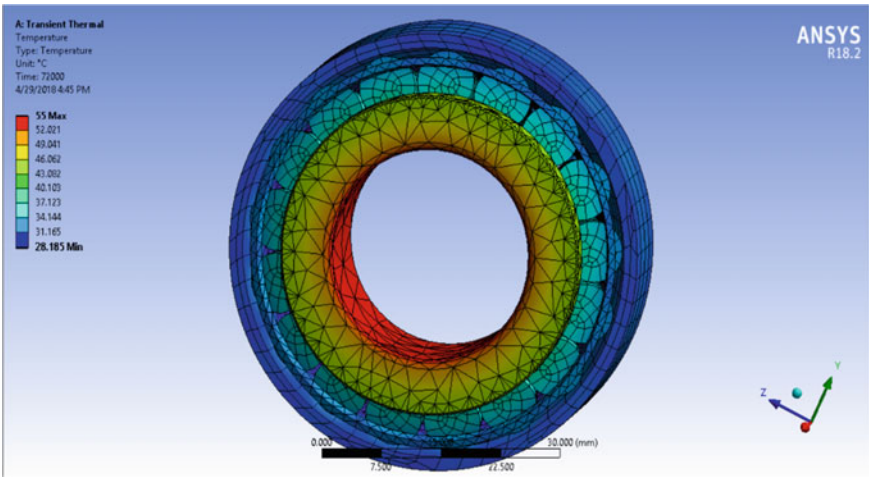


**Fig. 5** Temperature distribution in Bearing

seen that maximum temperature is developed in the inner ring or raceway and rollers. Maximum temperature is arising up to 55 °C at an ambient temperature condition which is 25 °C. Outer ring temperature is approximately 25–30 °C. Total heat flux in bearing is shown in Fig. 6. Here, for the contact stress, outer ring is fixed. The force or load is applied radially on the inner ring of bearing, i.e., 300 N. For rotational speed, rotational velocity 2050 RPM must be applied by using joint load condition.

Equivalent stress 220 MPa is produced on the bearing. The maximum total deformation is 0.8 mm. The changing temperature loads with respect to time is given in Table 3. After the analysis of bearing, the result obtained from FEA is presented in Table 4. Von Mises stress obtained by FEA is shown in Fig. 7. To show the temperature distribution on different parts of assembly like on inner ring, as bearing

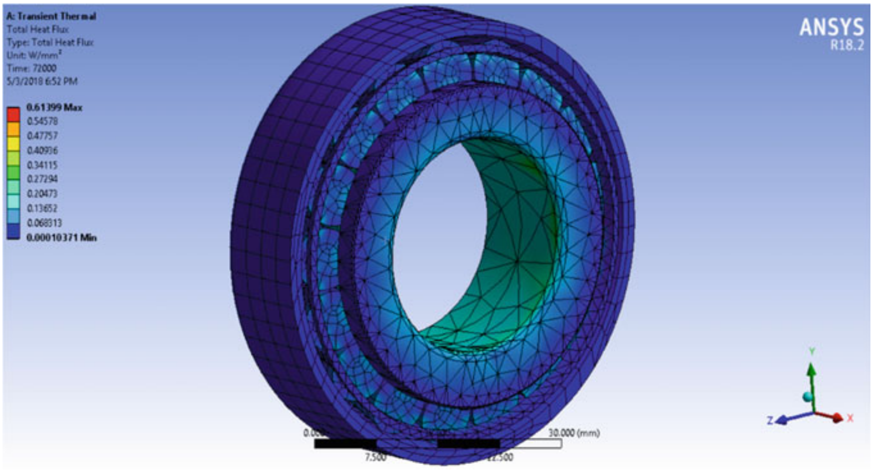


**Fig. 6** Total heat flux in bearings

**Table 3** Transient thermal temperature distribution results of taper roller bearing (NBC:30205) after 20 h

| S. No. | Time (s) | Temperature (°C) |
|---|---|---|
| 1 | 1 | 25 |
| 2 | 7200 | 32 |
| 3 | 14,400 | 35 |
| 4 | 21,600 | 37.5 |
| 5 | 28,800 | 40 |
| 6 | 36,000 | 42 |
| 7 | 43,200 | 45 |
| 8 | 50,400 | 47.502 |
| 9 | 57,600 | 50.001 |
| 10 | 64,800 | 52.501 |
| 11 | 72,000 | 55 |

**Table 4** Results of transient thermal analysis of the taper roller bearing (NBC:30205)

| S. No. | Parameter | Value |
|---|---|---|
| 1 | Total temperature of bearing (°C) | 55 |
| 2 | Temperature of rollers(°C) | 48.918 |
| 3 | Temperature of cone(°C) | 33.839 |
| 4 | Total heat flux (W/mm$^2$) | 0.614 |

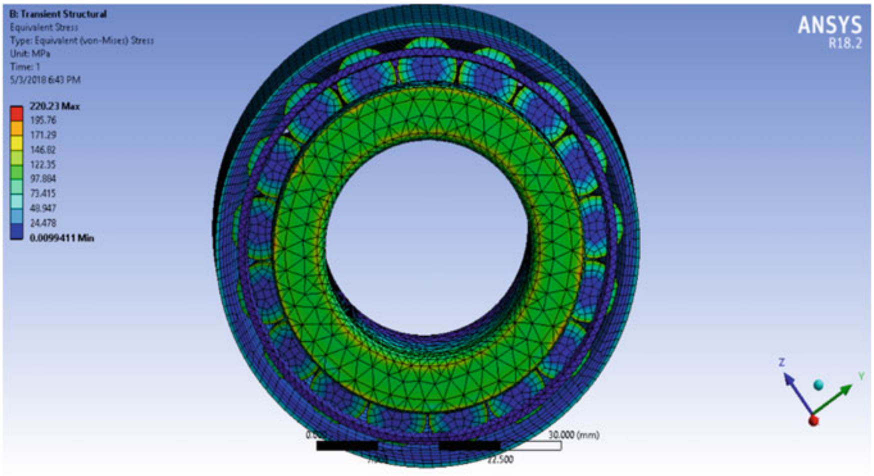


**Fig. 7** Equivalent (Von Mises) stress

service life is an important parameter to consider, the bearing is tested under working conditions approximately for 20 h to determine the rate of temperature change and maximum temperature. This data can be used for improving heat flux or reducing contact stress by applying proper lubrication.

Finally, the equivalent stress and total deformation of bearing using FEA are calculated and demonstrates in Table 5, The effects of transient coupled field analysis report of the taper roller bearing the stress found from the transient thermal and structure are beneath of ultimate stress and yield stress (Figs. 8 and 9).

Stresses are induced when a load is applied to two solid bodies. Hertz developed one theory for calculating the contact stresses between two surfaces and resulting in the stress and compression developed in the body [11, 12]. This theory was derived for the non-conforming surface, and mating parts have a point or line contact. This

**Table 5** Results of transient coupled field analysis of taper roller bearing (NBC:30205)

| S. No. | Types of Stress | Value Obtained |
|---|---|---|
| 1 | Equivalent stress (MPa) | 220.23 |
| 2 | Total deformation (mm) | 0.8 |

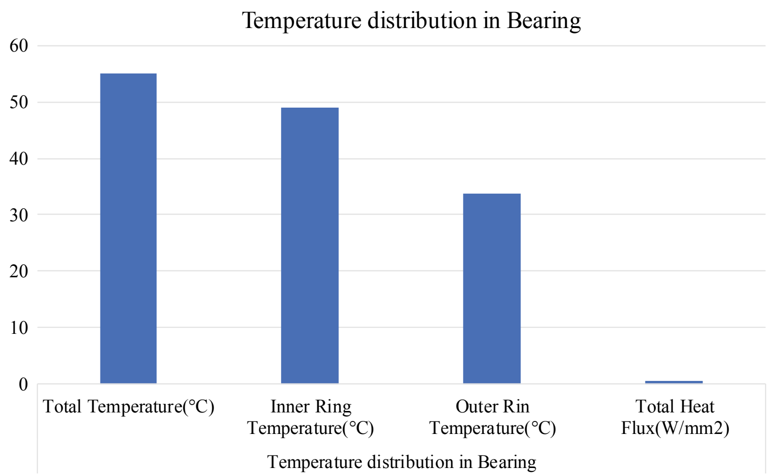


**Fig. 8** Transient thermal temperature distribution of Taper roller bearing (NBC:30205)

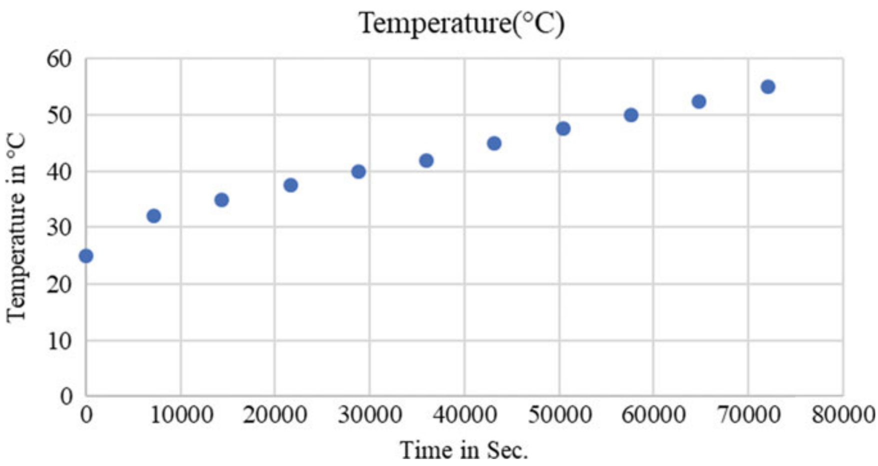


**Fig. 9** Transient thermal temperature distribution results of Taper roller bearing (NBC:30205) after 20 h

mechanics is only applied when the two bodies are in contact with each other; otherwise, this phenomenon has not been applicable. Tapered roller bearings are used as mechanical apparatus in most self-moving machines, and they withstand on the time-varying loads. It is defined the influence of the preload for taper roller bearing to avoid a different type of failure like pitting and fatigue failure. The aim is to get the homogeneous flow of contact pressure on the inside and outside of the bearing. The researchers focused on the Hertzian contact pressure of pure geometries [13–17]. The contact stress is very important to evaluate because there is a different type of

**Table 6** Input data of taper roller bearing (NBC:30205) for calculation

| | |
|---|---|
| Inner ring diameter $d_1$(mm) | 25 |
| Outer ring diameter $d_2$ (mm) | 7.22 |
| Force F (N) | 300 |
| Length of roller L (mm) | 10 |
| Poisson's ratio ($\nu$) | 0.30 |
| Modulus of elasticity (MPa) | 203,300 |

failure occur when there are contact friction between two bodies. The main cause of contact stress is a failure due to pitting, cracks, and flaking on the material surface.

Assumptions for Hertzian contact problems are:

- The strains are small as well as within the elastic limit
- Non-conforming and continuous surfaces
- The object surfaces are in frictionless contact.

Data for the calculation of contact Hertz stress is given in Table 6.

### 3.1 *Calculation of Hertz Contact Stress [18, 19]*

For calculation of Hertz contact stress, first we have to find the contact width ($B$),

$$\text{Contact width } B = \sqrt{\frac{2F}{\pi} \times \frac{d_1 \times d_2}{d_1 + d_2} \times \left(\frac{1 - v^2}{E_1} \times \frac{1 - v^2}{E_2}\right)}$$

$$B = 0.0978686\,\text{mm}$$

Later, after finding contact width, Hertz contact stress can be determined,

$$\text{Contact Hertz stress } P = \frac{2F}{\pi BL}$$

$$P = 195.2821\,\text{MPa}$$

So, finally the contact stress using hertz theory is found out to be 195.2821 MPa.

## 4 Conclusion

Accurate bearing service life prediction is one of the most critical effective condition-based maintenance for reducing overall maintenance cost and improving reliability. In this work, an effort is made to characterize and classify taper roller bearing temperature of different classes depending on their vibration features. In this paper, FEA

**Table 7** Taper roller baring (NBC:30205) Comparison of both results

| Load (N) | Theoretical value of contact Stress (MPa) | FEA Results of contact stress (MPa) | Percentage error (%) | Total deformation (mm) |
|---|---|---|---|---|
| 300 | 195.2825388 | 220.23 | 12.77 | 0.8 |

is used to detect the bearing defect because even one percent of bearing defect may lead to sudden failure of machine. The main motive behind the present work is to assess the temperature distribution or behavior in the bearing and to find the failure rate due to overheating and stresses. In bearings, there is continuous contact of metals which causes inside temperature to exceed their limit and results in bearing failure. If there is no proper system for heat dissipation, failure will take place due to evaporation of lubricant because of excessive increment in temperature due to friction, and it also degrades the material. An FEA method is proposed for achieving more accurate thermal distribution over different elements of the bearing to estimate the service life. Condition monitoring is proposed as a best new feature to improve the results. For the validation purpose, the condition monitoring data collected from bearings are used. From the experiment, it was concluded that the proposed method can produce satisfactory estimated life prediction results.

Transient thermal analysis results are obtained from a taper roller bearing; the temperature varying (25–55 °C) range is obtained with respect to 20 h, whereas maximum temperature of rollers is 49 °C. FEA results are compared with theoretical values and found to be approximately same as shown in Table 7; besides, the maximum value of stress, temperature, total heat flux, and displacement are well within safe limits.

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