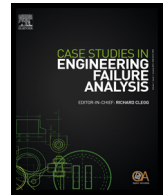




Contents lists available at SciVerse ScienceDirect

# Case Studies in Engineering Failure Analysis

journal homepage: [www.elsevier.com/locate/csefa](http://www.elsevier.com/locate/csefa)

## Case study

# Failure investigation of a taper roller bearing: A case study



K. Gurumoorthy, Arindam Ghosh\*

R&amp;D, National Engineering Industries Limited, Jaipur, Rajasthan, India

## ARTICLE INFO

### Article history:

Received 30 April 2013

Received in revised form 1 May 2013

Accepted 4 May 2013

Available online 20 May 2013

### Keywords:

Tapered roller bearing

Misalignment

Premature failure

## 1. Introduction

Bearing life refers to the total number of revolutions (or time period) a bearing performs satisfactorily under stated conditions before failure. In general, based on the operating conditions the scope of the bearing life is defined. In case of heavy machinery, small flaking or spalling on the bearing may not be considered as an immediate failure and its life can be prolonged with proper maintenance. On the other hand it may be a limiting factor where the application demands high precision control and sensitive even to very slight dimensional variation, noise or vibration.

More commonly, the life of a bearing is specified by  $L_{10}$  (or  $B_{10}$ ) life which is defined as the total number of revolutions in which 90% of identical bearings will survive under the same operating and environmental conditions before failure by fatigue. The operating load and speed are the prime factors in estimating the  $L_{10}$  life which is given by,

$$L_{na} = a_1 \cdot a_2 \cdot a_3 \cdot \left(\frac{C}{P}\right)^p$$

where  $L_{na}$  is the rated life in millions of revolution ( $10^6$ );  $a_1$  is the reliability adjustment factor;  $a_2$  is the material adjustment factor;  $a_3$  is the operating condition adjustment factor;  $C$  is the basic dynamic load rating in Newton;  $P$  is the equivalent dynamic load in Newton;  $p$  is 3 for ball bearings and  $10/3$  for roller bearing.

With the proper selection of bearing for a given application, the bearing fails predominantly by fatigue and can be estimated by the above equation [1,2]. There are several other parameters like improper selection of bearing for a given application, inadequate lubrication, improper installation, excessive loading/preloading, vibrations, impact loading,

\* Corresponding author. Tel.: +91 8003355551.

E-mail addresses: [arindam.ghosh@nbcbearings.in](mailto:arindam.ghosh@nbcbearings.in), [ghosh.arindam@gmail.com](mailto:ghosh.arindam@gmail.com) (A. Ghosh).

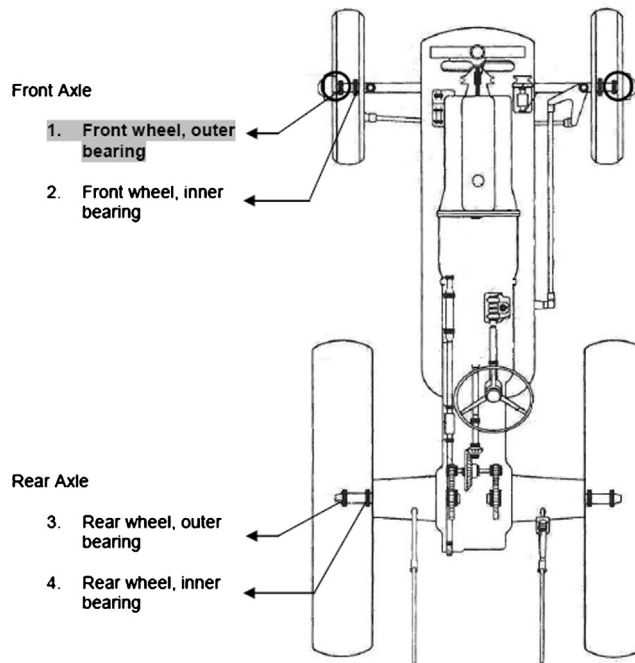


Fig. 1. A skeletal arrangement of tractor; investigated front wheel outer bearing is highlighted in circles (component number 1).

environmental factors like corrosive media, temperature, contaminated environment that can cause a bearing to fail before its predicted life time and are classified as premature failures. The failure modes of a bearing, besides fatigue, include plastic flow, fracture, wear, corrosion and electrical pitting. By gathering data on application of the bearing and operating conditions during running and at the time of failure, damage analysis can be made by studying the mode of failure and its most probable root cause for the premature failure can be established. If more than one parameter is involved in premature failure, it will increase the complexity of identifying the root cause [3–5].

In the present study, damage analysis made on the prematurely failed front wheel outer tapered roller bearing is discussed. A schematic view of tractor is shown in Fig. 1 and the location of front wheel outer bearing is highlighted in circles (in Fig. 1).

## 2. Experimental details

A detailed study on the failed bearing was made including visual examination, chemical composition, micro hardness, microstructure, retained austenite measurement, wear debris analysis and scanning electron microscope (SEM) studies. Visual examination was carried out using a stereo zoom microscope. The chemical composition of the failed components was carried out using spark emission spectrometry. Bakelite mounted and polished cut sections were used for metallographic observation and microhardness measurements. The microstructure was studied after etching with 3% Nital. Retained austenite content was measured using X-ray diffraction (XRD) technique, on the roller surface and cone raceway. The damaged cage was carefully cleaned using petroleum benzene and the wear debris collected after filtration of the solvent for particle size analysis using an image analyser.

## 3. Results

### 3.1. Material

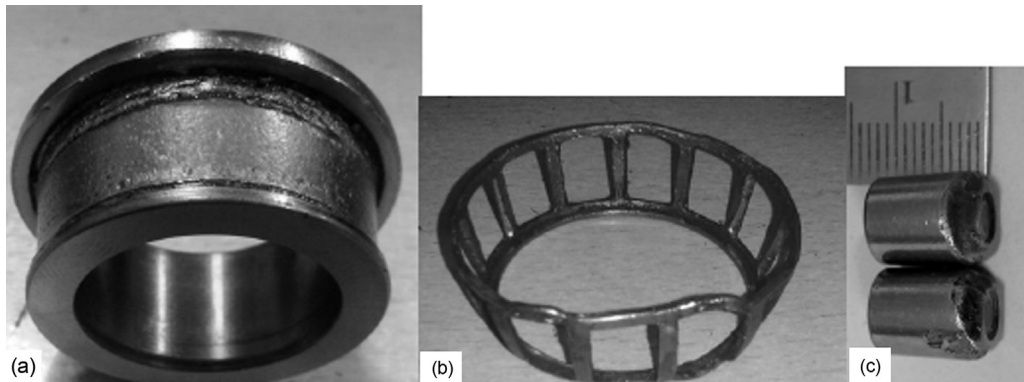
Material composition was evaluated by spark emission spectrometer and the chemical composition (in weight percentage) is shown in Table 1.

### 3.2. Macroscopic analysis

The cone, rollers and cage in as received condition are shown in Fig. 2. Under low magnification using a stereo zoom microscope, one end of the rollers was found to be severely damaged than the other. This feature was seen in all the rollers. In the cone, deep grooves were noticed along with pit marks on the race way; a crack was also observed on the inner surface of

**Table 1**  
Chemical composition of the bearing parts.

Component	C	Mn	Si	S	P	Cr	Ni	V	Al
Cone	0.97	0.35	0.27	0.003	0.013	1.46	0.01	0.002	0.03
Roller	0.98	0.31	0.23	0.005	0.014	1.42	0.02	0.002	0.02



**Fig. 2.** Premature failed bearing in as-received condition: (a) deep groove on the raceway of the cone; (b) distorted cage; (c) severely damaged tip at one side of the rollers.

the cone aligned with the deep groove as shown in Fig. 3(a). SEM observation made on the cut section of the cone shows the deep groove and the crack originating from the groove and propagating towards the bore surface as shown in Fig. 3(b).

### 3.3. Microstructural analysis

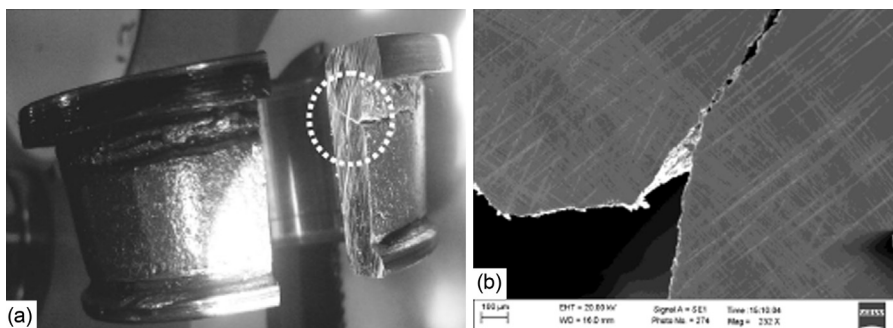
Longitudinal cut sections of a roller and cone showed fine tempered martensite with uniform distribution of carbides free from carbide network or any detrimental feature. The origin of crack was also free from decarburization indicating that the heat treatment conditions were normal. Microstructure observed on roller specimen is shown in Fig. 4(a). Near the damaged side of the roller, cracks were observed propagating towards the centre of the roller as shown in Fig. 4(b) and (c).

### 3.4. Hardness analysis

Hardness profiles taken along the cut section revealed that near the surface of roller and raceway surface of the cone, the hardness values were in the range of 64–65 HRC and in the core it were in the range of 61–63 HRC.

### 3.5. Retained austenite measurements

Retained austenite measurements were carried out on roller surface, raceway of the cone using XRD. RA was about 1.7% on raceway and 1.6% on roller surface



**Fig. 3.** Images taken on the cut section of the cone: (a) optical photograph of the cone section where a crack was observed beneath the deep groove which was propagating towards the bore surface shown within the circle; (b) SEM image showing the origination of crack from the deep groove.

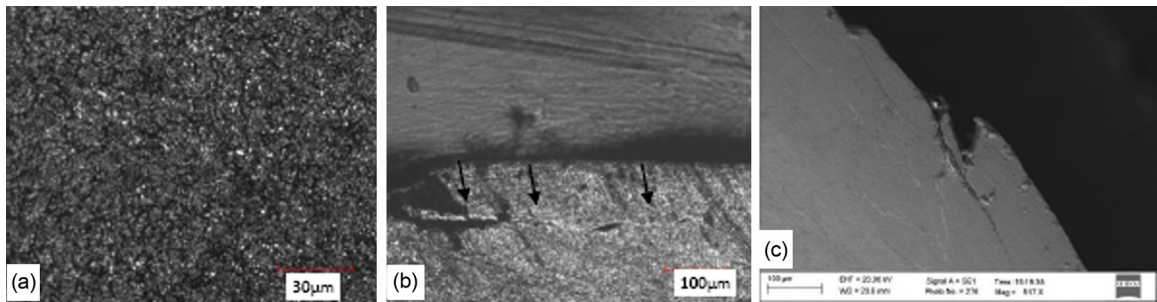


Fig. 4. (a) Tempered martensitic structure with uniformly distributed carbides was observed on the roller cut section. (b) Crack initiated at the tip of the roller was shown in arrows (optical micrograph). (c) SEM micrograph of damaged roller tip showing crack initiation from the tip.

### 3.6. Wear debris analysis

The metallic wear debris particles were recovered from the tiny patches of grease sticking at the cage surface. Very fine shiny metallic wear debris particles were filtered in the filter paper. Using image analyzer, the wear debris collected in the filter paper was analysed. The metallic wear debris particles were in the size range of 50  $\mu\text{m}$  to 1600  $\mu\text{m}$  and non-metallic particles were also observed in the same size range.

## 4. Discussion

The chemical composition of the bearing was in conformity with SAE 52100 material specification. The deep groove on the cone raceway and severe damage on one side of the rollers showed that there was uneven distribution of load with the roller tip experiencing higher stress during operation.

In general, load will be evenly distributed over the length of the roller and necessary crowning will be provided to accommodate any possible slight misalignment during assembly. Rahnejat and Gohar [6], studied the effect of misalignment and radial contact pressure distribution on tapered roller bearing and suggested that tapered roller bearing can be operated with misalignment, only to certain extent, by making appropriate design of ribs and axial profiling by providing crowning on the taper roller over its length. Sudden failure of roller bearing due to misalignment as result of shaft deflection above a critical point was reported in literature [5]. Andreason [7], studied the load distribution on tapered roller bearing and stated that bearing life can be reduced due to improper load distribution on the roller as a result of misalignment and this effect will be more pronounced if the rollers and raceways were not axially profiled (Non-crowned).

Due to either mounting error or when the vehicle happened to be under heavier than designed load, there is a possibility that the wheel end component would have undergone deflection; this in turn can result in bearing misalignment leading to uneven loading on the rollers as a consequence. The extent of uneven load distribution on the rollers will depend on the degree of misalignment. This uneven load distribution raises the contact stress towards the edges of the rollers abruptly.

This abnormal stress level at the tip of the roller can lead to boundary lubrication situation and direct metal to metal contact between the roller and the cone surface generating wear debris. The damage initiates at the tip of the roller, as the stress concentration is higher at the roller tip due to its size being smaller than the cone diameter. The above proposed mechanism is illustrated in Fig. 5.

This is apparent in the damaged roller samples where one end of the roller alone shows severe damage with the other end having only deep scratches. This phenomenon was observed in all the rollers. The scratches may be due to the abrading action of the wear debris (worn parts of the roller and cone surface). The wear debris analysis had confirmed the presence of

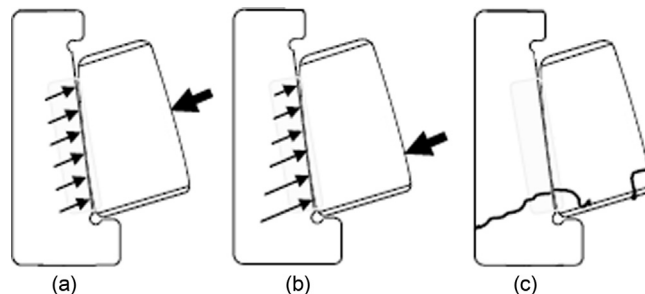


Fig. 5. Schematic illustration of load distribution: (a) evenly distributed load without any misalignment; (b) uneven distribution of load as a result of misalignment; (c) as a consequence of uneven load distribution, stress level at the roller tips increases causing severe damage near the tip of the roller.



Fig. 6. As illustrated in the schematic diagram (Fig. 5), damage at roller tip and deep groove on the cone were observed on the premature failed bearing.

metallic wear particles along with non-metallic particles. The presence of non-metallic particles indicates dirt/dust entrapment during service. Furthermore, the metal debris created due to adhesive wear could have interfered with smooth rolling and causing even periodic sliding rather than rolling between the rollers and cone. The severe damage to the cage can also be accounted for by this sliding action.

The deep grooves caused by the uneven rubbing action of the roller tip along with the wear debris over the surface of the cone acted as points of weakness. Such deep grooves, acting as stress raisers, have been responsible for initiating the crack from which the fatigue failure had progressed. This was exactly observed in the present study. Had the bearing been run in this condition, the crack would have reached the back face of the cone, resulting in total collapse of the bearing by chipping of the flange portion.

From the RA measurements, it is noticed that the retained austenite values measured on the surface of the roller and on the raceway of the cone were reduced drastically from the standard value (from the initial range of 8–15% to 1.6–1.7%). This is possible due to decomposition of retained austenite in service. The retained austenite transforming to work induced martensite causes compressive residual stress at the crack tip that is helpful in delaying the propagation of crack. This is considered beneficial for rolling contact fatigue. The transformation of RA to martensite is responsible for the higher hardness of 64–65 HRC at and near surface regions than the core.

The above proposed mechanism is in concurrence with the failure observed in the samples as shown in Fig. 6. This misalignment may have been caused at the time of installation or during operation where the bearing would have experienced any excessive load.

## 5. Conclusion

The failure is not on account of any defect in material or heat treatment. This failure is predominantly due to the misalignment, which caused uneven load distribution on the roller. While the intentionally designed crowning of the rollers may accommodate very small misalignment, it cannot prevent damage when the misalignment is excessive. In the present case, the misalignment may have been excessive. This may be due to mounting error or very heavy vehicle load beyond the designed limit resulting in abnormal deflection of wheel end component. Consequently the cup and cone, unable to balance the misalignment, experienced severe stress concentration at the roller tip leading to premature failure of the bearing.

## Acknowledgements

The authors wish to express sincere thanks to Mr. N.K. Gupta of Metallurgy division and Mr. M.M. Jaikumar of Customer application engineering division for their support and inputs.

## References

- [1] Harris TA, Kotzalas MN. Essential concepts of bearing technology. USA: Taylor & Francis; 2007.
- [2] <http://www.nbcbearings.in/nbcpdf/TechnicalCatalogue2012.pdf>.
- [3] Scott D. Bearing failures and diagnosis and investigation. *Wear* 1973;25:199–213.
- [4] Scott D. Failure diagnosis and investigation. *Tribology* 1970;3(1):22–8.
- [5] Savaskan T, Veinot DE. On the wear and failure of high speed roller bearings. *Wear* 1987;116:361–80.
- [6] Rahnejat H, Gohar R. Design of profiled taper roller bearings. *Tribology International* 1979;12(6):269–75.
- [7] Andreason S. Load distribution in a taper roller bearing arrangement considering misalignment. *Tribology* 1973;6(3):84–92.