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A Review of Design and Fault Analysis of Roller Bearing

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***Abstract*: This article presents an overview of fundamentals of rolling element bearing designs and fault diagnosis of the roller bearings which includes feature extraction, feature selection, and classification. The main aim is to find out interrelation of bearing stress and life capability with the rolling contact fatigue and the attainable bearing life. The article shows the various types of rolling bearing stresses and the analysis of the stress distribution under rolling contact area. It also demonstrates the effect of bearing lubrication, coating and additives on the attainable life and wear. This review addresses the use of new discrete wavelet features for feature extraction comparison of the result with energy definition of discrete wavelet features using Haar wavelet. The research reveals that the new proposed feature performs better than that of existing energy definition features. This article provides a guideline on how to design and study failure of roller bearing for an industrial application.

Keywords: *Rolling Contact Fatigue; Endurance life; Fault diagnosis, Discrete Wavelet Transform*

I. INTRODUCTION

There is always a research going on to develop bearing to provide higher efficiency, negligible friction, and more reliable under any practical application. It is important for the manufacturer to make sure that the bearing performance will meet the application requirements at the lowest system life cycle cost for the user[1].

Continuous research and development efforts which involves the bearing designs and analysis, materials, heat treatment, and surface engineering technologies have a direct impact on the bearing performance and operating reliability[1].

This article gives an overview of some of the basic aspects of the design and development of rolling element bearings.

Rolling bearing failures can be caused by various factors. Defects are mostly produced by material fatigue after a certain running time which begins with minute cracks below the surface of the bearing elements. This cracks give rise to spalling and surface pitting. Statistically[2], inner and outer race fault is 90% of the total amount of different roller bearing fault. Hence present research is focused on inner or outer race fault or combination of both.

As roller bearings are widely used in industry, faults must be detected as early as possible. Fourier analysis is major signal analysis tool having limitations of the Fourier transform[3] that the signal to be analyzed must be periodic or stationary. But the rolling element vibration signals are mostly non-stationary processes with their frequency component changing with time. Hence we have to use time-frequency analysis methods which can determine the time of impact of occurrence and frequency ranges of the impact location. Hence wavelet transforms have been widely used for roller bearing fault detection.

For roller bearing fault detection, the desired method should have good computing efficiency. But the computing of continuous wavelet transform (CWT) is not suitable for large size data analysis and on-line fault diagnosis.

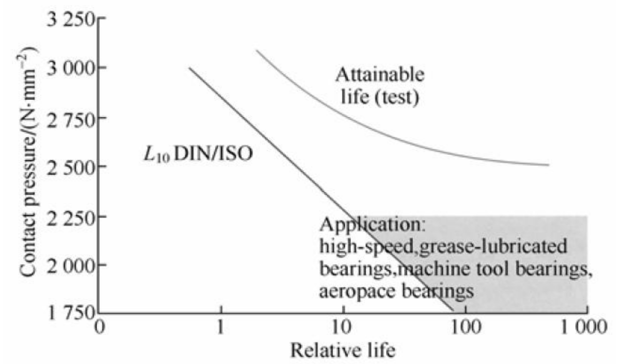
The discrete wavelet transform (DWT) can be used effectively to analyse the signal as long as the time dusration of the wavelet is large compared to the sampling period. This method reduces computation time and resources required. Hence, it is taken up for study.

J. Lin *et. Al* [4] used Morlet wavelet for decomposition and feature extraction from vibration signals from the rolling bearing and the gearbox[4]. Goumas *et al* [5]. used discrete wavelet transform to analyse the transient signals of the vibration velocity in washing machines and fault features were extracted from the wavelet coefficient[5]. The Morlet wavelet has better fault diagnosis capability[6]-[8].

II. BEARING LIFE AND ENDURANCE LIMIT

A. Rolling Bearing Endurance Strength

Fig. 1 displays the correlation which FAG discovered and introduced in 1981 which shows the actual correlation between the life and the specific bearing stressing. It has demonstrated that endurance life can be achieved by rolling bearings.



*L*₁₀ DIN/ISO - Rated life with 10% failure probability

Fig. 1 Actual attainable life in comparison to DIN/ISO life calculation (unfactored)

Attainable life is determined by stress and material strength. A high degree of cleanliness and good surface separation by lubricant film reduces the stress. Machining processes and heat treatments increase the strength.

B. Real fatigue life behavior of rolling bearings

Fig. 2 displays different life reactions of rolling bearings to changes in contact pressure in comparion to the unfactored DIN/ISO life. With minor load changes, major changes in the bearing life may result in well-lubricated elements in rolling contact and under a high degree of cleanliness.

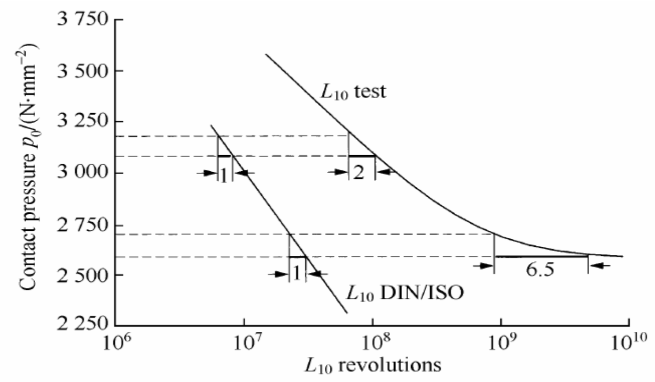


Fig.2 Contact pressure vs L_{10} revolutions

III. MATERIAL AND HEAT TREATMENT

Analysis of the stress condition is required for selecting the material. Technical, economical factors, and quality, reliability, availability, machinability are considered.

A. Types of rolling bearing stressing

There are four main types of streeses in rolling elemements (see Fig. 3)

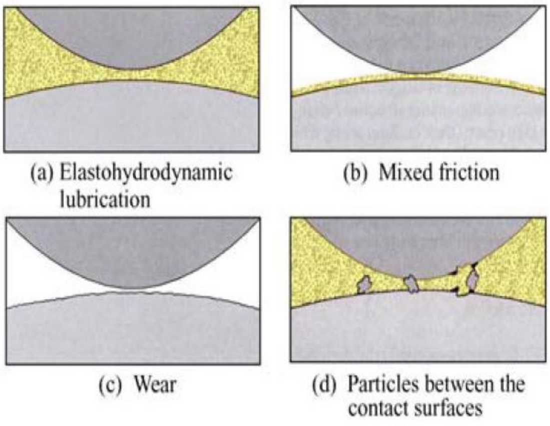


Fig. 3 Stressing types in a rolling bearing

- Electrohydrodynamic lubrication
- Mixed friction
- Wear
- Particles in contact area

Following factors are also considered for bearing design:

- Thermal stressing
- Chemical stressing
- Mechanical stressing from extreme operating conditions.

B. Optimizing material properties by heat treatment

1. Strength and toughness properties:

Martensitic heat treatment allows to achieve a wide range of material properties. Same hardness values can be achieved by different combinations of the austenitizing and tempering temperatures.

Hardness is not sufficient to maximize the fatigue capability of roller bearing. Elasticity or microstrain yield limit for varying austenitizing and tempering temperatures[9]. The result provides a guideline between often contradictory requirements relative to the material conditions, to achieve optimized solution for a bearing application.

2. Effect of residual stresses on component strength and life capability:

The residual stress condition has a positive effect on life capability (see fig. 4-5)

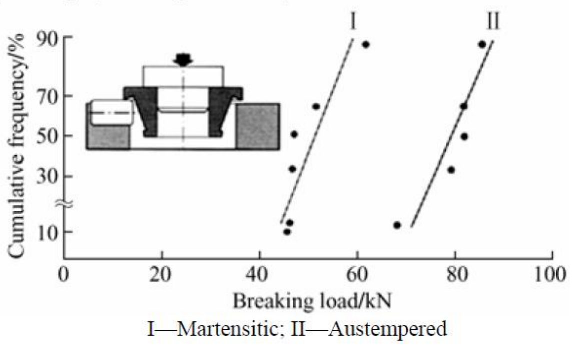


Fig. 4 Static lip fracture with a tapered roller bearing inner ring.

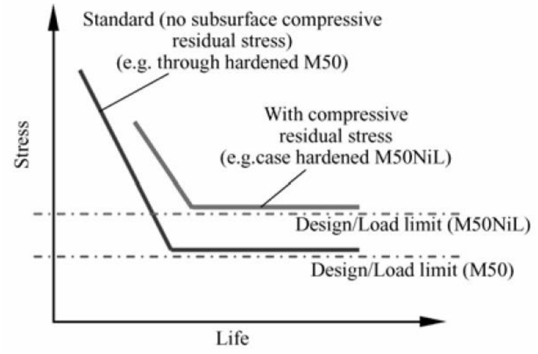


Fig. 5 Effects of compressive residual stresses on bearing life

3. Dimensional stability of rolling bearings:

Dimensional instability is caused by the retained austenite and martensite in roller bearing steel. Because of time-temperature effect, a reduction of retained austenite causes an icrease in volume whereas carbite precipitation in the martensite leads to a decrease in volume. Result is a total dimensional change of a component (see Fig. 6)[10].

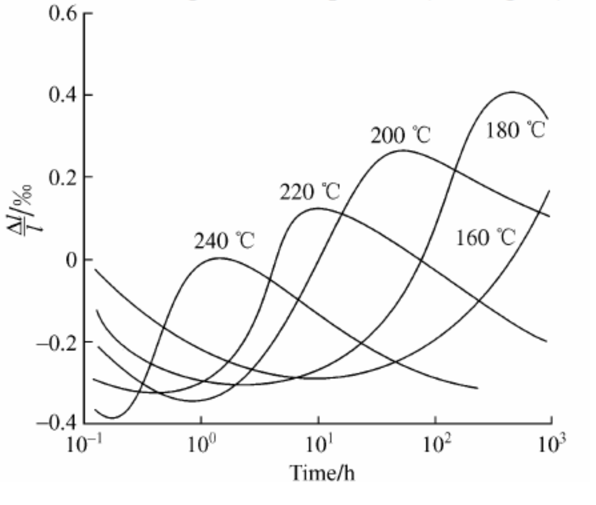


Fig. 6 Dimensional changes depending on time and temperature

IV. EXPERIMENTAL SETUP

The fault stimulator setup is shown in fig. 7. It detects faults in bearing and studies misalignments and eccentricity.

A variable speed DC motor with 0.5hp having speed up to 3000 rpm is the drive. A shaft of 30 mm diameter is attached to the shaft of motor . Shaft is supported by two taper roller bearings at its end out of which the bearing closer to the motor is a good bearing and the bearing at the farther end is the bearing under test.

A piezoelectric accelerometer (Dytron) is mounted on the flat surface. Voltage output of accelerometers is proportional to acceleration.

The accelerometers is connected to the signal conditioning unit (DACTRON FFT analyzer) where the signal goes through the charge amplifier and an Analogue-to Digital converter (ADC). The vibration signal (digital form) is input to the computer. It is stored in the computer's secondary memory. The signal is read from the memory and processed to extract different features.

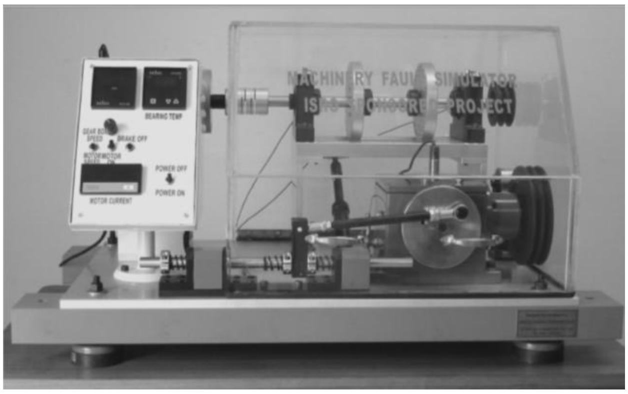


Fig. 7: Bearing Test Rig

V. EXPERIMENTAL PROCEDURE

For experiment, four SKF30206 roller bearings were used. One was new bearing and was taken to be free of defects. In the remaining roller bearings, defects were created. To get precisely defined defect, Electron Discharge Machining (EDM) was used. The inner race defect is 0.525mm wide and 0.827 mm deep and that of outer race is 0.652 mm wide and 0.981 mm deep. The sizes of the defects are little bit more than that in any practical situations.

The vibration signal from the piezoelectric pickup was taken, after allowing for initial running of the bearing. Sampling frequency was 12000 Hz and sample length was 8192 for all speeds and conditions. The sample length is chosen enough to ensure data consistency. Statistical measures are more meaningful, when the number of samples is enough large. But as the number of samples increases the computation time increases. Sample length of around 10000 was chosen to balance this. In wavelet based feature extraction, the number of samples is 2^n. The nearest 2^n to 10000 is 8192. Hence, it was taken as sample length. Trials were taken at the set speed (700 rpm) and vibration signal was stored in the data file.

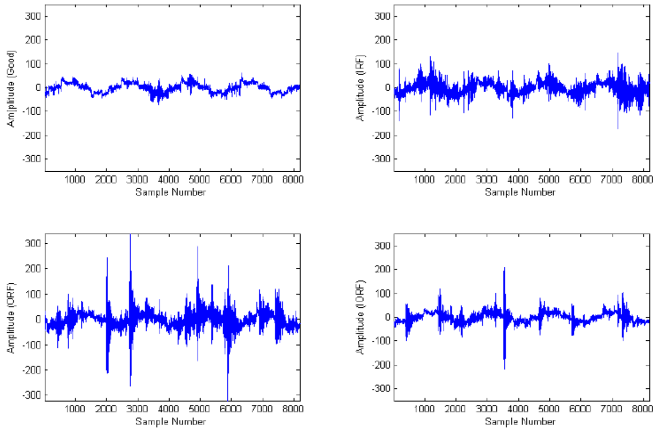


Fig. 8 Time domain plot of signals

CONCLUSION

Rolling element bearings can achieve endurance life if bearing stressing, lubrication and system cleanliness are taken into consideration.

Generally operation of rolling bearings in die mixed friction range cannot be prevented . In order to eliminate life reducing effects, the lubricant plays a major role.

With an appropriate adjustment of the bearing, lubricant, operating and environmental conditions including the bearing temperature, a long bearing life can be achieved reliably.

Rolling bearing are reliable under most diverse operating conditions in many applications. With the wide range of materials and heat treatment processes, operating temperatures between -200 ºC to 600 ºC can be accommodated.

A comparative study of bearing faults and their classification involving a new wavelet feature set and an existing wavelet energy feature set has been carried out leading to some conclusions regarding classification and fault identification.

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