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IMPLEMENTATION OF FREQUENCY RESPONSE FUNCTION ON TAPPER BEARING MAINTENANCE

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Abstract -- *Bearing acts as a pad that supports a shaft to rotate without excessive friction, hold the radial load and maintain the motion towards the left and right shafts (Thrust Load) when turning together. Due to frequent taper bearing damage to the wheels, predictive maintenance is therefore necessary. One of the predictive maintenance methods widely used today is vibration analysis. The principles of vibration-based bearing damage detection using the Frequency Response Function (FRF) method will be shown in this paper. Harmonics signal is given to the bearing surface in a vertical or perpendicular direction to the taper bearing surface. The vibration response measurement was carried out on three axes (x, y, and z). The results of this study indicated the ability of FRFs to predict any damage on the bearing taper.*

Keywords: Predictive maintenance; Vibration analysis; Frequency Response Function; Taper bearing

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INTRODUCTION

In motorized vehicles, bearings are necessary to support a shaft to rotate without experiencing excessive friction. Bearing widely used in motorized vehicles, especially four-wheeled vehicles, is bearing taper. It is usually placed at the end of the shaft that rotates together so that it can hold the radial load and hold motion towards the left and right shafts (Thrust Load) (Zoupas et al., 2019). Based on its structure, taper bearing has an inner ring mounted together with the roller while the outer ring is separated. This tool is widely used in vehicles, rolling mills, mining, metallurgy, plastic machinery, and other industries. The profile of the raceway crowned from the base design bearing and logarithmic raceway profile optimizes load distribution along the contact surface, reduces voltage peaks at the roller ends, and reduces sensitivity to shaft misalignment and deflection compared to conventional vertical raceway profiles. This process will cause the taper bearings to break faster.

On buses, taper bearing often damages the wheels. Therefore, predictive maintenance needs to be conducted. Predictive maintenance is a part of engine maintenance which monitors the condition of the engine when periodically operating, identifying components that have problems with the engine and performing maintenance planning. The next step, if necessary, is turning off the engine and replacing the damaged or unworked component (Dolenc et al., 2016). A predictive maintenance method that is widely used today is vibration analysis. It is used to monitor, predict, and analyze the conditions of the engine, including components and systems in certain parts to identify any problem occurring in a well-designed taper bearing which generates lower vibration.

However, after the long usage period, it will enlarge the vibration, which will affect the taper bearing condition. The vibration signal generated will have a specific frequency spectrum and vibration characteristics. The vibration effect that appears on the taper bearing is tremendous, which in turn will shorten the operating life of the taper bearing.

Li (2017) conducted a study on tapered roller bearings that detected any damages occurring in the raceway cone. The response of bearing vibration was analyzed in three directions. This research was conducted as preventive maintenance on taper bearings using vibration methods by measuring the Frequency Response Function (FRF) with the excitation force method given through the harmonic method. The FRF is the basis of measurement to find out the dynamic characteristics that exist in a mechanical structure. Experimental capital parameters (frequency, attenuation, and shape mode) can be obtained by measuring the FRF (Bilošová, 2011). Several studies on FRF methods have been carried out. Golafshan et al. (2018) used FRF to monitor the condition of roller bearings based on vibration analysis. The FRF method was also used to determine the comfort level of passengers to reduce vibrations originated in the bus frame (Dahil et al., 2016). The performance of a vehicle attenuation measured by the FRF method obtained from the excitation force given was then compared to the vibration obtained from the speed level with measurements at the same point carried out by Saha (2017).

In addition to vehicles, the FRF method has also been used to detect damage to a structure (Homaei et al., 2015). Kumar et al. (2011) compared the characteristics of two-cylinder blocks engine and bearing. The FRF characteristic of a system is the basis for determining the sensitivity of the system and any design changes that can change the FRF characteristics. The FRF method can be used to identify non-linear signals, Identification of nonlinearity using FRF method, which was then analyzed using wavelet packet decomposition was carried out by Subekti et al. (2018).

Testing was done on the taper bearing with bearing number 32310U, as shown in Fig. 1.

Figure. 1. Taper bearing with bearing number 32310U

This current study aims to investigate the application of FRF on tapper bearing maintenance.

MATERIAL AND METHOD

Vibration analysis, which is one of several methods generally applied in predictive maintenance, is used to monitor and analyze the critical conditions of machines, components, and systems in certain parts related to vibrations caused by these objects. The main advantage of vibration analysis is that it identifies problems early before they become more severe and cause unscheduled repairs. The benefit can be achieved by regular monitoring at scheduled time intervals. Assessment of the failure of an engine component can be read through the time domain vibrational data or frequency domain. FRF is a comparison between vibration response signals received by a mechanical structure due to the vibration excitation force of a system in the frequency domain. Both vibration response and excitation signals are measured simultaneously using a vibration sensor and bump test as an excitation force. Through Fourier transforms, the data obtained from the measurement and transformation is in the frequency domain (Broch, 1984). Some studies testing FRF have been carried out by several researchers, including Subekti (2018). He examined the dynamic characteristics of cylindrical piston motors, where a global vibration mode frequency is obtained. Masahiro (2015) compared the FRF method with multibody dynamic, showing the same tendency in their bolt stiffness, either on the amplitude or phase that occurs in the steering system. Delprete et al. (2010), who performed the frequency response function test in the powertrain on a cylinder engine using two excitation style methods: Impact Hammer and Exciter. The exciter is more suitable because of its ability to identify several modes with a smaller size allowing structural patterns to form as a deformation capital on a single-cylinder engine component. Then, Efendi et al. (2019) applied the dynamic characteristics for disc brake by using a bump test, which found global and local frequencies.

The identification of damage that occurs in the taper bearing is made by measuring the FRF. The excitation style is given to the taper bearing in the form of a harmonic signal originating from a cellphone which is then measured using a vibration analyzer. Signal harmonics are given to the bearing surface in a vertical or perpendicular direction to the taper bearing surface. The vibration response measured is carried out on three axes, as shown in Fig. 2, those are the direction of the axis x, y, and z, respectively.

(a) (b) (c)

Figure 2. Photo of measurement FRF

In the analysis of FRF in this study, a frequency range of 1 - 1200 Hz was applied. While a gallery set up of testing to obtain experimental data can be seen in Fig. 3. The vibration response read by the vibration analyzer was analyzed using MATLAB.

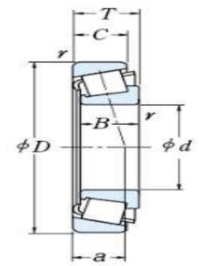
In Fig. 3, it can be seen the types of equipment used that is listed as follows:

- The accelerometer sensor serves to measure response vibrations
- Type: Piezoelectric accelerometer
- Conversion sensitivity ratio: pCs^2 m 5.0- 7.0
- Frequency range, Hz: 2 -10000 Hz
- Resonance frequency:> 28 kHz
- Transverse sensitivity: <5%
- Accelerometer cable: 1.5 m
- FFT portable type analyzer CF-3600A (4-ch) with touch panel computer utilizing simultaneous analysis and recording. The maximum range of frequency that can be analyzed is 40 kHz. Produced by ono Japanese sokki.
- FFT is used as a spectrum analyzer and data acquisition.
- The specifications of the bearing tapper can be seen in Table 1.

Figure 3. Photos of Setting-up the FRF testing

Table 1. The data of tapered roller bearing dimension: pinion shaft side

Symbol	Unit of Measurement [mm, kg]
A	25
D	50
D	110
T	36
d^1	73,5
B	35
C	30
r^1	2,5
r^2	2,5
m bearing	1,31 kg



RESULTS AND DISCUSSION

In this study, the excitation force was in the form of a harmonic signal originating from a cellphone, which can be seen in Fig. 4. This harmonic signal gave an excitation force to the taper bearing. Then the response was measured in three axes are the direction of the axis x, y, and z, respectively.

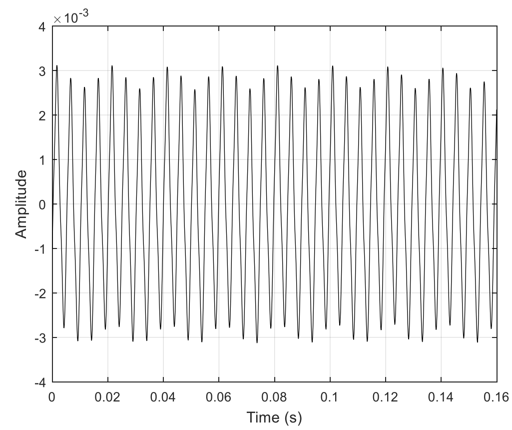


Figure 4. The excitation force in the form of a harmonic signal

Measurements were made on taper bearings both with and without a bearing house. Fig. 5 and Fig. 6 show one of the results of measuring FRF without bearing on the x-axis. Fig. 5 shows the FRF measurement results on the x-axis or FRF point, for the frequency range 0 - 1200 Hz (in normal bearing conditions, there were seven natural frequencies, 67 Hz, 97 Hz, 135 Hz, 169 Hz, 202 Hz, 236 Hz, and 840 Hz.)

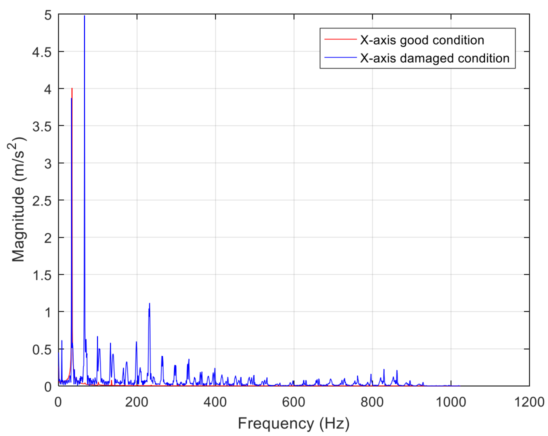


Figure 5. FRF measurement on the X axis

In a damaged bearing state, there were more than 7 Hz natural frequencies with the same range. For more detail about the differences in frequency changes that occur, the writer tried to draw a logarithmic form, as shown in Fig. 6. It can be seen clearly that there were differences and the emergence of new frequencies in damaged taper bearings.

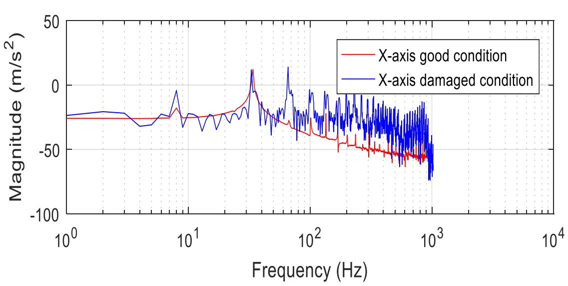


Figure 6. logarithmic FFT on the Y axis

Measurements were also made on the Y-axis to determine the effect of Y-axis direction bearing damage. Fig. 7 shows the results of FRF measurements on the Y-axis, for the frequency range 0 - 1200 Hz, wherein normal bearing conditions there were eight natural frequencies, 8, 20 40, 56, 73, 88, 104 and 120 Hz.

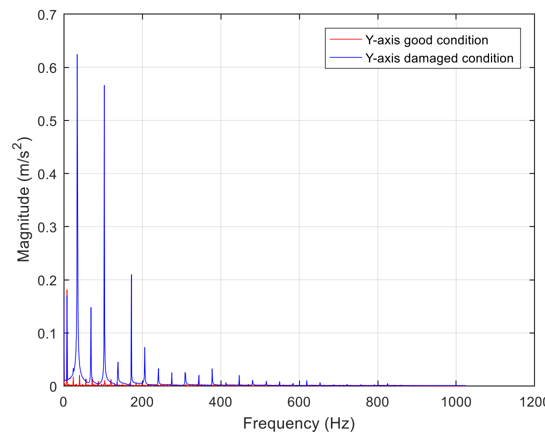


Figure 7. FRF measurement on the Y axis

The frequency was smaller compared to the natural frequency at the FRF point. Whereas in damaged bearing, it was found that the number of natural frequencies produced was more than the reasonable bearing taper condition.

Based on the logarithmic shown in Fig. 8, there was a shift in the frequency of normal bearing conditions. The shifting can be seen clearly in the frequency of damaged bearings.

On the Z axis, there was no significant difference between ordinary and broken bearings where the number of frequencies produced was the same, and there was no frequency shift that occurred in the FFT measurement results, as shown in Fig. 9.

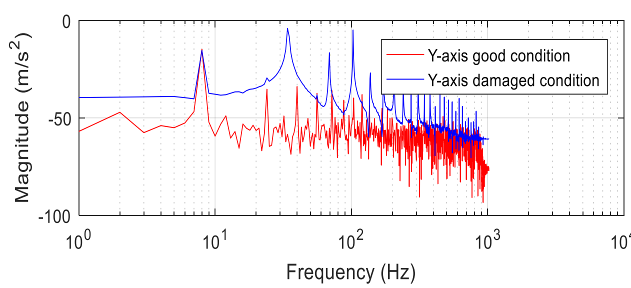


Figure 8. logarithmic FFT on the Y axis

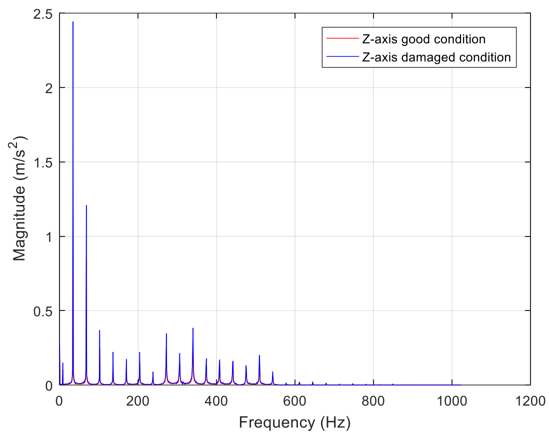


Figure. 9. The FRF measurement on the Z axis

In the logarithmic graph, there was no difference between the standard and damaged taper bearing. The situation shows that based on the Z-axis, the taper bearing did not indicate any damage, as shown in Fig. 10.

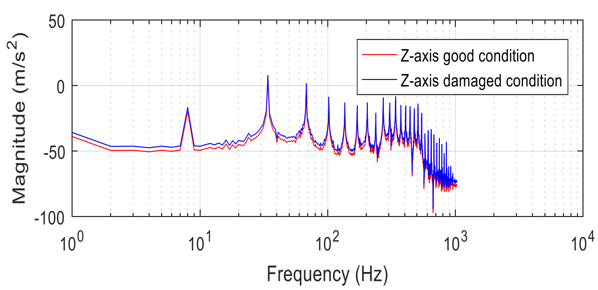


Figure 10. Logarithmic FFT on the Z axis

Furthermore, we conducted this study using a taper bearing house with the same testing procedure. In Fig. 11 and Fig. 12, one of the results of FRF measurement with the bearing housing on the x-axis is shown. Fig. 11 shows the results of FRF measurements on the x-axis or FRF point, for the frequency of 0 - 1200 Hz. In the standard bearing, there were two natural frequencies, 8 and 35 Hz.

On damaged bearing, there were more than ten natural frequencies with the same range. The one that appeared in a damaged state looked at a frequency of 8 Hz and 35 Hz. After a frequency of 35 Hz, on the damaged taper bearing, a new frequency emerged. For a more detailed, see Fig. 12.

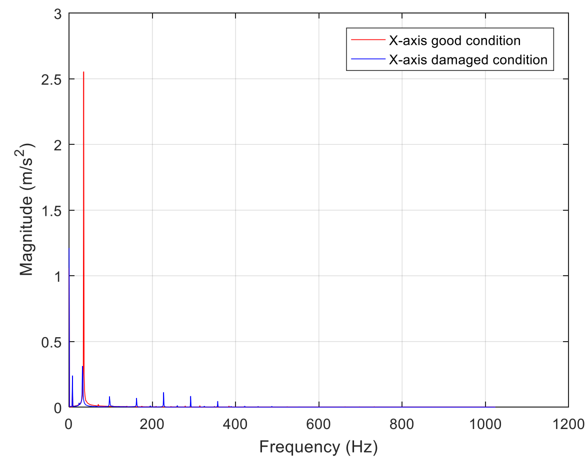


Figure 11. The FRF measurement on the X axis

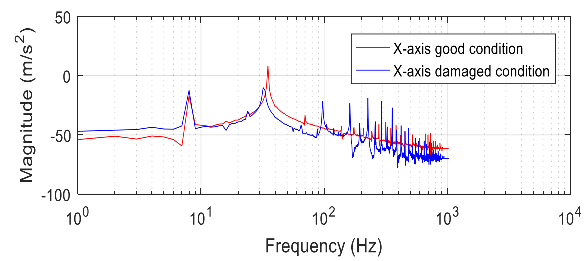


Figure 12. The logarithmic FFT on the X axis

In the Y-axis, the frequency that appeared in good condition was similar to the X-axis or FRF point where two natural frequencies appeared (8 Hz and 35 Hz). Then a frequency higher than 35 Hz would appear on the damaged taper bearing, as shown in Fig. 13.

Logarithmic FFT on the Y-axis clearly showed the shift and the emergence of new frequencies on the taper bearing in damaged condition, as shown in Fig. 14.

In the Z-axis, the frequency ranged from 0 to 1200 Hz, and in normal bearing conditions, there were eight natural frequencies (35, 103 and 138 Hz). The frequency was more significant than the natural frequency at the FRF point, as shown in Fig. 15.

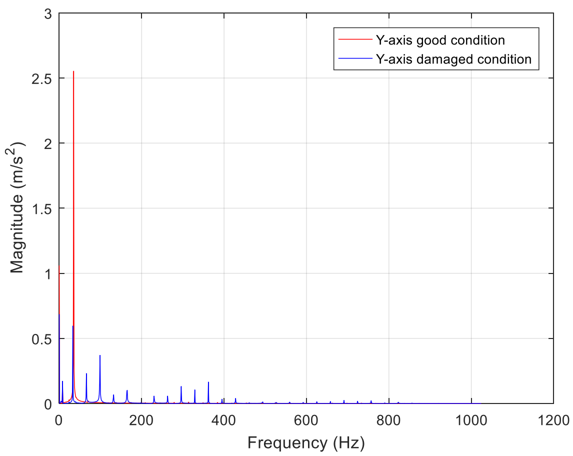


Figure 13. The FRF measurement on the Y axis

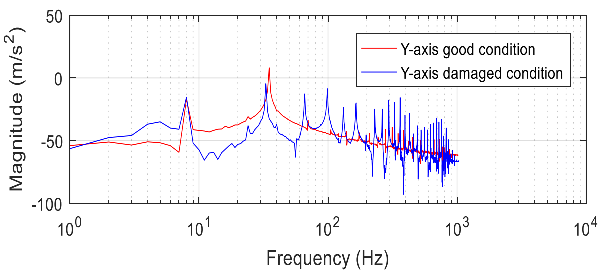


Figure 14. logarithmic FFT on the Y axis

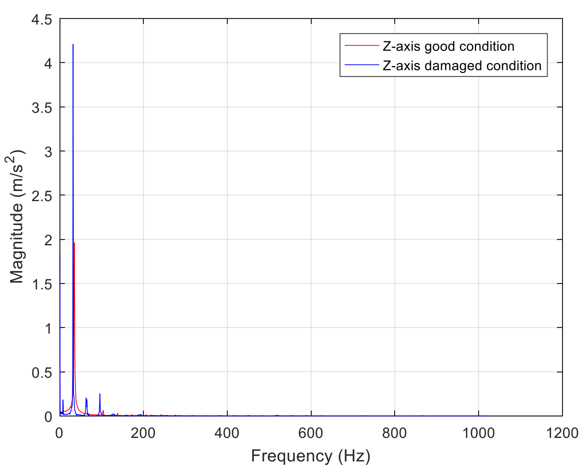


Figure 15. The FRF measurement on the Z axis

In Fig. 16, it can be seen clearly that there was a difference between damage on the taper bearing and the one the bearing house starting from the emergence of a natural frequency of 8 Hz, and the occurrence of shifts and the emergence of new natural frequencies.

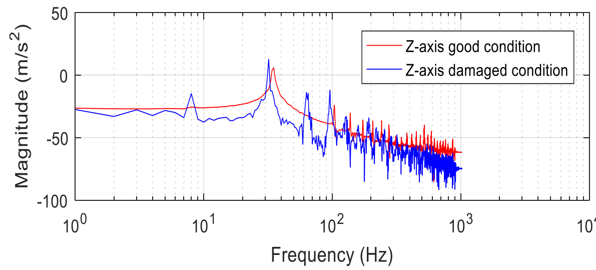


Figure 16. FFT logarithmic in the Z axis

After looking at the difference in the vibration signal on the taper bearing, the writer then identified the taper bearing we tested. It can be seen that there was damage (scratch) to the defect that occurred on the ball taper bearing and scratch defects in the taper bearing house, as shown in Fig. 17.

(a) (b)

Figure 17. Taper and House Bearing

CONCLUSION

In this study, it can be concluded that by applying the function response function, we can identify the following conditions. In the absence of bearing housing the damage to the taper bearing is in the X and Y axis, while the frequency that arises due to damage to the taper bearing is towards the Y-axis, for the frequency range 0 - 1200 Hz, wherein normal bearing conditions there are eight natural frequencies (8, 20, 40, 56, 73, 88, 104 and 120 Hz). The frequency is smaller than the natural frequency at the FRF point. With the bearing house, there are differences in the three axes of the test results. On the X and Y axis, there are two vibrate modes, namely at the natural frequency 8 and 35 Hz.

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