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BEARING FAULT DETECTION OF AUTOMOTIVE GEARBOX USING ORDER ANALYSIS

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Abstract: *This paper aims to detect the bearing fault of the automotive gearbox using order analysis. The delta-ANALYSER was used in the experiment for condition monitoring the powertrain. The delta-Evaluation.NET was used to analyse and evaluate the measured data. The Reilhofer Order Calculator (ROC) was used to calculate the orders of the bearing of the automotive gearbox. The results revealed that effect of clearance of inner ring of bearing 3 was detected at the 4th and 5th speed degree.*

Keywords: Rolling Bearings, Automotive Gearbox, Order Analysis, Powertrain, Envelope Analysis

1. Introduction

The automotive gearbox consists of several moving parts, such as gears, bearings, shafts, etc, causing several possible sources of errors and noise. Thus, a rigorous treatment of the data is necessary. The vibration signal analysis has been shown to be a very reliable method of monitoring bearings and gears. Its wide application in this kind of work takes place due to the periodic feature that the cyclic operating system of a gearbox generates signals. Imperfections in the bearings and gears impact specific frequencies governed by the angular velocity of the rotating component and its construction. Vibration signal analysis has been widely studied, and several works have developed several different techniques for treating this type of signal, either in the time domain or frequency (Barbieri et al., 2017).

The bearings as a noise source must be considered when designing a quiet gearbox (Tůma, 2014). The rolling bearings' noise and vibration are either wideband or tonal. Rolling bearing defects may arise due to material fatigue during operation on the inner ring, outer ring, and rolling elements. Imperfections in the production process cause the tonal noise and vibration of new and healthy rolling bearings. When analyzing the spectrum of noise and vibration of gearboxes, the effects of a rolling bearing defect are encountered; therefore, the frequencies of the tonal component are calculated.

An influence of the load on the car gearbox noise was studied (Tomeh, 2019). It was obvious that all three measuring techniques—running conditions at the device stand, test stand, and actual traffic—confirmed that vibration and noise levels decreased as loading increased.

The delta-ANALYSER is a measuring system used for early-stage damage detection of acoustic noise-emitting machines such as transmissions and engines under dynamic conditions. It detects failure-related changes in the machine by comparing the current vibration behavior to a previously built reference. The delta-ANALYSER processes data from the acceleration sensors combined with data from the revolution counters. From the measured signal of the structure-born noise, a spectrum is calculated via Fast Fourier Transformation (FFT). The delta-ANALYSER not only switches off early enough to analyze the defects but can also precisely locate the damage's origin. This is possible because almost every component of the test item, such as shaft, gear, bearing, etc., can be assigned to an order, a specific line of the order spectrum, which can be calculated accurately (Sann et al., 2024).

Early-stage detection of engine and transmission using order analysis was studied (Sann et al., 2024). The technical conditions of the engine and transmission with gear mesh order analysis were analyzed. It was

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found at the 4th-speed degree, the effect of the imbalance of the gear mesh between gearwheels zI4 and zII4 and the effect of the angular misalignment of the gear mesh between zIID and zIIID were found. It was also obvious that at the 5th-speed degree, the effect of eccentric gear mesh between zI5 and zII5 and the effect of clearance of the gear mesh between zIID and zIIID were detected. This should affect to the rolling bearing components of the automotive gearbox. However, the technical condition of the bearings has yet to be analyzed in the previous study. Therefore, this study aims to detect the bearing fault of the automotive gearbox using order analysis.

2. Research Methodology

Figure 1 shows an overview of the experimental setup. The three main components are the powertrain (engine and transmission or gearbox), speed box for RPM conditioning, and delta-ANALYSER. The piezoelectric acceleration sensor picks up the vibrations on the powertrain and passes them onto the delta-ANALYSER measuring system as an analog signal. Two acceleration sensors are used: the first vibration sensor is connected to the engine block, and the second acceleration sensor is connected to the transmission (gearbox housing). All orders are based on the shaft speed, which is measured by the speed sensor. The speed sensor is usually synchronized to the powertrain's input shaft.

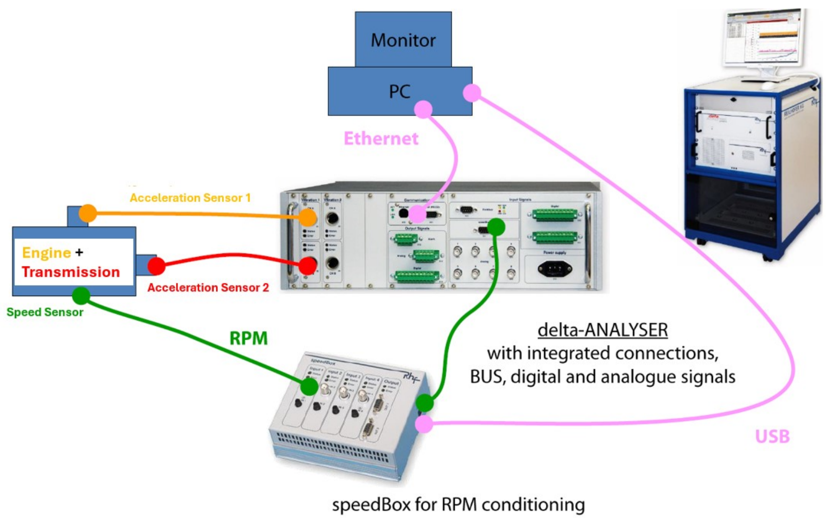
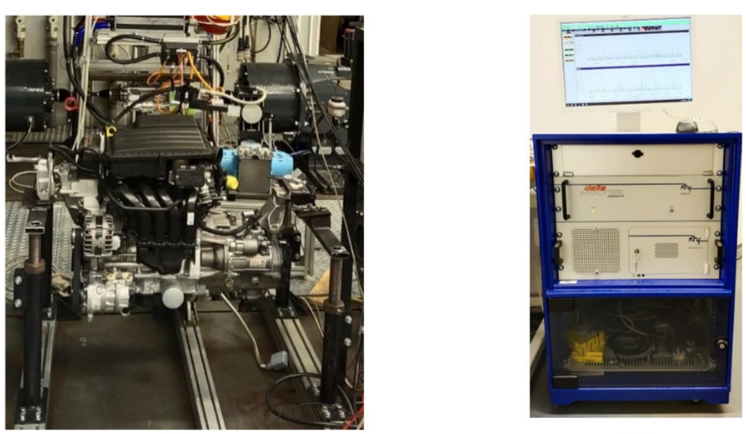


Fig. 1: Overview of experimental setup

The powertrain with a 1.6-liter MPI engine connected with a five-speed manual transmission was monitored. The powertrain to be measured and monitored by means of a delta-ANALYSER was running for 1311 hours, as shown in Fig. 2.



(a) (b)

Fig. 2: (a) Engine and transmission, (b) delta-ANALYSER (Sann, Tomeh, Petr, et al., 2024)

The delta-ANALYSER contains three software modules (Reilhofer, 2016). delta-ANALYSER Run is the setting and monitoring software. It controls and runs the measuring device, enables creating and editing load steps, and starts and stops the monitoring. delta-Evaluation.NET is used to analyze and evaluate the measured data. Reilhofer Order Calculator (ROC) can calculate each component of a test item and show essential orders, as shown in Fig. 3. Table 1 shows the fundamental harmonic order calculations using ROC.

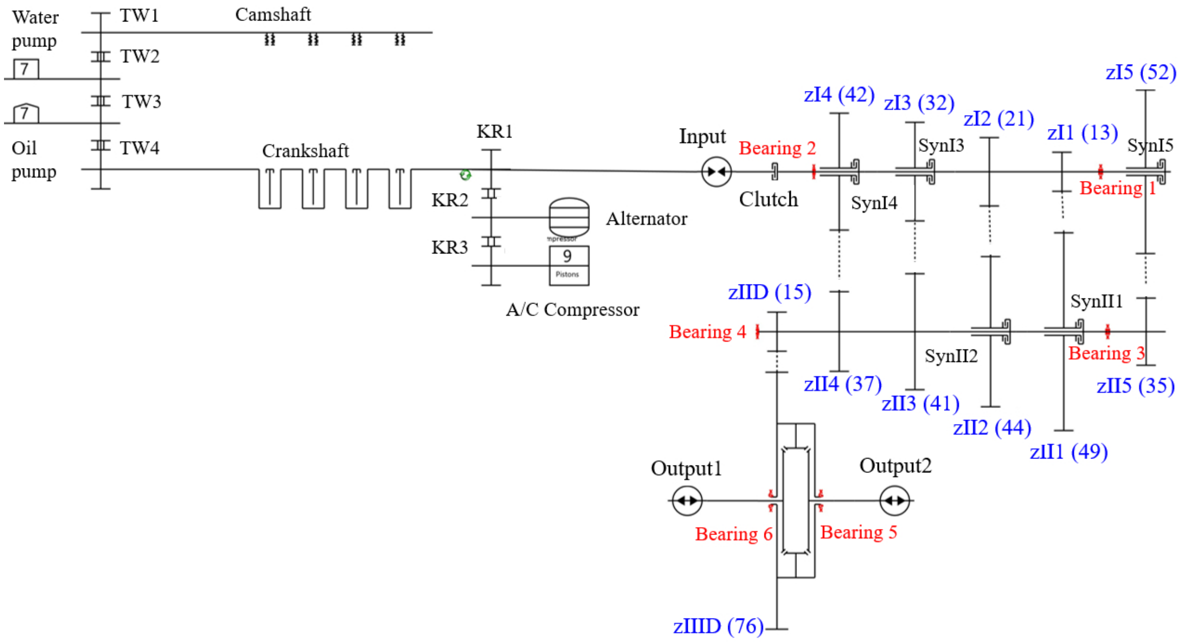


Fig. 3: Engine and transmission simulation using Reilhofer Order Calculator (ROC) software

Tab. 1: Fundamental harmonic order calculations using ROC at each speed of bearing 3

Fundamental Harmonic Order	1st	2nd	3rd	4th	5th
Cage	0.1055	0.1898	0.3104	0.4515	0.5909
Inner ring	2.3968	4.3117	7.0510	10.2549	13.4221
Outer ring	1.5828	2.8474	4.6563	6.7721	8.8636
Rolling elements	0.6214	1.1179	1.8280	2.6587	3.4798

3. Results and Discussions

The 4th-speed degree with load step 201 and the 5th-speed degree with load step 293 were selected for study.

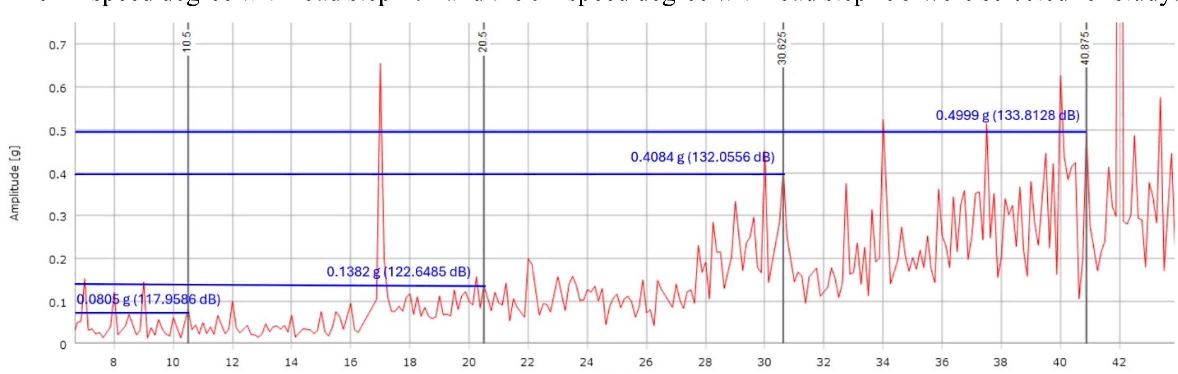


Fig. 4: Load step 201: crankshaft speed (3100-3399 RPM), gear (3.50-4.50), torque (50-100 Nm), oil temperature (79.50-103°C), Bearing 3: inner ring

In Fig. 4, load step 201 of inner ring of bearing 3 was chosen to analyse where crankshaft speed ranged from 3100 RPM to 3399 RPM, gear between 3.50 and 4.50, torque from 50 Nm to 100 Nm, and oil temperature ranged from 79.50°C to 103°C. The 1st, 2nd, 3rd, and 4th harmonic components of 0.0805g, 0.1382g, 0.4084g, and 0.4999g gradually increased. This indicates the effect of clearance of inner ring of bearing 3 at the 4th-speed degree.

In Fig. 5, load step 293 of inner ring of bearing 3 was selected to analyze where crankshaft speed ranged from 1600 RPM to 1899 RPM, gear between 4.50 and 5.50, torque from 100 Nm to 150 Nm, and oil temperature ranged from 79.50 to 103°C. The 1st, 2nd, 3rd, and 4th harmonic components of 0.1004g, 0.0448g, 0.1944g, and 0.8098g gradually increased. This indicates the effect of clearance of inner ring of bearing 3 at the 5th-speed degree.

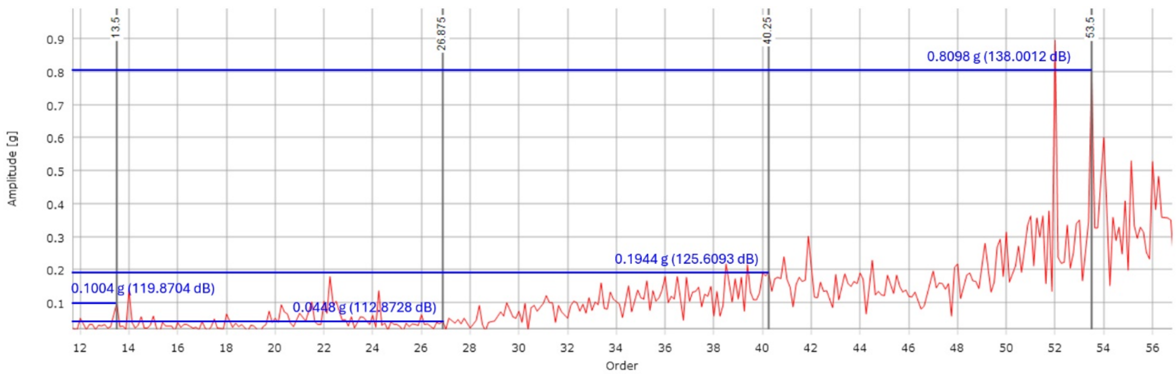


Fig. 5: Load step 293: crankshaft speed (1600-1899RPM), gear (4.50-5.50), torque (100-150 Nm), oil temperature (79.50-103°C), Bearing 3: inner ring

4. Conclusions

Order analysis proves to be a good and effective diagnostic method for shock forces induced by defects in gearbox rolling bearings. Rolling bearing defects generate shocks during shaft rotation and gear mesh. They create modulated vibrations with modulation frequencies that define the type of damage to individual parts of rolling bearings and their defect size. Order analysis was used to analyse the technical conditions of rolling bearings in the automotive gearbox. The results show that at the 4th and 5th-speed degrees, the effect of clearance of the inner ring of bearing 3 was detected after for 1311 hours running. The noise level of the acceleration vibration of the inner ring of bearing 3 exceeds 65 dB (A) which is the beginning of the manifestation of the negative effects of noise.

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