Frequency Domain Technique for Characterizing Spur Gears Defect Pattern

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Abstract. This paper presents information of detecting the gear using frequency domain technique in vibration analysis. In this study, vibration signal is very crucial in determining signal from defective gear. The quality of the signal displayed in the frequency spectrum are depends on the number of sampling frequency taken into account during acquiring the data. Insufficient number of samples may acquire poor signal in contrast with sufficient number of samples. The objective of this research emphasizes the various frequency resolution and centroid shifting frequency location to characterize the normal and defective gear. The development of test rig with a constant speed of 1493 RPM is designed and consist of simple pinion and gear. The DAQ (NI) with algorithm block diagram developed using LabVIEW is used to acquire the frequency domain data. It is found that by varying the number of samples will affect the resolution of the signal and subsequently tuned the shifting centroid of frequency. By calculating the centroid shifting frequency have indicate that the amplitude of normal gear is 0.0128g, defect gear (broken tooth) is 0.052 g and defect gear (broken tooth 90°) is 0.0938g. The amplitude of normal gear, defect gear (broken tooth) and defect gear (broken tooth 90°) are located at frequency 745.829Hz, 746.757Hz and 746.2Hz respectively.

1. Introduction

The gear is a mechanical component used to transmit power from one shaft to another shaft in machinery [1]. The smooth operation and high efficiency of gears are necessary for normal running of machinery. Therefore, the contact between gears have a tendency to produce wear, fatigue, subsequently tooth failure. The gear damage detection is a main topic in the field of condition base monitoring (CBM) and fault diagnosis. A number of methods, such as time domain analysis, frequency domain analysis, time- frequency analysis and pattern recognition, have shown a high potential for the vibration signal and it can show a typical signal pattern produced by a localized fault in the various components of rotating machine. [2] This project base on condition monitoring technique of a spur gear fault detection using frequency domain technique in vibration analysis. Spur gears are the most common type of gears. They have straight teeth and are mounted on parallel shafts. Sometimes, many spur gears are used at once to create very large gear reductions. The application using spur gear are metal cutting machines, automobile gear boxes, marine engines, mechanical clocks and watches, fuel pumps, washing machines, gear motors and gear pumps, Material handling equipment’s etc. The vibration signals were acquired from gearboxes and used to simulate various faults on spur gear tooth. Vibrations signals were applied to monitor a normal and various fault conditions of a spur gear such as normal, defect gear (broken tooth) and defect gear (broken tooth 90°) by using LabVIEW. Signal produced by meshing gears is very difficult to characterize its pattern using
vibration analysis base on condition monitoring DAQ (NI) of rotating machinery with the presence of many defects on gear teeth become more difficult to characterize its behaviour. Therefore, finding the resolution of the gear signal may assist in determining the defect behavior of the gears.

2. Literature Review
This section will discuss the knowledge gained from the article and journal reviewed. The purpose of this review is to link between the frequency domain techniques in vibration analysis with the fabricate gear test rig using spur gear for the lab uses. All findings have been summarized below.

2.1 Gear Failures
The engine defects tend to happen when a device works under conditions of increased pressure. Local faults are the more hazardous because, once launched, they tend to evolve quickly and generally have important impacts on the transmission of energy. If not identified soon, the most significant local faults can be drastic implications with teeth breakage, pitting and scoring. [3]

2.2 Vibration Signal
Vibration signals and acoustic emissions are the most prevalent waveform information in status surveillance. Ultrasonic signals, engine present, partial release are another waveform information. There are two primary types of stationary waveform information assessment in the literature which is analysis for time-domain and evaluation of frequency-domain. [1]

2.2.1 Time-Domain Analysis
Analysis of the time-domain is focused straight on the time waveform itself. Traditional time-domain assessment calculates characteristics from time waveform measurements such as mean, peak, peak-to-peak ratio, normal deviation, crest factor, and high-order data (root mean square, skew ness, kurtosis, etc.). Usually these characteristics are called time-domain characteristics. Time Synchronous Average (TSA) is a common time-domain analysis method. TSA's concept is to use the raw signal's ensemble average over a range of developments in an effort to extract or decrease noise and impacts from other sources to improve the interesting signal parts. [1]

2.2.2 Frequency-Domain Analysis
Analysis of the frequency-domain is focused on the transformed frequency domain signal. The benefit of frequency-domain assessment over time-domain assessment is its capacity to readily recognize and isolate some interesting frequency elements. The scope assessment by means of fast Fourier transform (FFT) is the most commonly used standard assessment. The primary concept of range assessment is either to look at the entire range or to look carefully at some important frequency parts and thus to remove characteristics from the signal [1]

2.3 Test Rig
It has been built to track the condition of the spur gear. This set-up consists of a single-stage gearbox powered by a switching electric motor (30 kW DC) and a controller designed to control engine speeds in the range of 0-3000 r / min. The test gearbox consists of a pair of standard involute profiled spur gears and bearings (URB32306 for the driving shaft and URB30307 for the driven shaft). Lovejoy coupling attaches the engine to the gearbox output shaft. The gearbox's output shaft connects the torque detector shaft by
Lovejoy coupling. An eddy current dynamometer (consisting of an LSG 2010 controller) coupled with the output shaft will apply torque (1-75 Nm) on the gears. [4]

2.4 LabVIEW
Lab VIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language mainly used to obtain, calculate and analyse information. In this research, the development of a device for measuring and analysing vibration using Lab VIEW. The DAQ (Data Acquisition) input is in the Time domain for this programming. Using the FFT (Fast Fourier Transform) analyser program converts the time domain graph to the frequency domain and finally picks up the frequency corresponding to the highest amplitude or peak amplitude using the peak detector after the FFT analyser. [5]

3. Methodology
3.1 Flow Chart

![Flow Chart](image-url)

**Figure 1.** Flow Chart
3.2 Experimental Rig Setup

The simple gear test rig is developed to investigate the condition of the spur gear through the frequency domain technique. In the gearbox test rig, the normal and specific fault conditions of the spur gear are monitored shown in figure 3 and figure 4. The accurate and reliable data were gained from the gearboxes through several signal processing technique, as shown in figure 2. The main objective of these experimental studies is to monitor the condition of the automobile gearbox running at the same speed. The gearbox was running at 1493 RPM. Shear accelerometer with sensitivity of 10.19 mV/g or 1.039 mV/m/s² is positioned on the housing bearing of the shaft rotate to provide the vibration signatures of the gearboxes. The gear ratio helps to determine the output and input of the speed as well as the torque and power. The gear ratio can be calculated by using equation (1). It is vital to determine the gear ratio respect to the individual spur gear rotating speed to determine gear mesh frequency in order to locate the appropriate frequency band as given in equation (2).

\[
G.R = \frac{D_G}{D_P} \tag{1}
\]

GR = Gear Ratio  
DG = Diameter of Gear (mm)  
Dp = Diameter of Pinion (mm)
3.3 Centroid Shifting Frequency

\[ G. M. F = \frac{T \cdot N}{60} \]  

(2)

GMF = Gear Mesh Frequency (Hz)

\( T \) = Number of Gear Teeth

\( N \) = Shaft Speed (rpm)

To calculate the centroid of the defect gear as recognition feature to characterize the gear type defect. The resolution of the signal produced by the defect gear will provide specific feature that can be easily detected. By zooming at the gear mesh frequency region, the calculation of the centroid of gear defect signal can be done easily using the equation (1) and (2). Therefore, for each type of defect produce light significant of signal feature that can be differentiated its characteristic.

\[
\bar{y} = \frac{\sum_{i=1}^{3} \bar{A}_i A_i}{\sum_{i=1}^{3} A_i}
\]

(3)

\[
\bar{f} = \frac{\sum_{i=1}^{3} f_i A_i}{\sum_{i=1}^{3} A_i}
\]

(4)

Figure 5. Signal shifting centroid

To calculate the centroid of the defect gear as recognition feature to characterize the gear type defect. The resolution of the signal produced by the defect gear will provide specific feature that can be easily detected. By zooming at the gear mesh frequency region, the calculation of the centroid of gear defect signal can be done easily using the equation (1) and (2). Therefore, for each type of defect produce light significant of signal feature that can be differentiated its characteristic.
3.4 Resolution Setup

Figure 6. Resolution setup using LabVIEW

Figure 6 show the resolution setup using LabVIEW by varying the number of sample from 2500, 5000 and 7500. To get a sufficient of data, the technique use was varying the number of sample. If the data is insufficient, the data resolution is ambiguous. The bandwidth frequency is fixed at 1000 Hz for both gear; normal and fault gear. The resolution setup using LabVIEW is to emphasize the various frequency resolution and centroid shifting frequency to characterize the defective gear.

4. Results and discussion

In this section the standard gear outputs are calculated as no defect condition. To get the quality of the signal displayed in the frequency spectrum, three different number of samples was taken from 2500, 5000 and 7500 using DAQ (NI) in LabVIEW. The detail of graph illustration is tabulated below:

Table 1. Sample LabVIEW normal gear table

| No. of gear | Rate | Number of samples | Gear condition | G.M.F centroid | y | \( \bar{f} \) |
|-------------|------|-------------------|----------------|----------------|---|-----|
| 1           | 1000 | 2500              | Normal gear    | \( A_1 = 0.0351 \) | 0.0178g | 744.440 Hz |
|             |      |                   |                | \( A_2 = 0.0360 \) |               |     |
|             |      |                   |                | \( A_3 = 0.0356 \) |               |     |
|             |      |                   |                | \( A_4 = 0.0292 \) |               |     |
| 2           | 1000 | 5000              | Normal gear    | \( A_1 = 0.0193 \) | 0.0168g | 745.526 Hz |
|             |      |                   |                | \( A_2 = 0.0427 \) |               |     |
|             |      |                   |                | \( A_3 = 0.0252 \) |               |     |
| 3           | 1000 | 7500              | Normal gear    | \( A_1 = 0.0310 \) | 0.0128g | 745.829 Hz |
|             |      |                   |                | \( A_4 = 0.00970 \) |               |     |
4.1 Normal gear

Figure 7. Frequency domain vibration signal of the normal gear at 2500 number of samples

Figure 8. Frequency domain vibration signal of the normal gear at 5000 number of samples

Figure 9. Frequency domain vibration signal of the normal gear at 7500 number of samples

The finest resolution of normal gear frequency is 745.829 Hz because the value is almost precise with gear mesh frequency that has been calculated. Other than mesh frequency, the resolution is also determined by
the smallest value of side band from the graph. From this data, the frequency domain technique for characterizing spur gears defect pattern can be detected.

4.2 Broken tooth

In this section the default gear outputs are calculated to define the gear in a defect condition (broken tooth). To get the quality of the signal displayed in the frequency spectrum, three different number of samples was taken from 2500, 5000 and 7500 using DAQ (NI) in LabVIEW. The detail of graph illustration is tabulated below:

Table 2. Sample Lab View defect gear (Broken Tooth) table

| No. of gear | Rate | Number of samples | Gear condition | G.M.F centroid $\bar{y} = \frac{y}{g_1832}$ | Result $\bar{F} = \frac{F}{g_746.360} Hz$ |
|-------------|------|------------------|----------------|----------------------------------|---------------------------------|
| 1           | 1000 | 2500             | Broken tooth   | $A_1 = 0.0527$ $A_2 = 0.166$ $A_3 = 0.0364$ | 0.0619 g 746.360 Hz            |
| 2           | 1000 | 5000             | Broken tooth   | $A_1 = 0.0477$ $A_2 = 0.134$ $A_3 = 0.050$  | 0.0491 g 744.526 Hz            |
| 3           | 1000 | 7500             | Broken tooth   | $A_1 = 0.0525$ $A_2 = 0.0526$ $A_3 = 0.143$ | 0.0524 g 746.757 Hz           |

Figure 10. Frequency domain vibration signal of the broken tooth at 2500 number of samples
The finest resolution of fault gear frequency is 746.757Hz because the value is approximately with gear mesh frequency that has been calculated. Other than mesh frequency, the resolution is also determined by the smallest value of side band from the graph. From this data, the frequency domain technique for characterizing spur gears defect pattern can be detected.

4.3 Broken tooth 90°

In this section the default gear outputs are calculated to define the gear in a defect condition (broken tooth 90°). To get the quality of the signal displayed in the frequency spectrum, three different number of samples was taken from 2500, 5000 and 7500 using DAQ (NI) in LabVIEW. The detail of graph illustration is tabulated below:
Table 3. Sample Lab View defect gear (Broken Tooth 90°) table

| No. of gear | Rate | Number of samples | Gear condition | G.M.F Centroid | Ŷ | Result | ð̅ |
|-------------|------|-------------------|----------------|----------------|---|--------|------|
| 1           | 1000 | 2500              | Broken tooth 90° | \( A_1 = 0.0804 \) \( A_2 = 0.224 \) \( A_3 = 0.0423 \) | 0.0843 g | 745.191Hz |
| 2           | 1000 | 5000              | Broken tooth 90° | \( A_1 = 0.0514 \) \( A_2 = 0.228 \) \( A_3 = 0.0437 \) | 0.0875 g | 745.213Hz |
| 3           | 1000 | 7500              | Broken tooth 90° | \( A_1 = 0.026 \) \( A_2 = 0.234 \) \( A_3 = 0.0475 \) | 0.0938 g | 746.2Hz |

Figure 13. Frequency domain vibration signal of the broken tooth 90° at 2500 number of samples

Figure 14. Frequency domain vibration signal of the broken tooth 90° at 5000 number of samples
Figure 15. Frequency domain vibration signal of the broken tooth 90° at 7500 number of samples

The finest resolution of fault gear frequency is 746.2Hz because the value is approximately with gear mesh frequency that has been calculated. Other than mesh frequency, the resolution is also determined by the smallest value of side band from the graph. From this data, the frequency domain technique for characterizing spur gears defect pattern can be detected.

5. Conclusion
This paper, through a range of experimental results, showed that the technique of vibration signal analysis has the potential to investigate the behaviour of the gearbox rotation. By using LabVIEW with National Instrument (NI) DAQ, the vibration signal of a normal gear and default gear has produced a best signal resolution for gear mesh of frequency domain technique. The signal pattern from the result obtained can be used to analyse the condition of gear. Show that the result for shifting frequency based on calculation for normal gear is 745.829 Hz. As for gear fault (broken tooth), the value of shifting frequency is 744.562 Hz meanwhile the value for gear fault (broken tooth 90°) is 746.2Hz. Compared to normal gear, it can be seen that the high signal shifting frequency of fault gear is increased. All parameters have higher values in tooth breakage gear than normal gear [6].

6. Reference
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