Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-16-0097

Identification of Vibrations in a Spur Gear Transmission System

Tauqir Muhammad[1], Shinn- Liang Chang[1], Jen-Yuan Chang[2#]
[1] Department of Power Mechanical Engineering, National Formosa University, Hu-wei, TAIWAN
[2] Department of Mechanical and Computer-Aided Engineering, National Formosa University, Hu-wei, TAIWAN
Corresponding Author / Email: james.chang@nfu.edu.tw, TEL: +886-5-631-5003

KEYWORDS: Gear vibration, Resonance frequency, Vibration analysis, Fast-Fourier Transformation, accelerometer-impact hammer.

Gears being one of the most significant machine components are frequently employed in the transmission design of automobiles and other rotating machinery. In engineering applications, failure of such critical components results in significant losses, of which failure is commonly caused by mechanical vibrations. As such, vibrations are found to be good indications for monitoring rotating machine's health. This paper discusses identification of vibrations generated by a spur gear transmission system based on acoustic and structural vibration signal processing and analyses. The vibration signals are used in the fault detection for the system in operations. Through numerical finite element parametric studies and experimental modal and acoustic analyses, it was found that tuning structural nature frequencies of the underlying rotating shaft where the spur gear is attached can efficiently reduce the system being excited by external disturbance that leads to structural failure. Two methods were used to overcome the external disturbance. Firstly, two different engineering allowable lengths of transmission shafts are studied to understand the geometric effect on the change of structure's natural frequencies and corresponding mode shapes. In this approach, the model system is investigated through finite element analyses. Secondly, an acoustic structure was created around the model to analyse the gear transmission system without the external disturbance. Using fast-Fourier transformation (FFT), the frequency response functions (FRFs) of the transmission shaft were obtained by using an accelerometer-impact hammer configuration. After employing the aforementioned approaches, the natural frequencies of the spur gear transmission system show a substantial change. The work presented in this paper has engineering implications in smart rotating transmission systems.

1. Introduction

Rotary machines are a crucial component of many mechanical systems, including industrial gears, aircraft engines, power plants, etc. Many rotor elements in rotor dynamic systems produce transverse vibrations as a result of fatigue, which can cause significant damage and catastrophic collapse of the machinery. The rotor hub, misalignment, coupling defects, shaft bow and cracks, belt and pulley, rotor unbalance, looseness, and coupling faults are a few examples of machine component flaws that cause synchronous vibrations [1]. Gear defects such as wear, cracking, pitting, scuffing, and spelling are common factors that contribute to the production of complicated transient vibration signals as a result of gearbox resonance, tooth meshing, and gear and pinion shaft rotation. Impulses, high frequency faults, and random noises all contribute to the mentioned transient nature of multistage gearbox vibrational signals [2].

Power spectrum, crest factor, kurtosis, time-domain averaging, and demodulation are common and well-established approaches in processing signals which have been proven effective in fault detection. Their primary drawback, on the other hand, is that it is assumed that the signal creation process is linear and stationary [3–7].

Utilizing vibration signals which are obtained from sensors can allow ones to find, locate, and identify faults of machines. Based on this, the lifespan of a machine can also be estimated based on the vibration signals processed by techniques like neural networks, genetic programming and algorithms, fuzzy logic, wavelet transforms, and machine support vectors [6]. In processing the vibratory signals, waveform analysis involving logging data time history is commonly adopted and is found effective for analyzing non-steady conditions and brief transient impulses.

The work presented in this study is divided into two sections. In the first section, two distinct transmission shaft lengths that are engineering allowable are examined to determine how the geometry factor can affect the system's modal contents, which are the natural frequencies and mode shapes of the structure. This method involves performing finite element analyses to study the system's modal contents. The gear transmission system was then examined without the interference of ambient noise in the second stage by building an acoustic framework around the model. With the use of accelerometers and an impact hammer to generate impulsive excitations, FRFs of the transmission shaft were calculated, and the results were compared to a numerical final element analyses.

2. Experimental Setup

The physical device and experimental apparatus are depicted in Figure 1. The motor serves as the power supply and uses a set of pulleys to drive the gear drive shaft. The driven wheel drive shaft's housing is where the accelerometers are mounted. As shown in Fig. 1, the accelerometers are oriented in orthogonal directions, two in radial direction, namely X and Y axes, and one in axial direction, namely the Z axis, of the shaft to pick up the measured vibration signals from the housing. The measured signals are processed through the capture card, which is then connected to the computer. Data from the X, Y, and Z axes are collected using piezoelectric-type accelerometers.

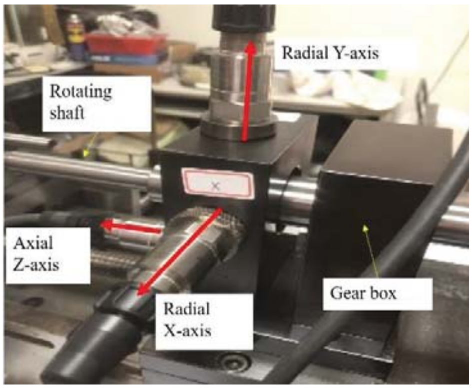


Fig. 1 Experimental apparatus showing placement of accelerometers for vibration measurements.

2.1 Design of Shaft for Investigation of Geometric Effect

Two spur gears are positioned across one another in the gear box at the rotating transmission shaft's end, as depicted in Fig. 1, and are utilized for vibration assessments. The length of the transmission shaft is crucial to the modal rotation system. In this study, transmission shafts with 120 mm and 60 mm in length as shown respectively in Fig. 2(a) and Fig. 2(b) are utilized to examined the geometric effect on the shaft's modal contents, namely natural frequencies and corresponding mode shapes. Numerical finite method

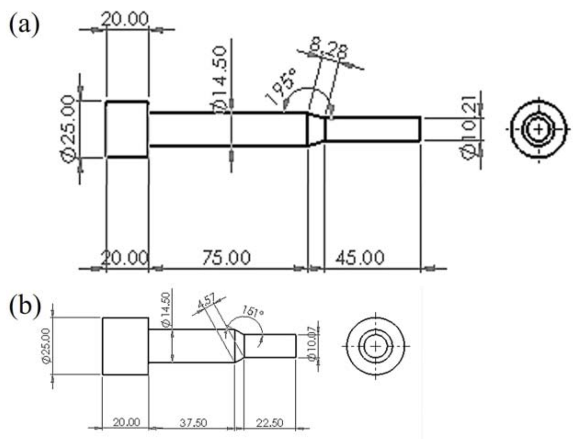


Fig. 2 Design of (a) 120 mm and (b) 60 mm long transmission shafts.

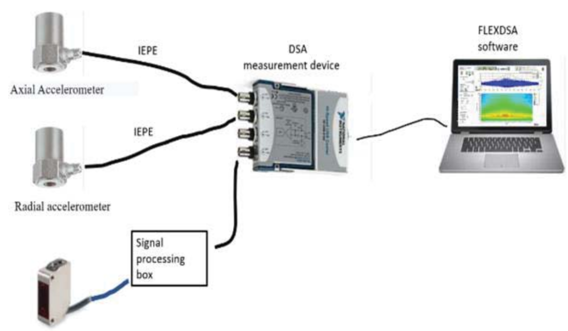


Fig. 3 Illustration of signal processing flow from accelerators to the computer with FLEXDSA program.

Table 1 Spur Gear Specifications

Type	Spur Gear
Number of Teeth	32
Hub Diameter	1.9200
Pitch Diameter	2.6670
Bore Diameter	0.6250
Material	Steel
Face Width	0.7500
Pressure Angle	14.5
PSC Code	3020

analyses and experimental modal analyses were employed in such studies.

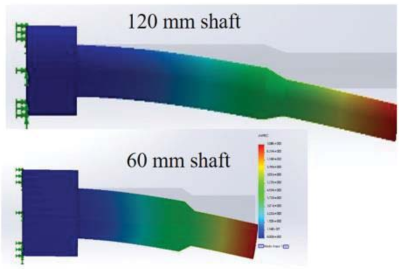
2.2 Setup for Vibration Signal Processing

Two spur gears of the same specifications are installed on the transmission shaft across from one another, as seen in Fig. 1 with specifications as tabulated in Table 1. As illustrated in Fig. 3, the rotating shaft's vibration signals were collected by the accelerometers, which were signal conditioned by the DSA measurement device later analyzed by the FLEXDSA software installed in the laptop computer. The rotating shaft's vibration signals excited by impact hammer were analyzed in form of FRFs. The results are shown in Section 3 in the following pages.

3. Vibrations of the Transmission Shaft

Free vibrations of stationary shafts were first examined with commercial finite element package ANSYS to understand the shaft's modal contents. With one end fixed and the other end free, as exampled by the 1st bending mode shape as shown in Fig. 4(a), it is apparent that the 120 mm shaft would render larger lateral vibratory modal response than the 60 mm shaft.

(a)



(b)

Mode	120 mm shaft	60 mm shaft
1st bending mode	780 Hz	2841 Hz
2nd bending mode	3370 Hz	11120 Hz
3rd bending mode	8147 Hz	16058 Hz

Fig. 4 (a) Illustration of 1st bending mode shape and (b) comparison of natural frequencies of first three bending modes of the model 120 mm and 60 mm shafts.

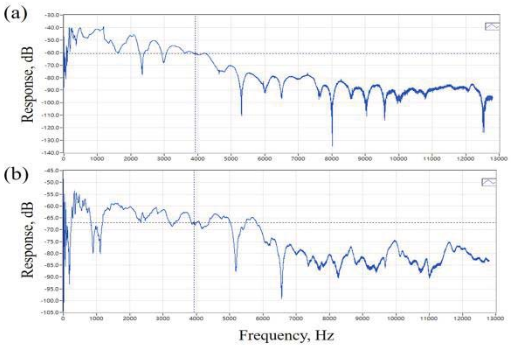
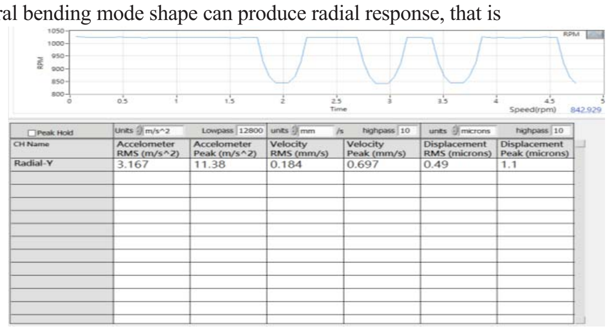


Fig. 5 FRF of the 60 mm shaft in (a) Radial-X (b) Radial-Y directions when excited by the impact hammer.

This lateral bending mode shape can produce radial response, that is in X and Y axes, when the shaft is rotating and is excited by external vibration sources.



As the length of the shaft is reduced by 50%, as shown in the table in Fig. 4(b), one can observe that the natural frequencies of the first three bending modes are significantly increased with 60 mm shaft as compared to the baseline 120 mm shaft. The implication of such increase in natural frequencies can be employed to detune the shaft's vibrations from excitation frequencies as well as de-coupling from other mechanical parts. Through our investigations, the 60 mm shaft offers much lower vibratory performances as opposed to 120 mm shaft as it is fully decoupled from other mechanical parts. Therefore, the following investigations are mainly focused on the results with 60 mm shaft. Using impact hammer as the input and the accelerometers along the X and Y axes as the outputs, the FRFs of the 60 mm shaft are shown in Fig. 5. It is observed that with the shaft being detuned from other mechanical parts, its vibratory responses to the impact hammer excitation in radial X and Y directions are negatable, that is the dB values are in negative range.

3. Effects of Spur Gear Matching

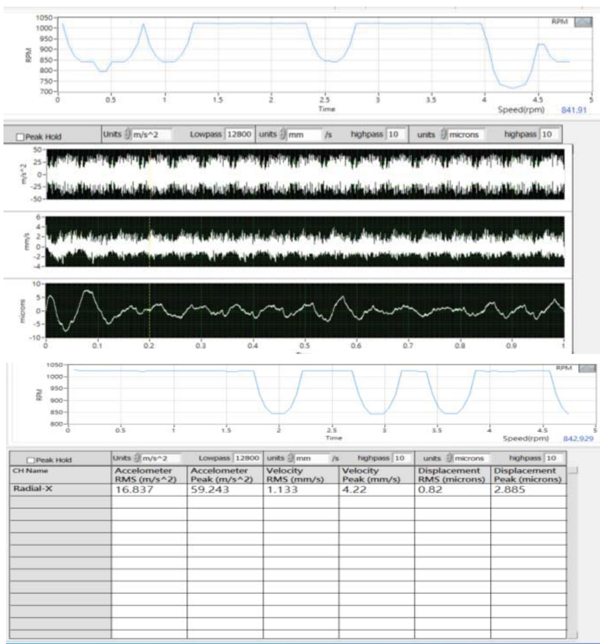


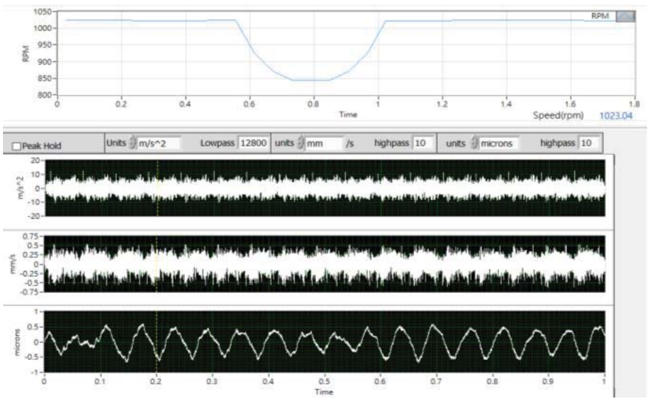
Fig.6 Vibration Test of Spur fully meshed (X-axis)
Fig.7 Vibration Test of Spur fully meshed (Y-axis)

4. Conclusions

One of the main causes of failures in mechanical systems is mechanical vibration. To reduce the vibration of the spur gear shaft system, we suggest two methods in this research. To examine the geometrical composition of the shaft, finite element analysis was used. To determine the frequency response and compare it to the impact hammer of an accelerometer, a fast-Fourier transmitting approach is used. The findings demonstrate the effectiveness of the suggested techniques in reducing system vibration, which has significance for engineering in smart rotating transmission systems.

ACKNOWLEDGEMENT

This work is encouraged by Gear laboratory, National Formosa University to carry out the research. Special thanks to Professor Shinn-Liang Chang and Professor Jen-Yuan Chang for providing technical guidance and conduction of experiment.



REFERENCES

1. J. Xuan, H. Jiang, T. Shi, and G. Liao, Gear fault classification using genetic programming and support vector machines, Int. J. Inf. Technol, vol. 11, no. 9, p. 37, 2005.
2. V. Karma and H. Borade, Fault diagnosis of single stage spur gearbox using narrow band demodulation technique: Effect of spalling, Int. J. Res. Eng. Technol., vol. 1, no. 3, pp. 11–16, 2013.
3. R.M. Stewart, Some useful data analysis techniques for gearbox diagnostics, University of Southampton Report MHM, R/10/77, July, 1977.
4. R.B. Randall, Advances in the application of cepstrum analysis to gearbox diagnosis, in 2nd Int Conf Vib Rotating Mach 1980, 1980, pp. 169–174.
5. P.D. McFadden and J. D. Smith, A signal processing technique for detecting local defects in a gear from the signal average of the vibration, Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci., vol. 199, no. 4, pp. 287–292, 1985.
6. W. J. Staszewski, K. Worden, and G. R. Tomlinson, Time–frequency analysis in gearbox fault detection using the Wigner–Ville distribution and pattern recognition, Mech. Syst. Signal Process., vol. 11, no. 5, pp. 673–692, 1997.
7. R. B. Randall, A new method of modeling gear faults, J. Mech. Des., vol. 104, no. 2, pp. 259–267, 1982.