Vibration signature analysis of two stage gearbox using Kurtosis, Skewness and Crest factor

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ABSTRACT

Keywords:
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Crest Factor,
Condition Monitoring

In recent years, innovations and methodologies have been developed in mechanical equipment, mainly in rotating equipment, to increase the reliability of fault finding. World wide vibration indexes such as RMS, Kurtosis, etc. are widely accepted in industry and are also suggested by international standards. Even so, these parameters do not allow reliable diagnosis of the condition of the machinery. Their apparent simplicity of interpretation makes them more attractive. This work presents a discussion based on these traditional parameters about the diagnostic possibilities. The database used includes vibration signals of gears, taking into account different conditions of speeds and load. The results obtained show that these global parameters of vibration are limited in the exact diagnosis of fault, especially in the condition of initial faults. This method tries to acquire a baseline parameter that improves characterization of fault condition. The outcomes of velocity magnitude are compared with RMS, skewness and Kurtosis.

1. Introduction

Sound and vibration are generated by all machines with moving parts. Each machine has a specific signature of vibration related to the machine's construction and state. With the change in machine state, the signature of the vibration will also change. Before becoming critical, a change in the vibration signature may be used to detect incipient defects. These are the basics of many methods of condition monitoring. Condition monitoring can save money by increasing efficiency in maintenance and by preventing breakdowns by reducing the risk of serious accidents. Jakub Obuchowski, et al., incorporate an alternative criterion which combines advantages of both of the previously used devonvolution criteria. Kurtosis is a widely used tool for impulsiveness detection even if they are hidden in the signal, although favoring single-spike signals is a disadvantage of kurtosis. On the other hand, skewness is more robust, since it incorporates statistical moment one order lower than kurtosis [1]. The Performance of the fault detection system using vibration signals are discussed by T. Praveen kumar, et al., In their studies, they examine good gears and face wear gears to collect vibration signals for good and faulty conditions of the gearbox. Two different speeds and loading conditions are used to test each gear. The statistical parameters such as Mean, Median, Mode, RMS, Kurtosis, Skewness, variance and standard deviation are calculated from the measured vibration signals. These parameters are used as an input to the support vector machine (SVM) for fault detection. Support Vector Machine shows superior classification capability to identify various faults in the gearbox and it can be used to automate fault diagnosis system [2]. Study by Tianyang Wang et al proposes a new method to solve the problem by using the meshing resonance and spectral kurtosis (SK) algorithms together. In specific, the raw signal is first decomposed into different frequency bands and levels, and then the corresponding Kurtogram and MRgram are calculated via the fault SK analysis and the meshing index [3]. Vibration signals were acquired from gearbox and used to simulate various faults on spur gear tooth. In this study, vibration signals were applied to monitor a normal and various fault conditions of a spur gear such as normal, scuffing defect, crack defect and broken tooth. The statistical parameters of vibration signal were used to compare and evaluate the value of fault

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condition. This technique can be applied to set alarm limit of the signal condition based on statistical parameter such as variance, kurtosis, and rms and crest factor. These parameters can be used to set as a boundary decision of signal condition. From the results, the vibration signal analysis with single statistical parameter is unclear to predict fault of the spur gears [4]. Shashikant Shukla, et al., (2014) uses time domain techniques with the use of MATLAB to detect faults in two stages of spur gearbox with tooth breakage and improper chamfering fault in gear. In order to find out different statistical parameters such as peak value, crest factor, RMS, kurtosis, data acquired is analyzed. Using statistical parameters, healthy and breakage gears are compared. In Tooth breakage gear, all parameters have higher values than healthy gear. Compared to healthy gear, faulty gear has a high kurtosis value. With increased speed in faulty gear, all parameters increase, but the values are almost constant in healthy gear. All time domain values are between healthy gear and faulty gear in improper chamfering gear [5]. Zhi Qiang Chen et al (2015) present a Convolution Neural Network (CNN) application used to detect and classify faults in gearboxes. They consider different combinations of techniques for condition monitoring based on certain basic conditions of fault. Vibration signals are pre-processed using time-domain signal indices such as standard deviation, skewness, and kurtosis. In the frequency domain, the spectrum obtained with FFT is divided into multiple bands and the value of the root mean square (RMS) is calculated to preserve the energy's shape at the peaks of the spectrum. The accuracy achieved indicates that the suggested approach is highly reliable and relevant in industrial reciprocating machinery fault diagnosis compared to other algorithms [6]. David G. Lewicki et al., (2011) provides insight into the Fault Detection Planetary Gearbox using NASA-backed vibration separation techniques. A total of nine condition indicators are used to determine the defect present in the helicopter's planetary gearbox. They are like RMS, factor of crest, ratio of energy, FM0, kurtosis, operator of energy, FM4, M6A and M8A. They found that M8A was performing the condition indicator. By using vibration analysis techniques, the fault in the sun and planet gear can be detected. Signal wrapping is an effective way to detect the planet's internal and external spalling fault. They found that there was a greater change in vibration when crack was closed instead of opening up during meshing [7].

2. Vibration Techniques

There are several vibration analysis techniques. Techniques for vibration analysis are classified as time domain, frequency domain, time - frequency domain, and other techniques into four categories.

2.1. Time domain techniques

Time domain technique is the easiest and simplest way to analyze the vibration signals waveform. Peak - to - peak amplitude is a measure of the negative peak from top to bottom. Root mean square (rms) measures the overall level of a discrete signal.

$$\text{RMS} = \sqrt{\frac{x_i^2}{N}} \quad \text{------- Eq. 1}$$

Where, N is the number of discrete points and represents each sampled point's signal. To determine the condition of the system, the resulting RMS values are compared with recommended values. However, to detect small or early-stage defects, this method is not sensitive. The crest factor is the peak-to-RMS acceleration ratio. Bearing damage spreads, RMS increases, and crest factor decreases at advance stages of material wear. Another important parameter for identifying bearing health is kurtosis. The kurtosis value calculation equation is given by:

$$K = \left\{ \frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum \left(\frac{x_i - \bar{x}}{s} \right)^4 \right\} - \frac{3(n-1)^2}{(n-2)(n-3)} \quad \text{---- Eq. 2}$$

Skewness is the third order's statistical moment, normalized by the standard deviation to the third power.

$$S = \frac{n}{(n-1)(n-2)} \sum \left(\frac{x_i - \bar{x}}{s} \right)^3 \quad \text{------- Eq.3}$$

This moment shows the asymmetry of the function of probability density (pdf), meaning the degree of deviation from a distribution's symmetry. If the calculated value of Skewness is negative, the curve (pdf) will be shifted to the left and the curve will be shifted to the right if that value is positive. The curve is perfectly symmetrical if it is null [4].

2.2. Frequency domain techniques

The most popular approach to bearing failure diagnosis is the frequency domain, or spectral analysis. Frequency-domain techniques use a fast Fourier transform (FFT) to convert time-domain vibration signals into discrete frequency components [5]. Simply stated, FFT mathematically converts trace vibration time-domain signals into a series of discrete components of frequency. The X - axis is frequency in a frequency spectrum plot and the Y - axis is the displacement, velocity, or acceleration amplitude. The main advantage of frequency - domain analysis over time - domain analysis is that it can easily detect the interesting components of certain frequency components.

2.3. Time - frequency domain techniques

Time - frequency domain techniques are capable of handling vibration signals stationary and non - stationary. This is the main advantage over techniques for the frequency domain. Analysis of time - frequency can show the components of the signal frequency, revealing the characteristics of their time variant. A number of methods for analyzing time - frequency have been introduced, such as the Short - Time Fourier Transform (STFT), Wigner - Ville Distribution (WVD), and Wavelet Transform (WT). STFT method is used for the diagnosis of faults with rolling elements. The STFT's basic idea is to divide the initial signal into short-time window segments and then apply the Fourier transform to each time segment in order to determine the frequencies in that segment. The advantage of wavelet transformation (WT) over STFT is that with sharper time resolutions it can achieve high frequency resolutions.

2.4. Other techniques

Many other techniques have been used to diagnose faults with rolling elements such as artificial neural networks (ANNs), fuzzy logic systems, etc. The main advantage of this time domain-based model that can detect faults using the structure of short data length Feed forward neural network (FFNN) is the most commonly used neural network structure in machine failure diagnosis. Usually, the signal processing is done by the methods, which presume statistically stationary signal features. According to the non-stationary characteristics of vibration signatures of roller bearing fault, a fault diagnosis method based on empirical mode decomposition (EMD). The analysis of bearing vibration signatures using singular spectrum analysis (SSA) is based on a novel method for diagnosing bearing failure. The analysis of bearing vibration signatures using singular spectrum analysis (SSA) is based on a novel method for diagnosing bearing failure. An intelligent rolling element bearings fault diagnostic system combined with auto - regression (AR) model and RBF neural networks and concluded that rolling bearings fault pattern can be accurately detected and the accuracy rate is over 90 %.

3. Experimental Setup

It consists of a compound gearbox (two stages incremental). The gearbox input shaft is connected to 1 HP; three phase 60Hz, electric motor induction by means of rubber coupling. With antifriction bearings, all drive shafts are supported at their ends. Using the RPM sensor, a VFD is used to vary the speed of the electric motor and the speed of the motor or input shaft. Using the accelerometer PV 57, the vibration data is collected from the gear box surface X, Y, and Z. The collected vibration data is processed for signal processing in the VA 12 excel macron sheet. A healthy gear vibration signals are collected at 250, 420, 710, 1200, 1600, 2000, and 2400 rpm shaft speeds.

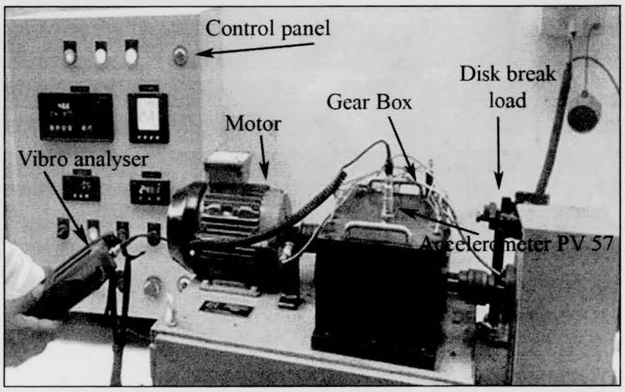


Fig. 1 Experimental gearbox setup.

VA 12 is specially designed for measuring in the field of vibration with FFT analysis function. It comes with the magnetically attached piezoelectric accelerometer PV 572. It provides three vibration meter mode analyzer, time waveform mode, and FFT mode. Acceleration, velocity, displacement, peak acceleration and crest factor acceleration and acceleration can be measured simultaneously in vibration meter mode. The waveform of acceleration velocity displacement or enveloping acceleration curve can be displayed in time waveform mode. The frequency analysis of the displacement of acceleration velocity or acceleration envelope curve can be displayed in FFT mode.

A variable frequency drive (VFD) is used to

Table 1
VA 12 Parameters set before experimentation.

Range (mm/s)	3160
Frequency Span (Hz)	200
Number of samples	1024
High Pass Filter	10Hz
Low Pass Filter	1kHz
Overload	Off
Sensitivity (mV/ms^2)	4.81

set desired RPM. The PIC101A-VI-230 Process Indicator is used for indication of set pressure on disk brake. RPM range is selected as 250, 420, 710, 1200, 1600, 2000, and 2400 as per standard machine tool. The vibration readings are taken in three directions namely X, Y, and Z Direction. Load is set from NO Load condition, 1 Kgf/cm2, 2 Kgf/cm2, 3 Kgf/cm2, 4 Kgf/cm2, and 5 Kgf/cm2 on brake system using screw adjustment. For each reading VA 12 Excel macron gives around 1020 instantaneous values of velocity. Store interval is 1 min. Vibration Analyzer parameters are set as

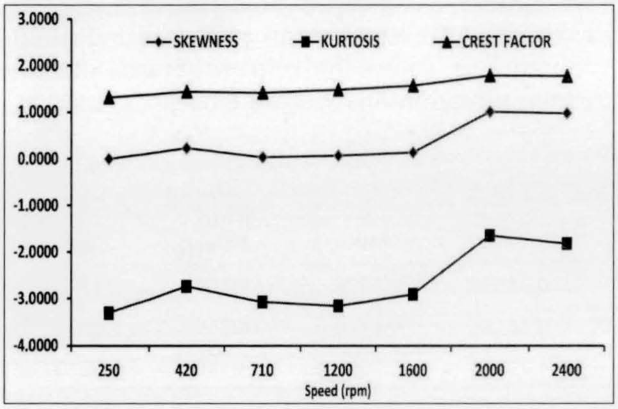
Table 2
RMS values of velocity for each RPM value in X, Y, and Z.

RPM	Axis	250	420	710	1200	1600	2000	2400
NO LOAD	X	0.1215	0.1402	0.2262	0.6555	0.5328	0.8156	2.4721
	Y	0.1239	0.1856	0.2897	0.6846	0.6779	1.2045	2.5603
	Z	0.1419	0.2232	0.5627	1.7920	0.6553	1.8598	1.0230
LOAD 1Kgf/ cm^2	X	0.1235	0.1737	0.2573	0.7669	0.5350	0.9264	2.3139
	Y	0.1184	0.1880	0.2793	0.9843	0.6280	1.3268	2.3844
	Z	0.1217	0.2169	0.5300	1.7773	0.6996	2.1095	1.1087
LOAD 2Kgf/cm^2	X	0.1209	0.1827	0.2609	0.7843	0.6553	0.1449	0.1809
	Y	0.1270	0.1725	0.2891	0.9907	0.8156	0.1441	0.1661
	Z	0.1220	0.2288	0.5619	1.8268	0.1141	0.1629	0.1356
LOAD 3Kgf/cm^2	X	0.0498	0.0620	0.0629	0.1244	0.1213	0.1444	0.1845
	Y	0.0380	0.0528	0.0798	0.1165	0.1113	0.1387	0.1679
	Z	0.0449	0.0625	0.0827	0.1513	0.1123	0.1632	0.1349
LOAD 4Kgf/cm^2	X	0.0539	0.0681	0.0835	0.1229	0.1171	0.1507	0.1868
	Y	0.0382	0.0605	0.0638	0.1208	0.1156	0.1446	0.1606
	Z	0.0462	0.0666	0.0843	0.1551	0.1132	0.1726	0.1394
LOAD 5Kgf/cm^2	X	0.0539	0.0696	0.0871	0.1304	0.1284	0.1469	0.1837
	Y	0.0503	0.0613	0.0686	0.1248	0.1166	0.1432	0.1686
	Z	0.0517	0.0615	0.0858	0.1559	0.1073	0.1588	0.1356

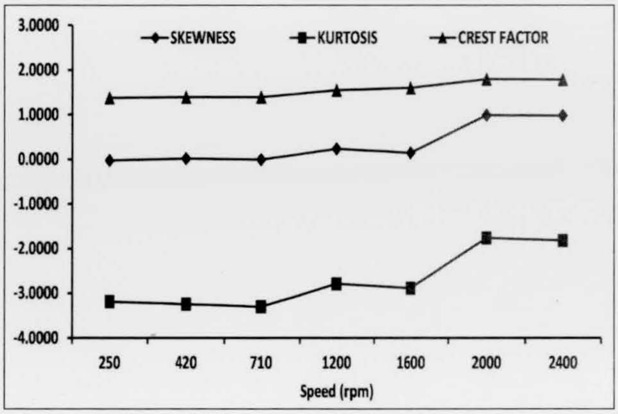
Table 3
Characteristic values in X, Y, and Z.

Axis	Characteristic	250	420	710	1200	1600	2000	2400
X	SKEWNESS	-0.0043	0.2268	0.0317	0.0670	0.1322	1.0058	0.9766
	KURTOSIS	-3.3085	-2.7410	-3.0751	-3.1579	-2.9117	-1.6483	-1.8247
	CREST FACTOR	1.3150	1.4404	1.4151	1.4820	1.5706	1.7886	1.7779
Y	SKEWNESS	-0.0239	0.0161	-0.0039	0.2355	0.1458	0.9874	0.9777
	KURTOSIS	-3.1872	-3.2457	-3.3004	-2.7858	-2.8839	-1.7592	-1.8180
	CREST FACTOR	1.3784	1.3900	1.3899	1.5463	1.6003	1.7911	1.7845
Z	SKEWNESS	0.1028	0.0060	0.0085	0.0013	0.9779	0.9986	0.9820
	KURTOSIS	-2.9521	-3.3074	-3.3096	-3.3295	-1.8149	-1.6921	-1.7918
	CREST FACTOR	1.4603	1.3953	1.4258	1.4310	1.7410	1.8249	1.7715

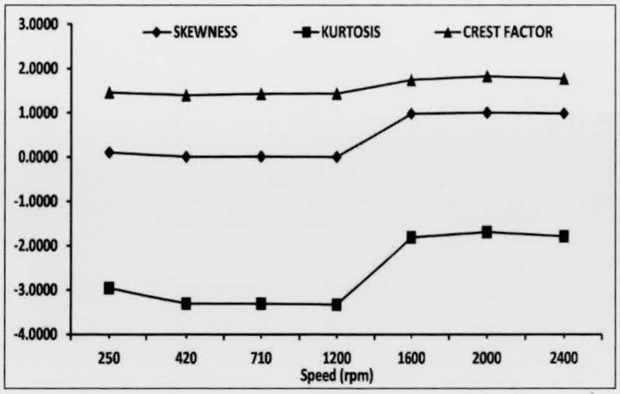
given in Table 1. For sensitive analysis Root mean Square Value is calculated for all instantaneous value i.e. 1024 values for each reading in each X, Y, and Z direction. Table 2 shows the RMS values of velocity(m/s) for each RPM value in X, Y, and Z direction respectively. Fig. 3 shows sample velocity spectrum with concern kurtosis and skewness plot.



(a)



(b)



(c)

Fig. 2. Graphs showing the values of skewness, kurtosis and crest factor in (a) x direction (b) y direction and (c) z direction.

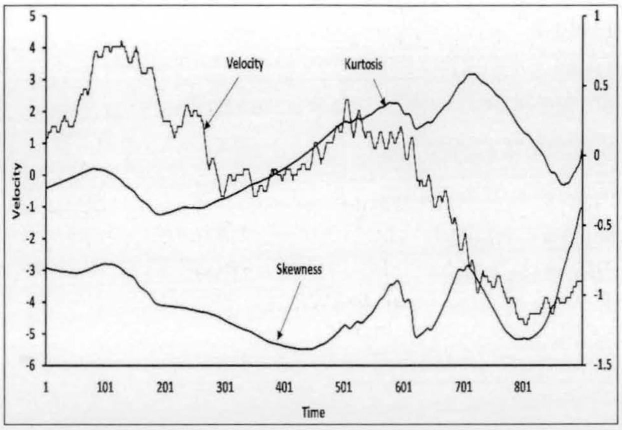


Fig. 3. Spectrum with kurtosis and skewness.

4. Result

In this work an attempt is done to analyze the Gearbox system through Vibration signature analysis and set operating levels. It has been observed that at no load condition with max. RPM, velocity is high and reduces with increase in loading. Normal level can set by using regular loading condition using Root Mean Square values (RMS) of values obtained by VA 12 Vibro Analyzer. Caution level can be set at twice that of Normal Values of RMS. Hazard level can be set at twice that of caution values. If Condition is close to normal, No Action Required, but monitoring required. If Condition is close to caution Level close monitoring required, Repair action may require soon. If condition is close to hazard Level condition is hazardous, immediate action required. The vibration signals are recorded with periodic interval of 2 hours for a week's span and it was observed that as time increases the noise factor is getting introduced which increases the level of Vibration signal. The wearing of gears gives alarming signal in terms of increased vibration in along the axis and system as a whole. When applied to vibration signals, Kurtosis ability to enhance the signature of a fault is well known. From the results obtained in this work, it can be concluded that Kurtosis can be a very useful tool for reducing background noise and improving the visibility of explosions in vibration signals. Kurtosis may converge to a single spike and skewness is not suitable for high noise levels. A criterion based on both kurtosis and skewness may be used to overcome these disadvantages.

5. Conclusion

Detailed vibration measurements on gearbox with low background noise and vibration were performed and limits for caution and hazard level can be set for the said system. Rms values between normal level and caution level will show satisfactory working of system, if any rms value is between cautions and hazard level it shows critical fault in the system. It will be seen from the Table no. 3 and plotted data as shown in Fig. 2 shows that the statistical variables can be used to identify the various types of defects present in the test gearbox. For this purpose it is possible to use the plot of skewness, kurtosis and crest factor for fault diagnosis.

This study also reveals that using the statistical parameters of skewness, kurtosis and crest factor is very useful to detect and identify defects in gearbox.

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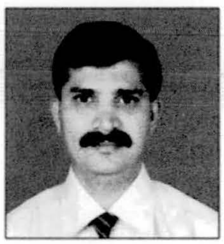

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