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Condition Monitoring of Gear Box by Using Motor Current Signature Analysis

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Abstract- Even though there is a number of condition monitoring and analysis techniques, researchers are in search of a simple and easy way to monitor vibration of a gearbox, which is an important power transmission component in any machinery. In gearboxes, load fluctuations on the gearbox and gear defects are two major sources of vibration. Further, at times, measurement of vibration in the gearbox is not easy because of the inaccessibility in mounting the vibration transducers. Techniques such as wear and debris analysis, vibration monitoring and acoustic emissions require accessibility to the gearbox either to collect samples or to mount the transducers on or near the gearbox. But dusty environment, background noise, structural vibration etc. may hamper the quality and efficiency of these techniques. Hence, there is a need to monitor the gearbox away from its actual location, which can be achieved through Motor current signature analysis (MCSA). An efficient and new but non intrusive method to detect the fluctuation in gear load may be the motor current signature analysis (MCSA). Motor current signature analysis (MCSA) has been the most recent addition as a non-intrusive and easy to measure condition monitoring technique. This analysis system can be used for measuring the characteristics for a perfectly working gearbox and use the data as a standard for measuring faults and defects in other gearboxes.

Index Terms- Motor current signature analysis, Condition monitoring, load fluctuations, Gear defects.

I. Introduction

GEARBOX are a critical component of all industrial processes and are frequently integrated in commercially available equipment and industrial processes.

The monitoring of a gearbox condition is a vital activity because of its importance in power transmission in any industry. Therefore, to improve upon the monitoring techniques and analysis tools for finding the gear ratios, gear faults, shaft misalignments in the gearbox and the current passing through the motor running the gearbox, there has been a constant improvement in these monitoring techniques. Techniques such as wear and debris analysis, vibration monitoring and acoustic emissions require accessibility to the gearbox either to collect samples or to mount the transducers on or near the gearbox. But dusty environment, background noise, structural vibration etc. may hamper the quality and efficiency of these techniques. Hence, there is a need to monitor the gearbox away from its actual location, which can be achieved through Motor current signature analysis (MCSA) which has already been successfully applied to condition monitoring of induction motor. Gearbox is an important machinery component in any industry. Any defect in gears lead to machine downtime resulting in a loss of production. A number of techniques have been applied in order to diagnose faults in gears. Fast Fourier transform (FFT) is a versatile technique using which the frequency contents of a signal can be found out. Randal and Hee [1] have cited the efficiency of cepstrum analysis in detecting the small sidebands of the tooth mesh frequency. Bayder and Ball [2] have compared acoustic signature with vibration signature using pseudo-Wigner–Ville distribution (WVD), whereas Stander et al. The objective of this article is to establish motor current signature analysis as the basis of condition monitoring of a multi-stage gearbox. The condition monitoring includes two major sources of vibration: load fluctuation and defects in gears. FFT analysis is used to correlate the components of steady vibration and current signatures. The demerit of this technique lies in the fact that good time resolution will give rise to poor frequency resolution and vice versa, as per the uncertainty principle. Hence, two different sets of data have been acquired to analyse the low-frequency components and the high frequency-components of vibration and current signatures.

II. BACKGROUND

THE Motor Current Signature Analysis (MCSA) is considered the most popular fault detection method now a day because it can easily detect the common machine fault such as turn to turn short ckt, cracked /broken rotor bars, bearing deterioration etc. The present paper discusses the fundamentals of Motor Current Signature Analysis (MCSA) plus condition monitoring of the induction motor using MCSA. In addition, this paper presents four case studies of induction motor fault diagnosis.[1] Modern rotating machinery often takes advantage of new designs of used gearwheels and rolling bearings. Usage of these new components enables machine to work quieter, increase its reliability, and lengthen working life. Machine vibration analysis belongs to important methods used for rotating machine conditions monitoring.[2] An automatic feature extraction system for gear and bearing fault diagnosis using wavelet-based signal processing. Vibration signals recorded from two experimental set-ups were processed for gears and bearing conditions. Four statistical features were selected: standard deviation, variance, kurtosis, and fourth central moment of continuous wavelet coefficients of synchronized vibration signals (CWC-SVS).[3] How current signature analysis can reliably diagnose rotor winding problems in induction motors. Traditional CSA measurements can result in misdiagnosis and/or false alarms of healthy machines due to the presence of current frequency components in the stator current caused by non-rotor related conditions such -as mechanical load fluctuations, gearboxes, etc. Through theoretical advancements, it is now possible to predict many of these components, therefore making CSA testing a technology that is much more robust and less error prone[4]. The main components in gear vibration spectra are the tooth-meshing frequency and its harmonics, together with sideband structures due to modulation effects. Sideband structures can be used as an important diagnostic symptom for gear fault detection. The main objective of the present paper is to unravel amplitude modulation effects which are responsible for generating such sidebands.[5]

III. MOTOR CURRENT SIGNATURE ANALYSES

A Common approach for monitoring mechanical failures is vibration monitoring. Due to the nature of mechanical faults, their effect is most straightforward on the vibrations of the affected component. Since vibrations lead to acoustic noise, noise monitoring is also a possible approach. However, these methods are expensive since they require costly additional transducers. Their use only makes sense in case of large machines or highly critical applications. A cost effective alternative is stator current based monitoring since a current measurement is easy to implement. Moreover, current measurements are already available in many drives for control or protection purposes. However, the effects of mechanical failures on the motor stator current are complex to analyze. Therefore, stator current based monitoring is undoubtedly more difficult than vibration monitoring. Another advantage of current based monitoring over vibration analysis is the limited number of necessary sensors. An electrical drive can be a complex and extended mechanical systems. For complete monitoring, a large number of vibration transducers must be placed on the different system components that are likely to fail e.g. bearings, gearboxes, stator frame, and load. However, a severe mechanical problem in any component influences necessarily the electric machine through load torque and shaft speed. This signifies that the motor can be considered as a type of intermediate transducer where various fault effects converge together. This strongly limits the number of necessary sensors. However, since numerous fault effects come together, fault diagnosis and discrimination becomes more difficult or is sometimes even impossible. A literature survey showed a lack of analytical models that account for the mechanical fault effect on the stator current. Most authors simply give expressions of additional frequencies but no precise stator current signal model. In various works, numerical machine models accounting for the fault are used. However, they do not provide analytical stator current expressions which are important for the choice of suitable signal analysis and detection strategies. The most widely used method for stator current processing in this context is spectrum estimation. In general, the stator current power spectral density is estimated using Fourier transform based techniques such as the periodogram. These methods require stationary signals i.e. they are inappropriate when frequencies vary with respect to time such as during speed transients. Advanced methods for non-stationary signal analysis are required.

IV. GEAR BOX FAULT ANALYSIS USING FFT BASED POWER SPECTRUM

A. Bearing fault analysis

THE bearing consists of mainly of the outer race and inner race way, the balls and cage which assures equidistance between the balls. The different faults that may occur in bearing can be classified according to the affected element are as follow,

1) Outer raceway defect.
2) Inner raceway defect.
3) Ball defect.

The relationship of bearing vibration to the stator current spectra can be determined by remembering that any air gap eccentricity produces anomalies in the air gap flux density. Since ball bearings support the rotors, any bearing defect will produce a radial motion between the rotor and stator of the machine. The mechanical displacement resulting from damaged bearing causes the machine air gap to vary in a manner that can be described by a combination of rotating eccentricities moving in both directions. Due to rotating eccentricities, the vibrations generate stator currents at frequencies given by

$$f_{bearing} = f_1 \pm m\, f_{io} \qquad (1)$$

where m=1,2,3,4……..and f_{io} is one of the characteristic frequencies which are based upon the bearing dimension

$$f_{io} = \frac{N_b}{2} \times f_r \left(1 \pm \left(\frac{D_b}{D_c}\right) \times \cos\beta\right) \qquad (2)$$

Where,
N_b = number of bearing balls.
f_r = mechanical rotor speed in hertz.
D_b = Ball diameter.
Dc = Bearing pitch diameter.
β = Contact angle of the balls on the races.

It should be noted from 2 that specific information concerning the bearing construction is required to calculate the exact characteristic frequencies. However, these characteristics race frequencies can be approximated for most bearings with between six and twelve balls.

$$f_o = 0.6\, N_b\, f_r \qquad (3)$$
$$f_i = 0.4\, N_b\, f_r \qquad (4)$$

Thus from above equation we can calculate expected fault frequencies for inner race fault and outer race fault at various load condition.

In order to diagnose the bearing fault of gearbox, above experimental setup will be use. The bearing of gearbox is single row, deep groove ball bearing, type 6206. Each bearing has eight balls. Experiments will conduct on four bearings; two of these are undamaged while two bearing will damage as shown in fig. 5.3 and 5.4.

Figure 1: Damage Bearing

B. Gear fault analysis

GEARS are used to transmit motion from one shaft to another or between the shafts. In most systems, the gear forms a part of the mechanical load that is coupled to an electrical device, which usually is an electric motor .Several faults can occur in the gear arrangement. A gear often consists of a pinion and a driven wheel. The motor is coupled to gear box. A gear defect such as a damaged tooth produces an abnormality in the load torque seen" by the motor. This abnormality is transferred to the motor current from the load. Depending on the abnormality, unique frequencies can be seen in the current frequency Spectrum. Mechanical oscillations in gear box changes the air-gap eccentricity results in changes in the air-gap flux waveform. Consequently this can induce stator current components given by

$$f_e = f_1 \pm m f_r \quad (5)$$

f_1 = supply frequency
f_r = rotational speed frequency of the rotor
m = 1,2,3.............harmonic number
f_e = current components due to airgap changes

As seen from above, mechanical oscillations will give rise to additional current components in the frequency spectrum. Gearboxes may also give rise to current components of frequencies close to or similar to those of broken bar components. Specifically, slow revolving shafts will give rise to current components around the main supply frequency components as prescribed by equation (5).

In order to diagnose the gear fault of gearbox, above experimental setup will be use. The gear of gearbox is spur gear. Experiments will conduct on two gears; one of these are undamaged while other will be were gear.

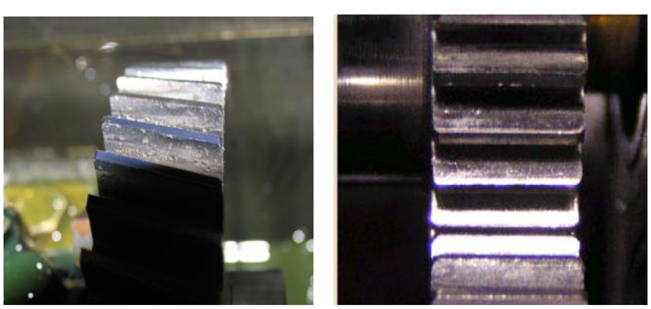


Figure 2: Were gear.

Figure 3: Gear tooth break

V. EXPERIMENTAL SETUP

IN order to diagnosis the fault of gear box, motor current analysis method use. Block diagram of these two experimental setup as shown in figure. Experimental setup consists of single phase DC motor, single stage spur gear box, Resistance, data acquisition card, Pentium-4 computer with softwear Labview. LabVIEW 2010 software is used to analyze the signals. It is easy to take any measurement with NI LabVIEW. The measurements can be automated from several devices and data can be analyzed spontaneously with this software. Data acquisition card are used to acquire the current samples from the motor under load. NI M Series high-speed multifunction data acquisition (DAQ) device can measure the signal with superior accuracy at fast sampling rates. This device has NI-MCal calibration technology for improved measurement accuracy and six DMA channels for high-speed data throughput. It has an onboard NI-PGIA2 amplifier designed for fast settling times at high scanning rates, ensuring 16-bit accuracy even when measuring all channels at maximum speeds. This device has a minimum of 16 analog inputs, 24 digital I/O lines, seven programmable input ranges, analog and digital triggering and two counter/timers. The PCI-6251 data acquisition card which is used in experiment.

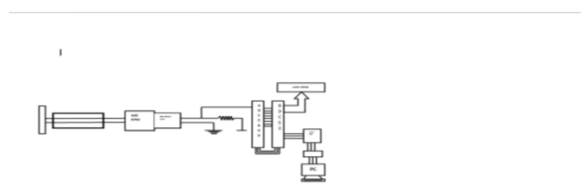


Figure 4: Experimental Setup

Table I : Expected fault frequencies for input shaft Inner race Of bearing at various load conditions

load	speed	frequency(fr)	frequency(f_i)	fault frequency m =1	fault frequency m =2
0	1000	16.666	79.99	79.99	159.99
2	890	15.833	75.98	75.98	151.968
5	830	14.80	69.19	69.19	138.38
8	830	13.834	64.38	64.38	128.76
10	770	12.60	59.29	59.29	118.58

Table II : Expected fault frequencies for input shaft outer race Of bearing at various load conditions

load	speed	frequency(fr)	frequency(f_i)	fault frequency	
				m =1	m =2
0	1000	16.6666	13.33	13.33	26.66
2	890	15.8333	11.46	11.46	22.93
5	830	14.80	9.8656	9.865	19.73
8	830	13.834	8	8	16
10	770	12.60	5.866	5.866	11.73

Table III :Expected fault frequencies for Input shaft wear gear at various load conditions

load	speed	frequency(fr)	fault frequency	
			m =1	m =2
0	1000	16.6666	16.6666	33.333
2	890	15.83333	15.83333	31.6667
5	830	14.80	14.80	29.66
8	830	13.834	13.834	27.66
10	770	12.60	12.60	25.66

Table IV: Expected Fault Frequencies for input Shaft one broken teeth gear at Various Load Conditions

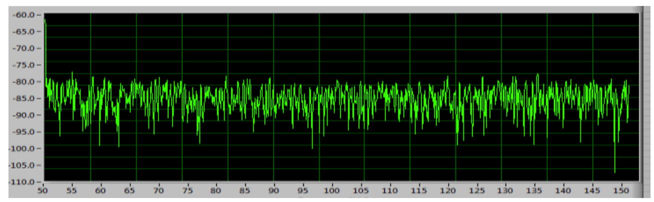
load	speed	frequency(fr)	fault frequency(mfr)	
			m =1	m =2
0	980	16.33	16.33	32.66
2	820	13.66	13.66	27.33
5	740	12.33	12.33	24.66
8	700	11.66	11.66	23.33
10	660	11	11	22

TableV: Expected Fault Frequencies for input Shaft two broken teeth gear at Various Load Conditions

load	speed	frequency(fr)	fault frequency(mfr)	
			m =1	m =2
0	910	15.25	15.25	30.50
2.5	760	12.66	12.66	25.33
5	680	11.33	11.33	22.66
8	600	10	10	20
10	550	9.16	9.16	18.33

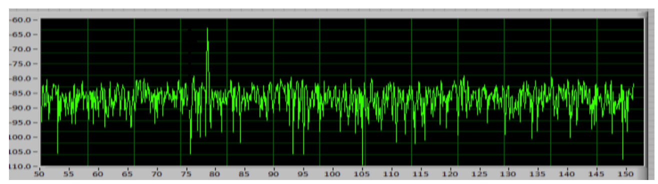
VI. RESULTS AND DISCUSSION

The experiments have been performed to detect bearing fault, wear gear, broken teeth gear in gearbox using Lab VIEW software. Gearbox is tested with three different defective conditions. Defective condition generates eccentricity in the air gap with mechanical vibrations. The air gap eccentricity causes variation in the air gap flux density that produces visible changes in the stator current. These changes are determined in power spectrums of motor due to different fault. Bearing fault, wear gear, broken teeth gear in gearbox are diagnosed under no load and full load.



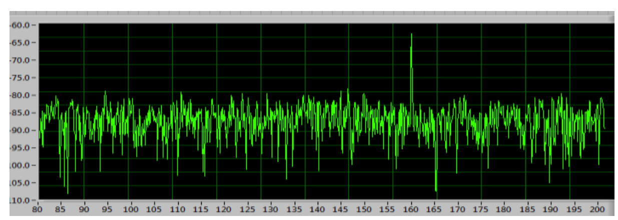
Frequency [Hz]

Figure5: Power spectrum of healthy gearbox under no load condition



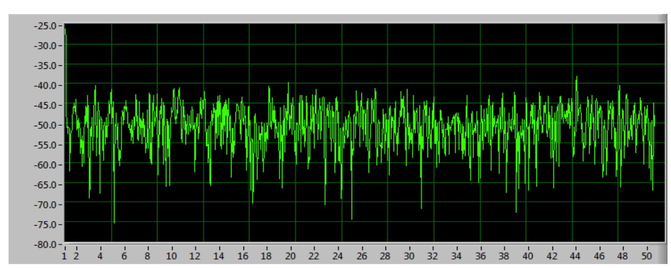
Frequency [Hz]

Figure6: Power spectrum of faulty gearbox with inner race of bearing under no load condition (m=1)



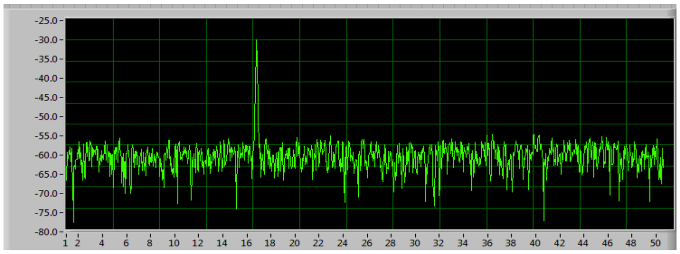
Frequency [Hz]

Figure7: Power spectrum of faulty gearbox with inner race of bearing under no load condition (m=2)



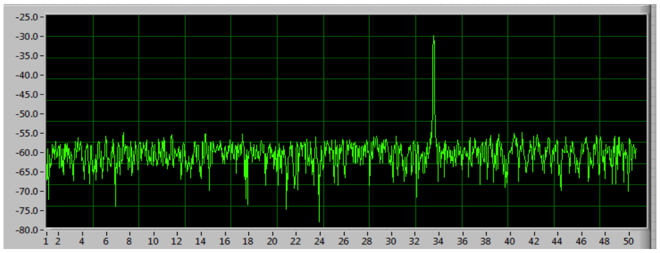
Frequency [Hz]

Figure8: Power spectrum of healthy gearbox under no load condition



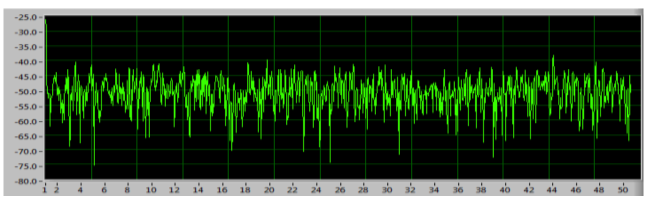
Frequency [Hz]

Figure9: Power spectrum of faulty gearbox with input shaft wear gear under no load condition (m=1)



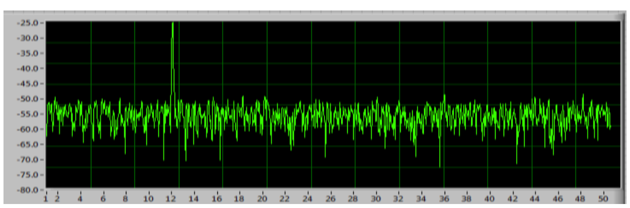
Frequency [Hz]

Figure10: Power spectrum of faulty gearbox with input shaft wear gear under no load condition (m=2)



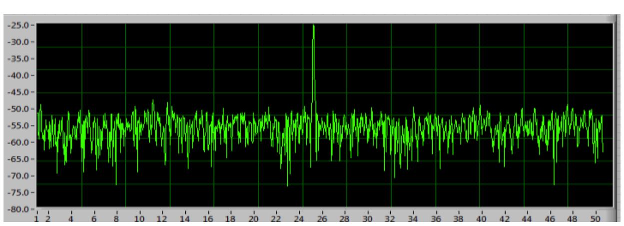
Frequency [Hz]

Figure 11: Power spectrum of healthy gearbox under 10kg load condition



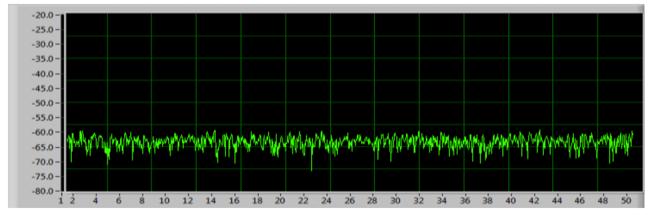
Frequency [Hz]

Figure12: Power spectrum of faulty gearbox with input shaft wear gear under 10kg load condition (m=1)



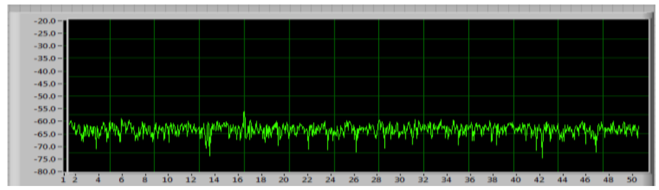
Frequency [Hz]

Figure13: Power spectrum of faulty gearbox with input shaft wear gear under 10kg load condition (m=2)



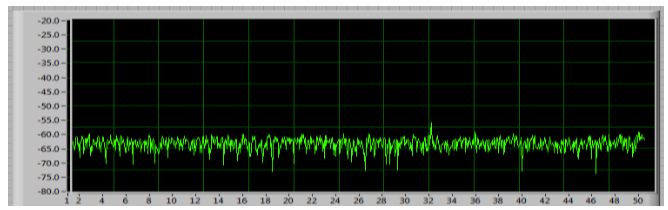
Frequency [Hz]

Figure14: Power spectrum of healthy gearbox under no load condition



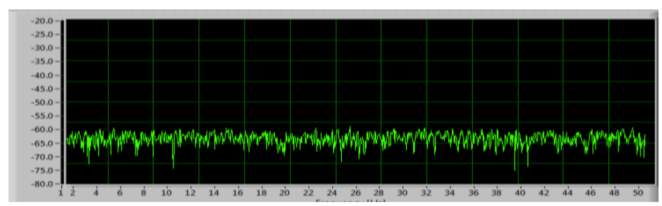
Frequency [Hz]

Figure15: Power spectrum of faulty gearbox with fault gear under no load condition (m=1)



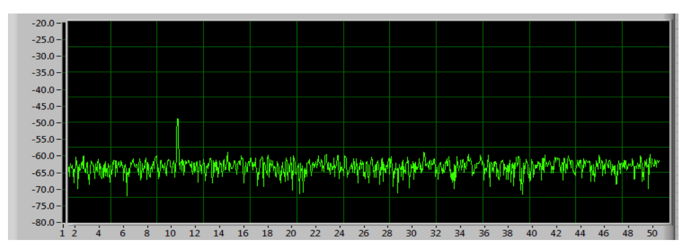
Frequency [Hz]

Figure16: Power spectrum of faulty gearbox with fault gear under no load condition (m=2)



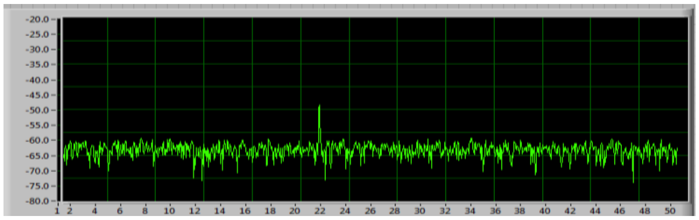
Frequency [Hz]

Figure 17: Power spectrum of healthy gearbox under 10 load condition



Frequency [Hz]

Figure18: Power spectrum of faulty gearbox with fault gear under 10 load condition (m=1)



Frequency [Hz]

Figure19 Power spectrum of faulty gearbox with fault gear under 10 load condition (m=2)

VII. CONCLUSIONS

The aim of this research is to advance the field of condition monitoring and fault diagnosis in gearbox operating under different load conditions. The common types of faults in gearbox are studied in the project. The various types of current based condition monitoring and fault diagnosis techniques are reviewed. The main aim of the research work is to diagnose the common mechanical faults experimentally with help of suitable signal processing techniques. In order to perform accurate and reliable analysis on gearbox, an experimental set up is designed that can accurately repeat the measurements of signals and can introduce a particular fault of the gearbox faults. In the present research work, Lab VIEW environment is used to diagnose the faults with direct online condition monitoring.

This research work investigates the feasibility of detecting mechanical faults such as bearing failure and wear gear failure, gear tooth broken failure using the spectrum of current of a motor. Defective bearings, wear gear failure, gear tooth broken failure generate eccentricity in the air gap with mechanical vibrations. The air gap eccentricities cause vibrations in the air gap flux density that produces visible changes in the current spectrum. The signal processing techniques FFT are applied to detect the bearing fault and gear faults of gearbox. Experimental results show that the characteristic frequencies could not seen in the power spectrum if bearing fault and gear fault are small in size. As severity of fault increases, the characteristic frequencies become visible. In the research work, an experiment has also been conducted to detect the gear box fault.

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