"Vibration Analysis of tooth failure in Gear Box by Condition Monitoring Technique"

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Abstract : Today most of the maintenance actions are carried out by either the predetermined preventive or the corrective approach. The predetermined preventive approach has fixed maintenance intervals in order to prevent components, sub-systems or systems to degrade. The concept of condition monitoring is to select measurable parameters on the machines, which will change as the health or condition of a machine. This paper deals with the technique of condition monitoring to be applied to selected gearbox to assess the condition of gear teeth. Any change in condition of gear such as wear, a crack, lack of oil or failure of tooth during working may cause a corresponding change in the motion. The signal for known defect is to collect by vibration accelerometer and sound pressure level probe during working of gearbox. By introducing gears of known faults, the vibration and acoustic spectrum can be collected by using Fast Fourier Transformer and the corresponding change in pattern is to compare with the signals obtained from gear without fault. These changes in signals than correlated to the faults of gear tooth.

Keywords: Condition monitoring, Vibrations, Gear box.

I. Introduction

1.1.Introduction to Condition Monitoring:

Productivity is a key weapon for manufacturing companies to stay competitive in a continuous growing global market. Increased productivity can be achieved through increased availability. Managing industries into the 21st century is a challenging task. Manufacturing productivity is found to be influenced by following major factors:

i) Greater availability of physical resources

ii) Improvements in the quality of the human resources

iii) Improved manufacturing methods and techniques.

It is the later sector of manufacturing, to which condition monitoring contributes significantly.Today, most maintenance actions are carried out by either the predetermined preventive or the corrective approach. The predetermined preventive approach has fixed maintenance intervals in order to prevent components, sub-systems or systems to degrade. The concept of condition monitoring is to select measurable parameters on the machines, which will change as the health or condition of a machine. Regular monitoring is done and the change is detected.

1.2.Thermography:

Electrical departments were the first to benefit from the user of thermal imaging cameras to obtain the temperature distribution maps, looking for a hot spot from the loose connection. The technique is being widely used to look at the pipe work vessels, as well as bearing and couplings. The cameras are getting smaller, lighter and the quality is better all the time.

Table 1.1: Available condition monitoring and diagnostic techniques

A. Acoustic Monitoring	B. Vibration Monitoring
a) Microphone	a) Overall monitor
b) Spectral analysis	b) Spectral analysis
c) FFT/ Zoom FFT	c) Discrete frequency monitoring
	d) Shock pulse monitoring
	e) Signal averaging
C. WEAR DEBRIS ANALYSIS	D. VISUAL INSPECTION
a) Ferrography	a) Radiography

b) Inductive sensors	b) Eddy current
c) Capacitive sensors	c) Ultrasonics
d) Spectrography	

1.3.Wear Debris Monitoring:

The condition of critical component surfaces subject to loading and relative movement is assessed from wear debris, which they generate. They are usually oil washed components, and the collection and analysis of debris is done via lubricating oil.

Available condition monitoring and diagnostic techniques are listed in Table 1.1 and the selection of the condition monitoring technique is given in Table 1.2

Table 1.2 Condition monitoring technique selectors.

	Vibration Analysis	Acoustic Analysis	Acoustic Emission	Debris Analysis	Thermal Imaging	Corrosion Monitoring
Bearing	YES	YES	YES	YES	YES	YES
Boilers			YES		YES	
Compressors	YES	YES		YES	YES	
Coupling	YES	YES				
Elevators	YES	YES			YES	YES
Escalators	YES					
Filters				YES		YES
Gearboxes	YES	YES	YES	YES	YES	YES
M/c Tools	YES	YES				
Pressure Vessels			YES		YES	YES
Pumps	YES	YES			YES	YES
Structures	YES		YES			YES
Transformers					YES	
Turbines	YES	YES	YES	YES	YES	YES
Welding			YES			
I.C. Engine					YES	YES

1.4.Gearbox Monitoring

1.4.1.Gearbox Diagnostic Techniques

There are number of causes, which leads to the failure of the gearboxes. The various techniques are discussed here under.

1.4.2.Noise and Vibration Sensing

Power losses in gearboxes are a normal consequence of less than perfect operating efficiency. These power losses result in energy dissipation as vibration and heat.

1.4.3.Acoustic analysis technique

In acoustical analysis technique either sound pressure measurement or sound intensity measurements are carried out. But sound intensity measurement is having distinct advantages.

1.4.4.Oil Debris Detection

While vibration analysis may allow one to infer gear faults, monitoring of the lubricating oil flow for metallic debris is a more direct method for the detection of wear and surface failure type faults in gearboxes.

1.4.5.Thermal Diagnostic Techniques

Perhaps the most economical monitor of gearbox condition is temperature. A rise in oil temperature increases the power loss in the gearbox. This is almost near to the failure. Parameters such as rate of temperature increase and the increase of this rate (temperature "acceleration") are useful in the detection in the final stages.

II. Objectives of the Paper

Condition monitoring emerged from being critical need into mainstream and widespread use as a critical element in the management strategy of companies operating rotating machines all over world. However, it is historically been bogged down in a focus on the technology involved in making the measurements, and not on achieving financial benefits.There are still improvements are made, and although many will come with the help of a computers and associated technologies.

2.1.Future Scope of Work

In this paper, the technique of condition monitoring is applied to selected gearbox to assess the condition of gear teeth.It is well known that any change in condition of gear such as wear, a crack, lack of oil or break will cause a corresponding change in the motion and hence in the vibration acoustic pattern. These signals for known defect are collected by vibration accelerometer and sound pressure level probe (microphone) during working of gearbox. The gear box is considered as a linear mechanical system and an individual meshed gear vibrate and produces sound which propagates from individual meshing gears to measuring points which is in gear box casing.By introducing gears of known faults, the vibration and acoustic spectrum are collected by using Fast Fourier Transformer (FFT) and the corresponding change in pattern is compared with the signals obtained from gear without fault. These changes in signals are correlated to the faults of gear tooth.The main focus of the paper as shown here is:

1. To prepare a test set up with different faults in gears and problem in gear box that can be detected without dis-mentling any gearbox for the diagnosis of faults.
2. To match the FFT results with concerned faults to prove the correctness of condition monitoring is successfully conducted.
3. To create particular precise defects in gear box system.
4. To learn use of FFT instrumentation to know its various applications.

III. Vibration and Sound Measurement

The measurement of vibration sound and its characteristics plays an important role in development of a systematic approach to vibration and acoustic analysis as shown in Fig.3.1. and Fig.3.2. In particular, the measurement of overall vibration and sound levels can be used to determine compliance with regulations. These measurements can also be used to assess the effectiveness of various condition monitoring technique and to establish realistic goals.

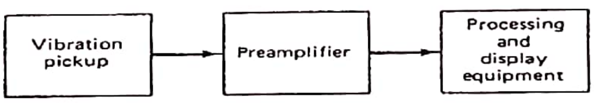

Fig.3.1. Basic vibration measurement system

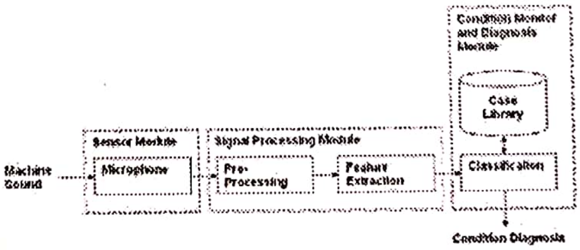

Fig.3.2. Basic sound measurement system

3.1.Causes of Machine Vibration and Sound

To generate noise from machine the primary cause must be a force variation which generates a vibration (in components), which is then transmitted to the surrounding structure. It is only when the vibration excites external panels that the airborne noise is produced.

3.2.Overall Path of Vibration Noise

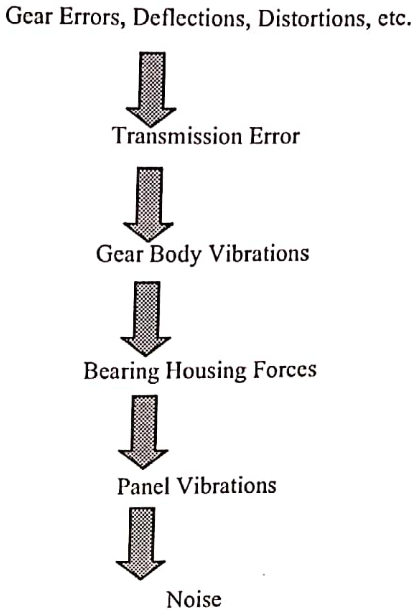

Fig.3.3. Path of Vibration and Noise in Gearbox

3.3.Fundamentals of Vibration and Acoustics

3.3.1.Accelerometers

Accelerometers are seismic type transducers, which have to be attached to the vibrating object. Inside the accelerometer is a mass mounted on a spring and damper. These devices are used for the measurement of absolute vibration in those cases where a fixed reference for relative motion is not available as in the case of a moving vehicle. In many other situations measurement of absolute motion is easier and more desirable.

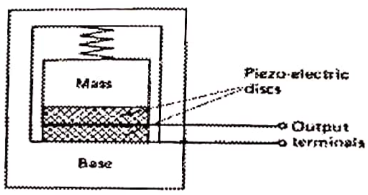

Fig.3.4. Constructional Features of Accelerometer

As shown in Fig.3.4., the transducer is attached to the object whose motion is to be measured. Inside the transducer, is a mass m supported on a spring of stiffness k and a viscous damper, with damping coefficient c. The motion of the mass relative to the frame or case gives an indication of the motion of the object and is the output of the instrument. These device may be used to measure acceleration at frequencies $\omega < 0.3 < \omega_n$. ω_n is the natural frequency of the spring mass system of the accelerometer. In case the value of frequency ω of the object is high, ω_n of the device should be high or a stiff spring should be used.

3.3.2.Acoustic (Noise) monitoring

The sound travels in the form of a longitudinal pressure waves . Noise is defined as unwanted sound . The audible frequency range of sound is from 20 Hz to 20 kHz.

3.3.3.Sound Pressure

The total instantaneous atmospheric pressure at a point, minus the static (average) pressure at that point. *p* is the symbol used for sound pressure. If the sound pressure is given in logarithmic or relative units, it is called sound pressure level.

3.3.4.Sound Pressure Measurement

Sound pressure measurement in decibels is defined as:

$$Lp = 10 \text{ Log } (P / Po)^2 \text{ dB}$$

where P is sound pressure measured and Po is the reference sound pressure measured of 20 micropascals. Pascal is N/m2. Reference value of 20 μPa is chosen as it is the quantity that represents the threshold of hearing of an average person. There should of pain occur at 100 Pa. The logarithmic scale of noise measurements is used to accommodate this large ratio. The sound pressure is a scalar quantity. In a free field condition (i.e. where there are no reflecting surfaces present) inverse square law applies according to which the sound pressure level decreases by 6 dB for each doubling of distance (i. e. if the SPL at 1 meter distance is 90 dB then at 2 meters it will be 84 dB)

The transducer for noise measurements is called a microphone. Two types of microphones are commonly used for noise measurements – condenser and electrolet type. Condenser microphones are of high performance and expensive. In the condenser microphone , its diaphragm is set in motion by sound pressure as shown in Fig.3.5.

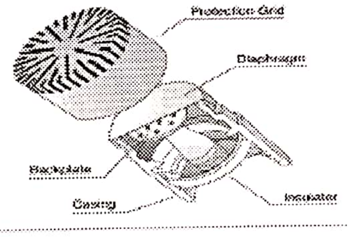

Fig.3.5. Microphone

IV. Gearbox Vibration And Noise

4.1.Causes of Gearbox Vibration and Noise

To generate vibration and noise from gears the primary cause must be a force variation (in the components), which is then transmitted to the surrounding structure. It is only when vibration excites external panels that airborne noise is produced.

4.2.Uniform Wear

There is sliding action between the contacting teeth on either side of pitch circle, but no sliding takes place at the pitch circle itself. Therefore the uniform wear tends to distort the harmonic nature of tooth mesh cycle and results into higher amplitudes of tooth mesh frequency and its harmonics.

4.3.Backlash

Excessive gear clearance or improper adjustment of backlash may result into frequency modulation and will give rise to excessive noise at gear mesh frequency. So far it has been assumed that the rotational speed of gear is constant, and tooth spacing perfectly uniform, but if either of the condition is violated, frequency modulation of the tooth meshing frequency may occur.

4.4.Cracked Tooth

As the gear rotates, the space left by the chipped tooth increases the mechanical clearance between the pinion and bull gear. The result is low amplitude sideband to the left of actual gear mesh frequency.

4.5.Broken Tooth

Broken tooth results mechanical clearance between the teeth. While shifting load from one tooth to another, impact is going to occur, this results in increase the noise of gear box.

4.6.Improper Lubrication

Proper lubrication is essential for gear box because majority of the problems arise due to lack of lubrication. Due to lubrication problem of is developed on the tooth flank, leading to rough gear mesh and rapid deterioration occurs in spectrum near meshing frequency. There will be increase in the amplitude of fundamental frequency and its harmonics due to improper lubrication.

4.7.Gearbox Internal Responses

When the internal responses of gearbox are considered, the input is relative vibration between gear teeth and the outputs (as far as noise is concerned) are the vibration forces transmitted the bearings to gear case. Internal responses are mentioned below

1. Gear Defects
2. Bent shaft
3. Misalignment
4. Effect of bearing characteristics
5. Type of housing

V.Test Criteria And Specification

Extensive experimentation will be done in laboratory for measurement of vibration and sound pressure level. Keeping in view the financial constraints a commercially available geared motor is chosen for experimentation eliminating the need of a separate costlier gearbox. For giving the rated load on geared motor, a rope-brake dynamometer is used, where by varying load the power can also be varied and it is easy to achieve the same condition for taking readings for different gears.

It is decided to make deliberate faults, such as wear, crack on one tooth of gear, and one tooth broken or missed on spur gear and lack or no lubrication of the gearbox. The analysis of vibration and acoustic signals of each fault is carried out separately. For that purpose, gears of same specifications is procured. And on each gear separate faults are made. The vibration and acoustic signals of each faulty gear and gear without any fault is obtained. Thus the signals obtained is analyzed which are valuable for fault diagnosis.

5.1.Experimental Setup

The schematic diagram of vibration and acoustic measurement for fault diagnosis of gearbox shown in Fig. 5.1 and a line diagram in Fig.5.2. The geared motor is rigidly mounted on concrete foundation to isolate vibration and acoustics from foundation.

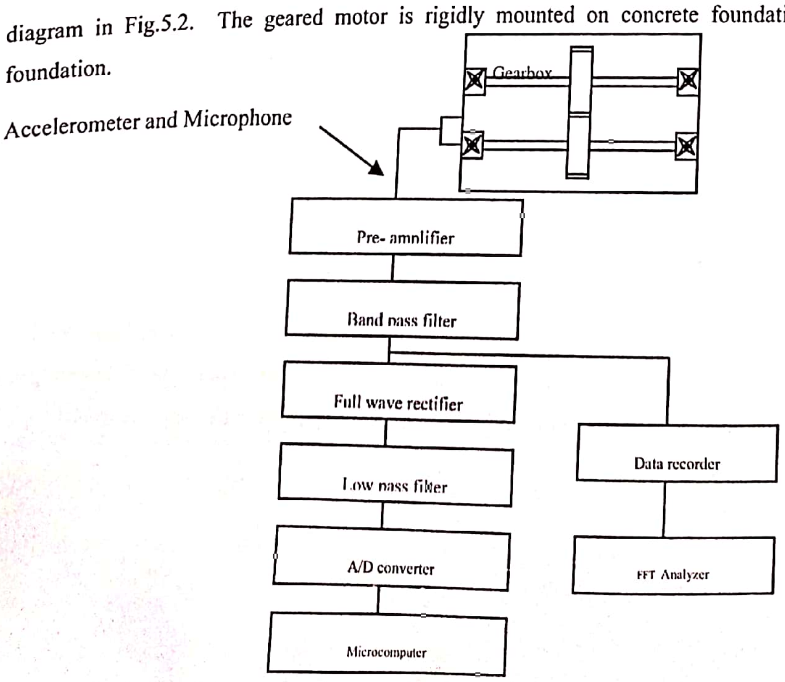

Fig. 5.1. Schematic Set Up For vibration and Sound pressure Measurement

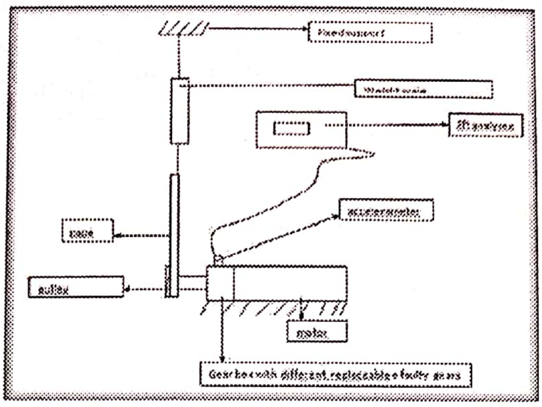

Fig.5.2. Line diagram for vibration and sound pressure measurement

specfication of the Instruments

The equipments, which are used for carrying out the experimental procedure with their specifications, are explained below;

Geared Motor

Gearbox is the main part used for the experimentation. Here the geared motor of following specification is selected.

1) The specification of the motor:

Make:	Shri Shakti
Make No:	SGO/63/4/B3
Motor type	Squirrel cage induction motor
Phase	3 Phase
Power	0.18 kW/ 0.25 Hp.
Operating Voltage	400/440 volts
No. of cycles	50
Supply	AC supply
Insulation	B class
Type of mounting	Horizontal foot mounted

2) The specifications of gearbox:

Power	0.25 Hp
Input rpm	1420 rpm
Input frequency	1420/60 = 23.67 Hz
Output rpm	200 rpm
Output frequency	200/60 = 3.33 Hz
No. of stapes	2 stage

Types of gears:

First pinion

Type	Spur
No. of teeth	12
Pitch circle diameter	18 mm
Module	1.5
Speed	1420 rpm

Rotational frequency (rpm/60) Hz $1420/\ 60 = 23.67$ Hz

Tooth meshing frequency (rpm x no. of teethes/60) Hz $1420 \times 12/\ 60$ = 284 Hz

First gear:

Type	Spur
No. of teeth	48
Pitch circle diameter	72 mm
Module	1.5
Speed	355 rpm
Rotational frequency	$355/60 = 5.92$ Hz
Tooth meshing frequency (rpm x no. of teeth /60)	$355 \times 48/60$ = 284 Hz

Second pinion:

Type	**Helical**
No. of teeth	19
Pitch circle diameter	32.37 mm
Module	1.7
Speed	355 rpm
Rotational frequency	355/60 = 5.19 Hz
Tooth meshing frequency (rpm x no. of teeth/60)	$355 \times 19/60$ = 112.42 Hz

Second gear:

Type	Helical
No. of teeth	34
Pitch circle diameter	57.8 mm
Module	1.7
Speed	200 rpm
Rotational frequency	200/60 = 3.33 Hz

Digital Frequency Analyzer (FFT)

For the experimental work the digital analyzer will used (Make- Larson-Davis, model is 2900B). Facility of selecting various parameters such as scale (linear or logarithmic), windows, base band ,filters and zoom analysis is available with this model .The specifications of FFT as below,

Make and model

Larson - Davis

2900B

Physical Characteristics-

Size -28 cm (width) x 19.7 cm (height) x 6.1 cm (thick)

Weight- 3.4 Kg

Input Characteristics-

Measuring range-10-200 dB

Impedance-10 GΩ

Polarization Voltage-0, 28, 200 VDC

Gain-30 to 90 dB in 10 dB steps

Analog Input filters -High pass 1 Hz, 20Hz

-Low pass 10 kHz, 20 kHz.

Digital Characterization-

Digitization-16-bit A: D per channel

Dynamic Range->80 dB

Amplitude stability- ± 0.1 dB

Fast Fourier Transform-

Lines – 100,200.400,800 line FFT analyser

Limit-Upper frequency limit: 20 kHz

Power-

Battery-Ni-Cd (Nickel- Metal Hydride)

DC Power-1.5 A @ 11 V and 0.5 a 216 V

Display Characteristics-

Internal LCD – Backlighting : Electroluminesent

-Resolution : 128 x 489 , with full

Graphics

External Display- 1,2 or 4 Display

Environmental-

Operating Temperature -10°C to 50° C

Acoustic Pickup (Sound Pressure Probe)

Condensor microphone is used for measuring sound pressure.

Vibration Pickup

As the acceleration signals gives good results for wide frequency range, the piezoelectric accelerometer was chosen for this work. The specification is given as follows.

Make- Dytron

Sensitivity- 10mV/g

Future Work

Creation of Faults on Gear Tooth

For creation of artificial faults on gear tooth, four different gears will be taken. For that, the spur gear having 48 teeth and module of 1.5 will be selected.

The common faults of gear tooth will be as follows.

1. Wear on one tooth
2. Crack on one tooth
3. One tooth broken or missed

4. Lack of lubrication

1. Wear: Wear on one tooth of gear will be made by filing one tooth and removing material from tooth in direction of rotation. The wear will be made near the pitch circle.

2. Crack on one Tooth: A crack will be produced on tooth of gear. This will be made by cutting the tooth with hacksaw blade at root of tooth in the direction of rotation.

3. Broken Tooth: For making this fault, one tooth of gear will be removed by hacksaw blade and original non-defective gear will be replaced with this gear.

4. Inadequate Lubrication or No Lubrication: Many times unsatisfactory operation of gearbox may be caused by failure of lubrication. To enable one to identify this condition an experiment will be carried out by completely darning lubrication oil from the gearbox. The gearbox will run for 15 minutes so that exact condition of no lubrication will be achieved.

Experimental Procedure

In experimental procedure the gearbox is to run at its rated power and speeds by applying different load condition of 0 kg, 2.5 kg, 5 kg, 7.5 kg on rope break dynamometer.

The positioning of sound pressure level probe will be done properly on the top of the gear under consideration for measuring sound pressure. For vibration measurement accelerometer will be kept on the top of gearbox.

By making all above arrangements, readings will be taken for non-defective gear and good lubrication condition. This data will be stored in FFT for further analysis.

Vibration and noise spectrums will be taken for gears having various faults and the data will be stored in computer for further analysis. For different condition of faults and different load conditions data will be collected.

VI.Conclusion

This paper highlights the various faults creation deliberately on spur gear of gearbox and acoustic pressure and vibration signatures. In this paper the faulty gear signatures compares with good gear signatures and an attempt is made to correlate them with their faults. The aim is to check the features of acoustic spectrum and vibration spectrum for different faults of gear tooth to condition monitoring and hence fault diagnose of gearbox.

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