Fault Diagnosis of Spur Gears by Analysis of Generated Vibration Signals

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Abstract: Condition monitoring and fault detection of gear transmission systems have attracted much attention in recent years. In this work the vibration analysis of spur gears is carried out. This work aims to investigate the correlation between vibrations produced and fault detection in spur gears. For this purpose an experimental test rig is fabricated. Two identical spur gears of known dimensions are taken in healthy and faulty condition. Vibration Signals of healthy spur gears are taken as standard. Readings were taken at two different rotational speeds and analysis is conducted. The whole research depends on the fact that during the meshing of two gears, cyclic vibrations are generated. The vibration signals of both gears are recorded with the help of piezo-electric device. These signals are then imported in digital signal process tool of Mat lab software .Finally the expected faulty frequency is captured and fault is detected. It is observed that vibration analysis is an efficient tool for fault detection of rotating mechanical components in its primary face to avoid their severe faults.

Keywords: Meshing frequency, Vibration analysis, Fault diagnosis, Spur gears, piezoelectric device.

I. INTRODUCTION

Condition monitoring is a perfect program in maintenance. Vibration Analysis VA is a key component of a Condition Monitoring program, and is often referred to as Predictive Maintenance (PdM). (VA) applied in an industrial or maintenance environment aims to reduce maintenance costs and equipment downtime by detecting equipment faults. .Vibration analysis can be used to detect the fault in early stage so reduces maintenance costs and increases up-time.There are many tools in VA for fault detection. Spectrum analysis is the most commonly used vibration analysis tool.As rotating mechanical components like gears are widely used, they are the object of interest of many researchers working in the field of condition monitoring. Many methods are devised to find an appropriate tool to enhance the fault diagnosis process as early as possible. An early identification of fault helps to reduce loss of time and severe damage to the machine.

This whole work depends on the fact that during the meshing of two rotating gears a periodic wave is generated which has a specific amplitude and frequency. The amplitude and frequency of the wave generated depends upon the velocity of both the meshing gears. Generally, a gear undergoes faults like spalling, chipping, pitting and crack etc. When two gears are running in healthy condition then it generates a vibration signature having a specific amplitude, phase frequency this wave is known as the Carrier wave & the frequency of this wave is the centre frequency called the carrier frequency. When a gear has a local fault then the vibration signal of the gearbox gets modulated.

There may be amplitude modulation or frequency modulation that are periodic with the rotation frequency of the gear. The modulation of the meshing frequency, as a result of faulty teeth, produces sidebands, which are frequency components equally spaced around a centre frequency. The important components in gear vibration signatures are the meshing frequency of the gear tooth and their harmonics along with the side bands (expected faulty frequency).

Amplitude modulations are present a gear meshes an eccentric gear or a gear running on a bent or shaft. Due to the local gear fault, the gear angular velocity could change as a function of the rotation.As a result of the speed variation, frequency modulations occur. In many cases, both amplitude and frequency modulations may present. Due to which the generation of sidebands takes place & the increasing in the number and the amplitude of such sidebands often indicates a rise in the faulty conditions. Since modulating frequencies are caused by certain faults of machine components, thus the detection of the modulating signal is very useful to detect gearbox fault. This paper proposes a technique for the fault detection which uses the analysis of vibration signals generated by pair of gears. This method is an very effective for the detection fault in the rotating machine component in its early stage.

II. DESCRIPTION OF THE EXPERIMENTAL SETUP USED

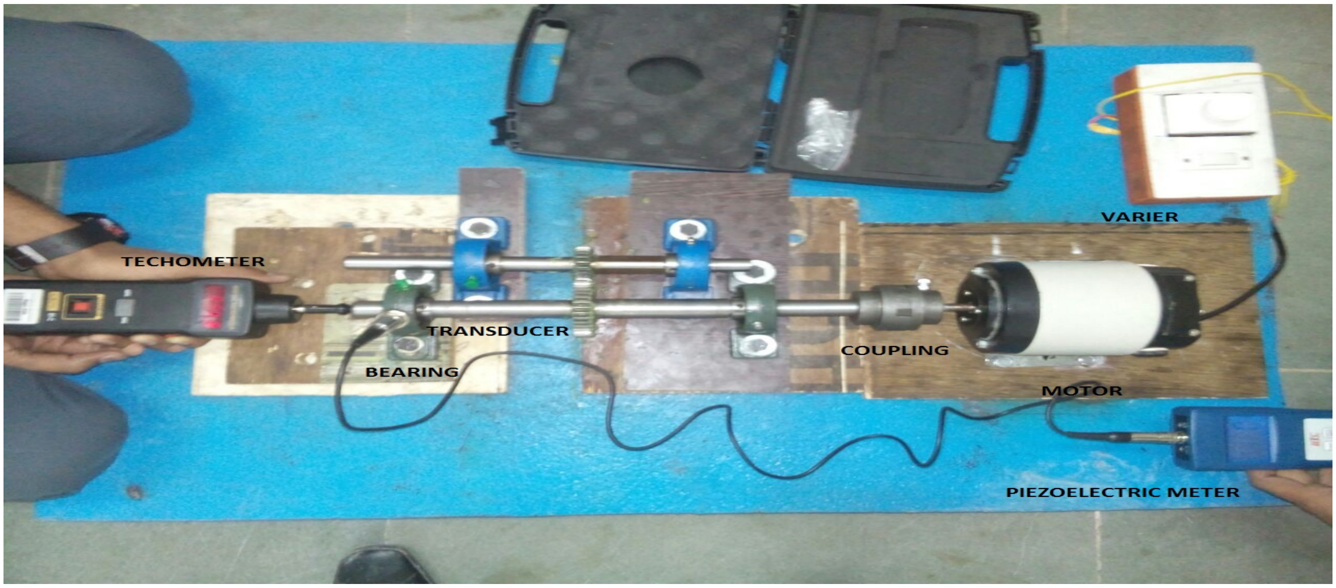


Image 1 : Pictures of the experimental test rig

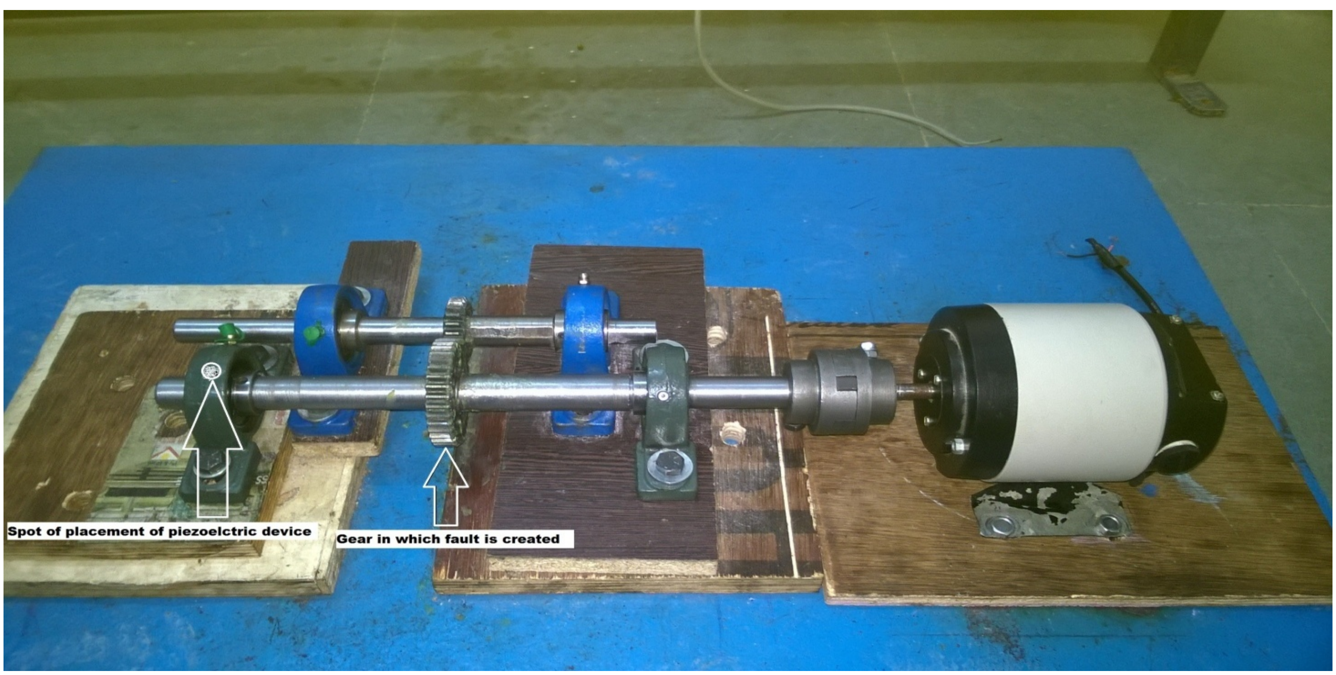


Image 2 : Spot where the piezo-electric device is placed

Table 1 : Details of the Experimental Setup

S.No.	Components	Dimension (in mm)
1	Diameter of driver (D1)	66.10
2	Diameter of driven (D2)	44.20
3	Center distance between shafts (O_1O_2)	54.87
4	No. of teeth on driver (T1)	35
5	No. of teeth on driven(T2)	23
6	Gear type	Spur
7	Gear ratio (G=T1/T2)	1.52
8	Bearing type	Roller
9	Shaft diameter of driver	22.18
10	shaft diameter of driven	18.80
11	Fault created	Half tooth cut Full tooth cut
12	Provision for mounting gear on shaft	Step turning
13	Loading Condition	Rope brake dynamometer
14	Heavy Iron base with rubber dampers	Better stability & machinability
15	Motor	1.5A/230V/6000 RPM
16	Coupling used	Flexible jaw coupling (3 jaw)

S No.	Components	Material	Quantity
1	Motor	-	01
2	Spur Gear	Steel	03
3	Nut & Bolt	Alloy steel	14
4	Rubber Dampers	Rubber	06
5	Iron Base	Iron	01
6	Coupling	Cast Iron	01
7	Pedestal Bearing	Cast iron	04
8	Dimmer	-	01
9	Shaft	Mild steel	03
10	Heavy Iron base	Cast iron thick plate	01

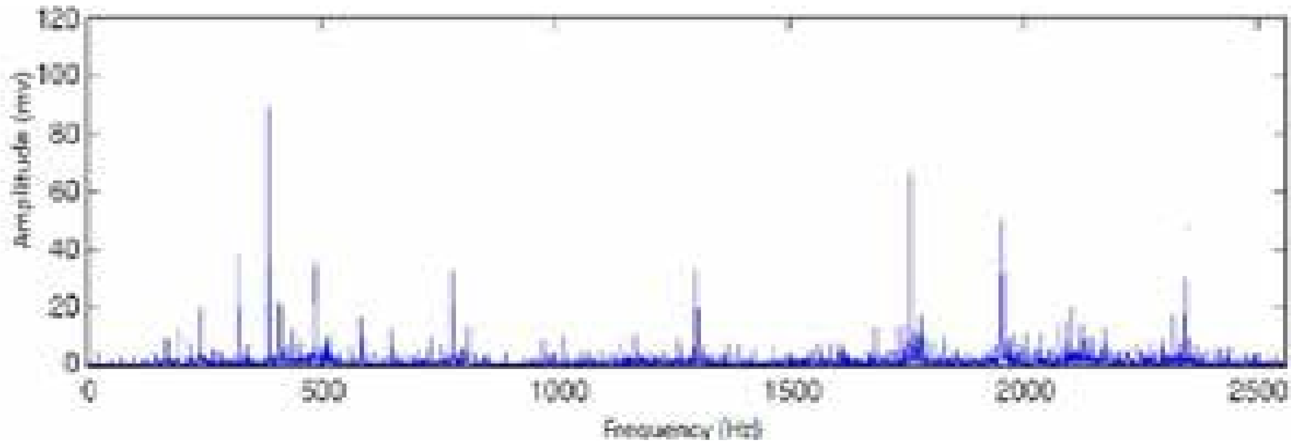
Image 3 : Picture of the driver gear in which fault is created

III. ANALYSIS OF GEAR VIBRATION SIGNALS COLLECTED

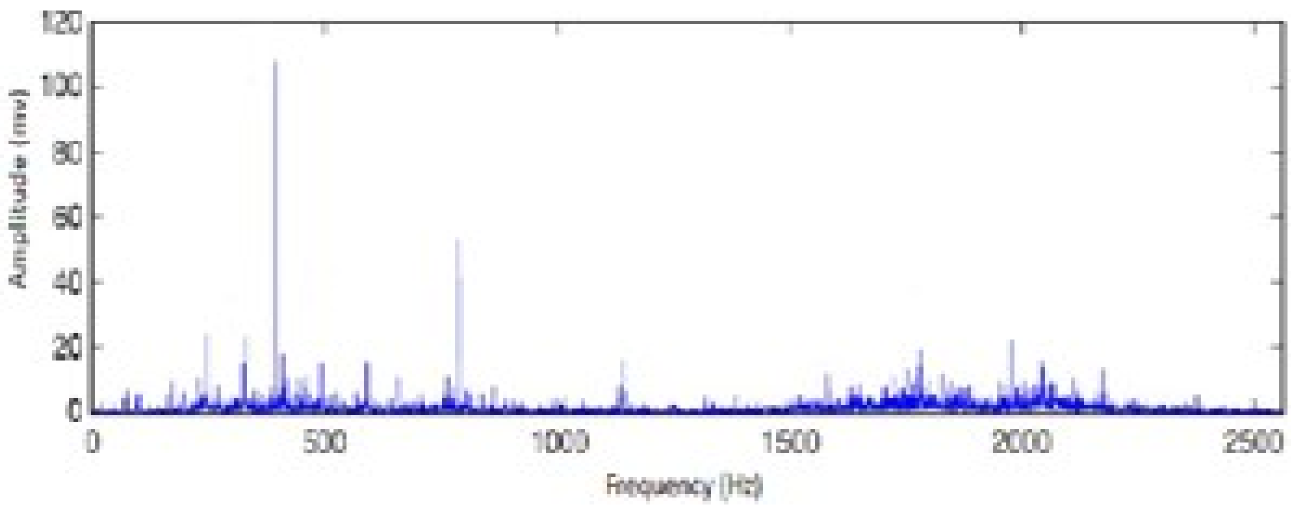
First of all the healthy gear & faulty gears (half portion of the tooth is chipped out i.e spalling) are mounted on the driver shaft one after another for this purpose the shafts and gears are provided by keyways. The vibration signals of the gears are collected at constant speed of 780 rpm.An accelerometer is used for this purpose and it is placed on the pedestal bearing supporting the shaft .The placement of the piezoelectric transducer is very significant while loading the vibration signals. This procedure is repeated at two different speed levels viz 970 rpm and 1850 rpm and the results are concluded. The speed of the shaft is measured by using an digital tachometer. The data is then feeded to MATLAB Software for its analysis then a Time domain signal is generated. As the it is very tedious to analyse the time –domain signal therefore it is converted into frequency-domain signal through FFT transform.

The vibration signatures of both the healthy & the faulty gear obtained in frequency-domain are:

Vibration Signature of the Healthy Gear in Time Domain.



Vibration Signature of the faulty Gear in Time Domain



IV. CALCULATION & OBSERVATION TABLE

Case-I: When speed of the motor is 970 rpm
Speed of driver shaft (N1) = 970 rpm.
Speed of driven shaft (N2) = 1470 rpm.
Frequency of driver shaft (F1) = N1/60 = 970/60 = 16.17 rps or Hz.
Frequency of driven shafts (F2) = N2/60 = 1470/60 = 24.5 rps or Hz.
Meshing frequency of driver shaft = T1*F1 = 35*16.17 = 565.95 Hz
Meshing frequency of driven shaft = T2*F2 = 23*24.5 = 563.5 Hz

Case-II: When speed of the motor is 1850 rpm
Speed of driver shaft (N1) = 1850 rpm.
Speed of driven shaft (N2) = 2810 rpm.
Frequency of driver shaft (F1) = N1/60 = 1850/60 = 30.84 rps or Hz.
Frequency of driven shafts (F2) = N2/60 = 2810/60 = 46.84 rps or Hz.

Meshing frequency of driver shaft = T1*F1 = 35*30.84 = 1079.4 Hz
Meshing frequency of driven shaft = T2*F2 = 23*46.84 = 1077.32 Hz

V. RESULTS AND DISCUSSION

S.No	PARTICULARS	ROTATING FREQUENCY (LOW FREQUENCY)		NO. OF TEETH		MESHING FREQUENCY (HIGH FREQUNECY)	
		SHAFT 1	**SHAFT 2**	**T1**	**T2**	**M.F= T*S.F**	**M.F= T*S.F**
1.	SPEED (r.p.m.)	970	1470	35	23	565.95	563.5
	FREQUENCY (r.p.s.)/ Hz	16.17	24.5				
2.	SPEED (r.p.m.)	1850	2810	35	23	1079.4	1077.32
	FREQUENCY (r.p.s.)/ Hz	30.84	46.84				
3.	SPEED (r.p.m.)	3000	4560	35	23	1750	1748
	FREQUENCY (r.p.s.)/ Hz	50	76				

VI. CONCLUSION

From the results we have concluded that only the amplitude of 13.85 Hz frequency has a significant difference from 14 mV to 25 mV in the final power spectrum signals and this 13.85 frequency is very close to the expected faulty frequency of 13 Hz.Thus,the results for the actual gearbox vibration signals shows the effectiveness of the method to extract the faulty signals buried in the noisy vibrations. This paper shows the importance of the co-relation between the vibration signatures of the machine component and machine's present condition. Also, the significance of vibration analysis in the field of condition monitoring is revealed. Any type of emerging fault in the gear box can be diagnosed in its early stage and its root cause may be sorted in a minimum time without hampering the running condition of a particular machine/set up. These fault diagnosis methods may play a vital role in industries where continous manufacturing is an important concern. Vibration analysis can be used as a troubleshooting tool to avoid failures.

VII. FUTURE SCOPE

After the successful application of this fault diagnosis technique for a rotating machine component in its early stage we can proceed with an aim to estimate the remaining useful life (RUL) of a component. Further which can be used to estimate its reliability.

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