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Detection of Gear Teeth Defect and Life Using Artificial Neural Networks

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***Abstract*— Gears are the most common means of transmitting power in mechanical engineering. This paper deals with to identify the defect the gear tooth. Experiments were carried out on Gear box. The input gear in the gearbox was intentionally faulted. For each gear configuration, tests were conducted. The experimental results show that due to the impact caused by the faulted tooth, strong sidebands arise around the meshing frequency in the spectra. At high severity level, the amplitudes of the sidebands may be even higher than that of the meshing frequency components. Artificial Neural Networks offer an efficient platform for devise condition monitoring strategies in machinery. Three-layer network architecture has been adopted. Back-propagation algorithm is chosen for network training due to its simplicity and faster convergence.**

I. Introduction

Gears are the most general type of machine component used in different machines to transmit power between two shafts with constant speed ration and they have to work with high performances. Unluckily, gears are subjected to defects due to that machine will failure and that leads to high maintenance cost, operating cost and production cost. That's why analysis is needed during service time. That in order reduces the production losses caused by the failure of machine component. The earlier analysis of gear defect produce more attention in the investigation of defects. Richmond, VA 23228, August, 2007 [1] proposed the vibration signature of gear tooth seeded fault has been studied in this tech note. Experiments were carried out on Spectra Quest's Gear box Dynamics Simulator (GDS). The test rig simulates a two-stage parallel gear transmission. The experimental results show that due to the impact caused by the faulted tooth, strong sidebands arise around the meshing frequency in the spectra. At high severity level, the amplitudes of the sidebands may be even higher than that of the meshing frequency components. N.S.Vyas and D.K.Padhy [2] proposed Artificial Neural Networks offer an efficient platform for devising condition monitoring strategies in machinery and plants where the number of components and processes are too many and complex to be mathematically modeled appropriately. Transformation and frequency domain display is done in Lab VIEW. Feature extraction from the frequency domain data, and network training codes are written in MATLAB. Three-layer network architecture has been adopted. Back-propagation algorithm is chosen for network training due to its simplicity and faster convergence. Zeping Wei, October, 2004 [5] investigates the characteristics of an involute gear system including contact stresses, bending stresses, and the transmission errors of gears in mesh. To estimate transmission error in

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a gear system, the characteristics of involute spur gears were analyzed by using the finite element method. The contact stresses were examined using 2-D FEM models. The bending stresses in the tooth root were examined using a 3-D FEM model. K.WORDAN and W.J.STASZEWSKI [6] proposed reports on the application of neural networks to the detection of local tooth faults in a spur gear. Acceleration vibration data and time domain averaged data are used to compute spectra which are used to classify different degrees of fault advancement. DING KANG, ZHIJIE WANG and YANCHUN WANG [7] expounds four different modulation phenomenon's such as gear tooth meshing modulation, gear natural frequency modulation, box resonant frequency modulation, and ball bearing outer race natural frequency modulation are caused by different extent exciting energy. This technique applies to the fault diagnosis of gear box.

II. TECHNIQUE USED TO FIND OUT TOOTH DEFECT

Vibro-test is a compact, portable, battery operated instrument for balancing, analyzing' and measuring vibration severity. It is designed to measure and evaluate mechanical vibration and helps in eliminating vibration problems in operational machines and equipment. It is suitable for all vibration measuring tasks required during manufacturing, quality control and testing of machines, and during installation and start-up. Vibro-test combines 5 functions into one measuring unit

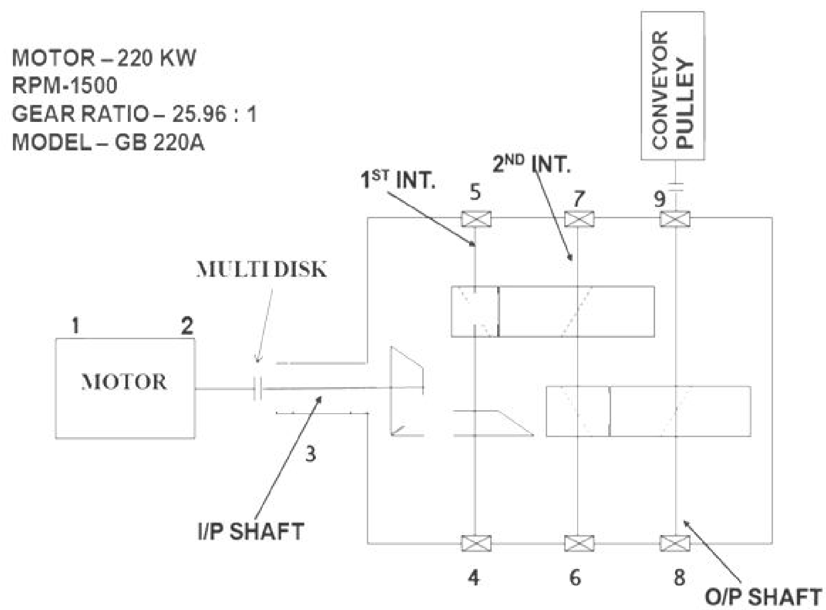

Fig. 1. Layout of Conveyor Gear Box

A. *Readings Fallowed at Initial Condition*

These are the vibration readings of gear box taken at all positions when it's at good condition (no noise from gear box).

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TABLE I: INITIAL VIBRATION READING (MM/SEC)

Directions	MOTOR		GEAR BOX						
	1	2	3	4	5	6	7	8	9
Vertical	1.0	1.0	6.8	3.0	-	1.6	-	2.2	3.0
Horizontal	1.0	1.4	3.0	2.0	-	1.8	-	1.8	1.0
Axial	0.7	0.7	1.1	2.0	-	2.0	-	2.0	3.0

Here vibration readings can be measured by using Vibrotest sensors, those are arranged in three directions vertical, horizontal and axial directions. All these readings measured, when this gear box is at running condition also it's at good condition so that the Vibration readings are very less. All these measurements have taken with Vibrotest measuring device. Finally Route Map Spectrum developed for same readings. From that Spectrum graph vibration amplitudes identified for total frequency range.

Also another Route Map Spectrum developed after 2 months of successful running of gear box, (Because of increasing vibrations).

B .Readings After Six Months

These are the vibration readings of gear box taken at all positions after 6 months when it's at bad condition (More noise coming from Gear box). Then these three graphs were compared to identify the vibration levels.

TABLE II: VIBRATION READINGS AFTER SIX MONTHS (MM/SEC)

Directions	Motor		Gear Box						
	1	2	3	4	5	6	7	8	9
Vertical	1.6	2.8	24.9	10.0	12.0	10.0	9.0	7.0	7.0
Horizontal	2.4	2.8	20.0	9.0	9.0	8.0	7.0	8.0	8.0
Axial	1.6	1.8	16.0	14.0	18.0	12.0	16.0	10.0	14.0

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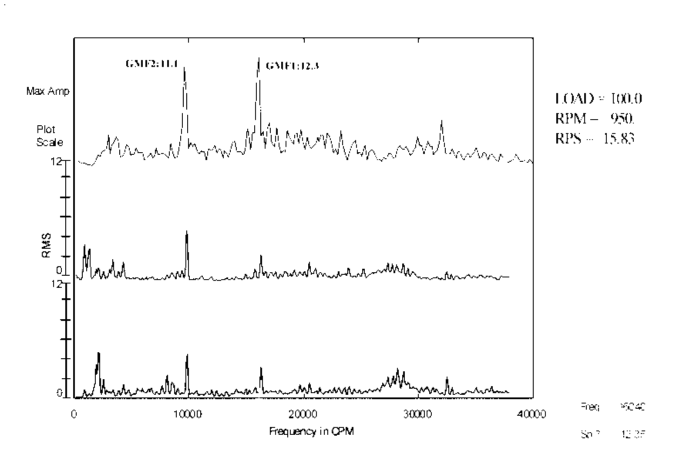

Fig. 2. Route Map Spectrums for Three conditions

From above three graphs we are observing that vibration amplitudes peak at both gear mesh frequencies. Where

- Gear mesh frequency at second pair is 9982CPM (11.1MM/S).
- Gear mesh frequency at first pair is 16490CPM (12.3MM/S).

So that vibrations at shaft increasing and reaches to maximum level (to 12.3 mm/sec). Due to this severe rattling sound coming from gear box also Multi disc crack age and Bearings were damaged. These damages were eliminated only by decreasing the vibrations. For that we brought some changes to the gear box.

III. INITIAL MAINTENANCE OR REDUCING VIBRATIONS

First Gear Box base frame has been changed. So that stiffness of Gear box increases, also bearings and multi disc. After that again Root map spectrum developed for re-modeled gear box, by comparing both spectrum graphs (Initial and to frame changed model), Then observed that peaks at gear mesh frequencies slightly drops with comparison of previous spectrum graph.

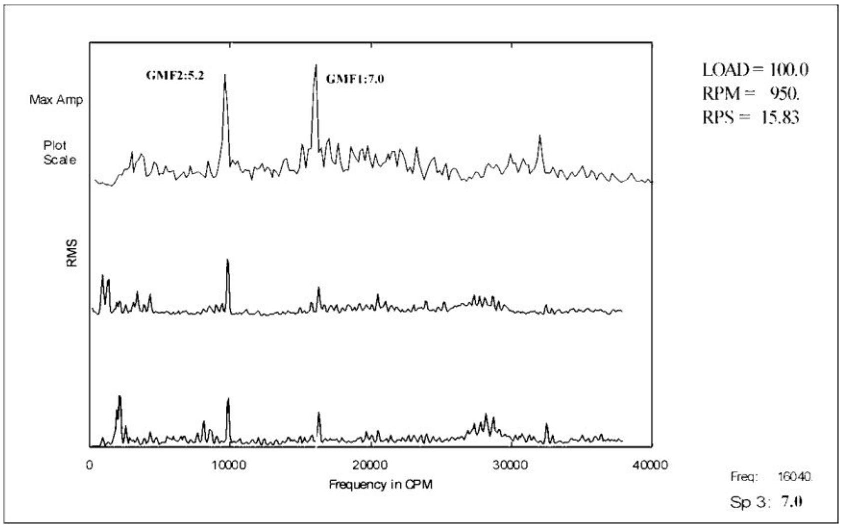

Fig. 3. Route Map Spectrum after Changing Base Frame & Input Gear

From the above graph we are observing that, Again problem remains same. Where

- Gear mesh frequency at second pair is 9982CPM (5.2MM/S).
- Gear mesh frequency at first pair is 16490CPM (7.0MM/S).

So that problem is not with base frame. Now we have to check whether defect is in bevel gear are not. As per gear manufacturing norms, in a perfect gear mesh, Minimum of 60% contact area, covering entire length of teeth for transmission of torque essential.

IV. ARTIFICIAL NEURAL NETWORKS

Artificial neural networks used to find out the tooth defect, it was a Multi Layer observation. The network was designed and trained using the Multi Layer observation package written by members of the Dynamics Group of Manchester. From this technique we successfully obtained the defect of the gear. Then the Bevel gear was replaced with proper matched gear. Again readings taken at all locations with three sensors those are as fallows. Also corresponding route map spectrum developed for modified layout, to find out how the vibrations.

TABLE III: READINGS AFTER PROBLEM RECTIFICATION (MM/SEC)

Directions	MOTOR		GEAR BOX						
	1	2	3	4	5	6	7	8	9
Vertical	1.0	1.0	7.0	3.0	-	1.6	-	2.2	3.0
Horizontal	1.0	1.4	3.0	2.0	-	1.8	-	1.8	1.0
Axial	0.7	0.7	1.2	2.0	-	2.0	-	2.0	3.0

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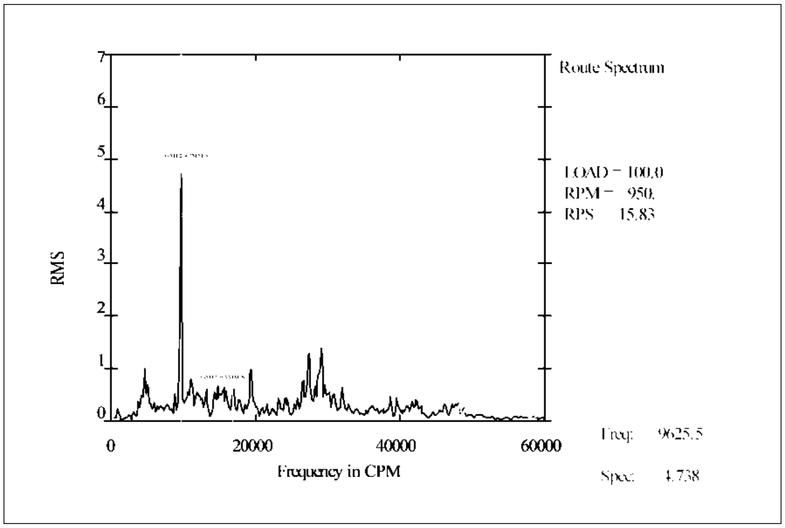

Fig. 4. Route Map Spectrum after Changing the Bevel Gear

From above graph we are observing that vibration amplitudes at both gear mesh frequencies are,

- Gear mesh frequency at second pair is 9982CPM (4.7MM/S).
- Gear mesh frequency at first pair is 16490CPM (0.6MM/S).

It is observed that after changing the input bevel gear no abnormal sound is coming from gear box, vibration levels also reduced and gear box is running smoothly.
By changing second pair of gears, it is observed that

- Vibration Peak at GMF2 also reduced and
- Overall vibration will further reduce

TABLE IV: SPECTRUM DATA INTERPRETATION

S.No.	Parameters	Old Value	New Value
1	Vibration peak at GMF 1 Reduced	12.3	0.6
2	Vibration peak at GMF 2 Reduced	11.1	4.7

V. NETWORK TRAINING AND VALIDATION

Set of vibration signals were acquired for each of the gear case. These sets were used as Input to Artificial Neural Networks training. This network consists of three layers they are input, hidden and output layer. All these layers contain nodes. For each gear condition 12 input and one output neuron was generated. Hidden layer neurons depend on the best solution by trial and error method. The 12 input neurons are as shown

TABLE V: HARMONIC NUMBERS TO GRAPH

Gear condition at First Month		Gear condition at Second Month		Gear condition at Sixth Month	
Harmonic Number	Peak Amplitude	Harmonic Number	Peak Amplitude	Harmonic Number	Peak Amplitude
I	4.8	I	3.1	I	3.1
II	4.5	II	4.7	II	11.1
III	3.1	III	2.1	III	12.3
IV	2.9	IV	1.7	IV	4.6

TABLE VI: DEDUCTION RESULTS

No of Hidden Neurons		6	7	8	9	10	11
Calculated Value	First output	0.949271	0.966381	0.979874	0.972273	0.974635	0.975386
	Second output	0.814086	0.845837	0.875876	0.854747	0.856687	0.861166
	Third output	0.252268	0.218490	0.179784	0.200594	0.206321	0.190562
Actual Value	First output	0.976	0.976	0.976	0.976	0.976	0.976
	Second output	0.656	0.656	0.656	0.656	0.656	0.656
	Third output	0.723	0.723	0.723	0.723	0.723	0.723
Health	First output	97.2%	99.0%	99.6%	99.6%	99.8%	99.9%
	Second output	80.5%	77.5%	74.8%	76.7%	76.5%	76.1%
	Third output	34.8%	30.2%	24.8%	27.7%	28.5%	26.3%

After successful Training, health of gears is calculated for three out puts of gear. By trial and error best result obtained at 11 hidden neurons. Here trial and error continued from 6 hidden neurons. By observing these results health increasing and reaches to 99.9%. So that best result obtained at 12 input neurons, 11 hidden neurons and 3 output neurons.

VI. CONCLUSION

In this investigation the developed Neural Network detect the health of gear. The data required for finding the health of the gear was obtained from Vibrotest. After replacing the faulted gears the same investigation was done on the layout and it is observed that of health increasing and reaches to 99.9% for a network layers of 12 input neurons, 11 hidden neurons and 3 output neurons by this the developed network provides an assessment for preventive maintenance of the gear box

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