DESIGN DEVELOPMENT AND FAULT DIAGNOSIS OF SPUR GEARBOX USING ARTIFICIAL NEURAL NETWORK

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Abstract: The aim of this work is to investigate the effectiveness of vibration analysis in an integrated machine condition monitoring maintenance program. To this end, a series of studies was conducted on a spur gearbox test rig. After a test under normal condition was conducted to obtain the baseline information, a number of different machine defect condition were introduced under controlled operating condition.

Key words: **spur gears, Bearings, SAE90 Grade Oil, Motor, ANN.**

I. INTRODUCTION

The mechanism which we use for transmission of generated power plays a major role. There are various forms of power transmission techniques e.g.: Gear drive, Belt drives, Rope drives, Chain drives etc. Gear drives are commonly applied in today's industries. People use them to meet various requirements. A Gear is a machine component, which is used to transmit mechanical power from one shaft to the other. Gear is a kind of machine element in which teeth are cut around cylindrical or cone shaped surfaces with equal spacing. It is useful for power transmission between two shafts. By meshing a pair of these elements, they are used to transmit rotations and forces from the driving shaft to driven shaft. Gears are one of the most used method of mechanical power transmission in the machines. Power transmission through gears have almost 100% efficiency. When two gears mesh, if one gear is bigger than the other, a mechanical advantage is produced, with the rotational speed, and the torques of the two gears differing in proportion to their diameters. The definite ratio that teeth give gears provides an advantage over other drives in precision machines such as watches that depend upon an exact velocity ratio. In cases where driver and follower are proximal, gears also have an advantage over other drives is the reduced number of parts required. A gear can mesh with a linear toothed part, called a rack, producing translation instead of rotation. An advantage of gears is that the teeth of a gear prevent slippage. Gears are compact in design and need less space, it provides large range of speed and torque for same input power. There is different geometry of gear which offers different advantages for varied applications. Good advantage is that it is a very good reliable service.

Other thing is gears are useful in transmitting power for parallel, non-parallel shafts, while belt or chain drive transmit power only when shafts are parallel. Gears have high life and efficiency than other drives. Due to the engagement of toothed wheel of gears, some part of machine may get permanently damaged in case of excessive loading. They are not suitable for transmitting motion over a large distance. Operating the gear is quite noisy. There is a close relationship between gear drives and the harmonic vibration. Even so-called "quiet drives" cannot be free of a certain amount of harmonic vibration. And no matter how well engineered they are.

II. SCOPE OF THE PROJECT

It is purpose to make vibration analysis of double stage spur gearbox, when both gear and bearing are defective. A condition monitoring set up is designed for analyzing the defect in outer race of bearing and damaged tooth of gear. MATLAB is used for feature extraction and neural network is used for diagnosis

III. METHODOLOGY

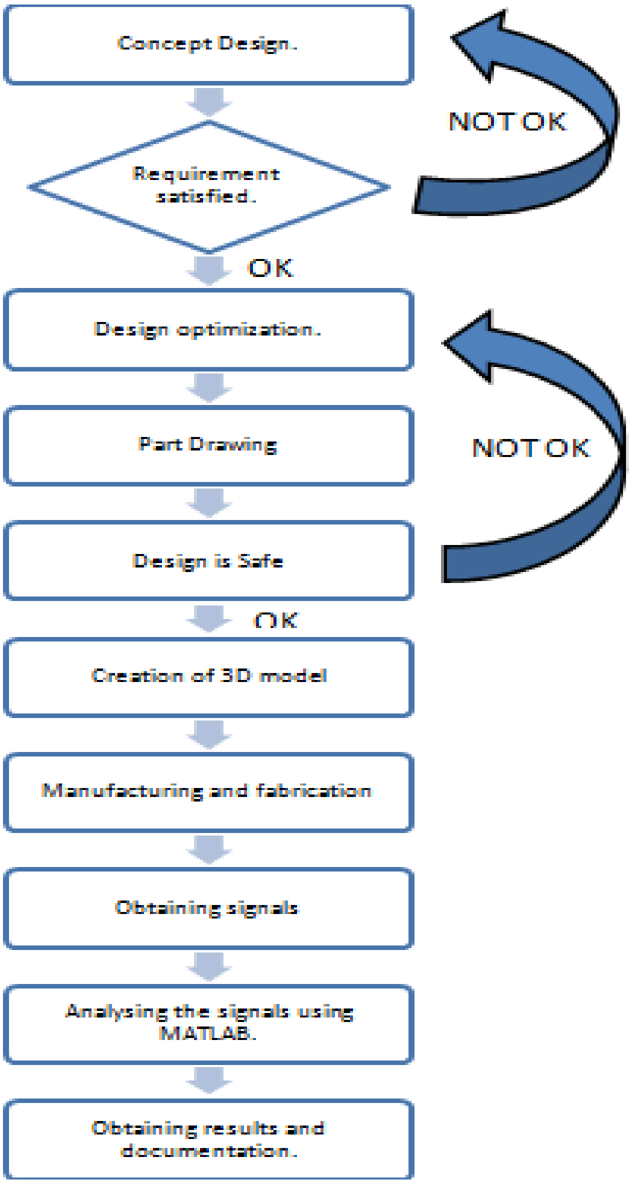


Fig:1 Methodology Steps.

3.1 COMPONENTS OF SPUR GEARBOX

Sl. no	Item	Quantity
1	Gears	2
2	Pinions	2
3	Bearings	10
4	Motor	1
5	Shafts	2
6	Hinged beam	1

Table 1: components of Spur gearbox.

3.2 EXPERIMENTAL WORK

Fig 2: Vertical milling of spur gear

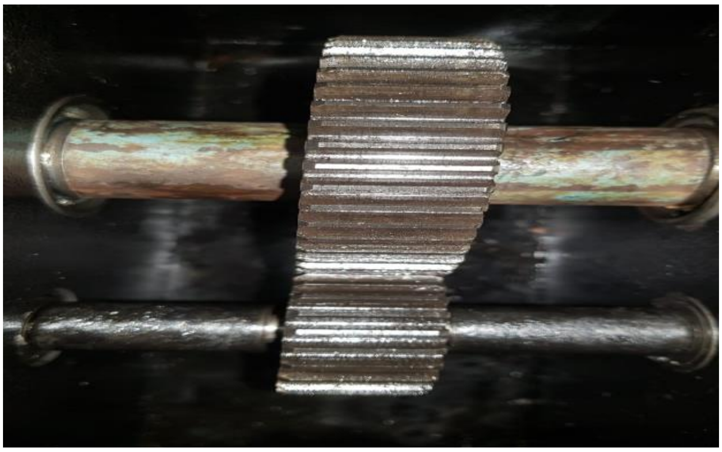


Fig 3: Assembled Spur gear

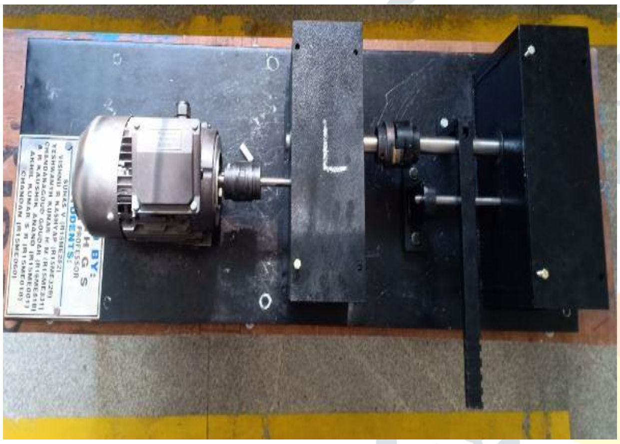


Fig 4: Top view of assembled gearbox

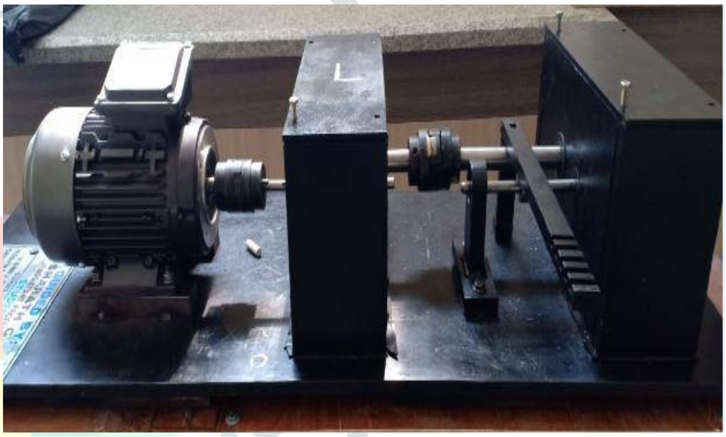


Fig 5: Front view of assembled gearbox

The aim of the experiment was to initiate and propagate wear under accelerated test conditions. Lubricant temperature, lubricant film thickness, vibration acceleration and tooth stiffness analyses were used in the detection and quantification of advancement of wear incurred by spur gear teeth. The experimental setup used for this study was designed in standard back- to-back arrangement.

The arrangement consists of two parallel steel shafts and four gears (two pinions with 12 and 24 teeth and the other two gears with 24 and 48 teeth) and a pair of pinions; gears have been assembled on either side of the shafts. The gear sets used in this experiment are made of En19 steel which heat treated for 1mm depth, 40HRC. The gears with 12 and 24 teeth had a module of 3mm and pressure angle of 20° FDI. The gears with 24 and 48 teeth had a module of 2mm and pressure angle of 20° FDI.

The setup consists of a 1 HP two stage spur gearbox. The gear box is driven by a 1 HP, 3-phase induction motor with a rated speed of 1500 rpm. The speed is controlled by sleeve gearbox and for the present study the motor is operated at 1500 rpm. In other words, the speed of gear shaft

in the first stage of the gearbox is 750 rpm. With a step-up ratio of 1:2, the speed of the pinion shaft in the second stage of the gear box is 1500 rpm.

Table 2 summarizes the specifications of the test rig.

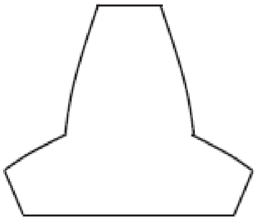
	First stage	**Second stage**
Number of teeth	12/24	48/24
Pitch circle diameter (mm)	36/72	96/48
Pressure angle (°)	20	20
Speed of shafts (rpm)	1500 (input) 750 (output)	750 (input) 1500 (output)
Modules (mm)	3	2

A piezo-electric accelerometer mounted to measure the vibration signals generated on the test gear box. The accelerometer outputs are conditioned using charge amplifier.

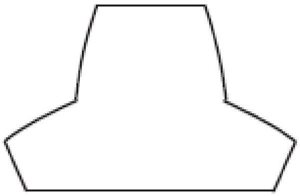
Overhaul time of a new gear box is more than one year. It is very difficult to study the fault detection procedures without seeded fault trials. The loss of a part of tooth due to breakage of tooth at root or at a point on working tip (broken tooth or chipped tooth). There are different methods to simulate faults in gearboxes. The simplest approach is partial tooth removal. This simulates the damage due to breakage at a point on the working tip. This type of fault is common in many industrial applications.

In the present experiment, depth wise damage is simulated on the spur gear tooth by wire EDM (Electrical discharge machining) technique.

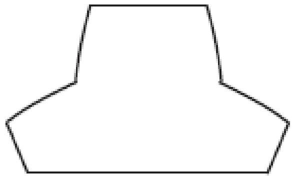
Five conditions of the gear are investigated such as: healthy gear and gear with four stages of depth wise tooth removal i.e. 0%, 25%, 50%, 75% and 100% tooth removal conditions across the tooth width. Fig. (a–e) shows healthy gear and tooth removal cases at different stages. For all operating conditions vibration signals are acquired and recorded after proper signal conditioning. The acquired signals are decomposed using ANN method developed in
MATLAB.



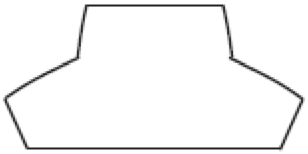
(a)



(b)



(c)

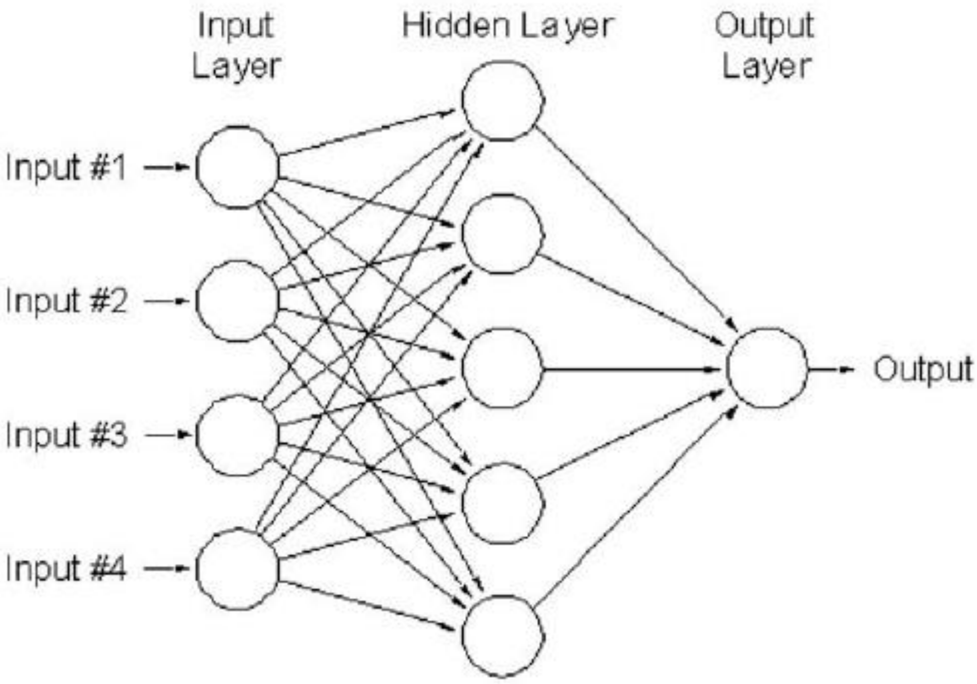


(d)

(e)

Artificial neural network (ANN)

The power of a neural model depends on how many neurons there are, how they are connected and how each neuron operates. In the following, the basic architectures of three ANN models, namely; FFBP, the functional link (FL), and the learning vector quantization (LVQ) are presented as they are used in this work.
The FFBP is a supervised algorithm consisting of the training and testing phases (Freeman and Skapura 1991, Bart 1992). Figure shows the architecture of the three-layer (FFBP)
ANN used in this research. Neurons in the input layer act as buffers for distributing the input feature data to neurons in the middle or hidden layer. Only one hidden layer was used in the present study. Each neuron in the hidden layer sums up its input signals after weighting them with the strengths of the respective connections and computes its output



ANN Architecture

ANN is one of the approaches to forecast and validate using computer models with some of the architecture and processing capabilities of the human brain. The technology that attempts to achieve such results is called neural computing or artificial neural networks. ANN mimics biological neurons by simulating some of the workings of the human brain. An ANN is made up of processing elements called neurons that are interconnected in a network. The artificial neurons receive inputs that are analogous to the electro-chemical signals that natural neurons receive from other neurons. By changing the weights given to these signals, the network learns in a process that seems similar to that found in nature. i.e., neurons in ANN receive signals or information from other neurons or external sources, perform transformations on the signals, and then pass those signals on to other neurons. The way information is processed and intelligence is stored depends on the architecture and algorithms of ANN. A main advantage of ANN is its ability to learn patterns in very complex systems. Through learning or self-organizing process, they translate the inputs into desired outputs by adjusting the weights given to signals between neurodes.

The proposed method diagnoses a gear box condition using ANN. A multi layered feed forward neural network trained with error back propagation was used. ANN's are characterized by their topology, weight vector and activation functions. They have three layers namely an input layer that receives signals from some external source, a hidden layer that does the processing of the signals and output layer that sends processed signals back to the external world.

V RESULTS AND DISCUSSION

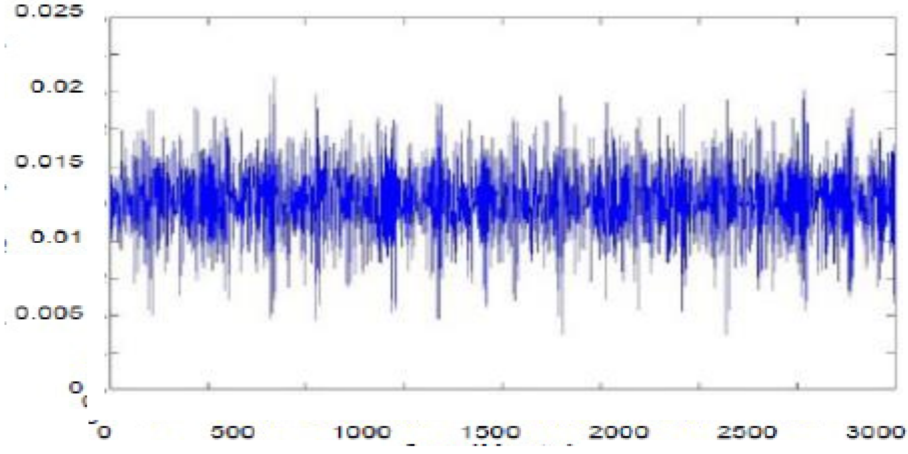
The architecture of the artificial neural network is as follows

Network type	Forward neural network trained with feedback propagation
Number of neurons in input layer	4
Number of neurons in hidden layer	Varied from 2 to 30
Number of neurons in output layer	1
Transfer function	Sigmoid transfer function in hidden and output layer
Training rule	Back propagation

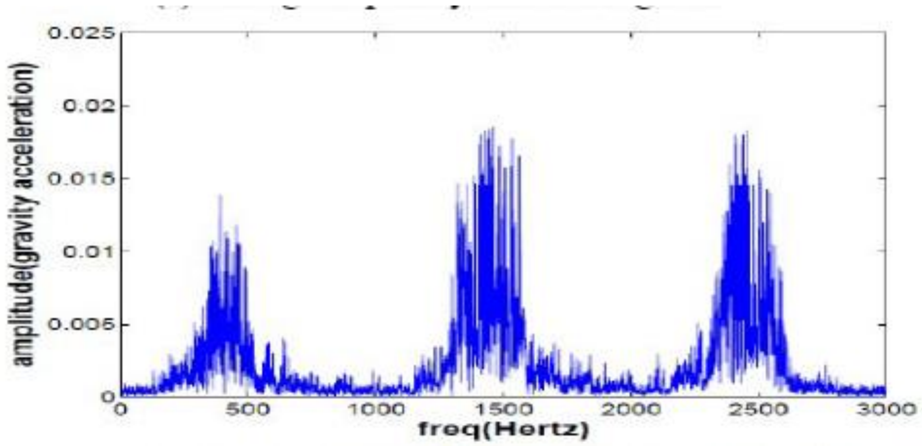
The efficiency of classification of gear box faults using above networks are reported in Tables. The RMS error corresponding to different neurons in hidden layer for all the six networks, respectively.

No. of neurons *In hidden layer*	RMS error	Training epochs	No. of data items	Number right	Number wrong	% Right	% Wrong
2	0.0212744	20,134	20	17	3	85	15
3	0.0479643	4234	20	19	1	95	5
4	0.145643	109,643	20	19	1	95	5
5	0.015954	14,506	20	18	2	90	10
6	0.0745217	8007	20	19	1	95	5
7	0.2565401	117,057	20	16	4	80	20
8	0.035429	10,775	20	19	1	95	5
9	0.2125693	3074	20	19	1	95	6
10	0.1956492	61,071	20	18	2	90	10
11	0.0986432	16,389	20	19	1	95	5
12	0.0176432	102,589	20	16	4	80	20
13	0.1959321	10,487	20	18	2	90	10
14	0.096543	2079	20	19	1	95	5
15	0.0169321	1989	20	19	1	95	5
16	0.0539342	10,189	20	18	2	90	10
17	0.1065431	20,467	20	18	2	90	10
18	0.515643	2067	20	20	0	100	0
19	0.095632	26,453	20	20	0	100	0
20	0.015432	50,512	20	17	3	85	15
21	0.065436	46,965	20	17	3	85	15
22	0.0735216	5064	20	18	2	90	10
23	0.0264321	4904	20	20	0	100	0
24	0.045432	6285	20	19	1	95	5
25	0.069432	14576	20	18	2	90	10
26	0.025621	10,567	20	18	2	90	10
27	0.0132671	4078	20	19	1	95	5
28	0.0256432	10,345	20	17	3	85	15
29	0.035432	4065	20	19	1	95	5
30	0.0065432	4779	20	19	1	95	5

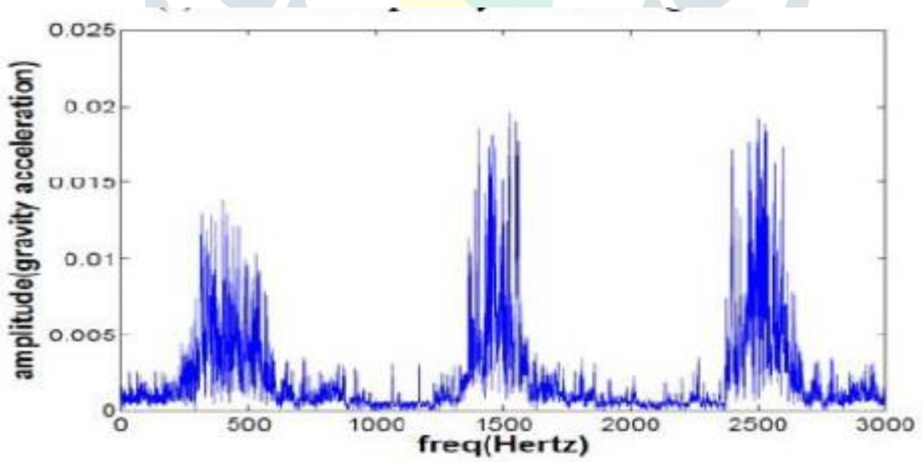
Signals Captured



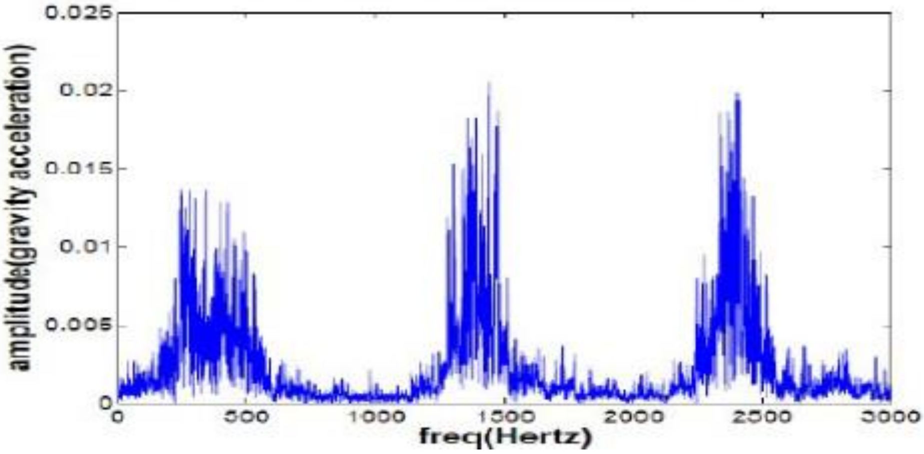
(a) Healthy Gear (0%) tooth removal removal



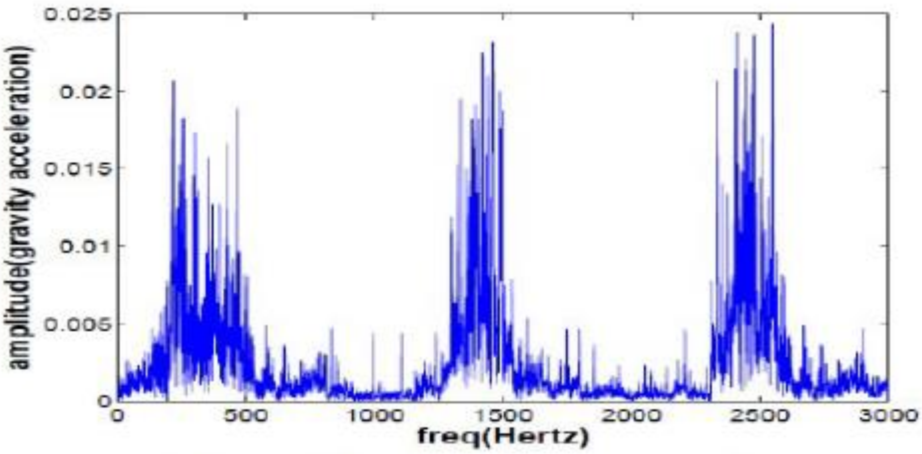
(b) Faulty Gear (25 %) tooth removal Gear



(c) Faulty Gear (50 %) tooth removal



(d) Faulty Gear (75%) tooth removal Gear



(e) Faulty Gear (100%) tooth removal

VI CONCLUSION.

An ANN techniques approach was proposed to improve the accuracy of prediction for spur gear. The results showed that FFBP was effective and this suggested technique attained 98% success in prediction and classification at high speed during training. The FFBP is found to be good during testing and gives very good result in prediction and classification. The present study concludes that FFBP is having better performance, prediction, classification, and less error. The architecture and topology of the network through specific systems can be used for online monitoring of gear box and to predict any causes of failure of spur gear operation.

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