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Research Article

Gear Fault Prediction by using Artificial Neural Network (ANN)–A Review

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Abstract

Basically in any rotating machinery so as to reduce the chances of complete breakdown due to severe fault conditions, it is necessary to monitor the condition for a scheduled time interval. Some of the traditional methods are complicated, time consuming and needs shut down of equipment for condition monitoring. Nowadays one of the most easy and renowned method used is experimental vibration analysis. In which, we record the vibrational signals in the form of time domain signals and use various prediction tools like Artificial Neural Network or Genetic Algorithm on the preprocessed raw signals. In this review paper, the basics related to fault prediction in case of a gear box by using Artificial Neural Network is discussed from the literature available.

Keywords: *Gear Fault Prediction, Artificial Neural Network, Experimental Vibration Analysis.*

1. Introduction

Gears are the most important mechanisms used for transmitting power, which plays an important role in many sort of machineries. Smooth operation and high efficiency of gears are necessary for the normal running of machineries. Therefore, gear damage assessment is an important topic in the field of condition monitoring and fault diagnosis.

Effective transmission is possible if the pairs don't have any sort of disorder in manufacturing and assembling. Some of the problems may cause improper working of gear pair or may create more noise and vibration. Some of those problems are as follows:

a. Deviations from ideal gear tooth profile,
b. Gear teeth manufacturing errors,
c. Deviations in the mesh angle,
d. Surface roughness of the gears,
e. Misalignment and looseness of the gears,
f. Gear eccentricity,
g. Wear of meshing surfaces,
h. Localized gear damage such as tooth wear, scoring, chipping and pitting, etc (C. Sujatha,2010).

In case of a complicated gear box, sometimes it becomes difficult to identify the fault. So the gearbox is to be disassembled and the faults are identified. But due to advances in research, it is possible to identify the fault in the gearbox just by taking observations from the accelerometer connected to FFT analyzer and analyzing the data collected. This will help to easily identify the fault condition and severity of the fault (Ajanalkar S. S., *et al*, 2015).

In practical condition, due to various vibrating elements like motor, bearing, foundation, rotating shaft, etc. it will becomes difficult to predict the exact fault condition. From literature it is observed that the setup can be developed to address the combined effect of gear defect and bearing defect on vibration signature in case of single gear pair. Also for proper condition monitoring, MATLAB is used for feature extraction and Artificial Neural Network (ANN) is used for fault prediction in case of single spur gear pair (Laxmikant S. Dhamande *et al*, 2016). From this literature it can be observed that the ANN tool is useful in fault prediction.

In one of the literature, the time domain data in the form of Continuous Wavelet Transform (CWT) is collected by conducting an experiment on the experimental setup by the use of FFT Analyzer. This collected data in the form of time domain is used for feature extraction into the statistical features like mean, standard deviation, root mean square, peak, skewness, kurtosis, crest factor, shape factor, clearance factor and impact factor. Also for reducing the complications due to many mathematical calculations, optimum features selection procedure is implemented on the basis of Genetic Algorithm (GA) and Rough Set (RS). These selected optimum features have been used as inputs for the further process. Using these input features, the Back Propagation Neural Network (BPNN, one of the ANN tool)classifiers and C 4.5 classifiers algorithms are used for predicting the fault condition

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in case of frosting, pitting and cracked gear defects. In this literature, the BPNN algorithm is prepared in MATLAB software. From this experimentation, it is observed that the BPNN approach is giving more classification accuracy than the C 4.5 classifier approach (Rajeswari C., *et al*, 2014).

2. Objectives

a. To study the gear fault diagnosis by using vibration analysis,
b. To understand the statistical parameters considered for fault identification,
c. To understand the various vibration signal preprocessing techniques,
d. To study fault prediction technique -Artificial Neural Network (ANN).

3. Gear Fault Prediction by ANN

For gear fault prediction by using ANN, some of the steps are to be followed. The methodology and details in methodology are discussed below:

3.1 Methodology

From literature it is observed that the flowchart shown below is to be followed for prediction of fault condition in gears (Sailendu Biswal, *et al*, 2016).

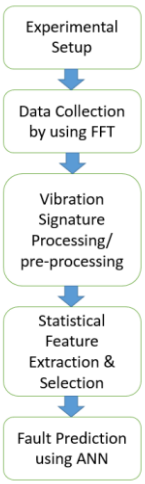

Fig. 1 Fault Prediction Methodology using ANN

3.2 Experimental Setup

As shown in the figure 2, the experimental setup is required along with accelerometer and Data Acquisition system like FFT analyzer with computer and supporting software. Here we can see that the electric motor is used as a prime mover and the shaft of electric motor is connected to the driving shaft of gear box by the use of coupling. Further the driven shaft of gear box is connected to the magnetic loader by using coupling and the torque sensor is provided on the shaft after coupling. Magnetic loader is used to apply the loading condition on the drive shaft of the gear box and torque sensor is used to measure torque conditions. The defective gear is placed inside the gear box whose defect condition has to be predicted. The accelerometer is placed on various positions of the gearbox and the data in the form of time domain is collected by the use of FFT analyzer (Renping Shao *et al*, 2011).

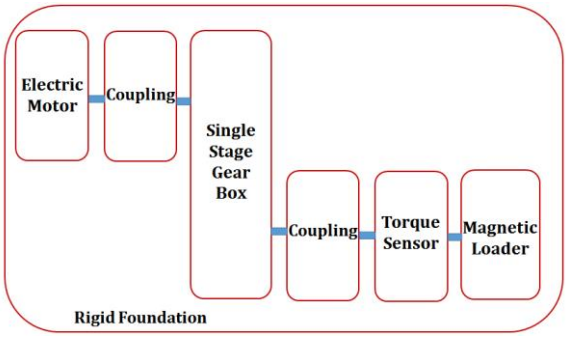

Fig. 2 Experimental Setup (Renping Shao *et al*, 2011)

3.3 Vibration Signature Processing Techniques

Various vibration signature processing techniques can be used for detecting and predicting the fault conditions in a gear box. As it is very difficult to judge the defect some of the modified signal processing techniques can be adopted along with Genetic Algorithm and Artificial Neural Network for simplifying the detection process. Some of the signal processing techniques enlisted below (Rusmir Bajric *et al*, 2011):

a. Time Waveform Analysis,
b. Analysis of Amplitude Modulations,
c. Cepstrum Analysis,
d. Time Synchronous Averaging Analysis,
e. Frequency Spectrum Analysis,
f. Wavelet Analysis.

3.4 Statistical Features

Usually the vibration data collected by the accelerometer and FFT analyzer is in the form of time domain. That collected time domain data can be utilized for fault prediction not only in case of gear fault but also in case of bearing faults and many more rotary components. These statistical features are also known as 'Condition Indicators (CI). Classification of CI is generally based on the data available as given below:

a. Time Domain Indicators,
b. Frequency Domain Indicators,
c. Time-Frequency Domain Indicators.

Some of them are enlisted below:

Root Mean Square (RMS), Crest Factor, Standard Deviation, Kurtosis, Shape Factor, Energy Ratio, Energy Operator (EOP), Zero Order Figure of Merit (FM0),

Fourth Order Figure of Merit (FM4), M6A, M8A, NA4, NA4*, NB4, Delta RMS, Sideband Level Factor, Sideband Index (SI), CAL4, Clearance Factor, Impulse Indicator, Correlated Kurtosis, Mean Frequency, Frequency Center (FC), Root Mean Square Frequency (RMSF), Standard Deviation Frequency (STDF), Spectral Kurtosis, Shannon Entropy, Fourth Order Normalized Power (NP4) (Vikas Sharma, *et al*, 2016).

3.5 Feature Selection Technique

Some of the statistical features are used as perfect indicators of the faults. It is observed from the literature that some are efficient to identify the defect correctly. Those are listed in the paper published by (Vikas Sharma, *et al*, 2016) and related data is given below in table 1.

Table 1 Statistical Features for Different Defects (Vikas Sharma, *et al*, 2016)

Sr. No.	Fault	Statistical Features / Condition Indicators
1	General Fault Progression	RMS, Delta RMS
2	Breakage, Wear	Kurtosis
3	Impulsive Vibration due to tooth break	Crest Factor
4	Heavy Wear	Energy Ratio
5	Scuffing, Severe Pitting	Energy Operator
6	Wear/Scuffing/pitting & tooth bending due to tooth crack	FM0, FM4
7	Progressive Damage	NA4
8	Misalignment	SLF
9	Pinion Quality Indicator	SI
10	Surface Damage Indicator	M6A, M8A
11	Localized Fault	NB4

Genetic Algorithm is one of the best suited methods to identify and select the optimum statistical feature for fault prediction by using ANN. Genetic Algorithm (GA) works on the 'Survival of the Fittest' principle. GA will going to perform the mathematical computations and will finalize the best possible statistical feature (or Condition Indicator, CI) to get the optimum solution. Further this selected optimum feature is used as input for the Artificial Neural Network (Rajeswari C., *et al*, 2014).

In one of the reference, Genetic Algorithm and GA based rough set approach is used for feature selection (Rajeswari C., *et al*, 2014).

3.6 Artificial Neural Network

Artificial Neural Networks are the algorithms which works similar as the brain works. They use the collected selective data in the form of patterns and convert it into predictive models. Neural Network is consisting of interconnected elements, which are also known as nodes. Each node is used for performing a part of complete task.

Basically a neural network is consisting of multi layers – input layer, hidden layer and output layer. This is also called as Multilayer perceptron. In this multi-layer structure, the hidden layer may consists of one, two or more layers in itself.

The features extracted are considered as independent variables, which are given as input to input layers as shown in figure 3. The hidden layer will take the inputs from the preceding layer and do mathematical computations along with the weights and bias parameters. The hidden layer node will process the mathematical computed value with an activation function and further it passes the values to the node in the output layer. This information output layer leaves it as predicted output. The network will compare the predicted value at the output with the actual value. If there is variation in the predicted value and actual value then again the weights in the middle layer are adjusted to improve the output value. Many iterations have to be performed to get the desired output. After getting the desired accuracy, the model can be used for fault prediction (Laxmikant S. Dhamande, *et al*, 2016).

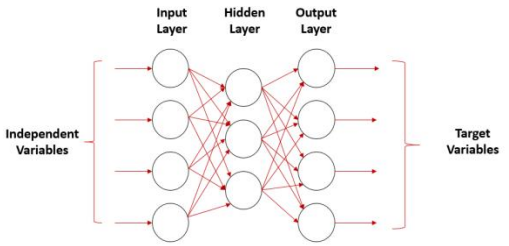

Fig. 3 Artificial Neural Network Model

As shown in figure 3, the independent variables are the inputs to the ANN and are the optimum feature extracted from the Genetic Algorithm (GA). The circles represents the nodes. Each node is connected by the previous and preceding nodes. The target variables are the outputs of ANN and are the predicted outputs. Those predicted outputs are compared with the actual values. Iterations are carried out until the difference between actual and predicted value will be minimum by varying the weights in the hidden layer, so as to create a perfect ANN model. After getting the efficient difference the ANN model can further be used to predict the different models.

In one of the literature, the author has collected 24 statistical features and used these features as input to the ANN algorithm. ANN is developed to find the combined effect of defective bearing and defective gear. In that paper, author has created a neural network of feed-forward type and trained the network by back propagation. The basic training of network is consisting of steps as followed:

a. Assemble the data,

b. Create the network object,
c. Train the network, and
d. Simulate the results.

In this, they have collected thirty sample readings for four different conditions viz. healthy gear and bearing, defective gear, defective bearing and defective gear and bearing. Out of thirty sample readings, for each readings they have extracted the twenty four features and out of thirty sample readings, twenty five samples are used to train the network and remaining five samples are used to test the ANN. The ANN is developed by using twenty three neurons, one hidden layer and four output neurons. Also the neural network is designed with MATLAB and ANN tool box. While training the response from the output layer is analyzed by varying the weights and number of hidden neurons. In this case, they have varied number of neurons in hidden layers from two to ten for improving the efficiency and the better results observed for three hidden neurons. From this literature, it is also observed that the classification of fault conditions like healthy gear and bearing, defective gear, defective bearing and defective gear and bearing. The accuracy of result findings is almost about 99.99 % is observed from the literature (Laxmikant S. Dhamande, *et al*., 2016).

Conclusions

From the literature in which Artificial Neural Network is used as fault predictive tool, various conclusions can be made. Some of those are as follows:

1) Artificial Neural Network is an algorithm based approach and can be used to accurately predict the fault conditions inside the gear box and in any rotating machinery.
2) For proper prediction of defects in gears by using ANN, the flow given in flowchart in figure 1 can be followed.
3) Also it can be observed that the Genetic Algorithm (GA) can be used as a optimum statistical feature selection tool for reducing the complications due to large number of mathematical computations.
4) For successful experimentation, proper setup is required. This can be possible by using the experimental setup given in figure 2.
5) For reducing the fault prediction time and complications due to more mathematical computations, Condition Indicators (CI) given in table 1 can be used.
6) FFT analyzer is an instrument used to collect vibration data and process the data. Which can be used for further calculation of the statistical features for giving as inputs to ANN.
7) The successful classifying the presence of different fault conditions like detection of combined gear and bearing fault can be possible with proper implementation of ANN.

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