Detection and Analysis of Faults in Gears using Frequency Domain and Artificial Neural Network

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Abstract - *Breaking down of gears, one of the most important machine components that are widely used in transmission design of automobiles and other rotating machinery, can cause heavy losses. This paper aims to present a processing technique used for the detection and analysis of faults in gears. A fault diagnosis test setup is made for experimental studies to accumulate vibration signal from a healthy as well as a simulated faulty gear which are processed to perform time and frequency domain analysis using the Fast Fourier Transform (FFT) with the help of LabVIEW. The results thus obtained are used to train the Artificial Neural Network in MATLAB to form a system that can detect faults in gears.*

Key Words: Fault analysis, gears, MATLAB, LabVIEW, healthy gear, faulty gear, time and frequency domain analysis, Fast Fourier Transform, Artificial Neural Network

1. INTRODUCTION

1.1 Background

The ubiquity of gears in rotating machinery has made the study of vibration a more interesting subject. One study found that 65% of gear box damage is thanks to faults within the gears (Allianz Versicherungs-AG, 1978). In engineering, they show a substantial number of various sorts of damage. The common types of gear damage mainly consist of pitting, scuffing, spalling, cracking and wear (Michel & Miller, 1983).

One of the main reasons for gear faults is excessive vibration. Vibration can be thought of as a ratio of the forces acting on the gear to its dynamic stiffness. The advantage of using vibration analysis for his or her monitoring and diagnosis has been demonstrated to achieve success since the first time due to the convenience of measurement. [9]

The approaches of gear vibration analysis are mainly subdivided into three categories consistent with analysis domains. [1] They are time domain, frequency domain and time-frequency domain. The time domain methods include time synchronous average and statistical analysis. The former may be a signal averaging process over an outsized number of cycles, synchronous with the running speed of a selected shaft within the gearbox. It can remove not only the background noise but also periodic events that are not exactly synchronous with the gear being monitored (McFadden, 1989; 1991). The latter consists of many descriptive statistics such as sample skewness, kurtosis and so on. The frequency domain methods include spectral analysis based ones such as power spectral density and Cepstrum analysis (Randal, 1982), and higher-order statistics and spectra (Zhang et al, 1999). The time-frequency domain methods are composed of the short-time Fourier transform (STFT), Wigner-Ville, Cohen distribution and wavelet analysis (Wang & McFadden, 1993; Lai et al, 2003). Feature extraction methods play a crucial role in machine condition monitoring and fault diagnosis, from which the diagnostic information is often obtained.

Through gear vibration analysis, tons of features are acquired, and therefore the next step is optimization and classification. In the present work the authors present a review of a spread of diagnosis techniques for gearbox fault identification with particular reference to vibration analysis. The vibration techniques were developed for two main reasons. The first purpose is to separate the gearbox related signal from other components and to minimize the noise that may mask the gearbox signal, especially in the early stages of the fault. The second purpose is to spot the status of the gearbox, to differentiate the great and therefore the faulty gear and to point the defective components. Nowadays the strain for condition monitoring and vibration analysis aren't any longer limited trying to attenuate the results of machine failures, but to utilize existing resources more effectively. [2]

1.2 Fault detection and diagnosis from vibration analysis

Diagnostics is known as identification of a machine's condition/faults on the idea of symptoms. Diagnosis requires a skill in identifying a machine's condition from symptoms. The term diagnosis is known here similarly as in medicine. It is generally thought that vibration may be a symptom of a gearbox condition. Vibration generated by gearboxes is complicated in its structure but gives tons of data. We may say that vibration may be a signal of a gearbox condition.

In order to detect (and diagnose) an impending failure, an honest understanding of the evidence concerning the failure mode and methods of collecting and quantifying the evidence is required. Even though many faults of a component may be easily detectable -physically, magnetic rubber, x-ray, dye penetrates, using techniques like microscopy, etc., these methods usually cannot be performed without removal of, and in some cases physical damage to the component. Even though physical examination techniques still play an important role during manufacture, assembly and overhaul, they're not practical in an operational large transmission and other (non-intrusive) fault detection methods got to be employed for routine monitoring purposes. Most modern techniques for gear diagnostics are supported by the analysis of vibration signals picked up from the gearbox casing. The common target is to detect the presence and therefore the sort of fault at an early stage of development and to watch its evolution, so as to estimate the machine's residual life and choose an adequate plan of maintenance. It is documented that the foremost important components of geared vibration spectra are the gear meshing frequency and its harmonics, alongside sidebands thanks to modulation phenomena. The increment within the number and amplitude of such sidebands may indicate a fault condition. Moreover, the spacing of the sidebands is said to their source. Identification of source and detection of fault from vibration signals linked with items which involves rotational motion like gears, rotors and shafts, rolling element bearings, journal bearings, flexible couplings, and electrical machines depend upon several factors:

i. The rotational speed of the items;

ii. The background noise and/or vibration level;

iii. The location of the monitoring transducer;

iv. The characteristics of load sharing of the item; and

v. The dynamic interaction between the item and other items in touch with it. [5]

The important reasons of mechanical vibration are looseness and distortion, unbalance, defective bearings, gearing and coupling in accuracies, rotor/stator misalignments, misalignment, critical speeds, bad drive belts, reciprocating forces, oil whirl, friction whirl, aerodynamic or hydrodynamic forces, various kinds of resonance, bent rotor shafts, defective rotor bars, and so on.[2]

2. METHODOLOGY

1. Study of various gear tooth defects
2. Study of literature regarding various techniques of fault diagnosis.
3. Acquiring vibration signal for healthy and faulty gears
4. Applying FFT on acquired signal to convert to frequency domain data
5. Applying ANN on the vibration signal.
6. Comparing results for the same.

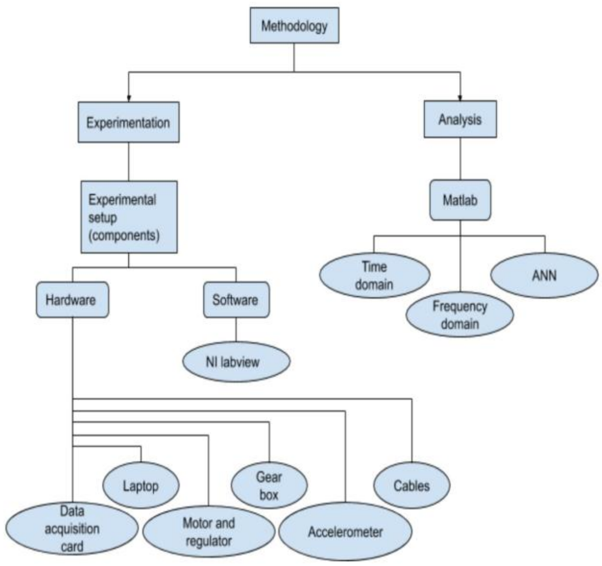
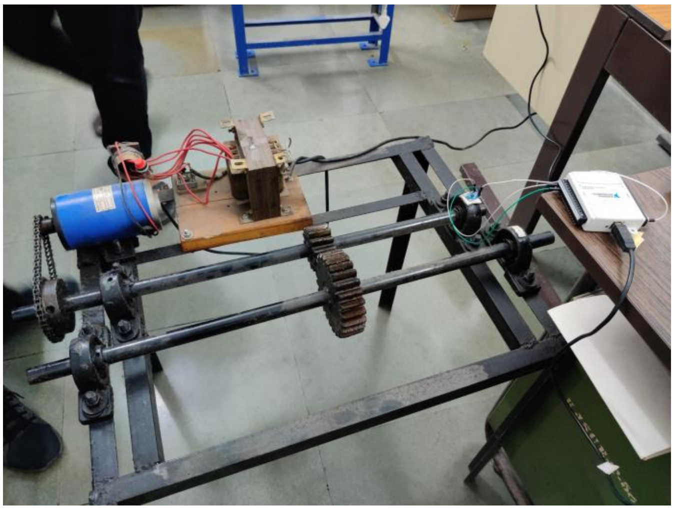


Fig -1: Methodology flowchart

3. EXPERIMENTAL SETUP

The setup consists of a gear mesh mounted on two rods held together by bearings and rotated by chain drive through a motor. Accelerometer has been mounted on the bearings and then further connected to the data acquisition card which is then connected to the laptop where the readings are taken using NI LabVIEW.



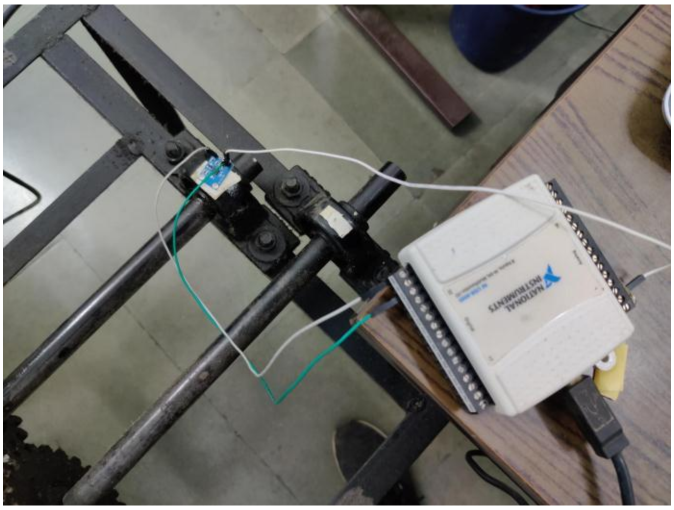


Fig -2, 3: Experimental setup

- The transducer used for measuring vibrations was ADXL3353-Axis.
- The data acquisition card used was from National Instruments.
- The data has been analyzed for a gear of 80 teeth meshing with a pinion of 32 teeth at no load condition and 600 rpm.
- The set of readings were taken at a time interval of about 2 minutes.
- Sampling frequency given was 20 KHz.

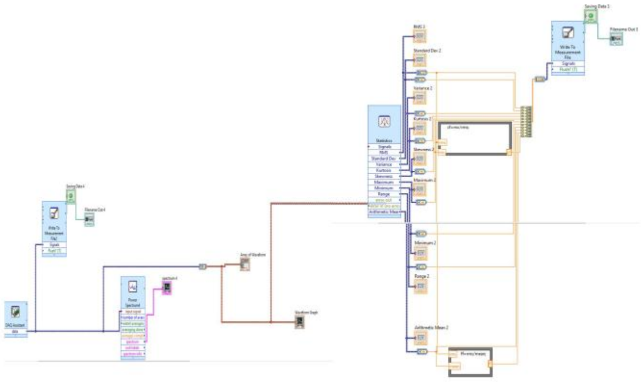


Fig -4: LabVIEW circuit

4. EXPERIMENT

4.1. FFT

The main aim to perform FFT is to convert and observe the derived time domain signal into frequency domain.

As we can see in Fig -5, the various amplitudes that occur in a vibration signal are superimposed to calculate the final signal graph in a time domain. It is very difficult to find the unnecessary vibrations caused due to a damaged tooth by observing a time domain signal. To make this task easy, we change the perspective of observing the signal. This change of perspective is the frequency domain. In the frequency domain. The abscissa is the frequency and the ordinate is amplitude. So this graph shows exactly how many frequencies are present in a particular signal. For instance in the diagram, three frequencies combine to form the signal which can be easily inferred using the frequency domain.

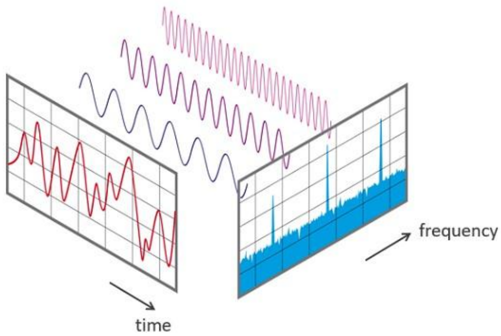


Fig -5: Time and frequency domain interpretation

We have performed this algorithm in MATLAB to convert our time domain signal to frequency domain and further come to a conclusion based on the following graphs.

4.2. FFT Results

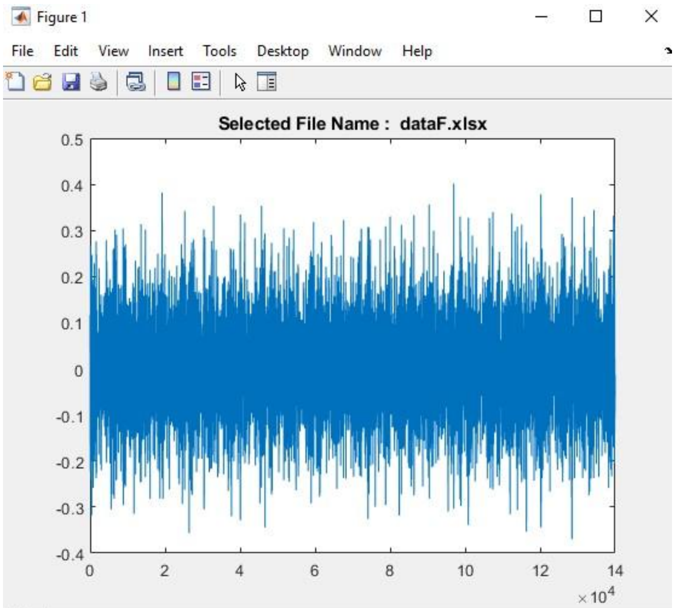


Fig -6: Healthy gear time domain plot

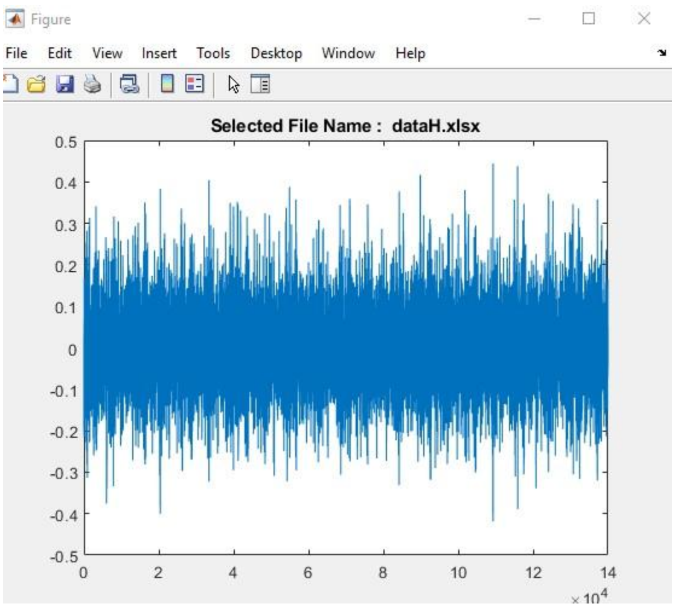


Fig -7: Faulty gear time domain plot

The peaks in the spectrum are expected as they represent the gear mesh frequency. Closely observing the graph shows us that the peaks are of increased amplitudes in the faulty gear. This tells us that the defect has caused an increase in the tooth load.

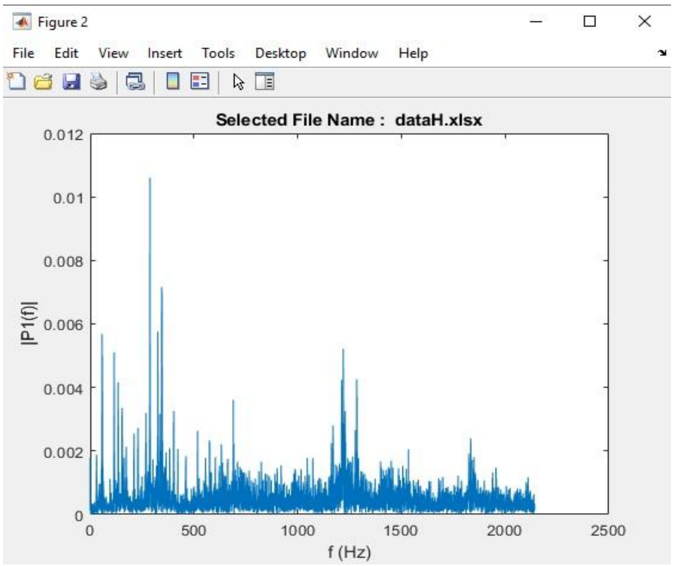


Fig -8: Healthy gear frequency domain plot

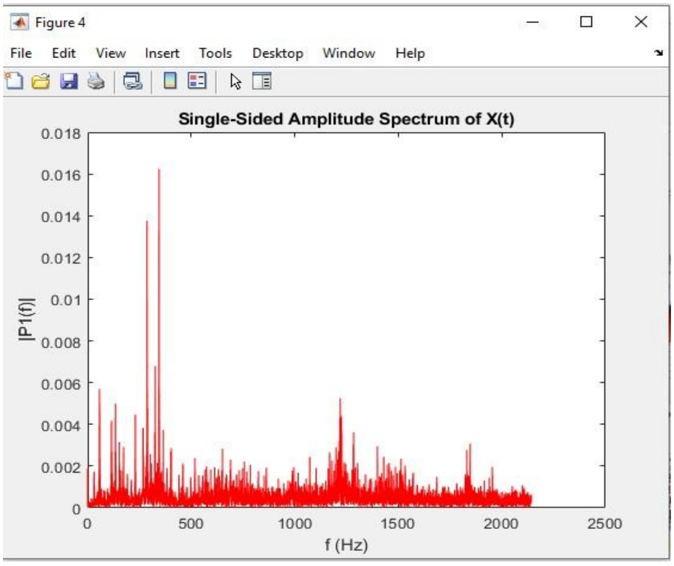


Fig -9: Faulty gear frequency domain plot

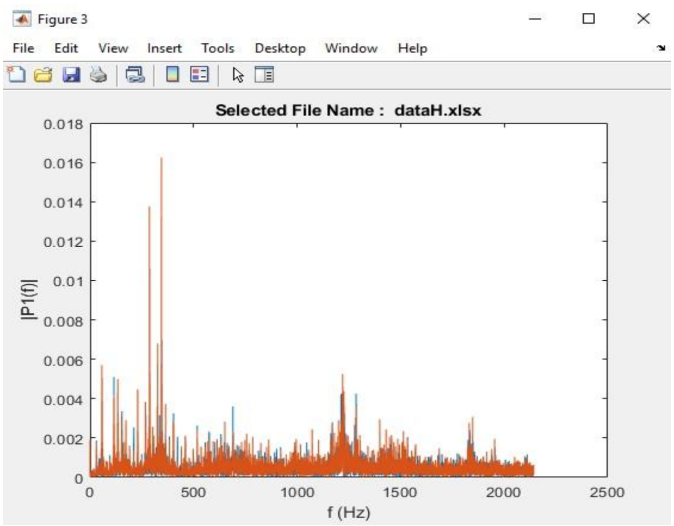


Fig -10: Faulty gear frequency domain plot superimposed on healthy gear frequency domain plot

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 10 | Oct 2020 www.irjet.net p-ISSN: 2395-0072

4.3. Drawbacks of time domain and frequency domain analysis.

It is hard to analyze data in time domain as the data has very less observational differentiations.

This is the reason we use frequency domain where the data which we observe is the frequencies present. Observational classifications need a lot of expertise. The data obtained is not very ideal. It contains a lot of noise. Also to pick up exact detail from the spectrum which points towards the fault has a lot of scope of human errors.

This makes us switch towards artificial intelligence.

4.4. AI technique for analysis

4.4.1. ANN working

Artificial neural networks are computational models which work similar to the functioning of a human nervous system.

Artificial Neural Network, work on the principle of training the software. We provide the software with statistical inputs derived from the amplitude vs time data. The inputs include, rms (g), Standard deviation, Variance, Kurtosis, Skewness, Maximum, Minimum, Range, Arithmetic mean and ratio of maxima and minima.

The statistical parameters of healthy and faulty gears were brought together and were randomized. The output of healthy gear was given “1” and that of faulty gear was given “0”.

This trained the software that the healthy set of readings gave the output as 1 and the faulty set gave the output as 0.

After the training when the software is provided with some unknown inputs, it is capable of giving the output as 1 or 0 indicating whether the given readings are of a healthy or a faulty gear.

4.4.2. Training data

70 readings of 12 statistical parameters were given as input for training the data. These readings include both faulty and healthy gear readings. The readings were taken at 600 rpm no load condition. Out of the data recorded, 70% was given to the network for the purpose of training and the remaining 30% was used for testing. Targets were assigned as follows:

Type	Target
Healthy gear	1
Faulty gear	0

Table -1: Healthy and Faulty gear target assignment in ANN

The following Table -shows 5 sample readings of statistical parameters of raw vibrational data.

Rms (g)	Standard deviation	Variance	Kurtosis	Skewness	Maximum	Minimum	Range	Arithmetic mean 1	Arithmetic mean 2	c f = max/rms
0.073131	0.073093	0.005343	3.439528	0.040236	0.30524	0.367525	0.672765	0.002365	30.919309	0.000157
0.077483	0.077446	0.005998	3.506844	0.099591	0.324784	0.372243	0.697027	0.002386	32.477455	0.000139
0.074653	0.074621	0.005568	3.501296	0.081717	0.332757	0.341329	0.674086	0.002217	33.671352	0.000141
0.075852	0.075816	0.005748	3.5259	0.055879	0.399706	0.433522	0.833227	0.002323	32.648227	0.000115
0.073009	0.072972	0.005325	3.395481	0.063613	0.295685	-0.35865	0.654335	0.00235	31.062837	0.000162

Table -2: Raw vibrations signal input

4.4.3. ANN Architecture

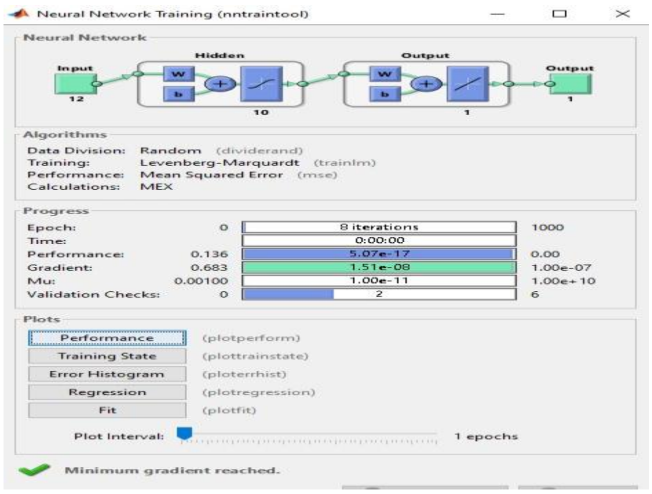


Fig -11: ANN Architecture

This architecture consists of 1 input layer with 12 nodes. 1 Hidden layer was selected with 15 hidden nodes and 1 output layer with 1 node. The training algorithm used here is Levenberg Marquardt. The training termination condition was set to 0.0001.

4.4.4. Performance and Regression curve

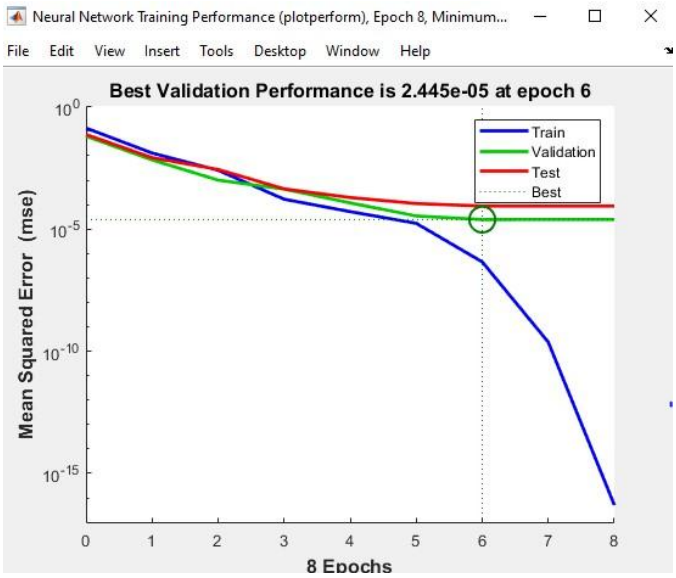


Fig -12: Performance curve

Performance graph: After the training is complete, a performance graph is obtained, showing the deviation between the training, validation and testing data.

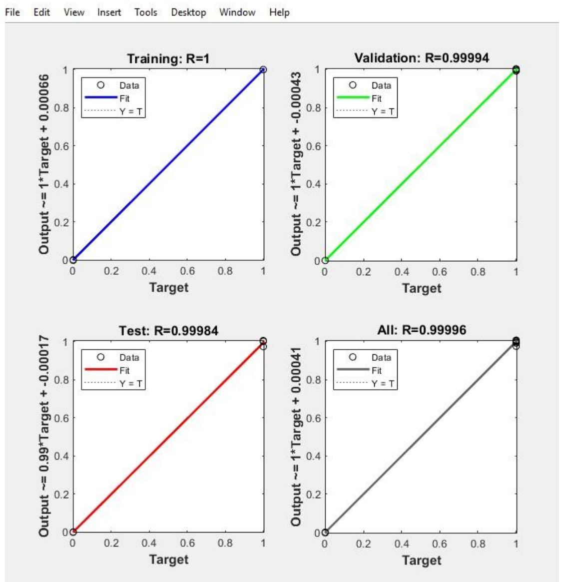


Fig -12: Regression curve

Regression graph: It includes graphs between the input and output for the training of networks, validation and testing of

5. RESULT AND CONCLUSIONS

Fault analysis was performed on a set of readings of a gear box. Different methods of data analysis were used. It includes time domain analysis (in MATLAB), frequency domain analysis (in MATLAB), ANN (deep learning toolbox MATLAB).

The data was acquired with the help of an accelerometer and a data acquisition card (DAQ) and various statistical features such as Kurtosis, RMS, skewness, and standard deviation were extracted from it.

FFT was carried out on a healthy as well as faulty set of gears, but it did not yield any accurate set of results. This proved to be a vague classifier which did not specify the type and location of the defect. This led us to adopt another classifier- ANN.

Artificial Neural Network (ANN) was applied for gear fault detection using the data collected during experimentation.

ANN results gave a 100% accurate training regression curve. It gave a 99% accurate testing regression curve. This gave pretty accurate results from the ANN.

Both FFT and ANN can be used for analyzing vibrational faults. But ANN being more statistical and accurate, yielded better results than FFT.

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