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Research Article

Artificial Neural Network and Finite Element Investigation of Cracked Rotor Shaft

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ABSTRACT: The rotary shaft is an important machine part. Due to cyclic loading and unloading fatigue cracks may appear in the rotary shaft. Crack generated in the rotary shaft causes sudden failure of machine parts. The presence of crack varies the dynamic properties of rotary shaft system such as an amplitude of vibration, natural frequency of vibration, and critical speed. In the present experiment, an experimental set up generated to identify the effect of crack severity on critical speed. Fast Fourier Transform set up used to plot frequency amplitude graph by varying crack depth. A model of a shaft with a single crack generated using 3D modelling software. Models with varying crack depth developed. Modal analysis of shaft models carried out to get natural frequencies of vibration. Variations in natural frequencies of shaft observed with respect to Severity of crack. Natural frequency and critical speed data used to identify crack location and severity using artificial neural network.

Keywords: Natural Frequency, Artificial Neural Network, Finite element method, Critical speed, Modal Analysis.

1. Introduction

Use of machine learning and artificial intelligence increasing now a days. In present paper problem of crack detection in shaftaddressed using artificial intelligence technique. Presence of crack causes changes in dynamic behaviour of a rotary system. Monitoring of these dynamic properties of the system helps to identify crack.

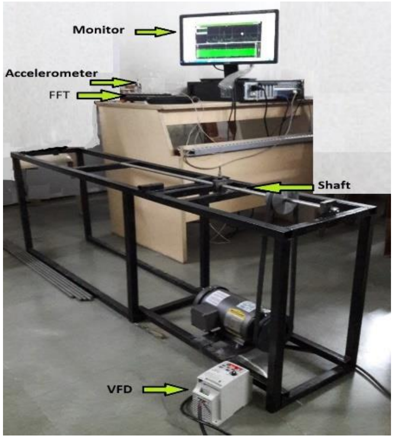
S.K.Sahu and P. Das investigated Crack depth and location using natural frequency numerically and experimentally[1]. Dinesh Satpute et al. extracted the first three natural frequencies of a shaft using the finite element method. The natural frequency of healthy and cracked shaft was observed. It was concluded that crack detection carried out using natural frequencies of the shaft [2]. A.P. Bovsunovsky carried out crack detection using the change in shaft compliance[3].Youngfeng Yang et al. developed the mathematical model of a shaft with transverse crack. Harmonic balance method used to find out dynamic characteristics of the cracked shaft. results validated using Monte Carlo simulation[4].Hamid Khorrami et al. developed the finite element model of a shaft with two transverse cracks.Cracks were investigated using harmonic balance method. The crack depth and position affect critical speed of shaft, Centre Orbit and Lateral response of shaft model[5].Debendra Gayen et al. developed a finite element model of a shaft with transverse crack. natural frequency and Critical speed of shaft observed with respect to crack depth[6].D. Koteswara Rao et al. carried out a comparison of the functionally graded shaft with steel shaft. It wasobserved that functionally graded shaft more suitable for modelling of the rotary shaft[7].T Szloc et al. carried out Crack detection using a Monte Carlo simulation approach. It was observed that the Monte Carlo simulation approach is appropriate for engineering applications[8].Sachin S. Naik et al. found Natural frequencies of Timoshenko and Euler Bernoulli shaft with respect to crack depth and crack location[9].Paolo Pennachi et al. identified Crack location and Crack depth using model-based crack detection approach. Resultswere validated with experimental set up[10].Lourdes Rulao et al. used Anti resonant frequencies to identify crack properties[11].M.J. Gomez et al. used vibration signals to detect a crack in the rotor shaft. Crack size of more than 1.77 % of shaft diameter were detected accurately[12].Anuj Kumar Jain et al. obtained natural frequencies of the shaft using impact hammer test. These natural frequencies used to identify the severity of crack. experimental results validated by analytical results [13]. A.A.Mohammed et al. generated different depth of crack in shaft and change in frequency of shaft observed. Change in crack depth can be identified by the change in an amplitude of vibration[14].K. Vighneswaran obtained Stiffness and natural frequencies of the shaft using eigenvalue analysis. Mode shapes of a healthy and cracked shaft were compared[15].Alok Ranjan Biswal et al. developed a governing equation of shaft with crack. It was observed that natural frequency and amplitude of vibration decreased due to change of crack depth[16].Sandeep Das et al. observed that frequency and amplitude of vibration vary due to the presence of a crack in shaft .fatigue crack propagation and life of shaft predicted by dynamic analysis of shaft[17].T Sunil Kumar et al. observed natural frequency and amplitude of vibration with varying crack depth. Eigenvalue analysis of shaft carried out for shaft with varying crack depth[18].A.C. Chasalervis et al. investigated bending vibration of the shaft with crack .variation in shaft compliance used to identify crack[19].Saber Al Arem et al.

generated finite element model of a shaft with crack .stability analysis of cracked shaft carried out[20].R Gasch et al. observed dynamic behaviour of single transverse crack and stability behaviour of shaft[21].L Rubio et al. used natural frequencies of vibrations to identify crack properties. Inverse problem solved using optimisation technique of least square[22].A.S.Sekhar and B.S.Prabhu examined the effect of eccentricity unbalance and acceleration on critical speed of shaft[23].Ashish K. Darpe et al. Compared transverse crack and slant crack for stiffness and coupled vibration .effect of the orientation of crack on stiffness value investigated[24].A. A. Mohammad et al. carried out the dynamic analysis of shaft for 3 crack depth. Power spectral density obtained from fast Fourier transform given input to the artificial neural network predicts crack properties accurately[25].M. I. Friswell carried out Structural health monitoring of shaft using low-frequency vibrations[26].T Ramesh Babu and A. S. Sekhar used Slope distribution curve to detect a crack in shaft[27].S.Chinchalkar et al. modelled Shaft with 3 crack depths to find stiffness and frequencies of the shaft. UsingEigenvalue analysis crack depth and correct location identified[28].Hai Ping Lin modelled shaft with crack using Timoshenko beam theory. Using natural frequencies location of the crack and Crack depth can be identified[29].Qinkai Han studied natural frequencies and parametric instability by varying crack depth and location. Slant crack and transverse crack observed with respect to natural frequencies of the shaft[30].Nicola Pugno et al. investigated crack depth and crack location using harmonic balance method. Analytical results were compared with experimental results[31].A. A. Deokar et al. used natural frequency mode shapes to detect a crack. Graph of natural frequency in terms of crack depth and location plotted[32].J. J.Sinou examined the change in amplitude of vibration due to crack depth .effect of crack depth and location on critical speed and harmonic response were studied[33].Debendra Gayen and Tarapada Roy generated finite element model of a shaft with crack. vibration and stability analysis of shaft carried out using Timoshenko beam theory[34].O.S. Jun et al. observed free bending vibration of the shaft using Timoshenko beam theory. Natural frequencies of cracked and healthy shafts compared[35].Kamil Aydin et al. observed vibration of the shaft using Euler Bernoulli beam. Effect of crack location and crack depth on natural frequencies observed[36].Mohammad A. Al Shudeifat et al. observed effect of crack depth on whirl orbit and amplitude of vibration. Finite element and harmonic balance equation of cracked rotor derived[37]. A. Morassi et al. detected a single crack in shaft using a pair of natural frequency. Single crack at a different location and different depth identified[38].Danilo Capecchi et al. carried out a dynamic analysis of beam to detect a crack. Mode shapes and natural frequencies of shaft investigated[39].J.J. Sinouet al. investigated resonant frequencies and modal properties of shaft. numerical results are validated by experimental result[40].M. Dilena et al.investigated natural and anti-resonant frequencies of a shaft with a single crack. Axial and bending vibrations of Steel shaft studied to validate numerical results[41].E. Douka et al. used time-frequency method to identify a crack in the cantilever beam. Numerical results of simulation method validated by experimental results[42].D Guo et al. analysed shaft with single crack using Hilbert hung transform. It was observed that HHT can be used to analyse the non-linear transient response of shaft[43].S.Stykov et al. developed a finite element model of the rectangular shaft with crack. UsingTimoshenko beam theory harmonic response and mode shapes of vibration were observed[44].A. Sekhar et al. developed a finite element model of a shaft with crack. Eigenvalue analysis and mode shape of vibration of the shaft with crack analysed[45]. A.H Kekan and B Raghu Kumar observed variation in natural frequency and critical speed with respect to crack depth and crack location. The artificial neural network used to identify the crack depth and crack location[46][47].

2. Experimental setup

The shaft was supported over two roller bearings supported by two fixed steel supports; the fixed steel supports were welded to the steel plate as shown in Figure 1. An experimental setup has the following parts.

Figure 1: Experimental set up of FFT Analyser



2.1 Induction Motor

Three-phase Induction motor used to rotate the shaft. The motor fitted at the bottom of the frame. A motor rotates the shaft through the pulley and V belt.

2.2 Variable Frequency Drive

Variable frequency drive varies input frequency and voltage to electric motor hence control speed and torque of the electric motor.

2.3 Fast Fourier Transform Analyser

A Fast Fourier transform is an algorithm that takes an input signal with respect to the time domain and converts that signal into the frequency domain graph. FFT used to draw frequency versus amplitude graph.

2.4 Bearing and Bearing Housing

A single row deep groove ball bearing used to support shaft. Bearings fitted inside Mild steel plate. These plates welded to the mainframe body.

2.5 Shaft

The shaft of 12mm diameter used for an experiment. A cut of 2mm, 4mm and 6mm generated in the shaft at different locations.

3 Working

An electric motor used to rotate the shaft. Variable frequency drive used to control speed and torque of the rotary shaft. Speed of rotary shaft measured with help of tachometer. A single crack of depth 2mm,4mm and 6mm generated in the shaft. Location of single crack measured from bearing support. Frequency versus amplitude graph plotted with help of FFT. The critical speed of shaft noted for various crack depth and crack location combinations.

4 Finite Element Analysis

A Model of shaft prepared using 3D modelling software and the same model imported to Ansys for finite element analysis.

4.1 Shaft Modelling

A modal of the shaft with crack depth 2mm, 4mm and 6mm prepared using CATIA V5. Modal analysis of these shaft models carried out using Ansys. Figure 2 represents a shaft model with crack.

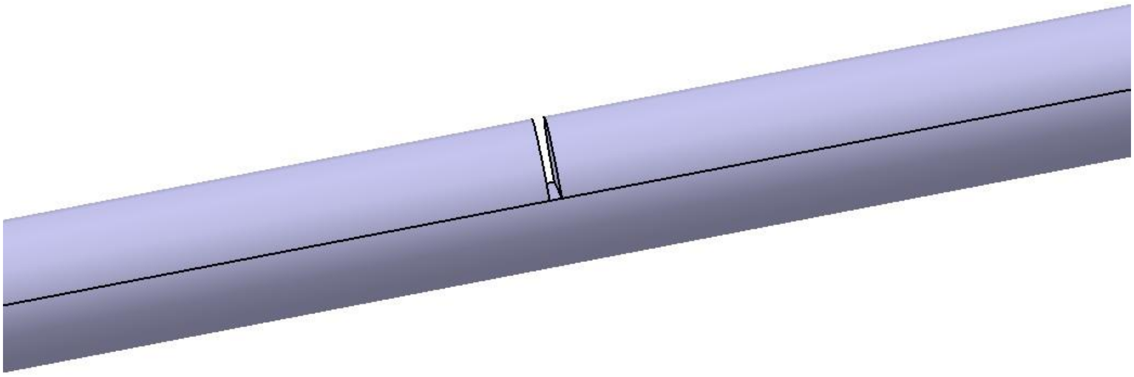


Figure 2. Shaft model with crack

4.2 Meshing

A tetrahedral Mesh generated using Ansys software. Element size used 0.01.boundries of mesh are continuous. The meshed model brings more accurate results of finite element analysis. Figure 3 shows the meshed model.

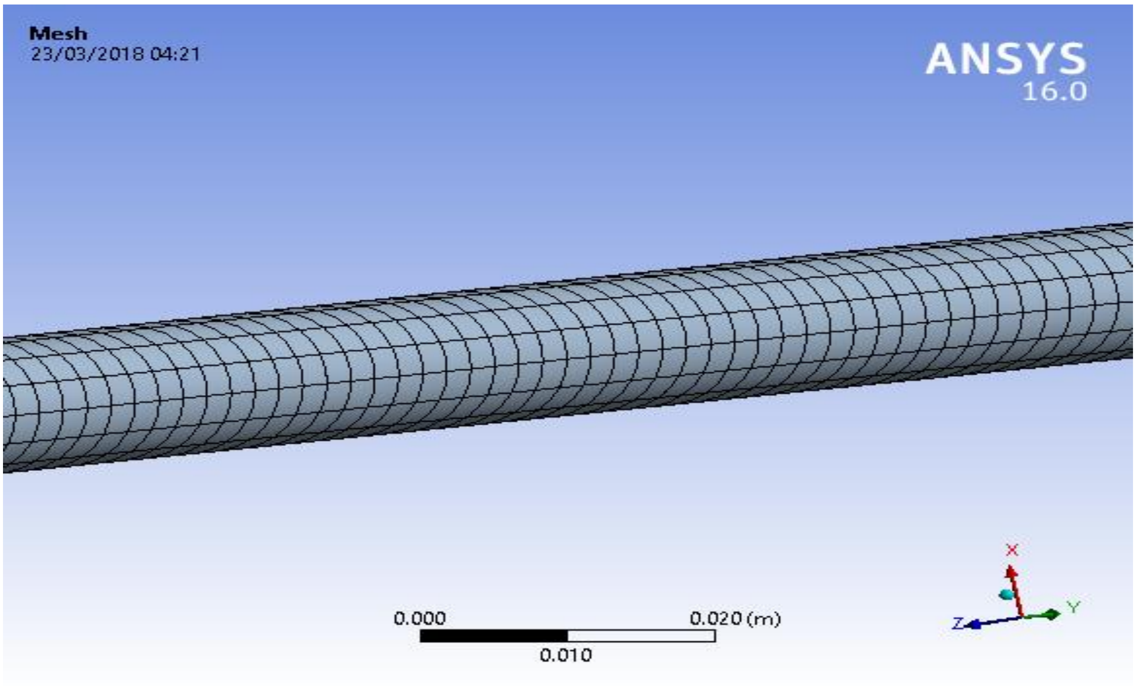


Figure 3. Shaft Mesh Model

4.3 Modal Analysis

After meshing boundary conditions applied to the shaft model. Modal analysis of shaft carried out to obtain natural frequencies of the shaft. Figure 4 represents the modal analysis of the shaft.

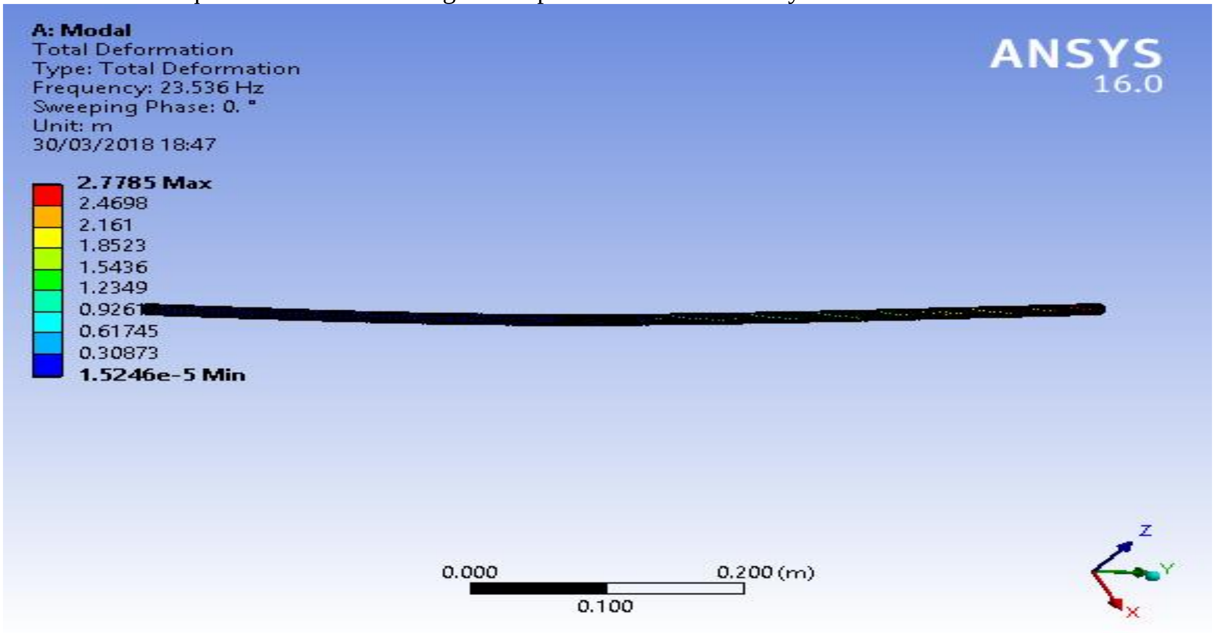


Figure 4. Modal Analysis of shaft

5. Result and discussion

Frequency versus amplitude graph drawn using FFT analyser. From frequency amplitude graphs variation in amplitude with respect to crack depth observed. From modal analysis Variation of natural frequencies with respect to crack depth and crack location observed.

5.1 Frequency versus Amplitude graph.

Frequency versus amplitude graph plotted using Fast Fourier Transform set up. Graph for crack depth 2mm, 4mm and 6mm shown in figure 5, Figure 6 and Figure 7 respectively. The amplitude of vibration increases as crack depth increases.

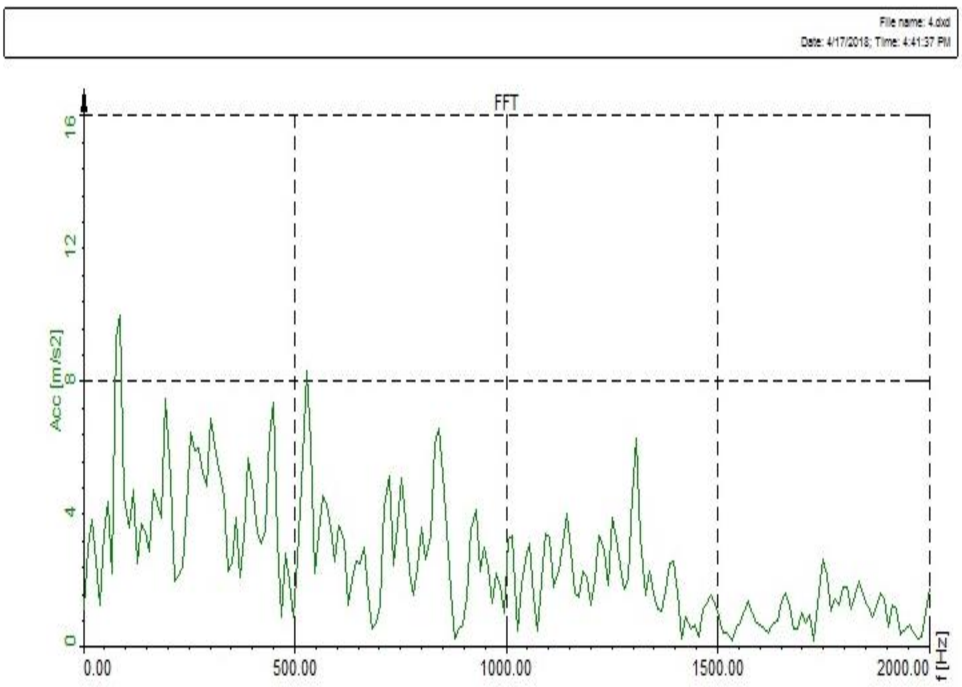


Figure 5. Frequency versus amplitude graph for crack depth 2mm

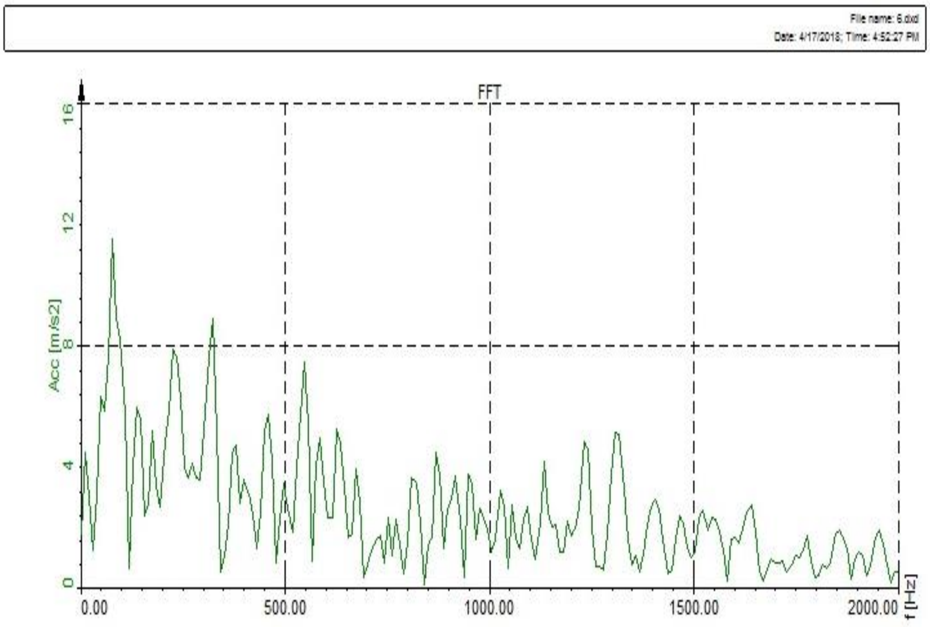


Figure 6. Frequency versus amplitude graph for crack depth 4mm

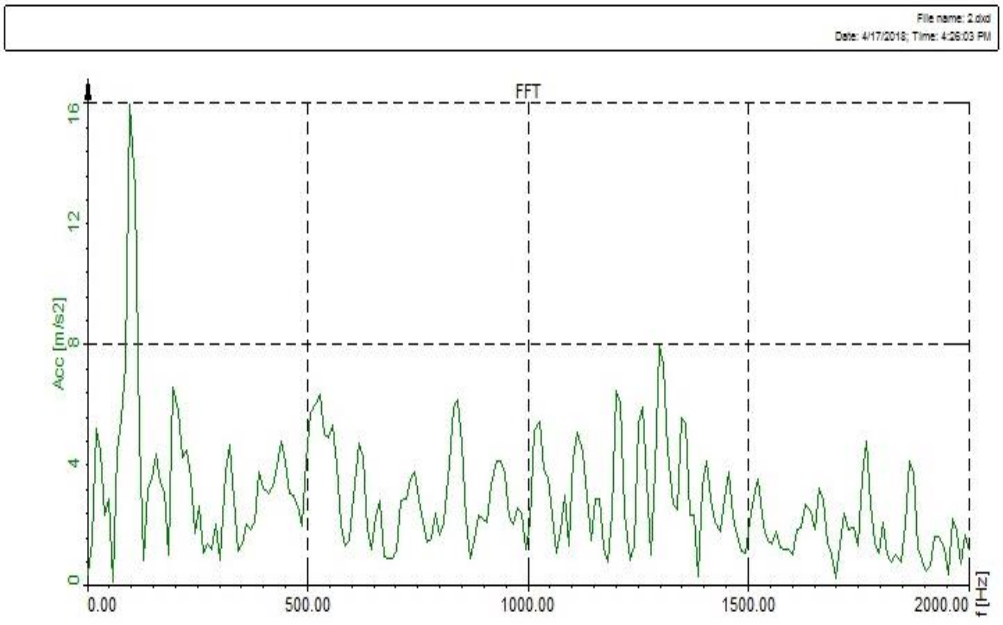


Figure 7. Frequency versus amplitude graph for crack depth 6mm

5.2 Modal Analysis

Natural frequencies of a shaft with crack depth 2mm, 4mm and 6mm obtained using finite element method. Variation in natural frequencies observed with respect to crack depth as shown in table1.

Depth of crack (mm)	Natural Frequency (Hz)	Critical Speed (rpm)
2	204.52	1370
4	192.56	1308
6	176.51	1280

Table 1. Variation in Natural frequency and critical speed

5.3 Critical speed

The critical speed of shaft with crack depth 2mm, 4mm and 6mm obtained using experimental setup. Table 1 represents variation in critical speed with respect to crack depth.

5. Artificial Neural Network Approach

Critical speed and natural frequency results used to train ANN. 40 percent of data used to train the ANN. Once the training of ANN complete 60 percent of data given as input to find the results of trained neural network. Figure 8 shows structure of artificial neural network.

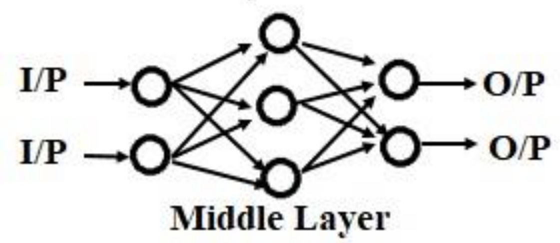


Figure 8: Artificial neural network structure

Conclusion

Results obtained by artificial neural network shows good accuracy with actual crack location and crack depth values.Experimental set up of rotary shaft supported in roller bearing prepared. Frequency versus amplitude graph for crack depth 2mm, 4mm and 6mm plotted using FFT analyser. 3D model of a shaft with crack depth 2mm, 4mm and 6mm prepared. Modal analysis of these shaft models carried out. The critical speed of shaft for 3 crack depths obtained using Experimental setup.

Natural frequencies of shaft reduced as crack depth increases. From the frequency amplitude graph, it was observed that as crack depth increases the amplitude of vibration increases. The critical speed of shaft reduced as crack depth increases. Presence of crack in the shaft can be identified using the method of natural frequency and critical speed. Natural frequency and critical speed efficiently detect the severity of crack in the rotary shaft.

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