Modeling of Amplitude and Frequency of Vibration for Rotor Bearing System using Ann and Taguchi Methods

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Abstract: *Vibrations in rotor bearing systems are mostly produced by misalignment, imbalance, mechanical looseness, cracks and other malfunctions. Now-a-days, diagnostics of rotor defects gaining importance day by day. This paper introduces a new methodology to detect cracks based on amplitude and frequency of vibration data. Experiments were conducted at different levels of crack depth, its position and shaft rotational speed on a shaft which was held between two bearings. Experimental results of amplitude and frequency of vibration were measured in axial, vertical and horizontal directions at both the bearings. Signal to noise ratios were calculated for the experimental results using Taguchi method to identify significant parameters which are having effect on the experimental results. Neural network models were developed for the experimental results to predict them. The neural network was trained with the experimental data and predicted the responses. In addition to that, Taguchi method was also used to predict the responses. A comparison was carried out among the experimental results, artificial neural networks (ANN) predicted values and Taguchi predicted values. The comparison reveals that there is good agreement among them and the ANN and Taguchi methods can be used to predict the amplitude and frequency of responses.*

Key words: *ANN, Taguchi method, S N Ratio, Rotor Bearing System, vibration Analysis*

I.INTRODUCTION

In every rotating mechanism faults, recognitions and their existence greatly dealt with aid of measuring vibration responses in the system. The vibration analysis of identifying common mass imbalance is developed well and conducted in several ways. However, the defects like shafts cracks, alignment faults in bearings and rubbing effects identification are basic in comparisons. In these areas still research scope exists greatly for designing defect diagnosing mechanisms. It is essential to understand basic principles about dynamics of rotor systems by engineering professional and scientists in power and transportation sector industries. As the designing and analysis of rotary machines is critical since the manufacturing and maintenance is a costly affair.

It becomes a complex affair to develop rotary machines with respect to the quickly improving technology. Hence it is of no surprise to the raise of need in the development of new fault diagnostic methods in rotary machine mechanisms.

Newly emerged condition monitoring methods incorporate variety of themes, one such significant and informative is vibration response analysis of rotating machines, this topic prompts high research capacity and developed literature regarding. Employing vibration analysis, machine state is regularly monitored and detailed analyses made considering health of machine and faults that may rise or already exists. Regular rotor dynamic faults are due to system instability, self-excited vibration and also vibration caused by externally applied load, like cracked or bending of shafts and unbalanced mass.

Vibration condition checking is utilized to blame conclusion examination is performed by Taylor [1]. It additionally incorporate data on the bona fide information investigation, how estimated information to be handled for analysis. Smalley et al. [2] presents a way to deal with appraisal of the seriousness in vibration as likelihood of harm by breaking down vibration flags and related expense, with help of the net present esteem system. While Maintenance the choice to stop machine is chosen by the standard rules figured by investigation of harm amendment cost against the expense of down time. By utilizing Pareto circulation approach of apparatus analytic testing, Cempel [3] demonstrated the methodology created for the condition checking of tribo-vibro-acoustical procedures is a fit summed up vibration task. Unwavering quality diagram drawn with vibration estimations are changed as an existence bend for a given machine with no trouble, henceforth Pareto dissemination approach empowers surveying both the hardware condition and its breakdown leftover time. Su and Lin [4] extended a formerly existing vibration demonstrate anticipated to disclose bearing vibration because of a solitary blame, giving an entire mindfulness about the vibration otherworldly examination.

As of now it is expressed that pivoting machines are developing in unpredictability as rotors getting to be lighter in weight, quicker and resilience's choked. With increment of multifaceted nature, significance to stay away from a few wellsprings of deformities is expanded. New innovations are ceaselessly creating to adapt up the interest for deformity free machines. As an occasion, Halliwell [5] uncovered how imperative the assessment of torsional vibration to investigate the vibration of riggings with help of a laser torsional vibrometer, staying away from the need of cumbersome mechanical parts.

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162

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The laser method profits significant favorable circumstances in sensible applications, where vibration assessment caused issues already. As it is because of the challenges of embedding estimating hardware, and furthermore additional mass and solidness parameters oftenly added to structures by traditional methodologies.

Sekhar and Prabhu [6] cleared up the coupling misalignment affect on the vibration of turning machines. The pole plan flaw is one of the huge causes to vibration, due to created reaction powers in shaft couplings. Generally it is recognized that a significant to vibration response is a key part in misalignment of bearing. A FEM of the rotor coupled bearing arrangement created and the misalignment affect introduced through a co-ordinate arrangement of coupling. This model predicts the vibration response caused by misalignment at the diverse symphonious assets as both distortion finding and machines outline. Sheng et al. [7] showed another approach to manage recognize rubbing disappointment in the middle of the turning and settled segments in a machine. The standard technique of rubbing range investigation is to survey the response spectra. A negative characteristic of this strategy is that the rub framework produces sound in certain repeat gatherings, called hued commotion.

The new technique proposed, combining principal components and autoregressive spectra (PCAT) could distinguish the main attributes of the shaded commotion. Firstly, an auto relationship framework was assessed from the vibration signal, from which the primary parts were acquired by utilization of the symmetrical change network of Eigen vectors. The auto regressive modular co-efficients and expectation errors are then decided. Computer recreations with noisy information have demonstrated that the PCAT strategy is an efficient instrument for the identification of colored noise in rub disappointment of large rotating machinery. An exhaustive investigation of the transient reaction caused by rotor stator communication has been given by Ghauri et al. [8], where the rubbing procedure was spoken to by a straight effect demonstrate (Coulomb friction). It was demonstrated that in specific situations, maintained rotor stator contact and switch spin could be deferred by asymmetry in the rotor support structure. A low coefficient of grinding at the contact interface is additionally appeared to defer invert spin. The issue of clearance effects on winding vibrations because of rubbing has been tended to by Childs and Jordan [9] and it was demonstrated that a clearance at the rub area enhances the soundness of the system, specifically with respect to insecure spiral vibrations.

For the assurance of anisotropy and asymmetry in pivoting hardware, Lee and Joh [10] have developed a technique fusing directional recurrence response capacities (DFRFs). Anisotropy and asymmetry may cause turn weariness and instability. And in addition influencing framework characteristics, for instance, unbalance and basic velocities. Complex particular testing was used to assess the DFRFs. A model was displayed, showing the proposed technique to be uncommonly efficient in recognizing anisotropy and asymmetry. An examination on the assortment of vertical vibrations of vehicles using a neural system (NN) has been shown [11-14]. In the paper the NN is an extended premise NN. Which is used to foresee the sufficiency of increasing speed of accelerating for different road conditions, for instance, concrete. Waved stone square

cleared and country lanes. Proposed neural framework was in like manner strove for different normal frequencies of the vehicle s body and the damping extents of safeguard. This strategy is sensibly immediate and it is in like manner suitable to other sort vehicles for down to earth purposes. The multilayer perceptron NN with Radial Basis has given prevalent execution rather than Standard Multilayer neural system.

Desavale et al.[15] proposed mathematical model for deep groove ball bearing considering single defects on races and ball is developed and vibration of the housing are studied. Vibration amplitudes (velocities) are obtained by solving equation of motion in MATLAB. Theoretical and experimental results of the housing vibrations of faulty bearings are compared and interpreted. Vyas et al [16] focused to generate data for healthy and faulty rotor systems and develop a preliminary neural network diagnosis frame. It has been found that the testing success in addition to the input and hidden layer architecture, is crucially dependent on the two training parameters, namely the learning rate coefficient and the momentum. In vertical direction the vibration parameters of the system, such as velocity, acceleration and amplitude were measured at the bearing points. Taplak et al. [17] has designed the neural predictor with three-layer, input, hidden and output layer in this hidden layer 10 neurons were used for this approximation. Vanraj et al. [18] proposed a methodology on a fixed axis gear box sound sensor is placed to get high quality information about the dynamic characteristics of the machine. Kalkat et al. [19] analyzed the dynamic behavior of rotating system designed in regard to vibration parameters in the vertical direction. Velocity, acceleration and amplitude are measured as vibration parameters. Goswami et al. [20] focused on using experimental design and taguchi method a theoretical study was carried on the multi objective optimization of depth of cut, feed and spindle speed in orthogonal turning. Mogal et al. [21] the unbalance and misalignment fault diagnosis is proposed. Using order analysis technique of vibration analysis phase, amplitude, the fault type and location are usually identified.

Pavan al. [22] examined that one of the real purposes behind breakdown of the rotating machines is faults in ball bearings. This examination is for the most part focused on fault diagnosis of bearing system utilizing ANN. The most essential mechanical properties of the tribological segments are quality, hardness, wear and corrosion resistance. The Taguchi symmetrical exhibit was utilized to measure the variables influencing the wear essentially. Ajit et al. [23] was seen that the slurry speed fundamentally impacted the more mass misfortune on unclad substrate. In Nilrudra et al. [24] examine, Taguchi strategy and Regression investigation have been connected to evaluate machinability of AISI 4340 steel with recently created Zirconia Toughened Alumina (ZTA) artistic supplements. It has been seen that profundity of cut has top level input on apparatus wear. The numerical model of flank wear has been created utilizing relapse investigation as an element of the previously mentioned autonomous factors.

The anticipated an incentive from the created display and trial esteems are observed to be near one another legitimizing the criticalness of the model.

In this paper introduces a new methodology introduced to detect cracks based on amplitude and frequency of vibration data. Experiments were conducted at different levels of crack depth, its position and shaft rotational speed on a shaft which was held between two bearings. Experimental results of amplitude and frequency of vibration were measured in axial, vertical and horizontal directions at both the bearings. Signal to noise ratios were calculated for the experimental results using Taguchi method to identify significant parameters which are having effect on the experimental results. Neural network models were developed for the experimental results to predict them. The neural network was trained with the experimental data and predicted the responses. In addition to that, Taguchi method was also used to predict the responses.

II. EXPERIMENTAL PROCEDURE

As in Fig. 1, the system contains a 25mm diameter steel shaft of 400 mm length bearing a disc weighing about 1.2 kg and located centrally. A crack with depth of 1mm is made on the shaft at L/D ratio of 1.6 between two bearings and experiments have been conducted at different shaft rotation speed of 500, 750, and 1000 rpm. An accelerometer is held at one of the bearing to evaluate vibration of shaft as acoustic emissions (AE) signals. The vibration signals are collected in three directions like axial, horizontal and vertical directions. The same procedure is repeated for crack depths of 2mm and 3mm and the same has continued for L/D Ratio's 3.2, 4.8, 6.4, 8.0, 9.6 and 11.2. A fast Fourier transformer is employed to process the signal in to frequency domain. The generated data from the FFT analyzer is again conveyed to the computer to generate the wave forms. Amplitude spectrums at crack depth of 1mm and shaft rotation speed of 1000rpm for bearing 1 and 2 in horizontal direction are shown in the Fig. 2.

Fig 1. Experimental set up of rotor - FFT analyzer kit

Taguchi analysis:

The experimental data of amplitude and frequency of vibration for bearing 1 in axial, horizontal and vertical direction was analyzed using the Taguchi method. During the analysis, the Taguchi technique will develop a relationship for the amplitude and frequency of vibration in terms of L/D ratio, Shaft speed and crack depth. As shown in the Table 1, as objective function of the present analysis is to minimize the amplitude and frequency of the bearing vibration, the experimental data was analysed using smaller the better characteristics. The analysis was
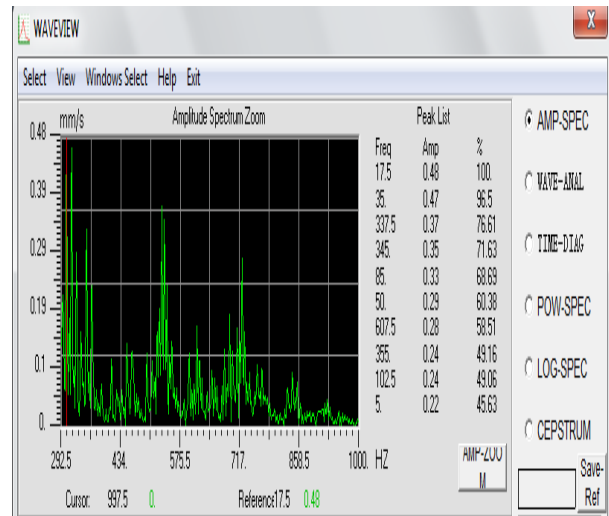

Fig. 2. Amplitude spectrum for 1000rpm for bearing 1 crack depth 1mm Horizontal Position

carried out for the amplitude and frequency of bearing 1 vibration in three directions such as axial, horizontal and vertical. The Taguchi method calculated delta value s for the input parameters such as L/d ratio, shaft speed and crack depth using the experimental data. Based on the larger delta value, the proposed method gave ranks to the input parameters. It was observed that the L/D ratio was found to be significant on the amplitude and frequency of vibration in the three directions.

Experimental data of amplitude and frequency of bearing 1 vibration in axial, horizontal and vertical direction was analyzed using Taguchi method. Signal to noise ratios for the vibration amplitude and frequency are calculated using smaller the better characteristics and the ratios are analyzed. Table 1 shows analysis of the signal -noise ratios and significant parameters which are having effect on the responses. Based on the delta values, it is found that shaft velocity has high delta value and is followed by the L/D ratio and crack depth. Hence, shaft speed was found to be dominant parameter among the three. Similarly, it was observed that the L/D Ratio has high delta value and followed by shaft speed and crank depth.

Modeling of Crack Vibration:

ANNs are made up of basic and much interconnected preparing units known as neurons each one performs two capacities: aggregating inputs from different neurons or outer condition and generation of results from the sources of input. The result from a neuron is encouraged to straightaway or different neurons to which it is associated by methods for weighted connections. Through this simple structure, NNs have been appeared to have the capacity to inexact most continuous capacities to any level of precision.

Table I. Taguchi analysis of signal-to-noise ratios for Amplitude and Frequency of vibration in the axial, Horizontal and Vertical direction (Bearing 1)

AMPLITUDE IN AXIAL DIRECTION, A_a				FREQUENCY IN AXIAL DIRECTION, F_a			
Level	L/D Ratio	Shaft Speed	Crack Depth	Level	L/D Ratio	Shaft Speed	Crack Depth
1	-10.057	-5.641	-9.380	1	-17.40	-14.38	-17.15
2	-8.294	-8.581	-10.299	2	-20.44	-16.50	-17.13
3	-5.022	-12.861	-7.405	3	-15.13	-20.56	-17.33
4	-10.645			4	-32.04		
5	-10.381			5	-19.04		
6	-10.272			6	-13.08		
7	-8.523			7	-15.87		
Delta	7.220	5.623	2.894	Delta	18.96	6.18	0.20
Rank	1	2	3	Rank	1	2	3

AMPLITUDE IN HORIZONTAL DIRECTION, A_h				Frequency in horizontal direction, f_h			
Level	L/D Ratio	Shaft Speed	Crack Depth	Level	L/D Ratio	Shaft Speed	Crack Depth
1	-5.383	-1.496	-5.008	1	-31.97	-23.15	-24.95
2	-6.094	-6.987	-7.374	2	-31.49	-27.87	-27.27
3	-1.624	-10.004	-6.105	3	-19.15	-26.91	-25.71
4	-1.883			4	-23.29		
5	-10.845			5	-29.33		
6	-7.724			6	-25.56		
7	-9.584			7	-21.04		
Delta	9.221	8.508	2.365	Delta	12.82	4.73	2.31
Rank	1	2	3	Rank	1	2	3

AMPLITUDE IN VERTICAL DIRECTION, A_V				FREQUENCY IN VERTICAL DIRECTION, F_V			
Level	L/D Ratio	Shaft Speed	Crack Depth	Level	L/D Ratio	Shaft Speed	Crack Depth
1	0.7383	1.8705	-1.8369	1	-29.35	-19.07	-24.70
2	-2.4546	-2.4838	-3.1190	2	-24.54	-25.45	-25.50
3	-1.7772	-5.8898	-1.5472	3	-18.43	-25.29	-19.61
4	6.3563			4	-19.33		
5	-5.4682			5	-28.48		
6	-6.7506			6	-20.39		
7	-5.8179			7	-22.38		
Delta	13.1069	7.7604	1.5717	Delta	10.92	6.38	5.90
Rank	1	2	3	Rank	1	2	3

In this study, a multi layered neural network (3-10-8-6) was constructed with 4 layers, they are input layer, output layer and two hidden layers. There are three nodes in input layer such as L/D ratio, spindle speed and crack depth and six nodes in output layers such as amplitude of bearing 1 vibration in axial, horizontal and vertical directions and frequency of vibration the three directions. There are two hidden layers between the input and output layers and the hidden layer 1 and 2 are having 10 and 8 nodes respectively. Number of hidden layers and the nodes in the layers were estimated in trial and error method. The same architecture was followed for the bearing 2 also.
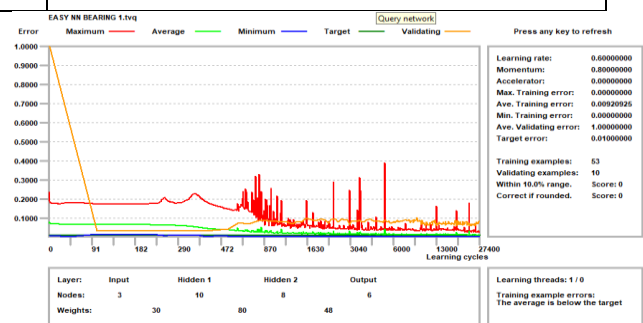

Fig 3. Learning progress graph with maximum, average and minimum training error (Bearing 1)
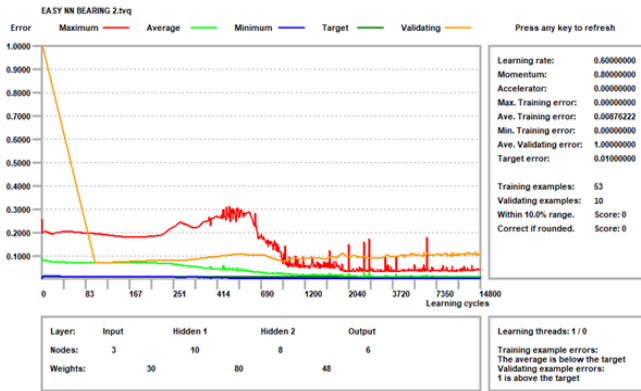
Fig 4. Learning progress graph with maximum, average and minimum training error (Bearing 2)

The network was prepared utilizing feed forward back propagation algorithm. Easy NN in addition to programming was utilized for preparing of this network. During the preparation, weights between the associations were naturally chosen by the product itself. Learning or preparing of network for bearing 1 and 2 were appeared in the Figures 3 and 4 individually and adoption of weights between the layers was likewise appeared in a similar figure. The network was prepared with 53 tests and 10 tests were chosen arbitrarily to test the information. The target training error was set to 0.01 and the training is stopped when the average training error was less than the target error. The network was trained at learning rate of 0.6 and force of 0.8. The red line is the most or maximum example error, the blue line is the minimum example error and the green line is the average example error. The orange line is the average validating error. Learning progress chart demonstrates the maximum, average and minimum training error. The average validating error is shown if any validating examples rows are included.
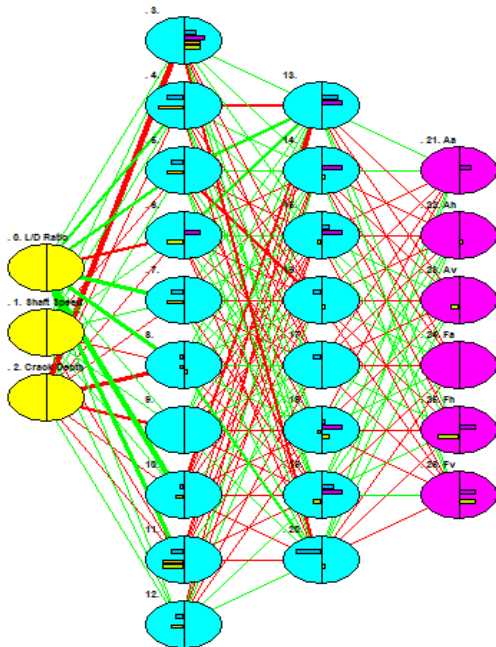

Fig 5. Neural Network Architecture (3-10-8-6)

The experimental data of amplitude of vibration for bearing in axial direction was analyzed using the Taguchi method. During the analysis, the Taguchi technique develop a relationship for the amplitude of vibration in terms of L/D ratio, Shaft speed and crack depth. Using that relationship, the amplitude of vibration was predicted as shown in the Figure 6.
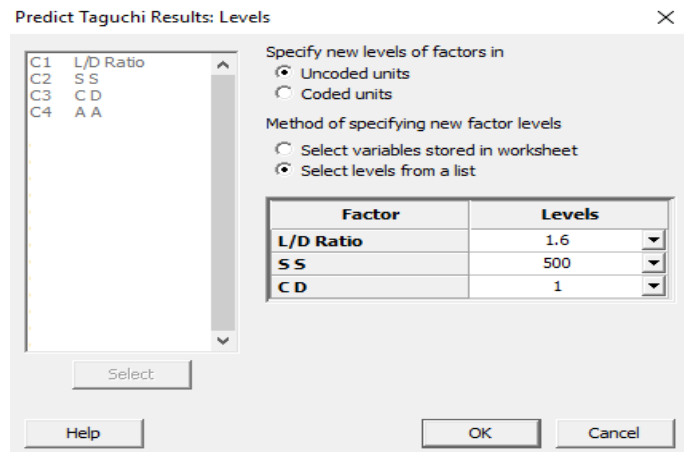

Fig 6. Prediction of amplitude of vibration for bearing in axial direction

Predicted values of amplitude and frequency of bearing 1 vibration with ANN, Taguchi predicted values were compared with the experimental values as shown in the Figure 7. It was observed that there is good agreement among the three values for the six responses. Now, it can be summarized that either Taguchi or ANN approaches can be used to predict and optimize the input parameters.
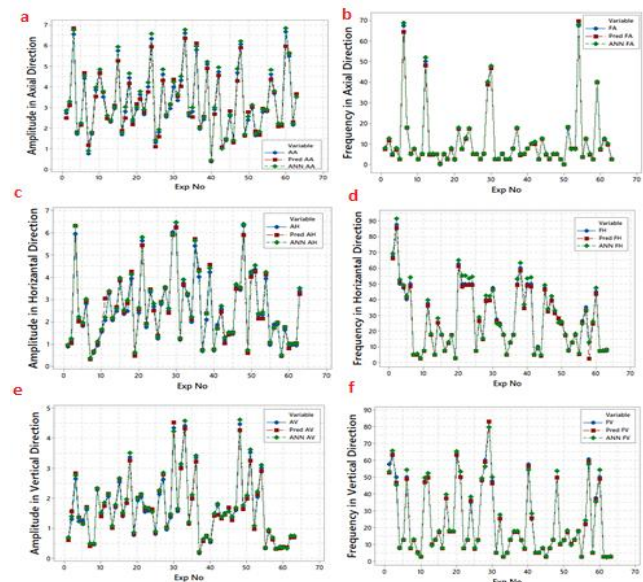

Fig 7. Comparison between Experimental, Taguchi Predicted and ANN values of amplitude and frequency of vibration in the axial, Horizontal and Vertical direction (Bearing 1)

III. TAGUCHI ANALYSIS:

The experimental data of amplitude and frequency of vibration for bearing 1 in axial, horizontal and vertical direction was analyzed using the Taguchi method. During the analysis, the Taguchi technique will develop a relationship for the amplitude and frequency of vibration in terms of L/D ratio, Shaft speed and crack depth.
Experimental data of amplitude and frequency of bearing 2 vibrations in axial, horizontal and vertical direction was analyzed using Taguchi method.

Signal to noise ratios for the vibration amplitude and frequency are calculated using smaller the better characteristics and the ratios are analyzed. Table 2 shows the analysis of the signal to noise ratios and significant parameters which are having effect on the responses. Based on the delta values, it was observed that the shaft speed has high delta value and followed by the L/D ratio and crack depth. Hence,

Shaft speed was found to be dominant parameter among the three. Similarly, it was observed that the L/D

Ratio has high delta value and followed by shaft speed and crank depth.

Figure 8 shows the experimental data, Taguchi method predicted and ANN predicted values of amplitude and frequency of bearing 2 vibrations in axial, horizontal and vertical direction, From the figure, it was observed that there is good agreement among the three values for the six responses. Now, it can be summarized that either Taguchi or ANN approaches can be used to predict and optimize the input parameters.

Table 2. Taguchi analysis of signal-to-noise ratios for Amplitude and Frequency of vibration in the axial, Horizontal and Vertical direction (Bearing 2)

AMPLITUDE IN AXIAL DIRECTION, A_a				FREQUENCY IN AXIAL DIRECTION, F_a			
Level	L/D Ratio	Shaft Speed	Crack Depth	Level	L/D Ratio	Shaft Speed	Crack Depth
1	-13.091	-3.045	-5.908	1	-25.98	-18.40	-23.93
2	-9.349	-7.360	-7.955	2	-19.12	-22.91	-21.41
3	-1.915	-9.908	-6.449	3	-19.12	-25.07	-21.04
4	-7.891			4	-17.28		
5	-7.024			5	-23.21		
6	-3.610			6	-28.19		
7	-4.513			7	-21.99		
Delta	11.176	6.863	2.046	Delta	10.91	6.67	2.89
Rank	1	2	3	Rank	1	2	3

AMPLITUDE IN HORIZONTAL DIRECTION, A_h				FREQUENCY IN HORIZONTAL DIRECTION, F_h			
Level	L/D Ratio	Shaft Speed	Crack Depth	Level	L/D Ratio	Shaft Speed	Crack Depth
1	-5.222	-1.314	-5.248	1	-28.62	-24.82	-27.47
2	-4.424	-6.719	-8.139	2	-31.63	-28.50	-29.29
3	-2.699	-11.311	-5.957	3	-18.04	-28.21	-24.77
4	-7.268			4	-30.30		
5	-9.462			5	-30.59		
6	-8.402			6	-25.65		
7	-7.659			7	-25.40		
Delta	6.762	9.997	2.891	Delta	13.58	3.68	4.52
Rank	2	1	3	Rank	1	2	3

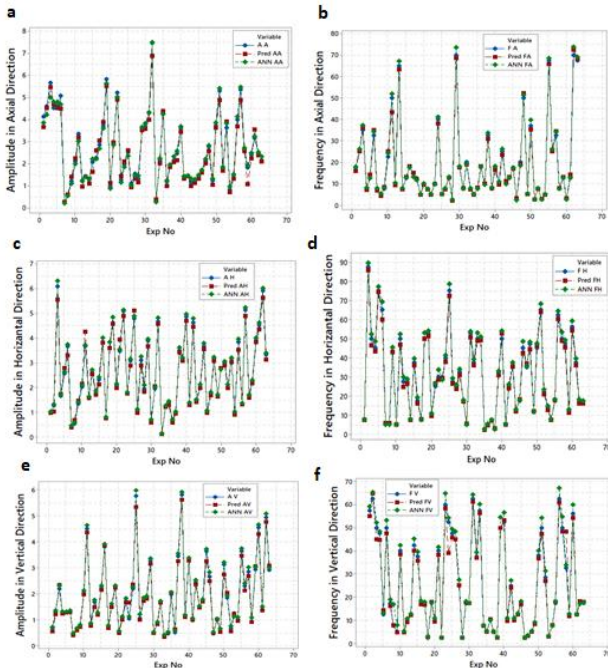| AMPLITUDE IN VERTICAL DIRECTION, A_V				FREQUENCY IN VERTICAL DIRECTION, F_V			
Level	L/D Ratio	Shaft Speed	Crack Depth	Level	L/D Ratio	Shaft Speed	Crack Depth
1	-1.7461	1.5496	-2.5183	1	-32.46	-24.83	-23.92
2	-0.6972	-3.5010	-4.5066	2	-24.35	-24.36	-26.01
3	-0.8803	-8.5884	-3.5149	3	-17.98	-24.75	-24.02
4	-2.6646			4	-21.10		
5	-5.9268			5	-28.20		
6	-5.5353			6	-25.06		
7	-7.1425			7	-23.39		
Delta	6.4453	10.1379	1.9884	Delta	14.48	2.09	0.47
Rank	2	1	3	Rank	1	2	3

Figure 8. Comparison between Experimental, Taguchi Predicted and ANN values of amplitude and frequency of vibration in the axial, horizontal and vertical direction (Bearing 2)

IV. CONCLUSION

The present study, developed a methodology using Taguchi and ANN techniques to predict amplitude and frequency of vibration. Experiments were conducted at different levels of crack depth, its position and spindle rotational speed on a shaft which was held between two bearings. Experimental results of amplitude and frequency of vibration in axial, vertical and horizontal directions were analyzed. Signal to noise ratios for the vibration amplitude and frequency were calculated using Taguchi method with smaller the better characteristics. It was observed that the L/D ratio (position of crack on the shaft) was found to be significant on the amplitude and frequency of vibration which were measured at two bearings in the three directions. ANN models which are developed for the amplitude and frequency of vibration and trained with experimental data using feed forward back propagation algorithm. The ANN and Taguchi techniques were used to predict the amplitude and frequency of vibration at both the bearings and compared with the experimental data. It was concluded that the both the Taguchi and ANN methods can be used to predict the responses with error less than 5%.

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168

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