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OPTIMIZATION OF INPUT PARAMETERS IN ROTOR BEARING SYSTEM: USING TAGUCHY METHOD AND ANOVA

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Abstract

Vibration in rotating machinery is caused by imbalance, misalignment, mechanical looseness, shaft crack, and other malfunctions. The diagnostics of rotor faults have been gaining importance in recent years. The present work deals with the effect of input parameters namely shaft speed, crack depth and L/D ratio. To examine the vibration characteristics of cracked shaft, a steel shaft with disk mounted at its center and supported by two bearings was used. An artificial crack was introduced to detect the vibration characteristics of the rotor. Initially, the signature data was obtained with crack depths ranging from 1mm to 3mm on the rotor of 25mm diameter. The effects of input parameters were analyzed by evaluating the amplitude and Frequency of vibration in Rotor bearing system. The amplitude and frequency were measured using FFT Analyzer (Fast Fourier Transform analyzer). A high-speed Fast Fourier Transform analyzer is used to process the acousto optic emission (AOE) signals. Taguchi and Analysis of Variance (ANOVA) methods were used to identify significant input parameters affecting the system vibrations. The ANOVA was carried out at confidence level of 95%. The process parameters which are having p-value less than 0.05 were said to be significant on the response. The effect of the input parameters on the amplitude and Frequency of vibration in Horizontal and Vertical Direction were carried using Taguchy Analysis. The input parameters such as l/d ratio, shaft speed and crack depth are optimized for minimum amplitude and Frequency of shaft in Horizontal and Vertical direction using S/N ratios of the experiments. In the Taguchi method, S/N ratios were calculated for all the experiments using smaller the better characteristics.

INTRODUCTION

Increasing demand for for higher speeds and loads, brought about enormously bendy rotors and this makes the examine of the vibratory movement important to layout. The dynamics and diagnostics of a cracked rotor have been gaining importance in latest years. The early detection of faults like fatigue cracks in rotor shafts are very critical to prevent catastrophic failure of the rotor system. Vibration monitoring throughout start up or/and shut-down is an crucial challenge in regular country operation to detect cracks particularly for machines which include aircraft engines which begin and forestall pretty regularly and run at excessive speeds. Detection, location and evaluation of faults play a vital role within the subject of rotor dynamics. Appearances and growth of fatigue crack in huge rotating machines may also lead to catastrophic failures. Online detection of

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cracks could be very critical for engineers who are operating inside the areas of system dynamics. Experimental layout techniques are smooth to simply accept and used with limited know-how of information as it has gained lot of popularity inside the engineering and clinical community. Layout and techniques consisting of factorial design, reaction floor method (RSM) and Taguchi methods are now extensively utilized in region of one thing at a time experimental approach. Taguchi strategies were broadly applied for optimization system in fabric processing noted in [9-14]. Experiments were conducted on lathe using reducing tool inserts with nostril radii and dull of AISI 1040 metal. According to chose orthogonal array 8 experiments (trials) had been conducted with two ranges of slicing parameters which includes paintings piece rotational speed, device insert nose radius and feed fee. Device existence turned into evaluated via reading floor roughness, amplitude of labor piece vibration and quantity of metallic removed with the help of Taguchi, ANOVA and Regression analysis [2].

The impact of drilling parameters including spindle speed, helix angle and feed price on floor roughness, flank wear and acceleration of drill vibration velocity became investigated. Response surface methodology became used to pick out huge parameters on the responses. A multi response optimization method turned into extensively utilized to optimize the drilling parameters for much less floor roughness, flank put on and drill bit vibration [6]. Marimuthu and Chandrasekaran [15] and Muthukrishnan and Paulo [16] additionally found that the feed has greater have an effect on on the floor roughness. The affirmation experiments were additionally executed for validating the end result. From S/N analysis and imply response traits, the foremost levels of manage factors were calculated as A2, B1 and C1. Therefore, the predicted suggest of excellent characteristics i.e. flank wear turned into computed the use of [7]. Taguchi advanced positive preferred orthogonal arrays via which the simultaneous and unbiased assessment of or extra parameters might be executed within the complete space. The arrays have been so designed that the numbers of experiments have been very low in comparison to classical design technique [8]. Bala Murugan et al. used this method at the side of Taguchi in optimization of slicing parameters in machining of hardened metal [17].

Taguchi technique became implemented for machinability evaluation of Zirconia Toughened Alumina (ZTA) reducing insert even as turning of AISI 4340 metal. The Taguchi L9 orthogonal array became applied, S/N ratio was calculated using smaller the higher standards and ANOVA technique became followed for finding the higher machinability parameters like cutting pace, feed charge and intensity of cut. The parameter optimization changed into additionally achieved with 95% self-assurance degree. The confirmation experiments have been also executed for validating the end result [1]. The system parameters consequences on floor roughness, surface hardness and device vibration amplitudes in flip-milling methods is been studied using ANOVA of SN ratios and regression fashions [3]. A unique micro W-bending system for a research of affects of the parameters, which include foil thickness, foil orientation, grain size and punch frequency, at the bending accuracy of the micro-bent parts. Micro W-bending experiments were carried out based on Taguchi L8 OA. S/N ratio, collectively with

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ANOVA, becomes applied to analyze the top of the line bending situations and the volume of the contributions from the parameters at the spring back and poor spring back respectively. Affirmation checks have verified the results acquired. Mathematical models of the spring back and poor spring back were established and its adequacy became evaluated [4]. The extensive factors of the wear and tear research were determined by using ANOVA. The slurry velocity was the most dominating aspect, accompanied by sand debris and impingement perspective in causing the mass lack of the unclad and clad surface of the substrates [5]. Taguchi technique turned into carried out for machinability evaluation of Zirconia Toughened Alumina (ZTA) slicing insert even as turning of AISI 4340 metallic. The Taguchi L9 orthogonal array was implemented, S/N ratio became calculated using smaller the higher criteria and ANOVA approach became followed for locating the higher machinability parameters like reducing pace, feed fee and depth of cut. The parameter optimization changed into also performed with 95% confidence level. ANOVA was used to find out the impact of reducing speed, nose radius and feed price on tool existence via reading the surface roughness, RMS of labor piece vibration and machining time until the tool is failed. Within the evaluation, the percentage contribution of each cutting parameter turned into determined and used to degree the corresponding outcomes on the metal reducing. The achieved experimental plan become evaluated at a self-belief stage of ninety five%. [17].

In this work, an artificial crack was introduced to detect the vibration characteristics of the rotor. Initially, the signature data was obtained with crack depths ranging from 1mm to 3mm on the rotor of 25mm diameter. The effects of input parameters were analyzed by evaluating the amplitude and Frequency of vibration in Rotor bearing system. The amplitude and frequency were measured using FFT Analyzer (Fast Fourier Transform analyzer). A high-speed Fast Fourier Transform analyzer is used to process the acousto optic emission (AOE) signals. Taguchi and Analysis of Variance methods were used to identify significant input parameters affecting the system vibrations and the input parameters are optimized using S/N ratios of the experiments.

Experimental Procedure

A steel shaft supported on two bearings at both ends (Fig. 1) and having a disc at the centre, with the subsequent statistics is taken into consideration for the evaluation: shaft diameter 25mm, length 400 mm, disc mass 1.2 kg. The FFT analyzer has a capability to measure velocities of 200 mm/sec with a decision of zero.1 mm/sec and frequency range of 10-1 KHz. An input of 1500 rpm is given to the rotor with various crack depth. The statistics concerning the set up and the location of the sensor is fed into the computer and then it was transferred to the FFT analyzer. The amassed facts from the FFT analyzer are again transferred to the computer for generating the wave forms.

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Figure 1: Experimental set up of rotor kit with FFT analyzer.

RESULTS AND DISCUSSION

Effect of input parameters on the Amplitude of vibration in horizontal direction

ANOVA is a universally accepted technique used to analyse the response or experimental data in various applications. The ANOVA was carried out at confidence level of 95%. The process parameters which are having p-value less than 0.05 were said to be significant on the response. In addition to that the input parameters should have F value more than 4.

Effect of l/d ratio, shaft speed and crack depth on the Amplitude of vibration in horizontal direction is shown in the Table 1. For bearing 1 the p-value and F-value, the linear model and square models are found to be significant. The shaft speed, crack depth and square of crack depth are having p-values 0.0, 0.019 and 0.11 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the amplitude vibration in terms of input parameters as shown in the equation (1).

Similarly, for bearing 2 the p-value and F-value, the linear model and square models are found to be significant. The crack depth, product of l/d, crack depth and square of l/d ratio are having p-values 0.019, 0.030 and 0.019 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the amplitude vibration in terms of input parameters as shown in the equation (2).

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Table 1: Analysis of Variance for Amplitude of vibration in horizontal direction bearing 1

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	81.661	9.0735	8.91	0.000
Linear	3	74.108	24.7026	24.25	0.000
L/D	1	2.658	2.6578	2.61	0.112
S S	1	69.660	69.6602	68.37	0.000
C D	1	1.790	1.7897	1.76	0.019
Square	3	3.340	1.1134	1.09	0.360
L/D*L/D	1	0.001	0.0006	0.00	0.981
S S*S S	1	0.748	0.7483	0.73	0.395
C D*C D	1	2.591	2.5915	2.54	0.011
2-W I	3	4.213	1.4044	1.38	0.259
L/D*S S	1	1.397	1.3970	1.37	0.247
L/D*C D	1	2.653	2.6526	2.60	0.113
S S*C D	1	0.164	0.1636	0.16	0.690
Error	53	53.999	1.0188		
Total	62	135.660			

Regression Equation in Uncoded Units for Bearing 1

A H = -1.25 + 0.088 L/D + 0.00045 S S + 1.20 C D - 0.0004 L/D*L/D + 0.000004 S S*S S - 0.430 C D*C D - 0.000243 L/D*S S + 0.0838 L/D*C D + 0.000306 S S*C D (1)

Regression Equation in Uncoded Units for Bearing 2

AH = 0.93 - 0.098 L/D - 0.0035 S S + 2.74 CD+ 0.0326 L/D*L/D+ 0.000004 S S*S S- 0.343 CD*CD - 0.000139 L/D*S S - 0.141 L/D*CD - 0.00017 S S*CD (2)

Effect of input parameters on the Amplitude of vibration in vertical direction

Effect of l/d ratio, shaft speed and crack depth on the Amplitude of vibration in vertical direction is shown in the Table 2. In bearing 1 the p-value and F-value, the linear model and square models are found to be significant. The l/d ratio, shaft speed and square of shaft speed are having p-values 0.0, 0.001 and 0.025 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the amplitude vibration in terms of input parameters as shown in the equation (3). Similarly, in bearing 2 the p-value and F-value, the linear model and square models are found to be significant. The l/d ratio, crack depth, product of l/d, crack depth and square of crack depth are having p-values 0.026, 0.021, 0.010 and 0.019 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the amplitude vibration in terms of input parameters as shown in the equation (4).

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Table 2: Analysis of Variance for Amplitude of vibration in vertical direction bearing 1

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	66.084	7.3427	8.69	0.000
Linear	3	58.518	19.5059	23.08	0.000
L/D	1	10.726	10.7260	12.69	0.001
S S	1	46.179	46.1791	54.64	0.000
C D	1	1.613	1.6127	1.91	0.173
Square	3	1.441	0.4802	0.57	0.638
L/D*L/D	1	0.001	0.0008	0.00	0.975
S S*S S	1	1.124	1.1239	1.33	0.025
C D*C D	1	0.316	0.3160	0.37	0.543
2-W I	3	6.126	2.0419	2.42	0.077
L/D*S S	1	2.140	2.1398	2.53	0.118
L/D*C D	1	0.003	0.0033	0.00	0.951
S S*C D	1	3.983	3.9826	4.71	0.034
Error	53	44.793	0.8451		
Total	62	110.877			

Regression Equation in Uncoded Units for Bearing 1

A V = 2.97 - 0.077 L/D - 0.00743 S S - 0.32 C D - 0.0005 L/D*L/D + 0.000005 S S*S S

- 0.150 C D*C D + 0.000301 L/D*S S - 0.0029 L/D*C D + 0.001509 S S*C D (3)

Regression Equation in Uncoded Units for Bearing 2

AV = 2.85 - 0.050 L/D - 0.00484 S S + 0.81 CD + 0.0196 L/D*L/D + 0.000002 S S*S S

- 0.107 CD*CD - 0.000069 L/D*S S - 0.1177 L/D*CD + 0.000732 S S*CD (4)

Effect of input parameters on the frequency of vibration in horizontal direction

Effect of l/d ratio, shaft speed and crack depth on the frequency of vibration in horizontal direction is shown in the Table 3. In bearing 2 the p-value and F-value, the linear model and square models are found to be significant. The l/d ratio, shaft speed and product of l/d ratio, crack depth are having p-values 0.015, 0.018 and 0.031 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the frequency vibration in terms of input parameters as shown in the equation (6).

Similarly, in bearing 1 the p-value and F-value, the linear model and square models are found to be significant. The l/d ratio, shaft speed and square of l/d ratio are having p-values 0.023, 0.044 and 0.0488 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the frequency vibration in terms of input parameters as shown in the equation (5).

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Table 3: Analysis of Variance for frequency of vibration in horizontal direction for bearing 2

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2883.6	320.401	0.80	0.062
Linear	3	905.3	301.762	0.75	0.052
L/D	1	829.9	829.873	2.07	0.015
S S	1	0.3	0.302	0.00	0.018
CD	1	16.5	16.546	0.04	0.840
Square	3	443.0	147.652	0.37	0.776
L/D*L/D	1	24.4	24.381	0.06	0.806
S S*S S	1	230.7	230.730	0.58	0.451
CD*CD	1	128.2	128.168	0.32	0.574
2-Way Interaction	3	436.7	145.568	0.36	0.780
L/D*S S	1	14.0	14.041	0.04	0.852
L/D*CD	1	418.3	418.328	1.04	0.031
S S*CD	1	3.9	3.877	0.01	0.922
Error	53	21227.3	400.515		
Total	62	24110.9			

Regression Equation in Uncoded Units for Bearing 1

F H = -46.7 - 0.33 L/D + 0.192 S S + 15.1 C D + 0.005 L/D*L/D - 0.000082 S S*S S

- 5.33 C D*C D - 0.00540 L/D*S S + 1.18 L/D*C D - 0.0065 S S*C D (5)

Regression Equation in Uncoded Units for Bearing 2

FH = 70.7 - 4.77 L/D - 0.090 S S + 6.6 CD + 0.096 L/D*L/D + 0.000065 S S*S S

- 3.24 CD*CD - 0.00080 L/D*S S + 1.38 L/D*CD - 0.0016 S S*CD (6)

Effect of input parameters on the frequency of vibration in vertical direction

Effect of l/d ratio, shaft speed and crack depth on the frequency of vibration in vertical direction is shown in the Table 4. Based on the p-value and F-value, the linear model and square models are found to be significant. The crack depth, shaft speed and square of crack depth are having p-values 0.018, 0.035 and 0.012 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the frequency vibration in terms of input parameters as shown in the equation (8).

Similarly, in Bearing 1 the p-value and F-value, the linear model and square models are found to be significant. The shaft speed, crack depth and square of l/d ratio are having p-values 0.001, 0.035 and 0.012 respectively. Their F-values are also observed to be more than 4 and then they are said to be significant. An empirical model was developed for the frequency vibration in terms of input parameters as shown in the equation (7).

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Table 4: Analysis of Variance for frequency of vibration in vertical direction

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	4946.1	549.57	1.31	0.254
Linear	3	1621.5	540.50	1.29	0.288
L/D	1	0.4	0.44	0.00	0.974
S S	1	531.2	531.23	1.27	0.026
CD	1	1021.6	1021.57	2.43	0.012
Square	3	2105.4	701.80	1.67	0.184
L/D*L/D	1	190.7	190.66	0.04	0.503
S S*S S	1	400.6	400.59	0.95	0.333
CD*CD	1	1149.5	1149.51	2.74	0.010
2-Way Interaction	3	641.1	213.70	0.51	0.678
L/D*S S	1	62.2	62.22	0.01	0.702
L/D*CD	1	599.2	599.22	1.43	0.023
S S*CD	1	2.8	2.83	0.01	0.935
Error	53	22246.6	419.75		
Total	62	27192.7			

Regression Equation in Uncoded Units for bearing 1

$$FV = 49.5 - 8.91\,L/D - 0.015\,SS + 12.2\,CD + 0.515\,L/D*L/D + 0.000005\,SS*SS - 5.05\,CD*CD - 0.00036\,L/D*SS + 0.67\,L/D*CD + 0.0050\,SS*CD \quad (7)$$

Regression Equation in Uncoded Units for bearing 2

$$FV = 57.1 - 5.24\,L/D - 0.107\,SS + 21.8\,CD + 0.269\,L/D*L/D + 0.000086\,SS*SS - 9.70\,CD*CD - 0.00168\,L/D*SS + 1.66\,L/D*CD + 0.0013\,SS*CD \quad (8)$$

Optimization of input parameters for the AH:

The input parameters such as l/d ratio, shaft speed and crack depth are optimized for minimum amplitude of shaft in horizontal direction. In the Taguchi method, S/N ratio were calculated for all the experiments using smaller the better characteristics. Here, the input parameters are optimized using S/N ratios of the experiments for bearing 1 and bearing 2. As shown in the Figure 2 and 3, 8 of l/d ratio, 1000rpm of shaft speed and 2mm of crack depth, the vibration amplitude if found to be less.

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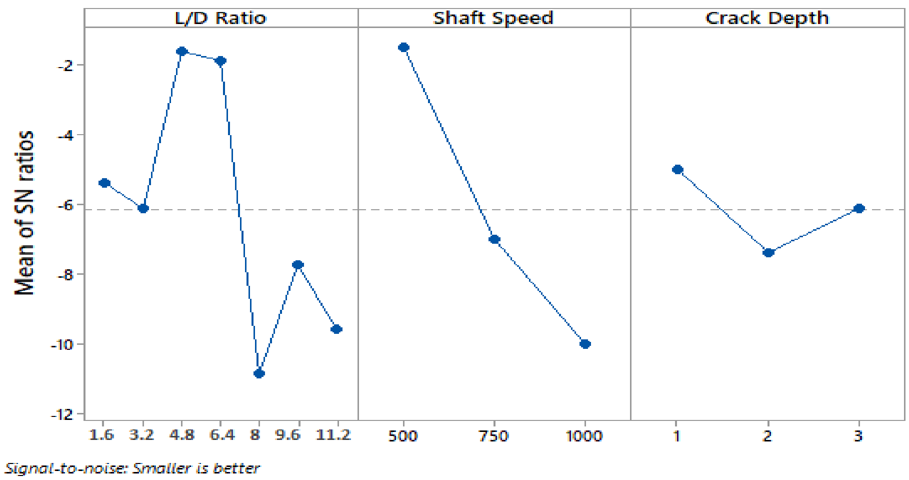

Figure 2: Optimization of input parameters for amplitude of vibration in horizontal direction for Bearing 1

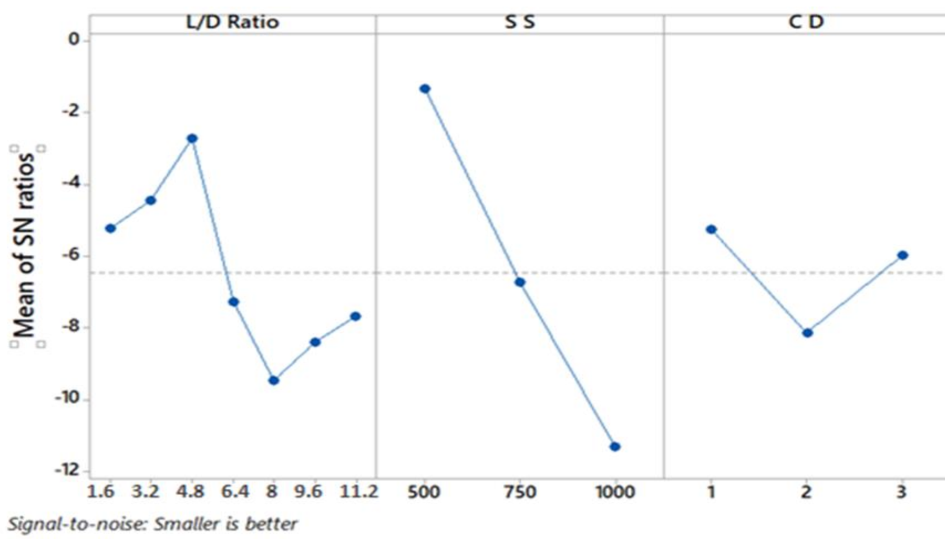

Figure 3: Optimization of input parameters for amplitude of vibration in horizontal direction for bearing 2

Optimization of input parameters for the AV:

The input parameters such as l/d ratio, shaft speed and crack depth are optimized for minimum amplitude of shaft in vertical direction. In the Taguchi method, S/N ratio were calculated for all the experiments using smaller the better characteristics. Here, the input parameters are optimized using S/N ratios of the experiments. As shown in the Figure 4and 5, 1000rpm of shaft speed and 2mm of crack depth for bearing 1 and 2 but, in bearing 1 at 9.6 of l/d ratio, and in bearing 2 at 11.2 of l/d ratio the vibration amplitude found to be less.

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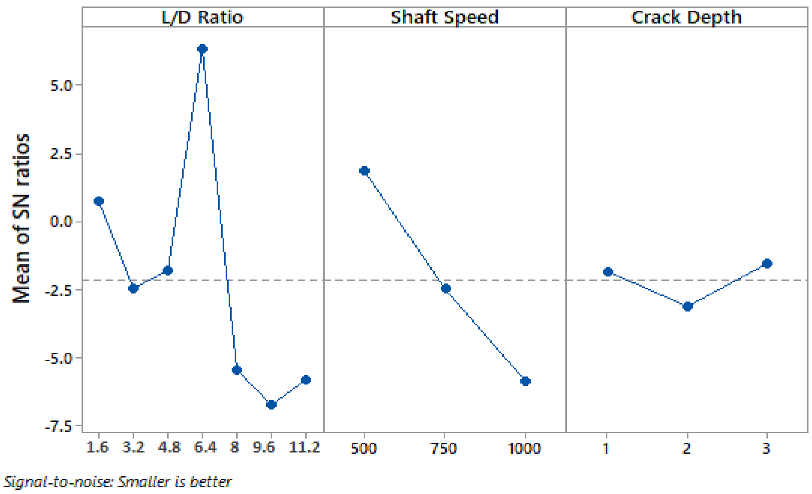

Figure 4: Optimization of input parameters for amplitude of vibration in vertical direction for bearing 1

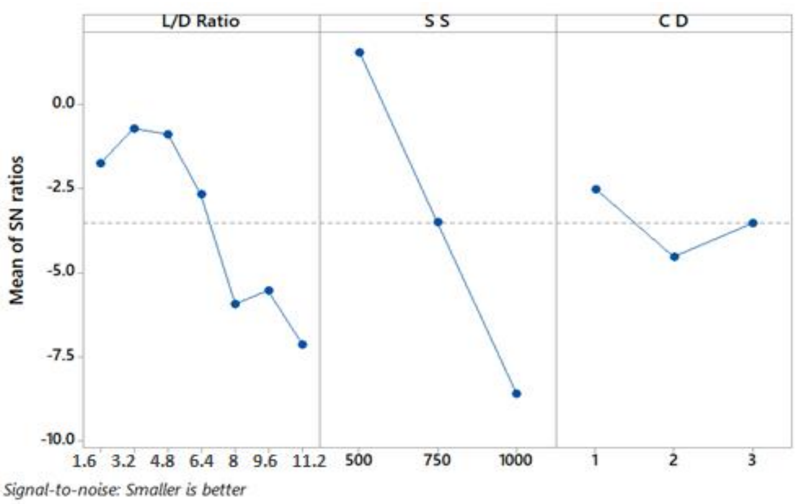

Figure 5: Optimization of input parameters for amplitude of vibration in vertical direction for bearing 2

Optimization of input parameters for the FH:

The input parameters such as l/d ratio, shaft speed and crack depth are optimized for minimum frequency of shaft in horizontal direction. In the Taguchi method, S/N ratio was calculated for all the experiments using smaller the better characteristics. Here, the input parameters are optimized using S/N ratios of the experiments. As shown in the Figure 6, at 1.6 of l/d ratio, 7500rpm of shaft speed and 2mm of crack depth, the vibration amplitude if found to be less. Similarly, As shown in the Figure 7, at 9.6 of l/d ratio, 1000rpm of shaft speed and 1mm of crack depth, the vibration frequency if found to be less.

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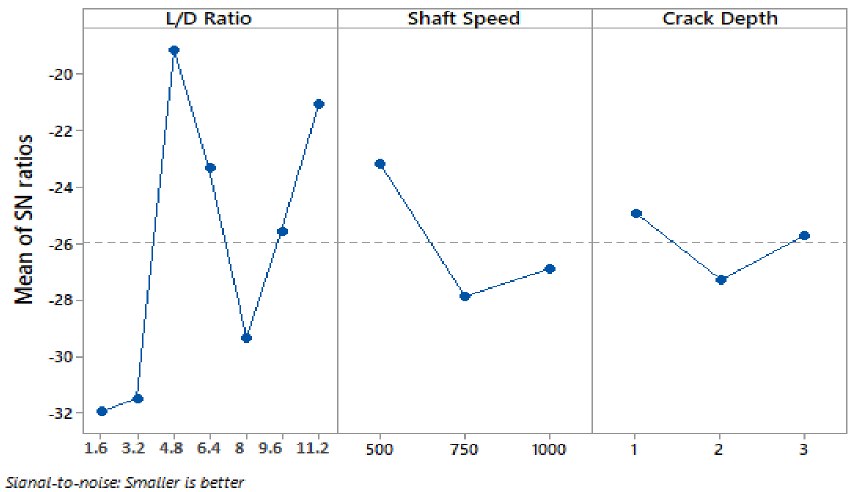

Figure 6: Optimization of input parameters for frequency of vibration in horizontal direction for bearing 1

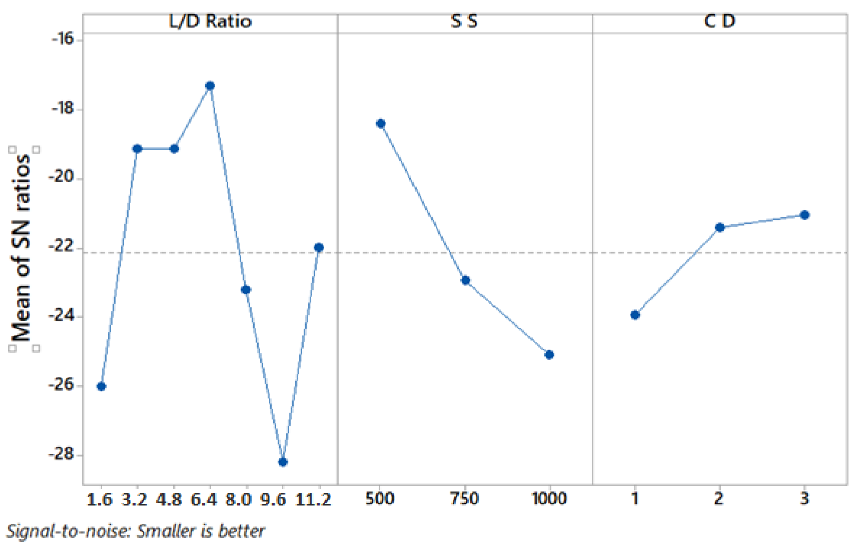

Figure 7: Optimization of input parameters for frequency of vibration in horizontal direction for bearing 2

Optimization of input parameters for the FV:

The input parameters such as l/d ratio, shaft speed and crack depth are optimized for minimum frequency of shaft in vertical direction. In the Taguchi method, S/N ratio were calculated for all the experiments using smaller the better characteristics. Here, the input parameters are optimized using S/N ratios of the experiments for bearing 1 and bearing 2. As shown in the Figure 8 and 9, at 1.6 of l/d ratio, 1000rpm of shaft speed and 2mm of crack depth, the vibration amplitude if found to be less.

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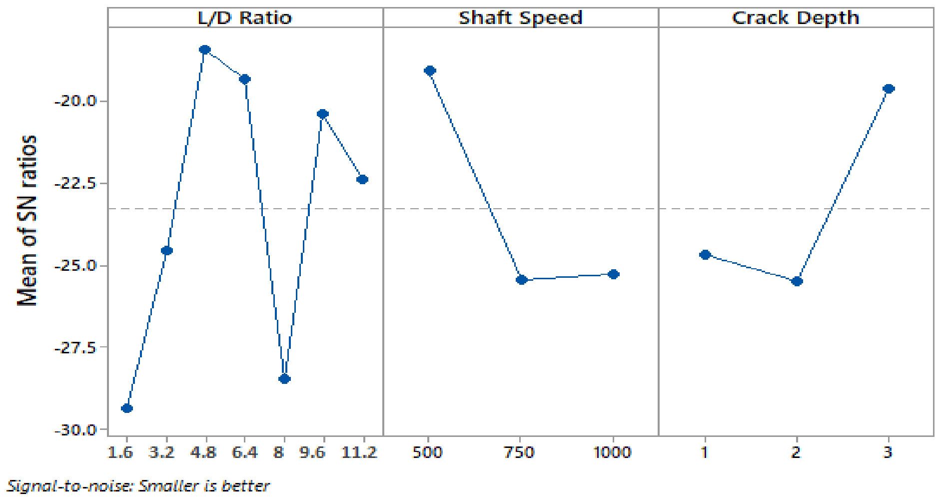

Figure 8: Optimization of input parameters for frequency of vibration in vertical direction for bearing 1

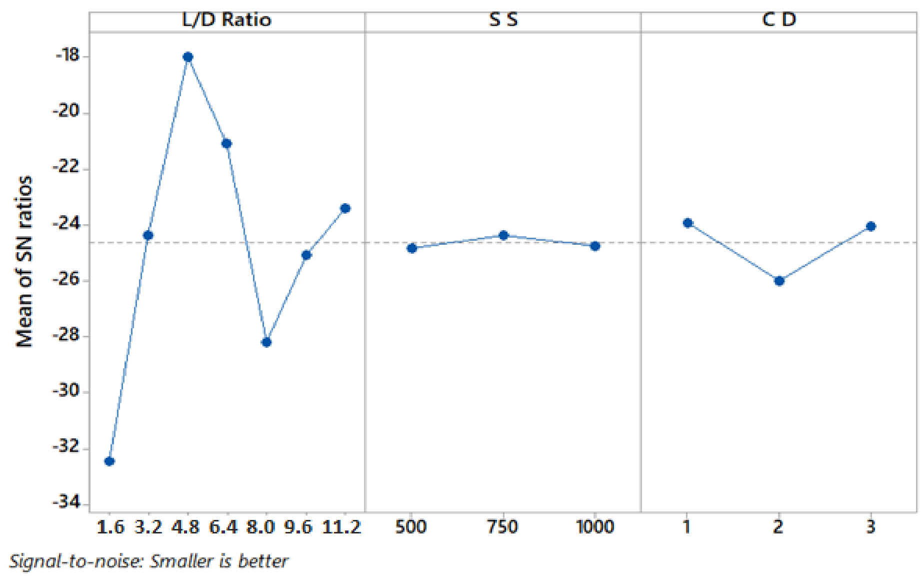

Figure 9: Optimization of input parameters for frequency of vibration in vertical direction for bearing 2

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 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 two 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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