Modeling and Optimization of Parameters in Condition Monitoring for Angular Misalignment Using the Desirability Concept and JAYA Algorithm

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Abstract: - In high-precision machines, aligned close tolerance rotating part condition is vitally important. It is usual practice that machines are examined critically for aligned conditions at the time of installation. It is seen that it is subject slowly to misaligned conditions during the working period. In the Industry 4.0 revolution, condition monitoring of machines is one of the main priorities. In the present work, misalignment in rotating parts and its effects on the machine are studied to determine the lowest overall vibration level (OVL) and find influencing process parameters for OVL. The output vibration signals are obtained for the different misaligned conditions through experimental setup. The experimental layout is designed using the design of experiments, response surface methodology, and central composite design. Further analysis is carried out using Minitab 16 software. The process parameter considered for experiments is speed and angular misalignment. The corresponding performance values are obtained for speed range 500 to 2100 rpm and angular misalignment 0.01 to 0.08 mm/inch. The process parameters are optimized to obtain the lower value of OVL. ANOVA analysis showed that both speed and angular misalignment, along with square terms, is significant. The obtained lowest OVL value is 0.544 mm by the desirability concept, and it is further improved to 0.448 mm by the JAYA algorithm. The average error of implementation is less than 2 %.

Keywords: - Misalignment, Design of Experiments (DoE), ANOVA model, JAYA algorithm, Vibration analysis.

1. INTRODUCTION

In the manufacturing and automobile industry, condition monitoring of machines is an important task to ensure efficient production. Any unexpected breakdown has a major impact on production costs. To avoid these unwanted conditions, it is necessary to monitor machine output in various forms. Therefore, statistical and mathematical-based models are more often used to establish co-relation between machine output signals and input parameters. Statistical-based studies also help to determine influencing parameters that are responsible for deteriorating machine conditions. The Fuzzy, Artificial Neural Network (ANN) and regression analysis are considered important modeling methods in data analysis. The author Elman C. Jameson [1] compared all models in his book and recommended the regression analysis model as a practical and easy approach to develop a correlation between input parameters and process responses.

The author elaborates on the role of online condition monitoring and diagnosis of power equipment[2]. With the help of big data, the Internet of things, and cloud computing techniques, a brief review of a transformer, gas-insulated switchgear, cable, generator, and capacitor is described. The wavelet packet energy ratio of re-sampled vibration signals is used in the detailed fault classification method. To extract fault features from the vibration signal, the analysis is performed at a multilevel energy ratio[3]. The author has presented an analysis of natural frequency and mode shapes for angular misalignment using Finite Element Method based on Von Karman strain theory and Kirchhoff plate theory[4]. The analysis also states that no largest frequency split on the nodal circle. The gyroscopic effect involved has also been considered through split frequency in plane mode.

The author has compared different electrodes in different methods in EDM analysis and claimed that the Taguchi technique is favorably good[5]. Mouloud Boumahdi et.al has explained the prediction of the remaining useful life of thrust ball bearing using full factorial design. The author has compared the accuracy of results obtained by different methods, viz. ANOVA, FFM16 and RUL[6]. The effectiveness in predicting output process variables for complaint micro gripper has been discussed with the hybrid approach of adaptive neuro-fuzzy inference system and Jaya algorithm[7]. The author has explained the optimization of process parameters in EDM for tungsten carbide composite by applying ANOVA and T-test models[8]. The effectiveness of ANOVA implementation for improvements in the ground rig and in assessing performance for pulse detonation engine dynamics has been explained [9]. The methodology based on signal processing and image processing is used to determine the fault in the rotor bar. These results are validated with the ANOVA model to improve prediction accuracy[10]. The performance of coated and uncoated cermet inserts has been analyzed with different machining parameters. To deal with influencing parameter, ANOVA and regression analysis is used [11], [12]. The super alloy VAT 32 is studied with coated carbide tools by physical vapor deposition. The influence of cutting parameters is further analyzed by ANOVA for optimization[13]. The design of the experiment is carried out with current density, pulse duration, and total electro-deposition time for the hydrogen evolution reaction. The data obtained by Design of Experiment (DoE) is processed with ANOVA to improve corrosion resistance efficiency[14].

The tensile strength of Aluminum alloy AA6061 is investigated through DoE to improve weld joint efficiency. The results obtained are re-ascertained by the ANOVA technique[15]. The suitability of the ANOVA technique to analyze variability has been explained for a wide range of engineering applications[16]. The Aluminum alloy with different weight percentages of Sic is tested to improve material damping strength. The best material combination is selected using response surface methodology (RSM)[17]. The effect of tool geometry on the turning of AISI1045 steel has been studied in the combined approach of DoE and Finite element method (FEM) analysis. FEM is considered to analyze lower cutting temperatures and resultant cutting forces[18]. The DoE is developed at five levels for surface roughness prediction[19]. The effect of feed rate and depth of cut has been studied for vibration analysis of high-speed milling tools. The most significant parameter is determined using ANOVA[20]. The effect of various parameters on nanoparticles of copper carbonates in the electro-chemical process has been studied with the help of ANOVA and optimized based on Taguchi's robust design[21]. R.V. Rao has compared various optimization techniques and claimed effective optimization using the Jaya algorithm[22].

In an overview of the literature study, it is seen that shaft misalignment and its effect analysis are done by mathematical modeling, FEM analysis, and thermometric analysis. The Design of Experiments and statistical tools like ANOVA, Taguchi, etc., are extensively used in the analysis of machine tool performance parameters, the parameter for improvement of the EDM process, analysis of different materials with varying compositions for their effective machining, etc.[23]. The central part of machine fault diagnosis, condition monitoring, and prognosis of machine conditions has yet to be explored with techniques of DoE and statistical tools. The vibration analysis and condition monitoring of shaft misalignment and its analysis can be further practice with the application of statistical techniques. The conventional methods, viz. experimental and analytical, require large amounts of data to be collected to get precise predictions and require high-end computational tools for analysis. The main advantage of the statistical technique is that it requires fewer data for fault analysis, and simple computational tools are used. In this technique, various parameters involved can be correlated with the most influencing variable. This will help to extend the analysis for a wide range of applications. Hence, concluding to the above facts, shaft misalignment study is focused in this work with DoE and statistical technique.

2. METHODOLOGY

2.1. Experimental setup

The experimental setup, as shown in Fig. (1), is prepared to obtain data for misalignment at different operating conditions. The setup has been made with a provision to introduce angular misalignment.

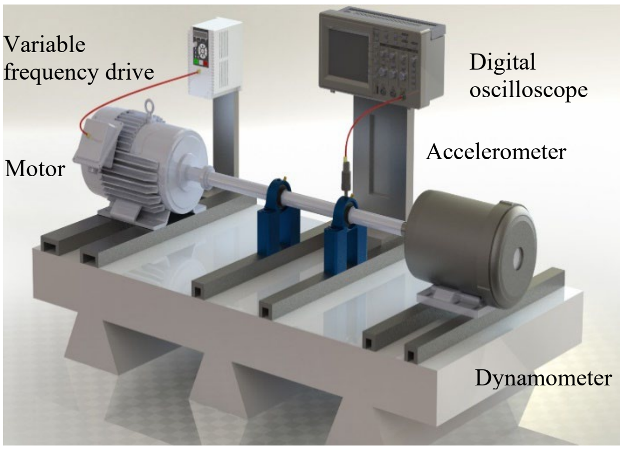

Figure 1. Experimental Setup

Table.1 Allowable Values of angular misalignment
Courtesy: Machinery Alignment book, Victor Wowk (1)

Speed, RPM	Allowable angular misalignment, mm/inch	Allowable angular misalignment, mils/inch
600	0.0635	2.5
900	0.0508	2
1200	0.0381	1.5
1800	0.0254	1
3600	0.0127	0.5

Table 2. Input parameters for pilot experimentation

Parameters	Conditions
Speed (RPM)	500, 740, 1440, 1800, 2100
Angular misalignment (mm/inch)	0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08

The allowable values for angular misalignment are shown in Table 1. The input parameters and their values considered for pilot experimentation are shown in Table 2. It is ensured that all other sources of vibration are eliminated before starting of actual experimentation of the misalignment condition. In the three phases, an A.C. induction motor with 2800 rpm is used. The variable frequency drive is used for the required speed variation. An accelerometer is used for sensing output vibration signals. The digital storage oscilloscope (Tektronix TBS 1064, 60 MHz, 4 channel, Measurement accuracy: vertical ± 3%, from 10mv/div to 5v/div) is used to store measured output signals for the above-mentioned input parameters. The vibration signals are obtained in all three directions. In the case of angular misalignment considered in the horizontal plane, higher values of OVL are expected in the x-direction[24].

2.2. Implementation for Design of Experiments (DoE):

To understand the behavior of an angular misaligned system, output vibration signals are collected from the experimental setup at different conditions. The speed (A) and angular misalignment (B) are taken as process parameters in DoE to examine machine condition in terms of Overall vibration level (OVL). The Response surface methodology retaining Central Composite Design (CCD) is preferred to analyze and derive regression response equation. To vary each parameter, two levels are considered in coded form as -1 and +1 i.e. – α and + α. If 'j' is several input parameters, then the expression for α can be written as $\alpha = \sqrt[4]{2^j}$ to assure rotatability. The factors and their levels considered for DoE are shown in Table.3. The levels are decided based on pilot experimentation and machine capability results.

Table 3. Factors and their levels

Sr. No.	Factors	Code	Levels	
			-1	+1
1	Speed (rpm)	A	500	2100
2	Angular misalignment (mm/inch)	B	0.008	0.07

Table 4 shows the variation of OVL for different speeds and angular misalignment obtained through experimentation set up in the x-direction. It is inferred from Table. 4 show that OVL is not following the trend of proportionality in the range of 0.01 to 0.07 mm/inch angular misalignment. Hence, this range is considered sensible to determine the most influencing parameters on OVL. It is also understood by experimental observations that OVL seen in x-directions is more dominant than in y and z-directions. The sample graphs are discussed in the later part of the result discussion, as depicted in Fig.3 and Fig.4. Hence, x-direction OVL observations are preferred as deciding factors and their levels for DoE analysis. It is important to note that the order of experimentation is randomized in a selected range to avoid the appearance of any systematic error. The required random combinations of speed and angular misalignment values are obtained by Minitab 16, as shown in Table.5. The total 14 runs are considered by repeating 3 center points, shown in Table.5.

3. RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) contains a good set of statistical techniques which has been used in the effective analysis of problems in which output depends on several inputs. It is one of the DoEs in which unknown dependent functions are evaluated with minimum computations. This analysis studies the relation between the parameters to investigate and the responses obtained.

Table.4 Experimental OVL values for angular misalignment in the x-direction

Speed, RPM →	500	740	1440	1800	2100
Misalignment, mm ↓	**OVL, mm**				
0	0.51	0.56	0.61	0.75	0.85
0.01	0.3	1.15	0.513	0.76	0.88
0.02	0.87	0.75	0.86	0.91	0.75
0.03	0.9	0.665	0.996	0.91	1.2
0.04	0.67	0.776	1.03	0.82	1.4
0.05	0.95	0.964	0.94	0.98	0.96
0.06	0.8	0.96	1.06	1.11	1.12
0.07	0.84	1.04	0.98	1.35	1.46
0.08	0.96	0.83	1.03	1.21	1.52

Table.5 Experimental layout as per CCD

Sr. No	Speed, RPM	Angular Misalignment, mm
1	1300	0.039
2	734	0.061
3	1300	0.039
4	734	0.017
5	1300	0.039
6	1866	0.017
7	1866	0.061
8	1300	0.039
9	1300	0.039
10	2100	0.039
11	500	0.039
12	1300	0.008
13	1300	0.070
14	1300	0.039

To improve the accuracy of prediction, CCD is used, which measures variable averages related to quantities measured in experimentation. The speed and angular misalignments are studied for OVL investigation. The arrangements to conduct experiments using CCD with two variables, the cardinal points used are 4 cube points, 4 axial points, and 3 center points. In total, 14 base runs are performed. When the response function is unknown and non-linear, usually, a second-order model is used. In the present work, the second-order model is considered to map the relation between responses obtained experimentally i.e., for speed and angular misalignment, and variables to be investigated i.e., OVL. The second-order model behavior of the system is explained by Eq. (1).

$$R = \beta_0 + \sum_{i=1}^{k} \beta_i A_i + \sum_{i=1}^{k} \beta_i B_i + \sum_{i,j=1, i \neq j}^{k} \beta_{ij} A_i B_i + ... (1)$$

Where R is a corresponding response, Ai and Bi are input variables, AiBi is the interaction term of input variables, and βo, Bi, βij are regression coefficients.

In the present study, Response surface designs are used for modeling speed, angular misalignment, and OVL. A response surface model can identify a point where a minimum or maximum value of the response occurs if one exists inside the design region.

4. ANALYSIS OF VARIANCE

Analysis of Variance (ANOVA) is a statistical examination of all variables used in experimentation for different conditions. It is a method of analyzing the statistical significance of variables. ANOVA test is implied to determine the influence of independent variables on dependent variables in regression analysis. A one-way ANOVA is used for three or more groups of data to gain information about the relationship between dependent and independent variables. In the present analysis of angular misalignment, one-way ANOVA is used. The ANOVA F-ratio tends to be 1 if no variance exists between the groups.

5. DESIRABILITY FUNCTION

Desirability Function (DF) is one of the most widely used methods for the optimization of multiple response processes. The variable targeted for optimization is defined with a desirability that ranges from zero outside of the limit to one at the goal. The optimization finds a point that maximizes the desirability function. Let, Y be the desirable function, x1 and x2 are the lower and upper limits of the respective parameter, and the mathematical function of DF can be written as shown below.

Objective function: Y, minimum (OVL)
Condition: $x1 \leq A \leq x2$, for speed.
$x1 \leq B \leq x2$, for angular misalignment.

6. JAYA ALGORITHM

JAYA algorithm is a very effective technique of optimization[22] of influencing parameters. In this work, speed, angular misalignment, and OVL are considered parameters to keep the minimum OVL of the machine. Jaya algorithm avoids undesirable solutions and converges to the desirable part of the solution.

Let P(X) be an objective function that is to be maximized or minimized at any generation 'i', number of design variables 'l', and population size 'n'. Let the maximum (mx) and minimum (mn) values of the objective function during generation are considered as P(X)mx and P(X)mn, respectively. In this analysis, P(X) is the OVL of the machine which should be the minimum possible. The value of the function considered is updated as shown in Eq. (2) for the i^{th} design variable value and nth population in the i^{th} generation.

$$X'_{1,n,j} = X_{1,n,j} + K_{1,i,j}(X_{1,mx,j} - |X_{1,n,j}|) - K_{2,i,j}(X_{1,mn,j} - |X_{1,n,j}|) \quad (2)$$

where $X_{1,mx,j}$ is the l^{th} variable value for maximum and $X_{1,mn,j}$ is the l^{th} variable value for minimum. $X'_{l,n,j}$ is the modified value of $X_{1,n,j}$. $K1_{i,j}$ and $K2_{i,j}$ are two random numbers in the range of -1 to +1. The term $K1_{i,j}(X_{1,mx,j} - |X_{1,n,j}|)$ shows the ability of a solution to go nearer to the maximum value solution, and term $-K2_{i,j}(X_{1,mn,j} - |X_{1,n,j}|)$ shows the ability of the solution to go nearer to minimum value solution. The $X'_{l,n,j}$ is accepted if it gives minimum function values.

7. RESULTS AND DISCUSSION

7.1. Experimentation analysis

The output vibration signals are recorded for different changes in the input condition, as shown in Table.2. The vibration signals are recorded in all three directions. The sample OVL variation for 740rpm and 1440 rpm has been demonstrated in Fig. 2 and Fig. 3. The OVL recorded in the x-direction are dominant. Therefore, x-direction responses are considered for analysis by DoE.

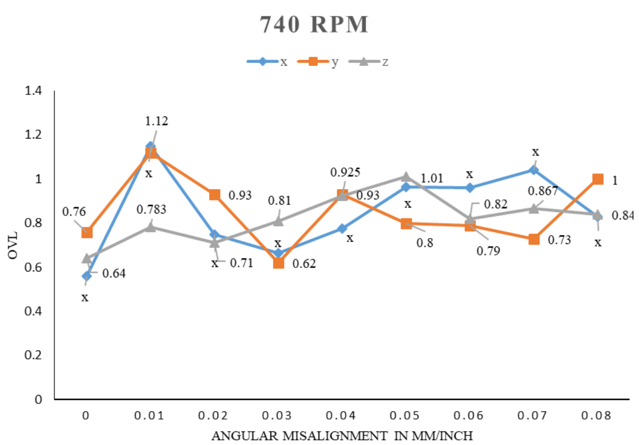

Figure 2. OVL variation at 740 RPM

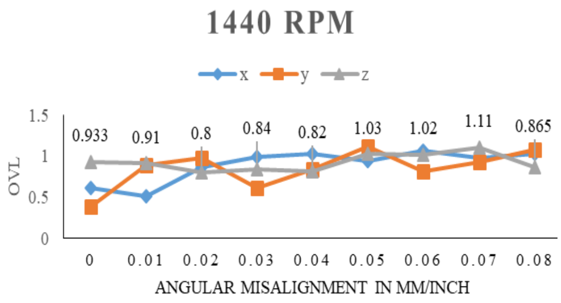

Figure 3. OVL variation at 1440 RPM

Table.6. Central composite design values

Sr. No	Speed, rpm	Angular misalignment, mm/inch	OVL, mm x-direction
1	1300	0.039	0.95
2	734	0.061	0.962
3	1300	0.039	0.864
4	734	0.017	0.83
5	1300	0.039	1.073
6	1866	0.017	0.943
7	1866	0.061	1.1
8	1300	0.039	0.962
9	1300	0.039	0.889
10	2100	0.039	1.38
11	500	0.039	0.7
12	1300	0.008	0.55
13	1300	0.070	0.97
14	1300	0.039	0.992

It is also observed from Table 4 that if misalignment is constant and speed is varied, or speed is constant and misalignment is varied, the OVL increases for both kinds of operating conditions. The central composite design values for speed and angular misalignment with their respective values of OVL in the x-direction as shown in Table 6. The total 14 base runs are considered by repeating 3 center points. It is inferred from Table.6 that the minimum and maximum OVL observed are 0.55 and 1.38 mm, respectively. Hence, operation conditions at speeds 2100 rpm and 0.039 misalignment need to be monitored. The OVL observed at 2100 rpm is seen comparatively to the higher side. Hence, 2100 rpm is a sensible parameter to be handled.

7.2. ANOVA modeling and process measures:

Table 7 represents ANOVA for OVL for angular misalignment. The level of confidence in ANOVA analysis is taken at 90%. It is inferred from the table that angular misalignment and speed are influencing terms for controlling the OVL of the machine.

Table.7. Analysis of Variance for OVL in x-direction

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0.362	0.362	0.072	5.28	0.019
Linear	2	0.281	0.070	0.035	2.56	0.138
Speed	1	0.184	0.004	0.004	0.29	0.605
Angular	1	0.097	0.048	0.048	3.52	0.097
Square	2	0.081	0.081	0.040	2.94	0.110
Speed*Speed	1	0.030	0.024	0.024	1.76	0.221
Angular*Angular	1	0.051	0.051	0.051	3.69	0.091
Interaction	1	0.000	0.000	0.000	0.01	0.918
Speed*Angular	1	0.000	0.000	0.000	0.01	0.918
Residual Error	8	0.110	0.110	0.014	---	---
Lack-of-Fit	3	0.082	0.082	0.027	4.86	0.061
Pure Error	5	0.028	0.028	0.006	---	---
Total	13	0.472				

7.3. Parametric optimization using the Desirability function:

The following inputs are referred to for the mathematical formulation of optimization of the misalignment problem.

Minimize function: f1(x) = OVL

Condition: $500 \leq x \leq 2100$ for speed

$0.01 \leq x \leq 0.08$ for angular misalignment

7.4. Response optimization:

The response optimization results are presented in Fig.4. This column of the plot represents a process parameter, and each row shows response optimization. The main part of understanding from this optimization plot is how to determine or identify the optimum operating condition for the considered middle range of speed and its minimum OVL, which is mentioned in the square bracket as shown in the top row in Fig.5.

It is observed for both parameters that composite desirability is 1. This indicates the successful implementation of ANOVA for the optimization of operating conditions with an objective of minimum OVL for angular misalignment. The lower limit of OVL is 0.55 mm which is set as a target value of OVL. The minimum OVL in the angular misaligned condition is 0.5442 mm at 500 rpm and 0.08mm/inch misalignment. Therefore, the value of OVL is less than 0.55 mm which is accepted. It is clear from the response optimization plot that speed and angular misalignment both affect the variation of OVL.

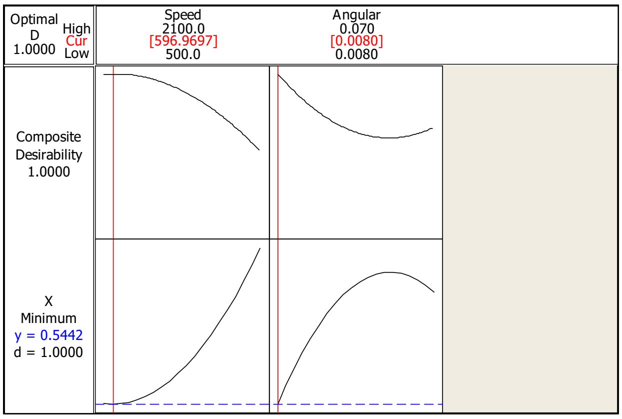

Figure 4. Response optimization plot

Parameters:

Goal	Lower	Target	Upper	Weight	Import
OVL _X Min.	0.55	0.55	1.38	1	1

Starting Point:
Global Solution:
Speed = 500
Speed = 596.970
Angular = 0.008
Angular = 0.008

Predicted Responses:
OVL_X = 0.544213, desirability = 1.000000

The residual plot for OVL in the x-direction is shown in Fig. 5(a-d). The normal probability graph shown in Fig. 5(a) demonstrates that the values of OVL predicted are closely spaced about the central value. It implies that the regression model is well-fitted with observed values. Fig. 5(b) shows a frequency histogram, which is seen as a symmetric plot of the normal distribution curve. This implies that the frequency of residual error in OVL measurement is proportionately deviating from the central value to either side. The residues are the difference between predicted and experimental values in the range of +0.18 to -0.18, as shown in Fig. 5(c) and Fig. 5(d). The plot of residues versus fitted values shows no noticeable pattern present in the data, as shown in Fig.5(c). It is inferred from the plot, as shown in Fig. 5(d), that no symmetry of error pattern exists. It shows the non-repeating behavior of the error curve. The symmetry of the error pattern misleads to evaluation of the most influencing variable for OVL prediction and control.

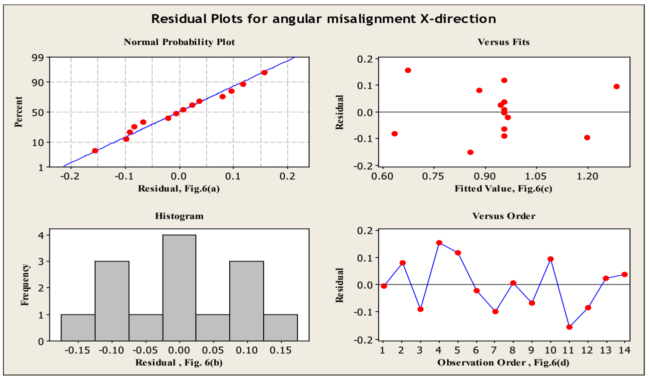

Figure 5. Residual plot for OVL measured in x-direction

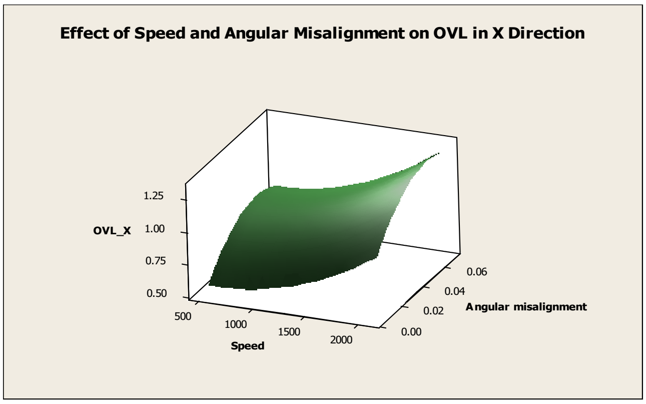

Figure 6. Surface plot for OVL

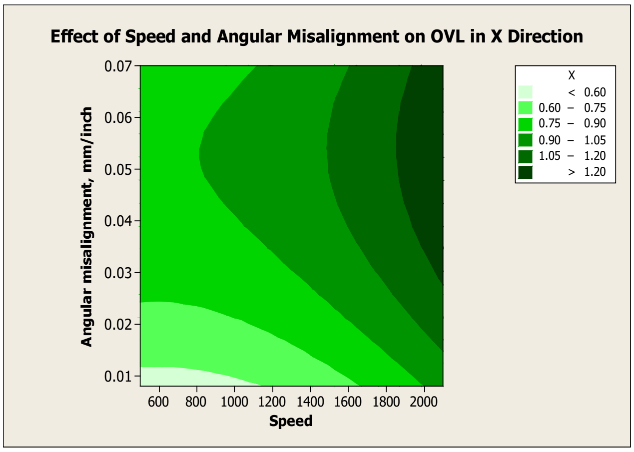

Figure 7. Contour plot for OVL

The surface plots are obtained to see the combined effect of speed and angular misalignment on OVL, as shown in Fig.6. The x-direction plot explains the speed and OVL variation for different values of misalignment. The y-direction plot represents misalignment versus OVL for different values of speed. It is understood that the OVL of the system is increasing in response to both speed and angular misalignment. When the system reaches far ahead of resonance frequency, its OVL responses are seen to be slightly decreasing than the initial one[24]. OVL is increased up to 1.12 mm for a maximum value of speed and misalignment for the considered range of operation, and then the system shows a decrease in OVL. This may be due to the attainment of stability in the high-frequency range. The concave contour obtained for both speed and angular misalignment shows stability phase at lower speeds, 1000 rpm, and 0.01 misalignments, respectively. Similarly, OVL is seen increasing for angular misalignment variation up to 0.07 mm/inch as speed increases. The counterplot of OVL, Speed, and angular misalignment is obtained, as shown in Fig.7.

The contour plot of OVL, speed, and angular misalignment portrays different bands representing the OVL range which help to describe the corresponding value of OVL at any speed and angular misalignment. It is observed that OVL is increasing with an increase in the value of parameters, viz., speed and misalignment. The contour plot of OVL referred to shows that operating speed in the range 1600 to 2100 rpm and angular misalignment from 0.035 to 0.08 registers the maximum range of OVL of the system. The system speed up to 1000 rpm registers the least OVL for angular misalignment up to 0.013mm/inch. This obtained value of OVL is within the limit of the optimized JAYA algorithm.

7.5. Empirical model

The experimental values of OVL are compared with predicted OVL for 14 runs, as shown in table.8. The average sum of error between these two is 1.81% which is less than 5% accepted variation. Hence, the regression equation for the prediction of OVL to referred speed and alignment is satisfactory. The empirical Eq. (3) is obtained by regression analysis for the prediction of OVL.

$$OVL = 0.395635 + 0.000267964*A + + 5.03511*B \quad (3)$$

The comparison between the experimental and predicted value of OVL is plotted in Fig.8.

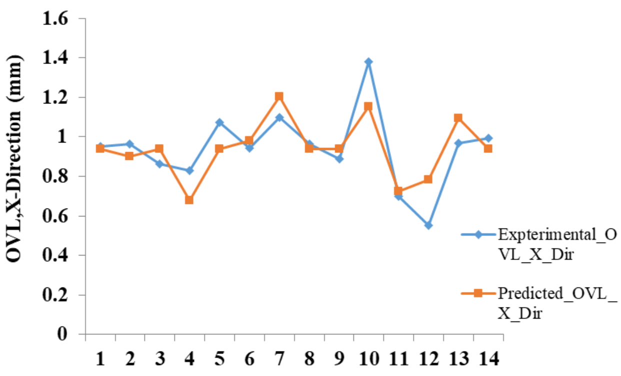

Figure 8. Comparison between experimental and predicted OVL in the x-direction

Table 8. Comparison between experimental and predicted OVL in Z-direction

Speed	Angular misalignment	OVL Experimental	OVL predicted	Percentage error
1300	0.039	0.95	0.940	-1.015
734	0.061	0.962	0.899	-6.534
1300	0.039	0.864	0.940	8.838
734	0.017	0.83	0.678	-18.265
1300	0.039	1.073	0.940	-12.362
1866	0.017	0.943	0.982	4.090
1866	0.061	1.1	1.202	9.301
1300	0.039	0.962	0.940	-2.250
1300	0.039	0.889	0.940	5.777
2100	0.039	1.38	1.155	-16.324
500	0.039	0.7	0.726	3.712
1300	0.008	0.55	0.784	42.594
1300	0.070	0.97	1.096	13.036
1300	0.039	0.992	0.940	-5.206
				Avg. Error = 1.81 %

7.6. Optimization by JAYA algorithm

The JAYA algorithm is implemented for design variables such as speed and angular misalignment in the present work. The limiting values for respective design variables are shown in Table.9.

Table.9. Limiting values of design variables

Sr. No	Design variable	Lower limit	Upper limit
1	Speed, RPM	500	2100
2	Angular misalignment, mm/inch	0.008	0.07

The input mentioned in Table.9 is considered for the JAYA algorithm. Eq. (4) is obtained by the JAYA algorithm, which converges with an objective of minimum OVL.

$$P(X) = 0.395635 + 0.0000267* X(i,1) + + 5.0351*X(i,2) \quad (4)$$

The output obtained by the implementation of JAYA algorithm is explained as follows:
Number of populations = 10
Number of iterations = 20
The optimized design variables are:
X(1) = 500.000000
X(2) = 0.008000

The corresponding optimum value of OVL = 0.448 mm/inch

The minimum OVL value, as per Table 6, is observed at the 12th experiment number. The minimum OVL predicted by the JAYA algorithm is different than this as well as shows a lower value as shown in Fig. 9.

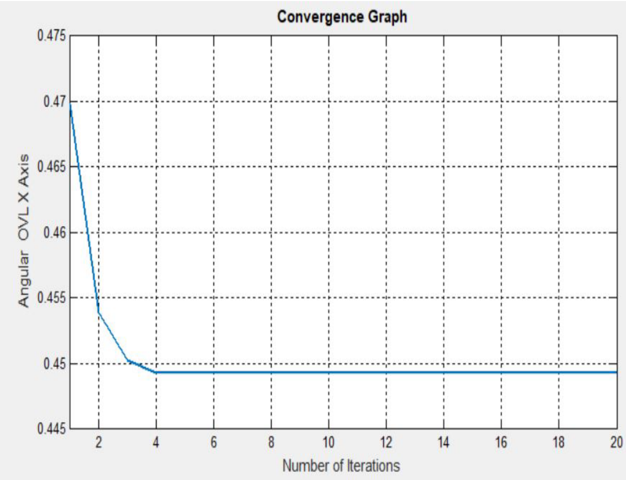

Figure 9. Convergence graph

Table.10. Comparison of analysis method

Sr. no	Optimization method	Design variable	Limiting values		No. of iterations required	Optimum value
			Lower limit	Upper limit		
1	Desirability function	Speed , RPM	500	2100	14	
		Angular misalignment, mm/inch	0.55	1.38		0.55
2	JAYA algorithm	Speed ,RPM	500	2100	04	
		Angular misalignment mm/inch	0.008	0.07		0.448

The optimum conditions, as per Table 6, belong to experiment 12 is 0.55. However, by the Jaya algorithm, the optimum condition is 0.448.

8. CONCLUSIONS

The angular misalignment and its effect on OVL, which affects machine condition monitoring, is studied. To ensure better machine health, OVL should be controlled minimum possible value. The process parameter and their effect on OVL are studied with DoE, ANOVA, and JAYA algorithms.

The necessary output vibration signals of the machine are obtained from the experimental setup. It is inferred from experimental data that the OVL of the machine is increasing with increasing speed and angular misalignment. It is also seen from experimental data that OVL obtained in the x-direction is dominant.

The output vibration signals are analyzed for desirable parameters with DoE using ANOVA statistical model and the JAYA algorithm. The ANOVA modeling output shows that the main influencing terms are speed (A) and angular misalignment (B). It is confirmed through the implementation of DoE that it requires fewer parameters to predict OVL as compared to analysis based on experiments.

In response optimization of the process parameter, the lower target value observed for OVL is 0.55 mm. The predicted value of OVL for the same parameter is 0.544 mm which is less than the target value. The predicted values of OVL are closely spaced, as shown in the residual plot. Hence, the implementation of DoE is satisfactory.

In DoE, it is seen that speed and angular misalignment are the most influential parameter of OVL. It is revealed from the contour plot that OVL can be kept lower by selecting a speed up to 1000 rpm and corresponding angular misalignment up to 0.0112 mm/inch. The predicted value and Experimental value of OVL are compared on a common plot and observed in close agreement.

JAYA algorithm satisfies an objective of minimum OVL more closely than the desirability function concept. The convergence graph of the JAYA algorithm shows an optimum value of 0.448 mm in just 4 iterations for considered design variables.

The lower and upper limits obtained by the JAYA algorithm are smaller and more realistic to permissible values compared with the alignment handbook. However, a higher-order regression model can be used for multi-objective optimization problems and can be used extensively in other problems of machine condition monitoring.

It is concluded for the present work that for the best health of the machine, it is necessary to operate it at minimum OVL. In a real-time implementation of machine condition monitoring JAYA algorithm is more effective.

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