EXPERIMENTATION AND OPTIMIZATION OF VIBRATION FOR FAILURE PREVENTION IN INDUSTRIAL MACHINES USING RSM

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Abstract - *This paper summarizes the advancements and challenges of vibration in industrial and automotive machines. Vibration is a major source for the origin of failure, to mitigate the impact of vibration in the equipment's, we can decrease the intensity of the source of vibration by analysing the equipment for a period of time to find the maximum withstand able limit. Vibration sources can be characterized using measurements from accelerometers from that we analyse the vibration and measurements to work out what structural improvement, vibration damping and or isolation strategy are often implemented to mitigate the impact of vibration. During the machining process the vibration will produce which will have negative impact during machining process of aluminium 6061 alloy and mild steel. Box-Behnken design of response surface methodology (RSM) has been used to conduct the design of experiments to create the regression models for the vibration output results to get an optimized speed, feed and depth of cut to improve the life of the machine by predictive maintenance and to enhance the quality of the work material.*

Key Words: Vibration, Mild steel, Aluminium 6061, Response Surface Methodology (RSM), Speed, Feed and Depth of cut

1. INTRODUCTION

Now a day's vibration measurement is necessary because vibration of any machine or its parts affects the result. Vibration monitoring is becoming a longtime technique for managing the upkeep of machinery. Machine condition monitoring is that the process of monitoring the condition of a machine with the intent to predict mechanical wear and failure. Vibration measurement is necessary to state the machine condition. Hence into this project we developed a system which can analyze the vibration .On the basis of that we can find out the problem into the machine or its parts. Hence we will protect our system from damage. Here we use Arduino, Accelerometer and LCD display for vibration analysis. Here accelerometer gives the information into 3-axis.Which gives this information to the Arduino. Here we use an ATmega328 8-bit microcontroller which is used to transfer the data into desired format which gives the output to LCD display. In this project we are going to measure the vibration of a device by using accelerometer which gives the value of a device in x, y and z axis. By using this we can prevent a machine from failures. The main aim of our project is to measure the vibration of machine and which helps to prevent the machineries from damage.

1.1 OBJECTIVES

- Main objective of my project is to eliminate the vibration in the machining process
- To reduce the cost of production process by eliminating the vibrating part
- To save/increase the life of industrial machine
- To improve the surface finish and to reducing the surface roughness by means of this machining process
- To improve the material removal rate during the machining process

1.2 CAUSES OF VIBRATION

The vibration analysis provides a complete machine diagnostic system and is not limited to only a certain number of faults. During the vibration of rotating machinery, many defects will be observed. The most common problems, which produce vibration, are mentioned below:

- Misalignment
- Uneven loading of a machine
- Gear wear
- Shaft rubbing
- Imbalance
- Blade fouling
- Gear defects
- Cracked shaft
- Mechanical looseness
- Blade rubbing
- Gearwheel backlash
- Rotor instability
- Critical speed excitation

1.3 CHARACTERISTICS OF VIBRATION

A lot can be learnt about the machine conditions & mechanical problems by noting its vibration characteristics. The vibration characteristics are as follows.

- Vibration displacement
- Vibration velocity
- Vibration acceleration
- Vibration frequency

2. LITERATURE SURVEY

[1] Dr.Ramachandra et al have discussed about the vibration analysis of machines and various types and methods of vibration analysis. They also deal with various methods of vibration analysis of machines and presented some case studies wherein the SPM was useful in finding the condition of the machine thereby saving the, cost work of replacement and loss of production.

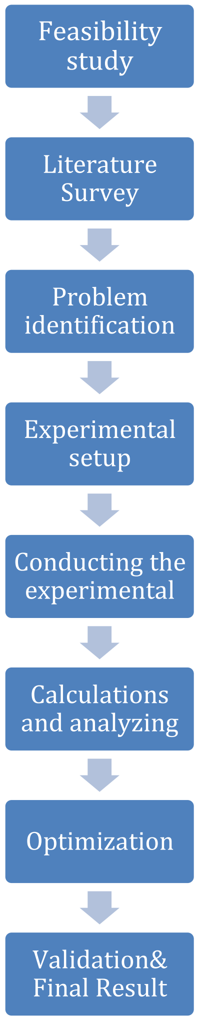
[2] Grzegorz Litak and Michael I. Friswell gave the information about Dynamics of a Gear System with Faults in Meshing Stiffness. Gearbox dynamics is characterized by a periodically changing stiffness. In real gear systems, a backlash also exist that can lead to a loss in contact between the teeth. Due to this loss of contact the gear has piecewise linear stiffness characteristics, and the gears can vibrate regularly and chaotically. In this paper they examine the effect of tooth shape imperfections and defects. Using standard methods for nonlinear systems they examine the dynamics of gear systems with various faults in meshing stiffness.

[3] J. Antoni Randall in the paper titled "Differential Diagnosis of Gear and Bearing faults" discussed the vibration-based diagnosis of rolling element bearings in the presence of strong interfering gear signals from the gearboxes. A strong emphasis is placed on how to distinguish between gear and bearing faults where the two signals may interact through the analysis of their vibration signals. The key idea consists in recognizing gear signals as purely periodic, whereas bearing signals experience some randomness. This is demonstrated by introducing a comprehensive model for the vibration generating process of bearing faults and the distributed faults.

[4] W. J. Wang and P. D. Mc Fadden et al described the decomposition of gear motion and the related dynamic measurements for the condition monitoring and fault diagnosis of gearboxes. In the case of gearbox monitoring, the teeth of the gears are the components to be monitored. The important signal generated in a gearbox is the meshing vibration, which propagates through all kinds of media and via all possible routes.

[5] J.J. Zakrajsek and D.P. Townsend are discussed about Transmission Diagnostic. A number of previously published and newly developed methods to specifically detect damage on gear teeth were applied to vibration data from the spur gear, spiral bevel gear, and face gear fatigue tests. The primary purpose was to verify the various methods with naturally occurring faults and to determine their relative performance. Of the various techniques investigated, only methods FM4, 9A4, and 9B4 responded to gear damage on a relatively consistent basis over the various gear types and failure modes.

3. METHODOLOGY



4. 1. EXPERIMENTAL SETUP

The machining performances of mild steel and aluminium alloy was carried out with the Centre lathe with variable speed and feed drive. The MONDIALE lathe machine is used for this experiment. The work piece was held over a three jaw chuck head for accurate holding. The machining was carried out for various spindle speed, feed and depth of cut and the vibration of surface roughness for each combination is taken with the help of accelerometer surface roughness profilometer and the cutting force measurement on the tool is taken with the help of lathe tool dynamometer.

FIG - 4.1: EXPERIMENTAL SETUP OF LATHE

In this experiment, three levels of spindle speed, feed rate and depth of cuts were used. The machining parameters were changed automatically according to different turning conditions for each run. The cleaning of the cutting tool is important after machining of every sample was necessary to avoid built-up edge formation which would affect the surface roughness of the following cut which was carried out by means of compressed air flow during machining which removes the chips away from machining zone.

The tool was also checked simultaneously to verify the build-up edge formation. All specimens in this experiment were conducted under dry cutting conditions. The surface roughness of the work piece and the temperature distribution on the tool was examined for these machining conditions.

4. 2. EXPERIMENTAL PROCEDURE

The machining process is carried out by means of MONDIALE central lathe with variable feed and variable depth, in order to machine the circular profile rod .The machining is carried out by thirty seconds count and the respective of vibrations and cutting force reading are noted down. Vibration measurement is an important process parameter value to measure the life time of machine. It is measured with the help of accelerometer. A set of reading is taken from chuck and tool. Vibration on the tool is also measured with the help of accelerometer for every thirty seconds and maximum vibrations readings are noted down and the values are optimized for graph value.

4. 3. DESIGN OF EXPERIMENTATION

Response vibration methodology is a combination of mathematical and statistical method and it can be used to develop the regression model and optimization of problems. In the dry machining process the required for every input parameter three levels are selected and they are shown in Table.

Table - 4.1: Process Parameter and Their Levels

Speed (RPM)	FEED (mm)	Depth of Cut (mm)
450	0.04	0.5
1000	0.08	1.0
2000	0.12	1.5

Table - 4.2: Vibration Reading at Chuck for Mild Steel

STD	RUN	SPEED	FEED	DEEP of CUT	VIBRATION
15	1	1000	0.08	1	302
4	2	2000	0.12	1	231
6	3	2000	0.08	0.5	218
13	4	1000	0.08	1	302
2	5	2000	0.04	1	211
1	6	450	0.04	1	258
3	7	450	0.12	1	265
17	8	1000	0.08	1	302
14	9	1000	0.08	1	292
9	10	1000	0.04	0.5	244
7	11	450	0.08	1.5	277
10	12	1000	0.12	0.5	234
11	13	1000	0.04	1.5	233
16	14	1000	0.08	1	302
5	15	450	0.08	0.5	277
8	16	2000	0.08	1.5	244
12	17	1000	0.12	1.5	243

Table - 4.3: Vibration Reading at Tool for Mild Steel

STD	RUN	SPEED	FEED	DEEP of CUT	VIBRATION
12	1	1000	0.12	1.5	150

5	2	450	0.08	0.5	239
17	3	1000	0.08	1	177
6	4	2000	0.08	0.5	139
14	5	1000	0.08	1	177
16	6	1000	0.08	1	177
10	7	1000	0.12	0.5	150
4	8	2000	0.12	1	160
3	9	450	0.12	1	190
13	10	1000	0.08	1	177
9	11	1000	0.04	0.5	149
11	12	1000	0.04	1.5	139
2	13	2000	0.04	1	140
1	14	450	0.04	1	232
8	15	2000	0.08	1.5	139
7	16	450	0.08	1.5	239
15	17	1000	0.08	1	177

Table - 4.4: Vibration Reading at Chuck for Aluminium

STD	RUN	SPEED	FEED	DEEP of CUT	VIBRATION
12	1	1000	0.12	1.5	150
5	2	450	0.08	0.5	239
17	3	1000	0.08	1	177
6	4	2000	0.08	0.5	139
14	5	1000	0.08	1	177
16	6	1000	0.08	1	177
10	7	1000	0.12	0.5	150
4	8	2000	0.12	1	160
3	9	450	0.12	1	190
13	10	1000	0.08	1	177
9	11	1000	0.04	0.5	149
11	12	1000	0.04	1.5	139
2	13	2000	0.04	1	140
1	14	450	0.04	1	232
8	15	2000	0.08	1.5	139
7	16	450	0.08	1.5	239
15	17	1000	0.08	1	177

Table - 4.5: Vibration Reading at Tool for Aluminium

STD	RUN	SPEED	FEED	DEEP of CUT	VIBRATION
5	1	450	0.08	0.5	171
14	2	1000	0.08	1	131
1	3	450	0.04	1	169
2	4	2000	0.04	1	122
8	5	2000	0.08	1.5	121
6	6	2000	0.08	0.5	119
15	7	1000	0.08	1	131
10	8	1000	0.12	0.5	129
12	9	1000	0.12	1.5	127
3	10	450	0.12	1	160
16	11	1000	0.08	1	149
7	12	450	0.08	1.5	171
11	13	1000	0.04	1.5	162
9	14	1000	0.04	0.5	152
17	15	1000	0.08	1	131
4	16	2000	0.12	1	110
13	17	1000	0.08	1	131

4.4 REGRESSION ANALYSIS

Regression analysis has been performed to find the relationship between input and output parameters. The tests for the significance of regression model individual and lack-of-fit have been performed to ensure the adequate fit of quadratic models. Analysis of variance (ANOVA) test was performed for calculating the F-value, Probe>F-value, the coefficient of determination (R2), adjusted R^2, predicated R^2 and the adequate precision (AP). F value and Probe> F-value are used to imply statistical significance of linear, quadratic, or interaction terms and regression model. Generally as preferred confidence level is set to 95%, Probe> F-value (<0.05) suggests that the regression model has a significant and a model has a significant effect on the responses. R^2 is defined as the ratio of the expected variation to total variation and is used to measure the degree of fit. If R^2 is a unity, the regression model is better to fit with actual data and if it is less than one, model has some error to fit. The adjusted R^2 is usually used to calculate the amount of variations from the mean and to decide the significant term presence in the model. Adjusted R^2 is also used to decrease the number of terms in the model. At the same time these models obtained higher values of the R^2, Adjusted R^2, and AP. The reduced quadratic models for MRR and R^2 were found to be the most suitable model based on the analysis of variance (ANOVA) sequential sum of square test as shown in Table.4.6

Table - 4.6: Surface Roughness Ra reduced quadratic model

Surface Roughness Ra reduced quadratic model	
R-Squared	0.9867
Adj R-Squared	0.9698
Pred R-Squared	0.8607
Std. Dev.	5.48
Adeq Precison	21.04

4.5 REGRESSION ANALYSIS FOR VIBRATION

The ANOVA table for the reduced quadratic surface roughness Ra distribution model is shown in Table 6. The F-value model value is 33.94 this shows that the model is a significant one. If (Prob> F-value) < 0.05, the model will be a significant or else it will be insignificant. For this work Speed (A), Feed (B), Depth of cut (C) then A*B, B*C, A*C, B2, C2 were the significant terms taken from reduced quadratic surface roughness model. The parameter values for the reduced quadratic temperature model is given by the Equation 3 and 4.The normal residual plot for reduced quadratic regression model of Surface roughness Ra is shown in table 4.6

Table - 4.7: Analysis of variance test for reduced quadratic Vibration model

Source	Sum of Squares	DF	Mean Square	F-Value	P-Value	
Model	15675.77	9	1741.75	58.06	<0.0001	Significant
A-Speed	3741.12	1	3741.12	124.71	<0.0001	
B-Feed	120.83	1	120.83	4.03	0.0847	
C-Depth of cut	125.93	1	125.93	4.2	0.0797	
AB	68.67	1	68.67	2.29	0.174	
AC	216.83	1	216.83	7.23	0.0312	
BC	100	1	100	3.33	0.1106	
A^2	949.55	1	949.55	31.65	0.0008	
B^2	5803.22	1	5803.22	193.44	<0.0001	
C^2	2501.64	1	2501.64	83.39	<0.0001	
Residual	210	7	30			
Lack of Fit	130	3	43.33	2.17	0.2346	Not Significant
Pure Error	80	4	20			
Cor Total	15885.76	16				

4.5.1 FINAL EQUATION IN TERMS OF CODED FACTORS

R1==295-21.6A+3.96B+4.05C+4.06AB+7.21+5.00BC-16.76A^2-37.13B^2-.2437C^2

The equation in terms of coded factors can be used to make predictions about the response forgiven levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

4.5.2 FINAL EQUATION IN TERMS OF ACTUAL FACTORS

R1=81.05214+0.011373A+3401.21692B+160.29406C+0.130929A*B+0.018612A*C+250.0B*C-0.000028B*C-0.000028A^2-23203.12500 B^2-97.50000 C^2

The equation in terms of actual factors can be used to make predictions about the response forgiven levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercepts not at the center of the design space

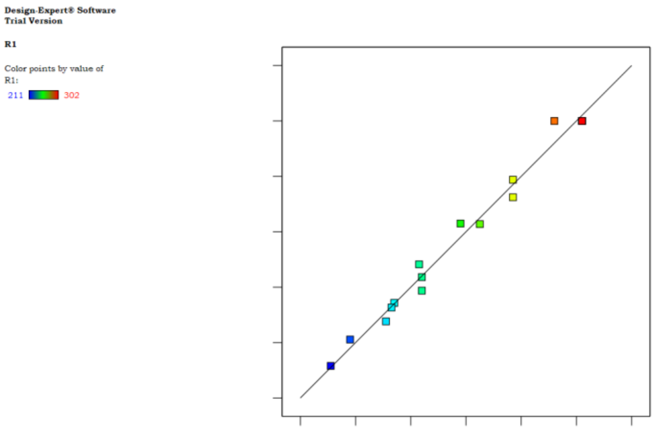


FIG - 4.2: NORMAL PLOT OF RESIDUALS FOR VIBRATION MODEL FOR MILD STEEL

4.5.3 FINAL EQUATION IN TERMS OF CODED FACTORS

R1=162.14-40.25A+8.70B-1.20C+15.50AB+3.3482AC+2.50BC+37.61A^2-19.25 B^2-10.75C^2 - 0.0000ABC-14.20 A^2B

The equation in terms of coded factors can be used to make predictions about the response forgiven levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

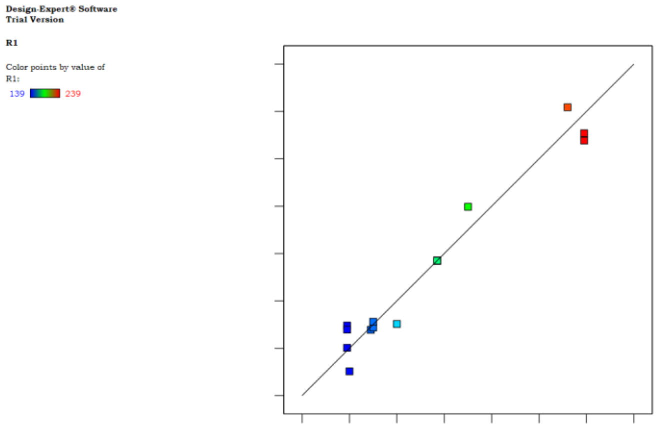


Fig - 4.3: NORMAL PLOT OF RESIDUALS FOR VIBRATION MODEL FOR MILD STEEL

4.5.4 FINAL EQUATION IN TERMS OF CODED FACTORS

Vibration=+136.80-23.11A-9.87B+1.25C

The equation in terms of coded factors can be used to make predictions about the response forgiven levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

4.5.5 FINAL EQUATION IN TERMS OF ACTUAL FACTORS

Vibration=+190.58177-0.029821 speed-0.029821 speed-246.87500 feed+2.50000 doc

The equation in terms of actual factors can be used to make predictions about the response forgiven levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercepts not at the center of the design space.

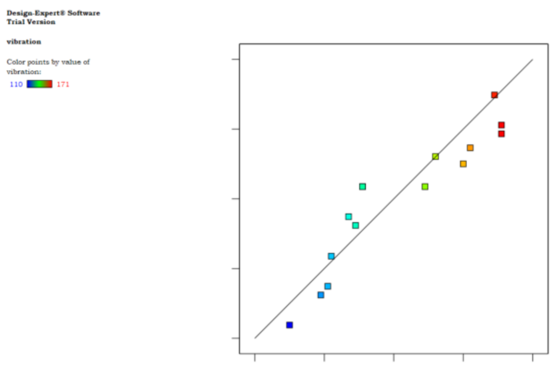


Fig - 4.4: NORMAL PLOT OF RESIDUALS FOR VIBRATION MODEL FOR ALUMINIUM

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4.5.6 FINAL EQUATION IN TERMS OF CODED FACTORS

Vibration=+138.77-26.75A-4.31B+2.60C-21.97AB+ 10.13AC+2.50BC+31.58 A^2+8.90B^2-4.60 C^2

The equation in terms of coded factors can be used to make predictions about the response forgiven levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

4.5.7 FINAL EQUATION IN TERMS OF ACTUAL FACTORS

Vibration=+253.15805-0.132770 speed-254.57189 feed-0.042736 doc-0.708812 speed *feed+ 0.026151 speed * doc+125.00000 feed * doc+0.000053 $speed^2$+5562.50000 $feed^2$-18.40000 doc^2

The equation in terms of actual factors can be used to make predictions about the response forgiven levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercepts not at the center of the design space.

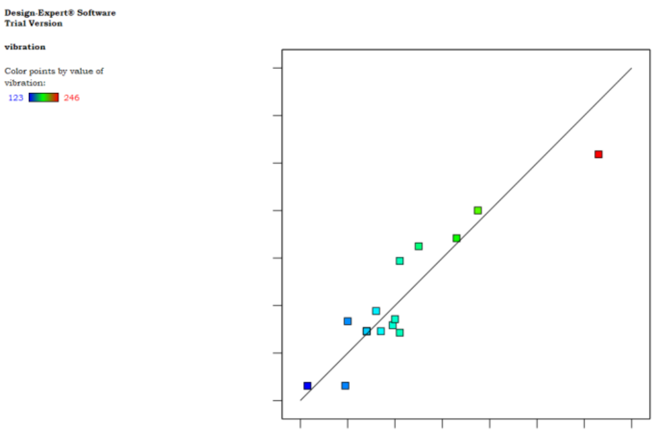

Fig - 4.5: NORMAL PLOT OF RESIDUALS FOR VIBRATION MODEL FOR ALUMINIUM

5.1 RESULT AND ANALYSIS

Response surface analysis of vibration on the tool and their interactions effects based on the response parameters are studied. At the lower speed the Surface Roughness on the material is high and when machining speed is increased the Surface Roughness on the material gets decreased, it is observed from Fig. The optimum value of surface roughness has been attained at high speed with low feed and depth of cut.

5.2 EFFECT OF PROCESS PARAMETER ON VIBRATION

It is clearly shown in the figure 5.1 that the surface roughness Ra is decreased by increasing the cutting speed during machining by making the feed rate to minimum. For the requirement of minimum (Ra) vibration is higher cutting speed preferred with optimum feed rate.

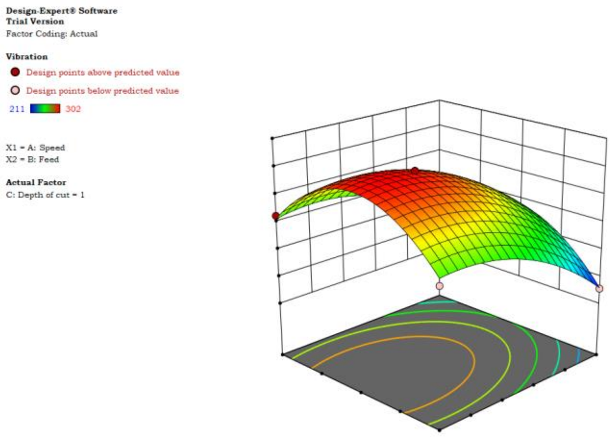

Fig - 5.1: RESPONSE SURFACE OF VIBRATION VS SPEED VS FEED

The above figures 5.1 shows that the response surface of vibration which state that higher the speed the vibration gets reduced and increased with increase in speed and feed. To achieve minimum vibration we have to optimize the depth of cut.

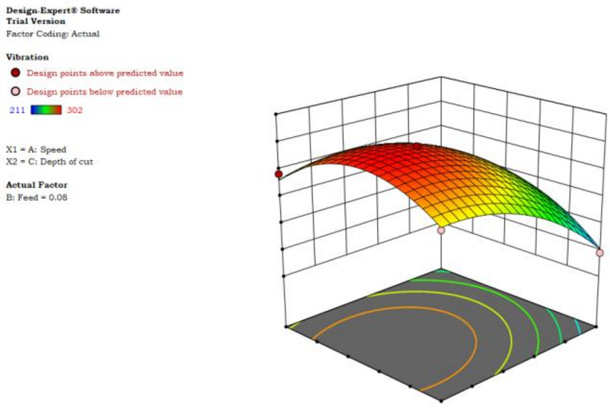

Fig 5.2: RESPONSE SURFACE OF VIBRATION SPEED VS DEPTH OF CUT

The above figures 5.2 shows that the response surface of vibration which state that, the vibration gets reduced when speed is higher and increased with increase in depth of cut. To achieve minimum vibration we have to optimize the depth of cut.

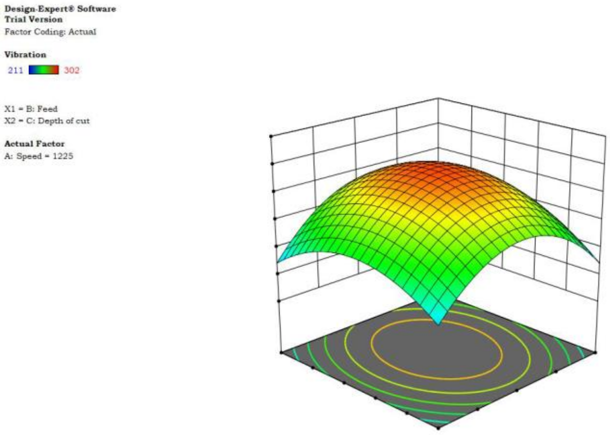

Fig - 5.3: RESPONSE SURFACE OF VIBRATION FEED VS DEPTH OF CUT

The above figures 5.3 shows that the response surface of vibration which state that higher the speed the vibration gets increased with increase in depth of cut and feed .To achieve minimum vibration we have to optimize the speed.

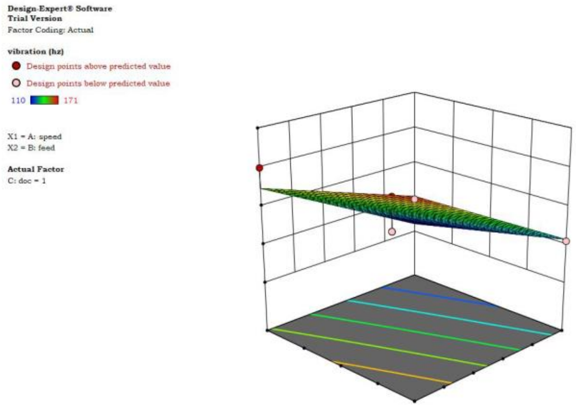

FIG 5.4 RESPONSE SURFACE VIBRATION SPEED VS FEED

The above figures 5.4 shows that the response surface of vibration which state that higher the speed the vibration gets reduced with increase in speed and feed .To achieve minimum vibration we have to optimize the depth of cut.

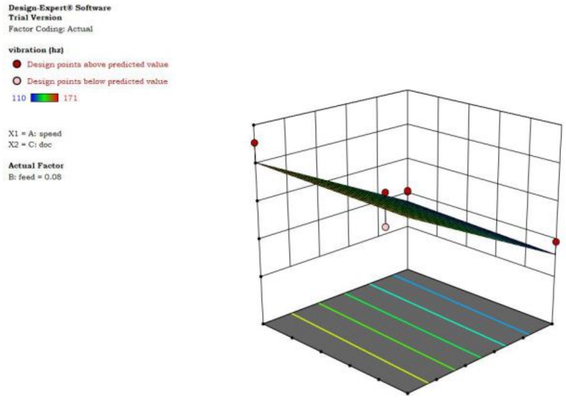

Fig - 5.5: RESPONSE SURFACE VIBRATION SPEED VS DEPTH OF CUT

The above figures 5.5 shows that the response surface of vibration which state that higher the speed the vibration gets reduced with increase in speed and depth of cut .To achieve minimum vibration we have to optimize the feed.

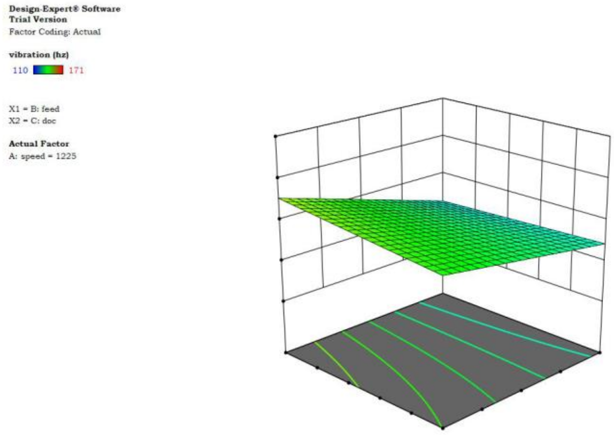

Fig - 5.6: RESPONSE SURFACE VIBRATION FEED VS DEPTH OF CUT

The above figures 5.6 shows that the response surface of vibration which state that higher the speed the vibration gets reduced with increase in Feed and depth of cut .To achieve minimum vibration we have to optimize the speed.

6. CONCLUSIONS

In this work we came to know the effect of the vibration after turning process of Aluminium 6061 alloy and mild steel is finished. Then the regression model of vibration are developed with the R2 (>99%) using Box-Behnken design of experiments for the given input parameters and the following results were obtained from the regression analysis.

- Cutting speed, Feed rate and Depth of cut of the machining process are the significant parameters for the vibration in lathe machines.
- The minimum vibration (µm) is obtained at higher cutting speed 1000 (rpm) with lower feed rate 0.02 (mm/rev) and moderate optimum depth of cut (1 mm).
- At higher feed rate (to mm/rev) the vibration of the material is maximum along with higher depth of cut (mm) the vibration get increased, when the cutting speed (rpm) got increased the vibration was gradually decreased. Moreover for higher temperature distribution the feed rate and depth of cut should be higher along with higher cutting speed (rpm), which helped for better material removal rate.

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