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IN-CAB NOISE AND VIBRATION ANALYSIS OF PASSENGER CAR BY RESPONSE SURFACE METHOD

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ABSTRACT

In-cab noise in passenger car plays main role in human comfort. Less In-cab noise provides more comfort to the passenger during the travelling. To improve the quality of products, in vehicle industries, it is necessary to minimize the In-cab noise effect. This paper discusses analysis of passenger car by using Response Surface Methodology (RSM). RSM will be very useful to predict and analyze the in-cab noise level. The parameters such as the car speed (S), pay load (P), road profile (R) and the door sealing condition (D) are considered as a processing parameters. A central composite face centered design with four factors and three levels has chosen to minimize the number of experimental conditions. Optimization of processing parameters can be done by using RSM. Study of output parameters such as sound level, vibration will be studied with respect to processing parameters. This analysis is helpful to many vehicle industries to improve quality of product. It is possible to provide more comfort to the passenger during the travelling with the help of this analysis

KEYWORDS: In-cab noise, Mathematical model, central composite design

INTRODUCTION

In-cab noise is an important and useful factor in the passenger car analysis. In-cab noise in passenger car plays main role in human comfort. Less In-cab noise provides more comfort to the passenger during the travelling. To improve the quality of products, in vehicle industries, it is necessary to minimize the In-cab noise effect. In recent years, there has been a desire by vehicle manufacturers to reduce the in-cab noise of vehicles, in order to improve driver comfort and enhance the enjoyment of in-vehicle entertainment systems. This reduction of in-cab noise is accompanied by policy initiatives to reduce transport related noise by implementing low noise road surfaces. As per reported by World Health Organisation(WHO) , traffic noise is a major cause of sleep deprivation, raised blood pressure and heart disease (WHO, 2000). It is not surprising then that substantial efforts have been made in recent years to reduce traffic related noise through measures such as infrastructure improvement. In parallel to such implementations, it is necessary to reduced In-cab noise in passenger car. This is chiefly because vehicle manufacturers are eager to increase driver comfort and pleasure, by creating vehicle cabs which convey little or no noise, thus allowing better use and enjoyment of in-car entertainment and communication systems. Noise is defined as undesirable sound. Sound pressure is measured on a logarithmic scale called the “decibel (dB) scale.” High level of interior noise in vehicle cabin is a bad factor in assessment of vehicle quality. To reduce cost of designing and cost of manufacturing in automotive industries and to manage the time of conceptual design process, machine element designing, interior noise modeling has been carried out at the first step of conceptual and elements design. There is the In-cab noise of structure vibration in most passenger vehicles. So, Reduction of In-cab noise is very important in design process. To reduce the time of engineering analyzing, it is essential to investigate In-cab noise before the manufacturing of primary prototype of a passenger vehicle [1]. The interior noise of vehicle cabin has been predicted by Y.Oka and H.Ono using boundary element method [2]. Z.S. Liu and C. Lu [3] studied Prediction of noise inside tracked vehicles using ADAMS software. To obtain more comfort by reducing In-cab noise, it is essential to have a complete control over the relevant process parameters to minimize In-cab noise and vibration of passenger car. Therefore, it is very important to select and control the process parameters for obtaining the minimum In-cab noise and maximum comfort. Various prediction methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. The response surface methodology (RSM) is helpful in developing a suitable approximation for the true functional relationship between the independent variables and the response [3].

In this paper, to optimized process parameter like speed, pay load, road profile, Door sealing condition and to get maximum comfort in passenger car second order quadratic model was developed.

EXPERIMENTAL WORK

Experimental set up

From the literature among many independent process parameter only speed (SPD), pay load (PL), road profile (RD), Door sealing condition (SEL) were selected as process parameters for this study. The experimental set up[Fig.1] consist of passenger car,CF-5220Z is 2-channel FFT analyzers mainly for analyzing sound and vibration at high speed and with high accuracy, computer for data store. During experiment first signal is passed through FFT analyzer. After analysis of FFT, output of FFT is stored in computer. Then obtained data is feed in Mini tab software for data processing.

Developing the experimental design matrix

Taguchi approach L27 was used, to minimize number of experimental run. Total 27 number of experiment carried out. A design matrix consisting of 27 sets of coded conditions was chosen in this investigation. Table 1 represents the range of process parameter considered, and Table 2 shows the 27 sets of coded values to conduct the experiments. In this work, central composite face centered design was used (Table 2).

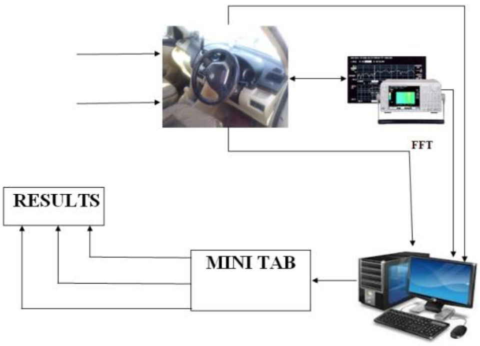


Fig.1 Experimental set up

DEVELOPMENT OF MATHEMATICAL MODEL

Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical technique useful for analysing problems in which several independent variables influence a dependent variable or response and the goal is to optimize the response[14]. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Eq.(1). Then these factors can be thought of as having a functional relationship or response as follows:

$$Y=\Phi(x1, x2, \ldots, xn)\pm \varepsilon \quad (1)$$

Between the response Y and $x1$, $x2$, … , xn of n quantitative factors, the function Φ is called response surface or response function. The residual ε measures the experimental errors.For a given set of independent variables, a characteristic surface is responded. When the mathematical form of Φ is not known, it can be approximate satisfactorily within the experimental region by polynomial. In the present investigation, RSM has been applied for developing the mathematical model in the form of multiple regression equations for In-cab noise analysis. In applying the response surface methodology, the independent variable was viewed as a surface to which a mathematical model is fitted. The second order polynomial (regression) equation used to represent the response surface Y is given by [15].

$$Y = b0 + \Sigma bi\ xi + \Sigma bii\ xi + \Sigma bij\ xi\ x\ j + e \quad (2)$$

To estimate the regression coefficients, a number of experimental design techniques are available. In this work, central composite face centered design was used which fits the second order response surfaces very accurately. Central composite face centered (CCF) design matrix with the star points being at the center of each face of factorial space was used, so α= ±1. This variety requires three levels of each factor. CCF designs provide relatively high quality predictions over the entire design space and do not require using points outside the original factor range. All the coefficients were obtained applying central composite face centered design using the Design Expert statistical software package. After determining the significant coefficients, the final model was developed using only these coefficients and the final mathematical model to estimate Vibration is given:

$$\text{Vibration} = \{0.35000 + 0.67333(SPD) + 2.33000(PL) - 1.97500(RD) + 0.25000(SEL) + 0.01333(SPD^2) - 0.49667(PL^2) + 0.56833(RD^2) + 0.03333(SEL^2)\} \quad (3)$$

Checking adequacy of model

The analysis of variance (ANOVA) technique is used to test adequacy of the developed model. The results of second order response surface model fitting in the form of analysis of variance (ANOVA) are given in Table 3.The determination coefficient (R^2) indicates the goodness of fit for the model. In this case, the value of the determination coefficient (R^2=97.50) indicates that only less than 3% of the total variations are not explained by the model. The value of adjusted determination coefficient (adjusted R^2=96.39) is also high, which indicates a high significance of the model. Predicted R^2 is also in a good agreement with the adjusted R^2. Adequate precision compares the range of predicted values at the design points to the average prediction error. Adequate precision measures the signal to noise ratio.

Table 1. Experimental design parameters and levels

Parameter	Code	Level 1	Level 2	Level 3
Speed km/hr	A	40	60	80
Pay Load	B	Partial	Smooth	Fully Closed
Road Profile	C	Medium	Medium	Partially Open
Door Sealing Condition	D	Full	Rough	Fully Open

A ratio greater than 4 is desirable. The value of probability $> F$ in Table 3 for model is less than 0.05, which indicates that the model is significant. In the

Table 2. Experimental design matrix and results

Exp No	SPEED	Pay Load	Road Profile	Door Sealing Condition	Minimum Sound
1	1	1	1	1	1.68
2	1	1	1	1	1.74
3	1	1	1	1	1.82
4	1	2	2	2	2.58
5	1	2	2	2	2.65
6	1	2	2	2	2.77
7	1	3	3	3	3.75
8	1	3	3	3	3.85
9	1	3	3	3	3.79
10	2	1	2	3	2.87
11	2	1	2	3	3.02
12	2	1	2	3	2.98
13	2	2	3	1	3.56
14	2	2	3	1	4.02
15	2	2	3	1	4.11
16	2	3	1	2	3.41
17	2	3	1	2	3.52
18	2	3	1	2	3.56
19	3	1	3	2	4.01
20	3	1	3	2	4.11
21	3	1	3	2	4.32
22	3	2	1	3	5.02
23	3	2	1	3	4.84
24	3	2	1	3	4.56
25	3	3	2	1	3.56
26	3	3	2	1	3.87
27	3	3	2	1	3.42

same way, speed (SPD), pay load(*PL*), road profile(*RD*) and Door Sealing Condition (*SEL*), second order term of speed (SPD), pay load(*PL*), road profile(*RD*) and Door Sealing Condition (*SEL*) have significant effect. All the above consideration indicates an excellent adequacy of the regression model.

Optimizing parameters

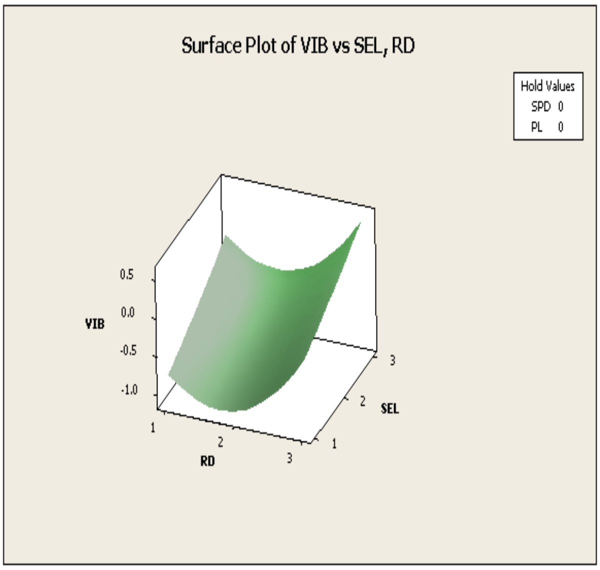
A contour plot is produced to visually display the region of optimal factor settings. Contour plots show distinctive circular shape indicative of possible independence of factors with response. For second order response surfaces, such a plot can be more complex than the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point

By identifying whether the stationary point found is a maximum response or minimum response or a saddle point. To classify this, the simple way is to examine through a contour plot. Contour plots play a very important role in the study of the response surface. Contour plots are generated by using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. Circular shape of contour plots to suggest independence of factor effects while elliptical contours as may indicate factor interactions [6]. Response surfaces have been developed for both the models, taking two parameters in the middle level and two parameters in the *X* and *Y* axis and response in *Z* axis. The response surfaces clearly reveal the optimal response point. RSM is used to find the optimal set of

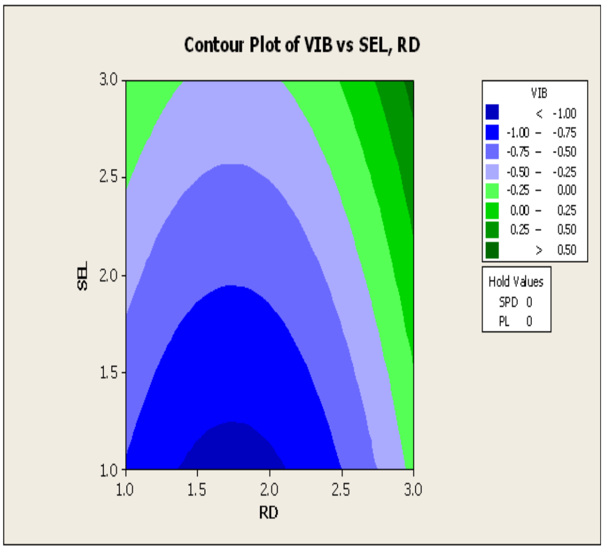
Table 3. ANOVA results for vibration

Source	DF	Sum of squares	Adj Mean square	F value	p-value
Regression	8	19.2995	2.41243	87.69	0
Linear	4	15.8737	0.90417	32.87	0
SPD	1	9.5048	o.16655	6.05	0.024
PL	1	2.1218	1.99429	72.49	0
RD	1	1.602	1.43288	52.08	0
SEL	1	2.645	0.02296	0.83	0.373
Square	4	3.4258	0.85645	31.13	0
SPD*SPD	1	0.0011	0.00107	0.04	0.846
PL*PL	1	1.4801	1.48007	53.8	0
RD*RD	1	1.938	1.93602	70.44	0
SEL*SEL	1	0.0067	0.00667	0.24	0.628
Residual Error	18	0.4952	0.02751		
Pure Error	18	0.4952	0.02751		
Total	26	19.7947			
Standard deviation	0.16587			R-sq =97.50	
				Adjusted R-sq = 96.39	
Press	1.1142			Predicted R-sq = 94.37	

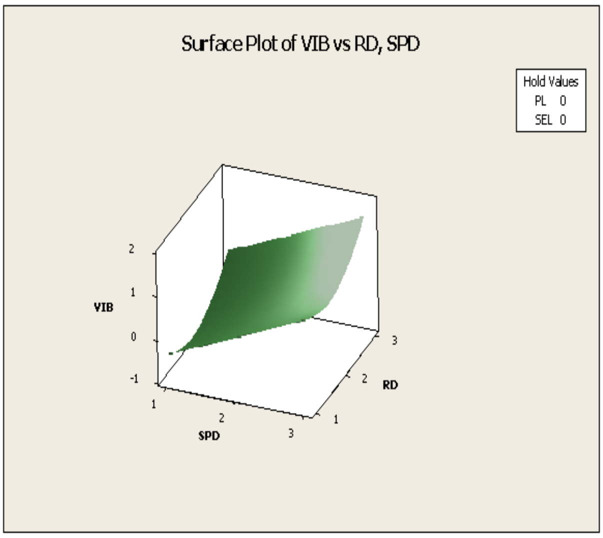
(a)


Surface Plot of VIB vs SEL, RD
Hold Values
SPD 0
PL 0
VIB
0.5
0.0
-0.5
-1.0
RD
1
2
3
SEL
1
2
3

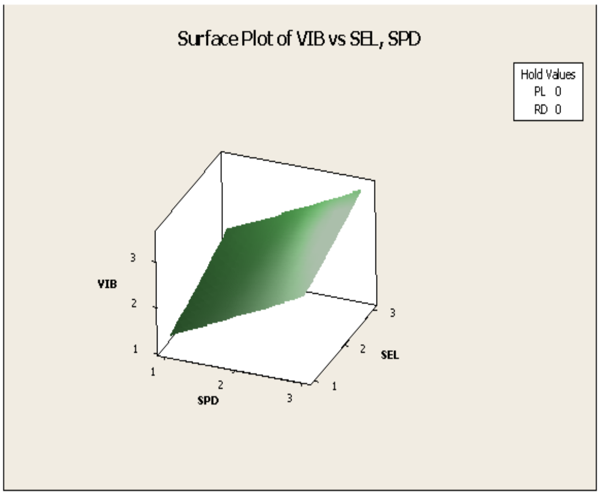
(b)


Contour Plot of VIB vs SEL, RD
SEL
3.0
2.5
2.0
1.5
1.0
RD
1.0
1.5
2.0
2.5
3.0
VIB
< -1.00
-1.00 – -0.75
-0.75 – -0.50
-0.50 – -0.25
-0.25 – 0.00
0.00 – 0.25
0.25 – 0.50
> 0.50
Hold Values
SPD 0
PL 0

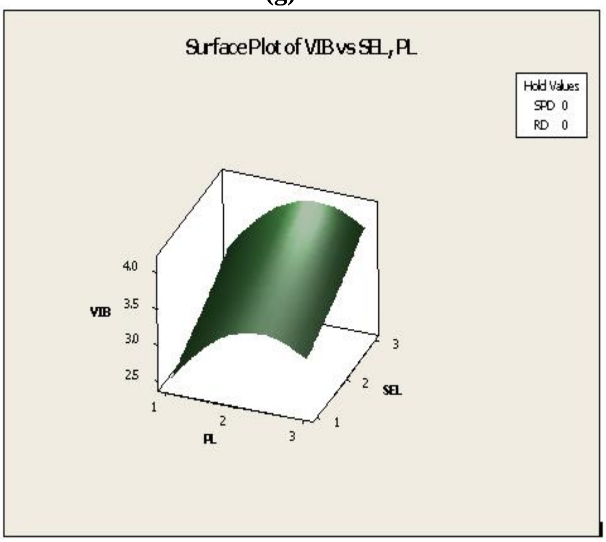
(c)


Surface Plot of VIB vs RD, SPD
Hold Values
PL 0
SEL 0
VIB
2
1
0
-1
SPD
1
2
3
RD
1
2
3

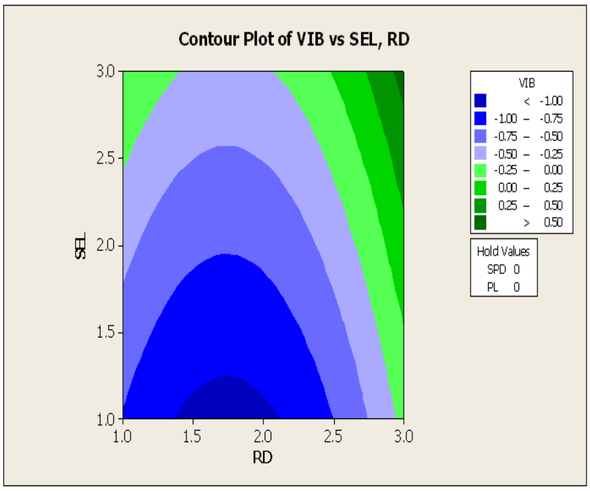
(e)


Surface Plot of VIB vs SEL, SPD
Hold Values
PL 0
RD 0
VIB
3
2
1
SPD
1
2
3
SEL
1
2
3

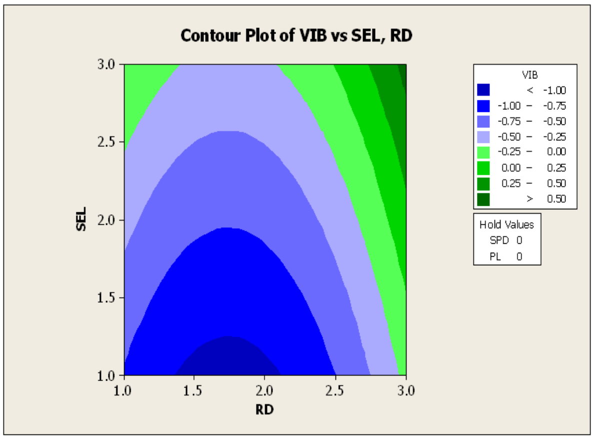
(g)


Surface Plot of VIB vs SEL, PL
Hold Values
SPD 0
RD 0
VIB
4.0
3.5
3.0
2.5
PL
1
2
3
SEL
1
2
3

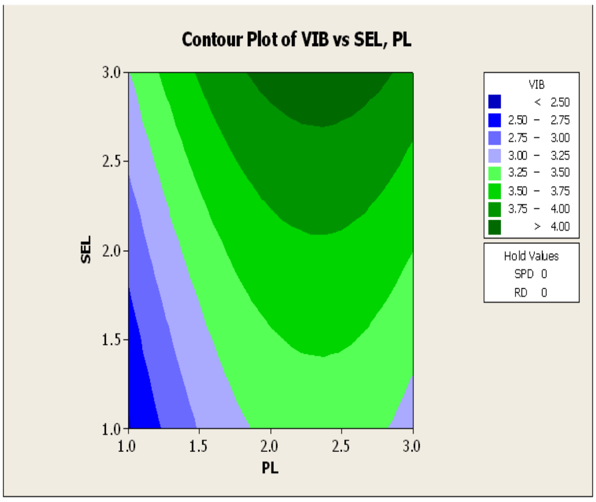
(d)



(f)



(h)



(i)

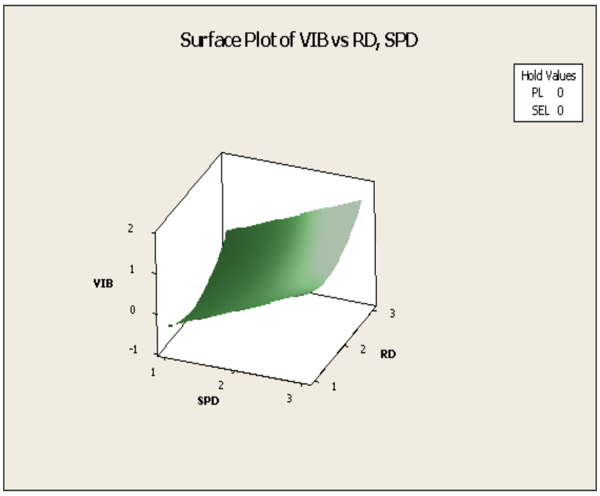


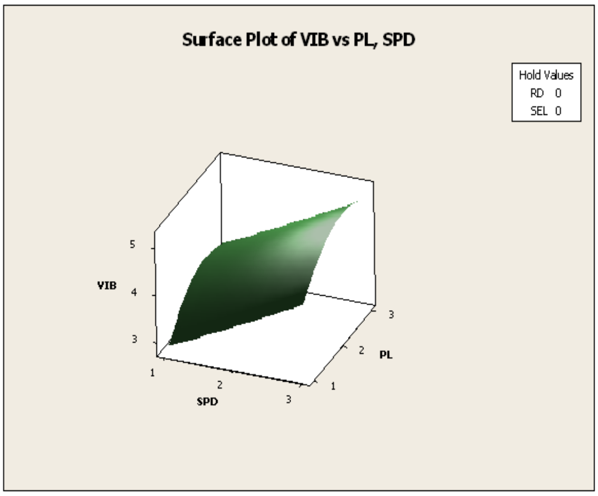
Fig2 Responce surface plots(a,c,e,g,i,j) andContour plotsb(b,d,f,g)

process parameters that produce a maximum or minimum value of the response [15]. In the present investigation the process parameters corresponding to minimum vibration are considered as optimum ,analyzing the contour graphs and by solving Eq.(3)). Hence, when these optimized process parameters are used, then it will be possible to attain the minimum vibration. Hence, when these optimized process parameters are used, then it will be possible to attain the minimum vibration. Fig 2(a,c,e,g,I,j) and fig 2(b,d,f,g) shows response surface plots and contour plots for response minimum vibration obtained from the regression model. The apex of response surface exhibits optimum vibration level. It is easy by examining the contour plots, that the change in vibration are more sensitive to change in pay load and Door Sealing Condition (Fig2(a,b,c,d))Interaction effect between the parameter speed and pay load on vibration level also exists, which is evidence from the contour plots. Contour plots shows, pay load, and Door Sealing Condition and speed are more sensitive parameter to change level of vibration as compare to other parameter. Minimum vibration occurs when pay load is smooth, road profile is medium, door sealing condition are rough and speed rang is between 40 to60 km/hr.

CONCLUSION

Response surface method is used to determine optimum condition of processing parameter. The RSM method shows significance of all possible conditions of interaction and square terms. Response plots and contour plots shows, pay load and speed are more significant parameter than other parameter on noise level. It is found that In-cab noise and vibration increase with increasing pay load and speed. Effect of Door sealing condition is not more significant. RSM is found to be capable of better prediction of In-cab noise and vibration of passenger car. It is possible to reduce In-cab noise and vibration by using optimize condition of parameter. Minimum vibration occurs when pay load is smooth, road profile is medium, door sealing

(j)



condition are rough and speed rang is between 60 to70 km/hrs

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