



# Analysis of Seat to Head Transmissibility for Human Sitting Posture Subjected to Vertical Excitation by using Response Surface Method.

<sup>#1</sup>Supriya Sambhaji More, <sup>#2</sup>Prof. R.V.Bhortake, <sup>#3</sup>Dr. M.R.Phate

<sup>1</sup>[suprivasmorennd@rediffmail.com](mailto:suprivasmorennd@rediffmail.com)

<sup>2</sup>[rupesh\\_bhortake@yahoo.com](mailto:rupesh_bhortake@yahoo.com)

<sup>3</sup>[mangesh\\_phate@rediffmail.com](mailto:mangesh_phate@rediffmail.com)

<sup>#1231,2,3</sup>Department of Mechanical Engineering, Savitribai Phule Pune University, TSSM's, PVPIT, Bavdhan, Pune, Maharashtra, 411051, India.

## ABSTRACT

Entire body vibration causes a multifaceted sharing out of vibration within the body and disagreeable feelings giving rise to discomfort or exasperation result in impaired performance and health menace. The current study proposed a 4-DOF analytic biomechanical model of the human body in a sitting posture without backrest in vertical vibration direction to investigate the biodynamic responses of different masses & stiffness and Analysis by using Response Surface Method. 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. The experimental set up will be design to get the entire speed range with the mass damper system. The mass damper system model will be formulated for the sitting posture like Auto Rickshaw human sitting posture. The biodynamic response characteristics of seated human subjects have been extensively reported in terms of apparent mass and driving-point mechanical impedance while seat-to-head vibration transmissibility has been widely used to characterize response behaviour of the seated subjects exposed to vibration. This Work helps to improve sitting comfort of commercial vehicle at various speed ranges and also improves Human work capability.

**Keywords—** Biodynamic Responses, Analytic Seated Human Body Model (4-Dof), Response Surface Method, Optimization.

## ARTICLE INFO

Received : 22<sup>nd</sup> May, 2015

Received in revised form :  
25<sup>th</sup> May, 2015

Accepted : 28<sup>th</sup> May , 2015

**Published online :**

**1<sup>st</sup> June 2015**

## I. INTRODUCTION

Human body vibration is a phenomenon affecting millions of worker in the world surrounded by these are light and heavy equipment operators, m/c tool operator and truck driver. Many harmful side effects of the vibration can be both physiological and neurological which in many cases lead to permanent injury. High speed vehicles frequently convey

dynamic forces to their inhabitant. Depending upon the intensity and period of such disturbances, serious damage of operator or passenger malfunctioning may occur. These problems have cause to extensive research directed towards defining and understanding the biodynamic response of the human body. Recently there has been increased fascination in the dynamics of the human body. Other attempts such as health and medical studies and even athletic interests have

also created a desire for comprehensive human biodynamic analysis.

The vehicle driving comfort has become one of the important factors of vehicle quality and receives increasing attention. A key functional performance characteristic in automotive design is the assessment of the vibrational comfort. Since the description to vibrations may cause adverse effects on the human health, the comfort performance of the final product must be carefully evaluated and optimized in the virtual engineering process, in order to assurance the comfort performance of the final product that strikes the road. The two wheeler and three wheelers like Auto Rickshaw riders are subjected to extreme vibrations due to the vibrations of its engine, irregular structural design of the vehicle and bad state of road. These vibrations are most hazardous to the health, if it run over the permissible limit and may cause the illness of the spine, musculoskeletal manifestation in the lower back as well as the neck and upper limbs. Experimental studies on the conveyance and tolerance of vertical vibrations excitation which are beyond the permissible limit according to the literatures confirms that, vibrations evidently affect the health of the two wheeler rider. Therefore it is mandatory to evaluate the influence of vibration to the human body and to make up appropriate guidelines for the two & three wheeler design and selection parts. The intensity of these injurious vibrations is reduced by providing a standard type of speed, cushion and spam of the driver. The composite model is analysed for vertical vibrations responses for various speed ranges.

The Taguchi approach and Response Surface Method will be used for the analysis and modelling of the various responses obtain from the human body.

## II. PROBLEM STATEMENT:

To analyse Biodynamic response of Analytic seated human body model (4-DOF)[1] by using Response Surface Methodology(RSM) using Input Parameters are Speed, Spam and Cushion level gives Output in the form of Seat to Head Transmissibility(STHT).

## III. LITERATURE REVIEW:

### 3.1 Mostafa A. M. Abdeen, W. Abbas[1]

The current study proposed a 4-DOF analytic biomechanical model of the human body in a sitting posture without backrest in vertical vibration direction to investigate the biodynamic responses of different masses and stiffness. The analytical approaches, numerical technique developed in the paper to facilitate and rapid the analysis. The numerical analysis used here register one of the Response surface technology to simulate and predict the response behaviors of seated human body for different masses and stiffness without the need to go through the analytic solution every time.

### 3.2 Cho-Chung Liang And Chi-Feng Chiang[3]

In this paper, a complete study on lumped-parameter models for seated human subjects without backrest support under vertical vibration excitation has been accomplished. As part of the study, all models have been analyzed systematically, and validated by the synthesis of miscellaneous experimental data from published literature. Depend on the analytical study and experimental validation, the four degree- of-freedom (DOF) model developed by Wan, Y. and Schimmels, J.M. [1995].

### 3.3 Wael Abbas<sup>1</sup>, Ossama B. Abouelatta, Magdi El-Azab And Mamdouh Elsaïdy[4]

This study developed a biomechanical model of the human body in a sitting posture without backrest for evaluating the vibration transmissibility and dynamic response to vertical vibration direction. In narrating the human body motion, a three biomechanical models are discussed (two models are 4-DOF and one model 7-DOF). In addition, an objective function is formulated comprising the sum of errors between the computed and actual values (experimental data). The studied response functions are the driving-point mechanical impedance, apparent mass and seat to head transmissibility functions.

### 3.4 S. Rakheja<sup>1</sup>, R.G. Dong, S. Patra, P.E. Boileau, P. Marcotte And C. Warren[5]

The reported data on biodynamic responses of the seated and standing human body exposed to whole-body vibration along different directions and the associated experimental conditions are systematically reviewed in an attempt to identify datasets that are likely to represent comparable and practical postural and exposure characteristics. Syntheses of datasets, selected on the basis of a set of criterion, are performed to identify the most probable ranges of biodynamic responses of the human body to whole-body vibration. These include the driving-point biodynamic responses of the body seated with and without a back support while exposed to fore-aft, lateral and vertical vibration and those of the standing body to vertical vibration, and seat-to-head vibration transmissibility of the seated body. The proposed ranges are expected to serve as reasonable target functions in various applications involving coupled human-system dynamics in the design process, and potentially for developing better frequency-weightings for exposure assessments.

### 3.5 Zengkang Gan, Andrew J. Hillis And Jocelyn Darling[6]

In this paper, a lumped-parameter biodynamic model of a seated human body (SHB) exposed to low frequency whole-body vibration in both vertical and fore-and-aft directions is developed. The model is based on all three types of biodynamic functions: seat to- head transmissibility (STHT), driving-point mechanical impedance (DPMI) and apparent mass (APM). The objective of this work is to match all three functions and to represent the biodynamic behavior of the SHB in a more comprehensive way. Three sets of synthesized experimental data from published literature are selected as the target values for each of the three biodynamic functions.

## IV. EXPERIMENTATION:

### 4.1 Experimental Setup:

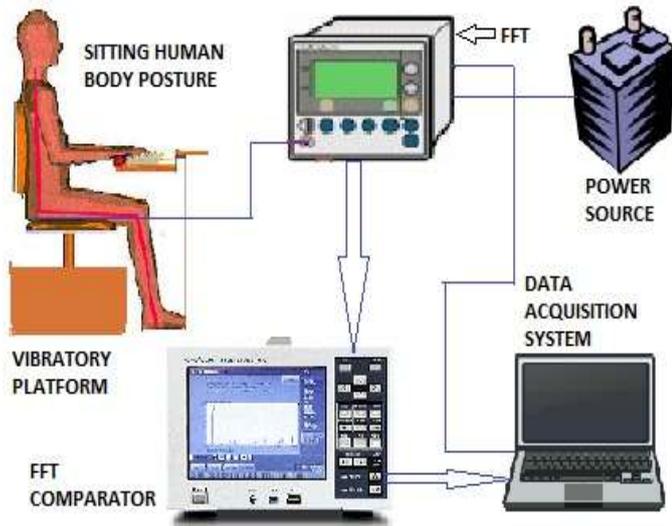


Fig.1. Experimental Setup

4.2 Important Identifying Parameters:

From the literature review and previous work done among many independently controllable parameters affecting biodynamic response of seated human model, the parameters viz Speed(A), Span(B), Cushion(C) and three Levels Low, Medium, High were selected as primary parameters for the study. Different combinations of parameters were used to carry out the trial runs. This was carried out by varying one of the factors while keeping the rest of them at constant values.

Table 1: Parameters Level Selected for the Experimentation

Parameters	Levels		
	Low(1)	Medium(2)	High(3)
Parameter A[Speed]	30rpm	50rpm	60rpm
Parameter B[Span]	30min	45min	60min
Parameter C[Cushion]	3cm	6cm	8cm

4.3 Conducting Experiment:

For conducting experiments three different speeds of vehicle, three different spans, and three different size of cushions ie 1,2,3 were selected. Using FFT (Fast Fourier Transformer) analyser vibration reading were recorded and Frequencies were measured. By using this Frequencies the Biodynamic response function STHT were calculated as follows.

V. RESULTS AND DISCUSSION:

5.1 Development of mathematical model:

5.1.1 Response surface methodology[1]:

Response surface methodology (RSM) is a collection of mathematical and statistical technique useful for analyzing problems in which several independent variables or response and the goal is to optimize the response. 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:

$$Y = \Phi(x_1, x_2, \dots, x_k) \pm e_r \dots \dots \dots \text{Eq.(1)}$$

Between the response Y and  $x_1, x_2, \dots, x_k$  of k quantitative factors, the function  $\Phi$  is called response surface or response function. The residual  $e_r$  measures the experimental errors. For a given set of independent variables, a characteristic surface is responded. When the mathematical

Term	Coeff	SE Coeff	T	P
Constant	-1.70322	0.34285	-4.968	0.000
SPD(A)	2.48650	0.20489	12.136	0.000
SPN(B)	1.62483	0.26654	6.096	0.000
CUSN(C)	-0.53978	0.20011	-2.697	0.015
SPD(A)*SPD(A)	-0.29294	0.04402	-6.655	0.000
SPN(B)*SPN(B)	-0.17461	0.05083	-3.435	0.003
CUSN(C)*CUSN(C)	0.13411	0.05083	2.639	0.017
SPD(A)*SPN(B)	-0.39589	0.05083	-7.789	0.000
SPD(A)*CUSN(C)	-0.08333	0.05083	-1.640	0.118

form of  $\Phi$  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 quality characteristics of noise. In applying the response surface methodology, the independent variable was viewed as surface to which a mathematical model is fitted.

The second order polynomial (regression) equation used to represent the response surface Y is given by,

$$Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum b_{ij} x_i x_j + e_r \dots \dots \dots \text{Eq.(2)}$$

And for the three factors, the selected polynomial could be expressed as,

$$\text{STHT}(X_2) = b_1 + b_1(A) + b_2(B) + b_3(C) + b_{11}(A^2) + b_{22}(B^2) + b_{33}(C^2) + b_{12}(AB) + b_{13}(AC) + b_{23}(BC) \dots \dots \dots \text{Eq.(3)}$$

5.1.2 Response Surface Regression: STHT Vs SPD(A), SPN(B), CUSN(C). (The analysis was done using coded unit):

In order to estimate the regression coefficients, a number of experimental design techniques are available. In this work, Table 4. was used which fits the second order response surfaces very accurately. The final modal was developed using only these coefficient and the final mathematical model to estimate STHT is given:

Table 3: Estimated Regression Coefficients for STHT

$$\text{STHT}(X_2) = -1.70322 + 2.48650 * \text{SPD}(A) + 1.62483 * \text{SPN}(B) - 0.53978 * \text{CUSN}(C) - 0.29294 * \text{SPD}(A)^2 - 0.17461 * \text{SPN}(B)^2 + 0.13411 * \text{CUSN}(C)^2 - 0.39589 * \text{SPD}(A) * \text{SPN}(B) - 0.08333 * \text{SPD}(A) * \text{CUSN}(C)$$

Table2: observation table

**5.1.3 Checking adequacy of Model:**

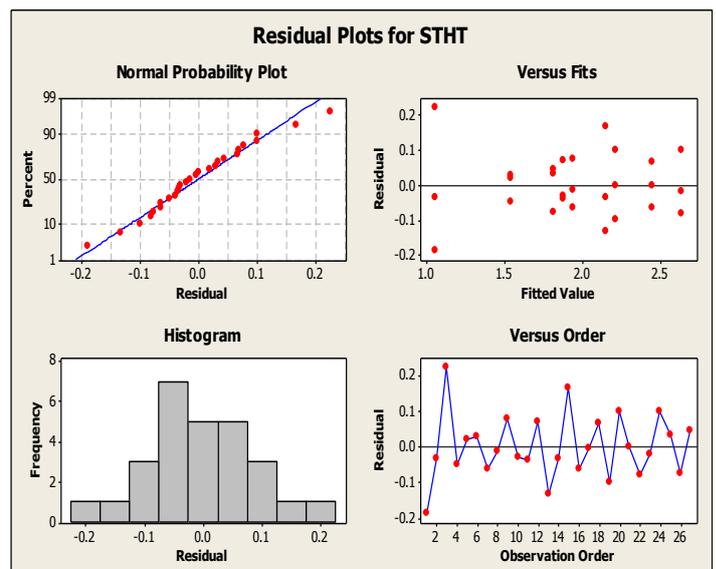
The adequacy of the developed model was tested using the analysis of variance (ANOVA) are given in the table 4. Table 4 shows the ANOVA results of the model. The data was provided in coded form for the variables. The ‘p-value’ in the last column represents the influence of the terms. For 95% confidence level the p-value less than 0.05 indicates significant influence of the parameter. Lower value of the regression model shows that the model is significant.

The determination coefficient ( $R^2$ ) indicates the goodness of fit for the model. In this case the value of the determination coefficient ( $R^2=0.9633$ ) indicates that only 7% of the total variations are not explained by the model. The value of adjusted determination coefficient ( $R^2=0.9470$ ) is also high, which indicates a high significance of model. Predicted  $R^2$  is also in a good agreement with the adjusted  $R^2$ . Adequate precision compares the predicted values at the design points to the average prediction error. At the same time a value of the press (0.470833) indicates improved precision and reliability of the conducted experiments. The value of probability  $>F$  in Table 4. for model is less than 0.02, which indicates that the model is significant. In the same way, Speed(A), Span(B), cushion(C), interaction effect of speed with span(AB), interaction effect of speed with cushion(AC), and second order term of speed, size, cushion have significant effect. Lack of fit is non-significant as it is desired. The normal probability plot of the STHT response  $X_2$  as shown in fig.(2a) reveals that the residuals are falling on straight line, which mean the error are distributed normally. All the above consideration indicates an excellent adequacy of the regression model. Each observed value is compared with predicated value calculated from model in fig.(2b).

Experiment No	Input to the Human Body			Responses from the Human Body
	A	B	C	STHT
1	1	1	1	0.867
2	1	1	1	1.02
3	1	1	1	1.28
4	1	2	2	1.49
5	1	2	2	1.56
6	1	2	2	1.57
7	1	3	3	1.88
8	1	3	3	1.93
9	1	3	3	2.02
10	2	1	2	1.85
11	2	1	2	1.84
12	2	1	2	1.95
13	2	2	3	2.02
14	2	2	3	2.12
15	2	2	3	2.32
16	2	3	1	2.39
17	2	3	1	2.45
18	2	3	1	2.52
19	3	1	3	2.12
20	3	1	3	2.32
21	3	1	3	2.22
22	3	2	1	2.56
23	3	2	1	2.62
24	3	2	1	2.74
25	3	3	2	1.85
26	3	3	2	1.74
27	3	3	2	1.86

**Table 3:** Analysis of Variance for STHT(ANOVA)

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Regression	8	5.495	5.495	0.687	59.1	0.000
<b>Linear</b>	3	2.858	2.465	0.822	70.7	0.000
SPD(A)	1	2.285	1.712	1.712	147.3	0.000
SPN(B)	1	0.559	0.432	0.432	37.2	0.000
CUSN(C)	1	0.014	0.085	0.085	7.3	0.015
<b>Square</b>	3	1.457	0.763	0.254	21.9	0.000
SPD(A)*SPD(A)	1	0.515	0.515	0.515	44.3	0.000
SPN(B)*SPN(B)	1	0.281	0.137	0.137	11.8	0.003
CUSN(C)*CUSN(C)	1	0.662	0.081	0.081	7.0	0.017
<b>Interaction</b>	2	1.180	1.180	0.590	50.8	0.000
SPD(A)*SPN(B)	1	1.149	0.705	0.705	60.7	0.000
SPD(A)*CUSN(C)	1	0.031	0.031	0.031	2.7	0.118
<b>Residual Error</b>	18	0.209	0.209	0.012		
<b>Pure Error</b>	18	0.209		0.012		
<b>Total</b>	26	5.705				
Std. deviation		0.108		R-Sq=		96.33%
Press		0.471		R-Sq(adj)=		94.75%
				R-Sq(Predi)=		91.75%



**Fig. 2:**Residual plots for STHT [Fig.2a-Normal Probability, Fig.2b-Versus Fits, Fig.2c-Histogram, Fig.2d-Versus Order]

**5.2 Optimizing parameters:**  
Surface Plot and Contour Plot:

Contour plots show distinctive circular shape indicative of possible independence of factors with response. A contour plot is produced to visually display the region of optimal factor settings [2]. 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 most straightforward way is to examine through a contour plot. Contour plots play a very important role in the study of the response surface. By generating

contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. If a contour patterning of circular shaped contours occurs, it tends to suggest independence of factor effects while elliptical contours as may indicate factor interactions. 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.

Fig.3 presents three and two dimensional response surface plots for the STHT response obtained from the regression model.

Contour plots for STHT

Surface plots for STHT

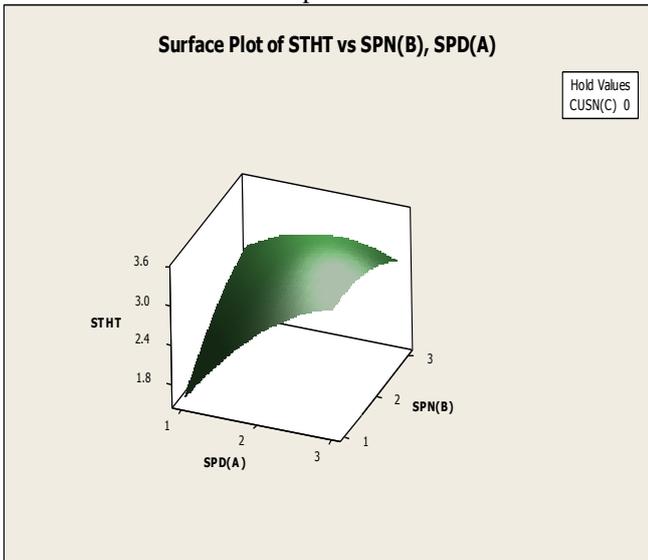


Fig.3(A)

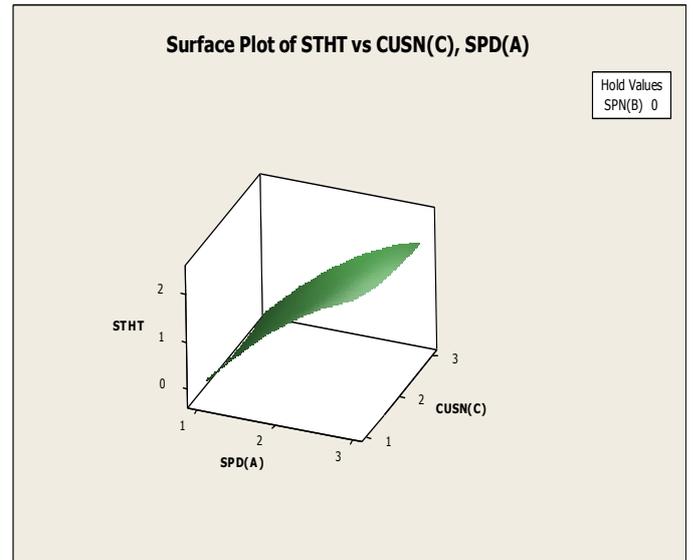


Fig.3(E)

Fig. 3 Response Plots of STHT

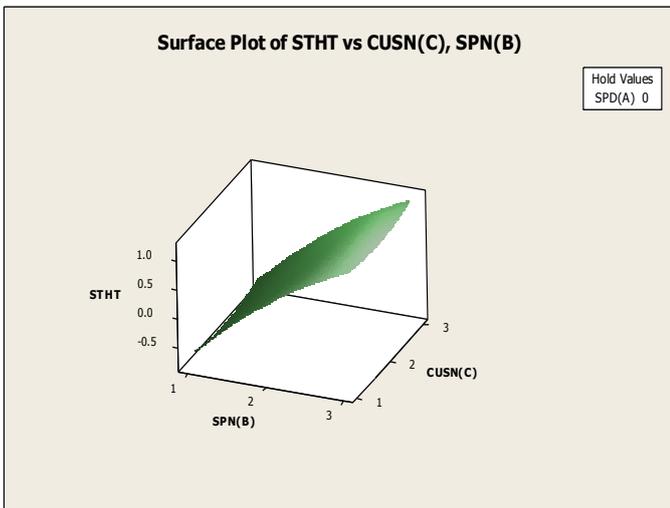


Fig.3(C)

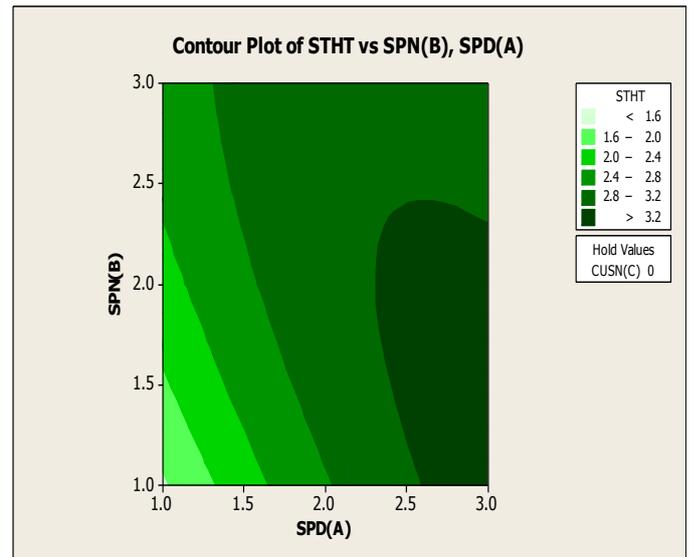


Fig.3(B)

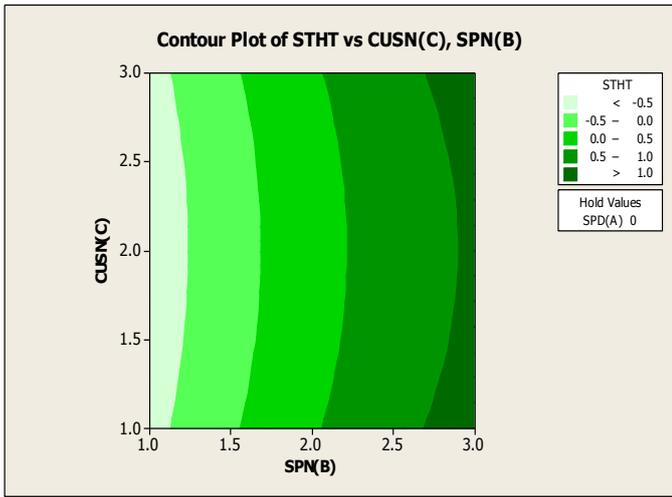


Fig.3(D)

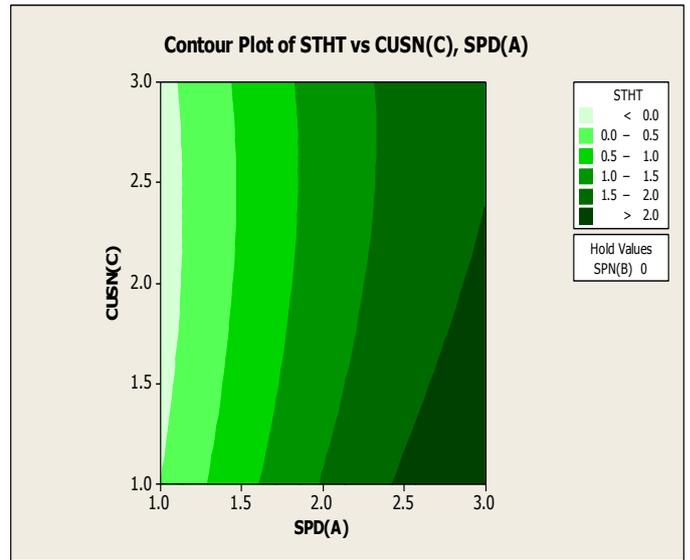


Fig.3(F)

5.3 Optimization of STHT:

5.3.1 Response Optimization

Parameters:

	Goal	Lower	Target	Upper	Weight	Import
STHT	Minimum	0.867	0.867	2.52	1	1

Global Solution:

SPD (A) = 1  
 SPN (B) = 1  
 CUSN (C) = 2.31313

Predicted Responses:

STHT = 0.820901,  
 Desirability = 1.000000  
 Composite Desirability = 1.000000

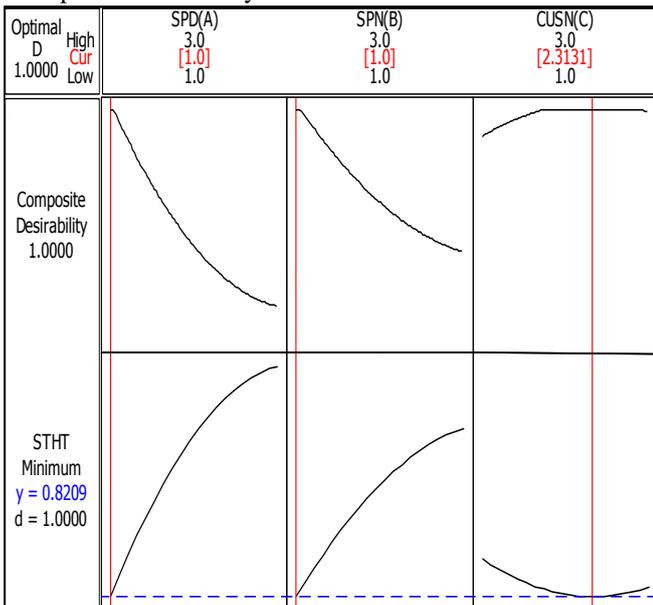


Fig. 4 Response Optimization of STHT

VI. CONCLUSION:

In this way From the Response surface Method analysis it is observed that the RSM Model is very closely fit with the actual Response. The values of R<sup>2</sup> is very close to 1. From ANOVA it indicates that contribution interaction effect. The surface plots indicates that,

1. STHT is directly proportional to A and B when C is constant.
2. STHT is directly proportional to B when A is constant and C is negligible.
3. STHT is directly proportional to A when B is constant and C is negligible

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