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Analytical And Numerical Analysis Of Multi Degree Vibratory Model By Using RSM

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Abstract

The effects of whole body vibration are complex. Exposure to whole body vibration causes motions and forces within the human body which may cause discomfort, adversely musculoskeletal disorders. The most common disorder reported from exposure to whole body vibration is low back pain. Two wheeler rider system is developed as spring mass system.17 degree of freedom model is prepared. This Response surface methodology is a good tool for analysis.

Keywords: *Response surface methodology, Whole body vibration, Multi degree vibratory model, two wheeler rider system.*

1. Introduction

In Today's world millions of people are using two wheeler in economic point of view. These two wheeler riders are exposed to whole body vibration i.e. mechanical vibration. As Per Experimental studies on (WBV) whole body vibration and as per literature certainly confirms that the health of rider is affected much therefore it becomes necessary to find out the effects of vibration on different body parts and according to make changes in design of two wheeler and selection parts.

RSM involves two phases are as below

Fit a linear regression model to some initial data points in the search space (through replications of the simulation model). Estimate a steepest descent direction from the linear regressions model, and a step size to find a new (and better) solution in the search space. Repeat this process until the linear regression model becomes inadequate (indicated by when the slope of the linear response surface is approximately 0; i.e., when the interaction effects become larger than than the main effects).

Fit a nonlinear quadratic regression equation to this new area of the search space. Then find the optimum of this equation.The response surface methodology (RSM) is supportive in developing a proper guess for the accurate functional connection between the independent variables and the response variable [3]. It has been showed by numerous researchers that capable use of statistical design of experimental techniques, allow development of an practical methodology, to fit in a scientific approach in analysis of multi degree vibratory model .Even though sufficient literature is available on analysis of multi degree vibratory model no organized study has been reported so far to associate the process parameters and transmissibility. Hence, in this research, the design was used to carry out experiments for exploring the interdependence of the process parameters and second order quadratic model for multi degree vibratory model was developed from the data obtained by conducting the experiments.

Response surface methods can get better combat air power because the techniques can hold the enormous number factors and interactions. RMS is on the cutting edge of modern engineering techniques that agree to quantitative estimation of massive amounts of variables and interactions. In a full factorial design, all likely factors and levels are studied at the same time. Other techniques, such as Fractional Factorial or Central Composite Designs, can be used. As the purpose of study was to discover if qualitative engineering could be used within an Air Power problem, a full factorial design method was selected [2]. The recent version of RSM provides only the mainly standard tools for first- and second-order response-surface design and analysis [4].In designing, formulating, developing, and analyzing new scientific studying and products the RSM is essential . It is also capable in the upgrading of existing studies and products. in Industrial, Biological and Clinical Science, Social Science, Food Science, and Physical and 3Engineering Sciences,the RSM is most frequently used[5].

2. Analytical Investigation

2.1 Methodology

The Methodology is briefly summarized from the following flow chart. The inspiration for this flow chart is taken from earlier paper and little bit variation is done [1].

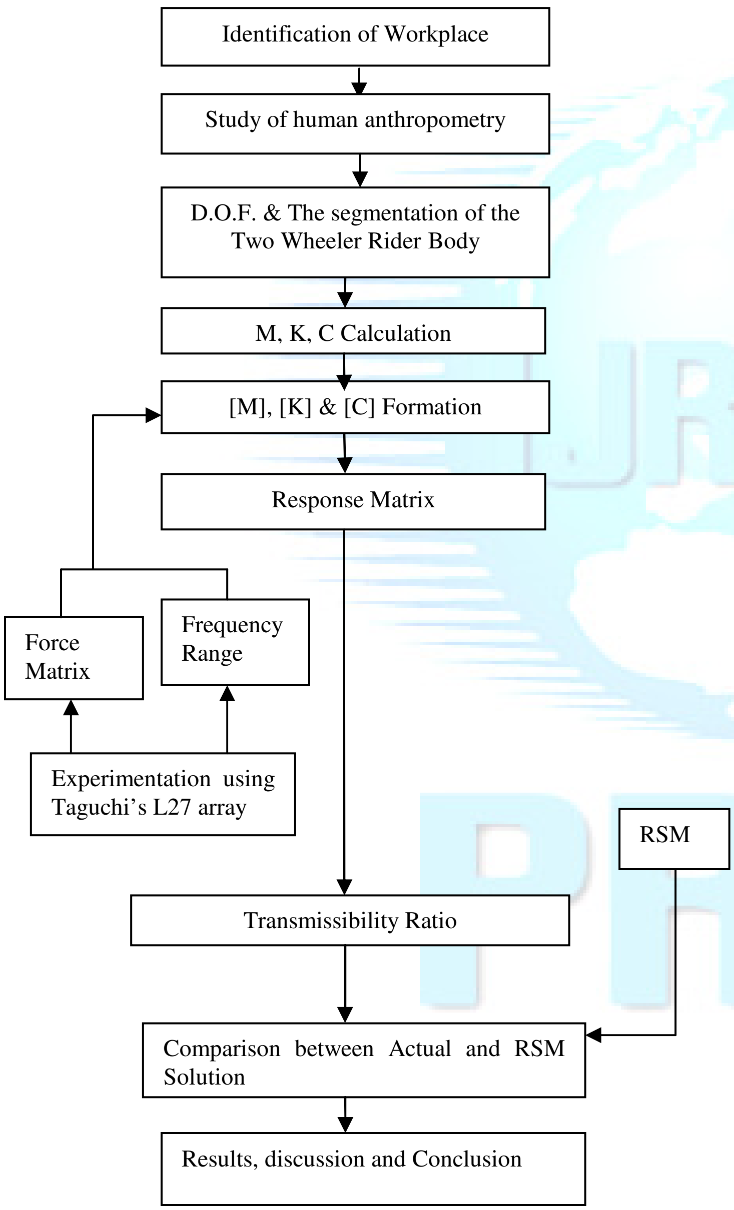


Figure1: Methodology

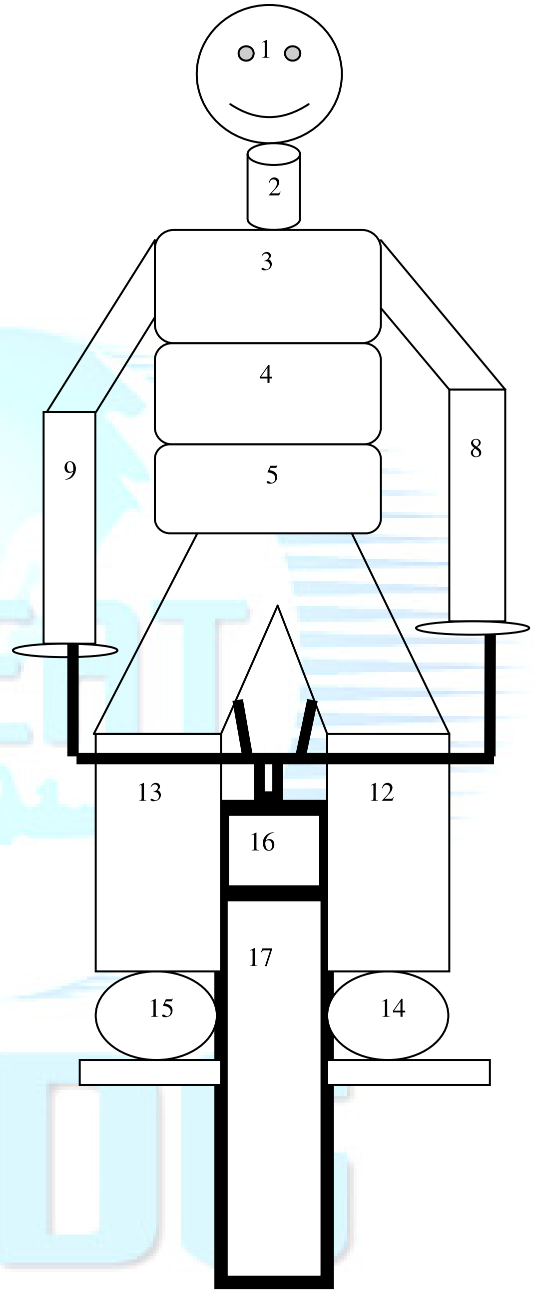


Fig 2: Sitting Posture for the Two Wheeler rider.

2.2 Plan of Experimentation

Table 1: Plan for the experimentation

Code	**1**	**2**	**3**
Speed(A) (Km/Hr)	Slow	Medium	High
Road Profile(B)	Poor Surface (P)	Rough (R)	Smooth (S)
Air in the wheels(C)	Min(L)	Average (M)	Max(H)

Table 2: parameters and their levels with values

Code	**1**	**2**	**3**
Speed (Km/Hr)(A)	20	40	60
Road Profile(B)	0.5	0.75	1
Air in the wheels(C)	25	30	35

From the above plan of experimentation, experiments are performed using FFT analyzer and From equation We get the value for [M], [K] and [C] matrices by using D'Alemberts principle. These matrices are form as mention in earlier paper by using matrix inversion method [1]. Results are given below in a tabular form for both male and female rider.

2.3 Conducting experiments

For conducting experiments one two wheeler is taken and two riders are chosen one male another female rider. Instrument required for calculation is FFT analyzer. From figure 2 we can see the experimental set up is made for both male and female rider.

Figure 3: Experimental set up

3. Development Of mathematical model

3.1 Response surface methodology

Response surface technology is a compilation of two techniques those are mathematical and statistical for analysis of the defined problem in which a dependent variable or response is influenced by more than a few independent variables. To obtimize the response is the main objective of response surface method RSM. Usually this methodology involves performance of many experiments and using result of one experiment for direction of others.
Response Surface Methodology (RSM) is useful for the modeling and analysis of programs in which a response of interest is influenced by several variables and the objective is to optimize this response.
For example: Find the levels of temperature (x_1) and pressure (x_2) to maximize the yield (y) of a process.

$$Y=\Phi(x1, x2\ldots xk) \pm er \qquad \text{Eqn.(1)}$$

Among the response Y and x1, *x*2… *xk* of k quantitative factors , the function *Φ* 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 form of *Φ* is not known, it can be estimated suitably within the experimental area by polynomial. In the current study, RSM has been applied for developing the mathematical model in the form of multiple regression equations for quality characteristics of transmissibility. In applying the response surface methodology, the self-governing variable was viewed as surface to which a mathematical model is fixed. The second order polynomial (regression) equation used to signify the response surface Y is given by

$$Y = b_0 + \Sigma\, bi\, xi + \Sigma\, bii\, xi + \Sigma\, bij\, xi\, x\, j + e \qquad \text{Eqn.(2)}$$

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

$$\text{Transmissibility(TR2)}=b0+b1(A)+b2(B)+b3(C)+b11(A2)+b22(B2)+b33(C2)+ b12(AS)+b13(AB)+b23(BC) \qquad \text{Eqn. (3)}$$

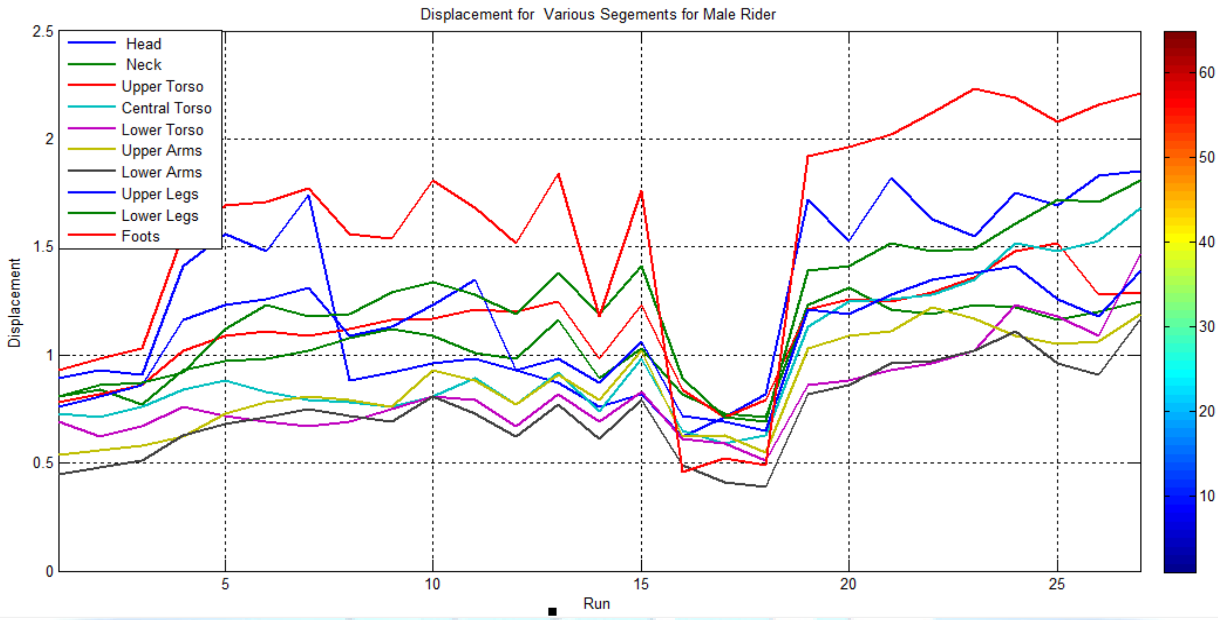
Table 3: Results of experimentation of male rider

Run	*Speed*	*Road*	*Air in Tube*	*f*	*F FW*	*FRW*
1	1	1	1	7.523	35.8346	40.6126
2	1	1	1	8.863	35.8346	40.6126
3	1	1	1	8.896	35.8346	40.6126
4	1	2	2	12.547	35.8346	40.6126
5	1	2	2	13.897	35.8346	40.6126
6	1	2	2	13.624	35.8346	40.6126
7	1	3	3	13.568	35.8346	40.6126
8	1	3	3	12.654	35.8346	40.6126
9	1	3	3	12.587	35.8346	40.6126
10	2	1	2	13.785	35.8346	40.6126
11	2	1	2	12.639	35.8346	40.6126
12	2	1	2	11.693	35.8346	40.6126
13	2	2	3	13.568	35.8346	40.6126
14	2	2	3	10.3632	35.8346	40.6126
15	2	2	3	13.123	35.8346	40.6126
16	2	3	1	8.638	35.8346	40.6126
17	2	3	1	6.126	35.8346	40.6126
18	2	3	1	7.236	35.8346	40.6126
19	3	1	3	22.125	35.8346	40.6126
20	3	1	3	20.148	35.8346	40.6126
21	3	1	3	23.854	35.8346	40.6126
22	3	2	1	25.693	35.8346	40.6126
23	3	2	1	26.587	35.8346	40.6126
24	3	2	1	28.639	35.8346	40.6126
25	3	3	2	24.874	35.8346	40.6126
26	3	3	2	23.568	35.8346	40.6126
27	3	3	2	28.369	35.8346	40.6126

Table 4: Results of experimentation of female rider

Run	*Speed*	*Road*	*Air in Tube*	*f*	*F FW*	*FRW*
1	1	1	1	6.235	28.6677	31.0567
2	1	1	1	7.625	28.6677	31.0567
3	1	1	1	6.528	28.6677	31.0567
4	1	2	2	10.361	28.6677	31.0567
5	1	2	2	9.528	28.6677	31.0567
6	1	2	2	11.251	28.6677	31.0567
7	1	3	3	13.025	28.6677	31.0567
8	1	3	3	12.654	28.6677	31.0567
9	1	3	3	13.028	28.6677	31.0567
10	2	1	2	14.361	28.6677	31.0567
11	2	1	2	11.354	28.6677	31.0567
12	2	1	2	14.026	28.6677	31.0567
13	2	2	3	16.354	28.6677	31.0567
14	2	2	3	13.254	28.6677	31.0567
15	2	2	3	12.021	28.6677	31.0567
16	2	3	1	10.325	28.6677	31.0567
17	2	3	1	8.254	28.6677	31.0567
18	2	3	1	9.021	28.6677	31.0567
19	3	1	3	10.325	28.6677	31.0567
20	3	1	3	18.231	28.6677	31.0567
21	3	1	3	19.251	28.6677	31.0567
22	3	2	1	22.254	28.6677	31.0567
23	3	2	1	23.254	28.6677	31.0567
24	3	2	1	20.214	28.6677	31.0567
25	3	3	2	26.254	28.6677	31.0567
26	3	3	2	22.235	28.6677	31.0567
27	3	3	2	24.231	28.6677	31.0567

3.2 Observations for displacement of various body segments for male and female rider



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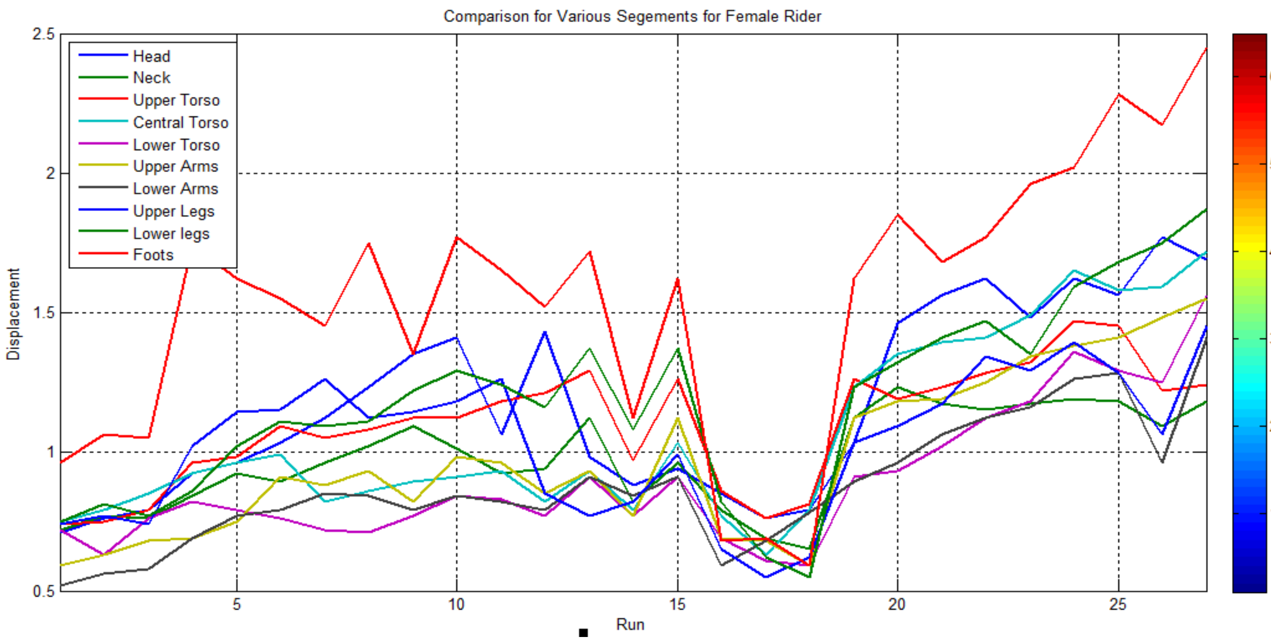

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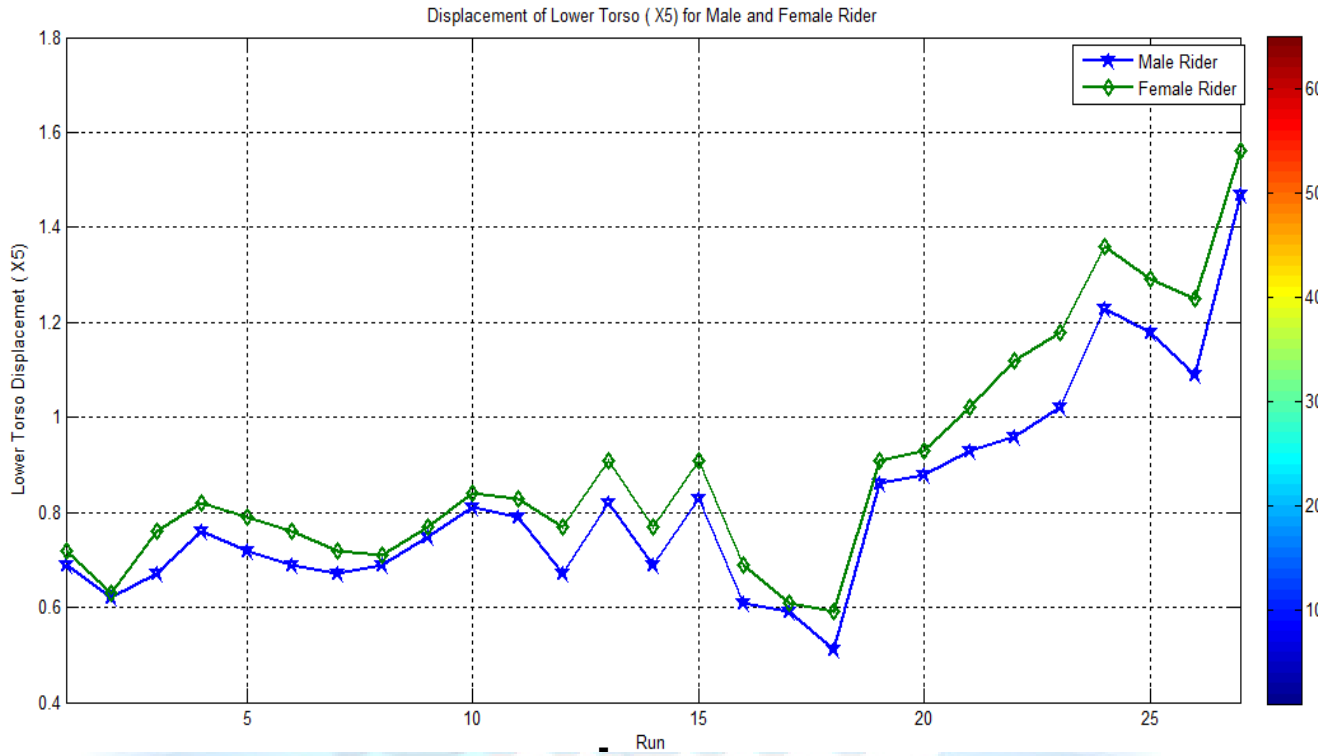

From above first two graph it is observed that neck, lower torso and lower arms are most affected parts hence the further work is only focus on one segments segments. The Transmibility ratio (TR) for these segments is calculated with respect to the displacement of upper legs
(X10 and X11).
From third graph for lower torso for Male and female of different body masses are used to investigate the effect of vibration on the lower torso displacement and it is observed that during the whole study the lower torso displacement is more in case of female rider than the male rider. The amplitude of the lower torso displacement is lower for the eighteen run.

Transmissibility ratio for lower Torso = X5/ /X10 or X5/ X11

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3.3 Response Surface Regression: TR2 versus A, B, C
The analysis was done using coded units.

Table 4: Estimated Regression Coefficients for TR2 for male rider

Term	*Coef*	*SE Coef*	*T*	*P*
Constant	0.90368	0.05127	17.626	0.000
A	0.02282	0.02093	1.090	0.290
B	0.04283	0.02960	1.447	0.165
C	0.02054	0.02960	0.694	0.497
*A*A*	-0.09149	0.03625	-2.524	0.021
*B*B*	0.03518	0.04186	0.840	0.412
*C*C*	0.13524	0.04186	3.231	0.005
*A*B*	0.0326 0	0.04186	0.779	0.446
*A*C*	0.07036	0.04186	1.681	0.110

Table 5: Estimated Regression Coefficients for TR2 for female rider

Term	*Coef*	*SE Coef*	*T*	*P*
Constant	0.895036	0.05366	16.679	0.000
A	0.096869	0.02191	4.422	0.000
B	0.086949	0.03098	2.806	0.012
C	0.005142	0.03098	0.166	0.870
*A*A*	-0.078909	0.03794	-2.080	0.052
*B*B*	-0.049262	0.04381	-1.124	0.276
*C*C*	0.113167	0.04381	2.583	0.019
*A*B*	0.136958	0.04381	3.126	0.006
*A*C*	0.111364	0.04381	2.542	0.020

In order to estimate the regression coefficients , a number of experimental design techniques are available .In this work ,table (4) ,(5) was used which fits the second order response surfaces very accurately. Central composite face cantered design matrix.The final modal was developed using only these coefficient and the final mathematical model to estimate transmissibility for both male and female rider is given by

Second order response surface equation for the TR2 Male Rider is as given below

TR2 =0.68663 +0.07602*A+0.05425*B+0.02595*C-0.01455*AA+0.002234*BB+0.09171*CC+0.14791*AB+0.03966*AC Eqn. (4)

Second order response surface equation for the TR2 Female Rider is as given below

TR2 =1.45039 -0.0841376*A+0.0100798*B+0.03495*C --0.670253*AA-0.0492616*BB+0.116167*CC+0.136958*AB+0.111364*AC Eqn. (5)

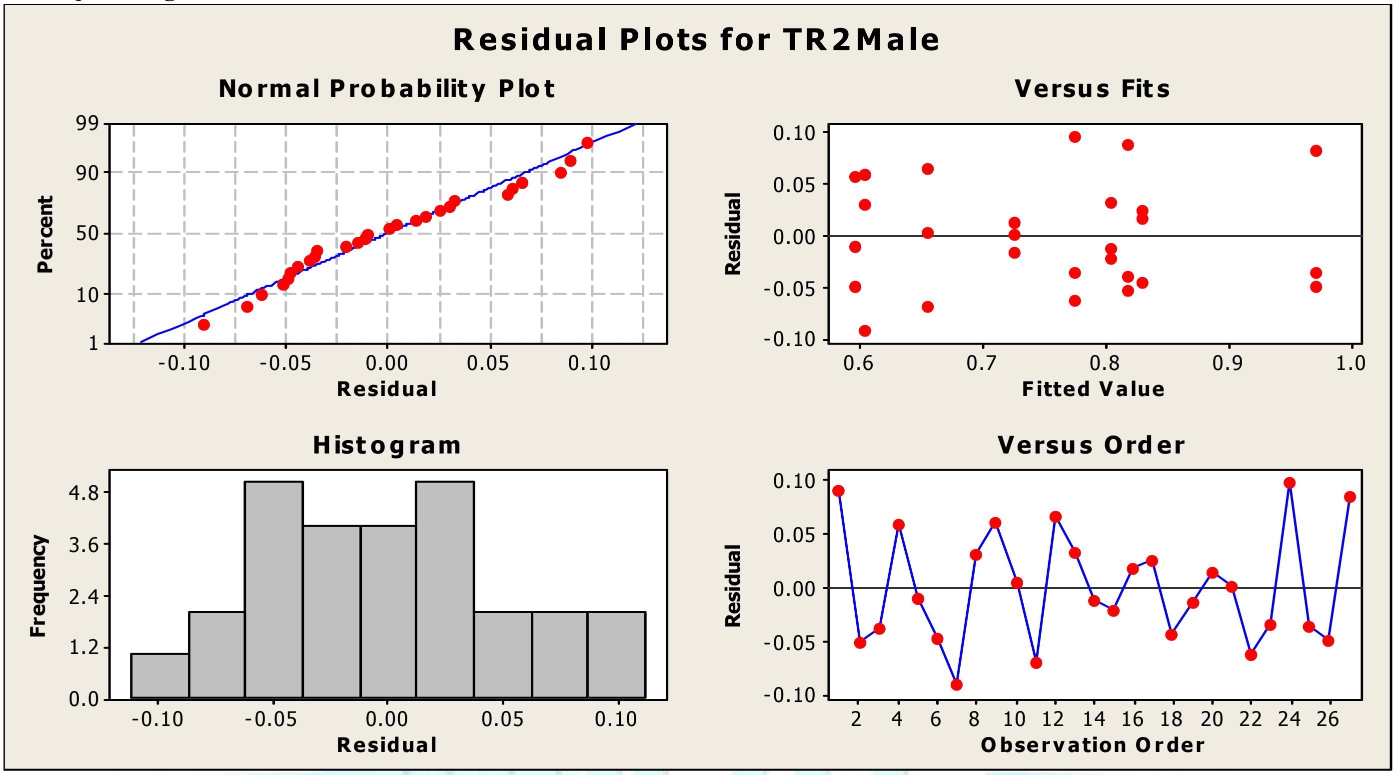
The sufficiency of the developed model was tested using the analysis of variance (ANOVA) are given in the table 6 and 7for male and female rider correspondingly The determination coefficient (R^2) indicates the goodness of fit for the model. In this case the value of the determination coefficient (R^2=0.8335 for male and 0.7905 for female) indicates that only 7% of the total variations are not explained by the model. The value of adjusted determination coefficient (R^2=0.7595 for male 0.7974 for female) 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 (73.68) indicates improved precision and reliability of the conducted experiments. The value of probability$>F$ in Table 6 and 7 for model is less than 0.05, which indicates that the model is significant. on the contrary, Speed Km/Hr (A), road profile (B), air in the wheels (C) , interaction effect of speed with road profile (AB), interaction effect of speed with air in the wheels(AC), and second order term of speed, road profile, air in the wheels, have significant effect. Lack of fit is non-significant as it is desired. The normal probability plot of the transmissibility TR2 as shown in figure 4 in showing residual plots revels 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 figure 2 in residual plots.

Table 6. ANOVA results for the TR2 Response of Male Rider

Source	**DOF**	**Square SS**	**Adjusted SS**	**Mean Square**	**F Value**	***p*-value probability**
Regression	8	0.356558	0.356558	0.044570	11.26	0.000
Linear	3	0.166832	0.145509	0.048503	12.26	0.000
A	1	0.104033	0.104033	0.104033	26.29	0.000
B	1	0.021324	0.026487	0.026487	6.69	0.019
C	1	0.041475	0.006062	0.006062	1.53	0.232
Square	3	0.013831	0.039657	0.013219	3.34	0.043
A * A	1	0.001270	0.001270	0.001270	0.32	0.578
B * B	1	0.010670	0.002246	0.002246	0.57	0.461
C * C	1	0.001891	0.037845	0.037845	9.56	0.006
Interaction	2	0.175895	0.185885	0.087948	22.23	0.000
A * B	1	0.168817	0.098446	0.098446	24.88	0.000
A * C	1	0.007078	0.007078	0.007078	1.79	0.198
Residual Error	18	0.071228	0.071228	0.007078		
Pure Error	18	0.071228	0.071228	0.003957		
Total	26	0.427786				
Std deviation	0.062929			R^2	0.8335	
Press	0.160262			Adjusted R^2	0.7595	
				Predicted R^2	0.7254	

Table 7. ANOVA results for the TR2 Response of Female Rider

Source	DOF	Square SS	Adjusted SS	Mean Square	F Value	*p*-value probability
Regression	8	0.586767	0.586767	0.073346	8.49	0.000
Linear	3	0.258708	0.243880	0.081293	9.41	0.001
A	1	0.168904	0.168904	0.168904	19.55	0.000
B	1	0.017597	0.068041	0.068041	7.88	0.012
C	1	0.072208	0.000238	0.000238	0.03	0.870
Square	3	0.049589	0.037790	0.037790	4.37	0.018
A * A	1	0.037360	0.037360	0.037360	4.32	0.052
B * B	1	0.000247	0.010920	0.010920	1.26	0.276
C * C	1	0.011982	0.057630	0.057630	6.67	0.019
Interaction	2	0.278469	0.139235	0.139235	16.12	0.000
A * B	1	0.222660	0.084408	0.084406	9.77	0.006
A * C	1	0.055809	0.055809	0.055809	6.46	0.020
Residual Error	18	0.155494	0.155494	0.008639		
Pure Error	18	0.155494	0.155494	0.008639		
Total	26	0.742261				
Std deviation	0.0929438			R^2	0.7905	
Press	0.349861			Adjusted R^2	0.7974	
				Predicted R^2	0.7287	


Residual Plots for TR2Male
Normal Probability Plot
Percent
Residual
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Fitted Value
Histogram
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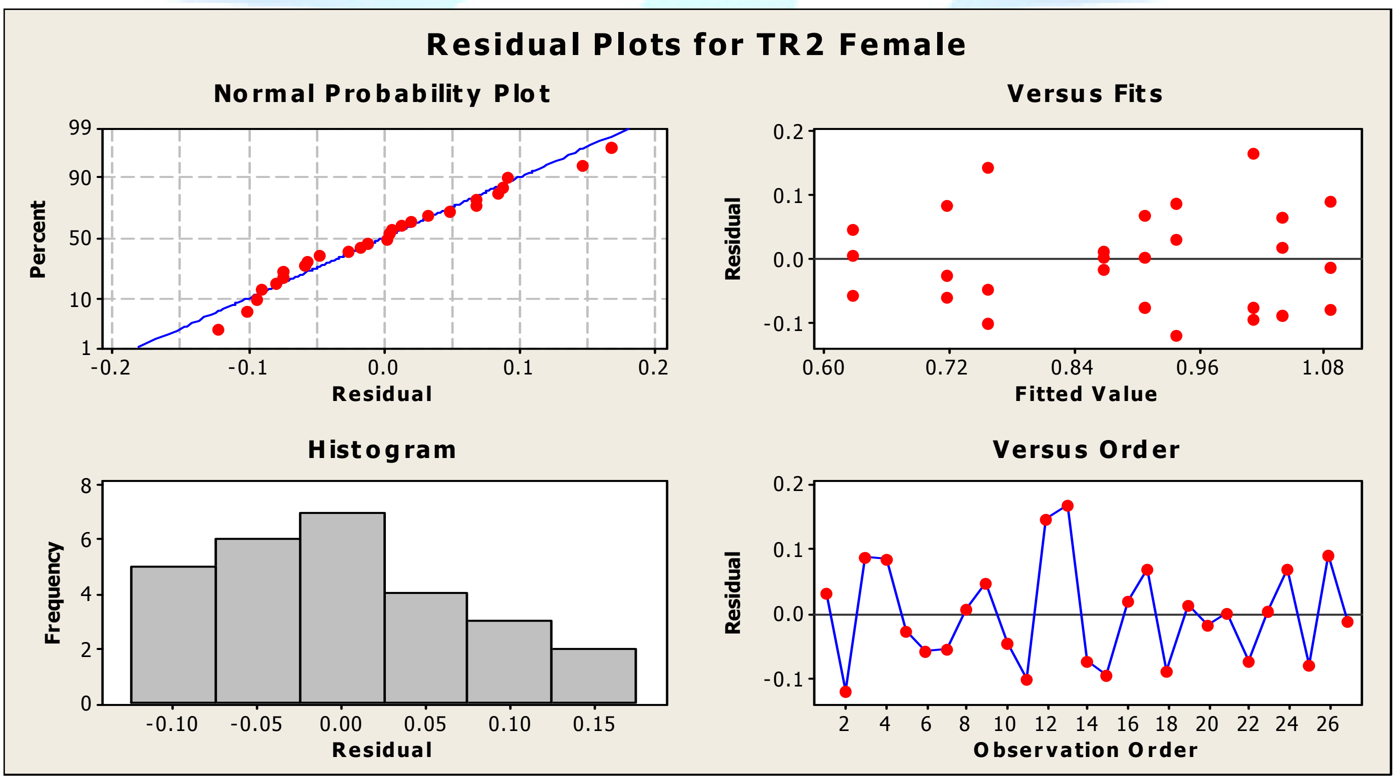
Versus Order
Residual
Observation Order


Residual Plots for TR2 Female
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order

3.4 Optimizing parameters

Contour plots show distinctive circular shape indicative of possible independence of factors with response. 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. The response surfaces clearly reveal the optimal response point. RSM is used to find the optimal set of process parameters that produce a maximum or minimum value of the response. In the present investigation the process parameters corresponding to the transmissibility are considered as optimum (analysing the contour graphs and by solving Eq.(4) for male rider Eq(5)for female rider. Hence, when these optimized process parameters are used, then it will be possible to attain the minimum transmissibilityFig.3 presents three dimensional response surface plots for the response transmissibility obtained from the regression model. Fig.4(a) exhibits almost a circular contour, which suggests independence of factor effect namely speed. It is relatively easy by examining the contour plots (Figs.4(b) and 4(c)), that changes in the transmissibility are more responsive to changes in speed as compared to changes in road profile and air in the wheels.

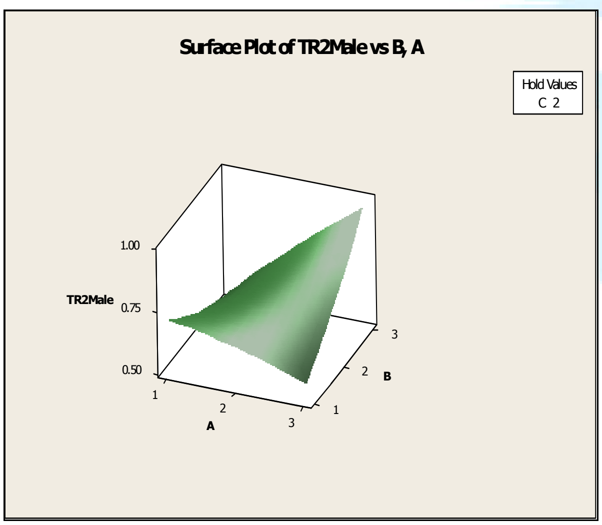


Figure 4:Surface plot of TR2 male

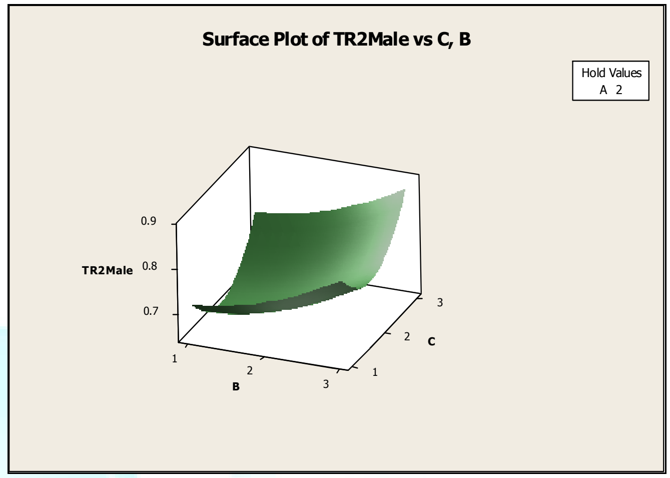


Figure5:Surface plot of TR2 male

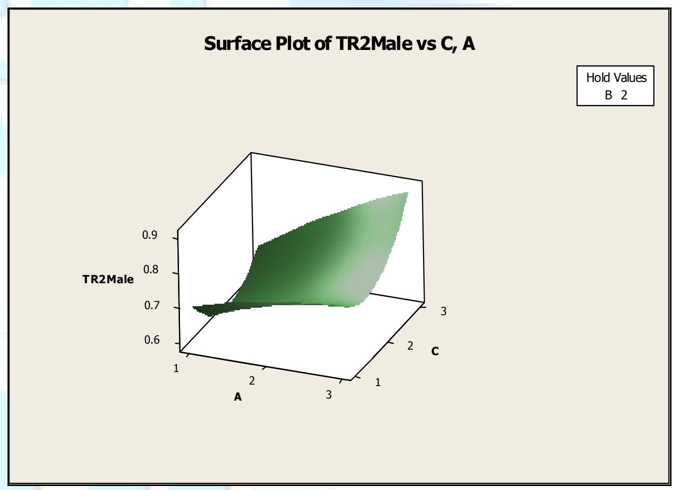


Figure 6: Surface plot of TR2 male

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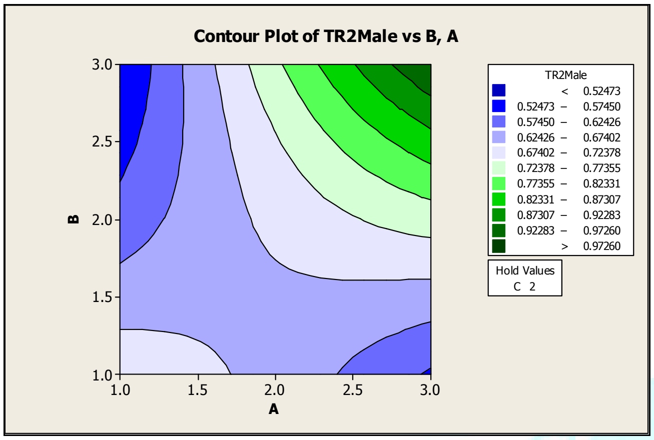


Figure 7:Contour plot of TR2 male

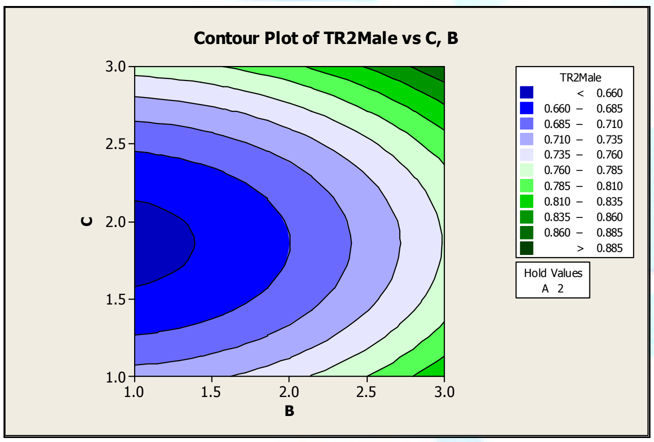


Figure8: Contour plot of TR2 male

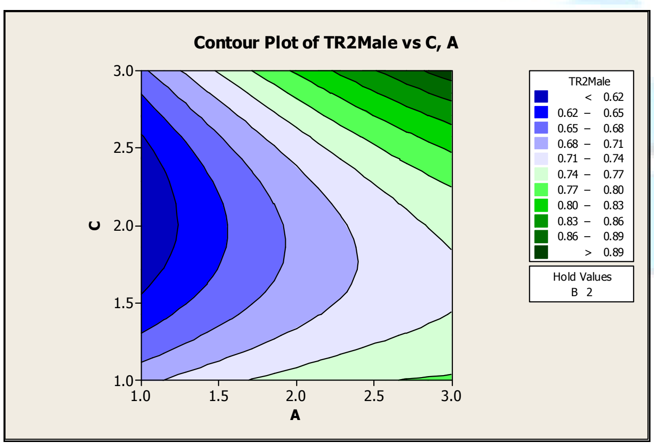


Figure 9: Contour plot of TR2 male

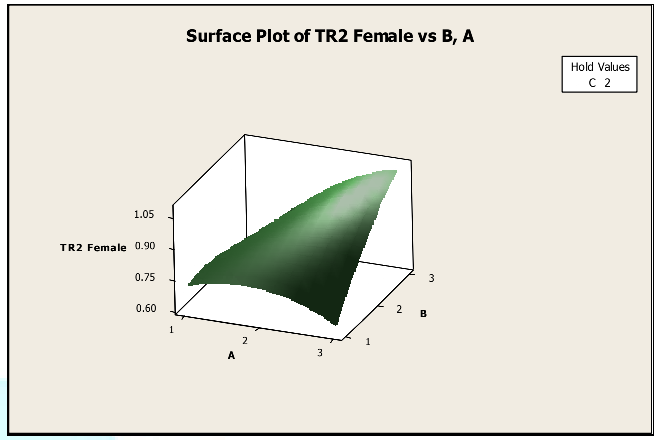


Figure 10:Surface plot of TR2 female

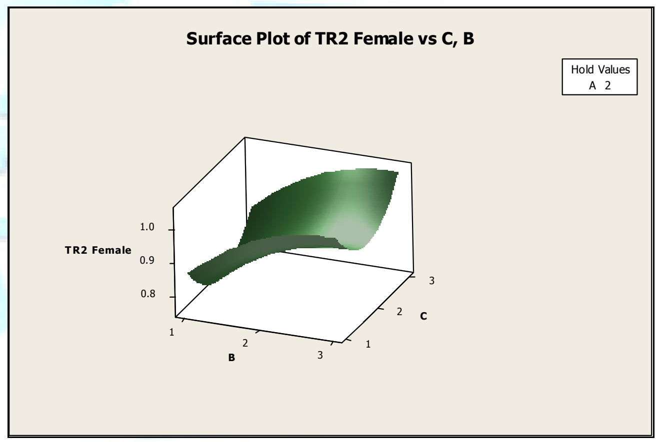


Figure11:Surface plot of TR2 female

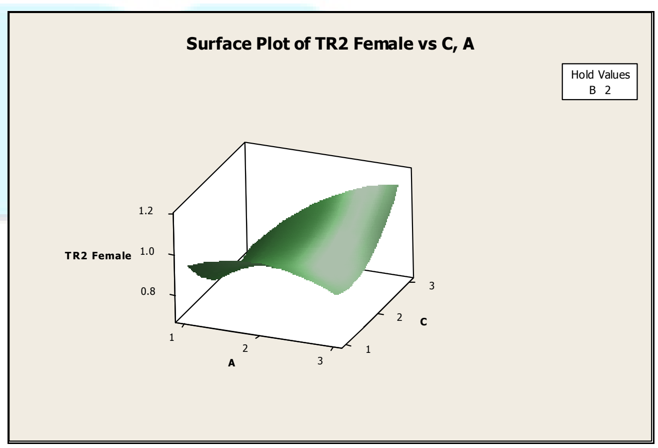


Figure12:Surface plot of TR2 female

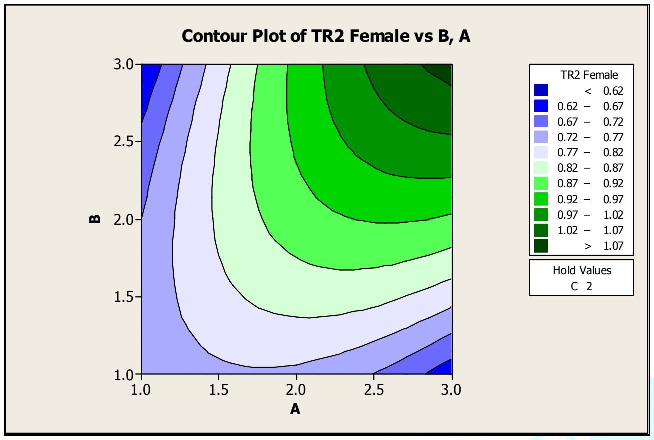


Figure 13: Contour plot of TR2female

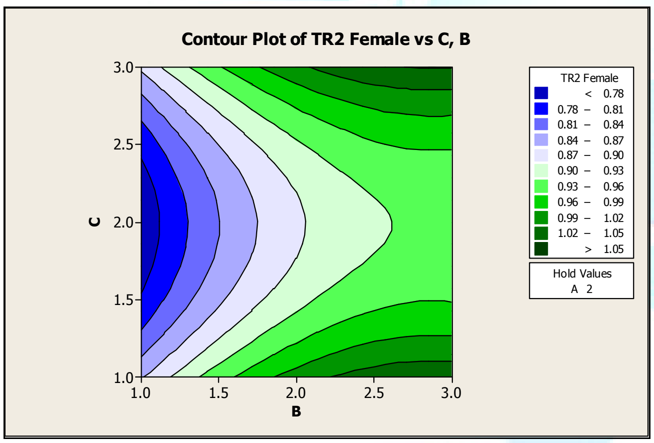


Figure14: Contour plot of TR2female

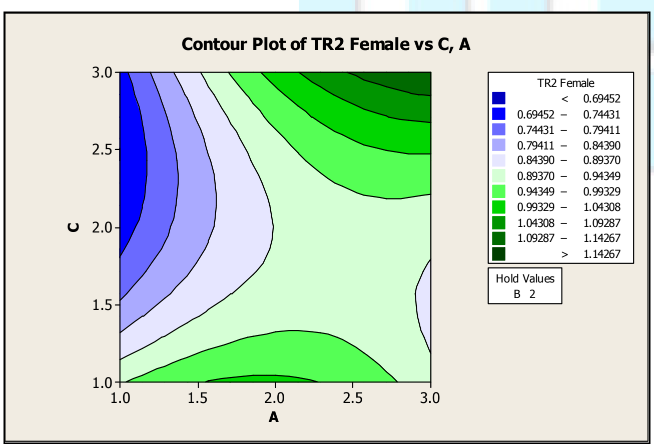


Figure15: Contour plot of TR2female

3.5Sensitivityanalysis

Sensitivity analysis, a method to identify critical parameters and rank them by their order of importance, is paramount in model validation where attempts are made to compare the calculated output to the measured data. This type of analysis can study which parameter must be most accurately measured, thus determining the input parameters exerting the most influence upon model outputs. Mathematically, sensitivity of a design objective function with respect to a design variable is the partial derivative of that function with respect to its variables. To obtain the sensitivity equation for speed, Eq.(4) and Eq.(5) is differentiated with respect to speed km/hr. The sensitivity equations (5), (6) and (7) for male rider and equations (8),(9) and (10)for female rider represent the sensitivity of transmissibility for speed km/hr, road profile and air in the wheels, respectively. In this study, it is expected to guess the tendency of transmissibility due to a small change in parameters . Sensitivity information should be interpreted using mathematical definition of derivatives. Namely, positive sensitivity values imply percentage increase in the objective function by a small change in design parameter whereas negative values state the opposite. Sensitivities of process parameters on transmissibility are presented in Table 8 and 9.From Figure 16 and 17 sensitivity of speed ,road profile and air in the wheels respectively on transmissibility for both male and female rider.The small varianion in speed causes large changes in transmissibility when speed increases.The result disclose that transmissibility is more sensitive to speed km/hr than road profile and air in the wheels.

Table 8: Transmissibility sensitivities of parameters for male rider

Parameters				***Sensitivity***		
S.N	***Speed***	***Road profile***	***Air in the wheels***	$\partial TR2/\partial A$	$\partial_{TR2}/\partial B$	$\partial_{TR2}/\partial C$
1	20	0.75	30	0.7947525	3.0156601	13.46055
2	20	1	35	1.03003	3.016718	14.37765
3	40	0.5	30	0.175775	5.972484	21.39
4	40	0.75	35	0.4110525	6.00376	22.30965
5	40	1	25	0.05143	5.974718	20.47545
6	60	0.5	35	-0.207925	8.930484	30.24165
7	60	0.75	25	-0.5675475	8.931601	28.40745
8	60	1	30	-0.33227	8.932718	29.32455
9	20	0.75	30	0.7947525	3.0156601	13.46055

Table 9: Transmissibility sensitivities of parameters for female rider

Parameters				***Sensitivity***		
S.N.	***Speed***	***Road profile***	***Air in the wheels***	$\partial TR2/\partial A$	$\partial_{TR2}/\partial B$	$\partial_{TR2}/\partial C$
1	20	0.75	30	-23.4506575	2.8231322	9.23225
2	20	1	35	-22.859598	2.847763	10.39392
3	40	0.5	30	-50.295017	5.5376614	11.45953
4	40	0.75	35	49.7039575	5.5622922	12.6212
5	40	1	25	-50.783358	5.586923	10.29786
6	60	0.5	35	-76.548317	8.2768214	14.84848
7	60	0.75	25	-77.6277175	8.3014522	12.52514
8	60	1	30	-77.036658	8.326083	13.68681
9	20	0.75	30	-23.4506575	2.8231322	9.23225

For Male Rider

$\partial_{TR2}/\partial A = 0.07602-0.291A+ 0.14791B +0.03966C$ (Eqn.5)

$\partial_{TR2}/\partial B = 0.05425 + 0.004468B + 0.1479A$ (Eqn. 6)

$\partial_{TR2}/\partial C = 0. 02595+ 0.1834 C +0.3966A$ (Eqn. 7)

For Female Rider

$\partial_{TR2}/\partial A=-0.0841376-1.340506A+0.136958B+0.111364C$ Eqn.8)

$\partial_{TR2}/\partial B = 0.0100798 + 0.0985232 B + 0.136958A$ (Eqn. 9)

$\partial_{TR2}/\partial C = 0. 03495+ 0.232334C +0.111364 A$ (Eqn. 10)

Figure 16 :Sensitivity analysis result for male rider (a) speed, (b) Road profile and (c) air in the wheels

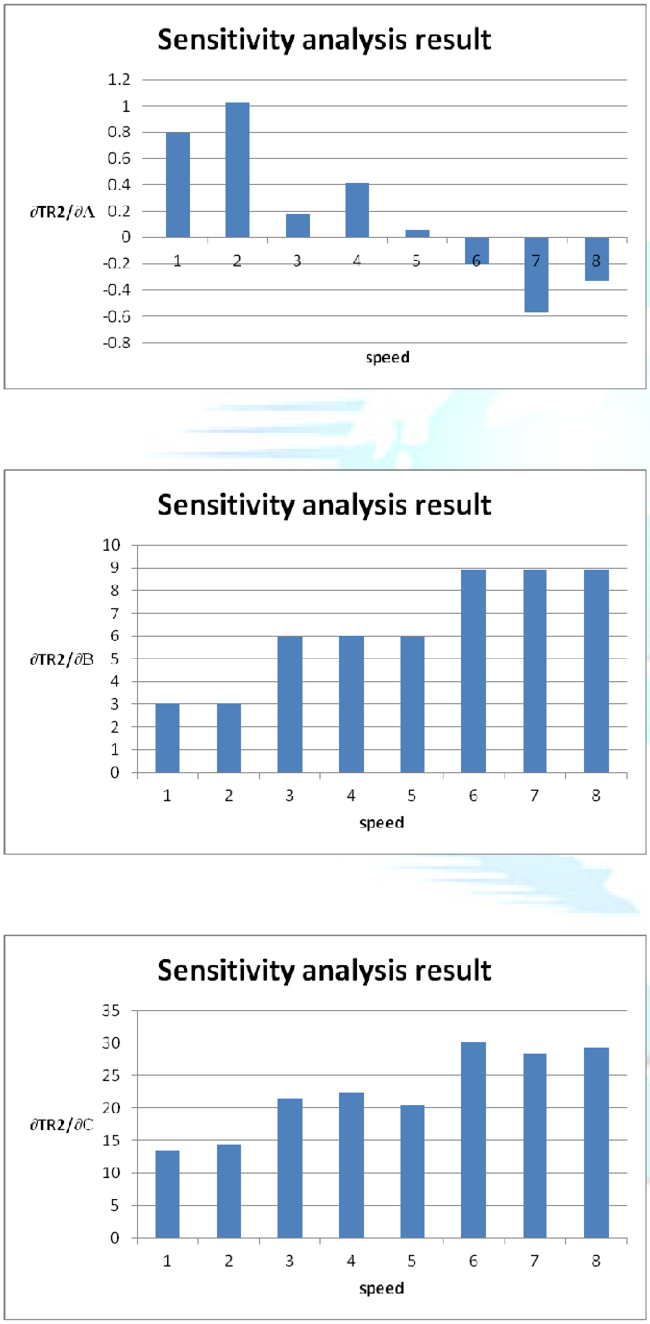
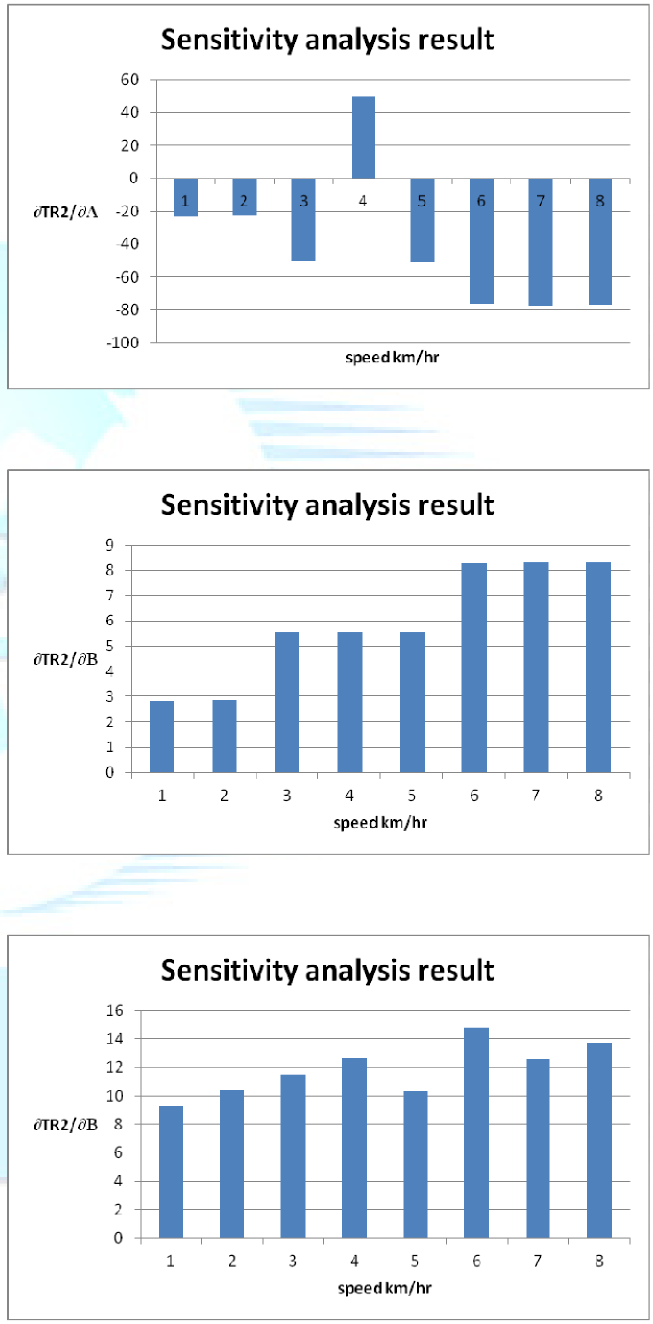


Figure 17 :Sensitivity analysis result for female rider (a) speed, (b) Road profile and (c) air in the wheels



4. Conclusions

This study paper has explained how to use o design of experiments for conducting experiments. Two riders were selected for predicting effect of whole body vibration on different body segments. for that analysis is done with the help of response surface methodology RSM we came to know that segments of human body is affected more is lower torso for both male and female rider. During the whole study it is observed that the lower torso displacement is more in case of female rider than the male rider.Form sensitivity analysis conclusion derived is that speed is the factor that has vast influence on transmissibility followed by road profile and air in the wheels.

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