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Hand Arm Vibration Alleviation of Motorcycle Handlebar using Particle Damper

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Abstract

Vibration induced in the vehicle affects the performance of the driver or rider because of reduction in comfort & safety level. In case of motorcycle, poor suspensions system & uneven road condition make driving difficult, these also introduces vibration. The vibrations are directly transferred to the body through the seat & handlebar. It has been seen that handlebar vibrations are more serious & creates physical problem to the rider. Particle damping technology is a derivative of impact damping with several advantages. Particle damping is the use of particles moving freely in a cavity to produce a damping effect. In this paper a passive damper using particle damping technique is designed and developed to reduce the hand arm vibrations (HAV). The experiments are planned and conducted using DOE. Optimum configuration of particle damper has been derived through this research work. Experimental tests shows by employing a particle damper the vibration amplitude is minimized significantly.

Index Terms: HAV (Hand Arm Vibration), damper, DOE (Design of Experiments), experimental, handlebar, particle, passive, vibration.

1. Introduction

The vibrations are introduced to the rider of two wheeler because of bad road conditions, engine as well as improper structural design of the two wheeler. The extreme vibrations may affect the body hazardously as it cause the musculoskeletal symptoms in the lower back, illness of spine, neck and limbs. Vertical vibrations are more serious and they are beyond permissible limit. It is confirmed from research paper that the vibration certainly effects on the health of motorcyclist. The vibration can be reduced by adding dampers, standard type of suspension system etc. The researchers in medical & engineering field have investigated that vibration

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affects the human health very badly [1].

I. Hand Arm Vibration & its Effects

Some hand held equipment like motorcycle handle bar, jack hammers and steering wheel transmits the vibrations into the hands and arms of the rider or operator. These transmitted vibrations are called as hand arm vibrations (HAV). Hand arm vibration syndrome (HAVS) causes due to hand arm vibrations. It is also called as vibration induced white finger (VWF) syndrome. Permanent disability may occur in the hand of rider if ignored this disease [1].

Fig.1. Motorcycle Handlebar (Hero Splendor Plus)

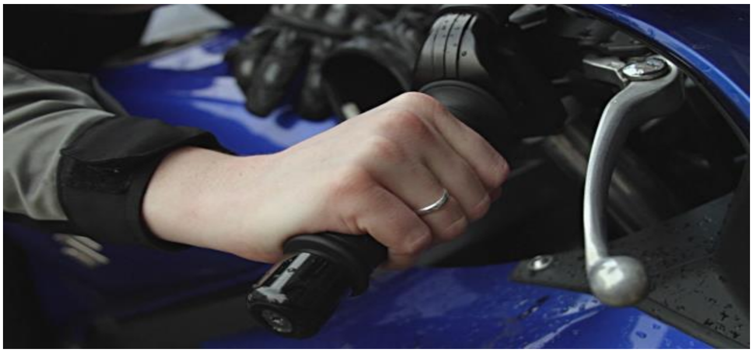

Fig.2. Hand Arm Vibrations in Case of Two Wheeler Handlebar

II. Vibration Control Techniques

The vibration control techniques mainly divided into three types namely active, passive and hybrid damping techniques. Active and passive damping techniques are common methods to mitigate the vibrations. Passive vibration control do not require power source as they are driven by vibration itself. It has more advantages because it provides simplest and cheapest solution to the problem. Its installation is simple and doesn’t require maintenance or little maintenance is required. While the active vibration control require power supply. It has several disadvantages like it requires maintenance, costly, complex mechanism and chances of failure. Both active and passive components are used in hybrid vibration control system [2].

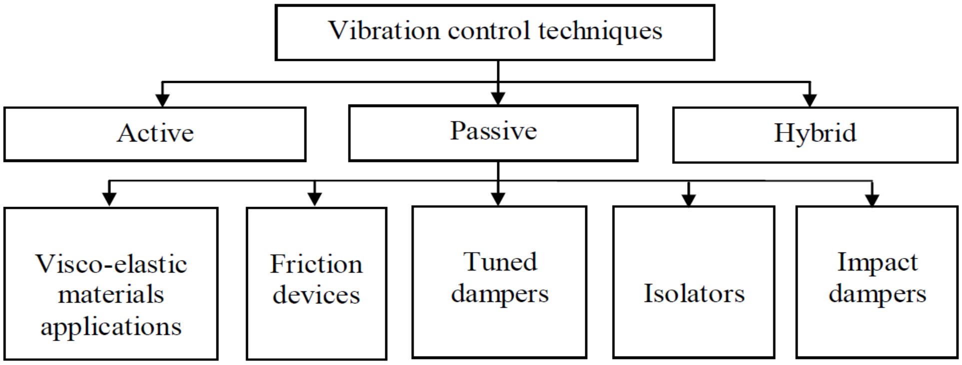

Fig.3. Vibration Control Techniques

III. Particle damping

It is a passive vibration control technique in which metal particles (e.g. lead, steel, tungsten carbide) are inserted within or enclosure attached to a vibrating structure. Due to vibrating motion of structure the collisions between particle to particle & particle to wall occurs. So exchange of momentum occurs between particles & structure & thus it dissipate KE due to frictional inelastic losses [5].

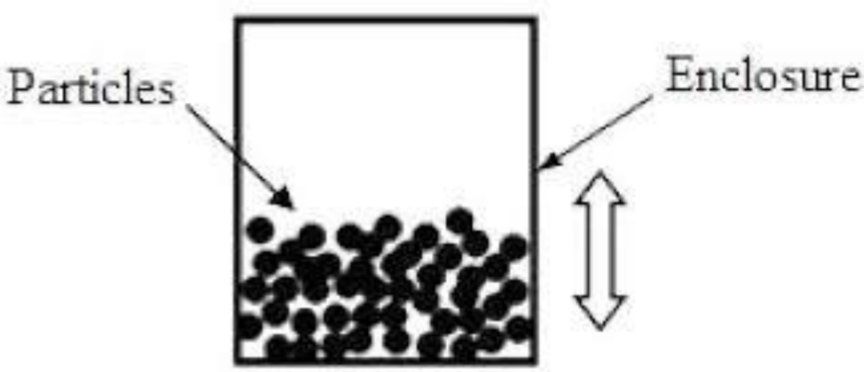

Fig.4. Schematic of a Particle Damper

Particle damping technology is derived from single particle impact damping technology. In impact damping it implies a single auxiliary mass or particle in a cavity whereas in particle impact damping it implies multiple auxiliary masses or particles of small size in a cavity. The mechanism for energy absorption is provided by the impacts and frictional forces amongst the particle and in between particles and walls. The performance of damping depends on many parameters such as geometric of structure, damper parameters, excitation frequency, excitation amplitude, particle material, particles size, packing ratio etc. [14].

2. Objectives of the Research Work

To minimize the level of vibration in motorcycle handlebar, there is need to design a particle damper. In this research work attempt has been made to design and develop particle damper for HAV reduction in handlebar. For this purpose of research, the objectives are listed below:

- To reduce the vibration level in motorcycle handlebar.
- To achieve the issue of human comfort by adding particle damper in the handlebar.
- To optimize the particle impact damper design parameters viz. particle size, particle material, packing ratio to alleviate the vibration.
- To develop the relation between excitation frequency, excitation amplitude, particle size, particle material & packing ratio with vibration acceleration.
- To test the developed particle damper under at different frequency & amplitude levels.
- To validate experimental result by developing mathematical model.

3. Development of Experimental Setup

By using CATIA V5 R20, 3D CAD model of experimental setup has been designed. Solid model contains all necessity features according to actual experimental setup. Following components which are assembled in experimental set up.

1. Exciter frame,
2. Handlebar,
3. Eccentric,
4. Accelerometer,
5. FFT Analyzer,
6. NV GATE Software,
7. DC variable speed motor

The experimental setup is manufactured as shown in fig 5. The handlebar is mounted on the exciter frame. The DC variable speed motor is also mounted on the exciter frame in such a way that the eccentric attached on the shaft of the motor should touch the handlebar. Eccentric is adjustable with bare handlebar as well as handlebar with grip as it is mounted on the disc attached to the shaft of the motor. Disc is fixed to the shaft by using grub screw. Working area considered is 10 cm from the free end of the handlebar. Accelerometer is mounted on the handlebar and connected to FFT analyzer which is connected to computer system in which NVGATE software is installed.

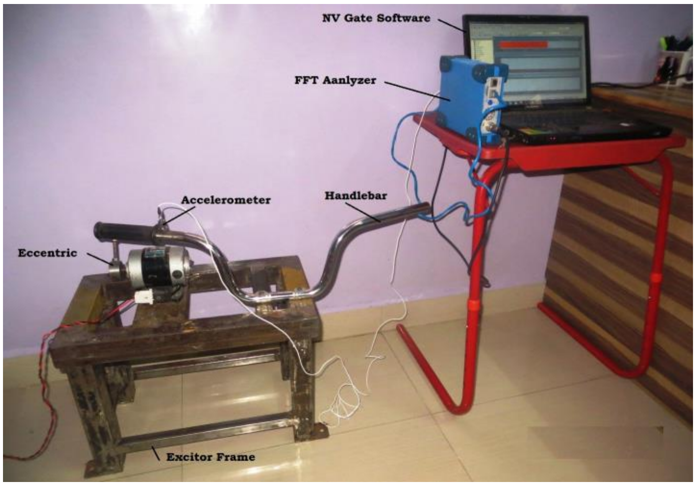

Fig.5. Experimental Setup

The handlebar is stroked by the eccentric. Eccentric is connected to the shaft of motor which is rotated at different speed. The accelerometer is attached to the handlebar vertically downward which transfers the vibration signal to FFT analyser. FFT analyser is a device which converts the time domain signal to frequency domain.

Some major components used in the experimental model are explained below.

I. Accelerometer

Accelerometers are commonly used for vibration measurement because of their small size and high sensitivity. Fig. 6 shows Dytran make 3056 B2 D accelerometer used to measure acceleration from the motorcycle handlebar.

Fig.6. Accelerometer (Dytran 3056 B2 D)

Model 3056 B2 shown is magnetic mount accelerometer. Features of Dytran 3056 B2 D accelerometer are;

- Weight, 10 grams
- Material, cap, base & connector titanium
- Operating range, -55 to +120 ℃
- Frequency range, 1 to 10,000 Hz
- Sensitivity, 100mV/g

II. FFT Analyzer

Four channel FFT analyzer is used when it is necessary to measure the data from more than two points from machine or structure. This type of FFT analyser is multipurpose and can be used in combination with relative vibration and sound transducer. The accelerometer is attached to vibration meter of make OROS. The vibration meter, OR34-2, 4 channels, shown in Fig. 7 displays the displacement and acceleration at handlebar.

Fig.7. FFT Analyzer (OROS OR34)

The instrument is intended to general acoustic and vibration measurements, environmental monitoring, occupational health as well as safety monitoring. OR34 provides significant number of results like RMS, PEAK in case of vibration measurements. The results can be viewed in real time or can be saved for further analysis using NV Gate application provided with instrument. Features of OR34 – 2, 4 channels compact analyzer include

- AC/DC power supply
- Real-time bandwidth 40 kHz
- 2 external tachometers/ triggers inputs

III. Particles used for Experimentation

Impact damping refers to single mass in a cavity but particle damping is used to imply multiple masses of small size in cavity. The principle behind particle damping is removal of vibration energy through losses which occur during collision of particles which move freely within boundaries of cavity [3].

Based on the material properties and availability of the particles, they are selected for the experimentation. Steel and polymer particles are selected of sizes 1, 2 and 3mm of each material. The combination used for the experimentation is steel, polymer and steel+polymer particles [3].

SS 302

SS 302 is an austenitic Chromium-Nickel stainless steel offering the optimum combination of corrosion resistance, strength and ductility.

3M™ Viscoelastic Damping Polymer 112P02

3M™ Viscoelastic Damping Polymers are acrylic polymer based materials and are useful in many engineered designs. They have proven to reduce vibration and shock problems in electronics, appliances, automobiles and aircraft. These versatile materials can be adapted to a wide variety of applications including constrained layer dampers, multi-layer laminates using metal or polymeric films, free layer dampers, suspension dampers, shock and vibration isolators, panel, pipe and wing dampers, and more.

Fig.8. Particles used for Experimentation

4. Results And Discussions

Results and discussions includes design of experiment (DOE), frequency response curve, main effects plot for SN ratios, contour plot of acceleration versus factors, comparison of acceleration for with and without damper.

I. Design of Experiment (DOE)

The success of any research work depends on the proper planning and execution of the experiments. The table II shows the 5 factor and its 3 level i.e. 3^5 Full Factorial, which yields to total 243 numbers of experiments. Taguchi technique helps to minimize this full factorial into fractional factorial number of experiments using the concept of orthogonal array. For 5 factors and 3 levels combination, L_{27} orthogonal array is suitable.

Table 1. Factors & Its Level

Factor		Level		
		1	2	3
A	Excitation Frequency (N rpm)	400	1200	3600
B	Excitation Amplitude (mm)	0.5	1.0	1.5
C	Particle Material	Steel	Polymer	Steel+Polymer
D	Particle Size (mm)	1	2	3
E	Packing Ratio (%)	25	50	75

II. Planning of experiments

Table III is L_{27} orthogonal array which shows the output results of the experimentation [3][14]. Different combinations of the factors such as excitation frequency, excitation amplitude, particle material, particle size and packing ratio with their three levels are used in this DOE method. The experiments were carried out as per the L_{27} orthogonal array as given in Table III. Total 27 tests and each test 2 times (for minimizing the effects of error) were carried out. The results obtained through these tests in terms of vibration acceleration are given in Table III.

Table 2. L27 Orthogonal Array and Result Table

Test No.	**Coded Values**					**Response Acceleration (mm/sec²)**	
	A	**B**	**C**	**D**	**E**	**Y_1**	**Y_2**
T_1	1	1	1	1	1	25	22.0
T_2	1	1	1	1	2	50	48.0
T_3	1	1	1	1	3	75	73.5
T_4	1	2	2	2	1	25	23.0
T_5	1	2	2	2	2	50	47.0
T_6	1	2	2	2	3	75	79.0
T_7	1	3	3	3	1	25	27.0
T_8	1	3	3	3	2	50	46.4
T_9	1	3	3	3	3	75	73.3
T_{10}	2	1	2	3	1	25	22.9
T_{11}	2	1	2	3	2	50	46.0
T_{12}	2	1	2	3	3	75	70.2
T_{13}	2	2	3	1	1	25	26.9
T_{14}	2	2	3	1	2	50	45.8
T_{15}	2	2	3	1	3	75	77.1
T_{16}	2	3	1	2	1	25	24.0
T_{17}	2	3	1	2	2	50	50.2
T_{18}	2	3	1	2	3	75	78.8
T_{19}	3	1	3	2	1	25	26.5
T_{20}	3	1	3	2	2	50	43.4
T_{21}	3	1	3	2	3	75	73.2
T_{22}	3	2	1	3	1	27	29.1
T_{23}	3	2	1	3	2	50	46.3
T_{24}	3	2	1	3	3	75	70.0
T_{25}	3	3	2	1	1	25	28.3
T_{26}	3	3	2	1	2	50	47.5
T_{27}	3	3	2	1	3	75	74.6

III. Frequency response curve

The sample tests are carried out to check effects of vibration in vertical and horizontal direction. From the experiments it is seen that the vibrations are predominant in vertical direction.

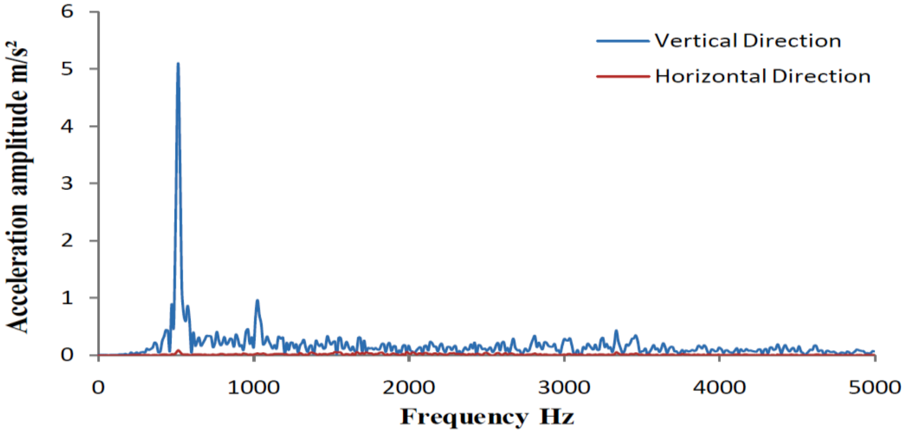

Fig.9. Plot of Vibration Measured in Vertical and Horizontal Direction

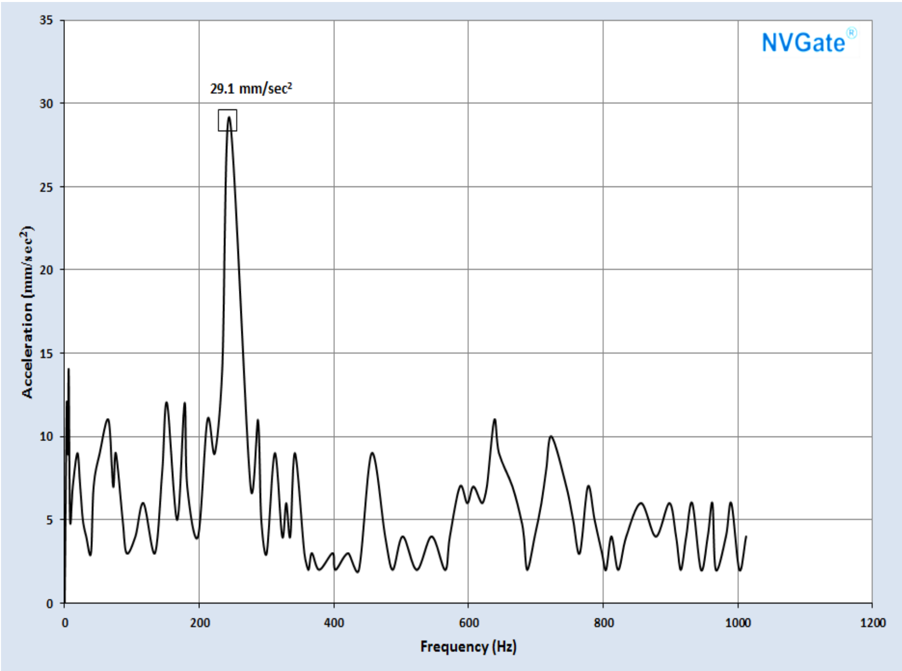

Fig.10. Frequency Response of Test No. 22

IV. Validation and Confirmation

In order to validate the optimum conditions we predict the performance of the product design under baseline and optimum settings of the control factors. Then we perform confirmation experiments under these conditions and compare the results with the predictions. If the results of confirmation experiments agree with the predictions, then we implement the results.

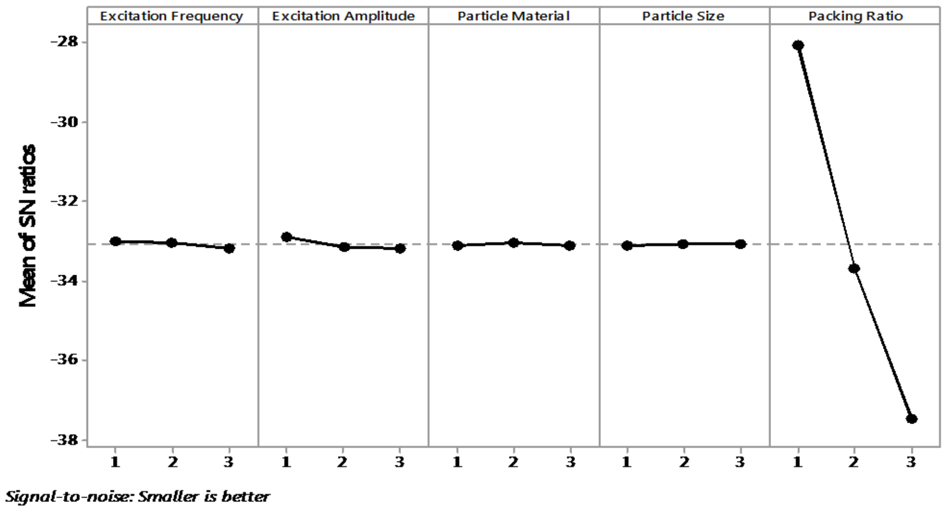

Fig.11. Main Effects Plot for SN Ratios

From S/N ratio (fig. 11) it is seen that the optimum design parameters of the particle damper are; $A_1B_1C_2D_2E_1$

Where,

A_1 = Excitation Frequency = 400 rpm
B_1 = Excitation Amplitude = 0.5 mm
C_2 = Particle Material Polymer (Viscoelastic)
D_2 = Particle Size = 2 mm
E_1 = Packing Ratio = 25 %

Referring full factorial (243 tests) results, $A_1B_1C_2D_2E_1$ belongs to test no. 13 whose predicted response is 13.33 mm/sec^2.

V. Contour Plot of Acceleration Versus Factors

In a contour plot the values for two variables are represented on the X and Y axes, while the values for a third variable are represented by shaded regions called contours. A contour plot is like a topographical map in which X, Y and Z values are plotted instead of longitude, latitude and altitude. In simple, it is a three dimensional plot shown on two dimension.

The contour plot is formed by:

Vertical axis: Independent variable 2
Horizontal axis: Independent variable 1
Lines: iso-response values

An additional variable may be required to specify the Z values for drawing the iso-lines. Fig. 12 shows the sample contour plot of total 10 numbers of contour plots.

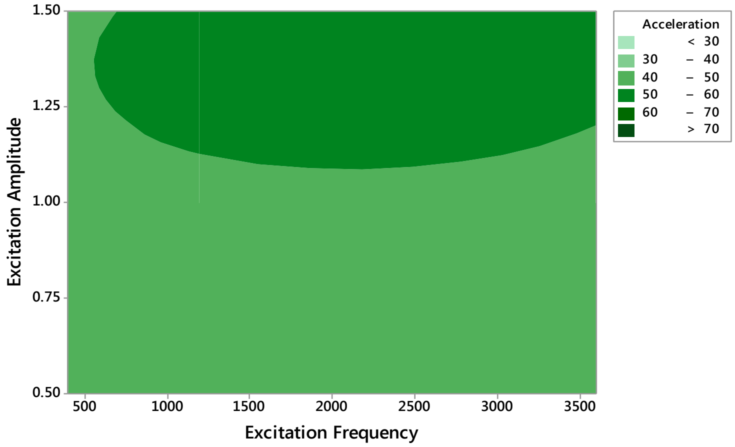

Fig.12. Contour Plot of Acceleration vs Excitation Amplitude, Excitation Frequency

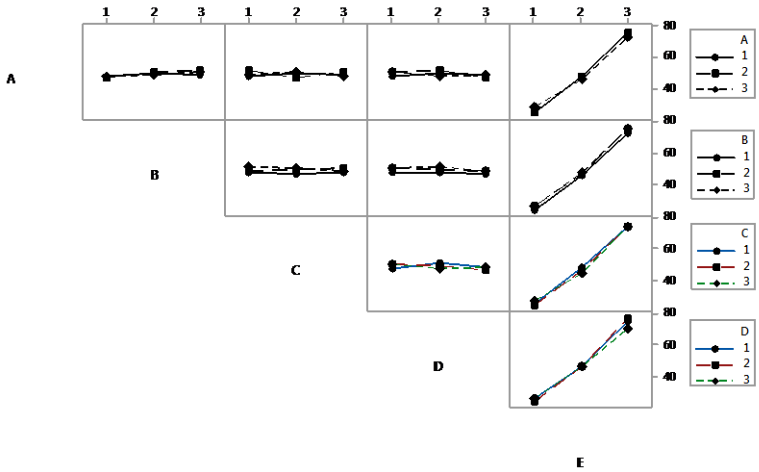

Fig.13. Interaction Plot

From Interaction Plot, there is a strong interaction is observed between all the design parameters of the particle impact damper developed for motorcycle handlebar.

VI. Multiple Linear Regression Analysis

Regression Analysis is a conceptually simple method for investigating functional relationships among variables. The separate mathematical model in the form of equation was developed with the help of regression analysis technique using MINITAB R-17 software.

Acceleration = -0.480 + 0.0472 Excitation Frequency + 0.6778 Excitation Amplitude - 0.1194 Particle Material - 0.2917 Particle Size + 24.6667 Packing Ratio.

VII. R-Square (Coefficient of determination)

R-Square, also known as the *Coefficient of determination* is a commonly used statistic to evaluate model fit. *R-square* is 1 minus the *ratio of residual variability*. When the variability of the residual values around the regression line relative to the overall variability is small, the predictions from the regression equation are good. *R-square* value is an indicator of how well the model fits the data (e.g., an *R-square* close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model).

R-Sq for equation of acceleration is 84 %.

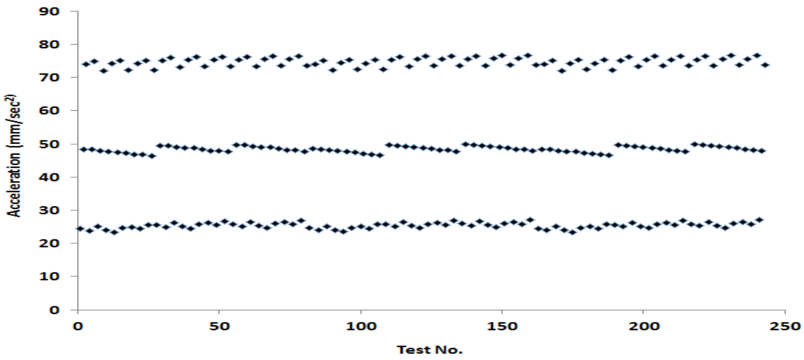

Fig.14. Scatter Plot

Scatter plot of full factorial (total 243) tests shows three distinct regions of vibration;

(i) Scattered about 20 to 30 mm/sec^2
(ii) Scattered about 40 to 50 mm/sec^2
(iii) Scattered about 70 to 80 mm/sec^2

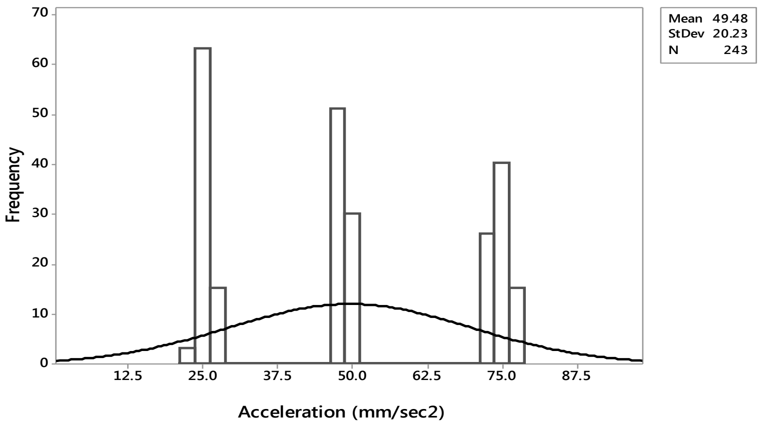

Fig.15. Normal Distribution Plot with Histogram

From normal distribution plot it is also further verified that there are three distinct groups of data, which are observed on scatter plot. The standard deviation of the data is 20.23 mm/s^2 and mean is at 49.48 mm/s^2.

5. Conclusions

There is extreme need to reduce the vibrations in motorcycle handlebar. So successful effort has been taken to alleviate HAVs in motorcycle handlebar. From the above results it is observed that the particle dampers with various configurations can be used for vibration reduction.

[1]. From S/N Ratio

The optimum design parameters of the particle damper are; $A_1B_1C_2D_2E_1$
Where,

A1 = Excitation Frequency = 400 rpm
B1 = Excitation Amplitude = 0.5 mm
C2 = Particle Material Polymer (Viscoelastic)
D2 = Particle Size = 2 mm
E1 = Packing Ratio = 25 %

From full factorial predicted response, the acceleration value is 13.33 mm/sec^2, whereas the confirmation test gives the actual acceleration value as 14.2 mm/sec^2.This clearly shows that the particle damper with above configuration will certainly reduce the vibrations up to 50%.

[2]. From Interaction Plot

There is a strong interaction is observed between all the design parameters of the particle impact damper developed for motorcycle handlebar.

[3]. From Contour Plot

- All the contour plots confirm the design parameters and their levels seen from S/N ratio which gives the optimum (minimum) value of vibration.
- From the contour Plot of Acceleration vs Excitation Amplitude, Excitation Frequency, maintain the excitation amplitude value 0.5 mm for all the values of excitation frequency.
- From the contour Plot of Acceleration vs Particle Material and Particle size for Excitation Frequency should kept minimum.
- From the contour Plot of Acceleration vs Packing Ratio, Excitation Frequency, the 25% packing ratio is effective at all the values of excitation frequencies.
- From the contour Plot of Acceleration vs Particle Material and Particle size, Excitation Amplitude, we conclude that keep excitation amplitude value less than 1 mm for any particle material and particle size.
- From the contour Plot of Acceleration vs Packing Ratio, Excitation Amplitude, the 25% packing ratio is effective at all the values of excitation frequencies.

[4]. From Multiple Linear Regression Technique

The multiple linear regression equation for acceleration is;
Acceleration = -0.480 + 0.0472 Excitation Frequency + 0.6778 Excitation Amplitude - 0.1194 Particle Material - 0.2917 Particle Size + 24.6667 Packing Ratio
This equation or mathematical model is nearly 84 % accurate.

[5]. From Scatter Plot

Scatter plot of full factorial (total 243) tests shows three distinct regions of vibration;

(i) Scattered about 20 to 30 mm/sec^2
(ii) Scattered about 40 to 50 mm/sec^2
(iii) Scattered about 70 to 80 mm/sec^2.

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