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Optimization of Shock Absorber Parameters by Using DOE and Validation by MATLAB Software

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Abstract: Shock absorber is very important term in automobile industries. They are used for the driving comfort and driving safety. This paper presents performance characteristics of the shock absorbers under real conditions. Dynamic behaviours of the absorber are studied by computer simulation and experimental testing and are validated with MATLAB results. The road disturbance is generated in the model by giving speed brakes fixed on drum which is rotated by using motor. In this paper study and analysis of single DOF spring-mass-damper system (Hero Splendor Rear Shock Absorber) and plotted its dynamic characteristics curve for different values of spring stiffness for different oils.

Keywords: Shock Absorber, MINITAB, MATLAB, Optimization-Fuzzy Logic.

I. INTRODUCTION

The Shock absorber is a Suspension system which designed mechanically to control shock impulse and dissipate kinetic energy. It reduces the amplitude of disturbances leading to increase in comfort and improved ride quality. Shock absorber minimizes the effect of travelling on a rough ground. Now-a-days Modern vehicles come along with strong shock absorbers to tolerate any type of bouncy conditions. If supposedly shock absorber is not used then to control excessive suspension movement, stiffer springs will be used. The suspension system of an automobile is one which separates the wheel assembly from the body. The primary function of the suspension system is to isolate the vehicle structure from shocks and vibration due to irregularities of the road surface. The Suspension system is used to support weight, absorb and dampen road shock, and help maintain tire contact as well as proper wheel to chassis relationship. A vehicle in motion is more than wheels turning.

As the wheel revolves, the suspension system turns in dynamic state of balance, continuously compensating and adjusting for changing driving conditions according to road profile. Suspension of vehicle need to analyse before the manufacturing. This is because to make sure components in shock absorber system remain in good conditions. The Shock absorber system need to analyse how shock to see how they are going to perform in worst case scenario. A safe vehicle must be able to stop and maneuver over a wide range of road conditions. The Good contact between the wheel tires and the road will able to stop and maneuver quickly.

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Shock absorber with its whole assembly is an important part of automotive suspension system which has an effect on ride characteristics. Shock absorbers are also critical for tire to road contact which to reduce the tendency of a tire to lift off the road. This affects on braking, steering, cornering and overall stability of the vehicle. The removal of the shock absorber from suspension can cause the vehicle bounce up and down. It is possible for the vehicle to be driven, but if the suspension drops from the driving over a severe bump, the rear spring can fall out. Basically, the shock absorbers must be replaced after driving exceeds certain distance. But this actually not should have been followed if there are no defective.

II. PROBLEM DEFINITION

The aim of the project is to study and analyse single degree of freedom spring-mass-damper system and plot its dynamic characteristics curve for different values of spring stiffness for various speed conditions using FFT Analyser validation with MATLAB Results.

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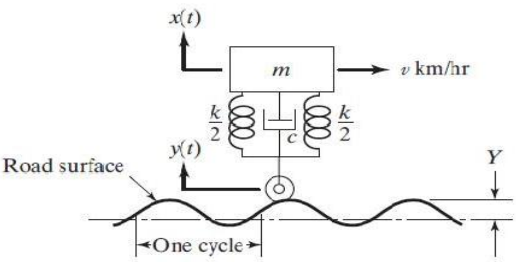

Fig.1. Problem Statement

III. OBJECTIVES

a) To test suspension on different types of oils and stiffness to find out optimum motion transmissibility using DOE
b) Suspension will be test for multiple stiffness by varying loads, speed and different oils
c) To determine dynamic characteristic of shock absorber.
d) Motion transmissibility develop suspension testing set up for testing a various suspensions.

IV. THEORETICAL BACKGROUND

In case of locomotives or vehicles the wheels act as base or support for the system. The wheels can move vertically up and down on the road surface during the motion of the vehicle. At the same time is relative motion between the wheels and the chassis is having motion relative to the wheels and the wheels are having motion relative to the road surface. The amplitude of vibration in case of support motion depends on the speed of vehicle and nature of road surface. The vibration measuring instruments are designed on the support motion approach. Such systems are supposed to have single degree of freedom for the simplicity of mathematical expression. In a vibratory system where the support is put to excitation absolute and relative motion become important from subject point of view.

4.1 Terminology Used

1) Natural frequency (ω_n)

When no external force acts on the system after giving it an initial displacement, the body vibrates. These vibrations are called free vibrations and their frequency as natural frequency. It is expressed in rad/sec or Hertz.

$$\omega_n=\sqrt{(K/M)}$$

2) Damping

The external force provided to reduce the vibration. Damping is produced by processes that dissipate the energy stored in the oscillation.

3) Critically damping co-efficient (Cc)

The critical damping co-efficient Cc is that value of damping coefficient C at which the frequency of free damped vibration is zero and the motion is a periodic.

$$Cc=2\sqrt{(K\times M)}$$

4) Damping ratio (ξ)

It is defined as the ratio of damping coefficient to critical damping coefficient. Mathematically

$$\xi = C/Cc$$

5) Amplitude

It is defined as the maximum displacement of vibrating body from its equilibrium position.

6) Time period (tp)

The time required to complete one cycle.

4.2 Absolute Motion

Absolute motion of a mass means its motion with respect to the coordinate system attached to the earth. As shown in figure, the absolute displacement if support is $y=B\sin\omega t$ and the absolute displacement of the mass m from its equilibrium position is x. The displacement of mass m relative to the support is z. The net elongation of the spring is $(x''-y'')$ and the relative motion between the two ends of the damper is (x-y).

Then $z= x-y$ and $z''= x''-y''$.

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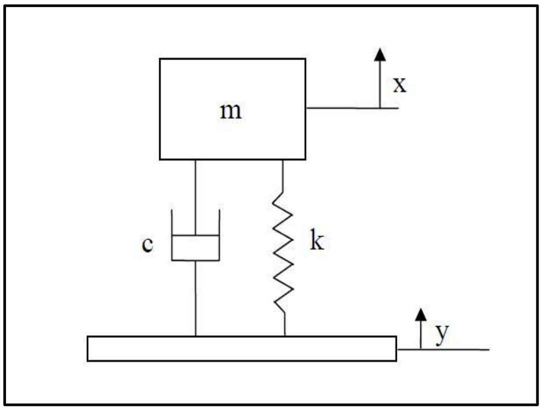

Fig.2. Absolute Motion

Fig.3. Experimental Setup

From Fig.2 the equation of motion can be written as, Steady state amplitude is

$$X=\frac{Y\sqrt{(k^2+c^2\omega^2)}}{\sqrt{\left\{\left[1-\left(\frac{\omega}{\omega n}\right)^2\right]^2+\left[\frac{2\varepsilon\omega}{\omega n}\right]^2\right\}}}$$

$$\frac{X}{Y}=\frac{\sqrt{\left\{1+\left[\frac{2\varepsilon\omega}{\omega n}\right]^2\right\}}}{\sqrt{\left\{\left[1-\left(\frac{\omega}{\omega n}\right)^2\right]^2+\left[\frac{2\varepsilon\omega}{\omega n}\right]^2\right\}}}$$

The ratio of $\frac{X}{Y}$ is called the displacement transmissibility which is the ratio of amplitude of the body to amplitude of the support.

V. DESIGN AND ANALYTICAL CALCULATIONS

5.1. Spring stiffness calculation

Table No. 1. Spring stiffness of Splendor and Honda Shine Shock Absorber

Sr. No.	Shock Absorber	Load on Spring (Kg)	Length (mm)		Spring Stiffness (K) (N/mm)
			Free Length	Compressed Length	
1	Splendor	60	230	205	23.540
2	Honda Shine	60	240	206	17.310

VI. EXPERIMENTAL SETUP

Fig.3. shows the constructional details for set up. It consists of following parts:

1. Frame: It is Base structure of setup. It is made of MS bars in C-Section. Total material used is about 35 Feet. Frame gives the support to all the assembly components.
2. Drum: It is made of MS sheet having thickness 4mm and diameter equal to wheel diameter of 640mm. It is manufactured by rolling of sheet metal. Standard speed breaker profiles are also made by sheet metal by giving radius and welded to drum. Drum is supported by 3 spokes
3. Wheel Assembly: It is wheel assembly of Hero Splendor Bike. Wheel is fitted in swing arm. Shock absorbers lower point is mounted on swing arm. A swing arm is assembled to Frame.
4. Motor: 1440 RPM 3 HP single phase motor is coupled to shaft. It rotates drum and ultimately drum
5. Dimmer stat: Dimmer stat is continuously variable voltage auto transformer. It has simple construction and output voltage variation is smooth, continuous, break less. It has high efficiency and excellent short time overload capacity. 20ampere dimmer stat is used to control the motor speed.
6. Shock Absorber: A shock absorber or damper is a mechanical device designed to smooth out or damp shock impulse, and dissipate kinetic energy, it's a device whose performance characteristics are to be measured.
7. FFT Analyzer: FFT- Fast Fourier Transform. It is a noise & vibration measurement instrument. Time domain data is converted into frequency domain. We will take reading by using accelerometer. DEWEsoft is used to display the results
8. Accelerometer: Accelerometer is a Piezo-electric accelerometer and it is considered as the standard vibration transducer for machine vibration measurement. Data capture regarding the vibration emitted by a machine, or other body, begins with the sensor.

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9. The DEWESoft Software: The analysis is carried out in DEWESoft Software. Various methods of dynamic signal analysis are present in the software such as Sound level, Torsional vibration, Human Vibration and Order Tracking.
10. Tachometer: A tachometer is a sensor device for measuring the rotation speed of an object such as the engine shaft in a car. This device indicates the revolutions per minute (RPM) performed by the object. The device comprises of a dial, a needle to indicate the current reading, and markings to indicate safe and dangerous levels.

VII. WORKING

Working procedure is as follows:
1. Shaft is mounted in bearing on which drum is mounted.
2. Speed breaker profile is welded on drum.
3. On drum wheel assembly is mounted.
4. Shaft is coupled to motor. Motor shaft rotates the Drum shaft which simultaneously rotates the wheel which in on drum.
5. Motor speed is controlled by using Dimmer stat.
6. As wheel and drum rotates wheel reaches to speed beaker profile it create bump on shock absorber.
7. Shock absorber will get compress.
8. FFT analysers sensors will attach to upper and lower point of shock absorbers and readings displayed on computers screen.

VII. OBSERVATION TABLE AND RESULTS

7.1 Experimental Readings :

1. Splendor Suspension (Oil 1)
Splendor suspension is mounted on setup for experimentation and by applying various loads acceleration is measured on either side. Since the suspension fluid chamber is filled with MOTUL as Oil 1.

Table 2. Experimental Readings-Splendor Suspension (Oil 1)

SR.NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak m/s2		Transmissibility TR=(A/B)
			Top (A)	Bottom (B)	
1	23540	27	17.085	23.347	0.7317
2	23540	32	14.420	24.23	0.6073
3	23540	37	11.71	22.955	0.4932
4	23540	42	10.59	23.544	0.4147

2. Honda Shine Suspension (Oil 1)
Now Splendor Suspension is replaced with Honda Shine suspension which is also filled with Oil 1 and by applying various loads acceleration is measured.

Table 3. Experimental Readings-Honda Shine Suspension (Oil 1)

SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak m/s2		Transmissibility TR=(A/B)
			Top (A)	Bottom (B)	
1	17310	27	13.34	24.32	0.5485
2	17310	32	11.54	25.66	0.45
3	17310	37	10.73	26.19	0.41
4	17310	42	10.30	28.61	0.36

3 .Splendor Suspension (Oil 2)
Now the fluid chamber of Splendor suspension replaced by YAMALUBE oil (Oil 2), is mounted on setup for experimentation and by applying various loads acceleration is measured on both top and bottom side.

Table 4. Experimental Readings-Splendor Suspension (Oil 2)

SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak m/s2		Transmissibility TR=(A/B)
			Top (A)	Bottom (B)	
1	23540	27	18.774	25.407	0.7371
2	23540	32	14.469	24.525	0.59
3	23540	37	11.375	21.876	0.52
4	23540	42	9.809	21.876	0.4484

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4. Honda Shine Suspension (Oil 2)

Further Honda Shine Suspension with Oil 2 is taken for experimentation.

Table 5. Experimental Readings-Honda Shine Suspension (Oil 2)

SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak m/s2		Transmissibility TR=(A/B)
			Top (A)	Bottom (B)	
1	17310	27	13.791	25.898	0.5325
2	17310	32	12.24	27.664	0.4427
3	17310	37	9.4176	24.721	0.3809
4	17310	42	7.651	23.093	0.3313

In this way motion transmissibility of Splendor suspension and Honda Shine suspension is calculated. Both the suspensions were tested with two different oils namely MOTUL oil and YAMALUBE oil which are used in suspension system.

7.2. FFT Output

The Accelerometer is a sensor explained earlier, which is used to measure vibration in terms of acceleration and is placed at upper and lower end of shock absorber. The DEWEsoft software gives the above readings directly on computer screen. Below figure shows the acceleration nature of Splendor Suspension for weight 32 Kg with oil 1 on top and bottom position

7.2.1 Oil 1

Fig.4. Splendor Suspension Bottom of weight 32Kg for Oil 1

7.2.2 Oil 2

Fig.5. Splendor Suspension Top of weight 32Kg for Oil 1

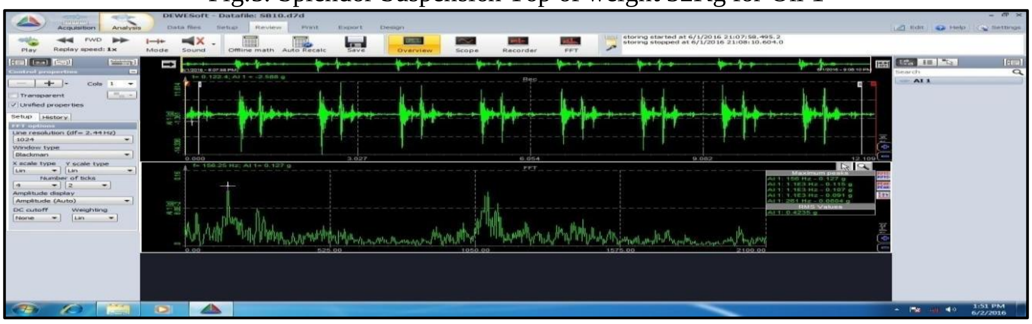

Fig.6. Splendor Suspension Bottom of weight 32Kg for Oil 2

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Fig.7. Splendor Suspension Top of weight 32Kg for Oil 2

Above figure shows the acceleration plot of Splendor suspension for weight 32Kg for oil 2 at bottom and top position.

VII. MINITAB PLOTS

Reading For oil 1 and load 10 kg

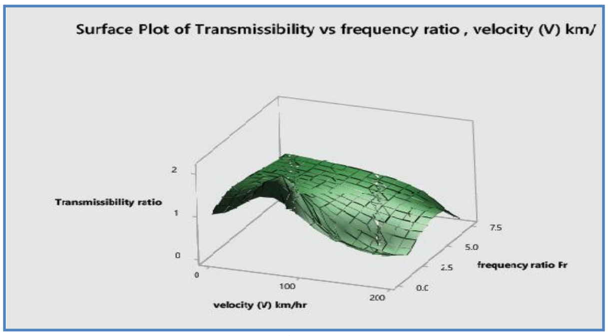

Fig.8. Minitab plot for 10 Kg load

Reading For oil 1 and for 60 Kg load

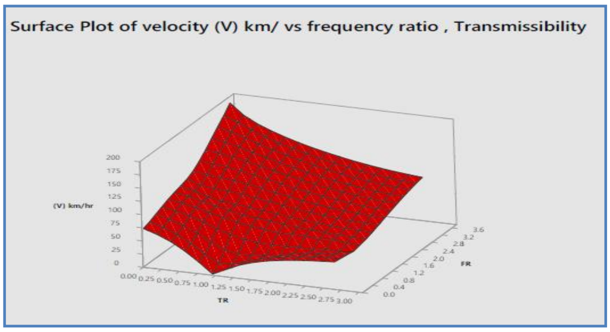

Fig.9. Minitab plot for 60 Kg load

Table 6. Various Shock Absorber Parameters

Stiffness (K)	Damping Coeff. (C)	Load (L)	Expt.TR	Input (L)	Output (TR)
23540	240	10	0.702	0.14	1.000
23540	240	20	0.144	0.29	0.206
23540	240	30	0.062	0.43	0.088
23540	240	40	0.032	0.57	0.045
23540	240	50	0.022	0.71	0.031
23540	240	60	0.014	0.86	0.020
23540	240	70	0.011	1.00	0.016

Table 7. Input & output values

Input Groups	Output Groups
[0 0.14 0.29]	[0 0.016 0.020]
[0.14 0.29 0.43]	[0.016 0.021 0.031]
[0.29 0.43 0.57]	[0.021 0.031 0.045]
[0.43 0.57 0.71]	[0.031 0.045 0.088]
[0.57 0.71 0.86]	[0.045 0.088 0.206]
[0.71 0.86 1]	[0.088 0.206 1]

Table 8. Gauss mf, input & output values

Gauss mf	Input Groups	Output Groups
mf1	[0.14 0]	[0.016 0]
mf2	[0.14 0.29]	[0.016 0.020]
mf3	[0.29 0.43]	[0.016 0.031]
mf4	[0.43 0.57]	[0.016 0.045]
mf5	[0.57 0.71]	[0.016 0.088]
mf6	[0.71 0.86]	[0.016 0.206]
mf7	[0.86 1]	[0.016 1]

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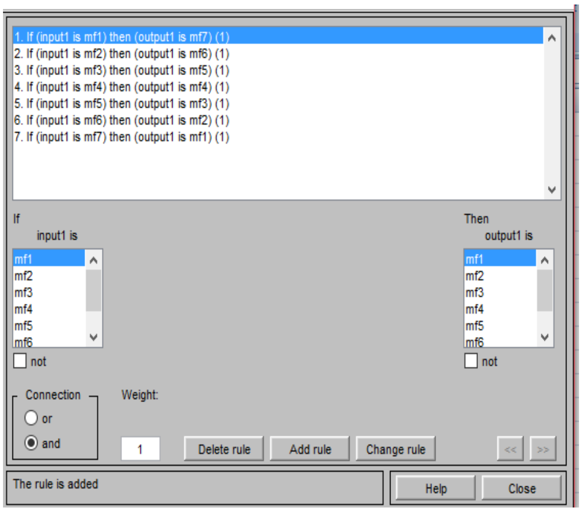

Fig. 10.Input & Output window

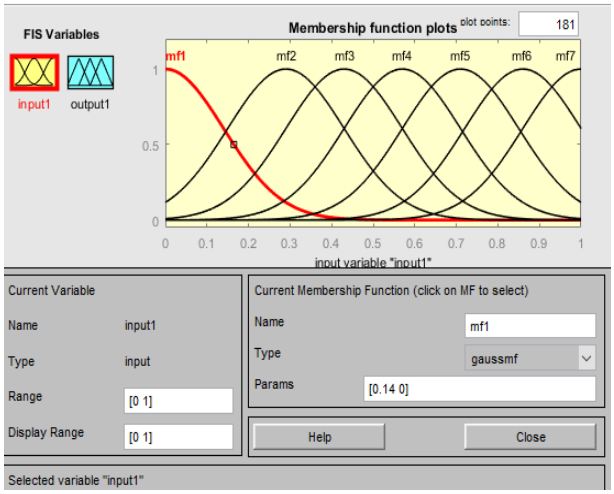

Fig.11. Input Membership function plot

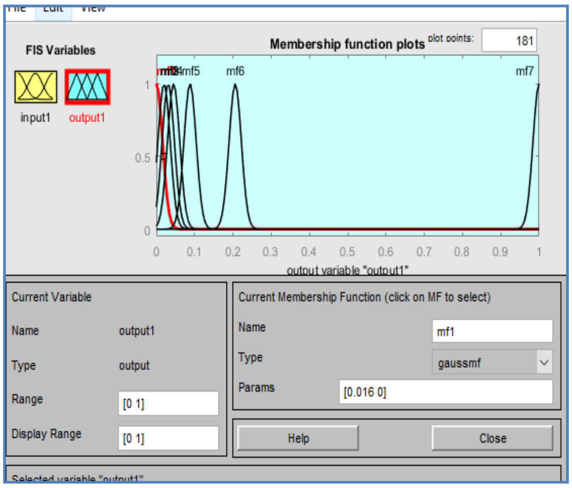

Fig.12. Output Membership function plot

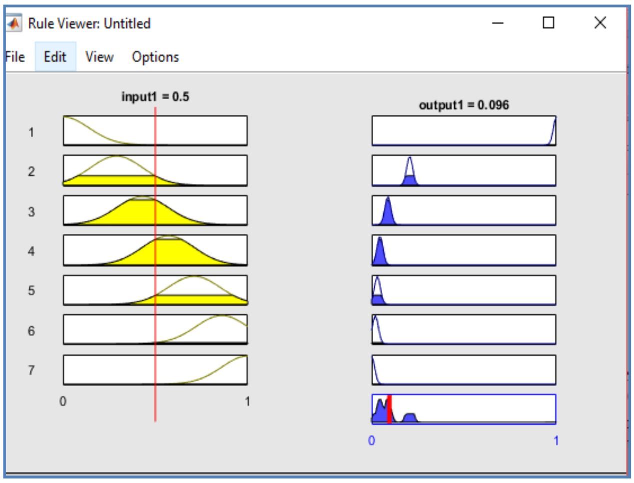

Fig.13. Rule Viewer window

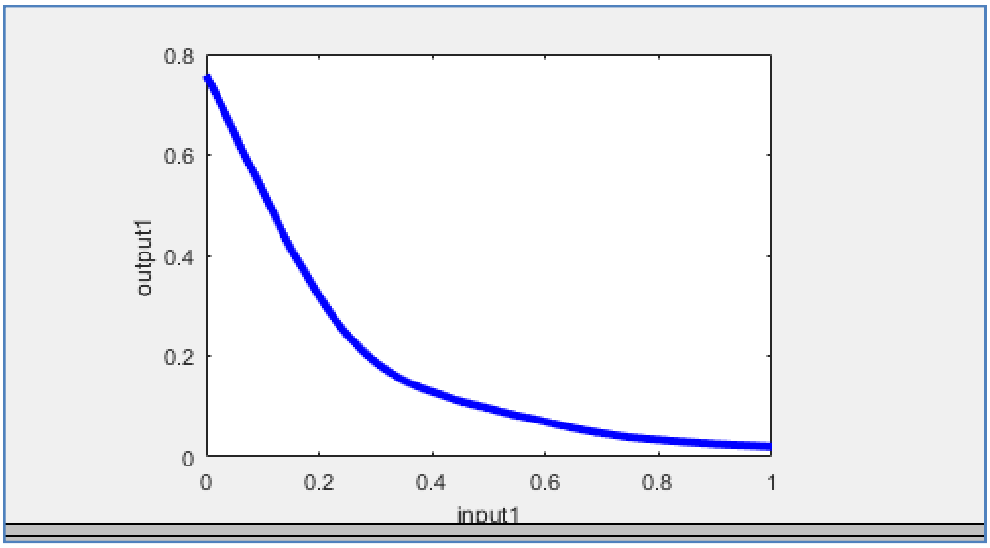

Fig.14.Input and Output graph

VIII. CONCLUSION

From this Suspension testing setup we can test multiple numbers of suspensions at different loads and different speeds.

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Also we can use suspensions of different height.
By changing different suspensions and oils we can find out optimum motion transmissibility. With ultimate objective of studying and plotting dynamic characteristics for Hero Splendor suspension and Honda Shine suspension using single wheel model of suspension analysis to produced large number of results. However it concludes the project work with following points:

1. The suspension system gives best performance when designed to be slightly under-damped.
2. From experimental results and graphs we can conclude that for good ride, transmissibility should be as low as possible and this can be attained by using low damping constant and high spring stiffness and Honda Shine suspension gives the better results as compared to Splendor suspension.
3. Gauss membership function is plotted for various load conditions.
4. Rule viewer window shows that system is varying as per load.
5. Input and output graph shows that the transmissibility is within limit.

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