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Performance Testing of Shock Absorber on Single DOF Spring-Mass-Damper System Using MATLAB

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Abstract – Shock absorber is very important term in automotive suspensions as used for the driving comfort and driving safety. The paper presents performance of the shock absorbers under real conditions and dynamic behaviors are studied by computer simulation and experimental testing. 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 spring stiffness values to various speed condition.

Index Terms – Shock absorber, Damping, Damping coefficient, Amplitude, Motion Transmissibility.

1. INTRODUCTION

Shock absorber is fabricated to reduce shock impulse on a rough ground. Now-a-days vehicles are designed with strong shock absorbers to withstand any type of bouncy conditions. To control excessive suspension movement in case of shock absorber is not used then stiffer springs will be used. The shock absorber absorbs or dissipates energy. While designing or selecting a Shock absorber the question is where that energy will go. In dashpots energy is converted to heat within the viscous fluid. Shock absorbers are connected at the end of the piston rod, which works against hydraulic fluid in the pressure tube. Movements of suspension force the hydraulic fluid through the minute holes inside the piston. Though very small amount of fluid is forced inside the piston. The insertion of fluid reduces the speed of the piston thus slows down the piston, and result in slowing down of spring and suspension movement.

1.1. Working

Shock absorbers work on the principle of fluid displacement on both the compression and expansion cycle. The motion of a vehicle's unsprung weight is controlled by the compression cycle, while expansion controls the heavier sprung weight. Shock absorber works in two cycles.

1.1.1. Compression

In compression cycle the piston moves downward and compresses the fluid situated below the piston in the chamber. During downward movement, fluid flows to upper chamber through piston from down chamber. Some fluid also flows into reserve tube through the compression valve. This flow is controlled by valves in the piston and in the compression valve.

1.1.2. Extension

The piston moves upwards toward the top of the pressure tube in the extension cycle. This results in the compression of the fluid in the chamber lying above the piston. The extension cycle provides more resistance than compression cycle.

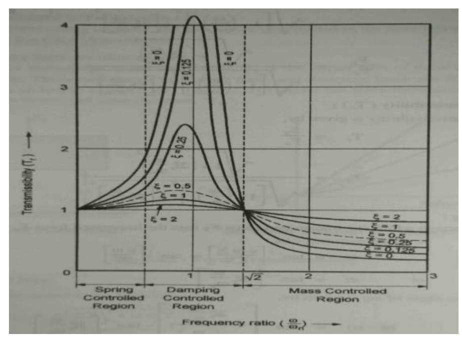


Figure 1 Transmissibility vs. Frequency ratio

According to graph, there are three regions,

- Spring controlled region-Larger value of spring stiffness gives higher natural frequency.
- Damping controlled region-This region should be avoided. When damping is zero then transmissibility goes to infinity.
- Mass controlled region-Larger value of mass gives lower natural frequency.

1.2. Suspensions in vehicle

The modern motorcycle uses suspension to accomplish several things; it provides a smooth comfortable ride minimizing bumps and imperfections in the road. It also allows the rider to better control over the machine when riding.

1.2.1. Springs

Suspension springs are used to support the motorcycle above its wheels. As the wheels roll over bumps, springs isolate the chassis and rider from the bumps of the wheels. A spring's rate is a measure of force required to compress the spring a given distance. If the more force it takes to compress it a given distance, higher is the rate and the less it compresses under a given force.

Spring rate is expressed in pounds per inch. A common spring rate is 100 pounds per inch i.e. to compress it one inch it takes 100 lbs and 200 lbs to compress it two inches, and so on until it's completely compressed. Ideally the spring rate on suspension is stiff enough to keep the vehicle from bottoming out on all but the very worst bumps soft enough to provide a comfortable ride.

Springs are of two basic types.

- Straight rate- If springs compress at one rate until coil bound is the straight rate.
- Progressive rate- If the spring rate that increases as the spring compresses is the progressive rate.

1.2.2. Damping

Motorcycle's suspension is designed to absorb the energy transferred to it from the wheel during vibratory motion. The front wheel force hitting a bump is transferred to the suspension. To damp this shock which stores energy in the spring, fluid is used as a shock absorber by pumping oil through small orifices as the suspension goes through its motion.

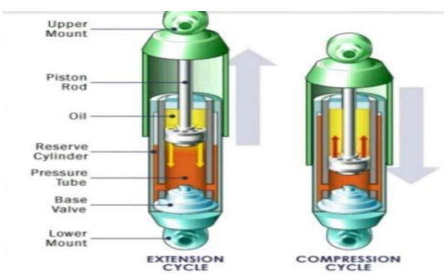


Figure 2 Damper

Springs and damping are used together to keep the wheels on the ground in motorcycles suspension. There is condition that damping and spring rates should be in balance. If there is more damping, it will move the spring and the suspension will not give response, forcing the wheels to jump and bounce over every little bump. If there is less damping, the motorcycle is in over sprung condition, and it rolls and pitches through the turns and after the least little bump. In both cases ride and handling suffer. Vehicles are generally designed for maximum ride comfort so approximately 0.25 damping ratio is used. In racing cars, 0.65 to 0.70 provides much better body control than passenger's car and better response than critical damping.

1.3. Problem Statement

The aim of the project is to study and analyze single degree of freedom spring-mass-damper system and plot its dynamic characteristics curve for different values of spring stiffness for various speed condition FFT Analyzer.

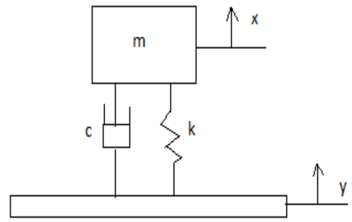


Figure 3 Problem statement

1.4. Objectives

The objective of the project is to determine dynamic characteristics of shock absorber.

- Motion Transmissibility
- Plot Dynamic Characteristics curve

1.5. Aim and Scope for Future Study

A vehicle suspension system is designed to absorb and minimize the forces experienced by the wheels of a vehicle. The maximum displacement and acceleration is needed to design suspension system. The objective of this test rig is to determine motion transmissibility and plot the dynamic characteristics curve of shock absorber system. This test rig actually designed to measure vibration and displacement and indicates the condition of shock absorber in automotive vehicles to investigate the performance of it.

2. TERMINOLOGY USED

2.1. Natural frequency (ωn)

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

2.2. Damping

The external force which is provided to reduce the vibrations.

2.3. Critically damping co-efficient

The value of damping coefficient c at which the frequency of free damped vibration is zero is critical damping coefficient and the motion is aperiodic.

2.4. Damping co-efficient (ξ)

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

$\xi = C/Cc$

2.5. Absolute Motion

Motion of a mass with respect to the coordinate system attached to the earth is known as absolute motion. As shown in figure, the absolute displacement if support is y=B sin ωt 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”.

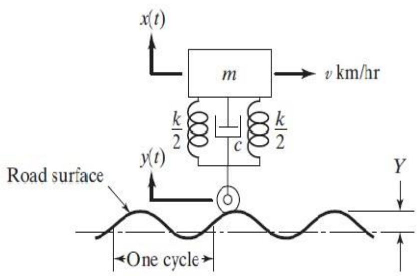


Figure 4 Absolute Motion

The equation of motion can be written as,

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0$$

Or $$m\ddot{x} + c\dot{x} + kx = c\dot{y} + ky.$$

The support is subjected to harmonic vibration, y = Y sin ωt. Substituting this value of y in equation, we get,

$$m\ddot{x} + c\dot{x} + kx = cY\omega * \cos\omega t + kY * \sin\omega t.$$

$$= Y*(c\omega * \cos\omega t + k*\sin\omega t).$$

$$= Y\sqrt{(k^2 + c^2\omega^2)} * \left[\frac{c\omega*\cos\omega t}{\sqrt{(k^2+c^2\omega^2)}} + \frac{k*\sin\omega t).}{\sqrt{(k^2+c^2\omega^2)}}\right]$$

$$= Y\sqrt{(k^2 + c^2\omega^2)}[\cos\alpha * \sin\omega t + \sin\alpha * \cos\omega t]$$

$$m\ddot{x} + c\dot{x} + kx = Y\sqrt{(k^2 + c^2\omega^2)} * (\sin\omega t + \alpha).$$

And $\tan\alpha = \left[\frac{c\omega}{k}\right]$.

Where $\alpha = \tan^{-1}\left[\frac{c\omega}{k}\right] = \tan^{-1}\left[\frac{2\varepsilon\omega}{\omega n}\right]$.

Steady state solution can be written as,

$$z = X*(\sin\omega t + \alpha - \emptyset)$$

Comparing equations, we see that,

$$F = Y\sqrt{(k^2 + c^2\omega^2)}$$

Let us go back to equation i.e.

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

Steady state amplitude can be written as:

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

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

The ratio of **X/Y** is called the **displacement transmissibility** which is the ratio of amplitude of the body to amplitude of the support.

3. MATERIAL SELECTION

3.1. Shaft material

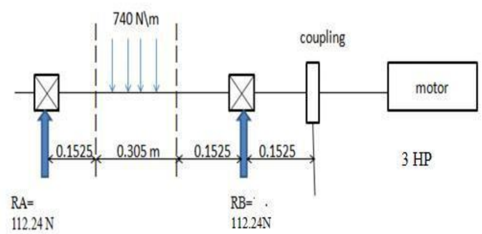


Figure 5 Force Diagram

EN19 Alloy Steel material used for shaft.EN19 Alloy Steel material used for shaft. EN19 is a high quality tensile steel having good shock resisting and ductility combined with resistance to wear.

3.2. Bearing

Bearing is mechanical element which locates two machine parts to permit a relative motion between them. It has two or more contacting surfaces through which a load is transmitted.

UCP210 bearing used for shaft.

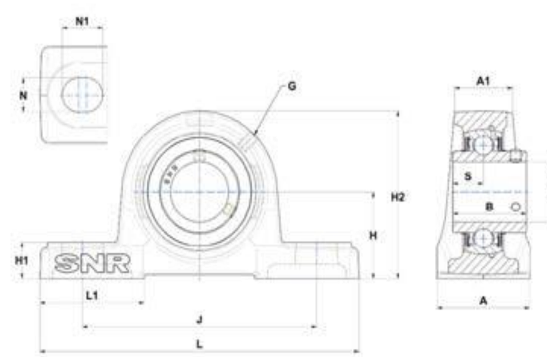


Figure 6 Bearing UCP210

3.3. Key

Key is a mechanical element used on shafts to secure rotating elements like gears, pulleys, or sprocket and prevents relative motion between two. The key transmits torque from the shafts to shaft supported element or vice versa. It is always inserted parallel to the axis of shaft.

4. EXPERIMENTAL SETUP

Figure 7 Experimental Setup

4.1. About Setup

4.1.1. 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.

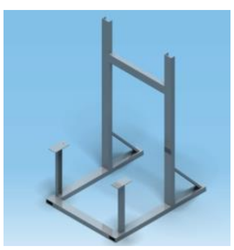


Figure 8 Frame

4.1.2. Drum

Figure 9 Drum

It is made of MS sheet having thickness 4mm. 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.

4.1.3. Wheel Assembly

Figure 10 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. Swing arms are assembled to Frame.

4.1.4. Motor

1440 RPM 3 HP single phase motor is coupled to shaft. It rotates drum and ultimately drum.

4.1.5. Dimmerstat

Dimmerstat is auto transformer having continuously variable voltage. It has simple construction and variation of output voltage is smooth, continuous and breakless. It has high efficiency and excellent overload capacity for short time. 20ampere dimmerstat is used to control the motor speed.

4.1.6. 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.

Figure 11 FFT Analyzer

Specification

Small USB- based system

8 analogue input channels (strain, voltage; with MSI adapters any input)

200 kS/s aliasing-free 24bit-ADC

8 precise real time counters

2 CAN bus ports isolated

4.1.7. Accelerometer

Accelerometer is a Piezo-electric accelerometer and it is considered as the standard vibration transducer for machine vibration measurement. The accelerometers consist of a piezoelectric crystal which has a mass attached to one of its surfaces. When the mass is subjected to a vibration signal, the mass converts the vibration (acceleration) to a force, this then being converted to an electrical signal. This is the basis of the "accelerometer".

4.1.8. 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.

4.2. Working

Shaft is mounted in bearing on which drum is mounted. Speed breaker profiles is welded on drum.

On drum wheel assembly is mounted.

Shaft is coupled to motor. Motor shaft rotates the Drum shaft which simultaneously rotates the wheel which in on drum.

Motor speed is controlled by using Dimmerstat.

As wheel and drum rotates wheel reaches to speed beaker profile it create bump on shock absorber.

Figure 12 Actual Setup

- Shock absorber will get compress.
- FFT analyzers sensors will attached to Upper and lower point of shock absorbers and readings displayed on computers screen.

5. RESULTS AND DISCUSSION

5.1. Experimental Results

5.1.1. Splendor Suspension (Oil 1)

SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak(RMS) m/s^2		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

5.1.2. Honda Shine Suspension (Oil 1)

SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak(RMS) m/s^2		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

5.1.3. Spendor Suspension (Oil 2)

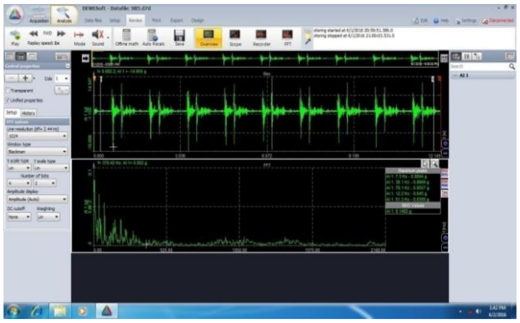
SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak(RMS) m/s^2		Transmissibility TR=(A/B)
			Top (A)	Bottom (B)	
1	23540	27	18.774	25.407	0.7371
2	23540	32	14.469	24.525	0.6045
3	23540	37	11.375	21.876	0.52
4	23540	42	9.809	21.876	0.4484

5.1.4. Honda Shine Suspension (Oil 2)

SR. NO.	Spring Stiffness (K) (N/m)	Load (Kg)	Peak(RMS) m/s^2		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	0.33134

5.2. Analytical Results

5.2.3. Splendor Suspension Bottom for weight 32Kg for Oil 1



Graph 1

5.2.2. Splendor Suspension Top for weight 32Kg for Oil 1

Graph 2

5.2.3. Splendor Suspension Bottom for weight 32 Kg for Oil 2

Graph 3

5.2.4. Splendor Suspension Top of weight 32Kg for Oil 2

Graph 4

5.3. Results and Discussion-

5.3.1. Splendor Suspension Oil 1(K=23540N/m)

Load (Kg)	ω/ ωn	Transmissibility		% error
		Experimental	**Matlab**	
27	1.524	0.7317	0.7859	6.896
32	1.659	0.5951	0.6073	2.009
37	1.784	0.51	0.4932	3.406
42	1.901	0.45	0.4147	8.512

5.3.2. Honda Shine Suspension Oil 1(K=17310N/m)

Load (Kg)	ω/ ωn	Transmissibility		% error
		Experimental	**Matlab**	
27	1.777	0.5485	0.5203	5.419
32	1.9348	0.45	0.4149	8.459
37	2.08	0.41	0.3445	19.013
42	2.21	0.36	0.2943	22.324

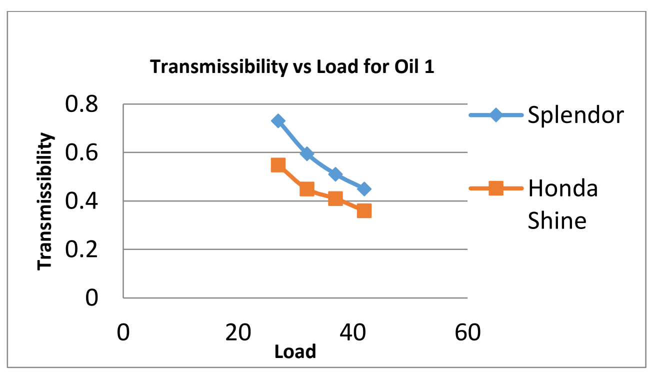
5.3.3. Splendor Suspension Oil 2 (K=23540N/m)

Load (Kg)	ω/ ωn	Transmissibility		% error
		Experimental	**Matlab**	
27	1.524	0.7371	0.7837	5.946
32	1.659	0.59	0.6045	2.398
37	1.784	0.52	0.4906	5.993
42	1.901	0.4484	0.4123	8.756

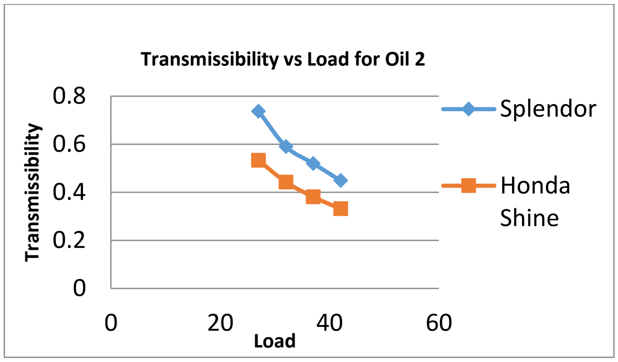
5.3.4. Honda Shine Suspension Oil 2 (K=17310N/m)

Load (Kg)	ω/ ωn	Transmissibility		% error
		Experimental	**Matlab**	
27	1.777	0.5325	0.5159	3.218
32	1.9348	0.4427	0.411	7.713
37	2.08	0.3809	0.3411	11.67
42	2.21	0.33134	0.2913	13.745

5.4. Characteristic Curves



Graph 5 Transmissibility vs Load for Oil 1



Graph 6 Transmissibility vs Load for Oil 2

6. CONCLUSION

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

- The suspension system gives best performance when designed to be slightly under-damped.
- 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.

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