Vibration Analysis of Two Wheeler Suspension System under Various Loading Conditions (An Analytical Approach)

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Abstract - - *It is evident that there is a constantly growing interest in providing acceptable system performances of vehicle suspension systems, especially in the past two decades as vehicle suspension systems have many vital functions: for instance, to support the vehicle weight, to provide effective isolation of the chassis from road excitations, to keep tyre contact with the ground, and to maintain the wheels in appropriate position on the road surface. Vehicle suspension systems play an important role in guaranteeing the stability and improving suspension performances of vehicles. In this Research a Suspension System is Analyzed by considering load. Vibration Analysis is done to validate the strength of suspension system. The Deformation of suspension system is checked under various loading conditions. Acceleration and Velocity of Suspension system is checked under various Road Conditions. For the Analysis purpose, Honda Passion is Chosen as a Base Model.*

***Key Words*: Suspension System, Vibration Analysis, Deformation, Acceleration, Velocity, Road Condition, Honda Passion**

NOMENCLATURE:

A	Amplitude
C	Spring Index
C	Damping co efficient
C_c	Critical Damping Co efficient
D	Mean Diameter of coil
D	Wire Diameter
D_o	Outer Diameter of spring
G	Modulus of rigidity
h	Height of spring
K	Spring stiffness
L_s	Solid Length
m	Mass
n	Number of Turns
r	Frequency ratio
V	Velocity
ω	Frequency
ω_n	Natural Frequency
X_1	Displacement
$\dot{X}_1$	Velocity of Vehicle
$\ddot{X}_1$	Acceleration
Z	Damping ratio
$\frac{X_1}{Y}$	Amplitude Ratio

1.INTRODUCTION

Vehicle suspension systems play an important role in guaranteeing the stability and improving suspension performances of vehicles. It is worth noting that the problem of control design for active suspension systems should be paid considerable attention[1]. In addition, the vehicle suspension systems can provide as much comfort as possible for the passengers and ensure the other suspension performance by serving the basic function of isolating passengers from road-induced vibration and shocks. Hence, the control design problem of proper active suspension systems is always an important research topic for achieving the desired vehicle suspension performances.

Several performance characteristics should be considered and need to be optimized for designing a good performance suspension system[3]. It is widely accepted that three main suspension performances should be taken into account when designing a suspension controller, namely, ride comfort (i.e., directly related to acceleration sensed by passengers), road handling (i.e., associated with the contact forces of tires and road surface), and suspension deflection (i.e., referred to the displacement between the sprung mass and unsprung mass) However, it is difficult to minimize all three parameters simultaneously as these performances are often conflicting with each other, For example, the minimization of suspension travel cannot be accomplished simultaneously with the maximization of the ride comfort. In other words, enhancing ride comfort performance results in larger suspension stroke and smaller damping in the wheel-hop mode[4]. Hence, how to derive an appropriate trade-off between these performances is the main task for successfully designing a vehicle suspension control system.

1.1 TYPES OF SUSPENSION SYSTEM

Most modern motorcycle suspensions are still based on a telescopic cartridge fork design, which houses both the spring and damper unit. This design proved to be lightweight, inexpensive, and sturdy enough to handle the loads of today's motorcycles. Damper technology, however, has continuously evolved. Mono-tube dampers have given way to twin tube dampers, while fixed orifice damper valving has been replaced by rider adjustable compression and rebound adjusters. The end goal has been to provide the rider with better ride performance while maintaining comfort[7].

1) Active Suspension system
2) Passive Suspension System
3) Semi active Suspension system
4) Adjustable suspension system

A passive suspension system is one in which the characteristics of the components (springs and dampers) are fixed. These characteristics are determined by the designer of the suspension, according to the design goals and the intended application. Passive suspension design is a compromise between vehicle handling and ride comfort. In an active suspension, the passive damper or both the passive damper and spring are replaced with a force actuator. In this type of system, the conventional spring element is retained, but the damper is replaced with a controllable damper.

1.2 LITERATURE SURVEY

The literature survey was mainly focus on the design of spring of the suspension system to increase the performance of the two wheeler suspension system. The design of the spring was varied depending upon the parameters of the springs, like wire diameter, outer diameter, pitch, number of active turns etc. material for the spring has also its advantages. Current trends have focused on the design of springs using various materials. Then the springs would be checked under various conditions. Stress and deflection would be checked of the springs under various materials and under various conditions to check the efficiency of the springs of the suspension systems. Analyses have been carried out by using software and efficient design would be carried out for the suspension system. Experimental set up have also been used to check the property and efficiency of the suspension systems.

2. DESIGN CALCULATION FOR HELICAL SPRING OF SUSPENSION SYSTEM (HONDA PASSION)

The vibration Analysis was carried out to check the suspension system under various road conditions. For the Analysis purpose, Honda Passion is chosen. According to the standard specification of Rear Suspension system, the design calculation was carried out. The standard dimension of Honda Passion is Describe Below.

Material: Structural Steel

- modulus of rigidity G = 79300 MPa
- Mean Coil Diameter D=42mm
- Diameter of wire d = 8mm
- Number of Active Turns n1= 17
- Height h = 220mm
- Outer diameter of spring DO= D +d =50mm
- Kerb Weight = 116kgs
- Let weight of 1 person = 60Kgs
- Weight of 2 persons = 60×2=120Kgs
- Weight of bike + 2 persons = 236Kgs

Now, Let us Assume that the Rear Suspension system can carry the load of 60% Of Overall Vehicle Weight.
So, 60% of 236 = 142 Kgs =1394 N
C = spring index = 5.25=5.3
Solid length, Ls=n1×d=17×8=136mm

2.1 VIBRATION ANALYSIS OF SUSPENSION SYSTEM

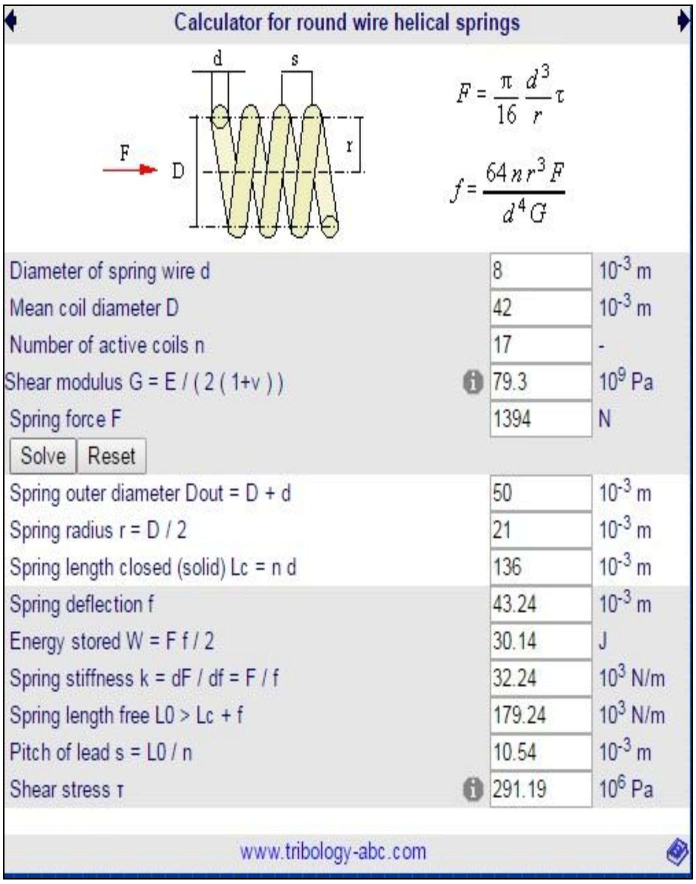
Here, we carried out Vibration Analysis of Rear Suspension System by Analytical. This Analysis was carried out to check the various Parameters of Two Wheeler Suspension System. For the Analysis purpose, we choose Rear Suspension of Honda Passion and Analysis was carried out under various Road Conditions. Vehicle has Mass of 236 Kgs including Bike Kerb Weight and considering 2 persons. The spring stiffness (Force required per Unit Deflection) was calculated by using Online spring Stiffness Calculator. We Analyze the suspension system under various Road conditions by varying speed of 50 Km/hr and 80 Km/hr. we assume that road surface varied sinusoidal with Amplitude 0.04 m and considering Wavelength 6m. Whole body vibration (WBV) occurs when workers sit or stand on vibrating seats or foot pedals. Prolonged Exposure to high levels of WBV causes motion sickness, fatigue and headaches. WBV is one of the strongest risk factors for low back disorders. Vibrations with less than 0.315 m/s^2 are found to be comfortable between 0.315m/s^2 and 2.5m/s^2 are found to be uncomfortable greater than 2.5m/s^2 are found to be extremely uncomfortable. Typical whole -body vibration exposure levels of heavy vehicle drivers are in the range 0.4 to 2.0 m/s^2.

Table 1 ISO standard with respect to the vibration exposure and its effect on health of driver[2].

Exposure Duration in Hrs	Likely Health Risk	Caution Zone	Comfort Level
8	0.8	0.5	0.315
12	0.7	0.4	0.315

Now, we want to find out the Spring stiffness value of the Helical Spring. The spring stiffness value was carried out by using the Online Spring Stiffness Calculator.

Table 1 www.tribology-abc.com [5].



Diameter of spring wire d	8	10^{-3} m
Mean coil diameter D	42	10^{-3} m
Number of active coils n	17	-
Shear modulus G = E / (2 (1+v))	79.3	10^9 Pa
Spring force F	1394	N
Spring outer diameter Dout = D + d	50	10^{-3} m
Spring radius r = D / 2	21	10^{-3} m
Spring length closed (solid) Lc = n d	136	10^{-3} m
Spring deflection f	43.24	10^{-3} m
Energy stored W = F f / 2	30.14	J
Spring stiffness k = dF / df = F / f	32.24	10^3 N/m
Spring length free L0 > Lc + f	179.24	10^3 N/m
Pitch of lead s = L0 / n	10.54	10^{-3} m
Shear stress τ	291.19	10^6 Pa

Now, Vibration Analysis Carried out by Analytically[6].
Natural Frequency:- the frequency at which a system oscillates when not subjected to a continuous or repeated external force.

$$\text{Natural Frequency } \omega_n = \sqrt{\frac{k}{m}} \qquad \text{Eq. (1)}$$

$$\omega_n = 15.06 \text{ rad/sec}$$

Frequency of the Object:- the rate at which something occurs over a particular period of time or in a given sample.

$$\text{Frequency } \omega = 2\pi f = 2\pi\left(\frac{V\times 1000}{3600}\right)\frac{1}{6} \qquad \text{Eq. (2)}$$

$$= 0.290889\times V$$

Now, We find out Frequency of the object at Various Speed. For the Analysis Purpose, we choose speed at 50 Km/hr and 80 Km/hr.

For 50Km/hr = 0.290889×50=14.54 rad/sec

For 80Km/hr = 0.290889×80=23.27 rad/sec

Frequency Ratio:- Frequency Ratio is defined as the Ratio of Frequency of the object to the Natural Frequency.

$$\text{Frequency Ratio } (\mathbf{r}) = \frac{\omega}{\omega_n} \qquad \text{Eq. (3)}$$

$$(\mathbf{r})_{50km/hr} = \frac{\omega}{\omega_n} = 0.965$$

$$(\mathbf{r})_{80km/hr} = \frac{\omega}{\omega_n} = 1.545$$

Now, for the Analysis purpose we want to carry out two different cases. The Analysis was carried out to check the different parameters. We done the Analysis at two different speeds. First case was consider the speed at 50 Km/hr and second case consider the speed at 80 Km/hr.

Case 1:- At speed 50 Km/hr

Here, we consider a Simple Harmonic Motion (S.H.M). According to Simple Harmonic Motion, the Acceleration is directly Proportional to displacement and always directed towards the mean position from the point. As we assume the Analysis was carried out At sinusoidal Amplitude of 0.04m and considering the Wavelength 6m[3].

Displacement, Velocity and Acceleration at Amplitude A(0.04m,0.08m,0.12m,0.16m).

Displacement, Velocity and Acceleration at Amplitude A(0.04m,0.08m,0.12m,0.16m)

Displacement:- Displacement is defined as the distance travelled per unit time. Displacement is carried out at various Amplitude According to the sinusoidal manner.

$X_1 = A_1 \sin \omega t$ = 0.0043 m At time period t= $\frac{2\pi}{\omega}$ =0.432sec

$X_1 = A_2 \sin \omega t$ = 0.0086 m At time period t= $\frac{2\pi}{\omega}$ =0.432sec

$X_1 = A_3 \sin \omega t$ = 0.0130 m At time period t= $\frac{2\pi}{\omega}$ =0.432sec

$X_1 = A_4 \sin \omega t$ = 0.0173 m At time period t= $\frac{2\pi}{\omega}$ =0.432sec

Eq. (4)

Velocity:- Velocity is defined as the rate of change of Displacement per Unit time. For the different Amplitude, velocity has been encountered as Following.

$\dot{X}_1 = A_1 \omega \cos \omega t$ = 0.243 m/s

$\dot{X}_1 = A_2 \omega \cos \omega t$ = 0.486 m/s

$\dot{X}_1 = A_3 \omega \cos \omega t$ = 0.729 m/s

$\dot{X}_1 = A_4 \omega \cos \omega t$ = 0.972 m/s Eq. (5)

Acceleration:- Acceleration is defined as the Rate of change of velocity per Unit time. According to the Amplitude, acceleration was carried out at S.H.M.

$\ddot{X}_1 = -\omega^2 \times X_1$ = 0.909 m/s^2

$\ddot{X}_1 = -\omega^2 \times X_1$ = 1.691 m/s^2

$\ddot{X}_1 = -\omega^2 \times X_1$ = 2.748 m/s^2

$\ddot{X}_1 = -\omega^2 \times X_1$ = 3.593 m/s^2 Eq. (6)

Now, after finding out the Velocity and Acceleration value, we want to find out the Damping Factor or Damping Ratio. Damping Ratio is a Dimensionless Parameter measure describing how oscillations in a system decay after a disturbance. Many systems exhibit oscillatory behavior when they are disturbed from their position of Static Equilibrium. A mass suspended from a spring, for example, might if pulled and released, it will bounce up and down.

Damping co efficient:-

c = $\frac{F}{\dot{X}}$ c = 5736.62 Ns/m Eq. (7)

Critical Damping Co efficient:-

$C_c = 2m\,\omega_n$ C_c = 1993.68 Ns/m Eq. (8)

Damping Ratio:-

$\zeta = \frac{C}{C_C}$ Eq. (9)

ζ =2.87

Amplitude Ratio:-

$$\left(\frac{X_1}{Y}\right)_{40km/hr} = \left[\frac{1+(2\xi r)^2}{(1-r^2)^2+(2\xi r)^2}\right]^{1/2} = 1.0324$$

$$\left(\frac{X_1}{Y}\right)_{60km/hr} = \left[\frac{1+(2\xi r)^2}{(1-r^2)^2+(2\xi r)^2}\right]^{1/2} = 0.988 \quad \text{Eq. (10)}$$

Above Analysis was carried out by considering the speed of Vehicle as a 50 Km/hr. now same Vibration Analysis carried out by using Vehicle speed as a 80 Km/hr.

Case 2:- At speed 80 Km/hr

Displacement, Velocity and Acceleration at Amplitude A(0.04m,0.08m,0.12m,0.16m)

$X_1 = A_1 \sin \omega t$ = 0.0042 m At time period t= $\frac{2\pi}{\omega}$ =0.270 sec

$X_1 = A_2 \sin \omega t$ = 0.0084 m At time period t= $\frac{2\pi}{\omega}$ =0.270 sec

$X_1 = A_3 \sin \omega t$ = 0.0127 m At time period t= $\frac{2\pi}{\omega}$ =0.270 sec

$X_1 = A_4 \sin \omega t$ = 0.0169 m At time period t= $\frac{2\pi}{\omega}$ =0.270 sec

Now find out the Velocity,

$\dot{X}_1 = A_1 \omega \cos \omega t$ = 0.230 m/s

$\dot{X}_1 = A_2 \omega \cos \omega t$ = 0.461 m/s

$\dot{X}_1 = A_3 \omega \cos \omega t$ = 0.692 m/s

$\dot{X}_1 = A_4 \omega \cos \omega t$ = 0.923 m/s

Second phase is Acceleration. Acceleration is finding out by considering the Amplitude Value.

$\ddot{X}_1 = -\omega^2 \times X_1$ = 2.274 m/s²

$\ddot{X}_1 = -\omega^2 \times X_1$ = 4.548 m/s²

$\ddot{X}_1 = -\omega^2 \times X_1$ = 6.876 m/s²

$\ddot{X}_1 = -\omega^2 \times X_1$ = 9.151 m/s²

3. RESULTS AND DISCUSSION

Above Analysis was carried out to check which parameters were directly affected the vehicle comfort ride and also the efficiency of the Vehicle suspension system. From the above Analysis, the value of Velocity and Acceleration were calculated at sinusoidal Amplitude of 0.04 m. the results from the Analysis was discussed below by using the table and graphs.

Table 2 Result of Velocity at various Amplitude

Speed (Km/hr)	Road One Velocity (m/s)	Road Two Velocity (m/s)	Road Three Velocity (m/s)	Road Four Velocity (m/s)
50	0.243	0.486	0.729	0.972
80	0.230	0.461	0.692	0.923

Table 4 Result of Acceleration at various Amplitude

Speed (Km/hr)	Road One Acceleration (m/s^2)	Road Two Acceleration (m/s2)	Road Three Acceleration (m/s^2)	Road Four Acceleration (m/s^2)
50	0.909	1.691	2.748	3.593
80	2.274	4.548	6.876	9.151

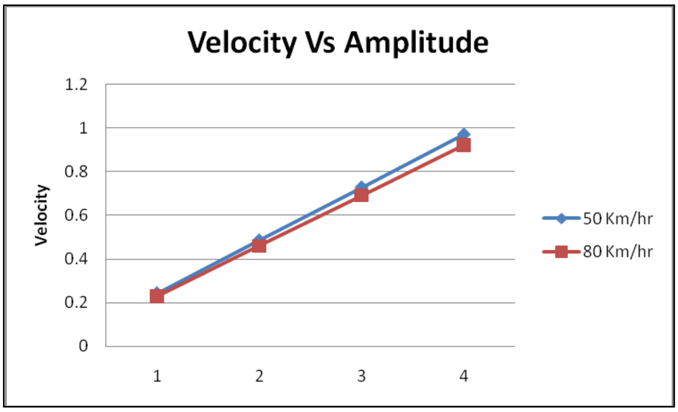


Chart -1: Amplitude Vs Velocity

Above Analysis shows the relation between Amplitude and Velocity at different conditions. From the Analysis we show that as the Amplitude increases, the Velocity is also increased. So we can say that Velocity is directly proportional to the Amplitude.

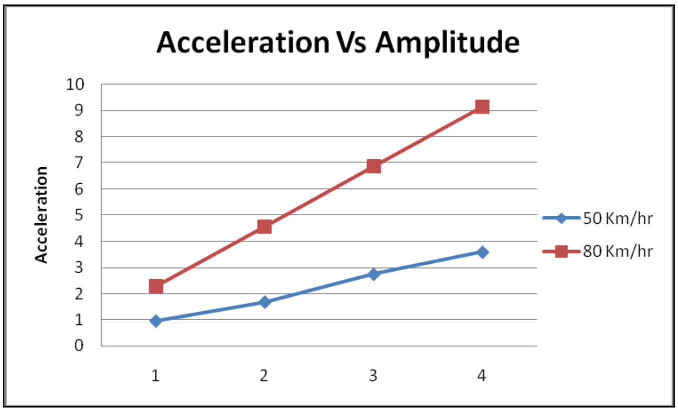


Chart -2: Amplitude Vs Acceleration

From Analytical analysis it was observed that as amplitude of road or road roughness raises acceleration may also going to be rise. Here through graph we can observe that acceleration is to be occurring is more than comfort level or as per international standard notified in above table. The nature of vibration present in a vehicle depends upon the dynamic characteristics of the two wheeler and road surface characters. From the results it is found that, for the given acceleration of two wheeler and human body the ideal operating conditions is more than comfort level that is mean above 0.315 m/s² or above total acceleration i.e. 0.8 m/s² as a safety standard level of vibration.

3. CONCLUSIONS

Acceleration because of is a physical disturbance that occurs in vehicles. Its effect on the human body depends mainly on the acceleration, frequency, magnitude, direction of vibration, area of contact and duration of exposure. From the above analysis it is found that for the given acceleration of two wheeler and human body the ideal operating condition is more than standard level. According to standard level, vibration less than 0.315 m/s^2 are found comfortable. vibration between 0.315 m/s^2 and 2.5 m/s^2 are found to be uncomfortable. Vibration greater than 2.5 m/s^2 are found to be extremely uncomfortable. so from above analysis we conclude that rise of speed or rise of amplitude may directly affect the Acceleration of vehicle. Hence we have scope to redesign the suspension system to reduce its vibration as possible.

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