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Vibration Analysis of a Two Wheeler (Analytically)

Mukesh Hadpe[1], Dr.D.S.Deshmukh[2], P.M.Solanki[3]

P.G. Student, Department of Mechanical Engineering, SSBT'S COET, Bambhori, Jalgaon, Maharashtra, India[1]

Head of Department, Department of Mechanical Engineering, SSBT'S COET, Bambhori, Jalgaon, Maharashtra, India[2]

Asst. Professor, Department of Mechanical Engineering, SSBT'S COET, Bambhori, Jalgaon, Maharashtra, India[3]

ABSTRACT: Majority of Indian population depends on a two wheeler for their transportation due to economic reasons. Because of improper design of vehicle and bad road conditions, people in the age group of 30 to 45 years have pains developed in their body. The percentages of people having musculoskeletal pain problems are found to be 14.33%. Hence an attempt has been made to analysis of vibration and would like prove that acceleration is to be obtained should have more than international standard. And also still have scope to reduce vibration of rear seat.

KEY-WORDS: Two Wheeler, HERO - IGNITOR, Mathematical model, Amplitude

I. INTRODUCTION

The two wheeler riders are subjected to extreme vibrations due to the vibrations of its engine, improper structural design of the two wheeler and bad road conditions. These vibrations are most hazardous to the health, if it exceeds the permissible limit and may cause the illness of the spine, musculoskeletal symptom in the lower back as well as the neck and upper limbs. Analytical studies on the transmission of vertical vibrations which are beyond the permissible limit according to the literatures confirm that, vibrations certainly affect the health of the two wheeler rider. Therefore it is necessary to evaluate the influence of vibration to the human body and to make up appropriate guidelines for the two wheeler design and selection parts. The intensity of these harmful vibrations is reduced by providing a standard type of seat, front and rear suspension. In this work, the coupled human body and two wheeler is modelled as a lumped parameter system. The mathematical model is analysed by analytical method for vertical vibrations responses of the rear seat to vertical vibrations inputs (sinusoidal) applied to wheels.

II. WHOLE BODY VIBRATION AND ITS EFFECTS:

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/s2 are found to be comfortable between 0.315m/s2 and 2.5m/s2 are found to be uncomfortable greater than 2.5m/s2 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/s2. Vibration is highest in the frequency range 2 to 4 Hz. For a seated person vibration in the range of 4 to 8 Hz cause the entire upper torso to resonate and should be reduced and avoided. Health effects that associated with WBV and especially the driving environment are piles, high blood pressure, kidney disorders and impotence. Following table depicts ISO standards with respect to the vibration exposure and its effects on health of rider/driver, Physical factors that influence the effect of vibration on rider during are acceleration and frequency, duration of exposure, automobile maintenance and protective practices.

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ISO STANDARDS WITH RESPECT TO THE VIBRATION EXPOSURE AND ITS EFFECTS ON HEALTH OF RIDER/DRIVER.			
EXPOSURE DURATION IN HRS	INTERNATIONAL STANDARD		
	ISO 2631-1,1997 AVERAGE RMS ACCELERATION LIMITS IN M/S2		
	LIKELY HEALTH RISK	CAUTION ZONE	COMFORT LEVEL
8	0.8	0.5	0.315
12	0.7	0.4	0.315

Table. 1. ISO standards with respect to the vibration exposure and its effects on health of rider/driver.

III. METHODOLOGY

The methodology of the study is briefly summarized as follows:

1. Mathematical model of two wheeler.

2. Mathematical formulation of model

3. Analysis of suspension system

1. Mathematical model of two wheeler:

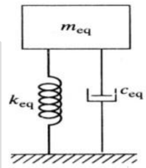
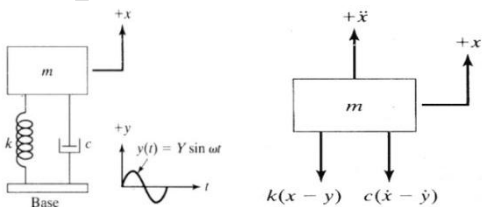


Fig. 1. Shows mathematical modelling of two wheeler with equivalent spring mass system and damper

2. Mathematical formulation of model: Response of a Damped system under the harmonic motion of the Base: Sometimes the base or support of spring-mass damper systems under goes harmonic motion, a shown in fig. A. Let y (t) denote the displacement of the base and x (t) denotes the displacement of mass from its static equilibrium position at time t. then the net elongation of the spring is x-y and the relative velocity between the two ends of the damper is $\dot{X} - \dot{y}$. From free body diagram as shown in fig. B. we obtain the equation of motion.



(A) (B)

Fig. 2. Spring mass system with sinusoidal excitation (A) free body diagram (B)

$$M \cdot \ddot{X} + C \cdot (\dot{X} - \dot{Y}) + K \cdot (X - Y) = 0$$

If Y (t) = Y sin ωt, above equation becomes

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$$M \cdot \ddot{X} + C \cdot \dot{X} + K \cdot X = K\, Y \sin \omega t + C\omega\, Y \cos \omega t = A \sin(\omega t - \alpha)$$

Where $A = Y\sqrt{K^2 + (C\omega)^2}$ and $\alpha = \tan^{-1}(-\frac{C\omega}{K})$. This shows that giving excitation to the base is equivalent to applying a harmonic force of magnitude A to the mass. By using the solution indicated by equation, the steady state of response the mass X_P (t) can be expressed as

$$X_P(t) = \frac{Y\sqrt{K^2+(C\omega)^2}}{(K-M\omega^2)^2+(C\omega)^2} \operatorname{Sin}(\omega t - \emptyset_1 - \alpha)$$

$$\text{Where } \emptyset_1 = \tan^{-1}\left(\frac{C\omega}{K - M\omega^2}\right)$$

Using trigonometry identities, above equation can be written as more convenient from as

$$X_P(t) = X \operatorname{Sin}(\omega t - \emptyset)$$

Where X and Ø are given by

$$\frac{X}{Y} = \left[\frac{K^2+(C\omega)^2}{(K-M\omega^2)^2+(C\omega)^2}\right]^{1/2} = \left[\frac{1+(2\varepsilon r)^2}{(1-r^2)^2+(2\varepsilon r)^2}\right]^{1/2}$$

$$\emptyset = \tan^{-1}\left[\frac{MC\omega^3}{K(K-M\omega^2)+\omega C^2}\right] = \tan^{-1}\left[\frac{2\varepsilon r^3}{1+(4\varepsilon^2-1)r^2}\right]$$

The ratio of the amplitude of the response X_P (t) to that of base of motion Y (t) is called the displacement transmissibility. The variation of $\frac{X}{Y} = T_d$ and Ø given by above equation.

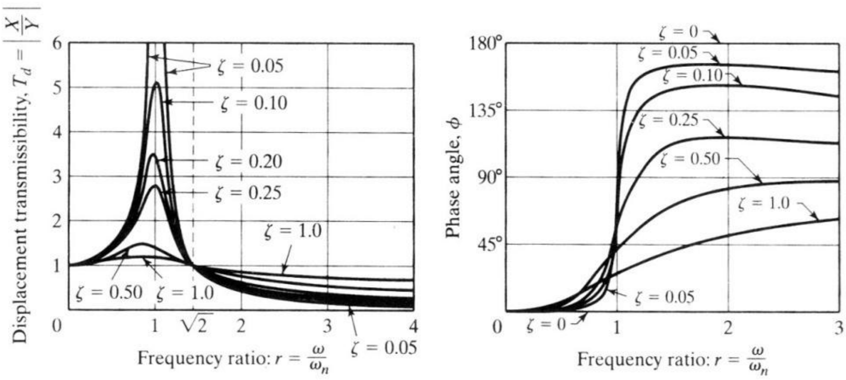

Fig. 3. Shows comparison of frequency ratio and displacement transmissibility, frequency ratio and phase angle

IV. Analysis of suspension system

Assumption of a simple model of motor vehicle as a Hero –Igniter bike that can vibrate in the vertical direction while travelling over rough road. Vehicle has mass of 129 kg (including weight of passenger). The suspension system has a spring constant of 15.28×10^3 N/M (Calculated by online spring stiffness calculator) and a damping ratio of $\varepsilon = 2.70$ for vehicle speed 20, 40, 60 Km/Hr .the road surface varies sinusoidal with a amplitude of Y = 0.05 m and wavelength here I consider 6 m,

Spring Stiffness calculation: as on the basis of dimensions measured from shock absorber

Wire diameter (d) = 7 mm, No of active coils (n) = 15, Outer diameter of spring coil = 54 mm, Mean diameter of spring coil = 47 mm, Force on spring = 1265.49 N.

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Calculator for compression springs, tension springs   http://www.tribology-abc.com/calculators/t14_1.htm

Calculator for round wire helical springs

Diameter of spring wire d	7	10^{-3} m
Mean coil diameter D	47	10^{-3} m
Number of active coils n	15	-
Shear modulus G = E / (2 (1+v))	79.3	10^{9} Pa
Spring force F	1265.49	N
Solve / Reset		
Spring outer diameter Dout = D + d	54	10^{-3} m
Spring radius r = D / 2	23.5	10^{-3} m
Spring length closed (solid) Lc = n d	105	10^{-3} m
Spring deflection f	82.81	10^{-3} m
Energy stored W = F f / 2	52.4	J
Spring stiffness k = dF / df = F / f	15.28	10^{3} N/m
Spring length free L0 > Lc + f	187.81	10^{3} N/m
Pitch of lead s = L0 / n	12.52	10^{-3} m
Shear stress τ	441.57	10^{6} Pa

www.tribology-abc.com

1 of 1   20/09/2014 6:49 AM

Table.2. Shows stiffness calculator with results for stiffness of spring and required dimension.

Damping ratio calculation:

Damping coefficient (c) = $\frac{F}{\dot{X}}$ = 4049.57 Ns/m , Critical damping constant (C_c) = $2m\sqrt{K/m}$ or $2m\omega$ = 1501.57.

Damping ratio (ε) = $\frac{C}{C_c}$ = 2.70

The frequency, $\omega = 2\pi f = 2\pi\left(\frac{v\times 1000}{3600}\right)\frac{1}{6} = 0.290889 \times v$ = rad/sec

For v_1 = 20 Km/Hr, ω = 5.81778 rad/sec,

For v_2 = 40 Km/Hr, ω = 11.6355 rad/sec,

For v_3 = 60 Km/Hr, ω = 17.4532 rad/sec,

The natural frequency of vehicle is given by:

$$\omega_n = \sqrt{K/M} = \left(\frac{15.28\times 10^3}{129}\right)^{1/2} = 10.89 \text{ rad/sec}$$

And hence frequency ratio r is:

$$(r)_{20\ Km/Hr} = \frac{\omega}{\omega_n} = \frac{5.81778}{10.89} = 0.54$$

$$(r)_{40\ Km/Hr} = \frac{\omega}{\omega_n} = \frac{11.6355}{10.89} = 1.068$$

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The amplitude ratio can be found as:

$$\left(\frac{X_1}{Y}\right)_{20\ Km/Hr} = \left[\frac{K^2+(C\omega)^2}{(K-M\omega^2)^2+(C\omega)^2}\right]^{1/2} = \left[\frac{1+(2\varepsilon r)^2}{(1-r^2)^2+(2\varepsilon r)^2}\right]^{1/2} = \left[\frac{1+(2\times 2.70\times 0.54)^2}{(1-(0.54)^2)^2+(2\times 2.70\times 0.54)^2}\right]^{1/2}$$

$$\left(\frac{X_1}{Y}\right)_{20\ Km/Hr} = 1.027.$$

Thus the displacement amplitude of vehicle at different road amplitude is given by:

$X_1 = 1.027 \times 0.05 = 0.052$ m.

$X_1 = 1.027 \times 0.10 = 0.11$ m.

$X_1 = 1.027 \times 0.15 = 0.16$ m.

$X_1 = 1.027 \times 0.20 = 0.21$ m.

$\dot{X}_1 = A\ \omega \cos \omega t = 0.32$ m/s, at time period $t = 2\pi/\omega = 1.079$ sec.

$\dot{X}_1 = A\ \omega \cos \omega t = 0.63$ m/s, at time period $t = 2\pi/\omega = 1.079$ sec.

$\dot{X}_1 = A\ \omega \cos \omega t = 0.94$ m/s, at time period $t = 2\pi/\omega = 1.079$ sec.

$\dot{X}_1 = A\ \omega \cos \omega t = 1.25$ m/s, at time period $t = 2\pi/\omega = 1.079$ sec.

$\ddot{X}_1 = -\omega^2 \cdot x_1 = 1.77\ m/s^2$

$\ddot{X}_1 = -\omega^2 \cdot x_1 = 3.73\ m/s^2$

$\ddot{X}_1 = -\omega^2 \cdot x_1 = 5.41\ m/s^2$

$\ddot{X}_1 = -\omega^2 \cdot x_1 = 7.11\ m/s^2$

$$\left(\frac{X_2}{Y}\right)_{40\ Km/Hr} = \left[\frac{K^2+(C\omega)^2}{(K-M\omega^2)^2+(C\omega)^2}\right]^{1/2} = \left[\frac{1+(2\varepsilon r)^2}{(1-r^2)^2+(2\varepsilon r)^2}\right]^{1/2} = \left[\frac{1+(2\times 2.70\times 1.068)^2}{(1-(1.068)^2)^2+(2\times 2.70\times 1.068)^2}\right]^{1/2}$$

$$\left(\frac{X_2}{Y}\right)_{40\ Km/Hr} = 5.77.$$

Thus the displacement amplitude of vehicle at different road amplitude is given by:

$X_2 = 5.77 \times 0.05 = 0.29$ m.

$X_2 = 5.77 \times 0.10 = 0.58$ m.

$X_2 = 5.77 \times 0.15 = 0.87$ m.

$X_2 = 5.77 \times 0.20 = 1.54$ m.

$\dot{X}_2 = (0.05)\ \omega \cos \omega t = 0.31$ m/s, at time period $t = 2\pi/\omega = 0.54$ sec.

$\dot{X}_2 = (0.10)\ \omega \cos \omega t = 0.62$ m/s, at time period $t = 2\pi/\omega = 0.54$ sec.

$\dot{X}_2 = (0.15)\ \omega \cos \omega t = 0.93$ m/s, at time period $t = 2\pi/\omega = 0.54$ sec.

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$\dot{X}_2 = (0.20)\,\omega \cos \omega\, t = 1.24\ \mathrm{m/s}$, at time period $t = 2\pi/\omega = 0.54$ sec.

$\ddot{X}_2 = -\omega^2 \cdot x_2 = 39.29\ \mathrm{m/s^2}$

$\ddot{X}_2 = -\omega^2 \cdot x_2 = 78.58\ \mathrm{m/s^2}$

$\ddot{X}_2 = -\omega^2 \cdot x_2 = 117.88\ \mathrm{m/s^2}$

$\ddot{X}_2 = -\omega^2 \cdot x_2 = 208.65\ m/s^2$

V. Result and Discussion

The acceleration is to be measured with assumption of different road condition and at two speeds

In following table.

Speed	Road One	Road Two	Road Three	Road Four
(Km/Hr)	(0.05 m/s^2)	(0.10 m/s^2)	(0.15 m/s^2)	(0.20 m/s^2)
20	1.77	3.73	5.41	7.11
40	39.29	78.58	117.88	208.65

Table.3. Shows results of acceleration is to be measured with assumption of different road condition and at two speeds

Along with that graphical representation of comparison between speed, vehicle acceleration and road roughness.

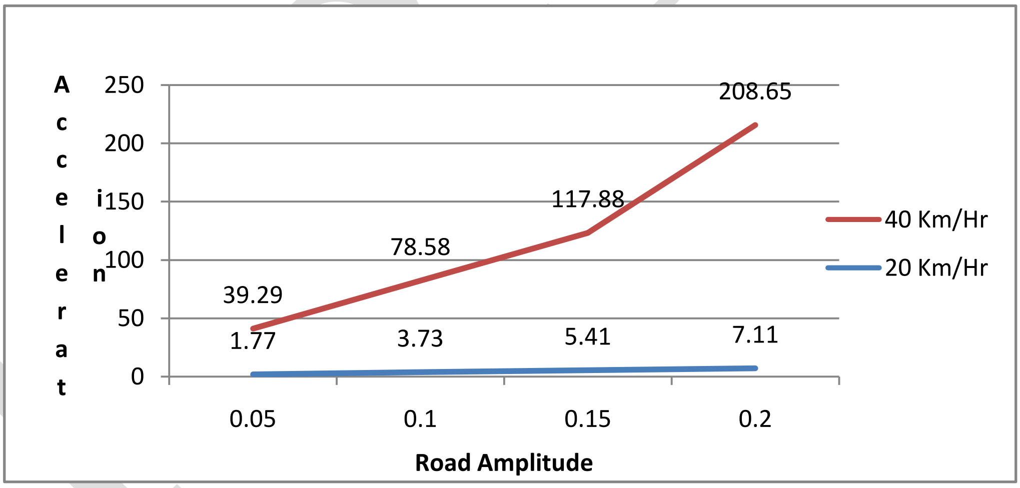

Fig. 4. Shows comparison between road amplitude and acceleration.

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.

VI. Conclusion

Acceleration because of is a physical disturbance that occurs in vehicles. The nature of vibration present in a vehicle depends upon the dynamic characteristics of the two wheeler and road surface characters. Its effect on

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the human body depends mainly on the acceleration, frequency, magnitude, direction of vibration, area of contact and duration of exposure. Exposure to human body will result in transmission of vibratory energy to the entire body and leads to localized effect. It affects comfort, normal functioning of body and health. Exposure to certain frequencies of vibration may have effects on specific segment of the body. 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. So from above analysis we may going to conclude that as rise of speed or amplitude may vary that should directly affected to acceleration of body, hence still we have scope to redesign of shock absorber to reduce vibration as possible.

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