International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Special Issue, Vol. 1, No. 1, January 2014
National Conference on "Recent Advances in Mechanical Engineering" RAME – 2014

Research Paper

PULSE ROAD TEST FOR EVALUATING HANDLING CHARACTERISTICS OF A THREE-WHEELED MOTOR VEHICLE

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Amid, the fastest growth of automotive industry and due to constant depletion of earth's energy resources automotive transportation will become smaller and lighter like three wheeled vehicle, in the search for better fuel efficiency. Regarding road safety and accident avoidance capabilities, handling behaviour of road vehicles is very important. Handling characteristics of road vehicle can be well determined by theoretically as well as experimentally. Practical testing methods are accurate and easy to reproduce. The various transient response test procedures, like step steering test, random steering test, sinusoidal steering test, steering sweep test, pulse input test etc. are popular in automobile industry. In this paper, pulse road test has been performed for a three-wheeled motor-vehicle due to its wide range of frequency and driver-vehicle system combination. It doesn't require much skill of a driver, as well as wide proving ground is required since test vehicle runs almost straight. Data are recorded using LAB View signal express software and these data are used for evaluating handling parameters for a three-wheeled motor-vehicle using MATLAB® code.

Keywords: Pulse road test, Handling behaviour, Handling parameters, Three wheeled vehicle

INTRODUCTION

Three wheeled vehicle configurations are commonly employed for automatic guided vehicles, mobile robot and passenger transport units, popularly known as tempos and autorickshas. The three wheeled motor vehicle likely to be most popular in India typically have a steering system like those of motorcycle and scooters with a single wheel in the front and the two wheels in the rear, with the differential and suspension system similar to those of automobile.

The handling characteristics of a road vehicle are concerned with its response to steering commands and to environmental inputs, such as wind gust and road disturbances that affects its direction of motion. Two basic problems come in picture regarding handling, one is the control of the vehicle to a desired path and other is the

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stability of vehicle motion. Subjective and objective measures of vehicle handling were carried out by Chen *et al.* (1998) and Data *et. al.* (2002). Schiehlen (1984) describes steering step input road test for four wheeled vehicle. A transient response test with steering pulse-input is the most popular test due to its good performance. Transient Response Test Procedures for Measuring Vehicle Directional Control were well described by Mukul K. Verma (1981). Pulse input test ideally requires an input of steering angle as impulse-function to road vehicle travelling at a constant speed. The dynamic state of the road vehicle, at any speed is then defined by gain (ratio of output to input) and phase difference between the input (steering angle) and the output (such as the lateral acceleration, yaw rate, etc.) as a function of input (steering) frequency. Starkey (1993) derived the yaw rate and side slip frequency function for a highway vehicle, using yaw-plane handling model. The dynamic parameters in this function (time constants, steady-state gains, natural frequencies, and damping ratios) are derived in terms of vehicle design parameters.

EXPERIMENTATION

An experimental setup has been fabricated to evaluate handling behaviour of the Bajaj-RE three wheeled vehicle. Rotary potentiometer used for measuring steering angle as input and accelerometer used to measure lateral acceleration as output of the three wheeled vehicle. The main objective of this experimentation is to record the real time signal of steering angle as input and lateral acceleration as output of three wheeled vehicle and evaluate handling parameters.

Figure 1 shows the schematic diagram and Figure 2 shows the experimental setup of Bajaj-RE three wheeled vehicle.

Figure 1: Schematic Diagram of Experimental Setup

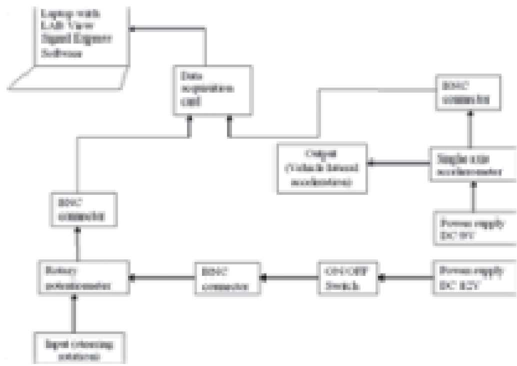


Figure 2: Experimental Setup of Bajaj-RE Three Wheeled Vehicle with Two Passengers

METHODOLOGY

A transient response test with steering pulse-input is the most popular test and has good performance. It gives wide range of frequency and driver-vehicle system combination and required straight proving ground. Pulse input test ideally requires an input of steering angle as impulse-function to road vehicle travelling at a constant speed.

Fabrication has been done for attachment of rotary potentiometer and accelerometer.

Potentiometer is attached at the centre of steering axis by clamping and accelerometer is mounted at the center of gravity of Bajaj-RE three wheeled vehicle by adhesive mounting.

To conduct the road test, the required amplitude of steering angle (around 4 degrees) in pulse form is given to the running test vehicle at specified constant speed like 20 km/h, 30 km/h, 40 km/h, because three wheeled vehicles are generally used in small city for transportation and they run with maximum speed not more than at 45 km/h. Pulse width of 0.15 s is determined to cover sufficient frequency range. The three wheeled vehicle (Bajaj RE) is driven at constant speed, the steering angle input of around 4 degrees is given in pulse form. The steering angle is measured through rotary potentiometer, while the output (lateral acceleration) is recorded using capacitive single axis accelerometer.

DC power supply of 12V is given to rotary potentiometer as input and corresponding voltage is recorded as output. This output voltage of rotary potentiometer is input for DAQ card which is connected to laptop through USB cable. A 9V DC battery is source of power supply for accelerometer.

EVALUATION OF HANDLING PARAMETERS

Data from road tests are not sufficient for evaluating handling behaviour of road vehicle.So,MATLAB codes are generated for the evaluation of handling parameters. Data are recorded for each input (steering angle) and output (lateral acceleration), with the help of rotary potentiometer, single axis accelerometer and LAB View signal express software, then the frequency response is calculated from the output/input ratio. The transfer function between input (steering angle θ) and output (yaw velocity γ') is given by, Kamachi et.al. [3] as follows:

$$\frac{\gamma'}{\theta} = \frac{A_G(1+T_G s)}{1+\frac{2\xi}{\omega_n}s+\frac{s^2}{\omega_n^2}} \quad ...(1)$$

where, A_G = steady-state gain

T_G = time constant

ω_n = natural frequency

ξ = damping ratio

γ' = yaw velocity

θ = steering angle

Handling evaluation should have many evaluation parameters, which affect each other. Steady state gain "a1", natural frequency "fn" and damping ratio "ξ" from yaw velocity response data, phase delay "φ" at 1 Hz from lateral acceleration response will help recognize vehicle performance, Mimuro *et.al* (1990) . Steady state gain of yaw response indicates the capability of producing yaw velocity per unit steering angle. Damping ratios determine vehicle oscillation response. Phase lag indicates, the vehicle response as steering angle given as input. For vehicle roll mode, natural frequency is generally found between 1 Hz to 1.14 Hz, so for the purpose of comparison between different vehicles handling performance 1Hz is taken as a standardfrequency. These handling parameters are evaluated with the help of MATLAB code and are given in Table 1.

Table 1: Handling Parameters Value at Different Speeds

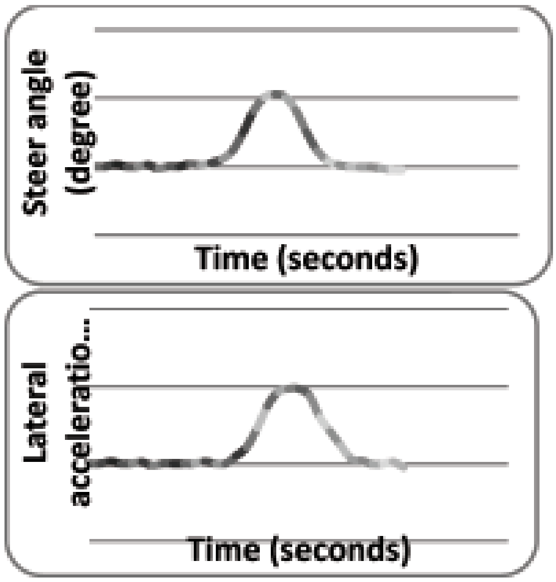
V(km/h)	a1 (1/s)		fn (Hz)		ξ		φ (Degree)		Time Constant (s)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
20	3.678	0.0834	0.7152	0.0127	0.861	0.0128	–73.9286	0.18125	0.2219	0.0145
30	2.26	0.064	0.6479	0.026	0.788	0.019	–79.3702	0.546	0.2456	0.0196
40	2.07	0.05	0.6301	0.117	0.756	0.1024	–82.5618	0.11509	0.2526	0.0315

RESULTS AND DISCUSSION

Handling evaluation is one of the most attractive and confusing themes in automobile engineering. The handling characteristics of a road vehicle are concerned with its response to steering commands and to environmental inputs, such as wind gust and road disturbances that affects its direction of motion. Suspension and tyre designers want to know how their design parameters contribute to handling characteristics and test drivers want to know where their feelings are derived from.

Three wheeled vehicles are generally used for travelling within the city with maximum speed not exceeding 45 km/h. So for the purpose of road test, the three wheeled vehicle (Bajaj RE) is driven at three constant speeds (20 km/h, 30 km/h, 40 km/h), for five trial and the steering angle input of around 4 degrees is given in a pulse form. To ensure the linearity of the vehicle motion, the steering-angle peak is applied such that the lateral acceleration peak is less than 0.3 g. Pulse width of 0.15 second is determined to cover sufficient frequency range. Time waveforms (steering angle and lateral acceleration) of experiment results are shown in Figure 3(a), (b) and (c) for three speeds.

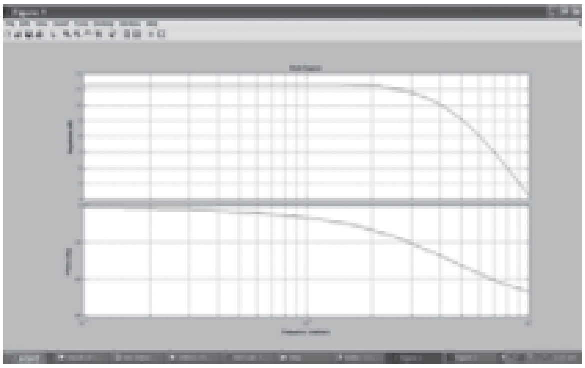
Figure 3: Steer Angle Response and Lateral Acceleration Response at 20 km/h



In accordance with Equation (1), the denominator for transfer function is set to be of second order and the numerator is set to first order. Bode diagrams of calculation results are shown in Figure 4(a), (b), and (c) for three speeds.

To express four parameters in a rhombus will help recognize vehicle performance intuitively. The key point of this method is making it possible to see the parameters that contradict each other at a glance. The area of

Figure 4: Bode diagram of transfer function (speed of vehicle at 20 km/h)



the rhombus denotes vehicle handling potential and the distortion denotes the handling tendency. Figure 9 shows the rhombus of three wheeled vehicle at speeds 20 km/h, 30 km/h, and 40 km/h.

From Figure 5 it reveals that, when vehicle speed increases from 20 km/h to 30 km/h area of rhombus decreases by 57.29% and when its speed again increases from 30 km/h to 40 km/h, then area of rhombus decrease further by 14.16%. Hence, with increase in speed, handling potential of three wheeled vehicle decreases as area of rhombus decreases.

Figure 5: Rhombuses of Three Wheeled Vehicle at Different Speed

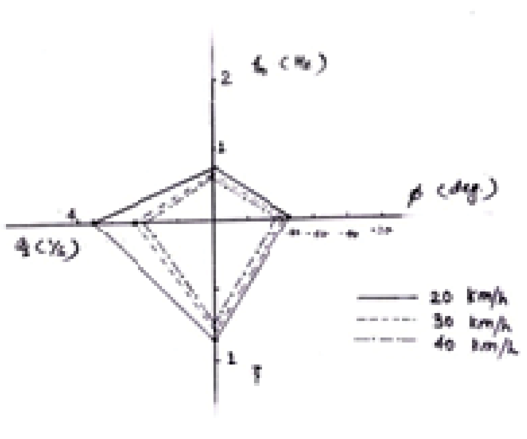


Table 1, shows that the capability of driver to produce yaw velocity per unit steering angle, i.e. steady state gain decreases (3.6781/s to 2.071/s) with increase in speed from 20 km/h to 40 km/h. As we give steering angle as input, the output yaw velocity decreases as speed increases, which denotes the poor handling behaviour of three wheeled vehicle.

The damping ratio for yaw velocity response data decreases from 0.8608 to 0.7558.Less damping indicates more oscillation. Hence, when the vehicle goes on road, it oscillates more as speed increases, which indicates bad handling characteristics.

Phase lag at 1 Hz of lateral acceleration increases from -73.9286 degree to -82.5618 degree, it means vehicle response to produce lateral acceleration increases as speed increases from 20 km/h to 40 km/h, which is not desirable for better handling behaviour.

The time constant values increase from 0.2219 second to 0.2526 second, with increase in vehicle speed, indicates that the vehicle takes more time to produce its response, which is not desirable for better handling.

The standard deviations of steady state gain, Natural frequency, Damping ratio, and Phase lag at 1 Hz of lateral acceleration for all speeds are less than 1, which indicates that there are no much more variations in recording the data and this method is easy to reproduce.

CONCLUSION

The four parameter evaluation method could be easily applied for three wheeled vehicle also. Handling behaviour has been analysed at different speeds for Bajaj RE three wheeled vehicle. The overall handling quality of a vehicle depends to a great extent on its transient behaviour. Vehicle handling potential decreases with increase in speed and handling parameters are analysed, that contradict each other at a glance.

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