EXPERIMENTAL INVESTIGATION IN ACCELERATION OF VEHICLES

Andris Linins, Dainis Berjoza
Latvia University of Agriculture, Faculty of Engineering, Motor Vehicle Istitute
dainis.berjoza@llu.lv

Abstract. Today, there is a variety of automotive constructions with different suspension designs that affect the character of running. Specific suspension may be more or less suitable for road and traffic conditions. Vehicle speed variations and acceleration can significantly affect cargo maintaining and passenger comfort, so these parameters were chosen for the object of the study. A method for recording and analyzing vehicle acceleration was developed and approbated. Vehicle suspension systems may be suitable for different motion modes and the road conditions and influences of the smoothness of running, handling and acceleration in the transverse direction. The main automotive softness indicators are technical frequency and angular frequency. Characteristics of running softness depends on the road surface and driving.

Keywords: acceleration, direction of acceleration, driving comfort, measurement methods, device.

Introduction

Vehicles of different age and technical condition are being exploited on roads with various condition levels in Latvia. Some vehicles are operated off-road. Acceleration in different directions seriously affects the cargo compartment and the passengers.

The study aims to find out what forces are acting on the vehicles, if to drive at different speed modes along different routes and cover corners. The investigational item is a vehicle, acceleration values and directions. The vehicle, the nature of the motion set at different driving modes, and bottom coverage of asphalt roads, as well as the acceleration changes in the law - in the city and beyond. So far, no approbated methodology for evaluating acceleration of the automotive operating conditions has been developed in Latvia. A simple method was developed during trials for accurate determination of the vehicle acceleration of an accelerometer EK3LV02DL. The method approbated tests of the car RENAULT TRAFFIC.

Materials and methods

Ride comfort. In general, passenger ride comfort boundaries are difficult to determine because of the variations in individual sensitivity to vibration and of a lack of a generally accepted method of approach to the assessment of human response to vibration. Considerable research has been conducted by a number of investigators in an attempt to define the ride comfort limits. A variety of methods for assessing human tolerance to vibration have been developed over the years. They include the following.

1. Subjective Ride Measurements. The traditional technique for comparing the vehicle ride quality in the automotive industry in the past was to use a trained jury to rate the ride comfort, on a relative basis, of different vehicles driven over a range of road surfaces. With a large enough jury and a well-designed evaluation scheme, this method could provide a meaningful comparison of the ride quality of different vehicles. The degree of difference in the ride quality cannot be quantitatively determined by this type of subjective evaluation.

2. Shake Table Tests. In an attempt to quantitatively study human response to vibration, a large number of shake table experiments have been performed. Most of this research pertains to human response to sinusoidal excitation. It is intended to identify the zones of comfort or discomfort for humans in terms of vibration amplitude, velocity, or acceleration in a given direction such as foot-to-head, side-to-side, or back-to-chest, over a specific frequency range.

3. Ride Simulator Test. In these tests, ride simulators are used to replicate the vibration of the vehicle travelling over different road surfaces, in some facilities an actual vehicle body is mounted on hydraulic actuators, witch reproduce vehicle motions in pitch, roll, and bounce or heave. Road inputs are fed into the actuators. Using the simulator, it is possible to establish the human tolerance limits in terms of vibration parameters.

4. Ride Measurements in Vehicle. The shake table tests and ride simulator tests described above are conduced under laboratory conditions. They do not necessarily provide the same vibration

environments to which the passenger is subject while driving on the road. Therefore, on-the-road ride measurements, particularly for passenger cars, have been performed. This test method attempts to correlate the response of test subjects in qualitative terms, such as “unpleasant” or “intolerable,” with vibration parameters measured at the location where the test subject is situated under actual driving conditions [1].

Any variation in the body can be described using the following parameters: oscillation period T, amplitude z, angular frequency ω_{sv} and technical frequency n_{sv}, speed of v_{sv}, fluctuations in the rate of change of speed or acceleration j_{sv}, fluctuations in the mean square acceleration δ_{sv}, the rate of change of acceleration j_{sv}. It is often used to describe fluctuations in the technical frequency n_{sv}, oscillation/min, which is characterized by fluctuations in the number per minute:

$$n_{sv} = \frac{1}{T} \text{ [Hz]}, \quad (1)$$

where T – oscillation period, s.

Motor fluctuation effects on the human organism depend on the oscillation frequency, amplitude, fluctuations in intensity, direction and duration of exposure, so this effect on the human organism is very impressive. The human body has best suited-oscillation parameters that are specific to the human body movements. Depending on the speed of walking oscillation frequency changes in the human body, and people are best adapted to fluctuations in the frequency of the n_{sv} = 65-110, and they cause the least fatigue. If the oscillation frequency is less than 60 fluctuations·min^{-1}, people feel the swinging, especially if there are large-amplitude fluctuations. Conversely, if the oscillation frequency exceeds 150 oscillations·min^{-1}, the fluctuations are unpleasant, harmful and cause fatigue. From these observations also it is desirable that the vertical oscillation amplitude does not exceed 35-40 mm. It has been experimentally shown that the human body is most sensitive to vertical movements, feels the fluctuations in the longitudinal direction and is very sensitive to fluctuations in the transverse direction. If the fluctuation rate is up to 0.035 m·s^{-1}, they are felt, if the speed is 0.1-0.2 m·s^{-1}, they are felt, and if the speed is above 0.3 m·s^{-1}, the fluctuations are uncomfortable. With increasing oscillation frequency, even small fluctuations in the acceleration in humans can cause discomfort (Table 1).

Table 1

Fluctuation of acceleration effects on human body

Oscillation frequency, n_{sv}, oscillations·min^{-1}	**Human sense that depends on oscillation acceleration, m·s^{-2}**	
	unpleasant	**painful**
60	2.3	2.7
90	2.1	2.5
120	1.9	2.3
180	1.7	2.0

Fluctuations in the car after their exposure to the human body can be divided into two groups: high-frequency fluctuations with what mainly the car wheels vary (1080-90 000 fluctuations·min^{-1}) and low-frequency fluctuations (up to 1080 fluctuations·min^{-1}), with what essentially the car body varies. When exposed to the frequencies of the car body fluctuations, the speed of acceleration changes has a great importance. If the fluctuation rate of the change of acceleration exceeds 25, m·s^{-3}, it causes discomfort for humans, but reaching 40 m·s^{-3} – they are very poorly tolerated [3].

Over the years, numerous ride comfort criteria have been proposed. One of such criteria for vertical vibration is described in the Ride and Vibrations Data Manual J6a of the Society of automotive Engineers. The recommended limits shown in the figure are also referred to as Janeway’s comfort criterion. It defines the acceptable amplitude of vibration as a function of frequency. It can be seen that as the frequency increases, the allowable amplitude decreases considerably. The Janeway comfort criterion consists of three simple relationships, each of which covers a specific frequency range. In the frequency range 1-6 Hz, the peak value of jerk, which is the product of the amplitude and the cube of circular frequency, should not exceed 12.6 m·s^{-3}. For instance, at 1 Hz (2π rad·s^{-1}), the recommended limit for amplitude is 12.6 m·s^{-3} $(2\pi \cdot s^{-1})^{-3}$ = 0.0508 m. In the frequency range 6-20 Hz, the peak value of acceleration, which is the product of the amplitude and square of the circular frequency, should be less than 0.33 $m \cdot s^{-2}$, whereas in the range 20-30 Hz, the peak value of velocity, which is the product of the amplitude and circular frequency, should not exceed 2.7 mm s^{-1}. It should be noted, that Janeway's comfort criterion is based on the data for vertical sinusoidal vibration of a single frequency [1].

Experimental studies of acceleration. The investigational object is a car produced in 2007 Renault Traffic (gross weight of 2835 kg, 1957 kg unloaded weight, tires 195/65R16C Roadstone EURO-WIN 650, the tread depth of 8 mm, tire pressure 3.4 bar front axle, rear axle 3.7 bar, the chassis type front axle independent McPherson-type suspension, dependent rear suspension system with a monolithic bridge beams and leaf springs, 1995 cm^3 diesel engine with 66 kW power).

The studies were conducted in 2009, on the 15th and 22nd of April in Jelgava, Jelgava region, Dobele and the region. The weather conditions were good, the wind speed was 2-3 $m \cdot s^{-1}$, the air pressure 770 $mm \cdot hg^{-1}$, no precipitation was. The bottom roads were in good condition, recently graded without pits.

In total in the experiments 99 426 measurements were obtained, of which the selection for characterization of specific motion regimes was done. Only the data, obtained performing the tasks in the planned regimes – different driving modes along the bottom road out of town, were used and processed.

In the experiments two devices were used:

- ELM SCAN 5 USB which transforms the engine speed and speed signals sent from the car in a format that may be perceived to be used by a computer program.
- EK3LV02DL 3 sharp outgoing low-voltage linear accelerometer or g sensor.

The *AUTO PROCESS MONITOR* can write data from the two facilities. First, calibrating accelerometer for changes to program settings. Calibration settings for each channel window installed in the appropriate parameters.

Technology research program.

1. Vehicles placed in a flat position. Turn on the ignition, the added diagnostic nest ELM SCAN 5USB converter.
2. Plug the computer power unit SBS adopter Car Notebook PC A090 cable car 12 V socket. Measuring equipment connected to the signal wire to the computer.
3. Place the tripod in the car accelerometer steel plate and secure to an accelerometer attached EK3LV02DL (Figure 2a).
4. Turn on the accelerometer program. Indicate a connection port and press the button "connect" the accelerometer illuminates the green diode. Then press the "start" button and "dir detect" – moving the accelerometer in the set operational direction. Once all parameters are entered, an accelerometer is attached to the stand in the car stand and levered.
5. The *AUTO PROCESS MONITORS* program is opened. The monitoring mode, data are shown in the graph in real time. Each channel corresponds to one specified colour line. The channels are in the following order: revolutions per minute (rpm), speed, air flow (MAP), 3 axis of accelerometer (Figure 1).
6. During the pilot runs the value of different driving modes was fixed in the computer. Depending on the time axis data the driving regime is recorded in the experiment notes. They are used for identification of the corresponding motion regime, through data processing after the experiment.

Results and discussion

Vertical acceleration Z studies have been conducted on ground travel, with 8-speed modes from 20 to 90 $km \cdot h^{-1}$ in increments of 10 $km \cdot h^{-1}$. The experiments were made on a highway to Dobele, Jelgava, Līvbērze.

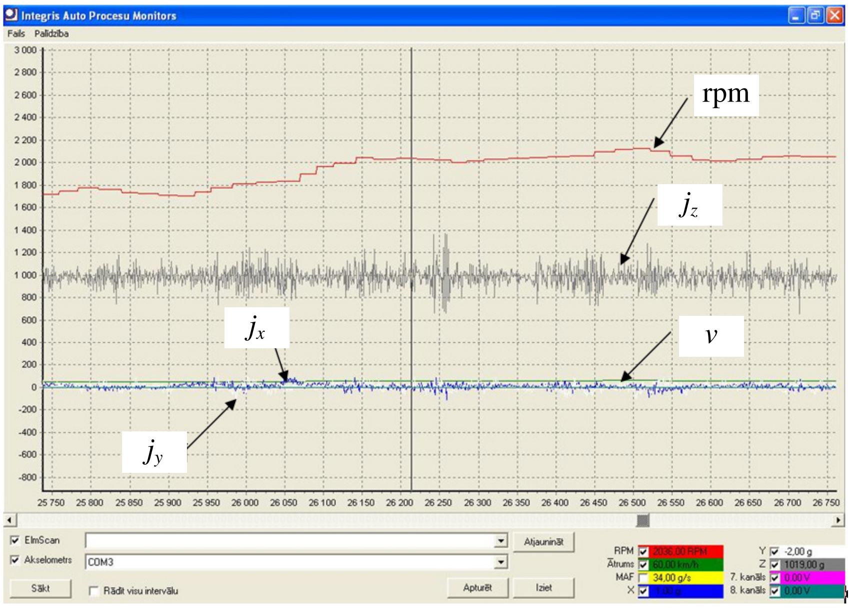

Fig. 1. **APM curve while driving at a speed of 60 km·h^{-1}**

Figure 1 shows the monitor window during the experiment on gravel road at speed v = 60 km·h^{-1}. From the acceleration curves of the data selection, the curves are designed in Figure 2. A separate increased vertical acceleration curve can be seen on Figure 3.

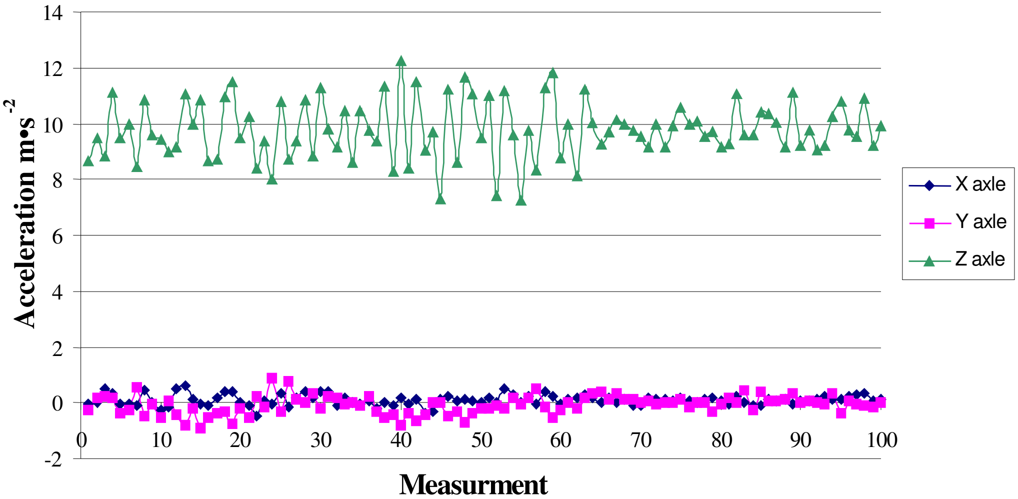

Fig. 2. **Value of acceleration driven at a speed of 60 km·h^{-1}**

The car body frequency at 60 km·h^{-1} on the bottom of travel:

$$n_{sv60} = \frac{1}{T} = \frac{1}{0.95} = 1.05 \text{ [Hz]} \tag{2}$$

The average vertical acceleration in this mode was 0.82 m·s^{-2}, the maximum vertical acceleration at 2.57 m·s^{-2}; as Table 1 shows this treatment results in human motion discomfort. The oscillation period T was calculated between the major peaks in the measurement range. Each subsequent measurement is recorded on each of 0.05 s. In-between the 1st and 2nd highest peak there were 19 measurements.

To analyse the mutual acceleration values demonstratively in different driving regimes Figure 4 was developed where the average acceleration values in the researched motion regimes are summarized. With increasing of the motion speed on gravel roads the vertical acceleration has a tendency to decrease at 70-80 km·h^{-1}, that could be related to coincidence of the body oscillation frequency with the suspension oscillation frequency or resonance.

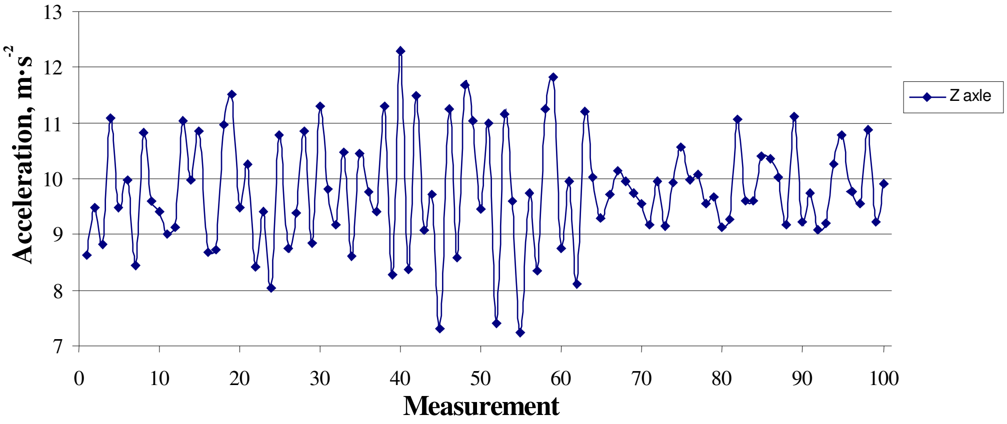

Fig. 3. **Vertical acceleration values**

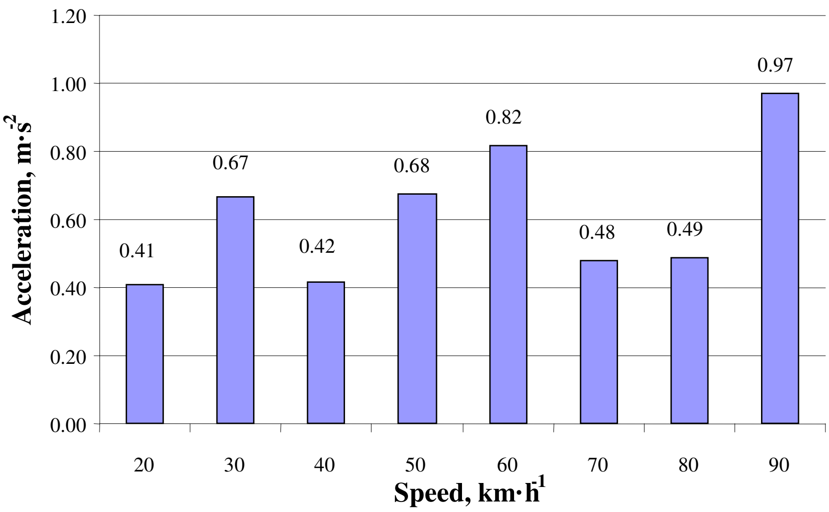

Fig. 4. **Vertical acceleration changes in various driving modes**

Conclusions

1. Automotive suspension systems may be suitable for different motion modes, and the road conditions and influences, mainly the car running smooth, handling and acceleration in the transverse direction.
2. The developed experimental methodology was approved and recommended for use in further research. In the next stages of the research the operation journal is to be replaced by synchronized web-cameras.
3. Increasing the movement velocity on the bottom of the road surface, the vertical acceleration has a tendency to decline at 70 to 80 60 km·h^{-1}, which could be related to coincidence of the body self oscillation frequency with the suspension oscillation frequency, or resonance.
4. Determining the frequency of various modes of technical regimes, it can be determined by what optimal rate people should be transported to feel comfortable in the particular vehicle.

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