AN ASSESSMENT OF TRAILER SUSPENSION DYNAMIC BEHAVIOR VIA VIBRATION MEASUREMENTS

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Abstract

A dynamic response of a semi-trailer suspension to a real road profile under two different loads was investigated in this study. The trailer was a low loader for transporting heavy and large loads which configuration could be adjusted to the current needs. During the described investigation the vehicle was composed of: detachable gooseneck, maximally extended low bed and 5 hydraulically steered axles comprised 2-axle and 3-axle assemblies. The experiments were performed for unloaded and loaded with 60 tons trailer, that was equal to maximum trailer pay load. Acceleration measurements at unsprung and sprung parts of the vehicle were applied. As a test surface a railway track crossing was chosen. Acceleration time series were analysed by the means of power spectral density. The isolation of free vibration and forced vibration frequencies and effectiveness of suspension damping over wide frequency range was done. Two characteristic signal bands were identified. In the frequency range up to 10 Hz vehicle vibration energy decreased for the load increase for both, sprung and unsprung parts. In contrast, in the range between 10 and 25 Hz at higher load increase of vibration energy was noticed, however only at unsprung mass. Data analysis revealed complexity of vehicle vertical acceleration as a response to the road profile. Nevertheless, it allowed for estimation of the trailer dynamic loads under real road conditions.

Keywords: *road transport, exceptional transport, semi-trailer, vibration measurements, suspension dynamics*

1. Introduction

The effect of a rough road surface on vehicle vibrations, and in particular, on the driver, passengers and load is still a subject of research among automotive manufacturers and research groups [1, 8-10], including authors [2, 7]. To better understand the behavior of different types of vehicle suspensions, there are many tests carried out under real road conditions. These tests are performed in order to identify and optimize the suspension parameters [6] and to minimize tire wear [3].

The relationship between anti-vibration performance and characteristics of a vehicle suspension has been recently analyzed by Zhang and Ren [12]. Based on real experiments, several models have also been developed which take into account both the kinematic road curvature and/or internal vehicle excitations [6, 11]. In addition, virtual tests have been proposed to study the damping characteristics of the suspension system [4]. There is much less literature dedicated to investigation of semi-trailer suspensions, especially heavier ones of modular design.

The aim of this study was analysis of vibration and estimation of dynamic loads acting on the main supporting structure of the trailer during its operation in different road conditions. The knowledge of the dynamic overloads is important during design process. The dynamic overloads should be taken into consideration in FEM analysis of the new design [5] as proper assumption of the overload factor influences the accuracy of calculations.

2. Experimental setup and procedure

The research was conducted on prototype of a modular semi-trailer for carrying oversized and heavy loads up to 60 tons. Depending on the requirements the length of the semi-trailer low platform can be expanded by 2 m with the step of 0.5 m, and the number of axles can be equal to 2, 3 or 5. The number of axles can be changed as a result of the modular structure of the trailer – it is possible to use the semi-trailer with: only 2-axle assembly, only 3-axle assembly or both of them (Fig. 1). All of the axles are equipped with steered twin wheels and tires 245/70 R 17.5. The nominal load of the axles is 12 000 kg. The maximum construction weight to the semi-trailer is 84 tons. The semi-trailer is equipped with a typical air suspension. The main parts of the suspension consisted of: control arm, air bag and hydraulic shock absorber.

a) low loader and its basic modules

b) low loader with extended platform and load

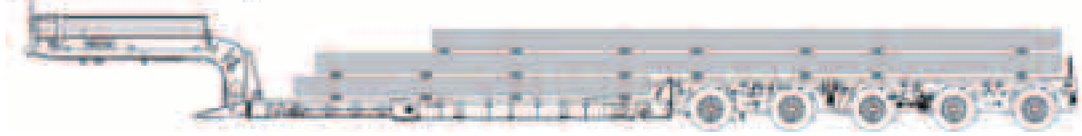


Fig. 1. Sketch of the semi-trailer used for investigation: a) unloaded and not extended (the main modules are shown), b) extended and loaded

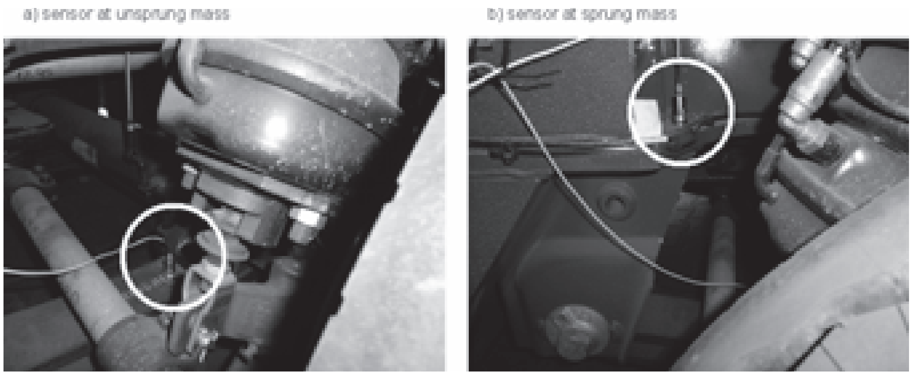
The vibration data was measured with the use of equipment from PCB Piezotronics. Single-axis accelerometers type ICP M338A34 with average sensitivity of 1 mV/(m/s^2) were used. Measurement range of the accelerometers was +/– 4900 m/s^2 and frequency range was equal from 1 to 2000 Hz. The acceleration signals were conditioned with the use of four channel amplifier type 482A16.

DAQPad 6070E from National Instruments was used for data acquisition. Maximum sampling frequency was 1.25 MHz and resolution of analog-digital converter was 12 bit. In order to utilize whole scale of the converter, voltage amplification of the signals was set to 100 and measurement range was varied according to maximum signal amplitude.

During the research 4 vibration transducers, mounted on the front axle of trailer suspension were used. Two transducers were mounted at flat spring rocker arms close to the wheel axes and two were mounted on the body above rocker arms mounting pins. Position of the accelerometers is presented in Fig. 2. Such configuration of the measurement points allowed for measurement of both sprung (body) and unsprung (wheels axles) vibrations.

During the experiments the semi-trailer was hauled by a 3-axle semi-trailer truck. Measurements were done on the unloaded and not extended semitrailer (Fig. 1a) and on extended to the maximum and loaded semi-trailer with evenly placed 60 tons mass (Fig. 1b). The vehicle was driven unloaded and loaded at two speeds of 20 and 40 km/h through the same road section in the same direction. As a test surface asphalt road with double-track railway crossing was chosen.

The vibration data was recorded in parallel from 4 measurement transducers with sampling rate of 20 kHz per channel. At each measurement point 20 000 samples were recorded. Data analysis was done by means of power spectrum density obtained via fast Fourier transform.



a) sensor at unsprung mass

b) sensor at sprung mass

Fig. 2. Positioning of the accelerometers at the trailer suspension

3. Experimental results

Figure 3 presents time series of acceleration for speed equal to 20 km/h. It can be seen that for unloaded vehicle railway crossing did not produce the vibration of unsprung mass much higher than only road surface roughness. However, waves at the beginning of presented time series could be produced by passing of the truck through tracks. It also should be noted that for unloaded trailer amplitudes of unsprung and sprung mass are similar, what suggests that suspension does not provide proper damping of relatively light vehicle. At higher speed (Fig. 4) acceleration of sprung mass increases in a lesser extend in relation to unsprung mass vibrations.

In the case of loaded trailer damping of the vehicle suspension could be clearly visible, as shown in Fig. 3 and 4. Twice higher acceleration of unsprung mass versus unloaded case was effectively damped resulting with negligible acceleration of the vehicle body. As a result such suspension behavior minimizes dynamic forces acting on the trailer structure and carried goods.

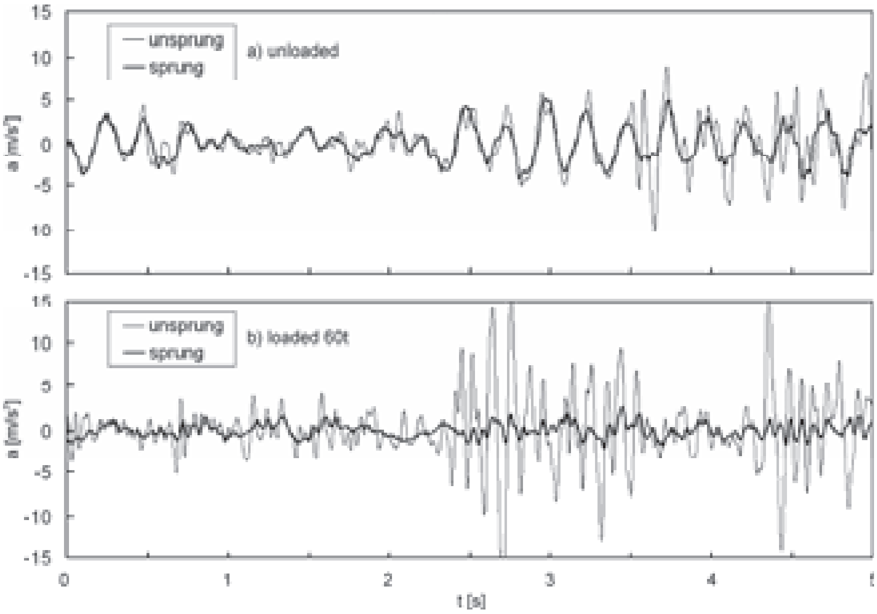


Fig. 3. Acceleration of unsprung and sprung parts of trailer suspension at vehicle speed 20 km/h, railway crossing at 2.3 s after start of measurement

Figures 5 and 6 present power spectrum density functions of the time series presented earlier for vehicle speed 20 km/h. For unloaded vehicle (Fig. 5) two characteristic frequency bands of approximately 4 Hz and 8 Hz can be isolated. It should be noted that power of the vibration signals had the same values for unsprung and sprung mass of the vehicle. Vibrations in the band from 10 Hz to 25 Hz generated by surface roughness were damped by suspension both for unloaded and loaded vehicle. Also, for loaded vehicle (Fig. 6) characteristic band of 8 Hz was not observed, however, band of 5 Hz was present both at unsprung and sprung masses at the similar level.

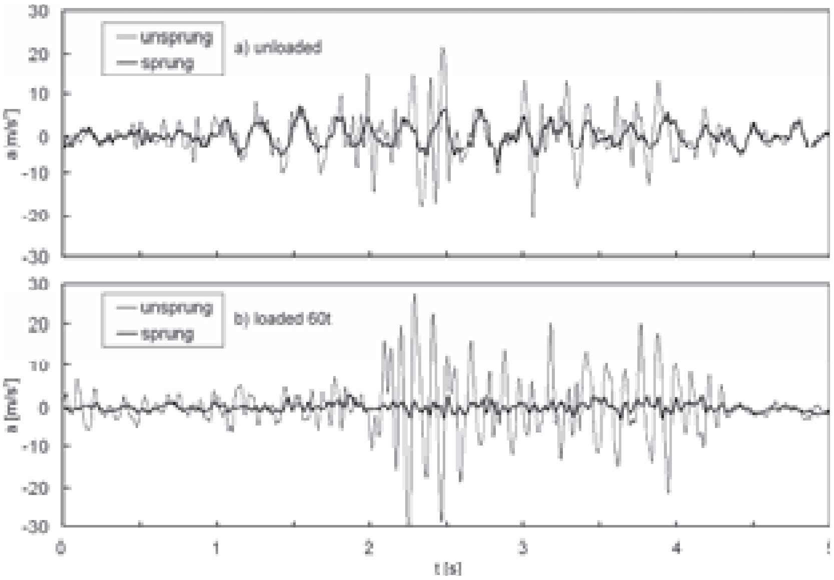


Fig. 4. Acceleration of unsprung and sprung parts of trailer suspension at vehicle speed 40 km/h, railway crossing at 1.9 s after start of measurement

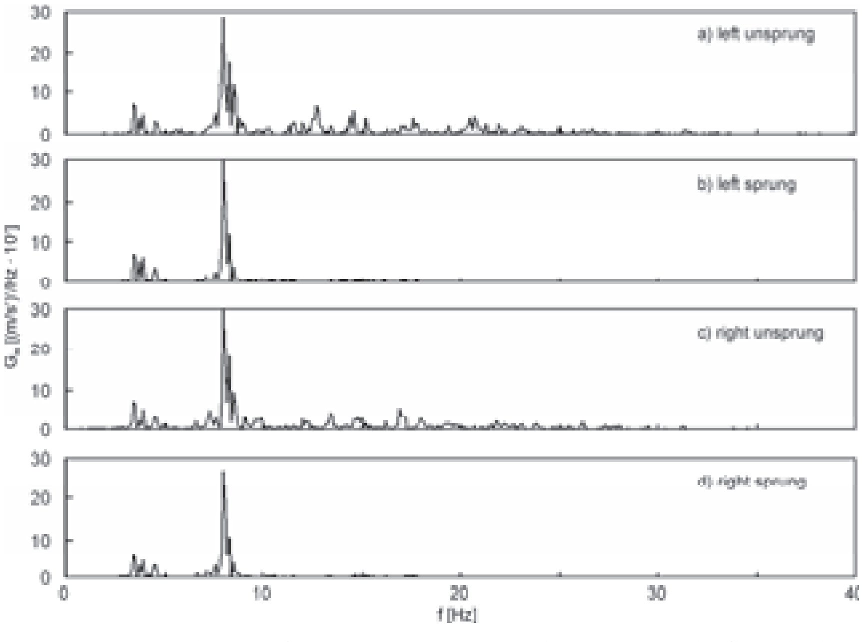


Fig. 5. Power spectrum density of trailer suspension acceleration at 20 km/h; vehicle unloaded

At higher vehicle speed of 40 km/h, behavior of the suspension differs from lower speed as shown in Fig. 7 and 8. In this case unsprung mass vibrations in the band from 10 Hz to 25 Hz are characterized by higher energy due to larger forces of cooperation of tires with the road surface. However, band of 8 Hz for unloaded vehicle is still present at the similar level, as well as band of 5 Hz for loaded vehicle.

4. Conclusions

Accelerations of unsprung and sprung masses were measured in order to assess the dynamic response of the semi-trailer suspension to the real road surface. Experiments were performed at two speeds of 20 and 40 km/h for the unloaded and loaded vehicle. Data analysis was done by

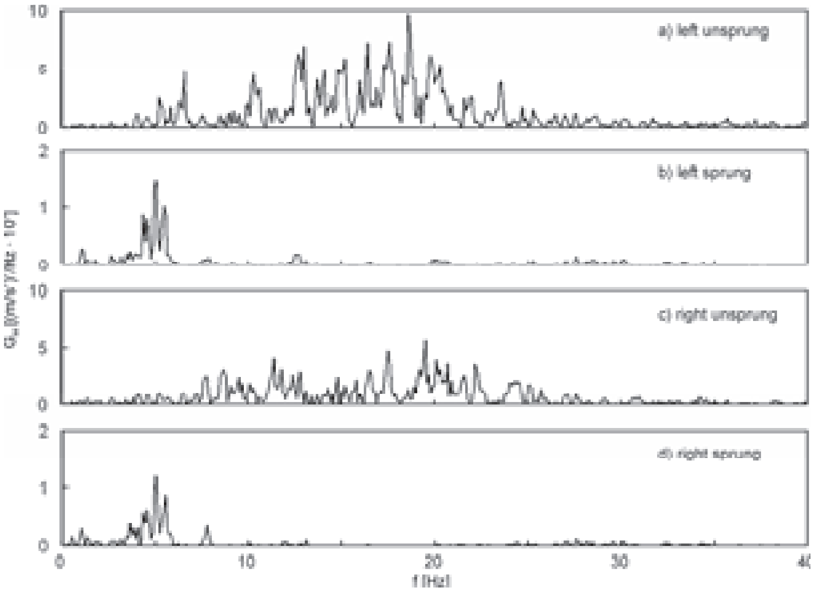


Fig. 6. Power spectrum density of trailer suspension acceleration at 20 km/h; vehicle loaded with mass 60 t; note different scales

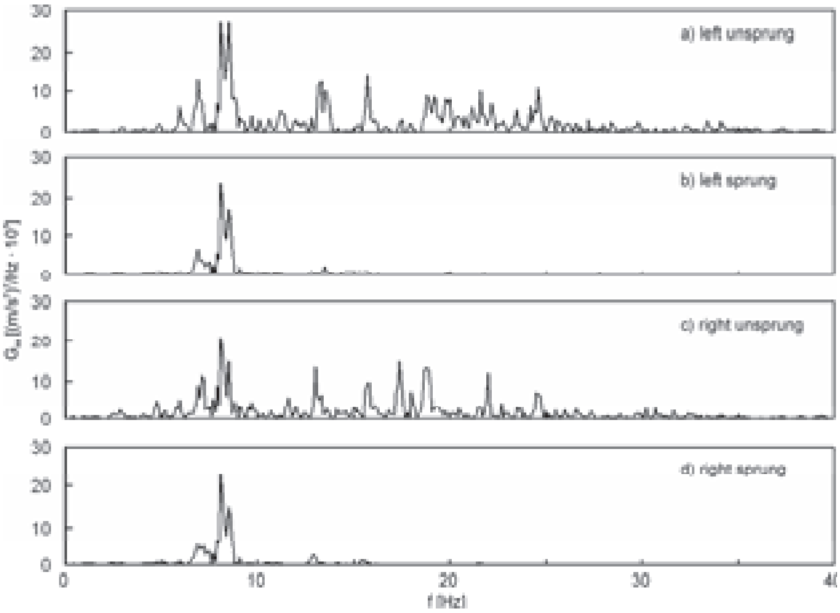


Fig. 7. Power spectrum density of trailer suspension acceleration at 40 km/h; vehicle unloaded

means of acceleration time series and power spectrum density obtained via fast Fourier transform.

The findings of this study are summarized below:

1. For unloaded trailer, acceleration amplitudes of unsprung and sprung masses in the low frequency range are similar, what suggests that suspension does not provide proper damping of relatively light vehicle.
2. In the case of loaded trailer, vehicle suspension provides effective damping resulting in negligible acceleration of the vehicle body.
3. In the range of higher frequencies, damping effectiveness increases both for unloaded and loaded vehicle.
4. The performed investigations proved correctness of the designed supporting structure and suspension of the semi-trailer. The higher the vehicle load, the more effective damping was observed. Suspension characteristics minimized dynamic forces acting on the trailer structure and carried goods.

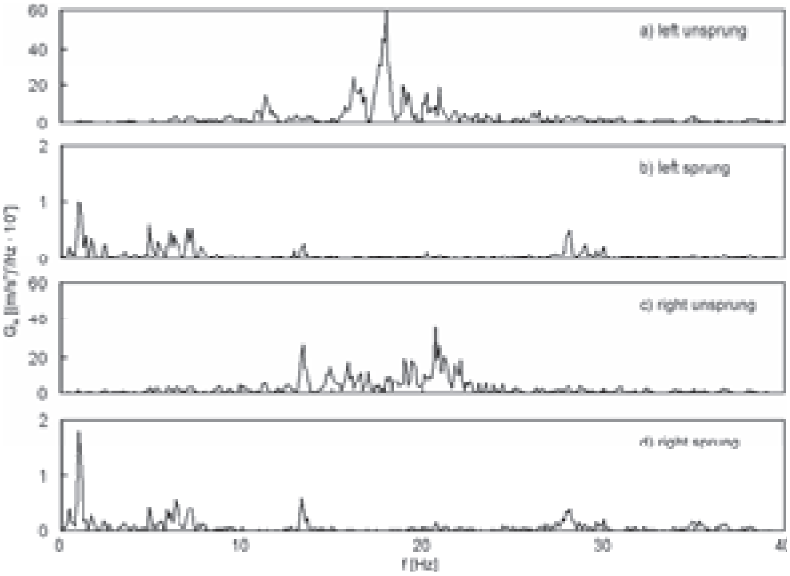


Fig. 8. Power spectrum density of trailer suspension acceleration at 40 km/h; vehicle loaded with mass 60 t; note different scales

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