VIBRATIONAL ANALYSIS OF ROAD CONDITIONS AND ITS RELATION WITH THE TRANSPORT OF FRAGILE FREIGHTS. MEXICAN CASE.

Alejandro LOZANO-GUZMAN[1] Juan C. JAUREGUI-CORREA[2]
Carlos S. LOPEZ-CAJUN[1] Jesús R. TAPIA-ARMAS[1]

(1) Instituto Mexicano del Transporte
Km. 4, Carretera Querétaro-Los Galindo
San Fandila, México

(2) CIATEQ
Calzada del Retablo 150
Querétaro, México

INTRODUCTION

The mexican economy is going through a great change. This involves adapting new technologies in most production activities. For these activities to be carried out succesfully, a better transport system is also required. Since almost 80% of the total cargo is transported by trucks, a good knowledge of the damage to delicate-freight due to road conditions is needed, in order to use the best-suited-transport equipment available. In fact, loses derived from damaging these freights accounts for a significant percentage of the total cargo cost. In this work, comparison of vibration patterns and their transmissibility to freight carried on trucks with two different suspension systems is reported, namely, leaf springs and air suspension. Although the latter is approximately 20% more expensive than the former, it seems to be more adequate for the transportation of certain type of freight.

Measuring vibrations on vehicles has been under study over the years. Moreover, the development of new transducers has opened the possibility of understanding and correlating more complex models. Amongst the studies regarding vibration analysis of vehicles, the state-of-the-art—by that time—was reported by Schneider (1976). In that work he presented the concepts of noise reduction and noise emission on vehicles. A procedure for conducting experimental research on torsional vibration of car bodies was reported by Simic, Jelic, and Aksic (1985). The purpose of that report was how to collect the necessary data and generate the appropiate models for laboratory tests. Hipol and Piersol (1987) developed a technique, using the finite element method, for the vibration prediction of structures under random vibration. The trends of suspension design for the 90's is described in Mabley (1989). In that work, he claimed that the growing acceptance of air suspension on heavy vehicles would lead significatively in improvements related to safety, control, and comfort. Indeed, the air suspension provides relatively low and variable spring rate and allows the improvement of the design of semiactive or adaptive suspension systems as the one shown in Fig. 1. Conceptually, such an air suspension could adapt to vehicle loading and deliver the same ride whether loaded or empty.

Vibration measurements were conducted using accelerometers. After processing the signals produced for these, a set of plots representing the vibration amplitude and frequency as a function of time was obtained. However, for this study, the dynamic-behavior difference between the two suspensions was identified by analysing the amount of energy being transmitted instead of analysing the direct plots obtained with the Fourier analyzer.

A mathematical model was developed in order to simulate the dynamic behavior of wide range of trucks under specified road conditions.

In the sections below, the experimental procedure is presented first, then the mathematical model and the parameter's identification is outlined. Experimental results are discussed in the third section, and the conclusions are presented in the final section.

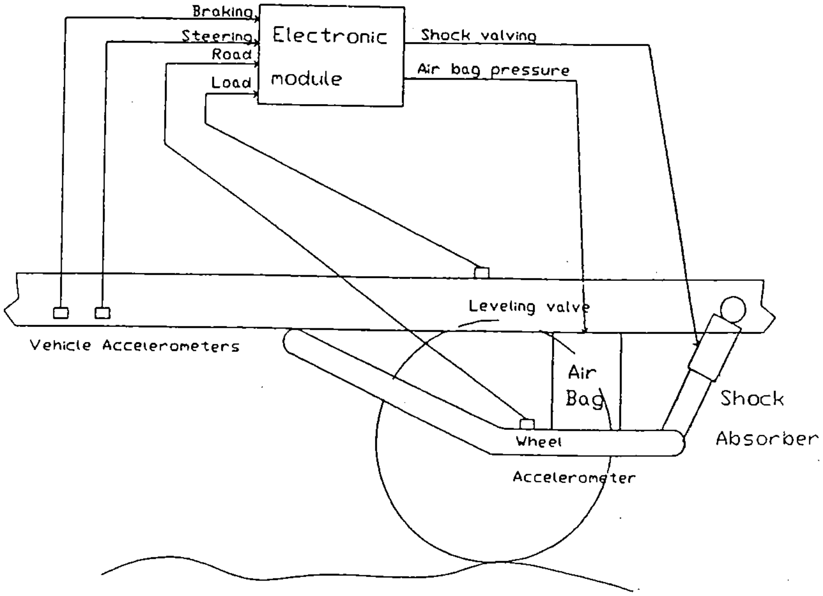


Fig. 1. Layout of an air suspension.

1. EXPERIMENTAL SETUP AND PROCEDURE

Tests were performed in pairs of 2 similar trucks. Each was equiped with a type of suspension under study, namely, leaf springs and air suspension. All tests were carried out on the same road and similar operating conditions. Moreover, the trucks were loaded with the same items, and they were driven by the same person. The experimental setup is shown in Fig. 2. It was composed of the items listed below:

- a piezoelectric accelerometer, with a sensitivity of 3.16 pC/ms^{-2} and a frequency response of 0.1 to 8,000 Hz;
- a charge preamplifier, with a sensitivity of 0.01 mV/pC to 10 V/pC and frequency range from 0.2 Hz to 100 kHz;
- a data logger; and
- a Fourier analizer.

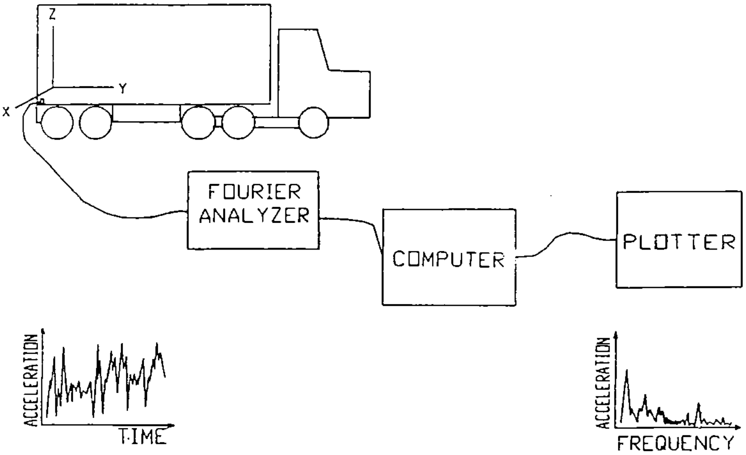


Fig. 2. Experimental setup.

The characteristics concerning dimensions, load, number of axles, tires' pressure and sizes, and the weight for each truck, were recorded. The road chosen was straight, located in a quite flat surface with a maximum slope of 2 % and roughness of approximately 3.00 m/km. A first test was run in order to define lower and upper limits of the measuring equipment. From this test, the main vibrations were identified to be within a frequency range from 0.2 to 1000 Hz. Higher frecuencies were detected, but these were due to structural vibrations rather than to suspension movement. Moreover, it was found that the accelerometers were sensible to their orientation rather than to their position. Indeed, a test with two accelerometers mounted over two different points of the rear axis showed that the results were similar regardless the position of the accelerometer. Therefore, it was decided to use only one accelerometer for each position.

Each test was divided in 4 stages of 10 minutes and the average truck speed was 70 km/h. In the first two stages the accelerometer was placed along the x and z directions in the rear of the truck as indicated in Fig. 2. In the last two stages the accelerometer was placed in the front of the truck along the aforementioned directions. At each stage, samples were recorded every 2 minutes as well as their corresponding speed and time.

2. RESULTS

Spectra taken for the tests and the corresponding to leaf springs and air suspension with the accelerometer placed on the rear are shown in Figs. 3 and 4. The square root of the integrated-averaged squared function is related to the vibration energy, and hence to the vibration's damage potential. The average rms of the acceleration for all tests are shown in Fig. 5. In that figure, the leaf-springs behavior is shown in dark whereas the air-suspension behavior is shown with crossed lines. At each stage, the rms values for acceleration, velocity, transmitted force, and kinetic energy are shown in Table 1. Moreover, it can be seen the dissipation effect of the shock absorbers for the case of air suspension. The results obtained with the model described below are shown in the same plot.

Table 1. Acceleration, transmitted force, speed, and kinetic energy.

	acceleration (10^{-3}m/s^2)		transmitted force (N)		speed (10^{-4}m/s)		kinetic energy (J)	
stage	(1)*	(2)	(1)	(2)	(1)	(2)	(1)	(2)
1	59.55	23.63	504.06	288.87	1.68	1.04	1.20	0.66
2	45.76	28.31	387.39	346.14	1.45	0.76	0.90	0.35
3	42.84	10.02	362.67	122.50	0.38	0.19	0.06	0.02

* (1): leaf spring suspension; (2) air suspension

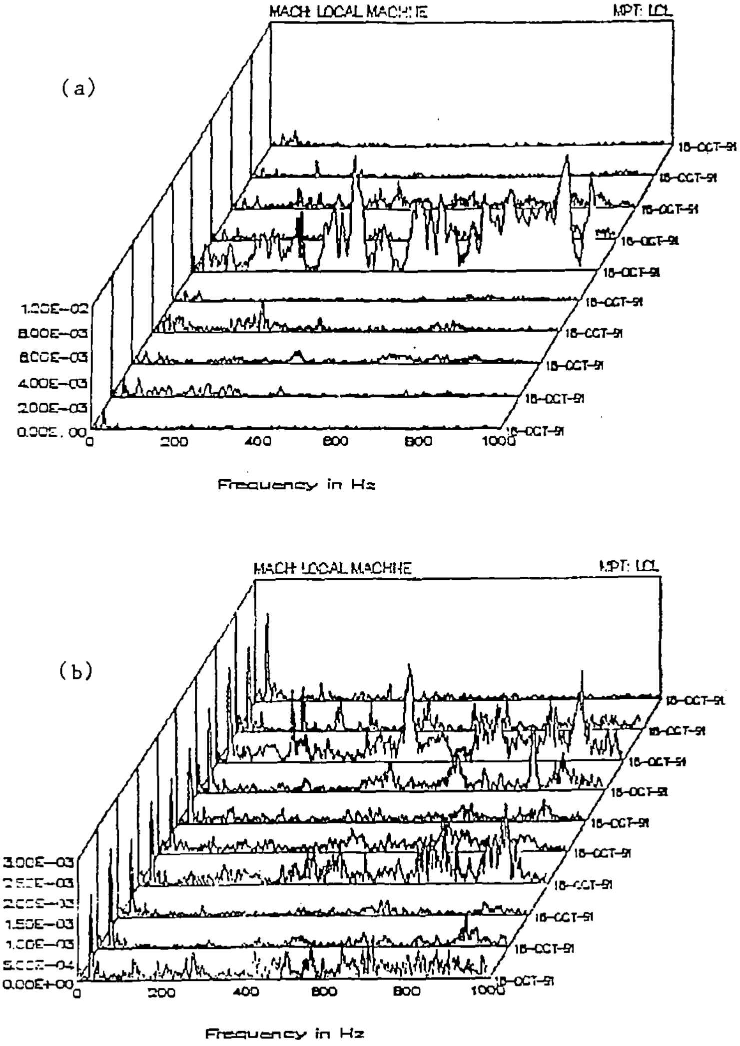


Fig. 3. Leaf spring suspension; accelerometer placed in the rear: *a*) z-direction; and *b*) x-direction.

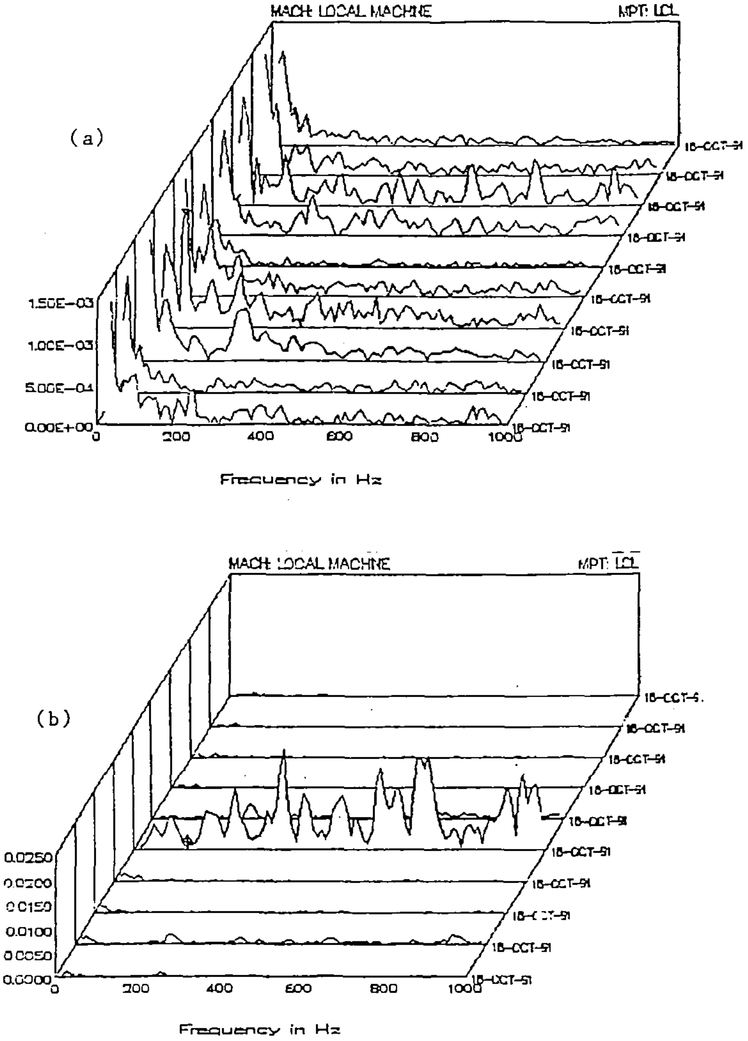
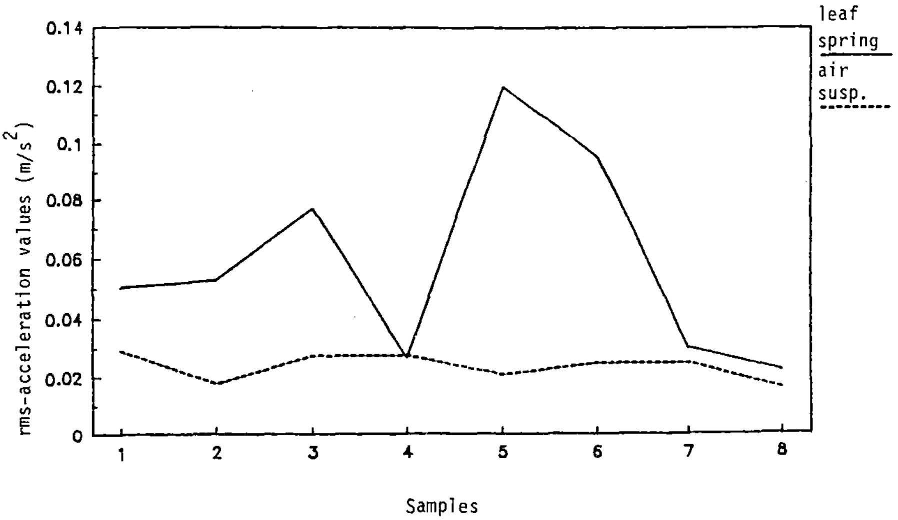


Fig. 4. Air suspension; accelerometer placed in the rear: *a*) z-direction; and *b*) x-direction.

Accelerometer placed in the rear z-direction



Accelerometer placed in the rear x-direction

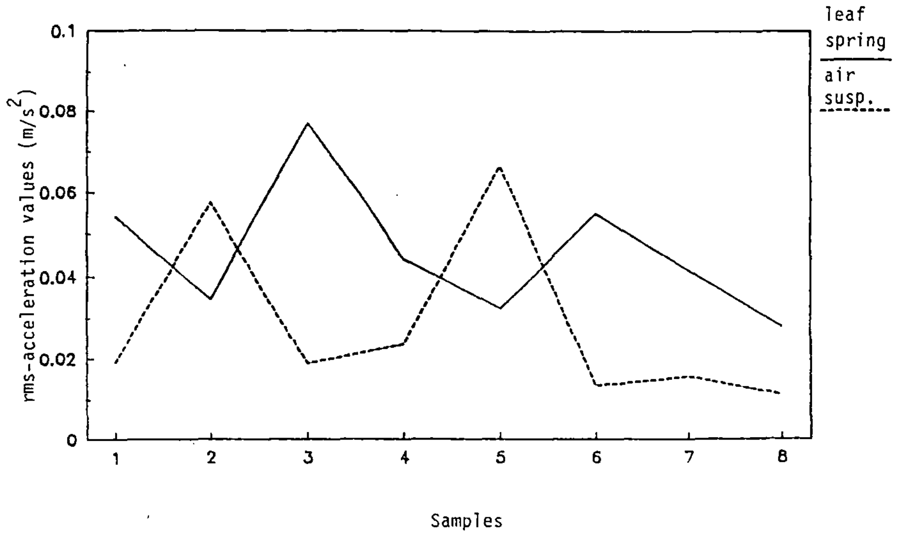


Fig. 5. RMS-acceleration values for both suspensions.

3. MATHEMATICAL MODEL

A mathematical model was developed in order to identify the dynamic behavior for a wide range of trucks under simulated road conditions. There have been many studies reported in the literature. However, a comprehensive dynamic study of a semitrailer truck has been reported by Potts and Walker (1974). They modelled the truck suspension by nonlinear elements which allow damping to vary nonlinearly as a function of velocity, and wherein the force-deflection relationship in the rear-axle spring is different in loading and unloading, thus allowing hysteresis to occur. Nevertheless, for the case at hand, it was considered sufficient working with a linear model that could give us a good approximation of the force—and hence an evaluation of the damage—being transmitted to the load. Thus, the semitrailer truck was modelled as a double-degree of freedom system and it is shown in Fig. 6. For this model, the equations of motion are given by

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{f} \tag{1}$$

where

$$\mathbf{M} = \begin{bmatrix} m_T & 0 \\ 0 & m_S \end{bmatrix}, \quad \mathbf{C} = \begin{bmatrix} c_S & -c_S \\ -c_S & c_N + c_S \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} k_S & -k_S \\ -k_S & k_N + k_S \end{bmatrix},$$

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}, \quad \ddot{\mathbf{x}} = \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix}, \quad \mathbf{f} = \begin{bmatrix} 0 \\ f(t) \end{bmatrix}$$

and the definitions given below:

c_N: tires' damping factor
c_S: shock-absorbers' damping factor
k_N: tires' stiffness
k_S: whole suspension stiffness
m_S: tires and suspension mass
m_T: truck mass

Moreover, $k_N = 16k_n$, $k_S = 4k_s$, where in turn k_n and k_s are the stiffness constants of the tires and springs, respectively.

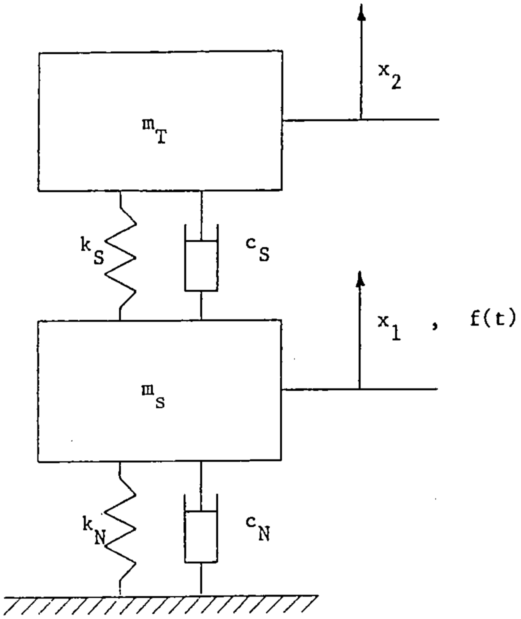


Fig. 6 Mathematical model of the truck.

Concerning the system parameters identification, this could have been done, for example, following the algorihm described in (Flannelly and McGarvey, 1970). However, the parameters were obtained through a simple least square technique, for the reasons abovementioned. This led to the following numerical values:

$$c_n = 4800\text{Ns/m}, \quad k_n = 682200\text{N/m}$$

The excitation force $f(t)$ was considered only due to the road-surface roughness. This was obtained in turn using the road-profile function $q(s)$, Fig. 7, as

$$f(t) = c_N \dot{q}(t) + k_N q(t) \tag{2}$$

where

$$q(t) = \frac{1}{v} q(s)$$

v being the truck speed. Thus, road conditions are simulated only by knowing the road profile.

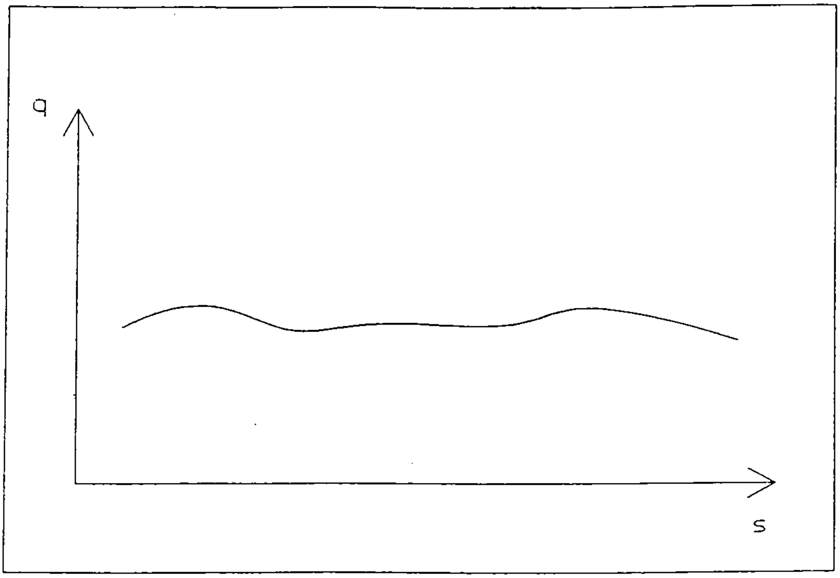


Fig. 7. Road-profile function $q(s)$.

4. CONCLUSIONS

Based on the test carried out and the above results, the conclusions listed below can be stated:

- the energy transmitted by the air suspension is 48% less than the one transmitted by leaf springs.
- the vibration amplitudes for the air suspension are 60% less than leaf springs.
- the force transmitted to the freight in trucks with air suspension is 48% less than the one transmitted with leaf springs suspension.

Two major conclusions were derived from this study. On the one hand, a recommendation for the truck manufacturers and transportation companies regarding the type of suspension they should employ, according with the kind of freight. On the other hand, a model characterization which allows to simulate the dynamic behaviour of trucks travelling along Mexican roads. This simulation model predicts truck vibrations once the truck characteristics and route are known.

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