Measurement and Analysis of Vehicle Vibration for Delivering Packages in Small-Sized and Medium-Sized Trucks and Automobiles

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In distribution, packaged products are subjected to the variation in vibration levels from transport vehicles that vary in frequency and acceleration while moving to their destinations. This vibration may negatively affect the product or packaging. This study measured and analysed vibration levels in vehicles commonly used to transport packages in the last leg of the package delivery service that is used by single-parcel carriers. Using data recorders, we monitored vertical, lateral and longitudinal vibrations over 75 h of travel time in five different types of small and medium package delivery vehicles. The study presents these data as power density (PD) spectra and compares it with previously measured PD vibration levels in commercial long-haul interstate tractor-trailer truck shipments. Data were collected in the USA and Thailand.

KEY WORDS: vibration; vans; small trucks; automobiles; package delivery

INTRODUCTION

One of the factors that determine product damage during shipping is the type and amount of vibration experienced. In order to efficiently protect a product, the levels of these vibrations must be known so that the product–package system can be accurately tested. The type of vibration varies depending on how the product is shipped because trucks, rail cars and airplanes all produce different types of vibration. Additionally, the specifications of each vehicle will affect the vibrations. For example, past studies have shown that air-ride truck vibration levels are significantly lower than leaf-spring truck vibration levels.[1]

A large portion of retail and consumer goods are distributed in the USA through various methods of truck transportation.[1] Insufficient packaging protection will be evident in a product that receives damage during shipping.[2] Previous studies have been carried out to measure and quantify shipping conditions.[3,4] This has led to an increased focus on designing cushioned packages that will enable products to overcome the severity of the shipping environment. The data acquired from these studies offer engineers the ability to create stronger product–package systems that reduce the amount of damage to products.

Previous studies have compared the shipping conditions for major carriers, such as DHL, FedEx and United Parcel Service. These studies primarily monitored drops and impacts that packages are exposed to during handling and have shown both similarities and differences based on the operating conditions of the carrier.[5]

The purpose of this study is to expand on the available data from previous studies by comparing the vibration conditions found in small transport vehicles. The study was conducted using a single-parcel distribution centre operated by FedEx in California, USA, and delivery pick-up trucks and automobiles used in Thailand.

INSTRUMENTATION AND TEST VEHICLES

This study used SAVER 3X90 electronic data recorders manufactured by Lansmont Corporation (Monterey, CA, USA). These recorders use tri-axial accelerometers to measure the vibration levels for vertical, lateral and longitudinal movements. The data recorders were attached to rigid metal plates that were rigidly attached to the vehicle, in the rear cargo section.

Figure 1 shows the cargo holds where packages are placed during shipping, and Figure 2 shows the data recorders mounted in the vehicles.

The specifications of the five vehicles monitored are shown in Table 1.

The recording parameters of the SAVER 3X90 were as follows:

- Timer-triggered interval: 5 min
- Timer event size: 2 s
- Signal-triggered threshold level: 0.5 G
- Signal event size: 2 s
- Pre-trigger data: 50%
- Post-trigger: 50%
- Acceleration ranges: 1.0–20.0 G
- Sampling rates: 500 samples/s
- Filter frequency settings: 250 Hz

[Insert Figures 1 and 2]

Vibration levels were recorded based on both a fixed time interval and all those that exceeded the trigger threshold level. The measurements were performed over a 5-day period, exceeding 70h of monitoring in the five different vehicles described earlier. The Ford van, the Dodge van and the Freightliner were driven in the USA, whereas the mid-sized car and the pick-up truck were driven in Bangkok, Thailand. The average distance driven per day for the Freightliner vehicle was 40 miles, mostly on well-maintained city roads with very limited highway travel. The Dodge van travelled an average distance of 124 miles and followed a route that featured both highways and inner-city roads. Finally, the Ford van travelled an average distance of 130 miles on a route that included highways, inner-city roads and unpaved roads. Each data recorder was turned on in the morning before each truck left for the day and was subsequently turned off once the trucks finished their daily routes. Delivery vehicles (car and pick-up truck) travel less than 50 miles in Thailand and are smaller than the vans and light trucks used in the USA. The two most common delivery vehicles are pick-up trucks and automobiles. Both car and pick-up truck were driven on highways and inner-city roads in Thailand.

[Insert Table 1]

RESULTS AND DISCUSSION

Both the American Society for Testing and Materials and the International Safe Transit Association have created standards for simulating ground transportation.[6,7] These standards use power density spectra that are developed as a composite profile based on summarizing various types of truck and rail shipping environments. The measured vibration results for this study were analysed and reported in the form of power spectral density spectra. The power spectral density plots represent the intensity of vibration that occurs inside the cargo hold of the vehicle where packages are placed for shipment.

[Insert Figures 3-5]

Three power density spectra (Figures 3-5) were created to show the power density levels versus frequency for the five types of vehicles in the longitudinal, lateral and vertical axes. Vertical vibration of leaf-spring suspension truck trailers used for interstate highway transportation in the USA for the upper 30% and lower 70% are also shown in Figure 5. Table 2 represents the overall G_{rms} for the various spectra shown in these figures for each type of trailer and orientation. It is important to consider both the G_{rms} level and the ‘shape’ of a given spectrum to estimate how a product/package with a known natural frequency will respond in a vibration test. Two different spectra with the same G_{rms} but with different ‘shapes’ and different peak intensities at different frequencies will excite products differently. Based on the levels of these spectra, it is clear that the Freightliner vehicle, which is a small truck, produces significantly higher vertical vibration as compared with the two types of vans. The vertical vibration levels in the two vans are similar. The lateral and longitudinal levels in all types of delivery vehicles are much lower than the vertical level, and because of the extremely low G_{rms} levels, they are not likely to produce damage. Figures 6 and 7 show the vertical vibration levels in a van or small truck, which are compared with previously measured vertical vibration levels in leaf-spring suspension truck trailers used for interstate highway transportation. These interstate trailers are usually 48 to 53 ft long and widely represent the majority of US trucking fleet.[1] The data in Figures 6 and 7 show the average power density spectra (representing the entire data), the spectrum representing the top 20% most severe events recorded and the spectrum representing 80% of the remaining data. In recent trends, the industry has started to use the 80% and 20% spectra to conduct testing as opposed to the average spectrum.[1]

[Insert Table 2]

Table 3 displays the highest analysed power density spectrum G_{rms} values, for each vehicle based on the three axes. Based on the data, the lowest vibration levels occur in the passenger car (Figure 8) followed by the pick-up truck (Figure 9) and then in the commercial small trucks and cargo-carrying small vans and small-sized delivery trucks. Based on the data presented in the power density spectra, the suspension frequencies for pick-up truck, passenger automobile and small cargo van are all approximately 2 Hz, whereas the suspension frequency for the small cargo-carrying trucks is higher at around 3-4 Hz. Low suspension frequencies at similar acceleration levels result in a longer suspension travel or displacement than those at high suspension frequencies.

CONCLUSIONS

[Insert Figure 6-9 and Table 3]

The study concludes the following:

- The vibration levels are significantly higher in the vertical axis as compared with the lateral and longitudinal axes for both small trucks and vans.
- The vertical vibration levels in small trucks are significantly higher than those in vans used for package delivery.
- The suspension frequency and the highest low-frequency power density level occur at 2 Hz in a van and at 3 Hz in both the small truck and the large tractor trailers with leaf-spring suspensions.
- For suspension response, the vertical vibration response (1–10 Hz) is higher in interstate tractor-trailer truck shipments than in other vehicles. However, for structural and higher-frequency responses (10-20 Hz), the levels in both the van and the small truck are more severe than in other vehicles.
- The G_{rms} levels are highest in the pick-up truck, followed by passenger automobile and lastly by the commercial shipping vans and small delivery trucks.
- The results from this study can be used to develop lab-simulated vibration test methods to simulate small-sized and medium-sized trucks and automobiles.

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Figure 1. Inside the cargo holds of the five vehicles.

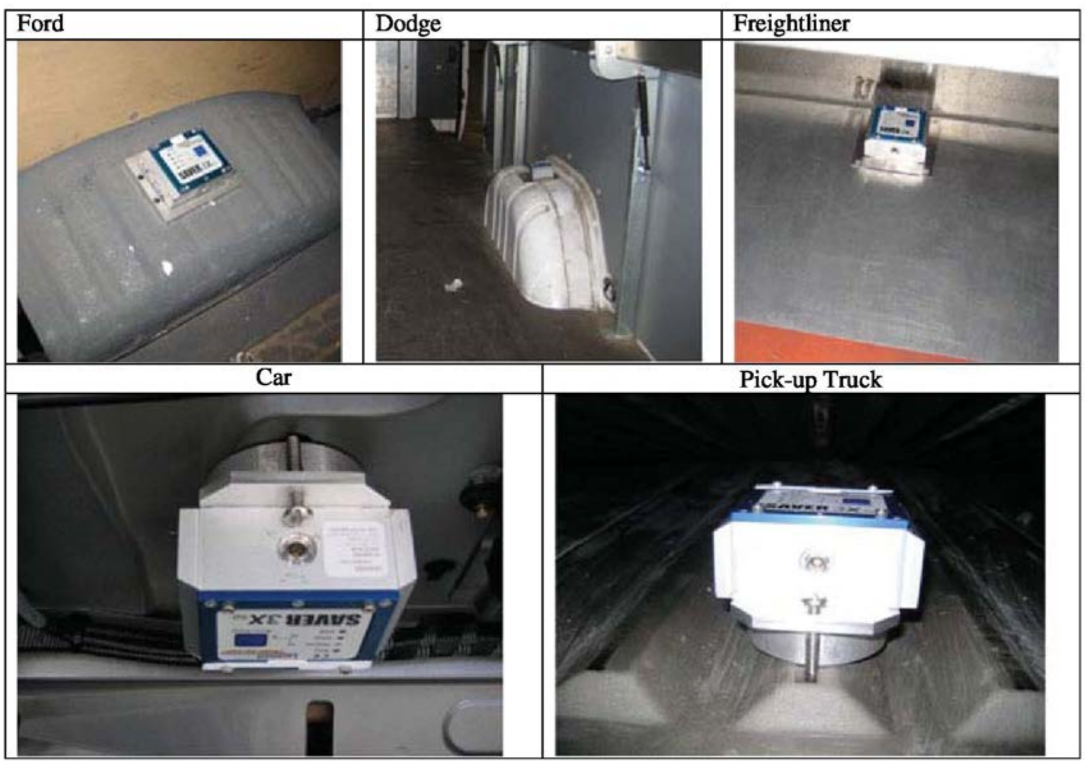

Figure 2. Instrument mounted inside the five vehicles.

Table 1. Vehicle specifications.

Chassis model year	2007	2005	2006	2008	2007
Chassis manufacturer	Ford	Dodge	Freightliner	Honda	Nissan
Vehicle type	Van 1	Van 2	Light truck	Mid-sized car	Pick-up truck
Suspension type	Leaf spring	Leaf spring	Leaf spring	Coil spring	Leaf spring
Gross vehicle weight	8600	8550	16 000	4500	6000
Equipment type	Panel van	Walk in	Walk in	Passenger	Top load

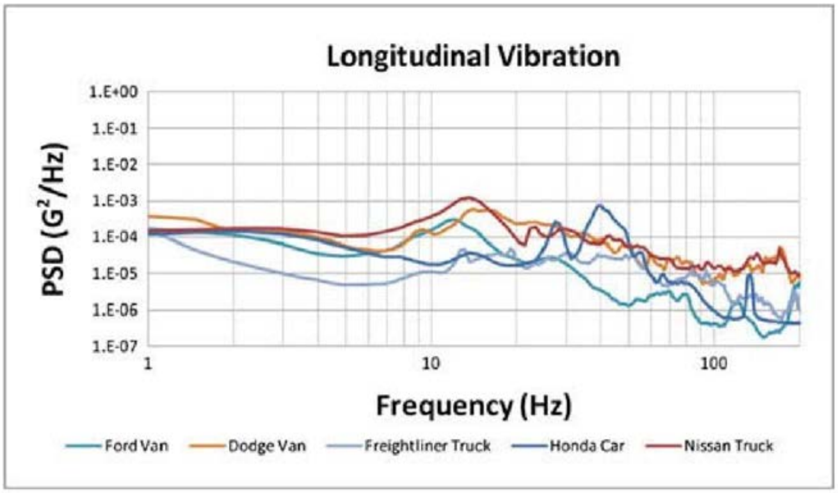

Figure 3. Power spectrum density (PSD) plot for longitudinal vibration levels.

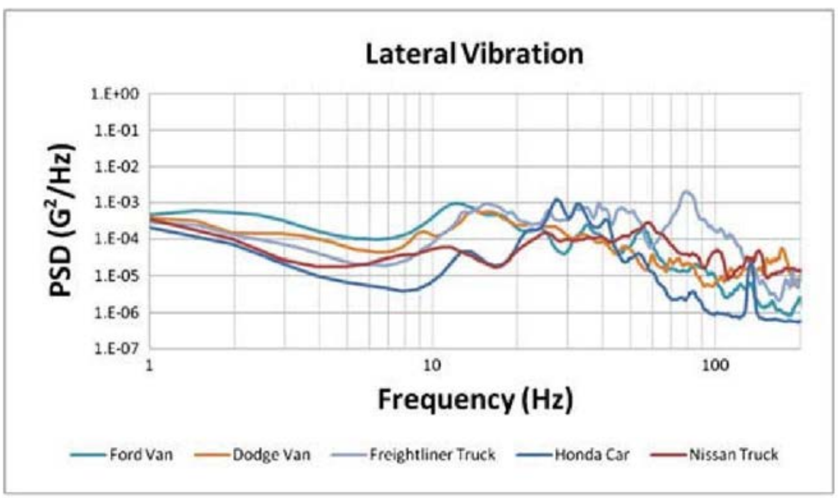

Figure 4. Power spectrum density (PSD) plot for lateral vibration levels.

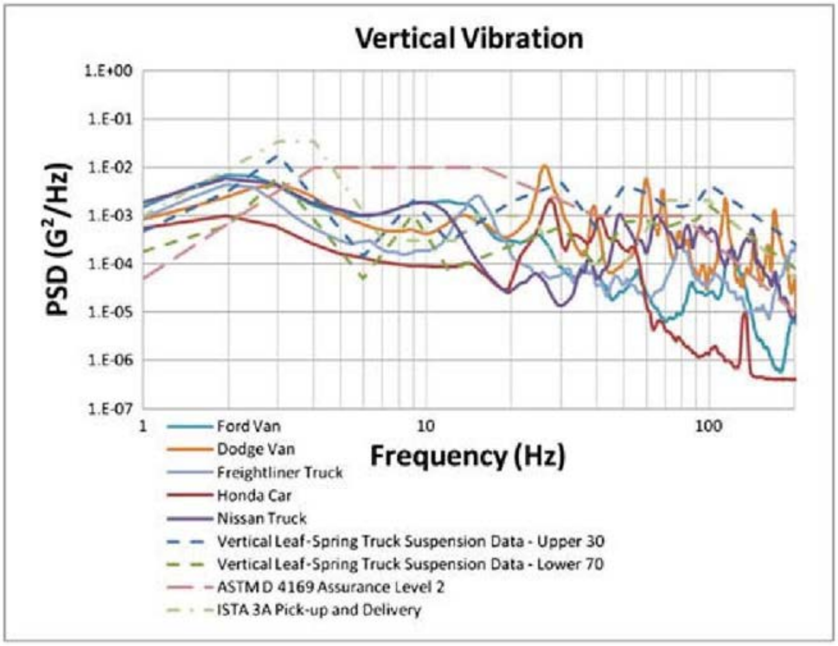

Figure 5. Power spectrum density (PSD) plot for vertical vibration levels.

Table 2. Overall G_{rms} values for delivery vehicles in the USA and Thailand.

	Overall G_{rms} values				
	Ford	Dodge	Freightliner	Mid-sized car	Pick-up truck
Longitudinal (x-axis)	0.054	0.053	0.066	0.091	0.120
Lateral (y-axis)	0.121	0.252	0.120	0.108	0.111
Vertical (z-axis)	0.207	0.231	0.377	0.144	0.259

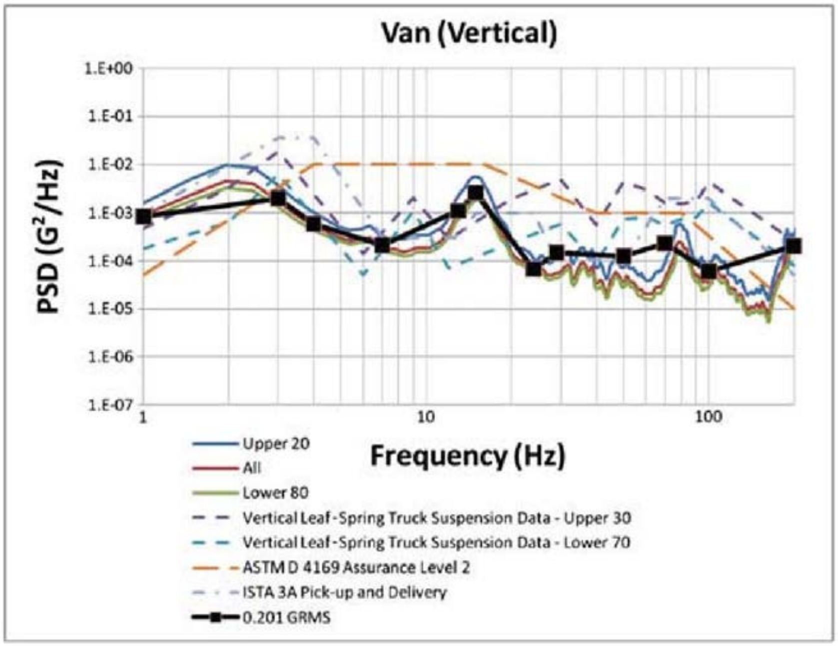

Figure 6. Power spectrum density (PSD) plot for vertical vibration in the parcel delivery van in the USA.

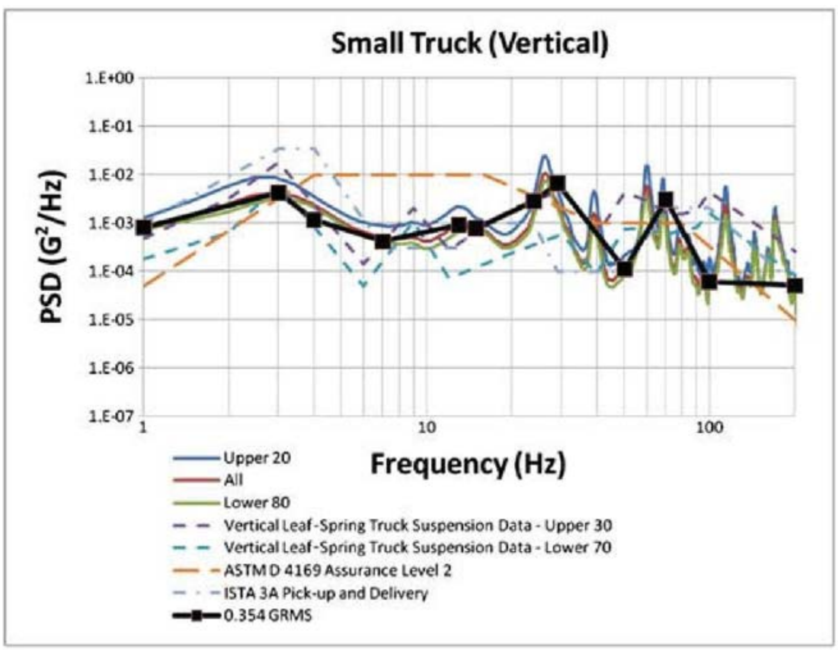

Figure 7. Power spectrum density (PSD) plot for vertical vibration in the parcel delivery small truck in the USA.

Table 3. Upper G_{rms} values for delivery vehicles in the USA and Thailand.

	Maximum level (G_{rms}) for the most severe event				
	Ford	Dodge	Freightliner	Mid-sized car	Pick-up truck
Longitudinal (*x*-axis)	0.402	0.52	0.553	0.724	0.935
Lateral (*y*-axis)	0.747	2.168	0.953	0.946	0.798
Vertical (*z*-axis)	2.514	1.838	3.403	1.399	1.700

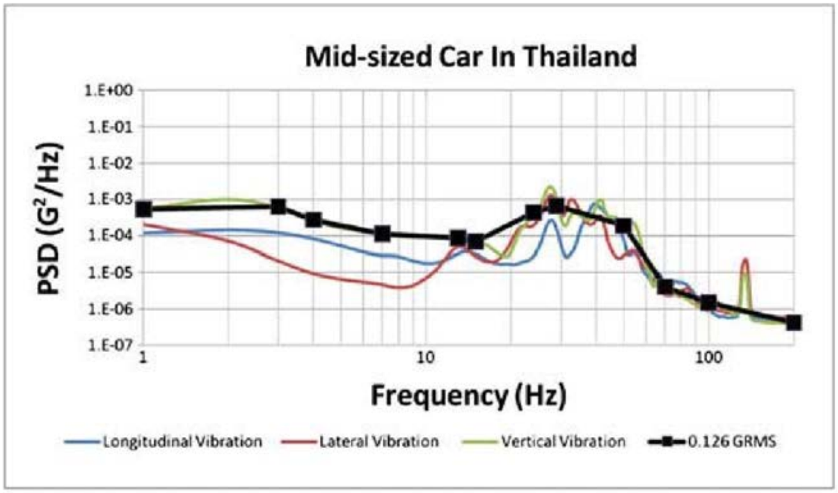

Figure 8. Power spectrum density (PSD) plot for vertical vibration in cargo of mid-sized car.

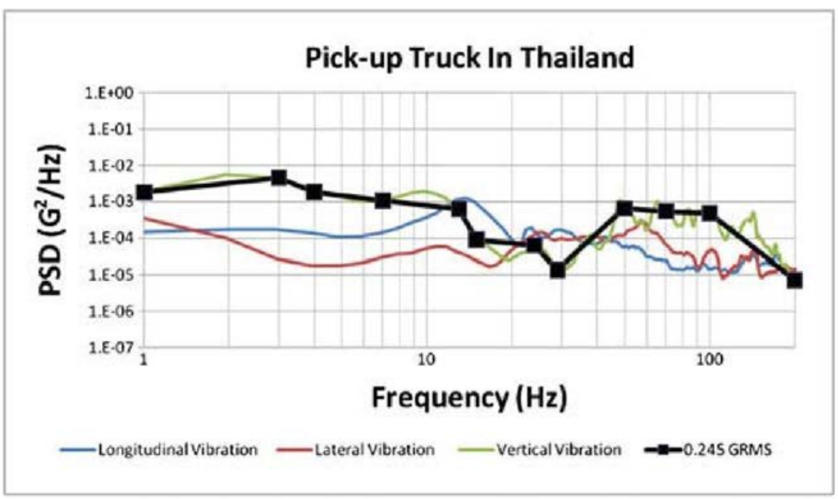

Figure 9. Power spectrum density (PSD) plot for vertical vibration in pick-up truck.