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Vibration levels of stacked parcel packages in laboratory test environment. Over-tested or under-tested?

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Abstract: Courier express parcel (CEP) shipments become one of the most important delivery methods in the Business-to-Consumer sales model. This paper observed and analyzed the vertical vibration levels that occur in stacked and unsecured parcels during express delivery versus the simulation in the laboratory. At the end, a detailed comparison is reported between the field and laboratory vibration levels (based on standard PSD test profile) in the frequency range of 1 – 200 Hz. For the measurement a three-layer stacked unit was used building from corrugated box samples. The result shows and analyzes the vibration levels in the stacked layers in comparison to the ISTA (International Safe Transport Association) vibration protocol where only a single parcel is required to be tested without any stacking configuration.

Keywords: Random vibration; packaging; PSD; stacked unit, parcel delivery

1. Introduction

The global parcel delivery service has grown significantly over the past decade [1]. In this service, the first and last step is practically a normal road transportation with small vehicles like vans, when the operators (Fedex, TNT, DPD, etc.) collect or deliver the parcels.

Of course, this mode of delivery brought some new physical circumstances that former was not analyzed by packaging engineers. This way the worldwide used standards has not focused on some aspect of the transportation environment yet. Here a very interesting circumstances should be highlighted, namely the unsecured and not unitized load of parcels. This can be seen in Fig. 1. The reasons of this later phenomenon are the very intensive flow and wide range of packages at the same time, in the same vehicle. This often means that the operators try to use the most of the vehicle capacity; thereby many identical or different kinds of parcels are stacked on top of each other [2]. This situation is more complex due to the fact that practically any fixation accessories are used in this transportation mode.

Figure 1. Stacked parcels in CEP service

As it can be seen the parcels practically can move in the vertical with unrestrained stacked configuration. This physical condition is very important to analyze in order for packaging engineers to design suitable protective packaging systems.

Many of former studies dealt with the vibration level during transportation and investigated the effect of payloads, suspension system and road condition to vibration levels [3-8]. The response vibration levels that can be observed on the vehicle can be grouped on factors such as vehicle body structure, type of vehicle suspension and tires, road roughness, vehicle speed and actual payload, respectively [9]. However, these studies measured and analyzed the vibration levels on the floor of the vehicle.

Another aspect is why the result of this study is important for the packaging engineers is that the generally widely used laboratory test standards for parcel shipment simulation deal with single package testing, not with stacked units.

The main goal of this paper was to measure the vibration levels in layers of stacked packages during laboratory test for stacked parcel delivery shipments and to compare the layers' vibration levels to the most popular standard test level. The new results can be useful for packaging engineers to make better and precise pre-shipment testing. Furthermore, the results help the use of the vibration test technique in the simulation of parcel delivery goods in a stacked way.

For the investigation a three-layer stacked unit was built to observe the vibration levels on vibration table at the laboratory using ISTA 3A pick-up-and-delivery vibration spectrum (International Safe Transport Association). The results showed that the vibration level increases in the stacked load upwards and how over-run or under-test can be experienced in the top most layer in comparison to the lower one. These findings are limited to single axis vibration simulation and unsecured loads.

2. Methods

2.1. Samples and laboratory circumstances

For this study three identical small, corrugated box parcels were set up for the measurements of the stacked unit. Each sample packaging contained a Lansmont SAVER 3x90 field data recorder (Lansmont Corp., CA, USA), which was fixed to an aluminum frame (Fig. 2). Inside the package this ITEM aluminum profile frame (©item Industrietechnik GmbH) ensured the rigid fixation of SAVERs and the best fitting to the boxes' geometrical sizes. Thereby, a total of four SAVERs were used for the measurements, three of the SAVERs were in the sample boxes and one of the SAVERs was mounted to the vibration table directly. Table 1 describes the sample specifications and SAVER settings for this study.

Table 1. Specifications for samples used and accelerometer sensors

Samples		***Sensors' setup***	
Corrugated board	35BC	Timer triggered data	1 s
Weight of board	742 g/m^2	Wake-up interval	1 s
ECT	9.0 kN/m	Recording time	1.000 s
BST	1 685 kPa	Sample / sec	500 Hz
Weight of box	190 g	Sample size	500
Size of box (w x d x h)	180x180x195 mm	Frequency resolution (PSD)	0.50 Hz
Weight of ALU frame	1 440 g	Anti-Aliasing frequency	200 Hz
Entire weight	2 630 g		

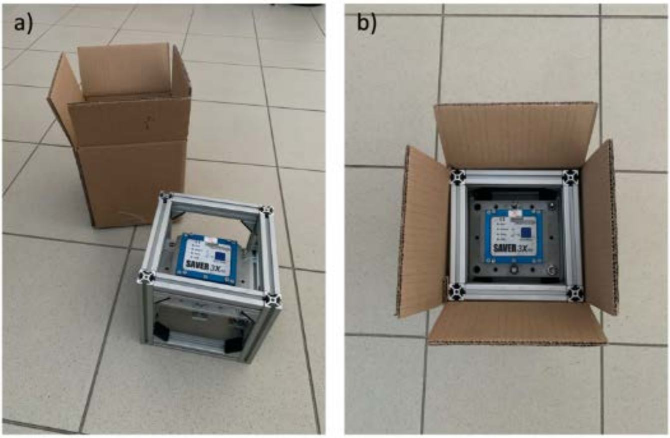

Figure 2. Samples used with the built-in accelerometer sensor

A measurement system was built for the laboratory standard test in order to obtain and compare vibration levels between the layers. This can be seen in Fig. 3. The stacked unit was located above the center of hydraulic vibration table and an aluminum fence was used to prevent the stacked unit from moving in lateral and longitudinal directions. This way, the stacked layers' motion in the vertical direction was not restricted at all.

Figure 3. Stacked parcels in CEP service

The laboratory measurement was performed at Packaging Laboratory, Hungary (University of Győr). The ISTA 3A Pick-up and delivery random vibration profile (Fig. 4) was programmed for the vibration system. This testing procedure is the one generally used for packed-products for parcel delivery shipment, but it uses only single parcel during the laboratory testing without stacking requirements or circumstances. The Power Spectral Density (PSD) spectrum of this vibration profile produces time-compressed random signal for small vehicle vibration during the test procedure. The frequency range and overall G_{rms} of this profile between 1 – 200 Hz is 0.46.

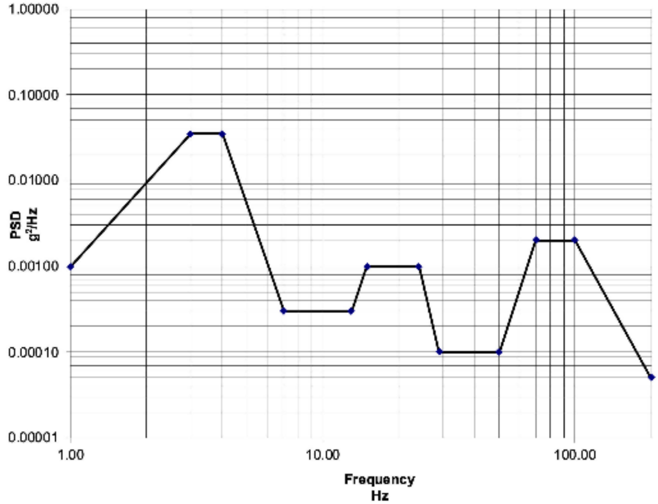

Figure 4. ASTM D7386 - Standard Practice for Performance Testing of Packages for Single Parcel Delivery Systems PSD spectrum.

The average power density (Eq. 1.) within a narrow band of frequencies (BW) of a given spectrum can be determined by G_{rms} values based on the number of samples of a given bandwidth. In this way G_{rms} is determined by the root mean square value of the acceleration in G's in the given bandwidth of frequency, based on the number of (n) samples. Table 2 contains the frequency breakpoints and vibration intensity for this ISTA spectrum.

$$PD = \frac{1}{BW} \sum_{i=1}^{n} (RMS\ G_i^2)/n \qquad (1)$$

Table 2. Frequency breakpoints and PD levels for ISTA 3A spectrum

Frequency (Hz)	PSD level, g^2/Hz
1	0.001
3	0.035
4	0.035
7	0.0003
13	0.0003
15	0.001
24	0.001
29	0.0001
50	0.0001
70	0.002
100	0.002
200	0.00005

2.2. Data analyst

PSDs were calculated from the measured vibration data using Fast Fourier Transformation (FFT) of Xware software and MATLAB R2014a (MathWorks Inc, Massachusetts, USA). The values of power density (PD) levels are presented between 1 – 200 Hz. This frequency range represents those vibration events, which have enough intensity to influence the integrity of product-package system used in general industry. Fig. 5 shows an example of a PSD lot for normal truck vibration during transportation with lead spring suspension.

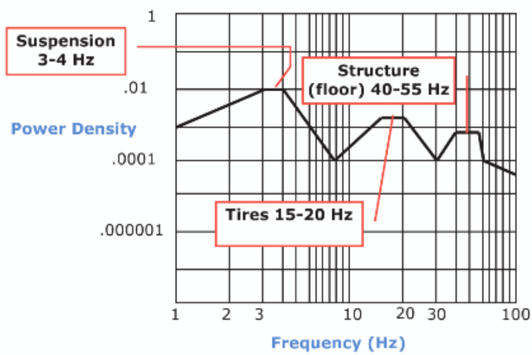

Figure 5. A typical PSD plot for heavy truck vibration

For a detailed and directed comparison the calculated PD levels of recommended ISTA 3A spectra and the observed PD levels in the layer were compared by splitting the entire spectrum to three frequency regions. This way the vibration intensity and the different response vibration can be comparable in those frequency bands where the real vehicle produces higher intensity or the recommended test spectrum has got peaks. The base of the splitting method can be seen in Fig. 6.

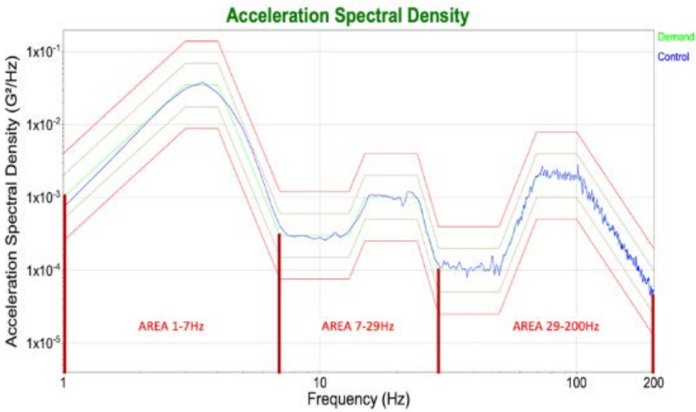

Figure 6. Frequency regions for comparison purposes

3. Results

3.1. Overall G_{rms} in the entire frequency bands

Fig. 7 shows the PSD plots for the recorded vibration on vibration table in the three layers. Fig. 8 contains the overall G_{rms} bar graphs of PSD for 1 – 200 Hz. Based on layers the highest values were in the 3rd level followed by 2nd, and the least in 1st level, respectively, of course increasing upward level by level. Below 50 Hz the vibration intensity was about 1 – 3 dB higher than the ISTA profile, over 50 Hz the reduction was between 8 – 26 dB.

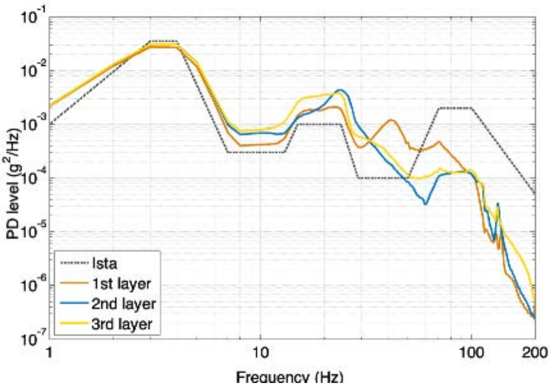

Figure 7. Recorded PSD plots for the three layers

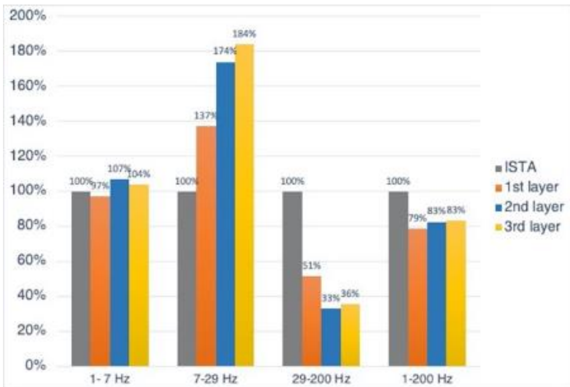

Figure 8. Overall G_{rms} values in the different frequency ranges

3.2. Comparison in varied frequency bands

Table 3 and 4 contains the numerical data for calculated Overall G_{rms} values and percentage comparison in the base of ISTA profile for the entire frequency band observed and for splitted frequency ranges. As it was former mentioned the reason of splitting these bands is to show a relative direct comparison to the standard ISTA 3A protocol.

Table 3. Numerical report for Overall G_{rms} in different frequency ranges

	1- 7 Hz	***7-29 Hz***	***29-200 Hz***	***1-200 Hz***
ISTA 3A Pick-up and Delivery	0.27915	0.11776	0.34597	0.45988
1st layer	0.27113	0.16145	0.17746	0.36204
2nd layer	0.29875	0.20497	0.11346	0.37966
3rd layer	0.29005	0.21652	0.12327	0.38237

Table 4. Percentage based comparison for Overall G_{rms} in different frequency range (ISTA = 100%)

	1- 7 Hz	***7-29 Hz***	***29-200 Hz***	***1-200 Hz***
ISTA 3A Pick-up and Delivery	100%	100%	100%	100%
1st layer	97%	137%	51%	79%
2nd layer	107%	174%	33%	83%
3rd layer	104%	184%	36%	83%

3.4. Limitations

Here has to be noted by the authors that the corrugated board that used for this study can influence to the results of measurements. Although the authors tried to fill the corrugated box perfectly with the aluminum frame to avoid the effect of damping mechanism by the box, the corrugated box may have slight damping effect. So, the readers have to consider that various corrugated board has different damping features to the results

Conclusion

- Results from the study show that it is obvious that between 7 – 29 Hz the G_{rms} levels show a high over-run for the layers upwards. It means almost double vibration intensity at the third layer. It can cause an over damage ratio in comparison to the standard circumstance where only a single parcel is under tested.
- In lower frequency range (1 – 7 Hz) the stack layers practically suffer in the same vibration intensity as the standard protocol perform.
- On the contrary, over 29 Hz, the G_{rms} value is lower upwards than ISTA test standard, which means an under-test in comparison to the standard requirement, if the upper layers are under investigated. This phenomenon can be attributed to the damping feature of corrugated samples used for this study.

- Obviously that the vibration response of stacked parcels cannot be same than a single parcel, but these parcels are often stacked in the industry practice. At the same time, it is definitely clear that the specification applied by the standard, namely only a single parcel is under tested, is not suitable for testing stacked parcels due to the not-uniformly vibration response over the entire spectrum, or a single parcel vibration test does not give properly feedback about the real vibration circumstances of industrial practice.

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