Averaged Vibration Levels During Courier Parcel Delivery Service in Small Truck in Hungary

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In recent years there continues to be an increase in courier parcel delivery services due to the growing global online economy and express parcel shipments. It is therefore important to measure and quantify the levels of vibration that occur inside the vehicle during transport, as it can be one of the primary sources of damages. The purpose of this study was to measure the averaged vibration levels in vertical, lateral and longitudinal directions that occur in courier delivery shipments from pickup to delivery involving small trucks over ground road transportation in Hungary. The recorded acceleration data were analyzed in terms of power spectral densities (PSD) and presented with overall G_{rms}. The results of the separated afnd averaged vibration levels provide physical circumstances for various road and load conditions showing those frequency bands that have significant intensities.

Keywords: *vibration; PSD; small truck; packaging; parcel delivery*

1. INTRODUCTION

Small truck transportation is used worldwide for distribution of small quantities of goods and mostly single and lightweight parcel packages for trade. Although it is relatively expensive compared to mid-sized and heavy truck transportation, it is often the most economical way to provide parcel courier services in places where inexpensive or other forms of distribution alternatives are not available. Furthermore, the global online economy is increasingly demanding that single parcels and products be distributed on a worldwide basis.

During transportation one of the primary sources of damages to products and packages can be attributed to the various vibration forces that occur in a vehicle [1]. Previous studies have been done to measure and analyse these vibration levels but were limited mainly to heavy truck trailers and these investigations usually consisted of a small section of road trips [2,3]. The speed of vehicle, the type of suspension system and tires used and its stiffness and damping, the load capacity, the road conditions, as well as the vehicle's general conditions can affect the vibration during transport [4-8].

The aim of this study is to gather data over a large section of the Hungarian highway network using 5 commercially available small trucks. The focus of this study was to analyse the vibration levels during daily parcel delivery service. The results present power spectral density (PSD) plots for the total number of recorded acceleration values, and for the top 5% and 20% highest values, and for the bottom 80% of the total, respectively. These conditions allow for the development of methods that can simulate these transport environments in the laboratory.

Shipments from three different courier operators were instrumented with tri-axial accelerometer to measure the vibration levels in all three orientations. The data was collected for various route, load and vehicle speed conditions.

2. ROAD NETWORK AND SMALL TRUCKS IN HUNGARY

Hungary has an extensive road network that originates from the capital Budapest. The total road network in Hungary in 2013 accounts for approximately 203,309 km and it is the fourth densest in the EU-28 [9].

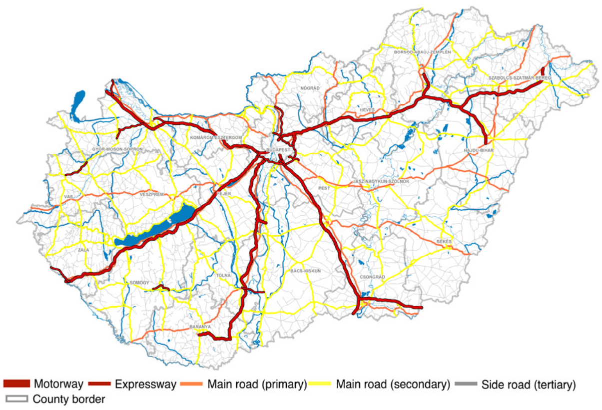

Figure 1. Map of Hungarian road transportation route network (source: GeoX Kft.)

The road network (Figure 1) can be divided into two major categories: the national highways (31,663 km [9]) and municipal roadways. Concrete national roads constitute almost 99.9 % of the total number of roads. The national road network can be further divided into two major subcategories such as the main roads consisting of motorways, express roads, first-class and second-class roads and minor (or secondary) roads.

Received: November 2017, Accepted: December 2017
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doi:10.5937/fmet1802211B

Table 1 contains data for the road network length per category and the number of trucks registered according to their gross vehicle weight (GVW) in 2013 in Hungary. In 2013, the total number of registered general trucks in Hungary was 401,723 [9]. For pick-up and delivery of relatively light loads and packages small trucks with a maximum possible payload of t.5 tons are the most popular vehicles (GVW 3.5 ton). The total road transport in 2013 in Hungary was 35.8 billion tkm [10]. The average transport distance for inner city and regional delivery was about 70 km and appro–ximately 720 km for national distribution.

3. INSTRUMENTATION AND ANALYSIS

3.1 Measuring device and setup

The vibration events during courier parcel delivery routes were measured for all three axes (vertical, lateral and longitudinal) using Lansmont (SAVER)™ 3X90 (Shock and Vibration Environment Recorder, Lansmont Corp., CA, USA) to collect the data. Then Saver XwareTM software and MathLab R2014a software were also used to analyse the data.

For each segment of the measurement the recorder was mounted directly to the floor and was located at the right rear of the vehicle cargo area. In those cases when the container floor was wooden the SAVER was fixed by screws, and when it was metal the SAVER was fixed with a magnetic kit. These can be seen in Figure 2a and 2b.

a) b)

Figure 2. SAVER in small trucks fixed with screws (a), and with magnetic kit (b)

The settings of the recorder used in this study are shown below, and can be seen in Figure 3.

- Timer trigger: 30 s
- Signal trigger: 2.5G
- Recording Time: 2.048 s
- Sample/sec: 500 Hz, sample size: 1024
- Frequency resolution for PSD: 0.488 Hz
- Anti-aliasing filter frequency: 250 Hz

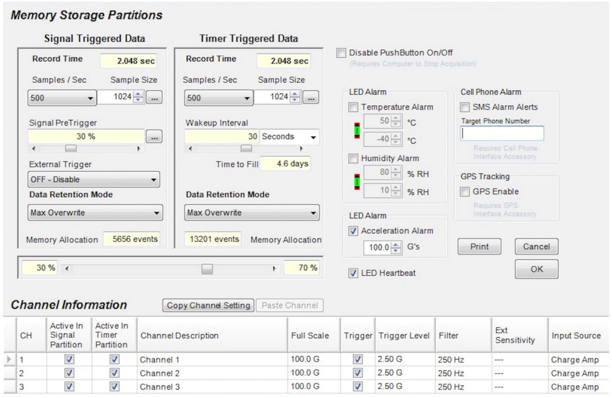

Figure 3. Setting the parameters of the SAVER data logger used for this study

3.2 Measuring circumstances

In order to analyse the averaged vibration levels from multiple vehicles five different small trucks were used by three different carriers (TNT, DHL and UPS). Each vehicle was monitored for approximately 8 hours of a total workday trip and the total duration the trucks were in motion was between 5.5–6.5 hours. The entire mea–suring time was from Monday to Friday. The mea–surements were conducted with various payloads and speeds in the range of 0-1340 kg to 1-130 km/h. The payload condition during shipping varied for the packages being delivered and picked up. The suspension system of all observed small trucks was a parabolic leaf spring at the rear axle.

To determine the averaged effect of the circum–stances of transportation such as road condition during shipping, the small trucks travelled on various roads, such as motorways, primary roads, secondary roads, tertiary roads and city roads.

Table 1. National road and truck data in Hungary for 2013 [10]

Road category	Length (km)		Truck category	Quantity (pcs)
Major network	8 361		General trucks	401 723
- Motorway road	1 336		– 3.49 t	280 390
- First Class road	2 147		3.5 – 7.49 t	85 640
- Second Class road	4 878		7.5 – 11.49 t	13 029
Minor network	23 399		12t –	22 664
- Connecting road	18 197			
- Access road	4 556			
- Other road	646			
Municipal	171 549			
Total	**203 309**			**401 723**

Obviously these trips depended on the daily route program of the courier company. The geographical locations of these measurements were as follows: county of Győr-Moson-Sopron (GYMS, Veszprém (V) and Komárom-Esztergom (KE).

Table 2 contains the specifications of the vehicles used in this study and Table 3 contains the details of those road conditions connected to the daily trips.

3.3 Data analyst

In the case of vibration analysis power density (PD) levels were determined as a function of frequency based on the recorded random vibration acceleration levels as used former researches [11] [12].

The average power density within a narrow band of frequencies (BW) of a given spectrum can be deter–mined 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.

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

The vibration environment was then represented by the power density spectrum (PSD) showing a plot of the power density levels versus frequency. The energy within a specific frequency range can be obtained by integrating PSD within that frequency range and is usually represented in G_{rms} for the entire or portion of the spectrum. The computation of PSD is done directly using the method called Fourier transformation or computing autocorrelation function and then transfor–ming it to use as diagnostic method [13] [14]. Figure 4 shows an example of a PSD lot for normal truck transportation with leaf spring suspension [15].

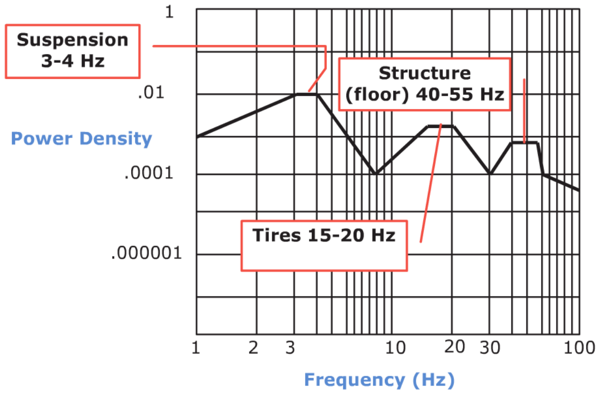

Figure 4. Typical PSD plot for heavy truck vibration [15]

In this study the data are presented and analysed from 1 to 200 Hz. First, the recorded vibration data were filtered to remove all undesirable events such as any noise or non-vibration featured movements from the analysis, i.e. stopovers that occur during daily trans–portations. So according to this data below 0.02 G_{rms} were filtered out.

This method was already used previously by the author [16] and other prior published researchers who removed inactive segments from the measured records [17] [18].

Table 2. Specifications of small trucks and details of daily trips for this study

	Vehicle	Vehicle weight (kg)	Load capacity (kg)	Container size (m^3)	Distance between axis (mm)	Average speed (km/h)	Load level (kg)
Monday	Fiat Ducato	1 935	1 165	8.0	3 000	53.7	110-400
Tuesday	Fiat Ducato	1 975	1 525	13.0	4 035	47.8	35-880
Wednesday	Fiat Ducato	2 010	1490	14.8	4 332	31.2	0-440
Thursday	Ren. Master	1 811	1 489	8.0	3 182	40.8	10-530
Friday	Ford Transit	2 018	1 482	15.1	3 750	45.6	180-1340

Table 3. Details of road condition details of the daily trips used in this study

	Motorway (km)	Primary road (km)	Secondary road (km)	Tertiary road (km)	City road (km)	*Total*
Monday	41	13	14	37	53	***158***
Tuesday	55	69	67	31	66	***288***
Wednesday	0	131	87	81	38	***337***
Thursday	27	103	63	61	72	***326***
Friday	7	67	66	47	87	***274***
Total	*130*	*383*	*297*	*257*	*316*	***1 383***

The PSDs were then created using the remaining measured data in which a spectrum for the top 5 and 20 percent of the highest measured data are shown, follo–wed by a lower spectrum representing the remainder 80 percent of all recorded data. Therefore spectrums are presented for the top 5 and top 20 percent of saved events and 80 percent of remaining events, as shown in previous studies [15] [19] [20]. In addition a spectrum representing the average for 100% of all events mea–sured is also presented. Finally the PSD plots of signal and timer triggered events are also shown separately [21]. Power density spectrums in all three directions (vertical, lateral and longitudinal) are presented in this paper and each PSD is reported with an Overall G_{rms}.

The reason for combining the various trips into one power spectral density (PSD) plot is that the measured small trucks (FIAT Ducato, FORD Transit and RENAULT Master) practically have the same vehicle body and structure, and so the statistical validity of vibration levels for vans could be averaged to represent the slight variation among trips [15] [16] [20].

3.4 Statistical analysis

Statistical analysis was conducted on the absolute peak acceleration values recorded for the five trips to determine cumulative distribution functions (CDF) using the Weibull two-parameter distribution model, for all three axes separately.

Here, it has to be mentioned that there was no particular reason for choosing the Weibull distribution; simply this distribution model was determined to be the best fit to the data. The Weibull distribution is widely used in reliability engineering due to its relative simplicity. Its CDF has two parameters, presented in equation (2), as follows: ▯ > 0 is the scale parameter, ▯ > 0 is the shape parameter.

$$F(x|\alpha,\beta)=\int_{0}^{x}\beta\alpha^{-\beta}t^{\beta-1}e^{-(t/\alpha)^{\beta}}\,dt=1-e^{-(x/\alpha)^{\beta}} \qquad (2)$$

4. RESULTS

4.1 Empirical acceleration data

Table 4 contains data regarding numbers of samples used to analyse the entire shipping section to create PSD plots. The total number of events recorded before filtering was 4349. Figure 5 shows all recorded and filtered dynamic acceleration levels of the resultant direction in G_{rms}. These events (over or equal to 0.02 G_{rms}) are represented in the time history domain.

As it was already mentioned above that circum–stance such as road conditions can affect the vibration levels. These differences can be seen in Figure 4 in the form of RMS acceleration. Those days when the truck travelled relatively more with bad road conditions the vibration levels were more severe. This was the situation from Wednesday to Friday when the truck predominantly travelled on tertiary and city roads.

Figure 6 shows the CDFs for the measured peak acceleration values in all three axes and the RMS values for the resultant acceleration. The CDFs show the percentage of the events that are below a certain level of the measured peak acceleration value. It can be seen that the acceleration values in the longitudinal direction were generally lower than those of the lateral. The highest acceleration values in this study were in the vertical axis. Tables 5 and 6 contain the statistical parameters of these distributions that use recorded acceleration data and are based on best-fit regression analysis.

Table 4. Number of samples for developing PSD

Events	Filter level by RMS	Filtered events
Top 5%	> 0.586 RMS	154
Top 20%	0.586 ≥ RMS > 0.401	624
Bottom 80%	0.401 ≥ RMS > 0.020	2 406
Signal tr. part	≥ 0.020 RMS	753
Timer tr. part	≥ 0.020 RMS	2 331
Total 100%	≥ 0.020 RMS	3 084

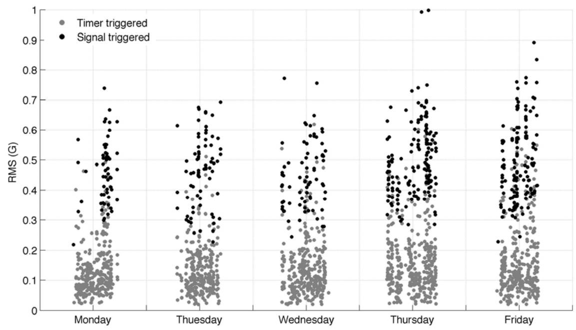

Figure 5. Vibration events recorded in the truck container in RMS (G) (resultant direction)

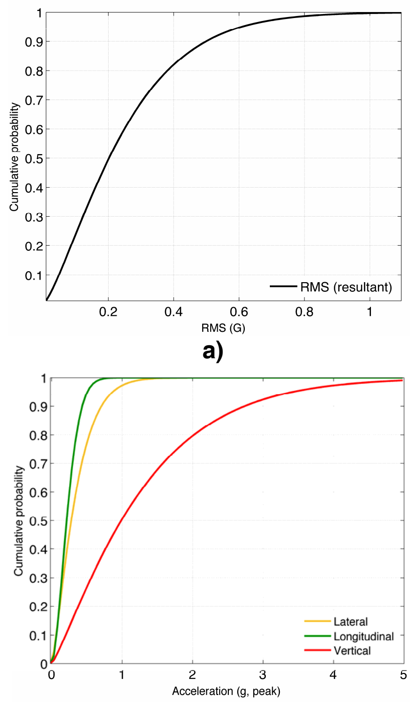

Figure 6. CDFs of RMS accelerations (a) acceleration peaks in vertical, lateral and longitudinal directions (b) for small truck

Table 5. Summary of empirical acceleration data measured

	Resultant (RMS)	Vertical (g, peak)	Lateral (g, peak)	Longitudinal (g, peak)
Max.	1.09	4.93	2.55	1.64
At 99% occurrence	0.74	4.02	1.09	0.76
At 95% occurrence	0.62	3.26	0.86	0.52
At 90% occurrence	0.54	2.96	0.76	0.43
Mean	0.24	1.26	0.33	0.23

Table 6. Statistical parameters of distribution based on best-fit regression analysis

	Predicted Mean	Variance	Estimate α	Estimate β	R-square	RMSE
RMS	0.24	0.03	0.26	1.32	0.914	0.05
Vertical	1.27	1.19	1.34	1.17	0.946	0.09
Lateral	0.34	0.07	0.36	1.28	0.885	0.06
Longitudinal	0.24	0.02	0.26	1.69	0.901	0.04

4.2 Power Spectral Density (PSD)

The data was further analysed in the form of Power Density Spectrums for all three orientations (vertical, lateral and longitudinal).

The data are presented in vibration spectrums deve–loped for the all trips based on total recorded events and also spectrums for the top 5% and 20% most se–vere events and the bottom 80% of the remaining events; this can be seen in Figure 7-9.

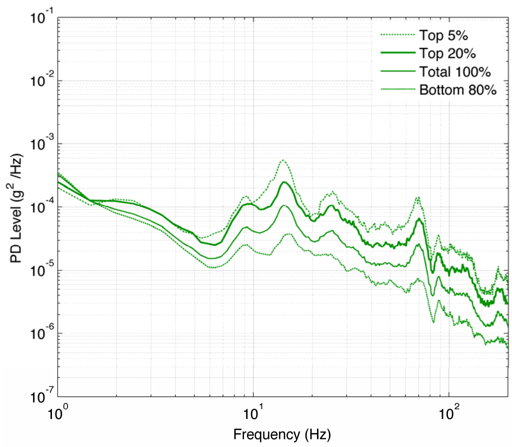

Figure 7. Longitudinal power density spectrums based on the highest 5%, highest 20%, bottom 80% and the average of all events

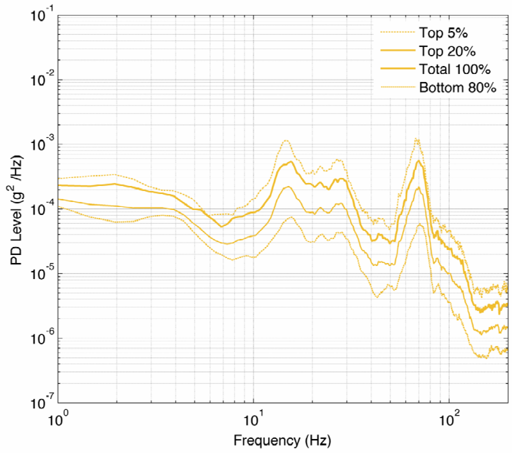

Figure 8. Lateral power density spectrums based on the highest 5%, highest 20%, bottom 80% and the average of all events

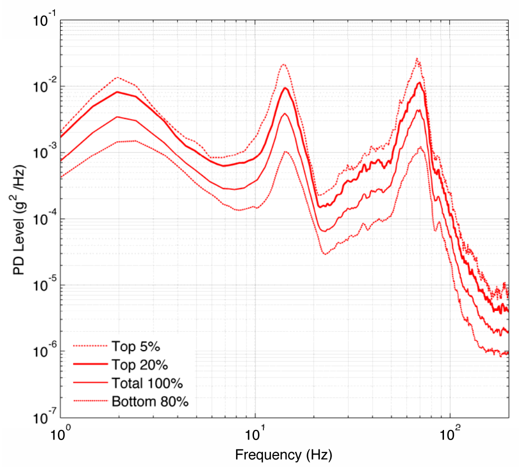

Figure 9. Vertical power density spectrums based on the highest 5%, highest 20%, bottom 80% and the average of all events

It is clearly visible that the highest vibration levels occur in the vertical direction around 2 Hz, 15 Hz and then 70 Hz, respectively. The PSD plots show that the vibration levels were the highest in the vertical axis. However, in the frequency range between 20 and 30 Hz the lateral vibration levels slightly exceeded those in the vertical orientation. Overall lateral vibration levels were generally higher than the longitudinal vibration levels. Over 100 Hz, in the higher frequency regions, the PD levels decreased rapidly in all three orientations.

In addition, Figure 10 contains PSD spectra sepa–rately for signal and timer triggered events of all recor–ded data. These are for information only because these events represent approximately 25% or 75% of all data covered, and the signal part shows only events above the threshold limit of 2.5G. Table 7 reports the overall G_{rms} values of recorded vibration events for the various routes in all three axes.

Table 7. Overall G_{rms} in the frequency bandwidth of 1 – 200 Hz

Events	Vertical	Lateral	Longitudinal
Top 5%	0.675	0.176	0.098
Top 20%	0.487	0.130	0.098
Total 100%	0.310	0.084	0.055
Bottom 80%	0.178	0.052	0.043
Signal t.	0.533	0.141	0.081
Timer t.	0.189	0.055	0.044

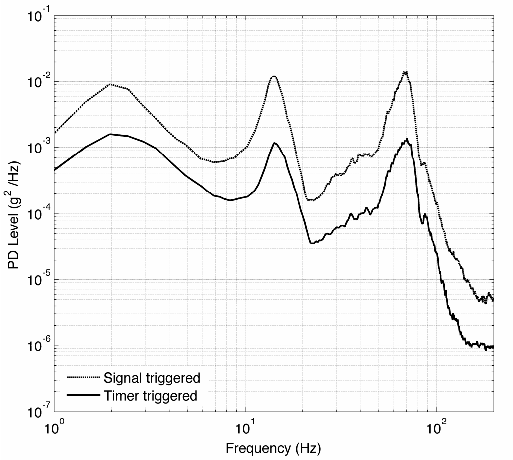

Figure 10. Vertical power density spectrums based on signal and timer triggered events

4.3 Limitations of the study

The author of this paper wants to call attention to the fact that the method of PSD involves the use of the Fast Fourier Transformation (FFT) process and due to this this it produces a PSD profile with average intensity of the vibration over the frequency range of interest [18].

Furthermore, the use of presented PD levels as vib–ration simulation conditions does not expose the test items to extreme levels of vibration or transients like shock events, which can occur during real transportation.

5. CONCLUSION

The following conclusions can be drawn from the re–sults of this study:

- The highest dynamic vibration levels in small trucks occur in the vertical direction, followed by lateral and then longitudinal direction, respectively.
- The most intensive vibrations can be found at around 2 Hz, 15 Hz and 70Hz.
- Over 100 Hz the PD levels decrease rapidly in all three orientations.
- The presented PD spectrums based on the measu–red data from this study can be used as test cir–cumstances for vibration simulations in small tru–cks during courier parcel shipments with diffe–rent severity.

ACKNOWLEDGMENT

This work was supported by the project EFOP-3.6.1-16-2016-00017 of Széchenyi István University. The author would also like to acknowledge the companies and partners (TNT Hungary Kft., DHL Hungary Kft. and UPS Hungary Kft) that allowed the measurements to be taken in their shipping environment.

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ПРОСЕЧАН НИВО ВИБРАЦИЈА КОД МАЛИХ КАМИОНА КУРИРСКЕ СЛУЖБЕ ЗА ИСПОРУКУ ПОШИЉКИ НА ТЕРИТОРИЈИ МАЂАРСКЕ

П. Берец

У новије време активности службе за испоруку пошиљки су све интензивније због развоја глобалне online економије и експресне отпреме пошиљки. Зато је важно измерити и квантификовати ниво вибрација које настају у возилу за време транспорта, јер оне могу бити један од главних узрока оштећења. Циљ рада је био да се измери просечан ниво вибрација у вертикалном, латералном и лонгитуffдиналном правцу у малом возилу, од тренутка подизања до испоруке пошиљке од стране курирске службе, у друмском превозу на територији Мађарске. Подаци о забележеном убрзању су анализирани са аспекта спектралне густине снаге (PSD) и приказани укупним G_{rms}. Резултати појединачних и просечних нивоа вибрација приказују физичке околности различитих услова друма и оптерећења који пока–зују фреквенцијске појасеве који имају значајан интензитет.