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Vibration and shock analysis of specific events during truck and train transport of food products

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ABSTRACT

In international test standards and literature averaged vibration spectra of truck and train transports are reported. However, cargo is exposed to extreme levels of vibrations and shocks for which the averaged vibration data are not representative. The objective of this study is to report evidence of the extreme vibrations and shocks during truck and train transport, and help food scientists design relevant vibration and shock simulation experiments. Results indicate that trains and trucks experience transient phenomena when traveling over train switches, accelerating and stopping the train, respectively road unevenness (e.g. potholes). The damping ratio (β) of shocks measured on the railcar is on average 0.05 ± 0.02, while on the truck 0.08 ± 0.02. Furthermore, the measured spectra of this study diverge from the spectra of international standards. A time-domain analysis indicates that traveling over cobblestones, and concrete pavement generates the most severe vibrations and shocks (dependency on truck velocity).

1. Introduction

Fresh fruit and vegetables, as well as electronic goods, are susceptible to quality losses or failure due to vibrations and shocks. Vibrations and shocks during transport are categorized as an important contributor to the decrease in product quality (Gołacki, Rowiński, & Stropek, 2009; Van Zeebroeck et al., 2007). Since postharvest losses can be quantified between 30 and 50% of all food that is grown (Parfitt, Barthel, & Macnaughton, 2010), increased attention goes to this topic. Postharvest waste is defined as losses arising during transport, handling, and storage of food products before they reach the customer (Parfitt et al., 2010). International test standards (ISO –International Organization for Standardization– and ASTM –American Society for Testing and Materials–) guide researchers and (food) scientists to experimentally test products on transport vibrations. However, there is a mismatch between the vibrations measured in reality and the proposed test methods of the international standards. This study was performed to demonstrate the importance of transient phenomena when doing simulation tests and to further discuss the proposed test methods of international standards and the vibration spectra described in literature.

The international test standards (ASTM D4728 and ISO 13355) suggest the use of averaged vibration data in combination with applying time-compression (i.e. vibrations are artificially amplified to better replicate product damage) to simulate transport. As a consequence, the power spectral density levels (PSD-levels) differ from the ones that are measured in reality (Böröcz & Singh, 2016). An extensive field of literature has been devoted to reporting realistic vibration levels measured on different transport vehicles traveling on a regional transport network (without time-compression). Similar to the international standards, the latter mentioned papers also report averaged vibration data, i.e. root mean square-levels (RMS-levels) and PSD-levels, to characterize vibration measurements (Böröcz & Singh, 2016; Chonhenchob et al., 2009; Lu et al., 2010; Rissi, Singh, Burgess, & Singh, 2008). However, limited evidence was reported in literature on the occurrence of transient phenomena during transport. Furthermore, the averaged vibration patterns to which test items are exposed during (recommended) transport simulations may differ substantially from the extreme levels of vibrations or shocks that are present during transport. Even the use of time compression in combination with averaged vibration data may not replicate damage that is produced by transients (Böröcz & Singh, 2016). Nevertheless, the influence of shocks on food products (for instance apples (Gołacki et al., 2009; Van Zeebroeck et al., 2007)) has been investigated in some papers. Therefore, in this study a thorough time-domain analysis of vibrations and shocks that occur during truck and railway transport was performed. Moreover, by offering additional insights on vibrations and shocks of specific events

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that occur during transport, researchers can simulate transports more realistically. With the information presented in this paper, researchers will be able to optimize experimental designs with better replication of damage to test items due to transport vibrations and shocks.

The literature on vibrations during transport is abundant; two categories of papers can be distinguished. The first category of papers (1) aims to identify the input spectra of different types of transport vehicles traveling on a regional transport network (Chonhenchob et al., 2009; Lu et al., 2008; Rissi et al., 2008; Rouillard & Richmond, 2007). The papers often aim to identify several relevant parameters that influence the magnitude of the vibrations and shocks (Garcia-Romeu-Martinez, Singh, & Cloquell-Ballester, 2008; Lu et al., 2010; Singh, Singh, & Joneson, 2006). In the second category (2), a myriad of papers aims to focus on the impact of vibrations and shocks on a specific food product. The influence of vibrations and shocks on an individual product (Van Zeebroeck et al., 2006), often fruit, or the interaction of products (Pang, Studman, & Ward, 1992) is regularly assessed. Also, the packaging strategy (i.e. damping and cushioning properties (Eissa, Gamaa, Gomaa, & Azam, 2012; Paternoster et al., 2017; Vursavus and Özguven, 2004)) and the configuration in a container (O'Brien, Gentry, & Gibson, 1965) was researched. Since vibrations and shocks have a direct influence on the product integrity and quality, it is essential to gain knowledge on the type and magnitude of the vibrations and shocks that occur during transport. Packaging engineers can adopt these insights to design a better packaging. On the one hand, a lack of knowledge could lead to insufficient packaging or cushioning of the products or, in other words, under-packaging of the products. An excess of protective cushioning, on the other hand, could lead to over-packaging. In the former scenario, under-packaging can easily be identified since the products will exhibit defects. The occurrence of over-packaging, which implies hidden costs, is more difficult to determine. From recent estimates, the total cost of over-packaging in Europe is 130 billion euros per year (Rouillard & Richmond, 2007).

The objective of the current paper is to identify vibration and shock patterns that are present when traveling over the Belgian road and railway network. Moreover, roads were segmented based on road type and speed limit to identify the vibration and shock characteristics. Similar research was performed by Jarimopas, Singh, & Saengnil (2005) indicating the influence of road type (laterite, asphalt, and concrete) with segmentation of the driving speed (20, 40 and 80 km/h) on vibrations and relating the measurements to damage of packaged tangerines. Current research further develops previous insights by also focusing on shock patterns when driving over different road types. While Lu et al. (2008) analyses shocks as individual events (e.g. metal joints, railway crossings), the current study investigates the magnitude and frequency of the shocks attributed to road type in combination with speed of driving. Furthermore, a time-domain analysis was completed to identify vibration and shock patterns that occur during railway transport (e.g. acceleration and stopping of a train, a passing train, etc.). The literature on shocks during railway transport is limited, which to the respect of the authors is remarkable due to the high magnitude of the shocks and the high frequency of occurring. This also emphasizes the unique contribution of this paper. In addition, shock analysis was performed in which the damping factor (β) and the acceleration amplitude (in time-domain) was calculated of diverse shocks measured during truck and railway transport. The last objective of this study was to identify the influence of cargo weight on the magnitude of the vibrations and shocks during transport. More extensive research on the influence of cargo weight on vibration levels was performed by Garcia-Romeu-Martinez et al. (2008), and therefore was used to benchmark research findings.

The scope of the paper is based on the Belgian transport network with specific reference to vibrations and shocks measured on trucks, with air-spring and leaf-spring suspension, and trains with leaf spring suspension within a Belgian context. The findings of this paper can be used by researchers and food scientists to simulate transport and optimize packaging design. The aim of this paper is to confront the simulation tester with the extreme levels of vibrations and shocks that are measured during transport and which are not reflected by the averaged power spectra described in international testing standards and literature.

2. Material & methods

2.1. Experimental design

Vibrations and shocks, defined as periodic or random in nature, respectively a single-event or transient phenomenon, were measured during truck and railway transport. The devices used to measure the vibrations included the following:

1) 3-Axial Accelerometers (SparkFun Triple Axis Accelerometer Breakout – ADXL337–SEN 12786, SparkFun Electronics, Niwot, Colorado, USA)
2) Data acquisition board (National Instruments USB-6361 – Part Number: 782256-01, National Instruments, Austin, Texas, USA)
3) Laptop (Dell 1708FP, Dell, Round Rock, Texas, USA with MATLAB Release 2015a, The MathWorks, Inc., Natick, Massachusetts, United States.)
4) External battery (Solar-accu 12 V 60 Ah GNB Sonnenschein – NGSB120060HS0CA, Conrad, Oldenzaal, Netherlands)
5) Transformer (Voltcraft SWD-300/12 Omvormer 300 W 12 V/DC 12 V/DC – 513124 – 8J, Conrad, Oldenzaal, Netherlands)
6) Camera (GoPro Hero 4, GoPro, Paris, France)

The first five elements of the experimental set-up, listed above, are connected to each other. The accelerometers (1) had a sampling rate of 1e5 samples per second in order to also analyze high-frequency vibrations [bandwidth: 1600 Hz (X- and Y-axis/noise density: 175 μg/√Hz rms) and 550 Hz (Z-axis/noise density: 300 μg/√Hz rms)][1]. and were linked by cable with the data acquisition board (2). The latter device transforms the electrical current passed along by the transducers to a digital signal that can be read by the programmable software of the computer (3). The software used in this research is Matlab 2015a. The devices were electrically charged by an external battery (4) connected with a transformer (5). The transformer converts the 12 V DC into a 220 V AC current. While performing measurements, a GoPro-camera (6), mounted over the shoulder of the driver, filmed the events during transport. As a consequence, the filmed events were matched with the corresponding vibration data.

Measurements were performed during seven transports ranging over two different modes of transport, more specifically train and truck transport. The accelerometers used in this study were attached on top of a wooden pallet (between food boxes and the pallet), in the case of the truck transports, and to a metal grill welded to the bogie of the railcar, in the case of the train transport. Since it is the industry standard to transport food products stacked on wooden pallets, for the purpose of this study accelerometers were mounted on top of a wooden pallet rather than on the container floor, as is the standard when doing vibration measurements. Furthermore, the railway vibrations were measured on the structure floor, i.e. fixed to a metal grill welded to the bogie of the railcar. Due to regulations out of our control, stakeholders and industry partners of this project were not able to unseal a container. Therefore, it was not possible to measure vibrations inside a container:

[1] In the current study, no filter was applied to the signal. However, in order to prevent aliasing phenomena and to investigate the measured high-frequency vibrations, the sampling rate was fixed substantially high. The researchers are aware that the current results are predominantly informative within the bandwidth of the sensors.