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Measurement and analysis of truck vibration levels as a function of packages locations in truck bed and suspension

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ABSTRACT

During transport, due to vibration fruits and vegetables could be damaged. The vibration levels that transfer to fruits and vegetables may depend not only on vehicle characteristics (speed and suspension) and the road characteristics but also on the position of boxes packed in truck bed. The purpose of this research was to determine and analyze the vibration that occurs during truck transport as a function of box position and fruit position within the truck bed. For this purpose, two commercial trucks were used (with leaf-spring suspension and air-ride suspension). Test controllable factors includes: height positions of the container column (Bottom, Middle and Up), position of the container along the truck-bed (front axle and rear axle) and depth of fruit inside the container (Down and Top). The obtained values of the power spectral density were used to survey the effect of container positions on fruit vibration. RMS values were also obtained for different positions. The results showed that the power spectral density (PSD) was dependent on the position along the floor of the trucks. Higher vibration levels were recorded for fruits on top of the column. As the fruit height within a box increased, the vibration levels increased. ANOVA test results indicated that the considered factors significantly affected PSD values (Average PSD in the range of 0.1–5 Hz and peak PSD) and root mean square of acceleration ($P < 0.05$).

1. Introduction

Consumers are expecting improved product quality from their retailers as well as a wider variety of fresh fruits and vegetables. The globalization of fresh crops trade is creating a need for better long distance transportation systems and handling methods to maintain produce quality (Vigneault et al., 2009). Trucks are the most important tools for agricultural products transportation (Jarimopas et al., 2005), and in Iran, there are approximately 348,000 trucks to meet the transport demand. Truck transport method dedicated to approximately 365 million tons of goods annually. During transport, vibration, compression and impact cause physical damage to agricultural products (Vigneault et al., 2009; Vergano et al., 1991; Gebresenbet et al., 2011). Fruits and vegetables in their fresh forms contain high percentages of water. They are living and hence do their physiological function through respiration. These activities are disturbed during transportation and this could lead to their deterioration, which is more rapid under conditions of high temperature and humidity. Thus, heavy losses are occurs in these products (Vigneault et al., 2009). Poor driving performance, improper suspension and oscillation and also irregularities created by the road are the main factors that cause damages and losses in the fresh produce (Jones et al., 1991). Packaging is another factor contributing to these damages.

Placement of the harvested products into shipping containers is one of the most activities described as packing operations. Packing may occur directly on the farm, or in specially designed installations called packing houses. Generally, the purpose of packing operations, removing foreign objects, sorting into specified size categories and inspecting fruits or vegetables is to ensure and comply with the specified standard of quality and packing into a shipping container.

The damage can be minimized by identify the type of forces and vibrations as well as by designing optimum packaging, good package management and correct placement in the vehicle (Vigneault et al., 2009; Jarimopas et al., 2005). Vibration damage is due to the motion of the fruit in the pack, the magnitude of acceleration was considered as the criterion for evaluating the intensity of vibration. It was shown that the magnitude of acceleration in the upper layers of fruit, where most of the damage occurred, depended upon, the fruit depth in the container, tightness of fill, the type of suspension system, magnitude of forced vibration from the road bed and the vibration characteristics of the fruit species. It is important to consider the effect of vibration as a criterion for

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evaluation as the damages of fruits due to vibration the fruit movement within the package. Upper layers of fruit have more acceleration which can lead to more injury. It depends on the fruit depth in the container, characteristics of the road, the truck and the vibration characteristics of fruit (Jarimopas et al., 2005; Mohsenin, 1978). The vibrations due to transportation are influenced by road roughness, distance, speed, packaging and some characteristics of the truck suspension and the number of axles. In the literature, only a limited number of studies deal with the effect of transient vibrations on fruit impact damage. Zhou et al. (2007) showed that the vibration levels were different depending on the box location, and vibration levels of the front position were less than levels of the rear floor, which led to heavier damage to pears. The movement of the truck bed can be specified by a frequency spectrum function according to the random vertical acceleration of the truck bed and can be indicated by the PSD curve (Timm et al., 1996). Berardinelli et al. (2003) stated that during eggs transport by trucks, transducers positions on the truck bed effective on power spectral density curves obtained from the accelerations measured. While all previous research have focused on the study of actual damages caused by fruit vibration during transport process through real experimentation and laboratory work and simulation of the vibration behavior is rare (Zhou et al., 2008), this research tends to investigate the vibration behavior of the fruit location inside boxes stacked vertically on top of each other off the floor truck, harnessing a highly sensitive electronic device resembling the actual fruit also known as electronic fruit.

The current trend towards the tailoring of test seventies has result in the emergence and proposal of many new vibration test severities. The main purpose of this study was to perform measurement and analysis of the vibrations transmitted from two typical trucks during transportation and study of vibrational levels as a function of RPCs location on truck in real transportation conditions.

2. Materials and methods

2.1. Fruit and vehicle and package design

To implement the objective of this research, apple fruit was used as a truck load. The apples were of 70–79 mm diameter, Golden Delicious variety and were hand-picked from a garden near Shiraz, Iran. Then, the apples were moved to the Hani fruit sorting and packing factory in the industrial town of Shiraz. After washing and sorting at the factory, apples were packaged in a reusable plastic container (RPC) of the dimension 410 mm $\times$ 290 mm $\times$ 210 mm and with a 12 kg capacity. Within each RPC; 6, 4 and 3 fruits in length, width and height, respectively were inserted. For this purpose, two commercial trucks (two-axle truck and three-axle truck) were used. Both trucks were loaded with columns (each column consisted of five superposed RPCs, approximately 1.1 m high) of RPCs containing apple. The shape sphere assembled was designed to have a diameter of approximately 72 mm, which is considered adequate for experiments with fruit like apples and the accelerometer was placed inside it (Fig. 1). This instrument for sensing accelerations is utilized to quantify the impact suffered by fruits during transportation. Accelerometers were placed in the first, third and fifth row of the columns RPC to measure vibration of fruits (Fig. 2). Figs. 2 and 3 shows the location of embedded accelerometers inside the package. As shown in Fig. 3, tri-axial piezo-electric accelerometer were fixed on the RPC containing at two different positions (bottom and top of the RPC) to measure vibration levels of the front and rear positions of the trucks. Tri-axial accelerometer was connected to a portable data acquisition system via cable. Vibration values (frequencies and accelerations) were measured at the vertical direction in real transportation conditions. Detailed characteristics of trucks that were used in this study are shown in Table 1. Experiments were performed on a highway and the speed of both trucks was 60 km/h during the whole measurements.

2.2. Measurement equipment

Measuring equipments used in this study included:

- Tri-axial piezo-electric accelerometer (Piezotronics-356A26-PCB; sensitivity: 50/1 Mv/g (X), 50/6 Mv/g (Y), 49/08 Mv/g (Z), USA), where g is acceleration and Mv is millivolt.
- Signal processing (ECON, AVANT Lite, Model MI-6004).
- Notebook (Dell Inspiron N5010, with Intel core i5).

The following set-up parameters were used for all measurements:

- Minimum time triggered sampling: 30 min.
- Sampling rate: 750 samples per second.
- Record time for each signal-triggered event: 1.36 s for every 3 min of road travel.
- The total recording time for each state and treatment was 217.6 s for about 8 h driving (160 sample periods of road vibration data were collected for each state and treatment).
- Sample size: 1024.

Test controllable factors include: height positions of RPC in truck (Bottom, Middle and Up) in the each column, RPC position in relation to truck axle (front axle and rear axle) and position of fruit inside the RPC (Down and Top). Vibration data were recorded in real time 1.36 s for each signal-triggered event. The obtained values of the power spectral density (PSD) were used to survey the effect of RPC position on fruit vibration. Each signal was analyzed with resolution of 0.01 Hz by using of Fast Fourier Transformation (FFT) algorithm to determine the PSD.

Effects of suspension system (two statuses), RPC position in relation to truck axle (two statuses), RPC height (three statuses) and fruit depth increasing (two statuses) were investigated according to factorial experiment in the form of multivariate factorial ($2 \times 2 \times 3 \times 2$) design. The Duncan's multiple range tests was used to compare the means and five replications were conducted for each combination of variables. SPSS software (version 19.0) was used for data analysis.

3. Results

During each transportation tests, vibration data was collected. Data obtained by recorder were analyzed using the Vibration Shock Analyzer software developed by superior multi-DSP (Digital Signal Processing) computing technology. The results of the data analysis are presented as PSD graphs. The signal were processed to determine the root mean square (RMS) by using pulse system, then the main PSD peaks were considered to obtain PSD profiles. The several PSD profiles were then averaged and weighted in the time considering the duration of transit of the mean on different kinds of road. The PSD plots within a narrow band of frequencies were constructed for each trip using the following relationship:

$$\mathrm{PSD} = \frac{1}{\mathrm{BW}}\sum_{i=1}^{n}(\mathrm{RMS}G_i^2)/N$$

where PSD is the power spectral density (G^2/Hz); N the number of samples; RMS the root mean square acceleration value (g); BW is the bandwidth of frequencies.