골판지 포장상자내의 배의 진동특성

Vibration Properties of the Pears in Corrugated Fiberboard Box for Packaging

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1. Introduction

Fruits are subjected to complex dynamic stresses in the transportation environment. During a long journey form the production area to markets, there is always some degree of vibration present. Vibration inputs are transmitted from the vehicle through the packaging to the fruit. Inside, these cause sustained bouncing of fruits against each other and container wall. These steady state vibration input may cause serious fruit injury, and this damage is particularly severe whenever the fruit inside the package is free to bounce, and is vibrated at its resonant frequency. The determination of the resonant frequencies of the fruit may help the packaging designer to determine the proper packaging system providing adequate protection for the fruit, and to understand the complex interaction between the components of fruit when they relate to expected transportation vibration inputs.

During handling unitized products, they are subjected to a various environmental hazards. Shock and vibration hazards are generally considered the most damaging of the environmental hazards on a product, and it may encounter while passing through the distribution environment. A major cause of shock damage to products is drops during manual handling. The increasing use of unitization on pallets has been resulted in a reduction in the manual handling of products and with it a reduction in the shock hazards. This has caused and increasing interest in research focused on vibration caused damage. Damage to the product by the vibration most often occurs when a product or a product component has a natural frequency that falls within the range of the forcing frequencies of the particular mode of transportation being used. Transportation vibration is also a major cause of fruit and vegetable quality loss due to mechanical damage. With fruits and vegetables, low level impacts can cause damage over time due to cell wall fatigue. Distribution packaging should protect the product from environmental hazards including transportation vibration. In the past the effect of the pallet used to transport the product was often ignored in the design of packages to protect products from vibration damage. The goal of packaging is to prevent product damage during distribution. Frequently, cushioning materials are incorporated into the packaging system to protect fragile products from shock and vibration

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damage. To prevent vibration damage cushions are used to attenuate the vibration inputs or to shift the natural frequency of the product/package system outside the range of the forcing frequencies. The goal of cushioning would be to shift the natural frequency of the product-package system away from the natural frequency of the critical element. The corrugated fiberboard (paperboard) has been receiving considerable attention as an alternative to polymeric foams in protective packaging, mainly due to the environmental advantage it offers and all fruits were packed in corrugated fiberboard boxes and unitized on disposable softwood pallets. Understanding acceleration levels and frequencies that occur during shipping of perishables in refrigerated trailers will help to determine method that dampen the vibration energy and reduce the present losses in produce quality.

As more mechanization in fruit distribution system is introduced, the recent interest in the distribution chain between the grower and the consumer has been directed toward the development of techniques for reducing the damage of fruits in the transportation environments. Sinusoidal vibration sweep tests of top loaded corrugated shipping containers and container columns, were conducted by several researchers. These were directed primarily to evaluations of the dynamic strength characteristics of shipping containers. OBrien et al (1965) found that in simulated test acceleration levels were positively correlated with position in a column stack of containers. They observed that the natural frequency of pears was inversely proportional to fruit column height and that for pear depths of about 60cm to 30cm the natural frequency was 30Hz to 50Hz, respectively. Peleg and Hinga (1986) conducted the simulation experiment of vibration damage in containers and unit loads of produce. They reported that the highest acceleration levels were encountered in the bottom tier containers, and that the low frequency end of the spectrum was significantly amplified in the top tier containers, especially then the column were strapped down. The high frequency end of the spectrum is generally attenuated from the bottom to the top tier containers. Slaughter et al (1993) reported that pallet loads of Bartlett pears were most susceptible to vibration damage at frequencies below 40Hz. Peleg (1985) reported that the container stack has to be so designed that the resonant frequency of the container stack cannot coincide with the resonant frequency of the fruits and vegetables to reduce damage. Hinsch et al (1993) observed that the top box of pears loaded on the rear pallet exhibited about three times the power spectral density level of the bottom box during the cross-country tests in refrigerated trailers and horizontal accelerations perpendicular to the direction of travel were much less then vertical accelerations for both suspension types. Slaughter et al (1998) reported that the skin of Bartlett pears can be severely discolored when vibrated at acceleration levels slightly above 0.7 G-rms for periods as short as 30 min. Therefore, the specific objectives in this study were to analysis the vibration characteristics of the pears in the corrugated fiberboard box for packaging and evaluate how the frequency response of the pear is affected by the cushioning materials such as polymeric foam and corrugated fiberboard.

2. Materials and Methods

2.1 Materials

The samples being tested in this study were double wall corrugated fiberboard boxes of type of RSC (regular slotted container), inside dimensions of 520 x 350 x 250 mm, weight of 15 kg, paper composition of KA210/S120/S120/S120/KA210. Pears in corrugated fiberboard boxes used in this study were packed in two stack tier as shown in Figure 1 and the cushioning materials (polymeric foam, single wall corrugated fiberboard(SK210/K180/SK210)) as shown in Figure 1 was inserted in corrugated fiberboard box for packaging to minimizing the damage of the pears by the impact. These samples were pre-cooled and stored in a commercial cold storage facility for a week. The corrugated fiberboard box for packaging of the pears was conditioned to stabilize at experimental room atmosphere of 23 ℃ and 50 % relative humidity is recommended by ASTM before tests were conducted. Table 1 shows physical properties of the pears in corrugated fiberboard box for packaging being tested in this study.

Table 1. Harvesting date and physical characteristics of the pears used in sweep vibration tests

	Date of harvest	Volume (10^{-4} m^3)	Mass (kg)	True density (10^{-2} kg/m^3)
Pear (Niitaka)	2002. 10	5.1444 (1.0028)	0.5535 (0.0691)	10.7593 (0.6417)

2.2 Experimental Apparatus and Methods

The most comprehensive method for determining the vibration properties of corrugated fiberboard boxes for packages is described in ASTM D999, *Standard Test Method for Vibration Testing of Shipping Containers.* According to the standard test method, the vibration test apparatus is adjusted to produce the specified constant acceleration amplitude (zero-to-peak) over the specified range of frequencies, and this test is started at the lowest frequency, sweep the frequency of the vibration at a continuous logarithmic rate 0.5 to 1.0 octave per minute to the upper frequency limit in vertical sinusoidal input, and an acceleration amplitude of 0.25 G and 0.5 G (zero-to-peak) over the frequency range from 3 to 100 Hz is recommended. In this study, the vertical sinusoidal vibration test was performed to measure the resonant frequencies and the acceleration gains in the single container resonance test with the acceleration amplitude of 0.25 G (zero-to-peak) over the sweep frequency from 3 to 150 Hz and the sweep rate of 1 octave per minute for the corrugated fiberboard boxes for packages. The hydraulic vibration exciter can generate much lower frequency and higher exciting force than the vibration table of electro-dynamic vibration exciter. Therefore, the hydraulic vibration table was used to measure the acceleration in the vertical direction of corrugated fiberboard boxes for packages of pears during the sweep vibration test as shown in figure 1 and 2. To control the function generator by computer, HP-IB (Hewlett-Packard interface bus) was used. Both the input frequency and the input voltage from the function generator were carried to servo controller of hydraulic vibration table by a BNC cable. One-dimensional piezoelectric accelerometers of 20 G capacity were attached on the vibration table and a side of pears using a double-faced adhesive tape in corrugated fiberboard box for packaging to measure the acceleration in the vertical direction during the sweep vibration test as shown in Figure 2, and the signals from the piezoelectric accelerometers were carried to the charge amplifier of 60 dB and the low-pass anti-aliasing filter of the filter bandwidth range from 0.8 kHz to 20 kHz, and then the amplified and filtered signal was carried to the digital oscilloscope of the sampling rate of 500 M samples per second when 4 channels were on. RS-232C serial data communication was used to talk to and exchange data with the computer and the digital oscilloscope. The amplitude (zero-to-peak) of output signal on the oscilloscope monitor was stored to the hard-disk memory in computer every one second by the RS-232C serial data communication.

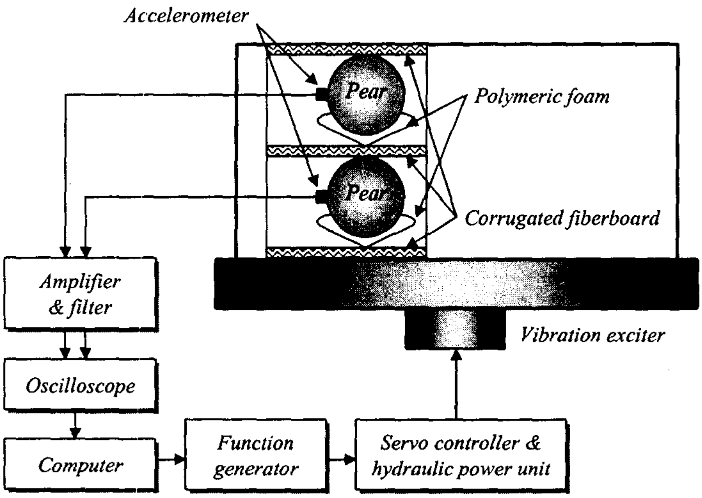


Fig. 1. Schematic diagram of the vibration test apparatus of hydraulic type.

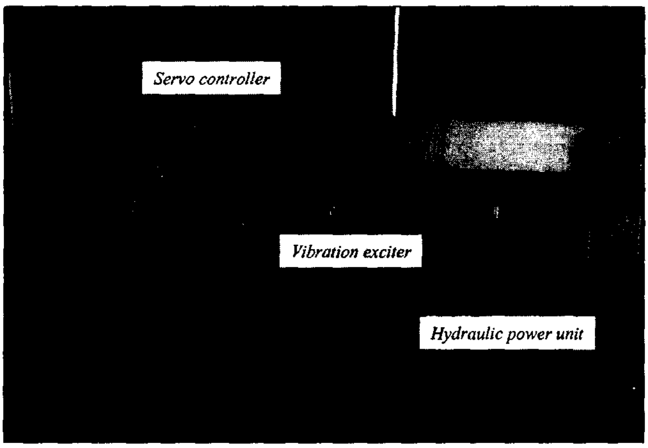


Fig. 2. Photograph of the sweep vibration test.

Specification of the vibration test apparatus is shown in Table 2.

Table 2. Specifications of the vibration test apparatus

Items	Specification	Remarks
Hydraulic Vibration Exciter	Frequency range : max. 300 Hz Weight range : max. 700 kgf Stroke range : ±25 mm	Engin.-Korea HVT-2
LVDT	Linear range : ±1.0 inches Standardized ±5 VDC output	Trans-Tek 1000-0014
Piezoelectric Accelerometr	Charge sensitivity : 0.094 pC/ms^{-2} Voltage sensitivity : 0.221 mV/ms^{-2} Frequency range : 0.5～400 Hz Measuring range : ±20 G	B&W Sensing Tech.
Function Generator	Waveform length : 8～16000 points Sampling rate : 40 Msa/sec Sine char. : 100μHz～15 MHz Sweep type : Linear or Logarithmic	HP-33120A
Digital Oscilloscope	No. of channels : 4 ch Sampling rate : 500 Msa/sec Vertical sensitivity range : 1 mV/div	HP-54542A
Charge Amplifier and Low-pass filter	Charge gain ranges : 1～1000 mV/pc Voltage gain range : 0～60 dB Frequency range : 0.3～20000 Hz Low-pass bandwidth : 0.8～20 kHz	M67-1F
Computer	RAM : 32 MHz, Hard-disk : 10.2 G	Pentium-166

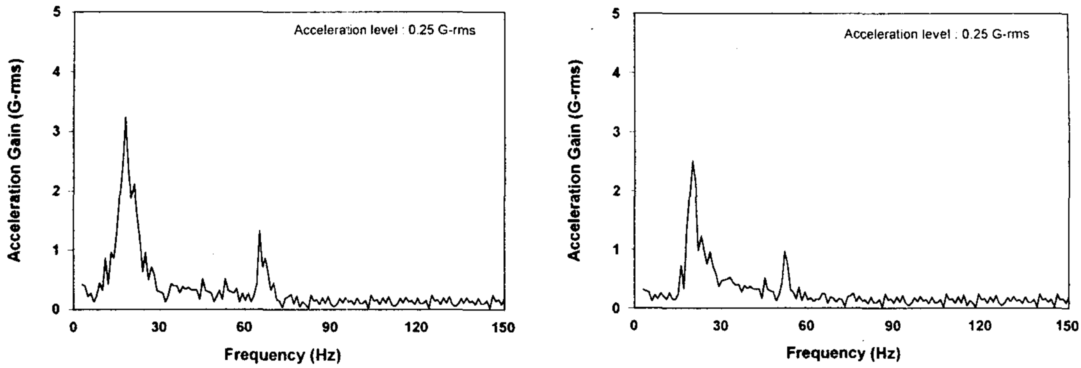
3. Results and Discussions

3.1 The vibration analysis of the pears in corrugated fiberboard box for packaging

Sinusoidal Sweep vibration tests were conducted to analyze the vibration characteristics of the pears in corrugated fiberboard box for packaging during transportation. Two peak frequency bands were measured as shown in Figure (3) and Table (2) shows the peak frequencies and peak accelerations of the pears according to positions.

It was found that the variances of peak frequency and peak acceleration in the pears according to positions not shown the obvious trend by statistical analysis. The decreasing rate of second peak acceleration by cushion working of polymeric foam and corrugated fiberboard was approximately 40 % in upper pears and 50 % in lower pears on resonance frequency band of 5 3～79 Hz (Kim and Jung, 2000) in pears and the second peak frequency of upper pears were larger then that of lower pears. However, the real decreasing rate of peak acceleration of the pears in corrugated fiberboard box in resonance frequency band of pear was larger then the measured decreasing rate because pears and cushioning materials were absolutely not fixed.

And also, it was thought that first peak frequency band had a relation with a resonance frequency band of corrugated fiberboard box for packaging of 15.40～22.02 Hz (Kim and Jung, 2002) and found that the first peak accelerations of the pears increased approximately 52 % in the upper pears and 39 % in the lower pears on resonance frequency band of 15.40 ~ 22.02 Hz of corrugated fiberboard box and the vibration amplitude of the pears in corrugated fiberboard box was larger then that of corrugated fiberboard box.



(a) Upper pear (No. 5) (a) Lower pear (No. 6)

Fig. 3. Acceleration gain of the pears in corrugated fiberboard box for packaging.

The first peak frequencies of the pears decreased approximately 18 % in the upper pears and 8 % in the lower pears on resonance frequency band of corrugated fiberboard box and the peak frequency of the pear produced at low frequency band as the vibration amplitude increased.

Table -. Vibration characteristics of the pears in corrugated fiberboard box

Position	Upper pears					Lower pears				
No.	M	1 PF	2 PF	1 PA	2 PA	M	1 PF	2 PF	1 PA	2 PA
1	0.6123	17.8	64.1	3.1684	1.3018	0.6021	19.8	53.2	2.4829	1.1692
2	0.5817	18.1	63.7	3.1726	1.3102	0.4981	21.3	53.9	2.5842	0.9424
3	0.4820	18.5	64.2	3.3108	1.3658	0.6290	22.9	53.4	2.4010	1.0482
4	0.6320	17.1	63.1	3.0428	1.2850	0.4283	18.5	55.6	2.6921	0.9924
5	0.4807	18.9	64.9	3.3657	1.3927	0.4771	21.9	53.8	2.6049	1.0830
6	0.5710	18.4	64.4	3.2457	1.3265	0.5692	20.2	52.4	2.5103	0.9653
7	0.5123	18.2	63.9	3.2953	1.3124	0.5213	20.8	54.2	2.5719	1.0924
8	0.6514	17.6	63.7	3.0112	1.2869	0.6638	19.2	51.4	2.4423	0.9420
9	0.4549	19.1	65.3	3.3727	1.4028	0.5328	23.1	52.6	2.4814	0.9730
10	0.5022	18.3	64.5	3.2958	1.3615	0.5123	20.7	54.8	2.5610	1.1583
11	0.6326	17.0	63.4	3.0109	1.2748	0.6296	18.9	53.2	2.4319	1.0110
AV	0.5557	18.09	64.11	3.2084	1.3291	0.5512	20.26	53.5	2.5240	1.0512
SD	0.0681	0.6388	0.6171	0.1304	0.0426	0.0700	1.1987	1.1062	0.0832	0.0579

***Note** : 1 PF = First Peak Frequency, 2 PF = Second Peak Frequency, M = Mass (kg), AV = Average
1 PA = First Peak Acceleration, 2 PA = Second Peak Acceleration, SD = Standard Deviation

And also, Kim and Jung (2001) proposed that the correlations of resonance frequency, peak acceleration (G-rms) and mass were very high. Therefore, the relations of them were studied as shown in figure 4 and 5 and it was found that the peak accelerations and peak frequencies of the pears in corrugated fiberboard box decreased with the increase of mass of the pears.

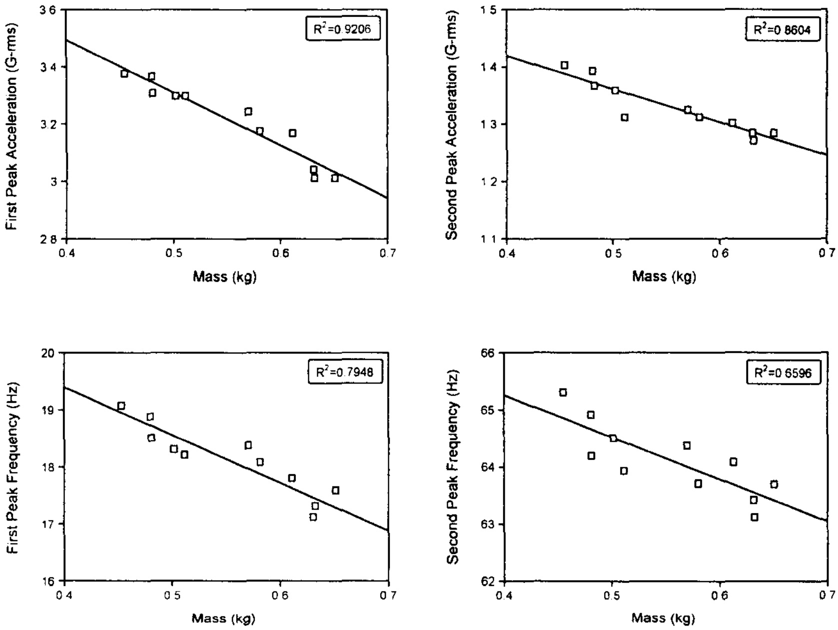


Fig. 4. Relations of peak acceleration, frequency and mass of the upper pears.

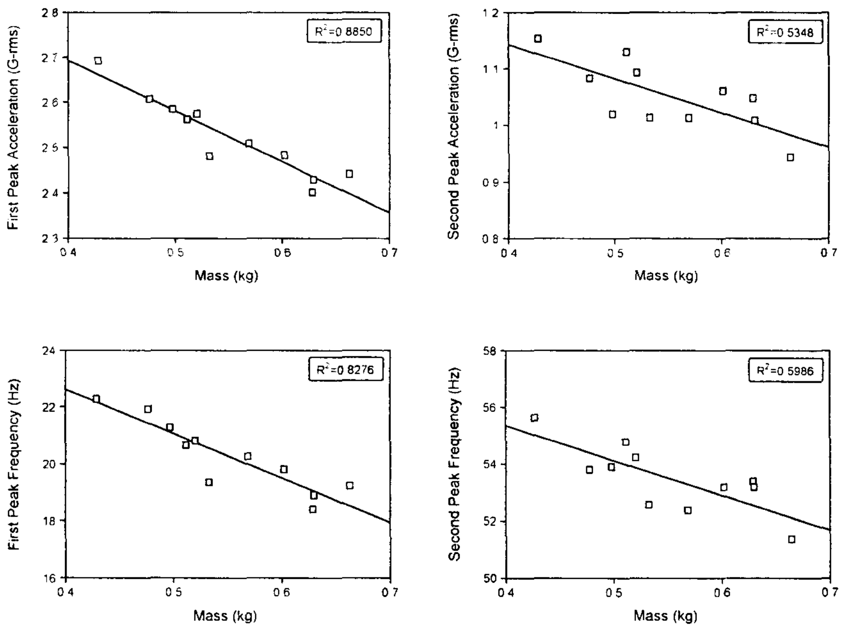


Fig. 5. Relations of peak acceleration, frequency and mass of the lower pears.

3. Conclusions

To analyze the vibration characteristics of the pears in the corrugated fiberboard box for packaging and evaluate how the frequency response of the pear is affected by the cushioning materials such as polymeric foam and corrugated fiberboard, sinusoidal sweep vibration tests were performed. The specific conclusions were:

1. The variances of peak frequency and peak acceleration in the pears according to positions not appeared the obvious trend by statistical analysis.
2. The decreasing rate of second peak acceleration by cushion working of polymeric foam and corrugated fiberboard was approximately 40 % in upper pears and 50 % in lower pears on resonance frequency band in pears and the second peak frequency of upper pears were larger then that of lower pears.
3. The first peak accelerations of the pears increased approximately 52 % in the upper pears and 39 % in the lower pears on resonance frequency band of corrugated fiberboard box. The first peak frequencies of the pears decreased approximately 18 % in the upper pears and 8 % in the lower pears on resonance frequency band of corrugated fiberboard box.
4. The vibration amplitude of the pears in corrugated fiberboard box was larger then that of corrugated fiberboard box and the peak frequency of the pear generated at low frequency band as the vibration amplitude increased and the peak accelerations and peak frequencies of the pears in corrugated fiberboard box decreased with the increase of mass of the pears.

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