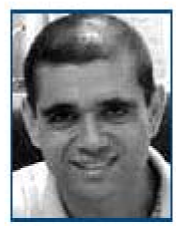
Update on Dynamic Compression Measurement and Testing

Dynamic compression occurs in transport due to vehicle vibration. Often designers only consider static compression (warehouse stacking), ignoring the effect of dynamic compression forces that cause higher stresses and damages to products and packages. This presentation will share some advances in field measurement and laboratory simulation of dynamic compression. The results show that packaging design may be improved to achieve a total reduction cost.



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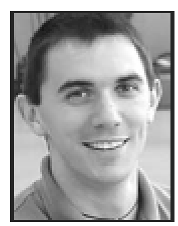

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Update on Dynamic Compression Measurement and Testing

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Abstract

The objective of laboratory performance tests is to simulate distribution environments. That is, to reproduce the same damage potential the packaged products will encounter in the field. Over the years, techniques for laboratory simulation have been improved considerably. As new and more sophisticated equipment becomes available, more can be done to better conduct laboratory packaging performance tests. This paper describes some of the new developments in dynamic compression measurement and testing. Various experiments were conducted applying dynamic compression forces. Some results show that the use of dead loads can be an efficient and economical way to test dynamic compression of corrugated fiberboard packages if force, rather than acceleration, is used to drive a vibration table.

Introduction

This paper explains some experiments conducted to explore the possibility of using a force random vibration spectrum to drive a closed loop random vibration system to simulate vibration in distribution, in a comparable way to the study conducted in the vibration testing of spacecraft (Scharton, 2002). One of the advantages of this method is the possibility of better quantification and simulation of damaging forces on packages. The other advantage is the possibility of better simulating the stresses encountered by packages tested with dead loads, because the use of dead loads is usually more economical than using full scale stacks (it uses more products and packages).

The study was conducted using loaded corrugated fiberboard packages. It is a continuation of a program to explore improved methods for simulating transportation environments in the laboratory, with the objectives of leading to lower damage rates to products and packages (Marcondes and Batt, 2002).

Background

A stack of packages with multiple degrees of freedom (MDOF) under vibration may be simulated by a single degree of freedom (SDOF) system as long as certain conditions apply (Urbanik, 1990). Fundamentally, the system has to reproduce the forces encountered in both situations (MDOF and SDOF). This procedure opens up an opportunity for a more realistic use of dead loads rather than actual stacks to evaluate packaging performance under dynamic compression. In addition, the use of dead loads to simulate an entire stack with acceleration control is not the most appropriate method since it neglects the dynamic properties of the MDOF system.

The advantages of using dead loads, rather than full stack reside in the simplicity and lower costs of the tests. The concept is shown in Figure 1. A system of force cells is placed under the stack to measure the variation of the force F (when the vehicle is not in motion, F = 0).

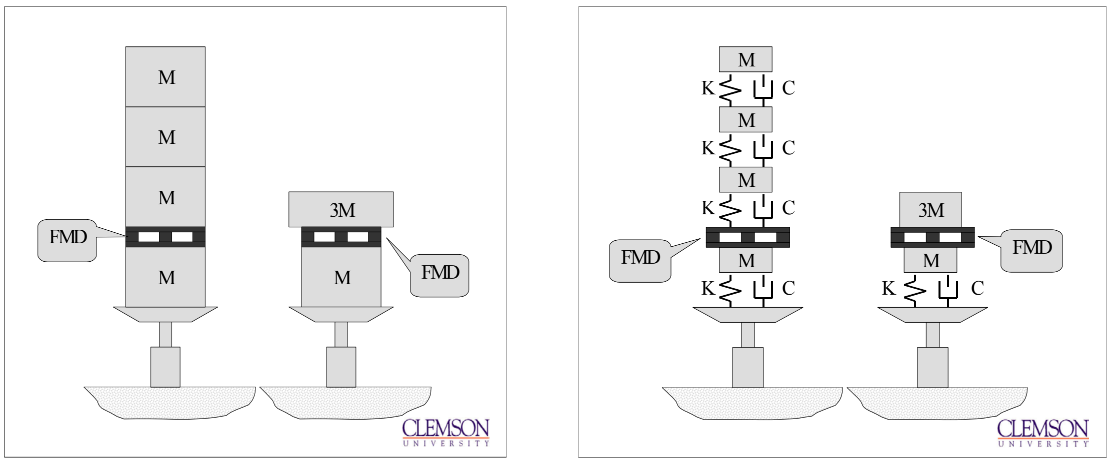

Figure 1. Using force measurement to for dynamic compression evaluation

Another possibility is to measure force applied on the top of the lowest package in the stack, as shown in Figure 1. The replication of the actual force received by the bottom package is a more realistic test than the vehicle acceleration test for conducting testing of shipping containers.

For corrugated fiberboard packages supporting the full weight of the stack, the tests can even be performed without any of the product (having enough headspace, the weight of the lowest box may be incorporated into the dead weight). If there is a load share with internal packages or product, then it is necessary that the bottom package be equally loaded since the load, combined with the box, will determine system characteristics (spring and damping).

Various studies show that the use of dead weight in an acceleration driven test can lead to totally wrong results. For example, Leinberger mentioned in his work (Leinberger, 1993) that lighter loads containing fewer boxes produced higher dynamic load / static load than heavier loads made up of more boxes. Later studies by Marcondes (Marcondes, 2000) showed that, for a specific type of package, within a frequency range of 12 – 16 Hz, the dynamic force measured at the bottom of a stack of 6 packages is equivalent to the force caused by just one package.

Pierce (1998) indicated that dynamic compression is often overlooked by standard testing protocols. This may lead to errors in the interpretation of laboratory testing results.

Experiments

A force measurement device (FMD) was constructed using three force transducers (sensitivity 0.2 mV/lb.), positioned between two stiff metal plates as shown in Figure 2.

Figure 2. Force Measurement Device (FMD)

The following experiments were performed:

<u>To validate the system:</u>

Part a:

1. Dead weight was placed on FMD.
2. Vibration table was run at 0.5 G peak.
3. Results were compared according to Newton’s 2nd Law: [F = m x G] at different frequencies

Part b:

1. Dead weight was placed on FMD.
2. Vibration table was run at 0.37 Grms following ASTM D-4169, truck, assurance level III
3. Results were compared at discrete frequencies according to: $PD_{(f)} = m^2 \times PD_{(G)}$

where $PD_{(f)}$ = power density force (lb^2/Hz) and $PD_{(G)}$ = power density acceleration (G^2/Hz).

To acquire data in a moving vehicle:

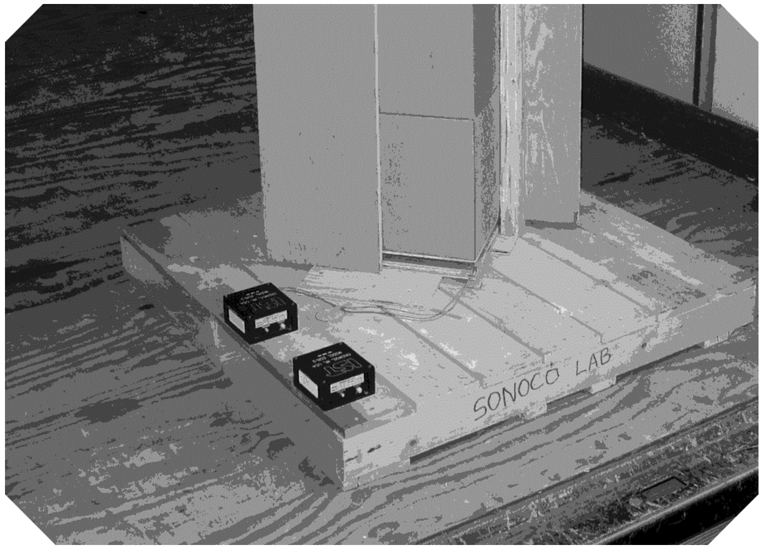

Figure 3. FMD (force measuring device) at the bottom of a stack to measure dynamic force in transport

The FMD was positioned at the bottom of the stack. Several measurements were taken in two types of vehicles: a 10 ft empty truck and a pickup truck.

To acquire data in the lab:

Part a: testing a stack of boxes to obtain force PSD:

A single stack of loaded corrugated fiberboard boxes (5 packages weighing 25 lb each) was placed on the

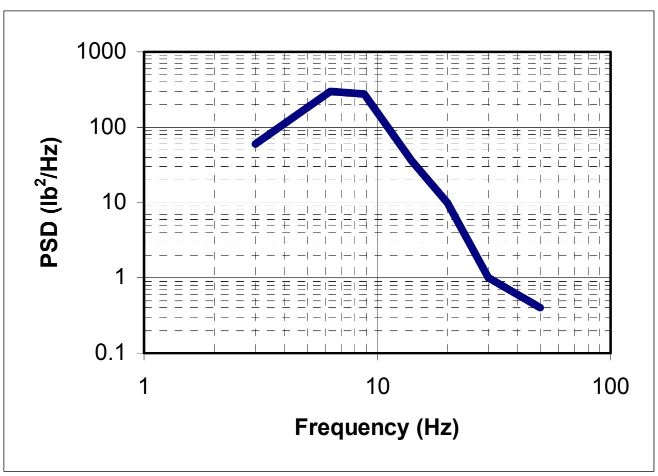

Figure 4. Force PSD measured at the bottom of a stack

FMD, which was placed on a single axis vibration table. The vibration table was controlled with a random vibration controller (RVC) using closed loop control acceleration. The acceleration power spectrum density (PSD) used was the Truck, ASTM D-4169, Assurance Level II. The FMD was used to measure the force at the bottom of the stack. Force transducers connected to a self-contained recording unit were used to measure the varying force. The recording unit was used to store data for later processing. The results are shown in the PSD force in Figure 4.

Part b: test a stack of packages with the force PSD as the RVC demand signal

Packages of 25 lb. each were stacked 3 high, and table was run as per force PSD shown in Figure 5.

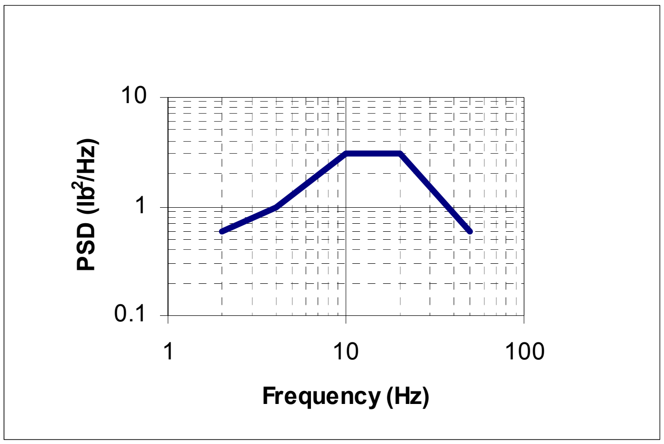

Figure 5. Demand PSD force controlling random vibration (using the force control device – FCD)

Part c: Comparing vibration acceleration response

The demand force PSD was run in two situations: first with the stack and then with dead weights. The stack configuration had one bottom box, the FCD and two boxes on top, and the second configuration have one

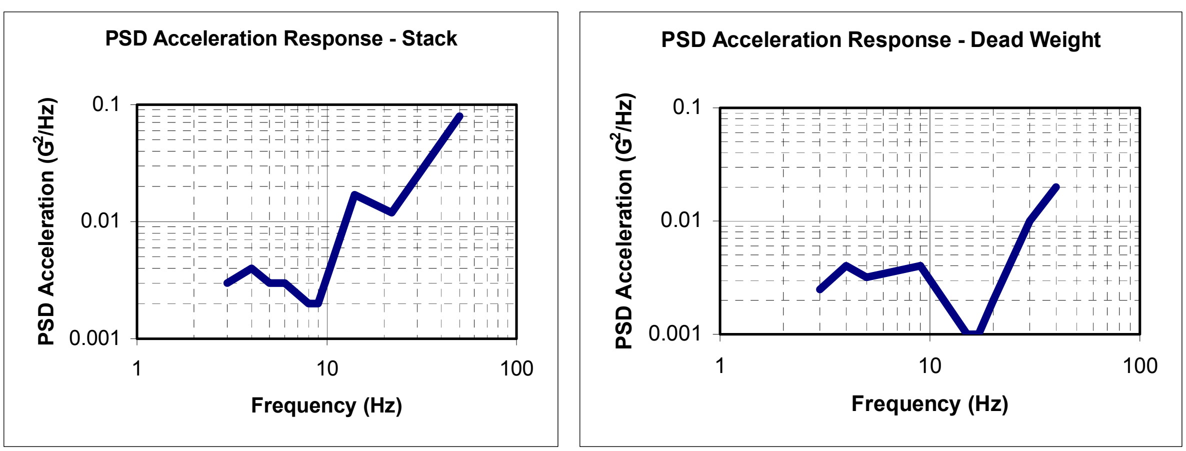

Figure 6. Response acceleration: Column stack versus dead weight

bottom box, the FCD and the dead weight of 50lb. The response acceleration was recorded for both situations, and shown in Figure 6.

For Part c, the table acceleration was recorded and compared. Notice that there is a difference in the acceleration response of the table. This is due to the difference between the actual stack and the dead weight. Assuming that the force at the bottom of the stack is the correct dynamic force, one can see why the same acceleration PSD would produce different forces. Since force is what causes packaging damage, it would be better to use the forces PSD profile to drive the table.

Results and conclusions

1. Should force be measured on the bottom of the stack or between the first and the second package in the stack? The best scenario would be to measure between the bottom box and the rest of the stack. There is a problem however if the lowest package collapses. Since we are calculating force applied on the bottom box (force applied on top of the bottom box, that is), it would be appropriate to measure the force and to reproduce it between the bottom box and the rest of the stack, or between the dead weight and the bottom box. However, if the bottom box fails the system can get out of control.

2. A comparison between the acceleration response functions for full stack versus dead weight shows a dramatic difference in the response acceleration of the table, for the same force inputs. This is due to the lumping of the mass into a dead load.

3. The greatest advantage in controlling the vibration table with force rather than acceleration is that a more realistic test can be performed with dead load only. This would be more economical in many cases.

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Acknowledgements

- IST, Inc. for donation of equipment and software for data acquisition and processing.
- USDA
- South Carolina Agricultural and Forestry Research
- Clemson University