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SHAPES OF SHOCKS IN SHOCK ENVIRONMENT
WITH TELEMENTRY SHOCK MEASURING
SYSTEM

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HIROYUKI IWASHIMIZU

has been accepted towards fulfillment
of the requirements for

M.S. degree in PACKAGING

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Major professor

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SHAPES OF SHOCKS IN SHOCK ENVIRONMENT
WITH TELEMENTRY SHOCK MEASURING
SYSTEM

By

Hiroyuki Iwashimizu

A THESIS

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ABSTRACT

SHAPES OF SHOCKS IN SHOCK ENVIRONMENT
WITH TELEMENTRY SHOCK MEASURING
SYSTEM

By

Hiroyuki Iwashimizu

The shocks encountered in the package were not measured sufficiently because of unavailability of self-contained, compact and accurate instrumentation. This thesis deals with the shapes of such shocks measured in the package. A telementry shock measuring system was designed for this testing. Four aspects of shock environments in the distribution system were chosen as simulated shock environments, such as 42" One Man Drop, One Man Throwing, Drop from Stack, and Drop onto Other Packages.

From the testing, triangular, half-sine, parabolic cusp, complex cusp, two-peak, trapezoidal, and other complex shapes were obtained.

As a "dummy" product, 11 3/8 lbs. of the telementry system instrumented wood block was used. Two-hundred pound test C-flute corrugated paperboard was used for the container, in which the wood block and cushion were packaged.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation for the guidance and support given in this research by Dr. James W. Goff, professor of School of Packaging at Michigan State University.

I also wish to extend my appreciation for the help and support to members of my committee, Dr. Hugh E. Lockhart, professor of School of Packaging and Dr. George W. Wagenheim, assistant professor of Marketing at Michigan State University.

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INTRODUCTION

Purpose

The purpose of this paper is to measure the shocks which a product would encounter in the package in the simulated shock environment by the telementry shock measuring system and to examine the shocks and their shapes.

Method

The telemetry system was built in a wood block in which three accelerometers were mounted triaxially. It was packaged in a corrugated paperboard container with a cushion and dropped in the simulated shock environments. The shocks were recorded on oscilloscopes and pictures were taken. The shapes of the shocks were observed, and the average accelerations were calculated from the durations and velocity changes of the shocks for reference.

Background

For the design of more sophisticated protective packages, the distribution environment, the performance characteristics of cushioning materials and the determination of product fragility are studied in the field of packaging.

The distribution environment has two aspects, i.e., the in-transit environment and the handling environment. The in-transit environment includes those motions resulting from movement on transport vehicles (trucks, railroads and aircraft). The handling environment includes those motions resulting from operations such as physical handling, loading and unloading, and movement within storage or warehouse areas (1) The in-transit environment was well studied compared to the handling environment. Ostrem (2) presented the frequency spectra measurements and the probability occurrence of accelerations from in-transit environments. Sharpe, Kusza and Goff (3) analyzed the vibration environment in common carrier trucks for the vibration testing of packages and indicated that the accelerations of shocks from the environment were not nearly as high as would be experienced in a drop test. Ostrem and Rumerman presented comprehensive literature surveys and searches for the in-transit environment (4) in 1965, and the handling environment (1) in 1967. In the latter survey the handling environment was described in drop heights, number of drops during the shipment of packages and so on.

This distribution environment data has been reflected in package shock and vibration testing programs.

The performance characteristics of cushions have been studied since the time of Mindlin's research (5). The static stress versus peak acceleration characteristics was employed and standardized package cushioniong (6). In determination of the shock fragility of products, the characteristics of shocks imposed on the products are important. With different shapes of pulses, shocks and the effects of shocks on product fragility were investigated, and the impact sensitivity curve (7) and the damage boundary curve (8) were introduced theoretically.

Nevertheless, the shocks experienced by products in packages in the distribution environment have not been measured due to the unavailability of an accurate self-contained instrumentation capable of measuring the shocks. This thesis deals with the shapes of the shocks of this sort, transmitted through a cushion and a container from simulated shock environments. To cope with the instrumentation problem, a telemetry shock measuring system was developed by Goff and Pierce (9). Based on the telemetry system, a new one was designed and built in a wood block as a "dummy" product for this testing.

TELEMETRY SHOCK MEASURING SYSTEM

Total System Description

The FM/FM telemetry shock measuring system had a frequency response from 1 to 2100 Hz and a shock response from 10 to 95 g's. The calibration procedure is shown in Appendix A.

The total view of the system is shown in Figure 1. The package contains the instrumented wood block or test product. The system is comprised of three, single channels. Three receivers are shown on the right-hand side of Figure 1. Each channel consists of an accelerometer, a coupler, an attenuator, a voltage controlled oscillator (VCO), a transmitter, a receiver, a discriminator and a recording device as shown in Figure 2 (8). The operation of a single channel is briefly described here, and the other channels operate in the same manner.

The shock received by the test product in the package is measured by an accelerometer in voltage as a shock pulse. This is once amplified by a coupler and attenuated to fit the input voltage for a VCO. The VCO changes a voltage signal to a frequency signal. The frequency signal is sent on a radio frequency carrier from a transmitter to a remote receiver. The receiver

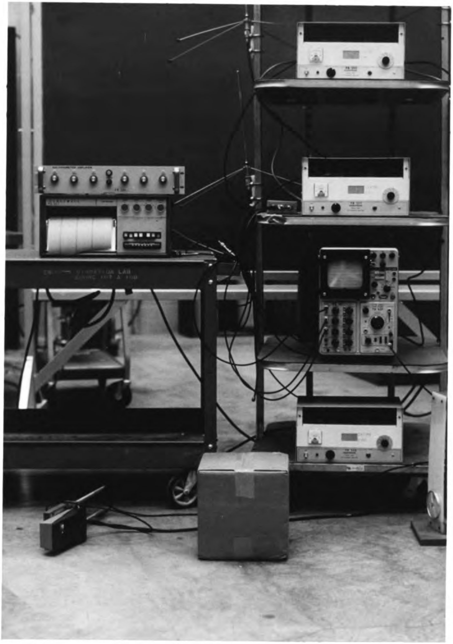

Figure 1. Total View of Telemetry Shock Measuring System with Instrumented Package

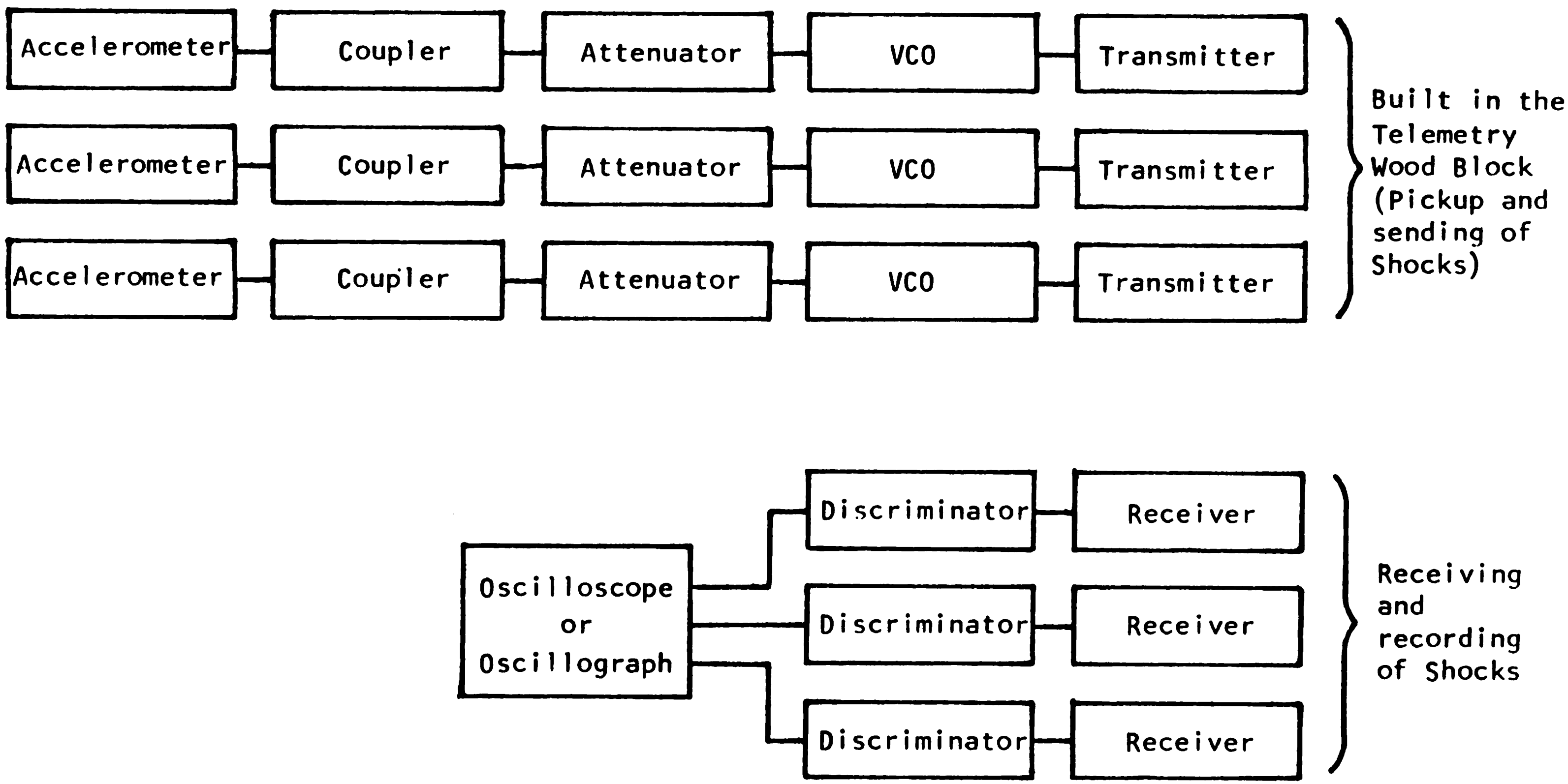

Figure 2. Telemetry Shock Measuring System Diagram

retrieves the original frequency from the radio frequency. The discriminator converts the frequency signal to the initial voltage signal, the shock pulse. The pulse is monitored on a recording device.

Instrumented Package Description

The instrumented package consists of three components; the telemetry wood block, the cushion and the container as shown in Figure 3.

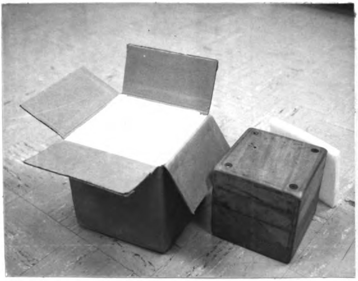

Figure 3. Three Components of the Telemetry Instrumented Package

The telemetry wood block is instrumented with the telemetry shock measuring system in its wood body. The shocks received by this wood block in the package were sent to remote receivers and recorded. This wood block is divided into two parts. One is the inner block, in which the telemetry system is directly housed and the other is the outer block, in which the inner block was enclosed from top and bottom (see Figure 4). Honduras mahogany wood was used for the body of the block, and its outer dimensions were 8 x 8 x 8 inches. The size of the inner block was 5 1/4 x 4 5/8 x 2 1/8 inches. To give orientation to the telemetry wood block, its two ends and four sides were numbered. Referring to the bottom block in Figure 4, the end shown in contact with the floor is designated as end 2, and the opposite end is designated as end 1. Side 1 is the front side of the block, and side 2 is the right-hand side of the block. Side 3 is opposite side 1, and side 4 is opposite side 2. End 2, side 3 and side 2 are the bottom sides of the three accelerometers. If a shock is sensed from those ends or sides, the corresponding pulses appear as positive pulses on an oscilloscope screen as shown in Figure 5.

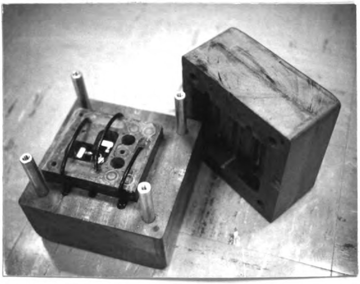

Figure 4. Telemetry Instrumented Wood Block

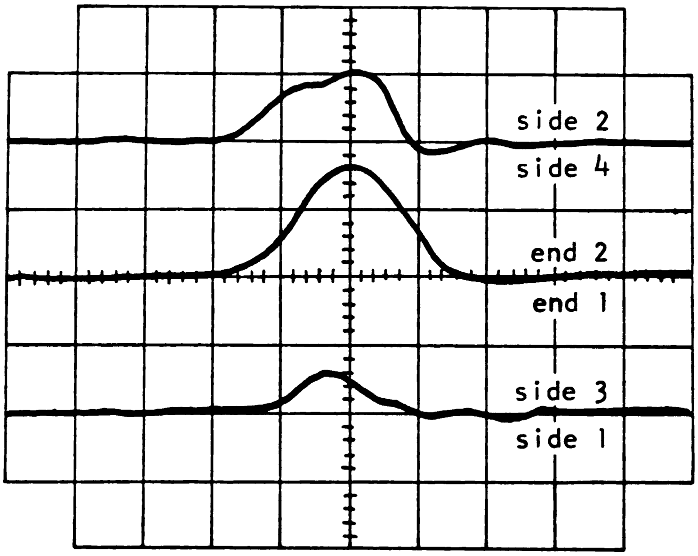

Figure 5. Shock Pulses from Side 2, End 2 and Side 3 on Scope Screen

For the cushion, Ethafoam* with density of 2.2 pounds per cubic feet was used. In terms of thickness, 3/4 inches was chosen to protect the wood block and the accelerometers of which the maximum input limits was 250 g's. The cushion was slipped in every corner and side of the block in the container.

The container was made of 200 pound test C-flute corrugated paperboard with the inside dimensions of 9 1/2 x 9 1/2 x 9 1/2 inches. Also, its type was a regular slotted box. For the manufacturer's joint and the top and bottom seals, Scotch brand tape, No. 351-2 was employed.

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*Trademark of the Dow Chemical Company

SHAPE OF SHOCK

Effect of Shock Shape

A shock is specified by three characteristics, such as its duration, acceleration and shape. These characteristics can be described by the shock pulse, which is the acceleration time history of the shock. With their pulses, shocks have been studied in their severity on shock sensitive products or spring-mass system models.

Kornhauser showed experimentally that no damage occurs until both a critical value of acceleration and a critical value of velocity change are exceeded (7). The same idea was introduced by Newton (8) as the damage boundary concept, that is, a product is subject to damage under any shock in the shaded area of its damage boundary curve as shown in Figure 6. The damage boundary curve is determined by a shock machine drop test (see the procedure in Appendix B).

The vertical line of the damage boundary curve is independent of the shape of the shock, however, the horizontal line is a function of the shape of the shock. Consequently, the type of shocks measured in this testing concern the horizontal line area. The pulses on the horizontal line have a long duration, and a short duration on the vertical line. Also, the average acceleration is important in the horizontal area, since this concerns the minimum acceleration required to cause damage.

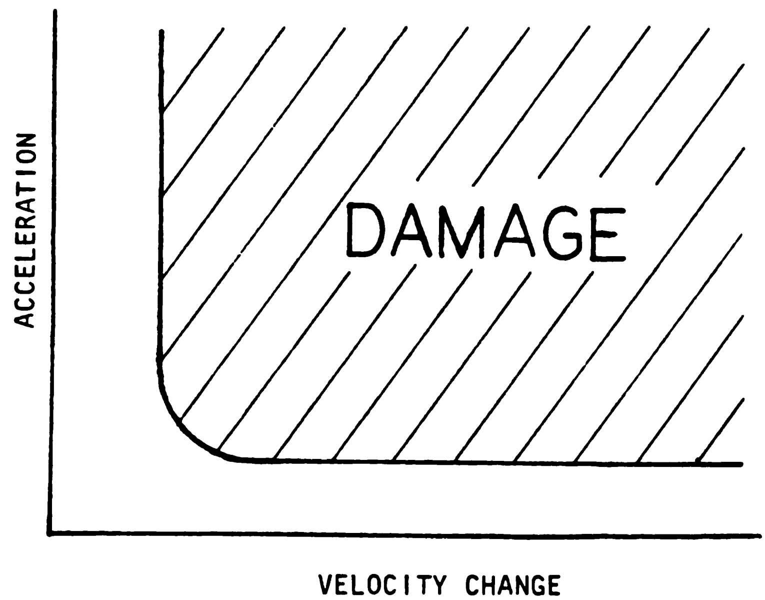


Figure 6. Damage Boundary Curve

The average accelerations of the shocks in the testing were calculated from the velocity change (ΔV), which was determined by the pulse weighing method (see Appendix C). With the ΔV and Duration, the Ave.-g is calculated as follows:

$$\text{Ave.-g} = \frac{\Delta V}{D \times 386.4}$$

where Ave.-g = the Average Acceleration (in/sec^2),

ΔV = the Velocity Change (in/sec),

and D = the Duration (sec).

Typical Shock Shapes and Average Acceleration

Typical shock shapes and their average accelerations are shown in Figure 7. The average values are the fractions of their peak accelerations. The calculations were made based on the mathematical expressions of the pulses (11) shown in Appendix D.

The rectangular pulse only has an average acceleration equal to its peak acceleration. In practical shock machine testing, trapezoidal pulses are used as rectangular pulses because of mechanical limitations. The half-sine pulse has 64% of the peak acceleration for the average acceleration. The average acceleration of the haversine pulse is 50% of its peak. Different shapes of triangles have equal average acceleration if the duration and peak acceleration are equal. However, it should be noticed that even if the accelerations are the same, the differences in shape will affect the vertical line (7) of the damage boundary curve shown in Figure 6. The parabolic cusp has the lowest average acceleration; 33% of the peak acceleration. Usually, the cusp is produced from bottoming of the cushioning materials or from the impact of rigid bodies.

With the average acceleration, the pulse shapes are sorted for the results. The half-sine pulse and haversine pulse were regarded as a half-sine pulse.

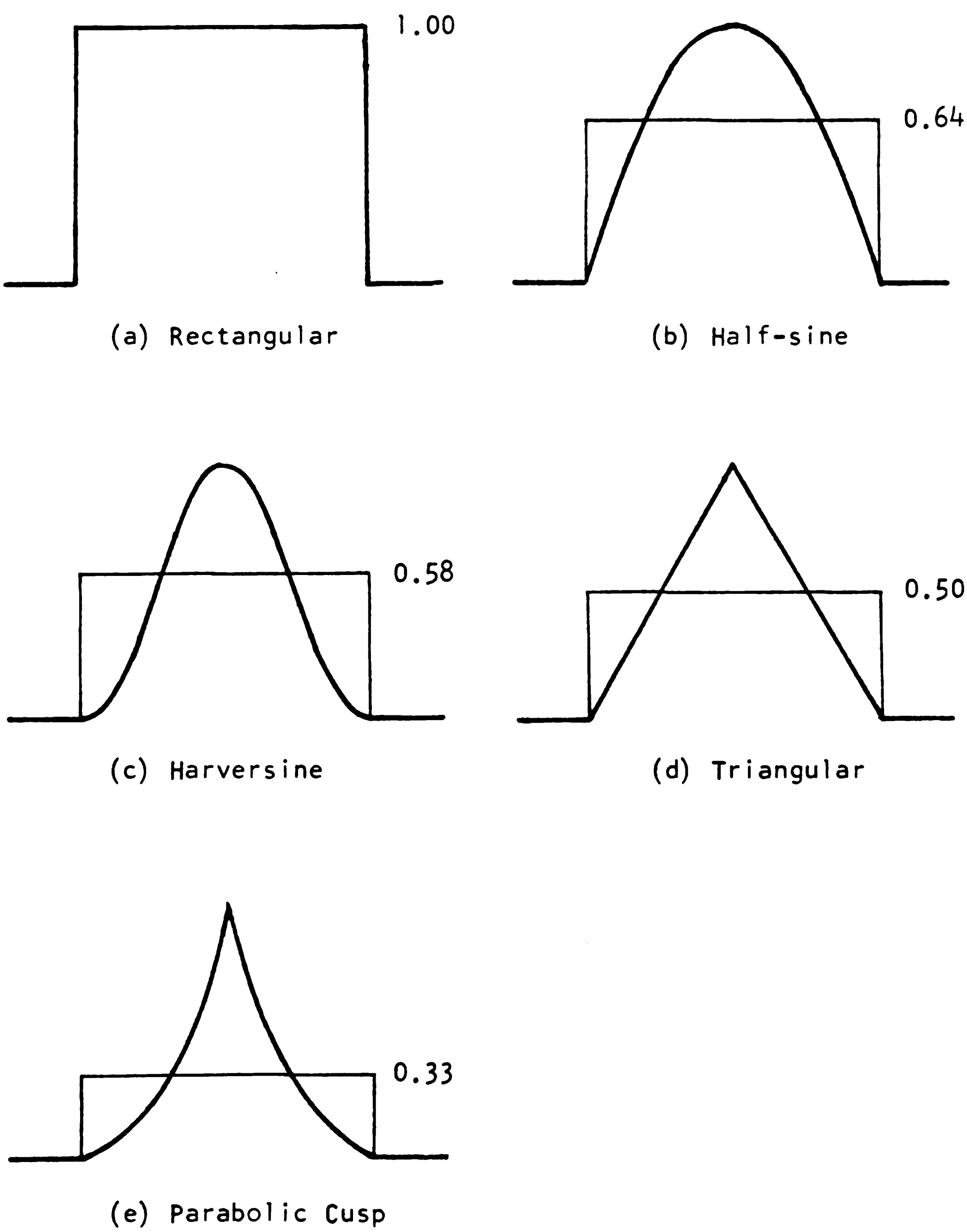


Figure 7. Typical Shock Shapes and Their Average Acceleration Ratios (Fractions of Their Peak Accelerations)

SIMULATED ENVIRONMENT DESCRIPTION

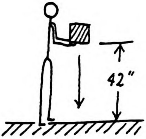
Four shock environments in distribution were chosen as the test environment, as shown in Figure 8 and explained below.

42" One Man Drop

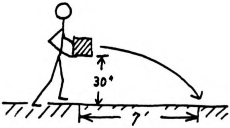
This is a basic aspect of the handling environment. The test package was held by a man at 42 inches from a concrete floor and is dropped freely. This height was chosen because of the total weight of 12 1/2 lbs. according to the Recommended Drop Height (1). (This is about the distance from the floor to the elbows of a man of average height.)

One Man Throwing

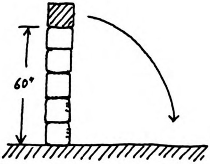
This is chosen as another aspect of physical handling by a man, assuming the situation that small and light packages are thrown to the floor during loading or unloading. The package was held at the height of 30 inches and thrown horizontally, approximately seven feet ahead.



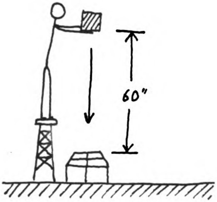
(a) 42" One Man Drop



(b) One Man Throwing



(c) Drop from Stack



(d) Drop onto Other Packages

Figure 8. Test Shock Environments

Drop From Stack

The package was dropped from the top of a stack of packages. The five boxes under the test package were stacked 60 inches high. These are the boxes used in the one man drop test and the one man throwing test. By using the used boxes, the stack fell simply by pushing the package with a finger. This is used in the situation where the top package falls off due to an inferior (i.e., damaged packages on the bottom) stack.

Drop Onto Other Packages

The package was dropped flat onto empty corrugated boxes from 60 inches above. This situation, where a package dropped onto other packages, occurs in the handling environment. In the in-transit environment it does happen when a package falls onto other packages from the top of a stack of packages due to vehicle vibration.

SHOCK ENVIRONMENT TEST PROCEDURE

42" One Man Drop Test

The package was held at a height of 42" from the concrete floor with end 2 of the test product facing down toward the floor and side 3 facing the man. It was released gently and it dropped freely. A reflex photo-electric relay and a retro-reflector were set so that when the package interrupted the light beam between them, the sweep of an oscilloscope would be triggered. A Tektronix Model 564B storage oscilloscope was used. The shock pulses from the test product were recorded on the oscilloscope and pictures were taken by a Textronix oscilloscope camer C-12.

One Man Throwing

The package was held by a man at a height of 30 inches from the floor with end 2 facing the floor and side 3 facing the direction of throwing. It was intended for the package to be thrown so that the package wouldn't rotate more than 90 degrees, or at least, so that end 2 would face the floor at the first impact. The reflex photoelectric relay and the reflector were set at 1 1/2 inches from the floor and 7 feet from the man. The package was sensed by the light beam and the shocks were recorded on the Tektronix Model 564B storage oscilloscope and pictures were taken by the Tektronix camera C-12. A Tektronix oscilloscope Model 17623 was used supplementarily. Also, a Honeywell Model 1508 VISICORDER was used to observe the shocks after the first impact. The container and cushion were replaced by new ones after six or seven throws.

Drop From Stack

The package was placed on top of five empty boxes at a height of 60 inches from the concrete floor. Two used boxes were set on the bottom of the stack so that the stack would fall down when a small amount of force was applied to the package. The other three boxes were the same as the test container. From the initial observations of the manner in which the stack fell, the package was found to rotate forward approximately 90 degrees. Therefore, end 2 and side 3 of the package were set to face forward and downward respectively on the stack so that end 2 hit the floor and side 3 faced forward at the first impact. This "falling-orientation" in terms of the first impact was the same as in the One Man Throwing test.

The photoelectric relay and the reflector were set to catch the drop of the package. The shock pulses were recorded on the Tektronix 564B storage oscilloscope and pictures were taken by the oscilloscope camera.

Drop Onto Other Packages

The package was held at 60 inches above the top of empty boxes and dropped freely onto them. The shock pulses were monitored by a Tektronix 564B storage oscilloscope and pictures were taken by an oscilloscope camera.

Two box configurations are shown in Figure 9. One is a single box, and the other is a set of four boxes. These boxes were made of 200 pound test C-flute corrugated paperboard.

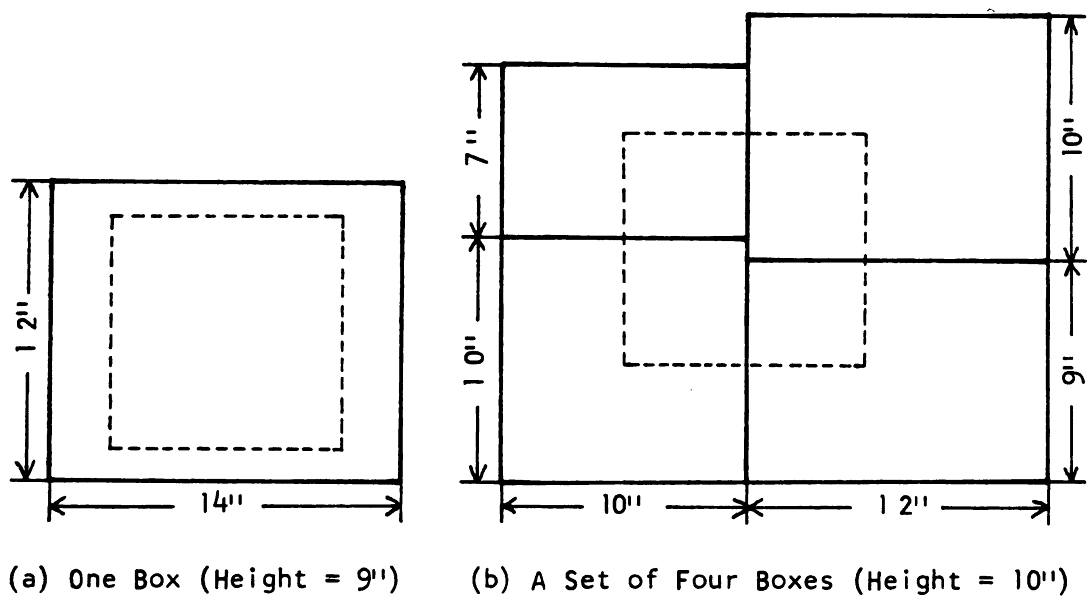


Figure 9. Top View of Boxes for Drop onto Other Packages Test with Drop POsition of Test Package (broken lines)

RESULTS AND DISCUSSION

42" One Man Drop

Shown in Figure 10 are typical pulses resulting from a 42" one man drop test and their input directions to the test product, indicated by side- and end- numbers. This numbering is held constant throughout this thesis unless indicated. An example interpretation of the result follows.

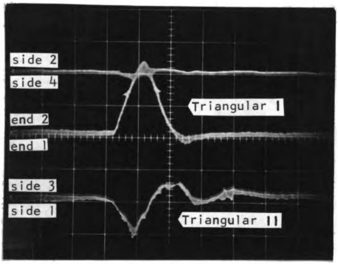


Figure 10. Typical Shock Pulses from 42" One Man Drop Test and Input Directions.

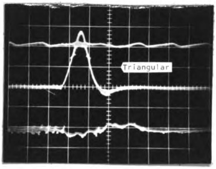
In the middle of Figure 10, a triangular pulse, numbered I, is recognized, implying that the shock at the first impact was mostly input to end 2 since the deflection of the sweep for end 2 is larger than any other pulses in the figure. The damped vibration on the bottom was began at the same time as the other triangular pulse II on side 1. This vibration means that the test product was excited by the shocks from side 1 and side 3 alternately. In other words, the package was dropped flat and end 2 hit the floor first, but, at the same time, side 3 hit it slightly. As a result, the test product inside the package started fluctuating between side 1 and side 3 while the main force was imposed on end 2. Little shock was recorded on side 2 and side 4. Channel 3 for these directions showed malfunctions, therefore, it was neglected thereafter. The package did not turn over after the first impact. In Table 1, readings of shocks in Figure 10 are shown.

Table 1. Readings of Shocks in Figure 10

Triangular Pulse I on end 2			Triangular Pulse II on side 1		
Peak-g	42	g's	peak-g	20	g's
Duration	9.0	ms	Duration	6.5	ms
ΔV	81	in/sec	ΔV	26	in/sec
Ave.-g	23	g's	Ave.-g	10	g's
Ave.-g/Peak-g	.55	--	Ave.-g/Peak-g	.50	--

The peak-g (peak acceleration in g's) and duration of the triangular pulse I can be read as 42 g's and 9.0 ms respectively. Its velocity change (ΔV) and average-g (average acceleration in g's) were calculated as 81 in/sec and 23 g's respectively. The duration of a pulse is the duration at the 10% level of its peak acceleration. The ratio of the average-g over the peak-g, expressed here as Ave.-g/Peak-g, was .55. This pulse is classified as a triangular pulse due to its shape, even though it has a high value of Ave.-g/Peak-g for a triangular pulse. The triangular pule II has 20 g's of a peak-g, 6.5 ms of a duration, 26 in/sec of a velocity change, and 10 g's of an average acceleration. The ave.-g/Peak-g value was .50.

In Figure 11, another result from the 42" One Man Drop Test is shown. The shape is designated as a triangle due to its ratio of Ave.-g/Peak-g. The average acceleration was 27 g's, while the peak acceleration was 54 g's.



Triangular

Peak-g	54	g's
Duration	8.5	ms
ΔV	89	in/sec
Ave.-g	27	g's
Ave.-g/Peak-g	.50	

Figure 11. Triangular Pulse from 42" One Man Drop Test.

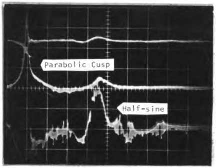
One Man Throwing

More complicated shock shapes and a variety of shock shapes were obtained from the One Man Throwing Test because of its rough motion or rotation of the package on the concrete floor.

A parabolic cusp pulse and a half-sine pulse are shown in Figure 12. This parabolic cusp pulse is a typical cusp and has a very high peak acceleration and a low average acceleration. The Ave.-g/Peak-g was .23. The half-sine pulse has the same velocity change of 44 in/sec as the parabolic cusp pulse and a lower peak acceleration, however, it has a higher average acceleration because of the shape. This half-sine pulse was the second impact from the rotation of the package on the floor.

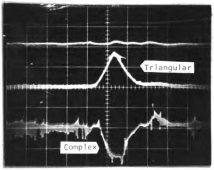
In Figure 13, a triangular pulse and a complex pulse are shown. The triangular pulse has a higher peak acceleration than that of the complex pulse, although it has a lower average acceleration. This complex pulse could be classified as a half-sine pulse, considering the value of Ave.-g/Peak-g.

A comparison is made between a complex cusp pulse on side 1 and a half-sine pulse on side 3 in Figure 14. The pulse on end 2 is also a complex cusp pulse at the impact on the floor. It should be noted that the half-sine pulse on side 3 was caused when the package was thrown and hit the wall of the steel table unintentionally. It was the first throwing after renewing the cushion and container. The same type of cusp pulse was obtained on end 2 in other throws with a used package as shown in Figure 15.



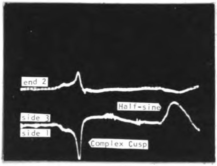
	Parabolic Cusp		Half-sine	
Peak-g	70	g's	36	g's
Duration	7.0	ms	5.5	ms
ΔV	44	in/sec	44	in/sec
Ave.-g	16	g,s	19	g's
Ave.-g/Peak-g	.23	-	.58	-

Figure 12. Parabolic Cusp and Half-sine Pulse from One Man Throwing Test



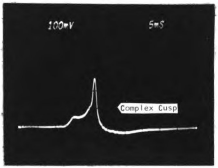
	Triangular		Complex	
Peak-g	32	g's	28	g's
Duration	10	ms	9.5	ms
ΔV	64	in/sec	65	in/sec
Ave.-g	17	g's	18	g's
Ave.-g/Peak-g	.52	-	.63	-

Figure 13. Triangular and Complex Pulse from One Man Throwing Test



	Complex Cusp		Half-sine	
Peak-g	40	g's	24	g's
Duration	14.	ms	17.	ms
ΔV	69	in/sec	101	in/sec
Ave.-g	13	g's	15	g's
Ave.-g/Peak-g	.32	-	.64	-

Figure 14. Complex Cusp Pulses and Half-sine Pulse from One Man Throwing Test with Wall



	Complex Cusp	
Peak-g	56	g's
Duration	10.	ms
ΔV	63	in/sec
Ave.-g	16	g's
Ave.-g/Peak-g	.29	-

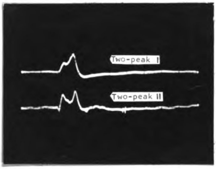
Figure 15. Complex Cusp Pulse from One Man Throwing Test

In Figure 16, the pulses with two peaks are shown. Complex motion of the test product is indicated by the presence of two peaks.

Drop From Stack

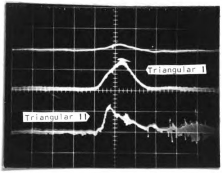
The pulses with relatively low accelerations were obtained from the drop test from a stack of packages, notwithstanding the 60" height of the stack underneath the test package.

In Figure 17, two triangular pulses are shown. They were classified as triangles because of their shapes and becasue the values of Ave.-g/Peak-g were close to .50. Another triangular pulse and a complex pulse are shown in Figure 18. The complex pulse as a .67 value, Ave.-g/Peak-g. Other pulses are shown from Figure 19 to Figure 21.



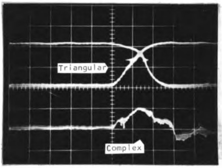
	Two-peak I		Two-peak II	
Peak-g's	20	g's	20	g's
	10	g's	14	g's
Duration	11	ms	12	ms
ΔV	49	in/sec	54	in/sec
Ave.-g	11	g's	12	g's
Ave.-g/Peak-g	.57	-	.58	-

Figure 16. Pulses with Two Peaks from One Man Throwing Test



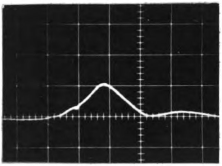
	Triangular I		Triangular II	
Peak-g	26	g's	24	g's
Duration	11.5	ms	12.5	ms
ΔV	60	in/sec	57	in/sec
Ave.-g	14	g's	12	g's
Ave.-g/Peak-g	.52	-	.49	-

Figure 17. Triangular Pulses from Drop from Stack Test



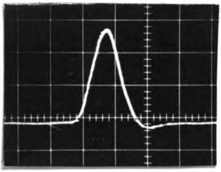
	Triangular		Complex	
Peak-g	30	g's	18	g's
Duration	12.0	ms	14.5	ms
ΔV	65	in/sec	56	in/sec
Ave.-g	14	g's	12	g's
Ave.-g/Peak-g	.46	-	.67	-

Figure 18. Triangular and Complex Pulses from Drop From Stack Test



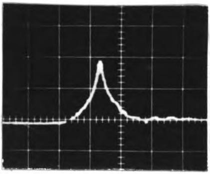
	Triangular	
Peak-g	20	g's
Duration	13.0	ms
ΔV	56	in/sec
Ave.-g	11	g's
Ave.-g/Peak-g	.55	-

Figure 19. Triangular Pulse from Drop from Stack Test



	Half-sine	
Peak-g	58	g's
Duration	8.0	ms
ΔV	99	in/sec
Ave.-g	32	g's
Ave.-g/Peak-g	.55	-

Figure 20. Half-sine Pulse from Drop from Stack Test



	Parabolic Cusp	
Peak-g	36	g's
Duration	10.0	ms
ΔV	42	in/sec
Ave.-g	11	g's
Ave.-g/Peak-g	.30	-

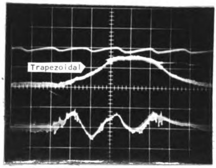
Figure 21. Parabolic Cusp Pulse from Drop from Stack Test

Drop on Other Packages

Shock pulses with a long duration and a flat top were obtained from the drop test on other boxes.

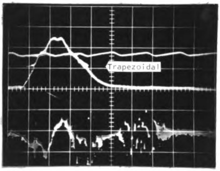
The duration was recorded as 32.5 ms for the relatively trapezoidal pulse in Figure 22. The peak acceleration was 14 g's and 8 g's for the average acceleration. The package was dropped on the empty box. Another trapezoidal pulse was recorded in Figure 23. This drop was made on the center of four empty boxes. The duration was 18.5 ms and the peak acceleration lasted for a period of 5 ms at 24 g's.

Half-sine pulses and other complex pulses are shown in Figure 24 and Figure 25. These pulses also have a long duration.



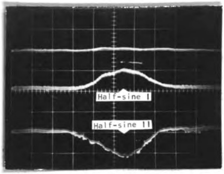
Trapezoidal		
Peak-g	14	g's
Duration	32.5	ms
ΔV	101	in/sec
Ave.-g	8	g's
Ave.-g/Peak-g	.58	-

Figure 22. Trapezoidal Pulse with 32.5 ms Duration from Drop on a Box



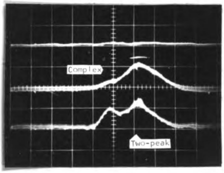
Trapezoidal		
Peak-g	24	g's
Peak Duration	5.0	ms
Duration	18.5	ms
ΔV	97	in/sec
Ave.-g	14	g's
Ave.-g/Peak-g	.57	-

Figure 23. Trapezoidal Pulse with 5.0 ms Peak Duration from Drop on Four Boxes



	Half-sine I		Half-sine II	
Peak-g	16	g's	24	g's
Duration	19.0	ms	20.0	ms
ΔV	77	in/sec	106	in/sec
Ave.-g	10	g's	14	g's
Ave.-g/Peak-g	.65	-	.57	-

Figure 24. Half-sine Pulses from Drop onto Other Packages Test



	Complex		Two-peak	
Peak-g	22	g's	24	g's
Duration	18.0	ms	18.0	ms
ΔV	79	in/sec	92	in/sec
Ave.-g	11	g's	14	g's
Ave.-g/Peak-g	.52	-	.55	-

Figure 25. Complex and Two-Peak Pulse from Drop on Other Packages Test

Summary

To summarize the four simulated shock environment tests, each test is characterized in terms of the shape, the peak-g, the duration, and the ratio, Ave.-g/Peak-g of the shock. The typical shock pulses are chosen and shown in Table 2.

Table 2. Typical Shocks from Test Environments

Shape	Peak-g	Duration	Ave.-g/ Peak-g	From Figure
42" One Man Drop				
Triangular I	42 g's	9.0 ms	.55	10
Triangular	54 g's	8.5 ms	.50	11
One Man Throwing				
Parabolic Cusp	70 g's	7.0 ms	.23	12
Complex Cusp	56 g's	10.0 ms	.29	15
Triangular	32 g's	10.0 ms	.52	13
Drop From Stack				
Triangular II	24 g's	12.5 ms	.49	17
Complex	18 g's	14.5 ms	.67	18
Half-sine	58 g's	8.0 ms	.55	20
Drop Onto Other Packages				
Trapezoidal	14 g's	32.5 ms	.58	22
Trapezoidal	24 g's	18.5 ms	.57	23

The 42" One Man Drop is characterized by its two simple triangular pulses. The One Man Throwing is characterized by sharp peak pulses, such as a parabolic cusp pulse, a complex cusp pulse, and a triangular pulse. These pulses have relatively small values of Ave.-g/Peak-g. The Drop From Stack is characterized by a variety of shock shapes. The complex pulse has a .67 Ave.-g/Peak-g value. The long duration and high Ave.-g/Peak-g value characterize the Drop Onto Other Boxes.

For the 42" One Man Drop, only the triangular pulses were obtained since the thickness of the cushion was made as low as possible for the telemetry system response.

CONCLUSIONS

Various shock shapes were obtained from the simulated test environments with the telemetry shock measuring system. The shapes obtained were half-sine, triangular, parabolic cusp, complex cusp, two-peak, trapezoidal, and other complex shapes.

The durations of the main pulses at the first impact of each drop ranged from 7.0 ms to 32.5 ms. The shortest one was from the parabolic cusp pulse from the One Man Throwing Test and the longest one was from the trapezoidal pulse from the Drop Onto Other Packages Test. The accelerations of the pulses were70 g's and 14 g's respectively.

APPENDICES

APPENDIX A

TELEMETRY SYSTEM CALIBRATION

The components and the total system of the telemetry measuring system were calibrated. The procedure followed the Development of the Telemetry Shock Measuring System (8).

Telemetry Wood Block

The shock transmission of the wood block was tested. The block was mounted directly on the shock machine table with a fixture as shown in Figure 26. The two ends and four sides of the block were tested. Each test accelerometer in the block was connected to the oscilloscope through a coupler. Its reading was compared with the signal from a control accelerometer on the same scope screen. The control accelerometer was connected through a coupler. Half-sine pulses were used as controlled pulses, generated by the shock machine with the gas programmer or plastic programmers with felt on them. Pictures of the pulses were taken. The results are shown in Table 3, indicating no effect on the shock transmission by the wood block intself and the whole assembly. The equipment used was a MTS gas programmable shock machine, a Kistler 808 accelerometer for control, three Kistler 818 accelerometers for test, Kistler 548B couplers for the test accelerometers, a Kistler 587D coupler for the control accelerometer, a Tektronix 7023 oscilloscope, and Textronix oscilloscope camera C-12.

Figure 26. Calibration of Telemetry Wood Block on Shock Machine with Gas Programmer

Table 3. Calibration of Telemetry Wood Block

	Control Accelerometer		Test Accelerometer	
	Deceleration (in g's)	Duration (in ms)	Deceleration (in g's)	Duration (in ms)
End 1	28	7.6	28	7.6
	68	5.5	68	5.5
	125	4.0	125	4.0
	220	3.6	220	3.6
End 2	28	7.6	28	7.6
	70	5.3	70	5.3
	125	3.8	125	3.8
	220	3.6	220	3.6
Side 2	24	7.6	24	7.6
	70	5.4	70	5.4
	125	3.8	125	3.8
	200	3.5	178	4.0
Side 4	24	7.6	24	7.6
	68	5.6	68	5.6
	125	3.8	125	3.8
	200	3.5	200	3.5
Side 1	27	8.0	27	8.0
	68	5.5	68	5.5
	115	3.8	125	3.5
	175	4.0	190	3.7
Side 3	28	7.4	27	7.6
	68	5.8	68	5.5
	125	3.8	125	3.8
	175	4.0	175	4.0

Attenuators

The attenuators were designed to reduce the voltage from the couplers to the voltage controlled oscillators for their input sensitivity limit. A combination of 50kΩ and 1kΩ registers of 5% tolerance were used as a voltage divider to provide an attenuation factor of 50.

A voltage from 0 to 2.5 volts was applied to an attenuator with a frequency from 0 to 5 KHz. Ths input voltage and output voltage of the attenuators were read on the same oscilloscope.

As a result, the attenuators had an attenuation factor of 50 and would not be affected by the frequency range from 0 to 5 KHz.

The equipment used was; a Hewlett Packard 202C Low Frequency Oscillator, a Hewlett Packard 5381A 80 Mitz Frequency Counter, and a Tektronix 564 B Storage Oscilloscope.

VCO, Transmitter, Receiver Discriminator

The VCO, transmitter, receiver and discriminator were tested together to see the effect of the frequency on voltage ouput from the discriminator.

A sinusoidal input of 50 millivolts was input to the VCO and monitored on an oscilloscope. The output from the discrminator was monitored on the same scope and a voltmeter. The frequency of input was varied from 1 to 2100 Hz. The results are shown in Table 4.

Table 4. Discriminator Output for Different Frequency Input

Frequency Input (Hz)	Channel 1 Output (volts)	Channel 2 Output (volts)	Channel 3 Output (volts)
1	2.5	2.5	2.0
50	2.5	2.5	2.0
100	2.5	2.5	2.0
150	2.5	2.5	2.0
200	2.46	2.44	1.96
250	2.44	2.42	1.94
300	2.42	2.38	1.92
350	2.38	2.34	1.90
400	2.38	2.30	1.86
450	2.34	2.26	1.84
500	2.32	2.20	1.78
600	2.24	2.12	1.68
700	2.16	2.00	1.64
800	2.08	1.86	1.64
900	1.98	1.76	1.56
1000	1.92	1.66	1.48
1100	1.84	1.56	1.40
1200	1.74	1.46	1.34
1300	1.66	1.34	1.24
1400	1.56	1.26	1.18
1500	1.48	1.16	1.12
1600	1.40	1.06	1.04
1700	1.30	.98	.98
1800	1.24	.90	.92
1900	1.16	.84	.86
2000	1.08	.78	.80
2100	1.02	.72	.76

Channel 3 did not have the correct VCO center frequency so that the discriminator did not have enough gain. It was set at the maximum 2.0 volts. Bsides that, each channel had a flat frequency response up to 150 Hz.

The equipment used was; a Hewlett Packard 202C Low Frequency Oscillator, a Tektronix 564 B Storage Oscilloscope, a Hewlett Packard 5381A 80 MHz Frequency Counter, and a Hewlett Packard 3403C RMS Voltometer.

Total System

The telemetry instrumented block (the test product) was assembled and mounted on a shock machine. All the ends and sides were tested and with half-sine pulses from a gas programmer or a plastic programmer with durations from 3.5 to 7.6 milliseconds.

The shocks were compared with the ones from a control accelerometer directly mounted on the table of the shock machine.

Results were shown in Table 5, 6 and 7 for Channel 1, 2 and 3 respectively and the total system was calibrated. Channel 1 in Table 5 was calibrated and capable of measuring up to 170 g's and 95 g's for side 1 and side 3. This was found to be caused by the system of a battery and a spring of the coupler, since the direction of the battery and the spring was the same as the drop directions, side 1 and side 3 as shown in Figure 27.

Table 5. Total System Calibration of Channel 1

Control Accelerometer Deceleration (in g's)	Test Accelerometer Deceleration (in g's)
	Positive Direction (Side 3)
50	48
90	88
130	128
170	168
190	*
	Negative Direction (Side 1)
16	16
52	54
95	98
125	*

*Pulses were not obtained.

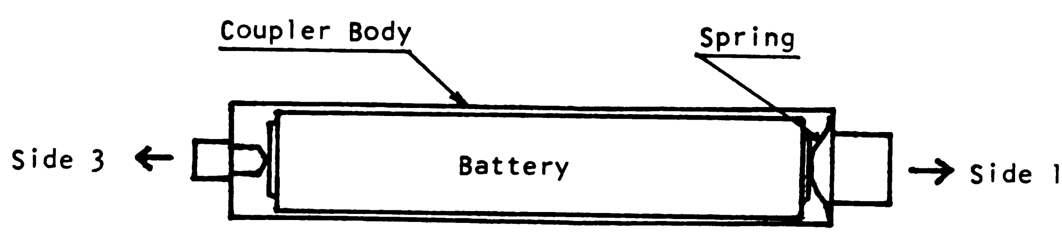


Figure 27. Brief Structure of Coupler

Table 6. Total System Calibration of Channel 2

Control Accelerometer Deceleration (in g's)	Test Accelerometer Deceleration (in g's)
	Positive Direction (End 2)
16	18
40	40
72	72
100	100
125	128
150	152
180	180
210	210
230	240
	Negative Direction (End 1)
16	17
40	40
70	70
100	96
125	120
150	144
170	170
200	190
230	200

Table 7. Total System Calibration of Channel 3

Control Accelerometer Deceleration (in g's)	Test Accelerometer Deceleration (in g's)
	Positive Direction (Side 2)
10	10
15	15
50	50
90	90
130	131
160	171
	Negative Direction (Side 4)
15	15
50	50
90	92
125	127
160	162
200	200
230	231

APPENDIX B

PROCEDURE FOR DETERMINING DAMAGE BOUNDARES

This procedure to determine damage boundaries (10) was developed by Goff and Pierce and shown here briefly.

Procedure:

1. A test item is fixed on the table of shock machine.

2. A series of rectangular pulses of constant velocity change and increasing peak acceleration is applied to the item until damage occurs (see Figure 28).

3. The vertical line is determined by the level, one drop before the damage, the fourth drop in this example.

4. A series of half-sine pulses, beginning with a peak acceleration of two to three times, caused the damage at step 3 with a small velocity change, is input to a new item until the damage occurs.

5. The horizontal line is determined by the level, one drop before the damge, the tenth drop in this example.

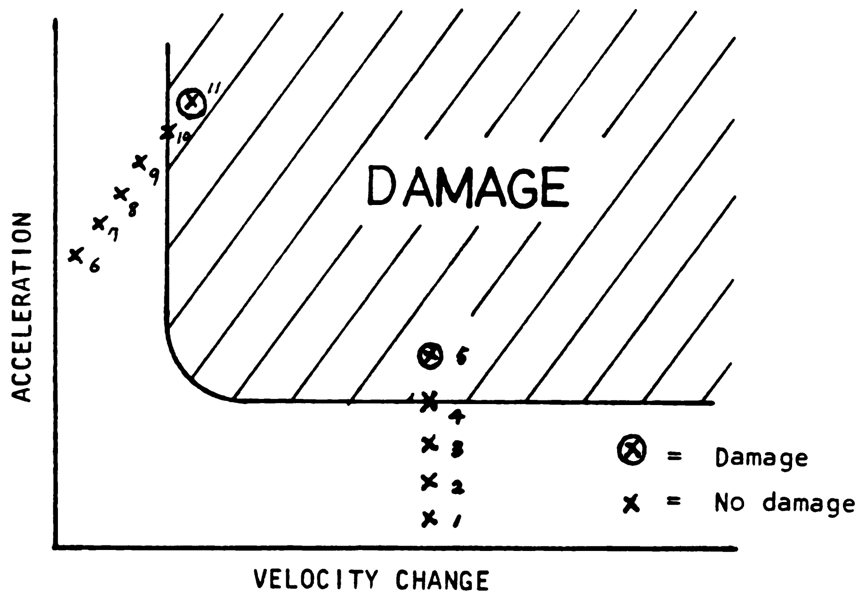


Figure 28. Damage Boundary Determination

APPENDIX C

PULSE WEIGHING METHOD FOR VELOCITY CHANGE

This is a method to determine the velocity change by using a photographic copy from an oscilloscope screen, and this method is effective when the pulse shape is complicated and other pulses or noises are around the pulse concerned.

The velocity change will be calculated as follows:

$$\Delta V = C \times W = \frac{M \times D \times 386.4}{UA \times SD} \times W$$

where

C = Conversion factor in (in/sec)/grams,

W = the weight of the measured pulse in grams,

M = Magnitude per unit div. in g's,

D = Duration per unit div. in sec.,

UA = the unit area of a section on the copy in in^2.

and

SD = the Sheet Density of the copy paper in $grams/in^2$.

APPENDIX D

MATHEMATICAL EXPRESSION OF SHOCK PULSES

Rectangular;

$$a = A \qquad 0 \le t \le D,$$

Half-sine;

$$a = A \sin \left(\frac{\pi t}{D}\right) \qquad 0 \le t \le D,$$

Haversine;

$$a = \frac{1}{2} A \left[1 - \cos \left(\frac{2\pi t}{D}\right)\right] \qquad 0 \le t \le D,$$

Triangular;

$$a = 2 A \left(\frac{t}{D}\right) \qquad 0 \le t \le \frac{D}{2},$$

$$a = 2 A \left(1 - \frac{t}{D}\right) \qquad \frac{D}{2} < t \le D,$$

Parabolic Cusp;

$$a = 4 A \left(\frac{t}{D}\right)^2 \qquad 0 \le t \le \frac{D}{2},$$

$$a = 4 A \left(1 - \frac{t}{D}\right)^2 \qquad \frac{D}{2} < t \le D,$$

where a = amplitude at time t ($a = 0$ for $t > D$),

A = maximum amplitude,

and D = pulse duration at zero line.

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