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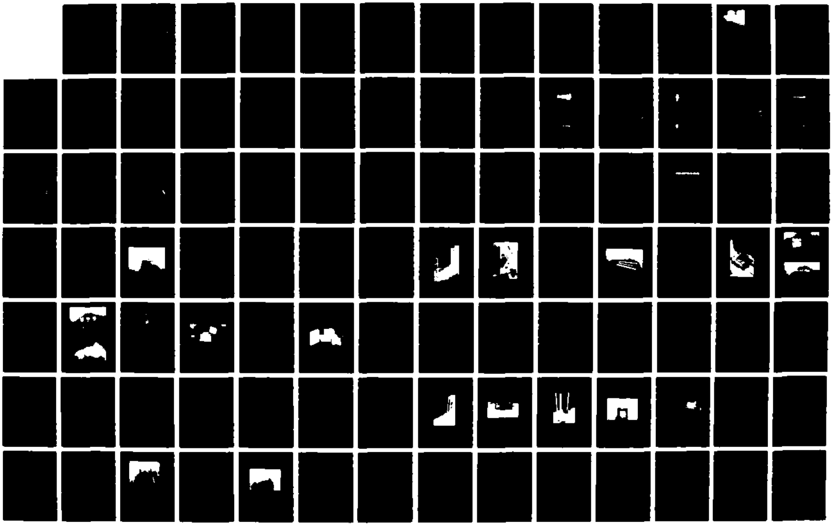

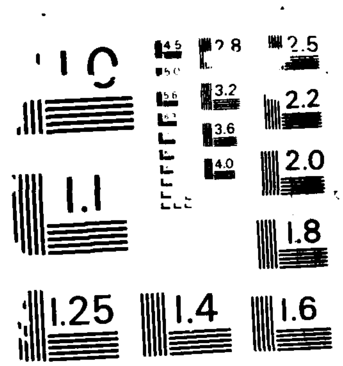
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US ARMY AVIATION SYSTEMS COMMAND

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PEAK ACCELERATION DEVICE (PAD)

Paul Ibanez, John F. Gray

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October 1987

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Each year a number of aircraft are involved in incidents/accidents of varying ground impact severity. The object of this project was to develop a small, passive, low-cost triaxial indicator that in the event of an incident/accident would record the magnitude of the acceleration experienced at their location in the aircraft. Analysis of this data would provide an insight into the performance of crashworthy structures and vehicles, thereby contributing to efforts to reduce loss of life, injury and equipment damage.

Three basic concepts for the design of the peak acceleration device (PAD) were examined. Initially, the use of foam that would crush predictably under the action of a metal [illegible] was explored. Unfortunately, this arrangement was found to be impracticable as was a variation of the same concept where metal foils were to be pierced by pointed rods. The drawback in each case being primarily related to material characteristics. The [illegible] approach utilized a filament under tensile stress as a g-force indicator. Testing [illegible]

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that this mechanism provided predictable and repeatable measure of impact levels and therefore it was this concept that was developed into the PAD.

The final configuration of the Peak g indicator conforms to the target criteria established for the device. It has the capability to measure impacts of 15-100 g in each of three axes, will fit within a 2-1/4-in. cube, has a mechanical filter system that isolates the indicators from energy at frequencies above 100 Hz, and is housed in a rugged aluminum casing that provides high resistance to mechanical damage.

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This work was conducted under a DOD SBIR Phase II award, Contract DAAK-85-C-0009. Mr. Kent Smith at AATD was contract monitor. He provided valuable assistance in both the definition and execution stages of the project. At ANCO, Dr. P. Ibanez was project manager and Mr. John Gray project engineer. Charles Kidd, Bruce Taylor, John Stoessel, Alex Levi, Jiri Jilek, and Kelly Merz also contributed to the success of the project.

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1.0 INTRODUCTION

1.1 PURPOSE

Each year a number of aircraft are involved in incidents/accidents of varying ground impact severity. The goal of this project was to develop a small, passive, low cost triaxial indicator that could be installed at various locations in aircraft and other vehicles. In the event of a crash, these devices would provide an indication of the peak acceleration experienced at their specific locations within the structure. Analysis of the data obtained would be helpful in assessing performance of crashworthy structures and vehicles, thereby contributing to efforts to reduce loss of life, injury, and equipment damage. The device had to be relatively insensitive to very high frequency accelerations, as these do not significantly affect humans or damage structures.

1.2 PHASE I REVIEW

The original concept investigated in Phase I was a device utilizing pellets embedded in a brittle matrix. After the device had been subjected to an impact, the magnitude of the resulting deceleration would be indicated by the relative displacement of the various sized pellets within the matrix. The Phase I work established that the necessary relationship between pellet masses and matrix strength could not be attained with materials currently available without exceeding the constraints of size and weight that had been established as practicable for the Peak Acceleration Device (PAD).

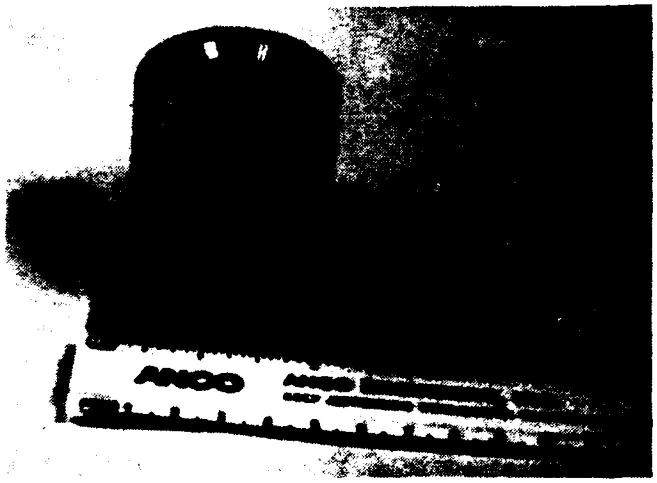
However, an alternative approach using cylindrical metal rods and low strength phenolic foam appeared to be a feasible alternative, and it was this approach that was the basis for the Phase II investigations.

1.3 PHASE II SCOPE OF WORK

The Phase I work produced a feasible design concept. Phase II envisaged the development of the concept into a final design of a PAD suitable for manufacturing. In addition, ANCO Engineers, Inc., (ANCO) undertook to build sixteen prototype devices and furnish them to the United States Army Aviation Systems Command for evaluation.

1.4 PHASE II FINAL DESIGN

The final configuration of the PAD sensor is illustrated by Figure 1.



Weight ≈ 7 oz.
Size - 2¼ x 2¼ x 2¼ in.

Figure 1. PAD sensor.

It is comprised of a triaxial sensing cube suspended by a vibration isolation system within an aluminum housing.

The triaxial sensing cube indicates the magnitude of an applied shock by the displacement of slugs from their original position. The isolation system filters the cube from the majority of impact energy whose frequency is greater than 100 Hz; shocks of these higher frequencies have minimal damage potential for both personnel and equipment. Peak g is indicated either directly, if the shock was coaxial with one of the three primary sensing axes, or by vector addition when the axis of impact bisects them. The amount of slug displacement is determined by opening the housing and visually examining the sensing cube. The cover of the aluminum housing is attached with mechanical fasteners to make it tamper resistant. It is intended that post-crash evaluation of the sensing cube be performed in a laboratory environment and not at the crash site to minimize the risk of the data being inadvertently lost. The sensor may be installed at any attitude. It has a 2-1/4-in. square base, which has four mounting holes for No. 6 diameter attachment screws.

2.0 EVOLUTION OF FINAL DESIGN

2.1 ROD-FOAM CONCEPT

The initial Phase II work pursued the cylindrical rod-phenolic foam concept found promising in Phase I (see Figure 2).

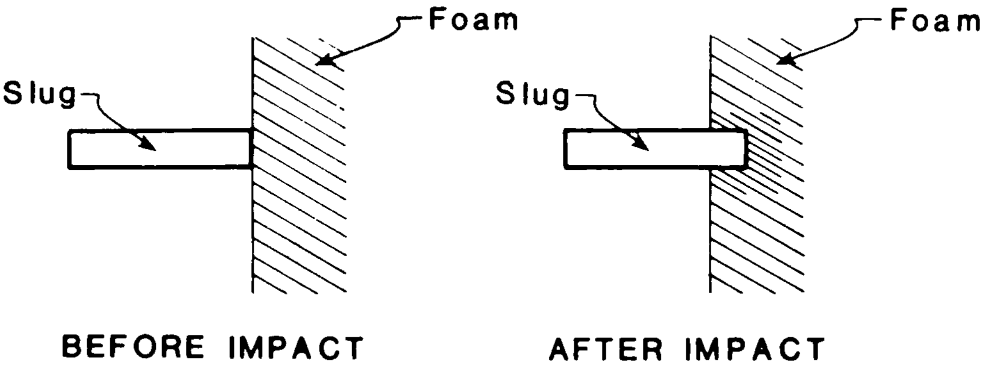


Figure 2. Principle of rod-foam concept.

Considerations of device size and weight mandated that a crushable foam material possessing 1/5 of the compressive strength of the foam tested in Phase I be used in the final design. Although a material with this characteristic could not be located, it became apparent that a material with such low strength would be unsuitable for the application for other reasons. These include fretting between it and the cylindrical slugs, questionable resistance to environmental degradation over an extended period, and the manufacturing difficulties associated with fragile materials. This led to the examination of metallic foils as an alternative implementation of the same basic approach.

2.2 SLUG-FOIL CONCEPT

This concept replaced the crushable foam with a thin metallic foil which was to be penetrated under impact by cylindrical rods with stepped or pointed ends (slugs). It was anticipated that once a suitable foil material and thickness was determined, slug end-geometry could be varied to permit the desired range of "g" values to be indicated. Extensive dynamic and static testing was conducted with a variety of foils of different compositions and thicknesses in conjunction with slugs of differing weights and end geometries in an effort to find a satisfactory combination.

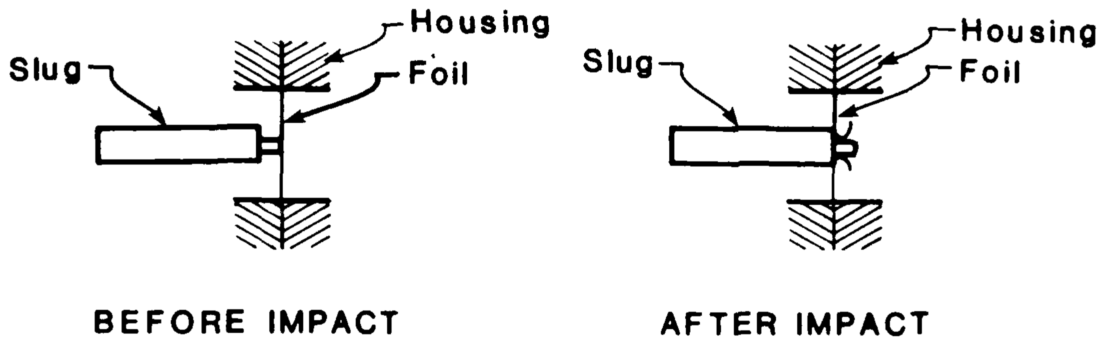


Figure 3. Principle of slug-foil concept.

The foil materials included low carbon steel, aluminum, brass, stainless steel, and plastic. Of these candidates, 302 stainless steel was deemed to be superior owing to:

- Low ductility.
- High resistance to environmental degradation.
- Uniform composition and thickness (mandatory requirements for repeatability).

A variety of stainless steel foil thicknesses between 0.003 and 0.0002 in. were investigated. It was concluded that the 0.0002-inch foil was the minimum thickness that would be practical for use in the final design. Slugs with both stepped (Type A) and conical (Type B) points were evaluated. These two profiles are illustrated in Figure 4. Initially, the Type A profile was considered to be the more attractive, as it was believed that slug masses could all be similar, and only the ratio of outside to step diameter varied to give the desired range of "g" indications. Anticipated stress values calculated from a formula which applies to "circular plates clamped at their circumference and concentrically loaded" indicated that such an arrangement should be viable.

Figure 4. Slug end-geometries.

Unfortunately, testing revealed a sensitivity to material ductility and impact duration, which invalidated this basis for calculating applied stress. Forces necessary to pierce the foil with Type A point geometries being two orders of magnitude higher than those anticipated by calculation.

Tests conducted with Type B points showed extreme sensitivity to point profile. A 0.002-to 0.003-in.-diameter flat increased the penetrating force required by a factor of 2 to 3 over that required by a slug with a "perfect" conical point.

It was foreseen that in practice such variations in point profile could arise from a number of different circumstances (manufacturing tolerances, slug/foil fretting during service, etc.).

The possibility of fretting altering the penetration force required, either by blunting the slug or reducing the strength of the foil, posed a significant problem to the long-term reliability of the slug-foil concept. This concern, coupled with the unexpectedly high forces required to pierce foils of 0.0002 in. thickness, led us to conclude that a satisfactory PAD could not be based on this concept.

2.3 SLUG-FILAMENT CONCEPT

Our investigations into the use of foam or foil showed that the PAD sensing mechanism required an indicating medium that was significantly weaker than either of them. It also established that this medium should be subjected to a primary stress system to minimize the influence of strain rate, complex stress, and similar factors which had led to the abandonment of the foam and foil approaches.

After examination of possible alternatives, the plastic strain of a copper wire under tensile stress was chosen as the concept to be pursued. The major factors influencing this choice were:

- Material strength appropriate for application.
- Ready availability in a graduated range of strengths.
- Uniform composition and properties.
- Low cost.
- High resistance to environmental degradation.

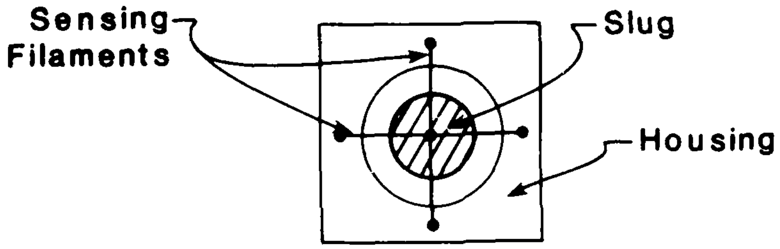


Figure 5. Principle of slug-filament concept.

It was appreciated that the final design would require a mechanism to obviate the effects of fatigue. The in-service environment was anticipated to be a steady ± 2 g vibration of random frequency interspersed with periodic 5 g shocks that occur during landing. The incorporation of a spring detent that would only allow slugs to move at "g" values greater than those experienced in normal service appeared to be a practicable method of eliminating the effects of fatigue.

Preliminary testing substantiated that the slug-filament mechanism provided predictable and repeatable indication of impact levels and that wire fatigue could be prevented. Consequently, this concept was developed into the final design.

3.0 FINAL DESIGN

3.1 GENERAL DESCRIPTION

The final configuration of the Peak g indicator is illustrated by Figure 6. It generally conforms to the target criteria set forth in the technical abstract of the contract. It has the capability to measure impacts of 15-100 g in each of three axes, will fit within a 2-1/4-in. cube, has a mechanical filter system that isolates the indicating cube from the majority of impact energy at frequencies above 100 Hz, and is housed in a rugged aluminum casing that provides high resistance to mechanical damage. The total weight of the device is less than 7 ounces. A maximum weight limitation was not specified in this proposal; however, a target value of 8 ounces was established informally and used as a design parameter.

3.2 FUNCTIONAL COMPONENTS

3.2.1 Indicating Cube Assembly

An aluminum cube forms the structural element of this module. Housed within it are three pairs of conical slugs constrained in position by a combination of spring pressure and copper sensing wires.

It was appreciated at an early stage in the design process that the incremental steps between the "g" indicating values should be based upon a geometric progression in order to accommodate the increasing influence that material strength variations and similar factors would have on the accuracy of the indication mechanism.

Arbitrarily, the original plan was to use a 1.414 multiplier to calculate the "g" increase between successive steps. When copper wire was selected as the indicating medium for the slug-filament concept, the tensile strength of 38 through 44 gage was researched. It was found that the tensile strength difference between adjacent gages was approximately 26% for these sizes. This equates to a 58% difference in strength between two alternate gauges. It was decided to adopt the 26% value as the basic incremental step between "g" indicating values and arrange the slug weight and wire gages accordingly.

The target size of the PAD sensor limited the size of the sensing cube to about 1 in., which in turn restricted slug size. Practical considerations associated with manufacturing the device mandated that the wire diameters should be the maximum possible, which necessitates the slug being as heavy as possible. To achieve this objective, the slugs were made from tungsten and conical in form. The resulting weight was 13.5 grams.

Two constraints resist slug movement during impact. They are the filament wire and the friction between the slug and the spring clip that retains it in position.

Static tensile tests of 44-gage copper wire yielded an ultimate tensile strength (UTS), value of 33,000 lb/sq-in. plastic deformation commencing at approximately 22,000 lb/sq-in. Dynamic sled tests indicated a higher UTS, suggesting that strain rate considerations increased the strength in impact situations by a ratio of approximately 9 to 5.

QTY -100	ITEM	PART NO	DESCRIPTION	SOURCE
1	1	166311-117-1	CASE	
1	2	166311-116-100	CUBE ASSEMBLY	
	3		SILICONE OIL	AMSOIL
2	4	TA-2177	TAPERED SPRING	CENTURY SPRING CO
1	5	166311-121-1	ORIENTATION CLIP	
1	6	166311-117-2	COVER	
1	7	2-030N674-70	O RING	PARKER SEALS
6	8		NO 0 x 1/8 LG TYPE U DRIVE SCR	DUCOMMUN

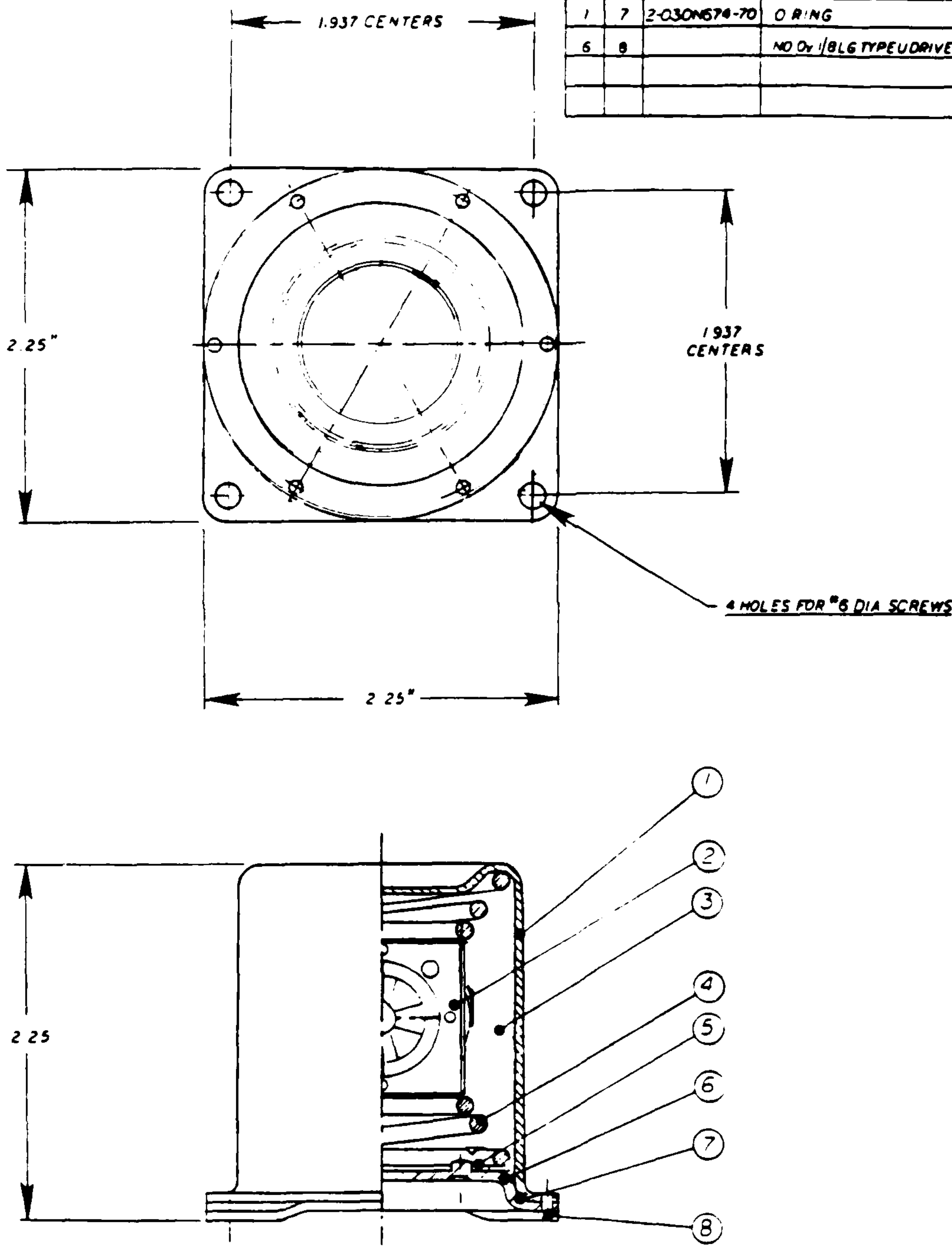


Figure 6. Peak acceleration device.

The cross-sectional area of 42 gage wire is 4.8695 x 10^{-6} sq-in. The approximate "g" force required to create plastic deformation of a 42-gage wire filament attached to a 13.5 gram slug is:

$$\frac{1}{13.5 \text{ grms}} \times 22{,}000 \frac{\text{lb}}{\text{sq-in.}} \times 4.8695 \times 10^{-6} \times \frac{453 \text{ grms}}{1 \text{ lb}} \times \frac{9}{5} \approx 6.5 \text{ g}$$

For design purposes 15 g was selected as the minimum response level of the PAD, this value being 3 times the nominal shock value experienced during helicopter landings. This threshold level has 2 components; the 6.5 g value provided by the 42 gage filament, the balance being provided by the pressure of the spring clip which retains the slug in the cube cavity.

Figure 7 illustrates a spring clip installed on one face of the cube. Its primary purpose is to provide the pressure on the slugs necessary to eliminate fatigue. This is accomplished by the central spring finger. Secondary functions are: cube-housing orientation and anchoring of sensing wires during the assembly process.

Calculations based on wire strength, slug weight, the observed influence of strain rate, and the planned frictional constraint of the spring finger, suggested that 4 gages of wire (42, 40, 38 and 35) would be required to span the 15-100 g indicating range. These sizes were adopted subject to verification by testing, it being a simple matter to change to the intermediate sizes should test results mandate. Each slug has two sensing wires arranged at 90 degrees. The cube has a total complement of six slugs, each sensing a pair of values, thereby providing the twelve indications required by the triaxial device. Figure 8 illustrates this arrangement and indicates the axis-g range relationships.

3.2.2 Isolation Housing Assembly

The indicating cube is suspended within an aluminum housing by two conical compression springs. The void between the cube and housing is filled with SAE 80-90 weight silicone oil. This mechanism provides the desired triaxial filtering of impact energy at frequencies above 100 Hz. The housing is of two-piece construction, the cover and O-ring gasket being attached to the body with drive screws. This provides a leak-free, tamper-proof package which is only intended to be opened for crash impact evaluations.

The housing is provided with four attachment holes, suitable for No. 6 diameter screws, spaced at 1.937-in. centers. These allow it to be attached to any 2-1/4-in. x 2-1/4-in. flat surface.

The device may be installed at any orientation. However, the value of Peak g is indicated directly when the direction of impact coincides with one of the three primary axes and is calculated by vector summation in other circumstances. Accuracy will be greater when the value is obtained by direct indication, an important factor to consider when selecting installation sites in the vehicle.

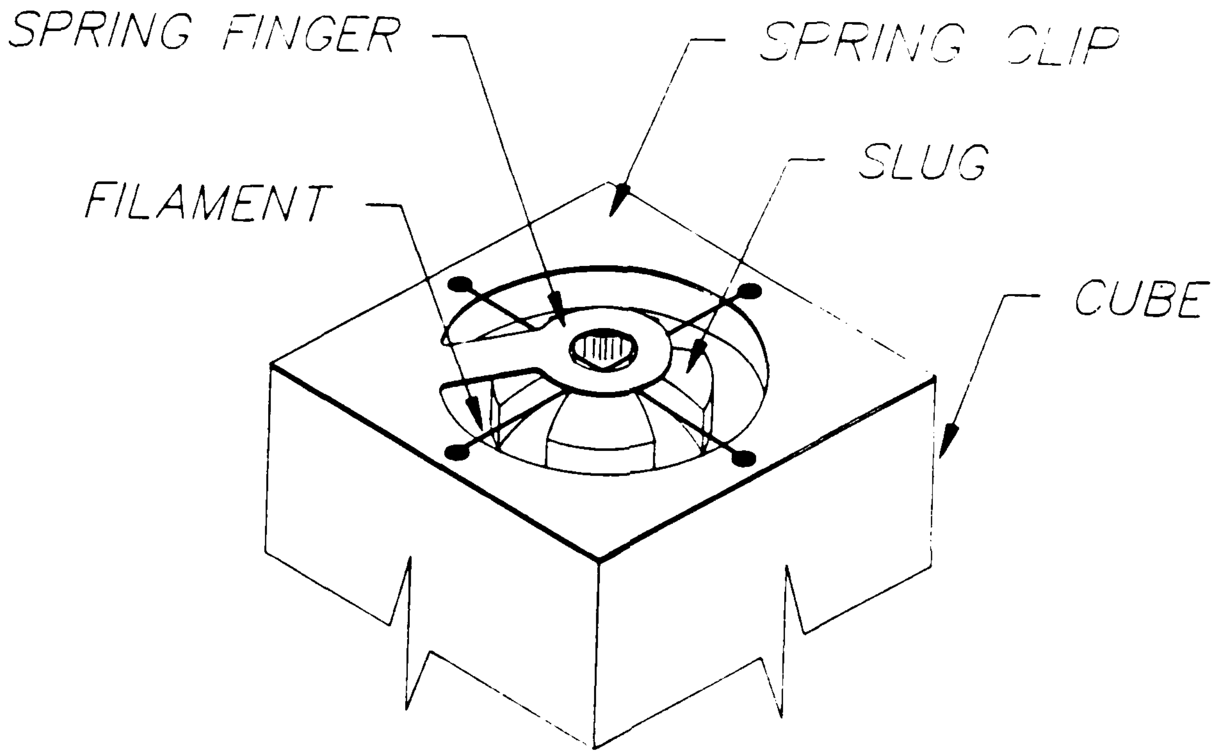


Figure 7. Spring clip arrangement.

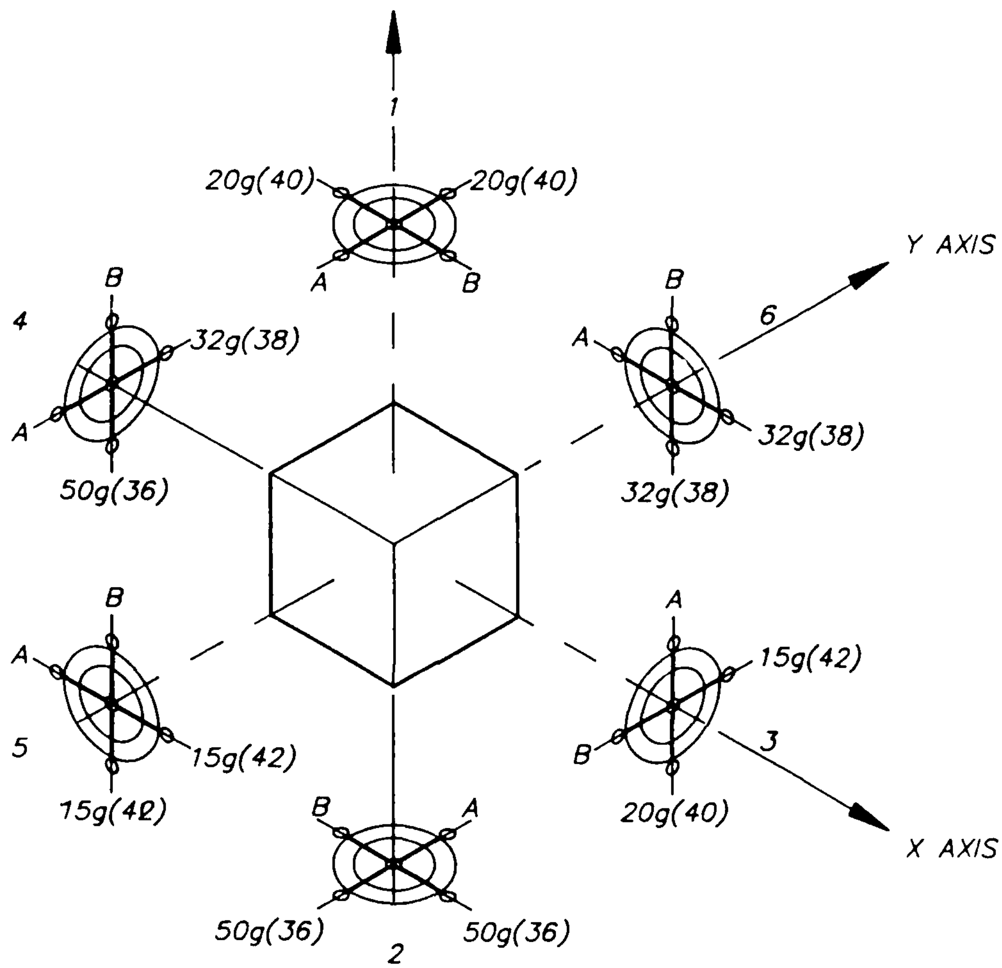


Figure 8. Slug-sensing wire arrangement.

4.0 FUNCTIONAL VERIFICATION

4.1 ISOLATION

The indicating cube is isolated within the housing by two conical springs. The cavity between the cube and housing is filled with viscous oil to provide vibration damping. A spring-oil isolation system was explored when it became apparent that the susceptibility of the various foams to environmental degradation rendered it unsuitable for use as a mechanical filter as well as a Peak g indicator.

4.1.1 Suspension Springs

Initially, six compression springs were used for isolation, one positioned in each face of the cube to hold it equidistant from the sides of the housing. Tap and impact tests verified that this arrangement met the desired isolation criteria, although the possibility of doubling the spring count to twelve to increase rotational constraint was planned (see Appendix B). Although this isolation arrangement functioned satisfactorily, cost considerations prompted a search for a simpler system that would be less expensive in material and labor but still provide the required functional capability.

After considering a variety of possibilities, a conical spring arrangement was selected as the most promising and a test fixture utilizing conical springs was constructed for conducting tap and impact tests.

The data obtained during sled testing of this fixture is shown in graphical format in Figures 9 through 16. Testing was performed at both high and low "g" levels in both the Z and X-Y cube axes. Data is shown in both raw form and after Fourier transformation. This allows comparison of sled and cube accelerations and shows the attenuation of high frequency energy provided by the conical spring-oil isolation arrangement.

The conical springs provide isolation similar to that obtained from the six compression spring arrangement. Although the "roll-off" frequency is not identical for the Z and X-Y axes, both values are close to the desired cut of frequency of 100 Hz, making the arrangement a satisfactory mechanical filtering system for the PAD.

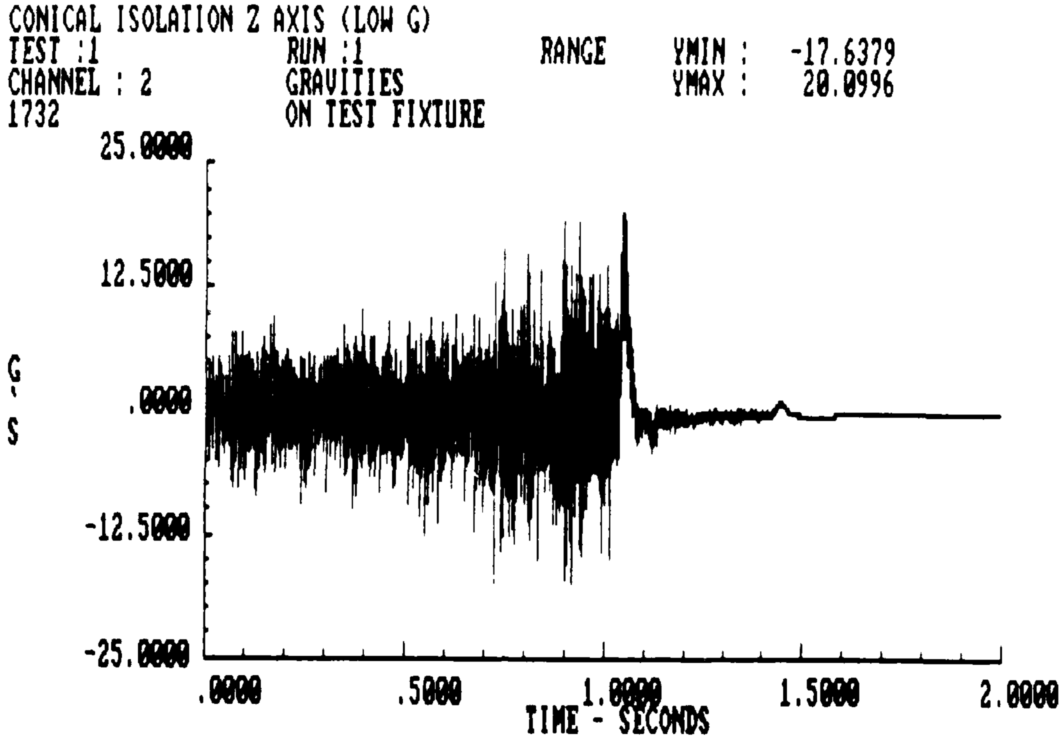
4.1.2 Damping Fluid

The primary selection criteria for the damping fluid were:

- Viscosity
- Long-term stability

The range of viscosities to be evaluated by testing were limited by quantitative assessment to SAE 80-140 weight. Testing indicated that SAE 80-90W provided the desired degree of damping, and consequently, it was the choice for the final design.

The capability of synthetic oils to maintain their properties over extended periods made them the logical choice for the damping fluid. The "in-service" environment of the sensor is benign in comparison to the conditions under which



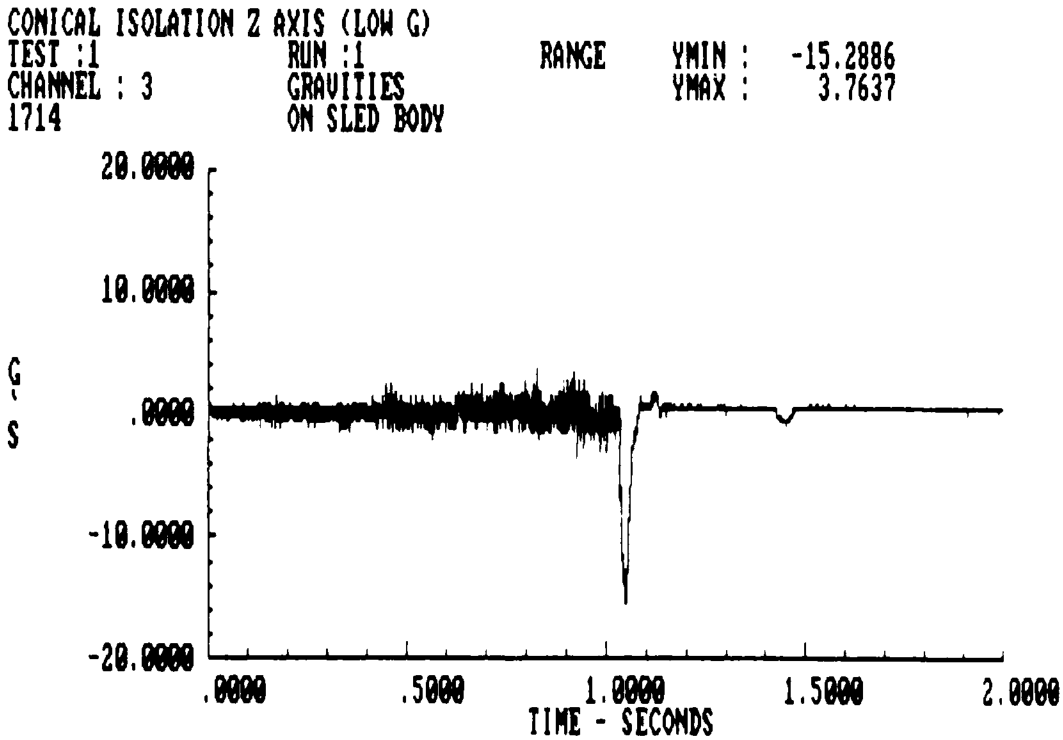


Figure 9. Z-axis impact time history (low g).

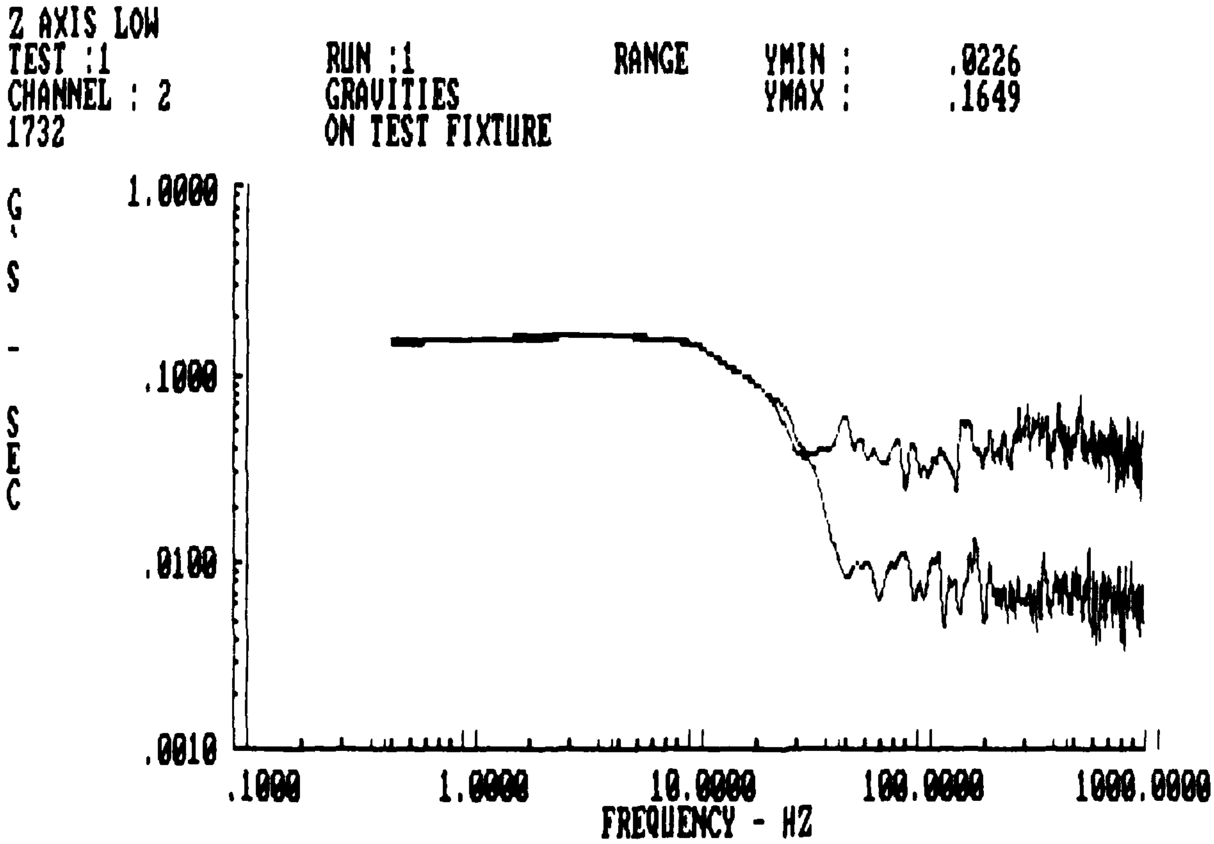
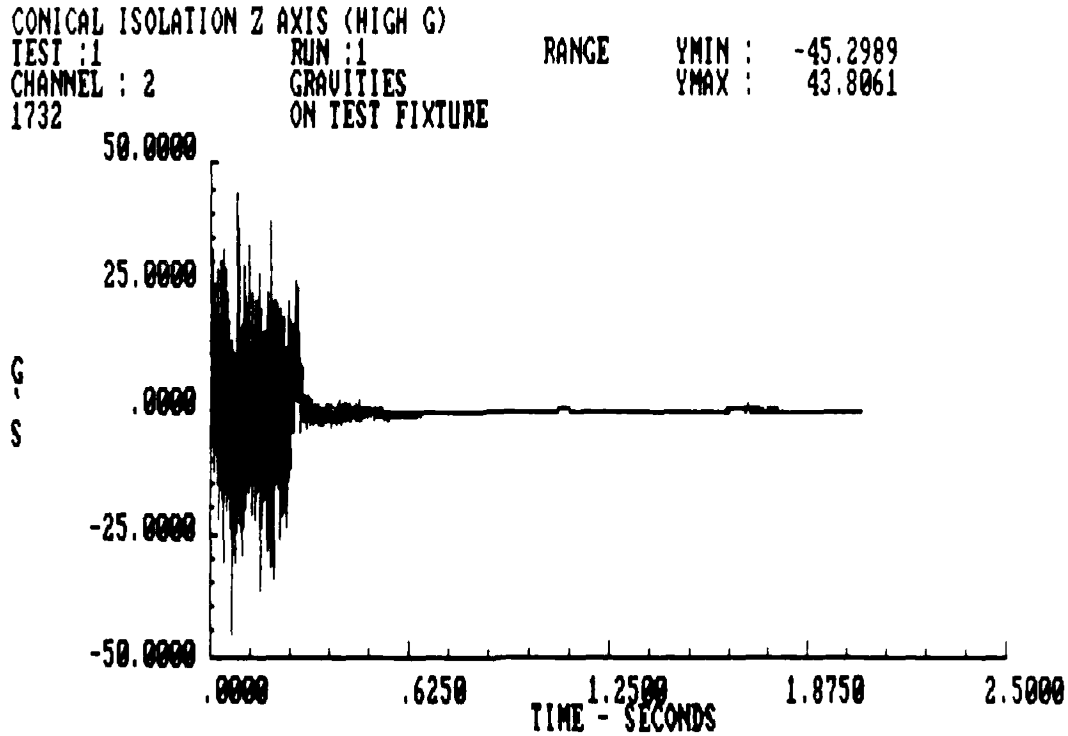


Figure 10. Fourier transforms (low g impact).



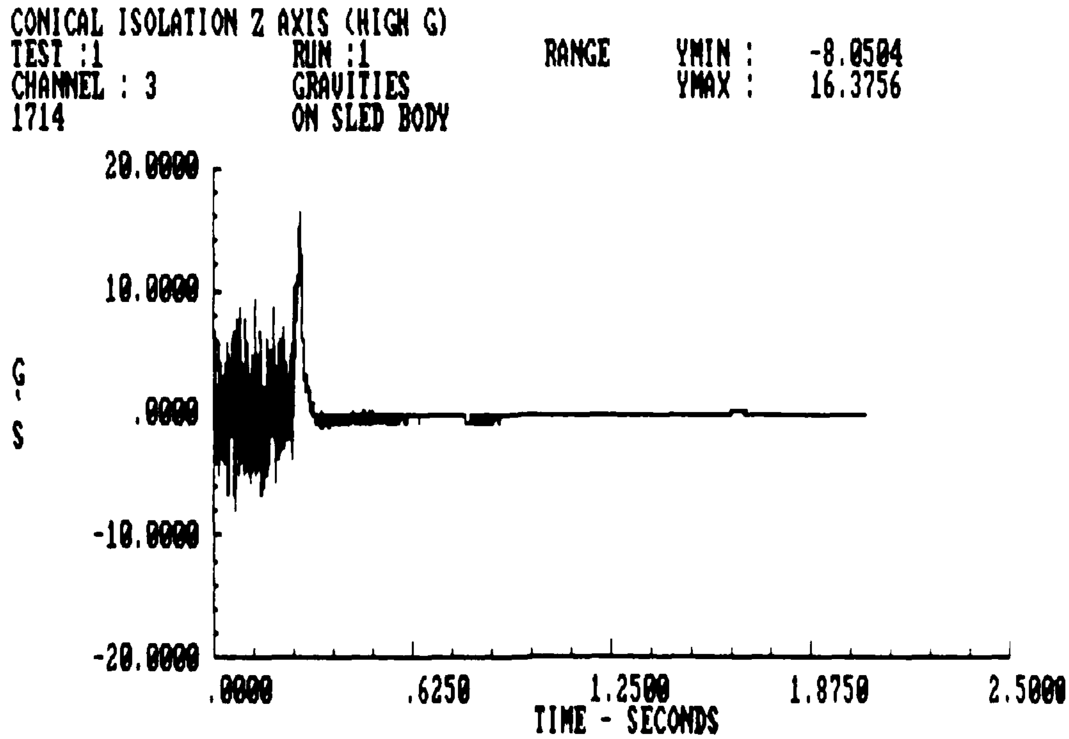


Figure 11. Z-axis impact time history (high g).

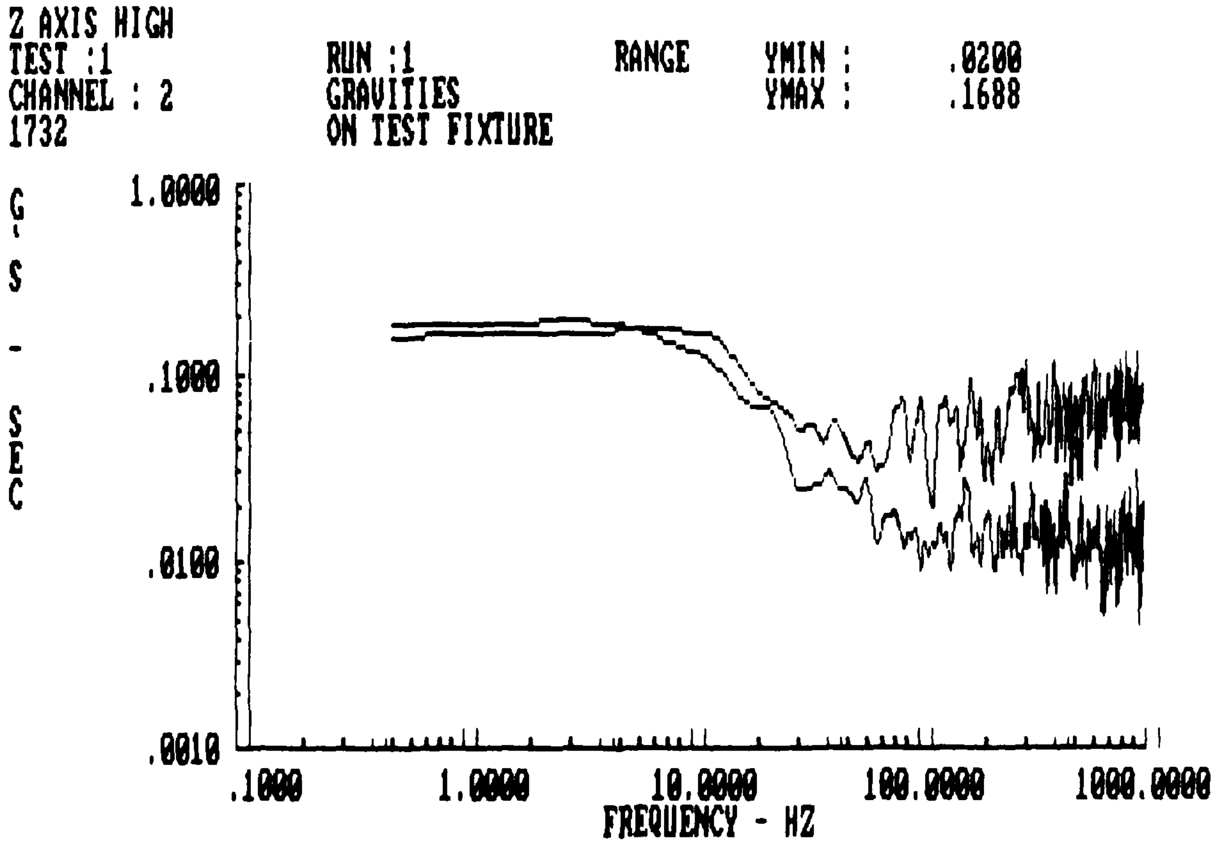
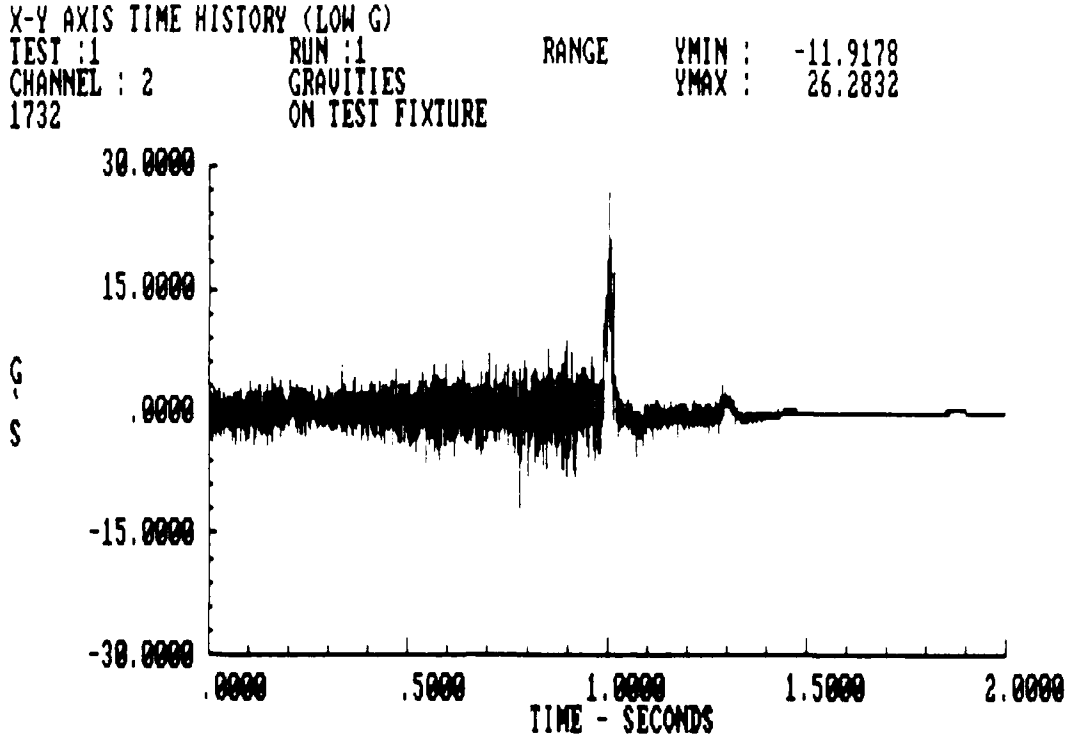


Figure 12. Fourier transforms (high g impact).



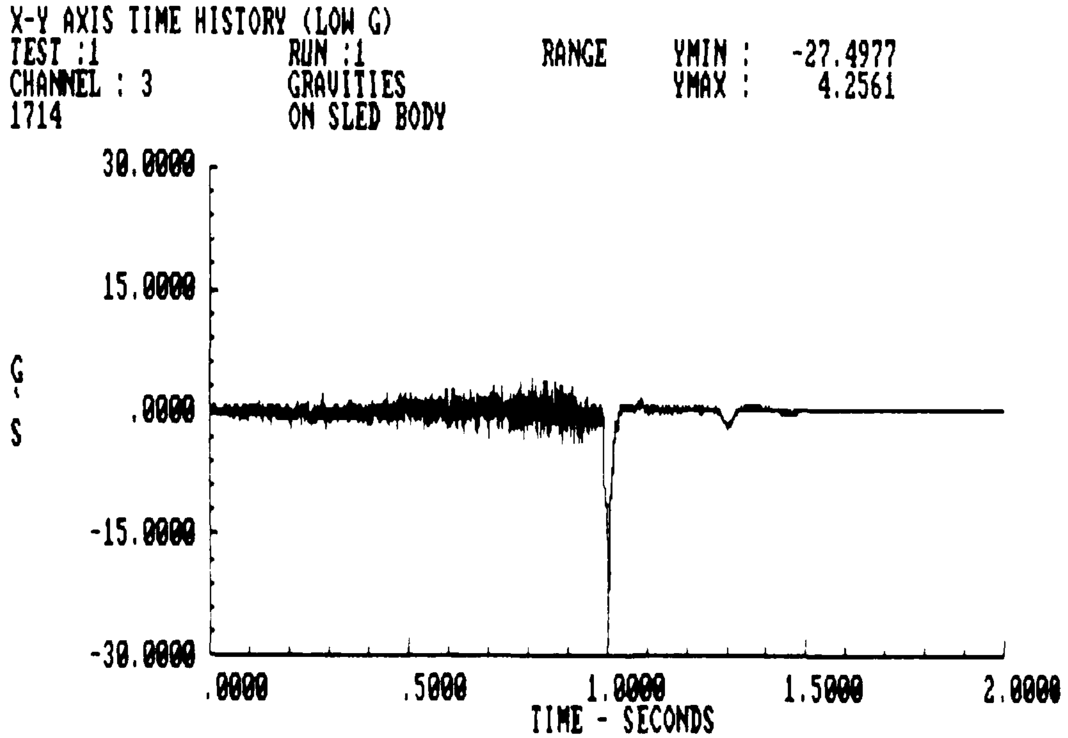


Figure 13. X-Y axis time history (low g impact).

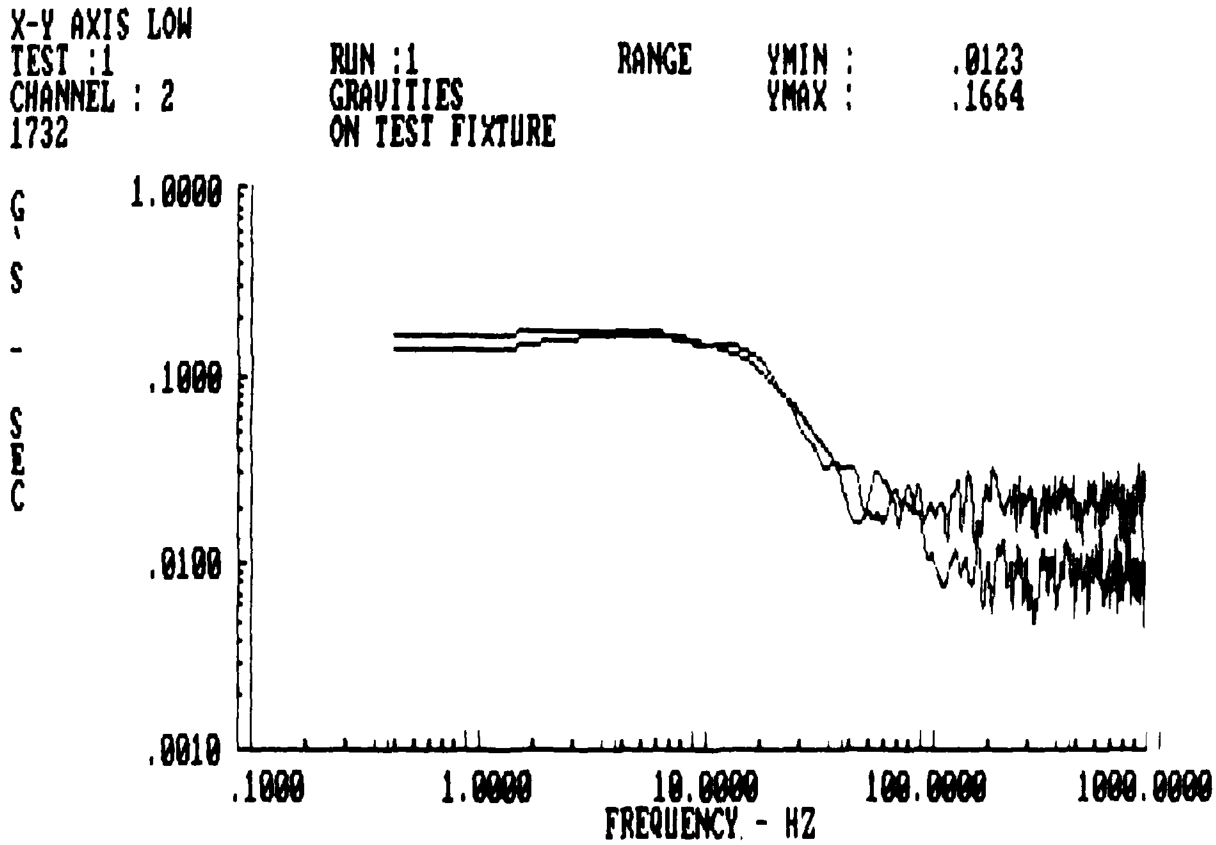
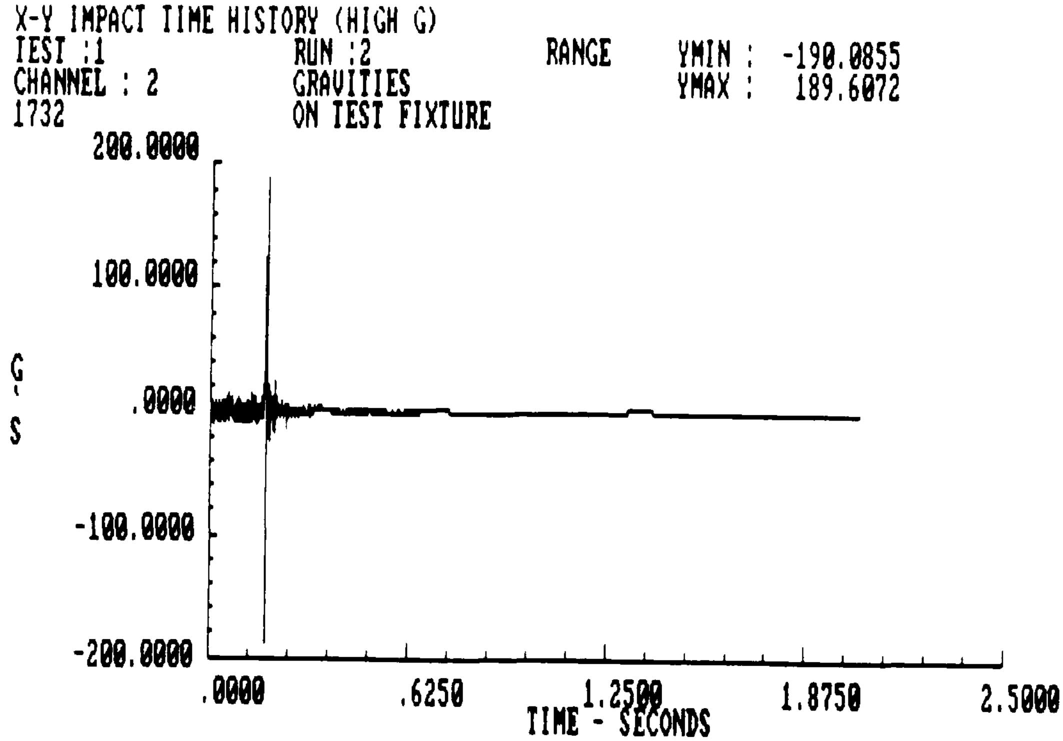


Figure 14. Fourier transforms (low g impact).



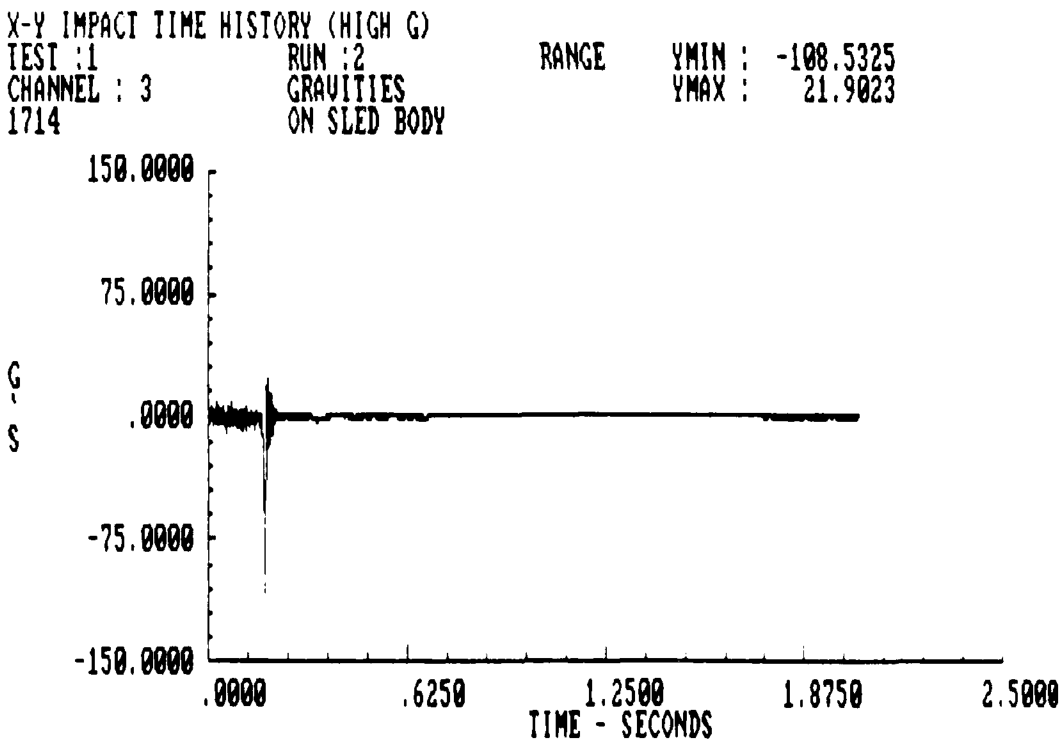


Figure 15. X-Y impact time history (high g).

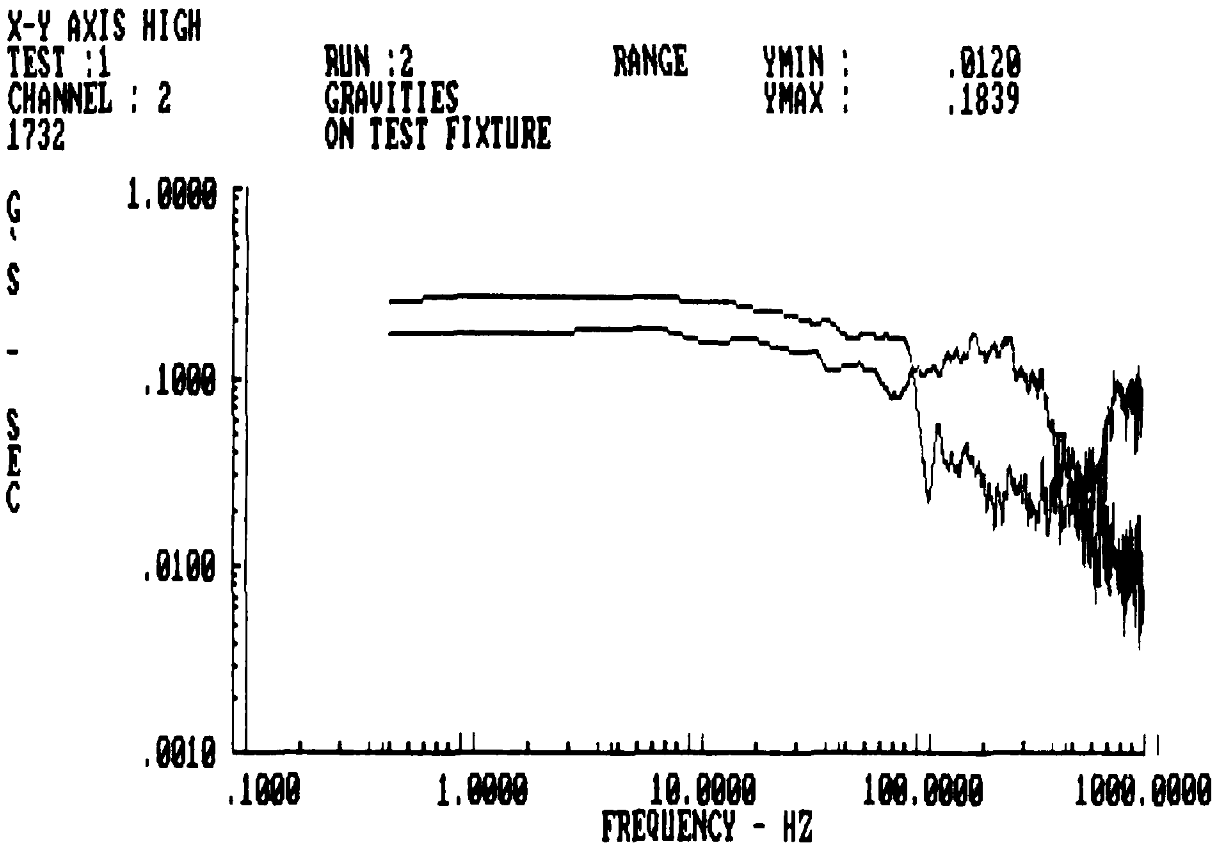


Figure 16. Fourier transforms (high g impact).

synthetic oils are compounded to perform; consequently, it is not anticipated that there will be any degradation in properties over the 10-15-year life of the PAD sensor.

4.2 INDICATION

Early investigations were based upon using an indicating mechanism that would be responsive to a force of approximately 50 grams. This value represents a 5-gram slug being acted upon by a 10-g impact. Forty-four gage copper wire (which is readily available) will break under a tensile load of that magnitude, and this, together with the other properties enumerated in 2.3, made copper wire an ideal candidate for the sensing filament. However, experimental work with 44-gage copper wire highlighted the difficulties that manufacturing a PAD with such fine gage wire would encounter, and consequently, 42-gage was deemed to be the minimum gage practical for PAD use. The increase in wire strength was offset by a corresponding increase in slug weight accomplished by increasing the volume and material density of the slug.

4.2.1 Sensing Wires

The tensile strength, ductility, and strain hardening characteristics of copper wire were investigated by performing four static loading tests. These characteristics should be identical for copper wires with similar compositions and therefore 40-gage was selected for testing, it being in the mid range of the sizes selected for use. Loading to failure was continuous in Tests 1 and 2, the loading rate being 1.5 grams/min. The resulting stress/strain relationships are shown in Figures 17 and 18. The same loading rate was used for Tests 3 and 4. However, the loading process was stopped and the accumulated load removed when the strain had reached approximately 5%. Loading was then recommended and continued to failure. Figures 19 and 20 show the strain hardening effects of this loading procedure.

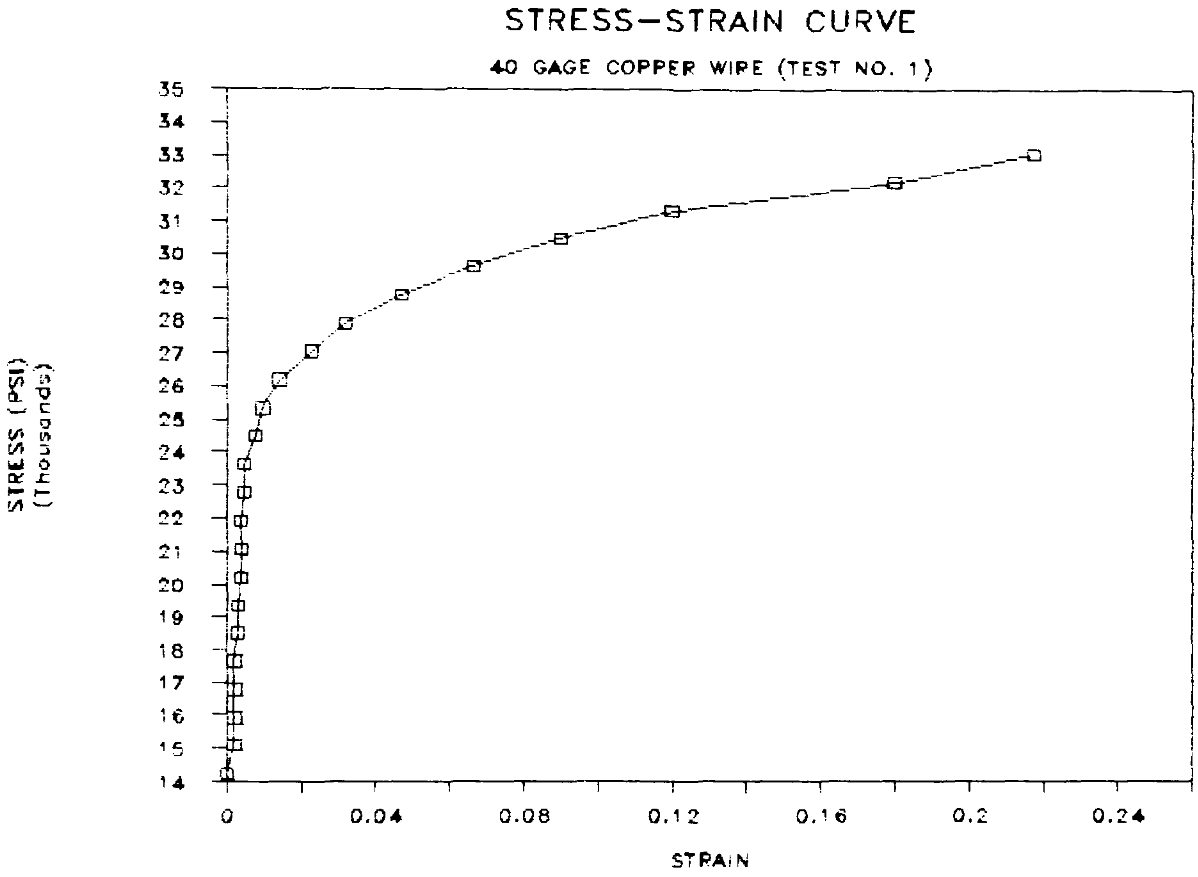
Strain hardening of copper wire was investigated to explore the possibility of stressing the filaments prior to assembly to reduce ductility. It was concluded that the resulting increase in tensile strength was undesirable because the higher yield point increased the threshold value to an unacceptable level. Consequently, the research into the use of strain-hardening for sensing wires was terminated and they were not incorporated into the final design.

4.2.2 Test Program

Section 2.0 of this report traces the evolution of the PAD from the Phase I concept to the final design. Throughout the program, the various approaches considered have been subjected to rigorous testing. Appropriately, the most exhausting test program was reserved for the final design. The object of the test program was to verify that:

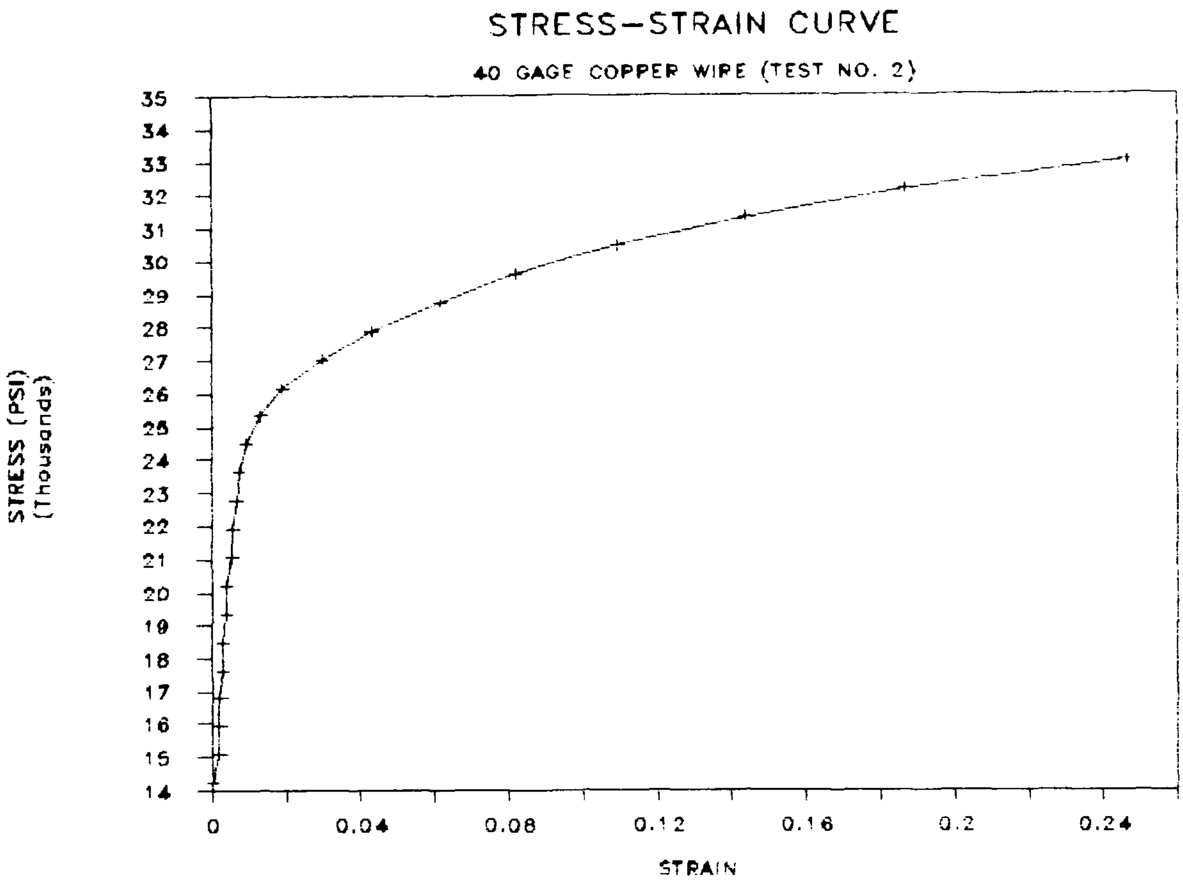
- The slug-filament concept provided predictable and repeatable results.
- The concept was resistant to environmental fatigue.

The equipment used for the test program is described in detail in Section 5. The conical slug test fixture (see Section 5.4.3) was used for both vibration and impact tests. Initially, separate vibration and impact tests were performed to



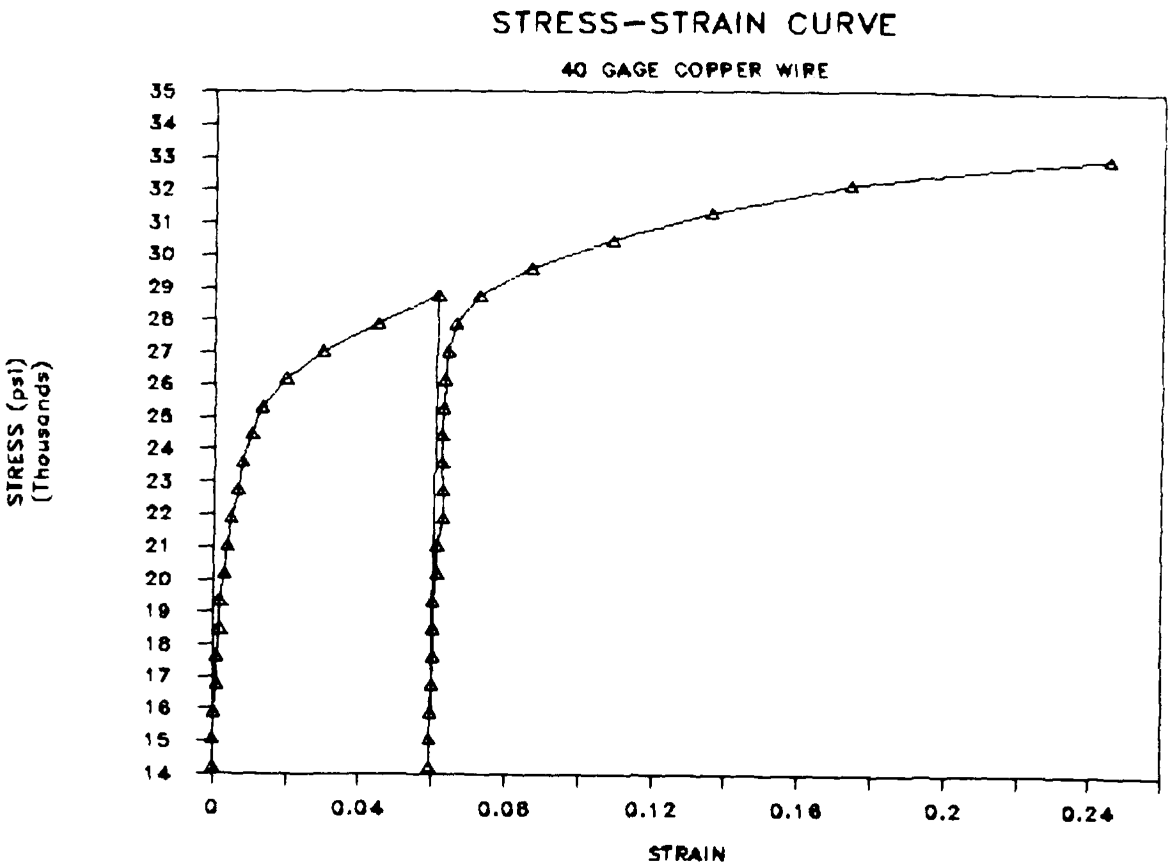
LOAD (g)	LOAD (lb)	STRESS (psi)	DEFLECTION (DELTA)(in)	STRAIN (in/in)
50.0	0.1102	14234.7	0.0000	0.00000
53.0	0.1168	15088.8	0.1250	0.00187
56.0	0.1235	15942.9	0.1250	0.00187
59.0	0.1301	16797.0	0.1250	0.00187
62.0	0.1367	17651.0	0.1250	0.00187
65.0	0.1433	18505.1	0.1875	0.00281
68.0	0.1499	19359.2	0.1875	0.00281
71.0	0.1565	20213.3	0.2500	0.00375
74.0	0.1631	21067.4	0.2500	0.00375
77.0	0.1698	21921.4	0.2500	0.00375
80.0	0.1764	22775.5	0.3125	0.00468
83.0	0.1830	23629.6	0.3125	0.00468
86.0	0.1896	24483.7	0.5000	0.00749
89.0	0.1962	25337.8	0.6250	0.00936
92.0	0.2028	26191.9	0.9375	0.01404
95.0	0.2094	27045.9	1.5000	0.02247
98.0	0.2160	27900.0	2.1250	0.03184
101.0	0.2227	28754.1	3.1250	0.04682
104.0	0.2293	29608.2	4.4375	0.06648
107.0	0.2359	30462.3	6.0000	0.08989
110.0	0.2425	31316.3	8.0000	0.11985
113.0	0.2491	32170.4	12.0000	0.17978
116.0	0.2557	33024.5	14.5000	0.21723

Figure 17. Tensile Test No. 1.



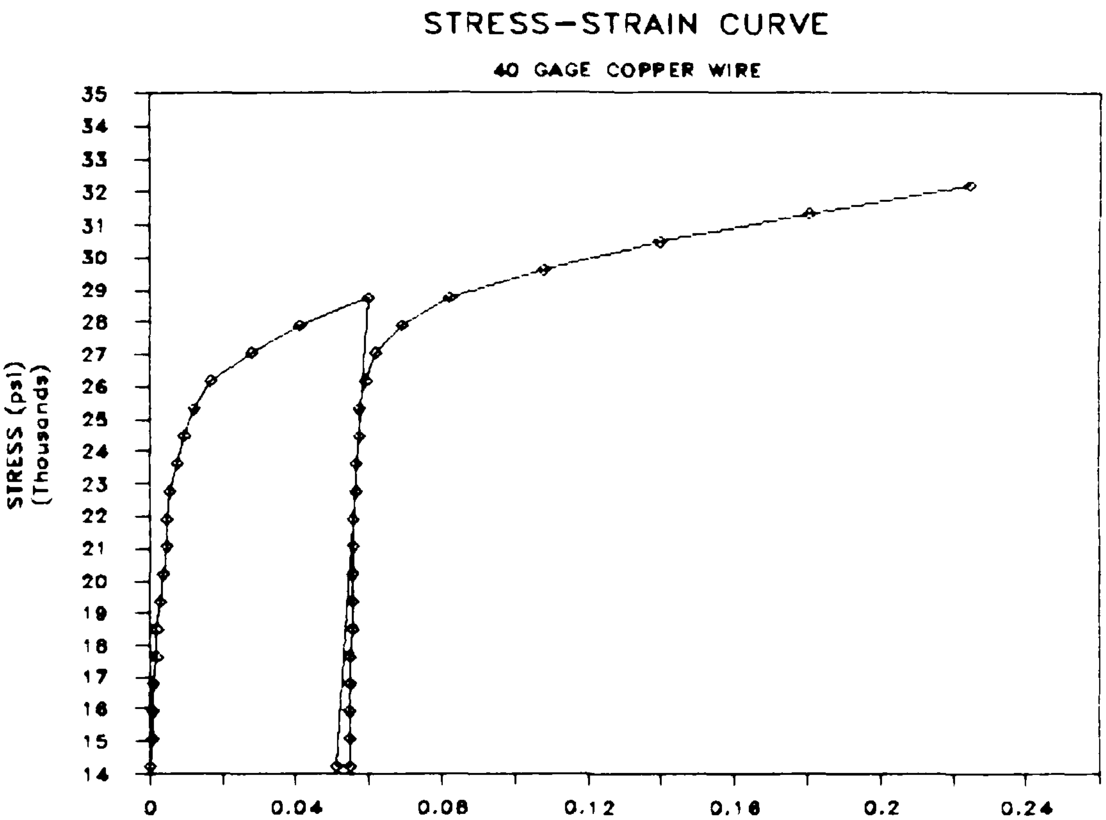
LOAD (g)	LOAD (lb)	STRESS (psi)	DEFLECTION (DELTA)(in)	STRAIN (in/in)
50.0	0.1102	14234.7	0.0000	0.00000
53.0	0.1168	15088.8	0.1250	0.00187
56.0	0.1235	15942.9	0.1250	0.00187
59.0	0.1301	16797.0	0.1250	0.00187
62.0	0.1367	17651.0	0.1875	0.00280
65.0	0.1433	18505.1	0.1875	0.00280
68.0	0.1499	19359.2	0.2500	0.00373
71.0	0.1565	20213.3	0.2500	0.00373
74.0	0.1631	21067.4	0.3750	0.00560
77.0	0.1698	21921.4	0.3750	0.00560
80.0	0.1764	22775.5	0.4375	0.00653
83.0	0.1830	23629.6	0.5000	0.00746
86.0	0.1896	24483.7	0.6250	0.00933
89.0	0.1962	25337.8	0.8750	0.01306
92.0	0.2028	26191.9	1.2500	0.01866
95.0	0.2094	27045.9	2.0000	0.02985
98.0	0.2160	27900.0	2.8750	0.04291
101.0	0.2227	28754.1	4.1250	0.06157
104.0	0.2293	29608.2	5.5000	0.08209
107.0	0.2359	30462.3	7.3125	0.10914
110.0	0.2425	31316.3	9.6250	0.14366
113.0	0.2491	32170.4	12.5000	0.18657
116.0	0.2557	33024.5	16.5000	0.24627

Figure 18. Tensile Test No. 2.



LOAD (g)	LOAD (lb)	STRESS (psi)	DEFLECTION (DELTA)(in)	STRAIN (in/in)
50.0	0.1102	14234.7	0.000	0.00000
53.0	0.1168	15088.8	0.063	0.00093
56.0	0.1235	15942.9	0.063	0.00093
59.0	0.1301	16797.0	0.063	0.00093
62.0	0.1367	17651.0	0.125	0.00187
65.0	0.1433	18505.1	0.125	0.00187
68.0	0.1499	19359.2	0.188	0.00280
71.0	0.1565	20213.3	0.250	0.00374
74.0	0.1631	21067.4	0.313	0.00467
77.0	0.1698	21921.4	0.313	0.00467
80.0	0.1764	22775.5	0.375	0.00561
83.0	0.1830	23629.6	0.500	0.00748
86.0	0.1896	24483.7	0.625	0.00935
89.0	0.1962	25337.8	0.813	0.01215
92.0	0.2028	26191.9	1.125	0.01682
95.0	0.2094	27045.9	1.875	0.02804
98.0	0.2160	27900.0	2.750	0.04112
101.0	0.2227	28754.1	4.000	0.05981
50.0	0.1102	14234.7	3.625	0.05124
50.0	0.1102	14234.7	3.875	0.05477
53.0	0.1168	15088.8	3.875	0.05477
56.0	0.1235	15942.9	3.875	0.05477
59.0	0.1301	16797.0	3.875	0.05477
62.0	0.1367	17651.0	3.875	0.05477
65.0	0.1433	18505.1	3.938	0.05565
68.0	0.1499	19359.2	3.938	0.05565
71.0	0.1565	20213.3	3.938	0.05565
74.0	0.1631	21067.4	3.938	0.05565
77.0	0.1698	21921.4	3.938	0.05565
80.0	0.1764	22775.5	4.000	0.05654
83.0	0.1830	23629.6	4.000	0.05654
86.0	0.1896	24483.7	4.063	0.05742
89.0	0.1962	25337.8	4.063	0.05742
92.0	0.2028	26191.9	4.188	0.05919
95.0	0.2094	27045.9	4.375	0.06184
98.0	0.2160	27900.0	4.875	0.06890
101.0	0.2227	28754.1	5.813	0.08216
104.0	0.2293	29608.2	7.625	0.10777
107.0	0.2359	30462.3	9.875	0.13958
110.0	0.2425	31316.3	12.750	0.18021
113.0	0.2491	32170.4	15.875	0.22438

Figure 19. Tensile Test No. 3.



LOAD (g)	LOAD (lb)	STRESS (psi)	DEFLECTION (DELTA) (in)	STRAIN (in/in)
50.0	0.1102	14234.7	0.000	0.00000
53.0	0.1168	15088.8	0.000	0.00000
56.0	0.1235	15942.9	0.000	0.00000
59.0	0.1301	16797.0	0.063	0.00093
62.0	0.1367	17651.0	0.063	0.00093
65.0	0.1433	18505.1	0.125	0.00186
68.0	0.1499	19359.2	0.125	0.00186
71.0	0.1565	20213.3	0.188	0.00279
74.0	0.1631	21067.4	0.250	0.00372
77.0	0.1698	21921.4	0.313	0.00465
80.0	0.1764	22775.5	0.438	0.00651
83.0	0.1830	23629.6	0.500	0.00743
86.0	0.1896	24483.7	0.688	0.01022
89.0	0.1962	25337.8	0.875	0.01301
92.0	0.2028	26191.9	1.313	0.01952
95.0	0.2094	27045.9	2.000	0.02974
98.0	0.2160	27900.0	3.000	0.04461
101.0	0.2227	28754.1	4.125	0.06134
50.0	0.1102	14234.7	4.000	0.05948
53.0	0.1168	15088.8	4.000	0.05948
56.0	0.1235	15942.9	4.000	0.05948
59.0	0.1301	16797.0	4.031	0.05994
62.0	0.1367	17651.0	4.063	0.06041
65.0	0.1433	18505.1	4.063	0.06041
68.0	0.1499	19359.2	4.063	0.06041
71.0	0.1565	20213.3	4.125	0.06134
74.0	0.1631	21067.4	4.125	0.06134
77.0	0.1698	21921.4	4.219	0.06273
80.0	0.1764	22775.5	4.219	0.06273
83.0	0.1830	23629.6	4.188	0.06227
86.0	0.1896	24483.7	4.188	0.06227
89.0	0.1962	25337.8	4.219	0.06273
92.0	0.2028	26191.9	4.250	0.06320
95.0	0.2094	27045.9	4.313	0.06413
98.0	0.2160	27900.0	4.438	0.06599
101.0	0.2227	28754.1	4.875	0.07249
104.0	0.2293	29608.2	5.813	0.08643
107.0	0.2359	30462.3	7.313	0.10874
110.0	0.2425	31316.3	9.125	0.13569
113.0	0.2491	32170.4	11.688	0.17379
116.0	0.2557	33024.5	16.500	0.24535

Figure 20. Tensile Test No. 4.

establish a fatigue threshold level. Later, consecutive vibration-impact tests were performed on the same samples to verify the "in-service" performance of the design. Tables 1 and 2 present data collected from typical tests with the conical fixture. Initially, the fixture was vibrated for approximately 100,000 cycles at random frequencies between 0-100 Hz with intensities of ± 5 g maximum. A typical vibration time history is shown in Figure 21. The fixture was then subjected to a series of impacts of increasing severity, slug movements being noted after each impact. A total of 22 combined tests were performed (copies of the test data sheets are included in Appendix E). Figure 22 presents the data obtained in Experiments 21, 22, 23 and 24. In addition to conducting the 24 combined tests of the filament concept with the conical slug test fixture, the use of copper wire as an impact severity sensing medium was investigated with two prior test series with the Rectangular Slug-Filament Fixture and the Dual-Filament Fixture.

The results obtained during all testing provided convincing evidence that copper wires behaved in a repeatable and predictable manner when subjected to impacts ranging in severity from 15-100 g. In early tests, a range of masses and wire gages were used so that data generated would permit slug weight-wire strength tradeoffs to be carried out. Having thereby established the mass-gage parameters for the sensing mechanism later investigations concentrated on simultaneous tests where in two or more identical mass-gage configurations were impacted together so that comparative data was developed for evaluation. There emerged from the testing program a clear indication that copper wire would provide a true indication of acceleration when utilized in the PAD. The accumulated data from the many tests establishes that the slug deflection is predictable with respect to both g-force and wire gage.

The severity of impact is indicated by the displacement of the conical slugs from their original position (see Figure 23). Each slug is held in place by four copper wires and a spring finger (which provides the fatigue threshold). When subjected to an impact with a magnitude greater than the threshold value, the slug pivots, which stretches or breaks one or two of the sensing wires, depending upon the direction of the shock. The original PAD concept envisaged "g" indication by a series of incremental steps, the approximate magnitude of the applied shock being known to have occurred between the highest indicated and the lowest nonindicated step value.

The slug-filament concept permits a more precise assessment of the severity and direction of impact to be made. After impact, the center finger of the spring clip (see Figure 24) retains the slug in the deflected position. Should the copper wire be only partially stretched, the percentage offset of the slug within the cavity permits the slug travel to be easily estimated and a corresponding judgment of "g" level within the appropriate range to be made.

4.3 ENVIRONMENTAL

It is intended that an installed PAD sensor will be operational for a minimum period of 10 years without requiring any periodic service or maintenance. This requirement mandates that it be immune to any environmental factors which would cause it to fail prematurely.

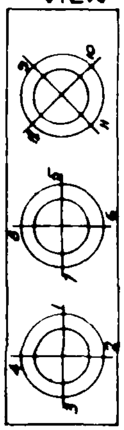
TABLE 1. TEST DATA EXPERIMENT CONICAL NOS. 21 AND 22

ANCO ENGINEERS INC

MADE BY [illegible] DATE 3 13 86
CHECKED BY DATE

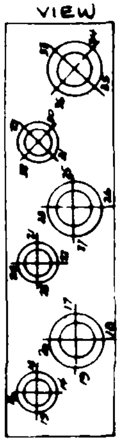
16631
EXPERIMENT No [illegible]
TITLE CONICAL

TOP VIEW



DIRECTION OF TRAVEL

SIDE VIEW



RUN NO	START POS	BACKS	BUMP
1	122	ø	2±1
2	112		
3	101		
4	87		
5	78		
6	66		
7	55		
8	46		
9	35	ø	
10	35	1	
11	37	2	
12	35	3	
13	36	4	2±1
14			
16			

KEY F = FAILED (BROKEN OR 100% STRETCHED)
δ/R = APPROXIMATE SNUG DEFLECTION

WIRE NO.	3	7	11	12	15	25	31	32	19	27	35	36	G'S	COMMENTS
GAGE	42											42		
RUN 1													11.1	
2	60/40	60/40											14.6	
3	80/20	70/30											19.1	
4	F	F	60/40	60/40									23.8	
5			80/20	80/20									27.7	
6			F	F									32.9	
7									60/40	60/40			38.3	
8									70/30	70/30			46.6	
9									80/20	80/20			58.2	
10									90/10	90/10	60/40	60/40	73.7	
11					70/30	70/30			F	F	90/10	90/10	103.7	
12					90/10	90/10	60/40	60/40			F	F	126.7	
13					F	F	80/20	80/20					152.2	
14														
15														

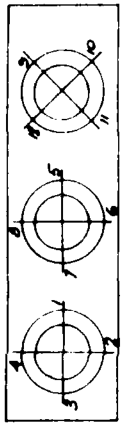
NOTES:
1 OIL IMMERSED FOR VIBRATION + IMPACT TESTS
2 VIBRATED AT ± 20g RMS FOR 100,000 CYCLES PRIOR TO IMPACT TESTS
3 WIRES ATTACHED WITH DEXTER HYSOL EA966 EPOXY ADHESIVE

ANCO ENGINEERS INC

MADE BY [illegible] DATE 8-21-86
CHECKED BY DATE

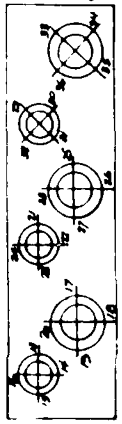
16631
EXPERIMENT No 22
TITLE CONICAL

TOP VIEW



DIRECTION OF TRAVEL

SIDE VIEW



RUN NO	START POS	BACKS	BUMP
1	113	ø	2±1
2	102		
3	94		
4	83		
5	73		
6	64		
7	54		
8	47		
9	39	ø	
10	39	1	
11	39	2	
12	39	3	
13	40	5	
14	40	6	
16	22	0	±1

KEY F = FAILED (BROKEN OR 100% STRETCHED)
δ/R = APPROXIMATE SNUG DEFLECTION

WIRE NO.	3	7	11	12	15	25	31	32	19	27	35	36	G'S	COMMENTS
GAGE	40											40		
RUN 1													15.6	
2	60/40	60/40											20.6	
3	70/30	70/30											28.2	
4	90/10	F											28.6	
5	F		60/40	60/40									34.7	
6			90/10	90/10									41.1	
7			F	F									50.0	
8									60/40	60/40			56.4	
9									70/30	70/30			62.1	
10									F	F	60/40	60/40	101.0	
11					60/40	F					80/20	80/20	130.2	
12					70/30							F	147.3	
13					F								182	
14													203	
15							70/30	70/30					258	

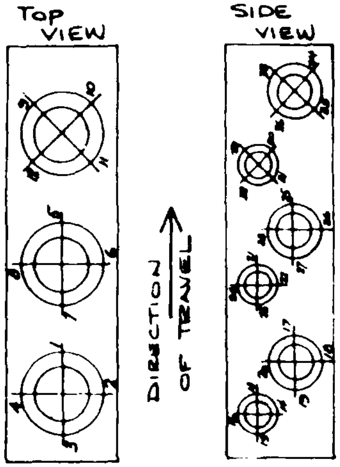
NOTES:
1 OIL IMMERSED FOR VIBRATION + IMPACT TESTS
2 VIBRATED AT ± 20g RMS FOR 100,000 CYCLES PRIOR TO IMPACT TESTS
3 WIRES ATTACHED WITH DEXTER HYSOL EA956 EPOXY ADHESIVE
4 SPRING PRESSURE SETTINGS AS EXPERIMENT #21

TABLE 2. TEST DATA EXPERIMENT CONICAL NOS. 23 AND 24

ANCO ENGINEERS INC
9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY [illegible] DATE 11-20-86
CHECKED BY Pcl DATE 11-86

JOB NUMBER K663.11 PAGE OF
DESCRIPTION
EXPERIMENT No 23
TITLE CONICAL



RUN NO.	START POS.	BACKS	BUMP	
1	101	0	2x1	
2	91	0	2x1	
3	80	0	2x1	
4	60	0	2x1	
5	44	0	2x1	
6	25	0	2x1	
7	24	1	2x1	
8	25	2	2x1	
9	25	3	2x1	
10				
11				
12				
13				
14				
16				

KEY: F = FAILED (BROKEN OR 100% STRETCHED)
x/x = APPROXIMATE SLUG DEFLECTION.

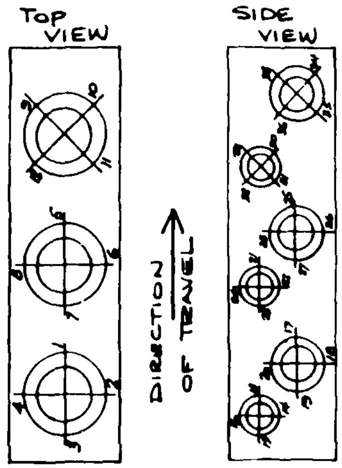
WIRE NO.	3	7	11	12	15	25	31	32	19	27	35	36	G'S	COMMENTS
GAGE	38	38	38	38										
RUN 1	-		-	-									11.8	
2	-	-											13.2	
3		-											15.2	
4		-											17.1	
5	-	-	-										21.7	
6	60/40	-	-										27.6	
7	70/30	70/30		-									36.8	
8	80/20	80/20	70/30	6/30									49.3	
9	F	F	F	F									77.6	
10														
11														
12														
13														
14														
15														

NOTES:
1 Oil immersion impact test
2 Wires attached with Dexter Hysol [illegible] adhesive
3 String pressure setting as experiment #21

ANCO ENGINEERS INC
9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY [illegible] DATE 11-20-86
CHECKED BY Pcl DATE 11-86

JOB NUMBER K663.11 PAGE OF
DESCRIPTION
EXPERIMENT No 24
TITLE CONICAL



RUN NO.	START POS.	BACKS	BUMP	
1	54	0	2x1	
2	40	0	2x1	
3	24	0	2x1	
4	24	1	2x1	
5	24	2	2x1	
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: F = FAILED (BROKEN OR 100% STRETCHED)
x/x = APPROXIMATE SLUG DEFLECTION

WIRE NO.	3	7	11	12	15	25	31	32	19	27	35	36	G'S	COMMENTS
GAGE	35	35	35	35										
RUN 1	-	-	-	-									28.0	
2	-		-	-									36.0	
3	60/40	60/40	-	-									51.3	
4	80/20	80/20	60/40	60/40									89.9	
5	F	F	90/10	90/10									126.4	
6			F	F									165.1	
7														
8														
9														
10														
11														
12														
13														
14														
15														

NOTES:
1 Oil immersion impact test
2 Wires attached with Dexter Hysol [illegible] sticky adhesive
3 Spring pressure as experiment #21.

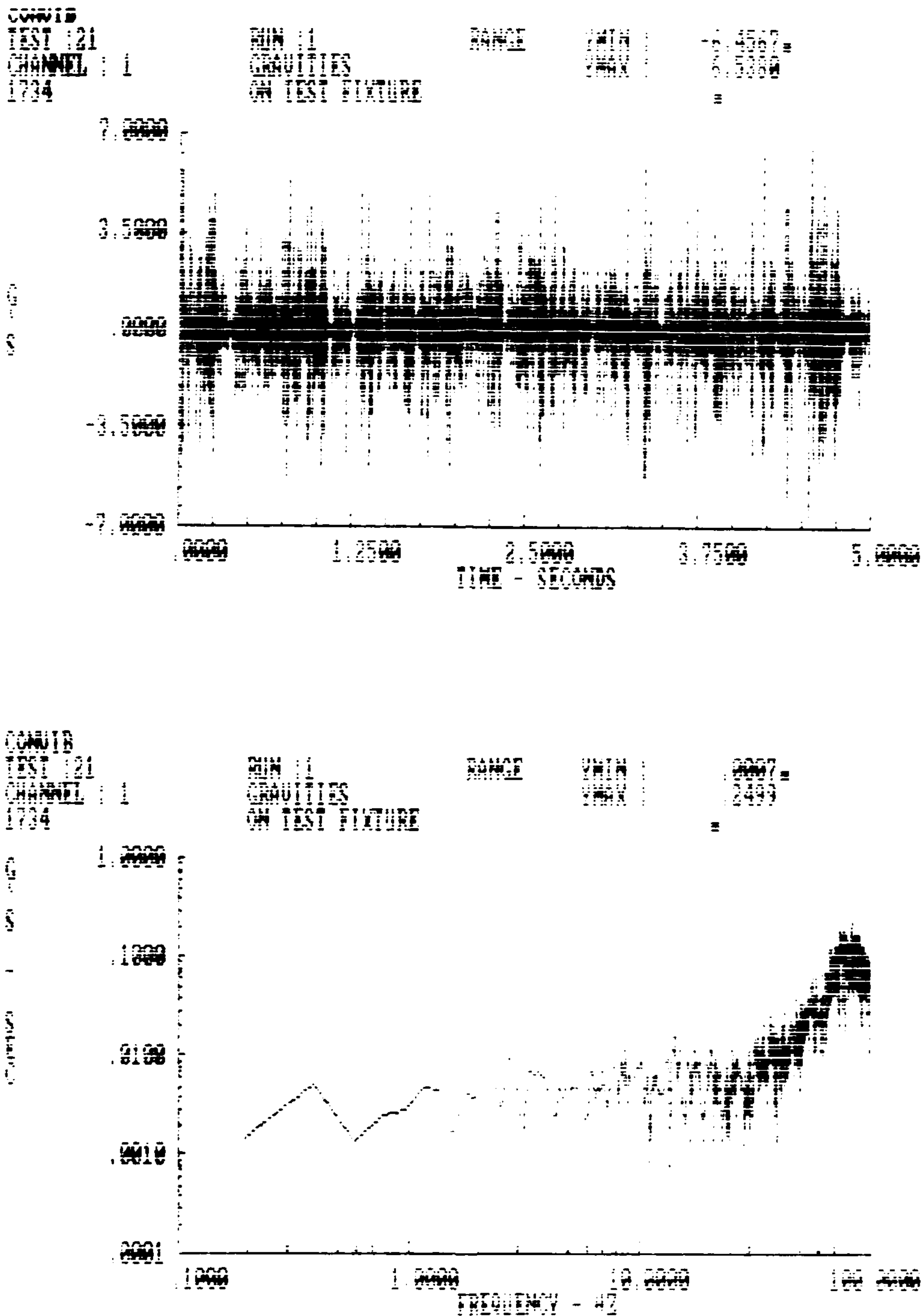


Figure 21. Typical Vibration Time History.

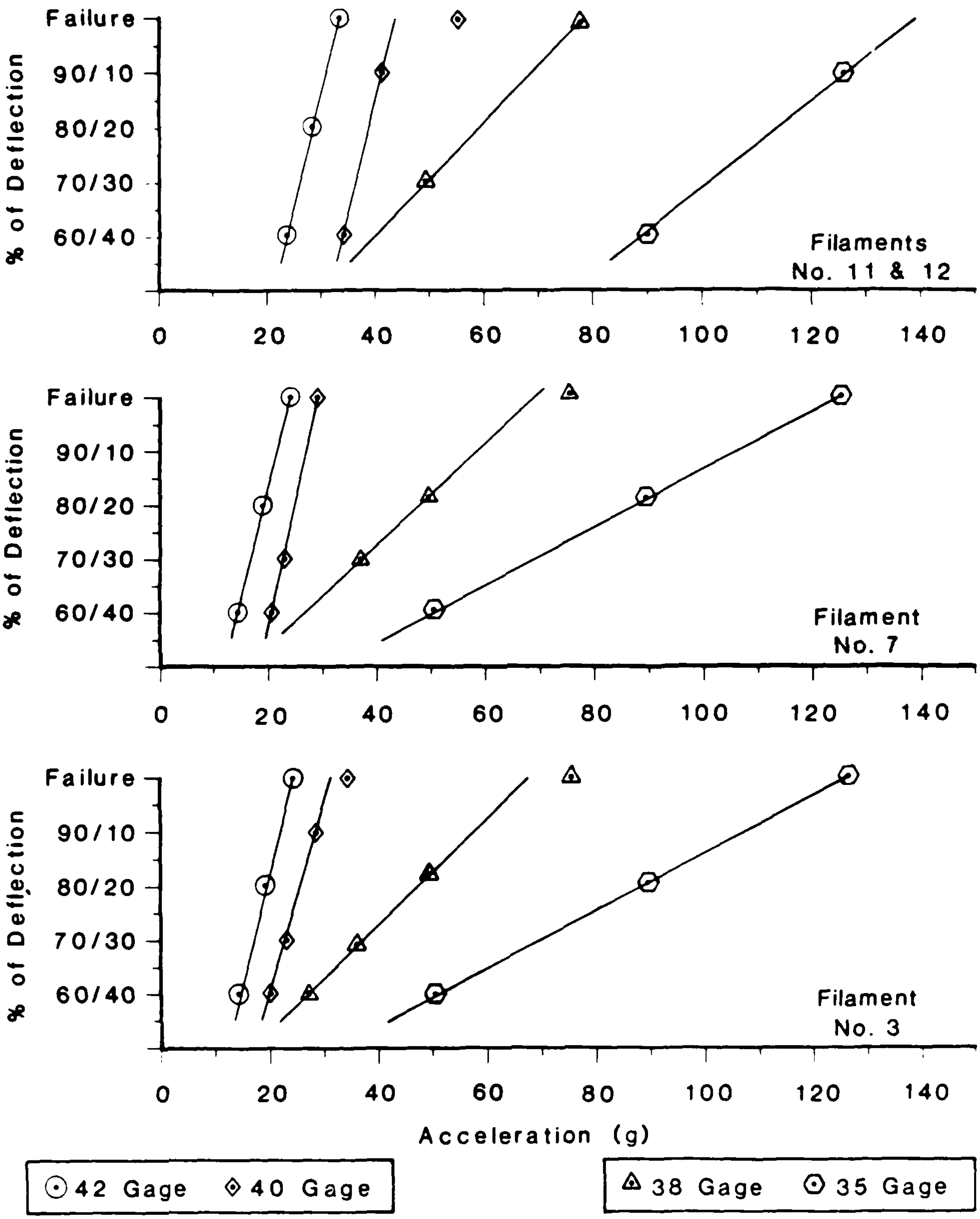


Figure 22. Conical slug deflection plots from Experiments 21, 22, 23 and 24.

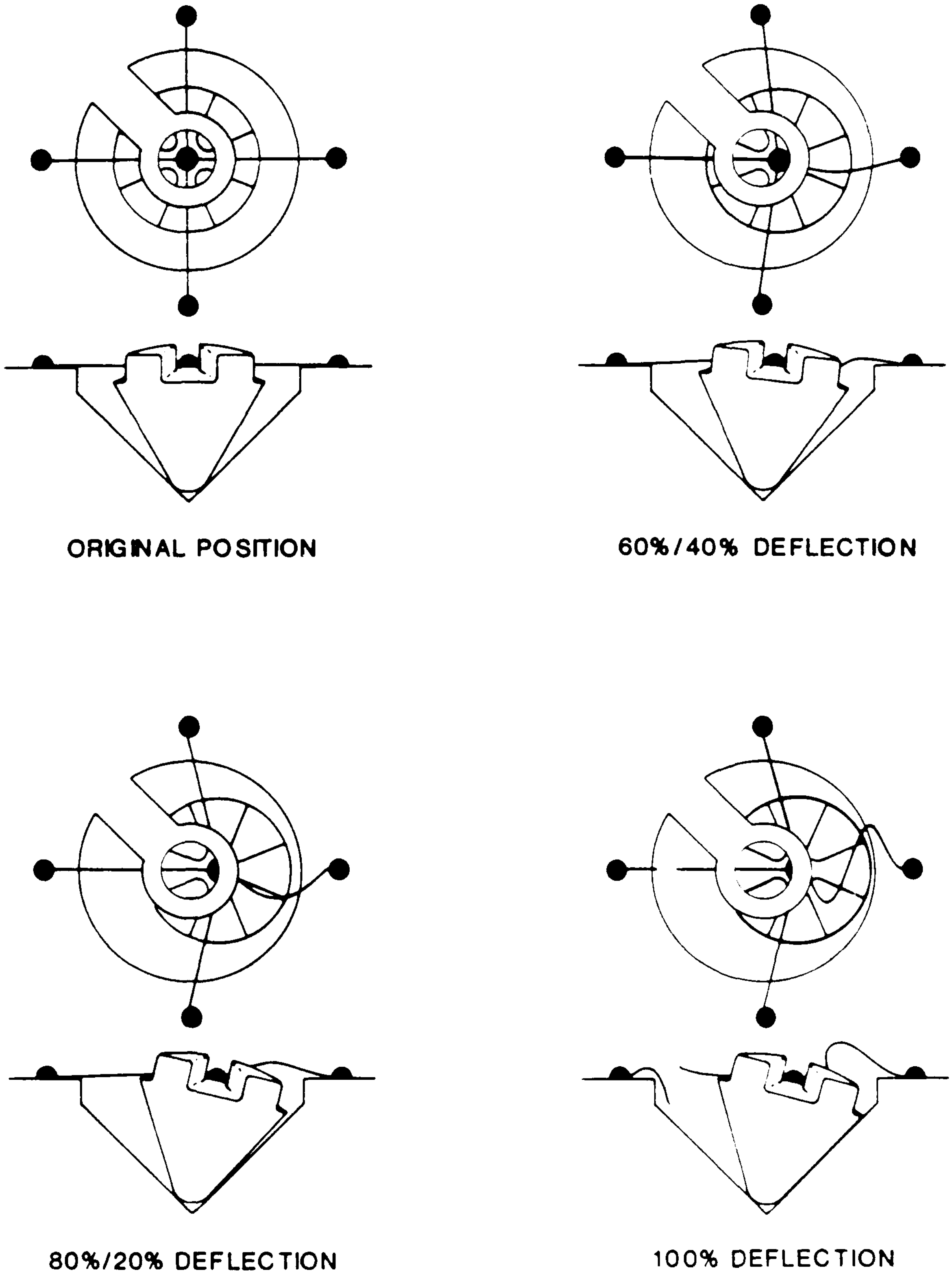


Figure 23. Impact indication.

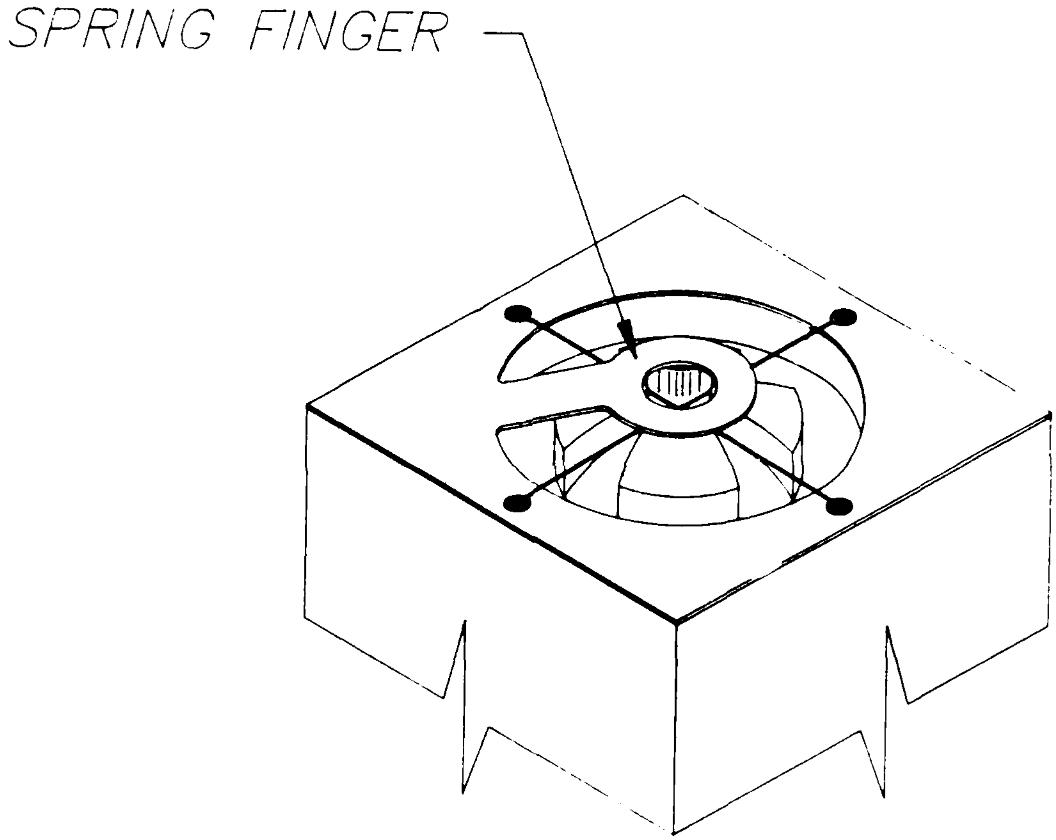


Figure 24. Spring clip arrangement.

Three possible causes of failure have been identified:

- Vibration
- Adhesive degradation
- Physical abuse.

The final design incorporates features to negate the effects of these environmental influences.

4.3.1 Vibration

The elimination of possible fatigue failures arising from prolonged exposure to low-level vibration was a critical design factor. It was achieved by the incorporation of a spring finger which establishes a minimum "g" threshold value below which the slugs do not move and, hence, do not stress the copper wire when subjected to low-level vibration. Extensive testing was conducted to verify that this arrangement provided the desired resistance to fatigue.

4.3.2 Adhesive Degradation

During the design process, two methods of attaching the sensing wires to the cube and slug were considered. Epoxy adhesive was the primary choice because it would not impair the sensing wire characteristics, a major drawback with soldering.

A search was undertaken for an adhesive that possessed the requisite properties for the application. The foremost of these are:

- High strength.
- Immunity to degradation from prolonged exposure to silicone oil.

Dexter Hysol EA 956 AB was recommended by an adhesive company as an epoxy adhesive that was likely to meet the requirements of the application. The company also suggested a test procedure to verify that it was resistant to degradation from prolonged exposure to silicone oil. A test was performed in accordance with their recommendations. Two identical test samples (aluminum plates with five sensing wires epoxied to each) were prepared--one for testing purposes and the other a control (see Figure 25). The test plate was immersed in Amsoil synthetic gear lube oil (SAE 80W-90) and heated to 170°F and maintained at that temperature for 238 hours. This heating process accelerates any chemical reaction between the epoxy and oil by a factor of about 50 and, therefore, approximates over 1 year of service. Three wires on each sample were then subjected to static tensile loads until failure occurred. The results of the tensile loading are shown in Figure 26.

It was apparent that the strength of that adhesive bond between the plate and wire was not significantly reduced by the exposure to silicone oil, as all failures on the test sample were wire breakages.

It was planned that, should some impairment of the adhesive bond be found by this initial test, further research and testing would be necessary; however, the results obtained being satisfactory, Dexter Hysol EA 934 NA was selected for wire attachment.

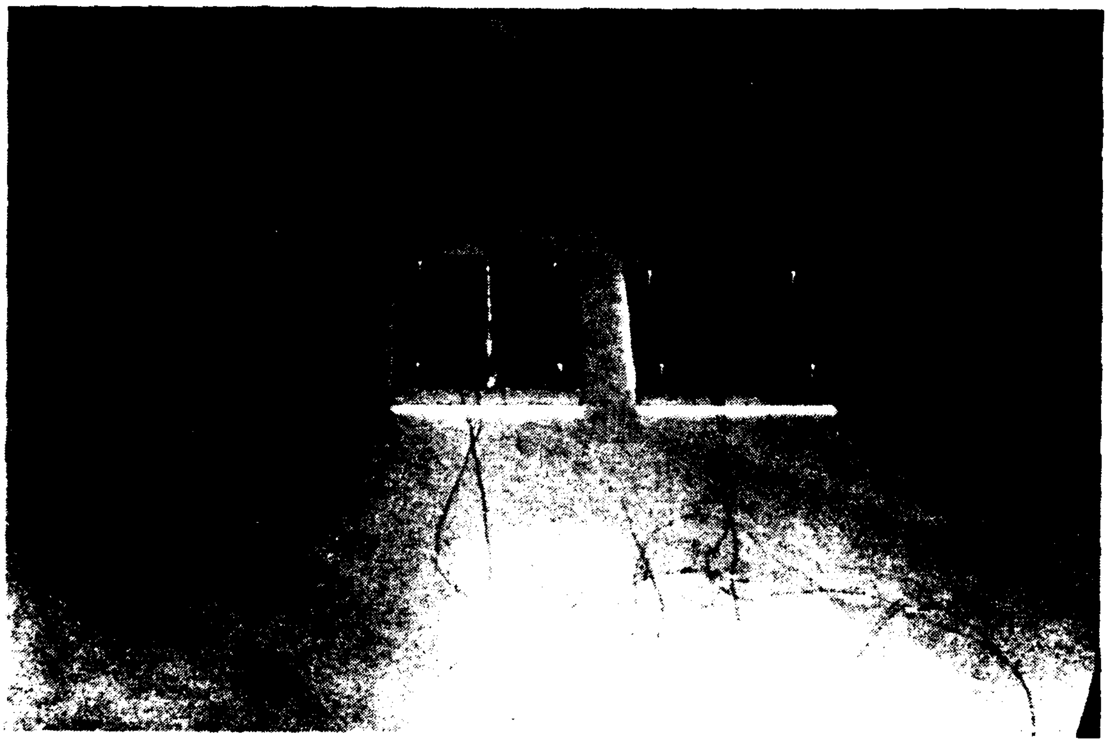
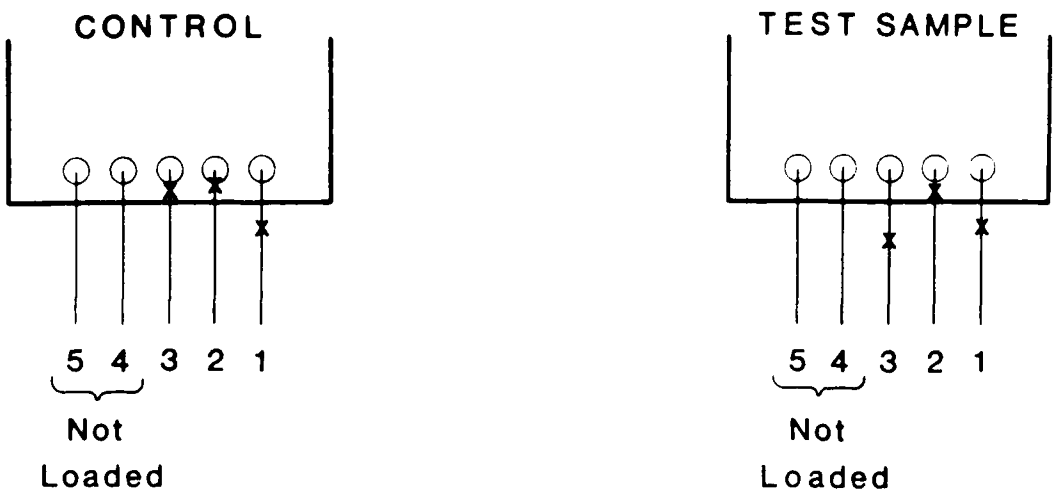


Figure 25. Adhesive test sample.



x = Point of failure

Sample		Test	Failure	
Title	Wire #		Load (Grms.)	Time (Mins.)
CONTROL	1	Loaded	110	1.25
	2	Loaded	110	1.25
	3	Loaded	100 117	10.0 3.5
	4	Not loaded	-	-
	5	Not loaded	-	-
TEST	1	Loaded	110 117	6.0 1.5
	2	Loaded	110	1.5
	3	Loaded	110 117	6.0 2.5
	4	Not loaded	-	-
	5	Not loaded	-	-

Figure 26. Adhesive Test Results.

4.4 PROTECTIVE PACKING

The problems involved in transporting a device sensitive to low-level shocks were recognized at the inception of the design process and methods of mechanically constraining the indicating mechanism during shipping were considered. Unfortunately, to meet the requirement for isolation and resistance to damage, the PAD requires a rugged outer case. This restricts access to the sensing module, and unless shipped disassembled, prevents locking the indicating medium stationary during transit. It was decided that on-site assembly of the PAD was impracticable, and, consequently, a shock-absorbing shipping container would need to be developed to protect the device during transit.

Tests were conducted with the conical slug fixture and a variety of boxes and filling materials (i.e., a 4-inch padding of styrofoam, foam rubber, shredded paper, etc.). It was determined that adequate protection could not be achieved with these conventional packing techniques and materials.

Success was achieved by suspending the conical fixture centrally within a 9-inch cardboard box with resilient elements. The fixture remained unaffected after the box was dropped repeatedly from a height of 10 feet. The general concept of the transit packing suggested for the PAD sensor is shown in Figure 27. This technique appears adequate for protecting the product during shipment.

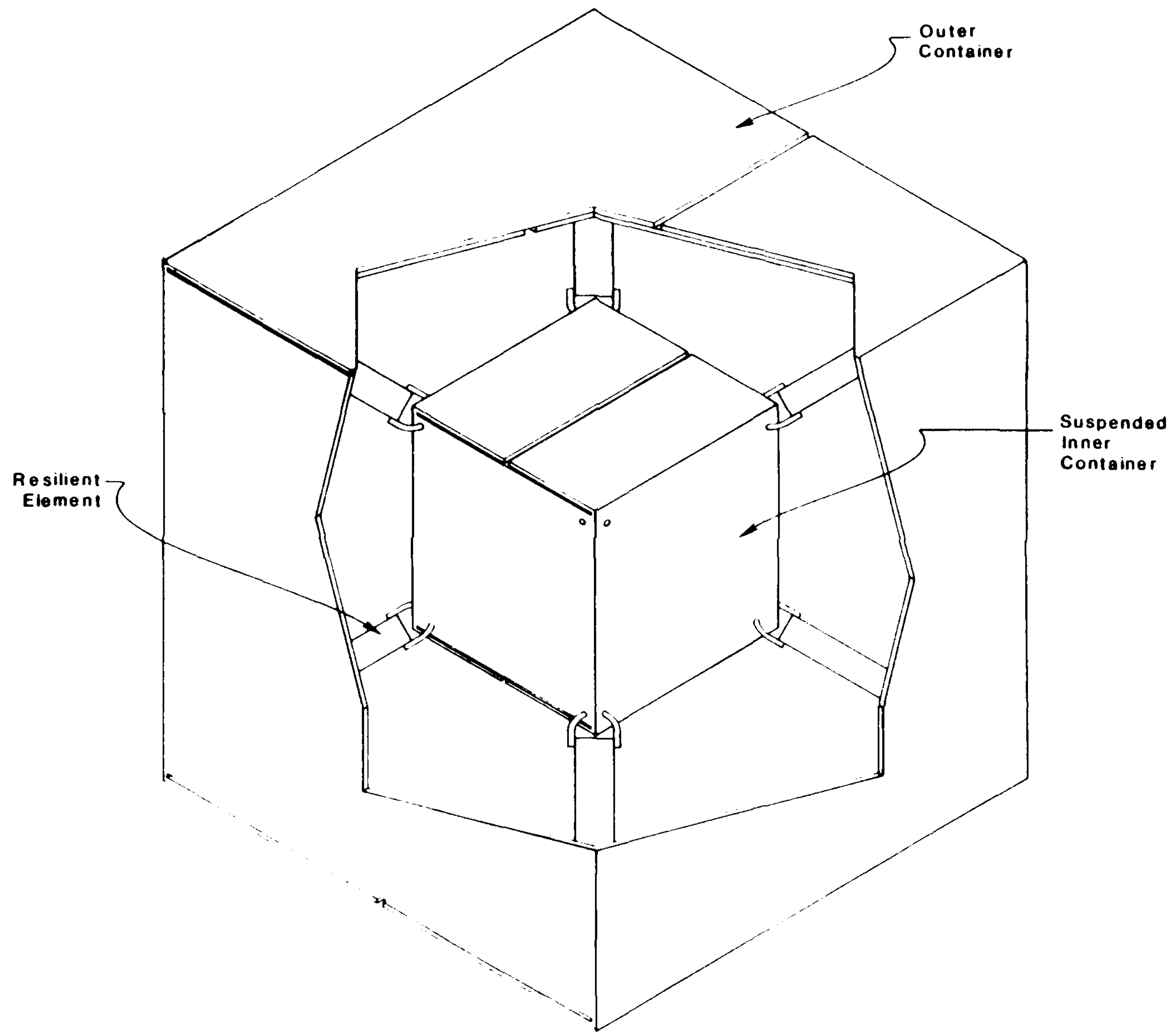


Figure 27. Transit packing concept.

5.0 TEST APPARATUS AND FIXTURES

5.1 IMPACT SLED

The impact sled was used to accelerate test specimens and then rapidly decelerate them in a controlled manner. The functional elements include two platens. The first is used to accelerate the test fixtures, the second to provide for their controlled impact. Both platens traverse freely and independently on rails mounted on a 20-ft-long beam. Platen acceleration is accomplished by means of a falling weight and pulley system. The start point of the acceleration run can be altered by means of an adjustable trigger mechanism, thereby permitting the velocity at impact to be increased or decreased as desired. The velocity can also be controlled by adjusting the magnitude of the falling weight.

The second platen is used to regulate the severity of impact. It has a paddle immersed in a water trough attached to the underside. By altering the water depth and interposing rubber bumpers between the two platens, the magnitude and duration of sled impacts can be varied. The general arrangement of the test sled assembly is illustrated in Figure 28.

The functional capabilities of the test sled (crash sled) are described in detail in Appendix A. In essence, it provides the facility to repeatedly generate impacts of up to 300 g magnitude and capture and process the resulting impact history by means of an ANCO "VIPAC" vibration testing workstation. The "VIPAC" system permits the data to be examined in both the time and frequency domains, allowing detailed analysis of impact time histories.

5.2 VIBRATION ACTUATOR

An MTS hydraulic servo controlled actuator was utilized to simulate the vibrational environment that the PAD will experience during service. The actuator was mounted vertically with the rod end at the bottom, as illustrated by Figure 29. An adaptor bracket permitted the attachment of the various test fixtures to the rod end. The excitation and data acquisition arrangement for vibration testing is shown in Figure 30.

5.3 FOAM/FOIL TEST FIXTURES

5.3.1 Cylindrical Slug Test Fixture

This fixture was originally designed for dynamic testing of foam materials (see Appendix A). During Phase II, it was modified to accommodate foils. The modified version is shown in Figure 31.

In the original design, twenty cylindrical slugs of varying sizes and materials were arranged in two parallel rows. Strips of the foam material under test were clamped in the fixture and arranged so that the foam surface just contacted one end of each slug. On impact, the slugs crushed the foam to an extent proportional to their masses.

For foil testing, the fixture was modified to accommodate special clamping bars to suit the foil strips. Registration pins for positioning these bars were required, with the result that space for only sixteen slugs was available. Two sets of eight matching slugs were used for the foil tests. This arrangement

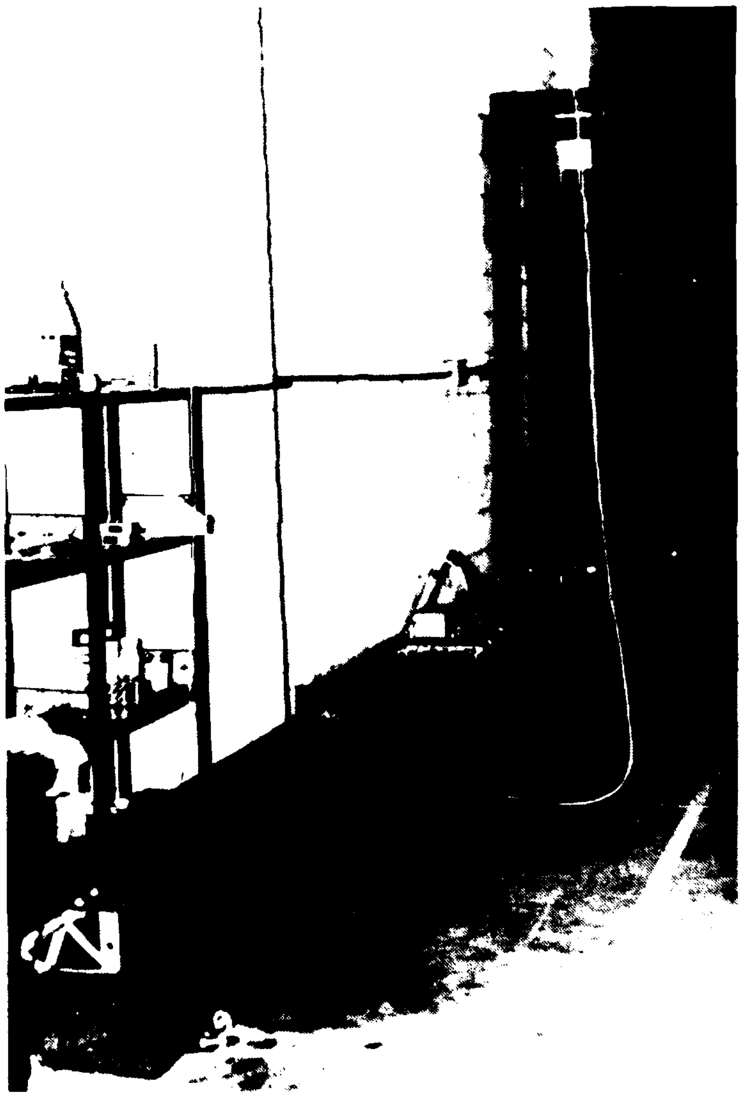


Figure 28. General arrangement of test sled assembly.

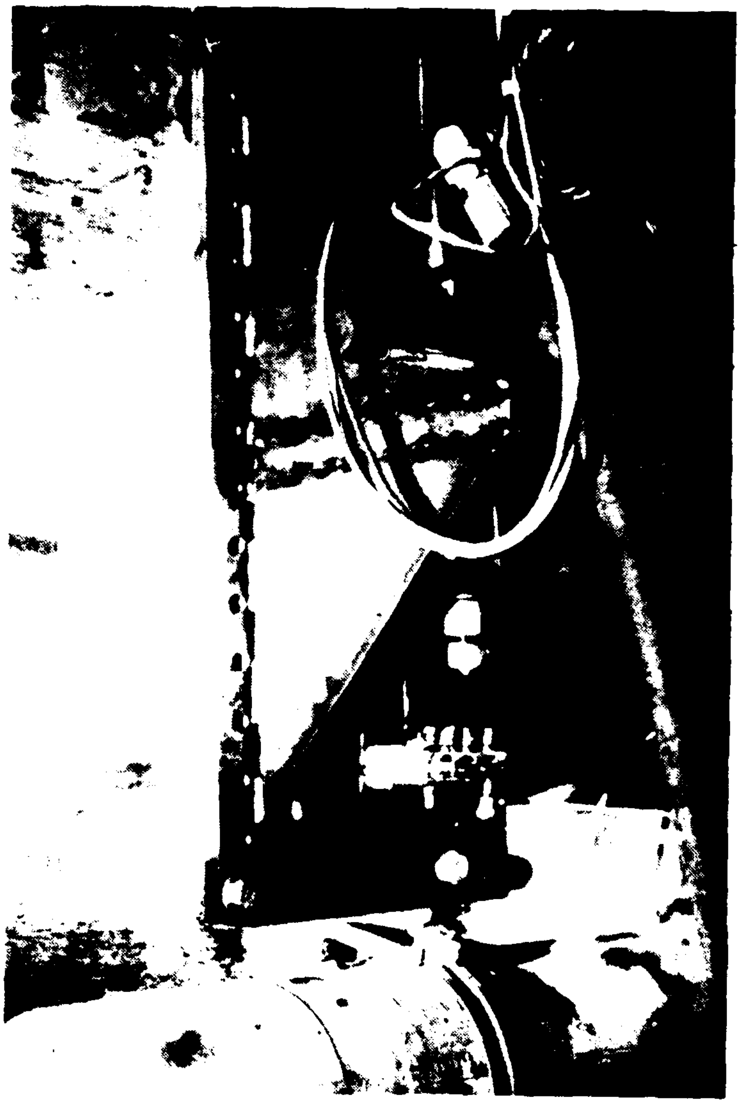


Figure 29. Vibration actuator.

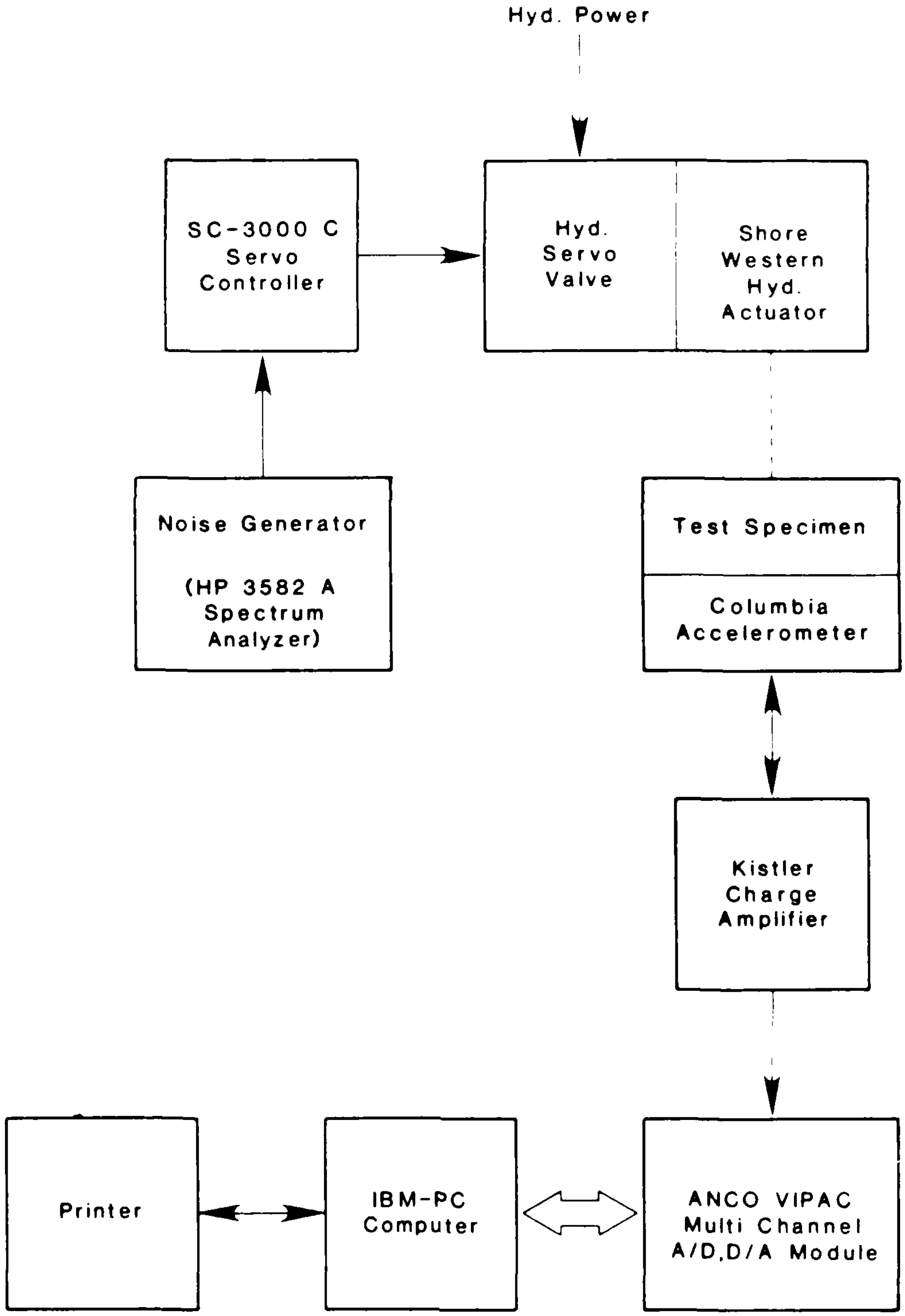


Figure 30. Block diagram of vibration testing system.

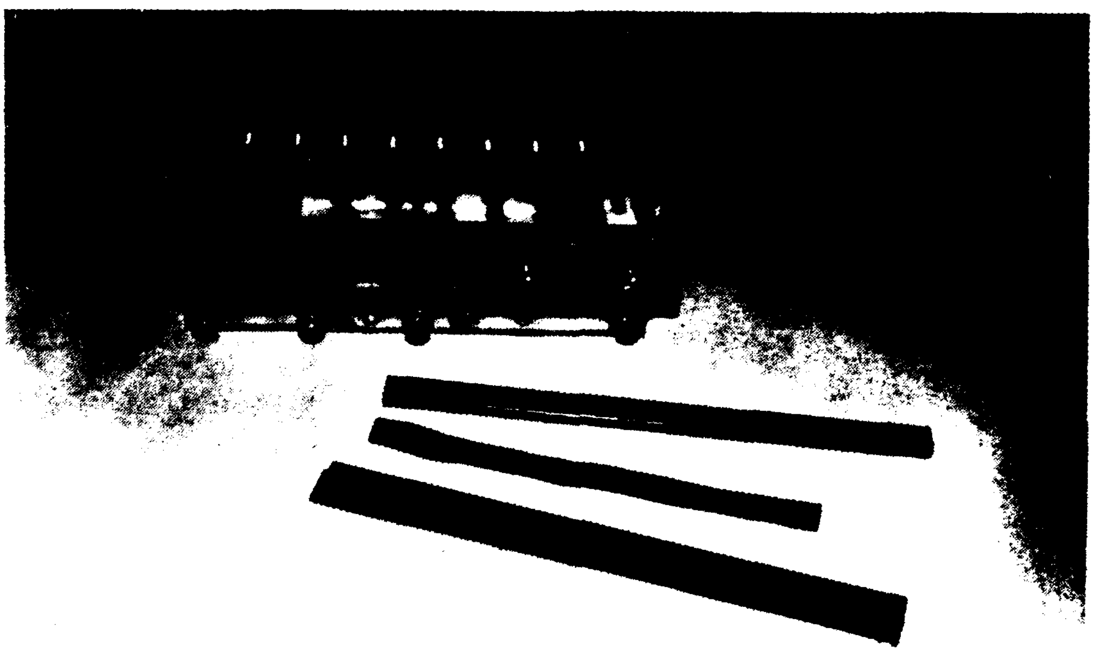


Figure 31. Cylindrical slug test fixture.

allows each test to simultaneously generate two sets of data for comparison purposes.

5.3.2 Mechanical Filter

A design requirement for the PAD sensor was a mechanical filter system that would isolate the indicating device from the majority of impact energy whose frequency was above 100 Hz. Consequently, impact and vibration testing was conducted with fixtures isolated with mechanical filters to simulate this "in-service" condition.

For Phase I and early Phase II impact tests, this filter took the form of two brackets with foam inserts which were attached to the slug test fixture (see Appendix A). For later Phase II tests, this device was redesigned so that it would accept the variety of fixtures necessary to test the functional components of the PAD.

The redesign employed the same basic concept as before--metal brackets and foam inserts. However, the new design was a freestanding device no longer relying upon a fixture to provide mechanical support. The mechanical filter is illustrated in Figure 32.

5.3.3 Static Test Fixture

The initial investigations into the characteristics of foils were conducted dynamically. However, when a sensitivity to impact duration became evident, a static test fixture was manufactured to permit point profiles and foil clamping arrangements to be investigated independent of strain rate. The fixture is illustrated in Figure 33.

During testing, foil samples are clamped between the upper body and the base plate, which are aligned by two registration pins (an important requirement to ensure uniform conditions of loading from test to test). Four cylindrical slugs are used to pierce the foil. They are guided vertically by the body and are loaded with brass weights by means of a special loading platform. The horizontal slot in the body permits viewing of the cylindrical slug during loading so that the process can be stopped once penetration is achieved.

The fixture was designed to utilize the slugs previously used for foil testing in the cylindrical slug test fixture. As testing progressed, additional point profiles were developed and tested in an effort to determine the optimum point profile.

5.4 FILAMENT FIXTURES

5.4.1 Rectangular Slug Fixture

This fixture was designed to explore the use of filaments for Peak g indication. Ten brass slugs, varying in weight from 0.4 to 6.6 grams, were located in parallel channels cut transversely in an aluminum block. The slugs were held in place by a brass cover plate, which permitted them to slide freely along the channels. The cover plate was equipped with a pair of anchor points at the end of each channel for attaching the individual filaments. When assembled and ready for a test run, each slug was centered along the length of its channel and was constrained from moving in either direction by an individual filament. The fixture with the slugs disassembled is illustrated by Figure 34.

Figure 32. Mechanical filter.

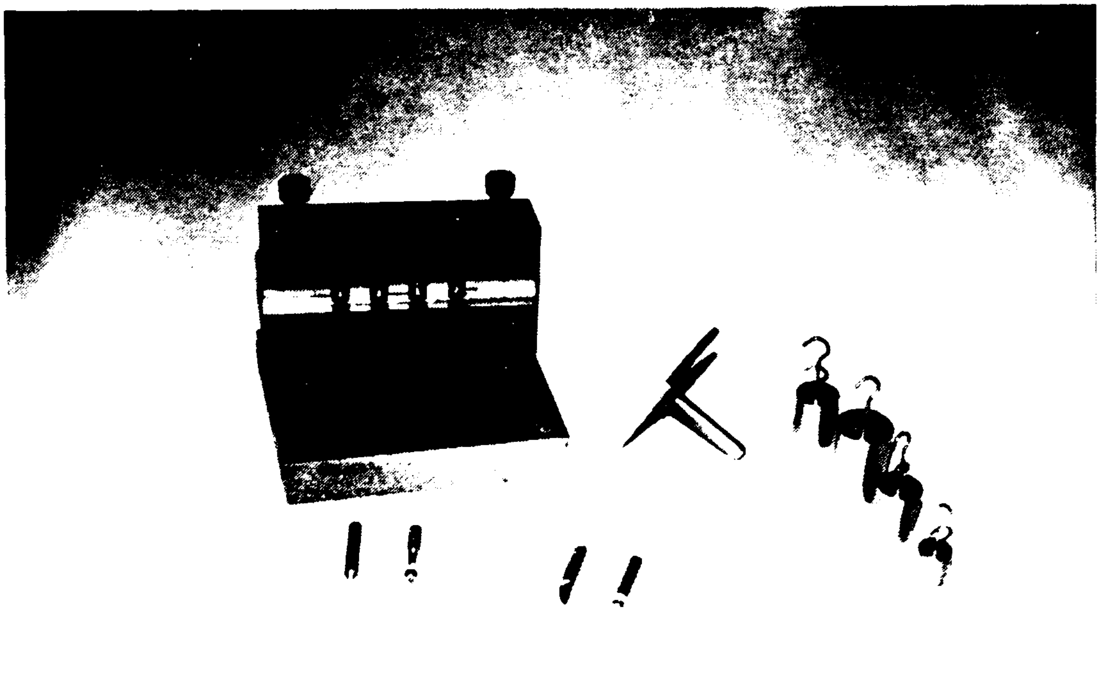


Figure 33. Static test fixture (foils).

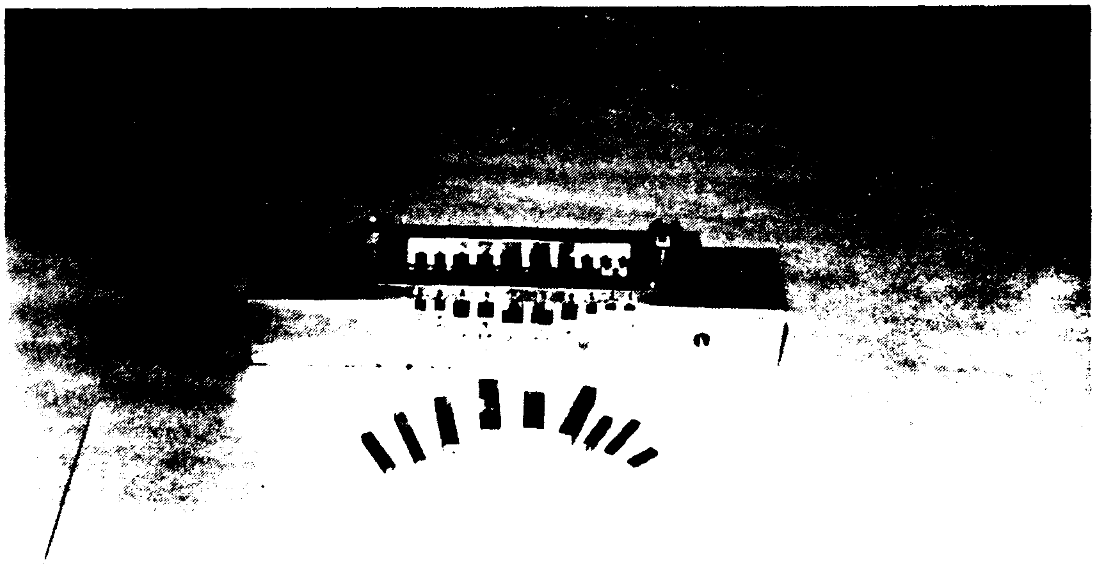


Figure 34. Rectangular slug-filament fixture.

The fixture was used for both impact and vibration testing and, consequently, was designed so it could be readily attached to the isolation mount of either system.

5.4.2 Dual-Filament Fixtures

This fixture was used to verify the premise that, at strains of 20% or less, a second filament positioned at 90 degrees to the axis of shock does not absorb a significant amount of the impact force and, consequently, has minimal influence on the "g" value indicated by the primary filament. The fixture was produced at a stage in the PAD evolution when a 1-in. cube housing metal slugs of circular form was perceived to be a likely final configuration of the PAD sensing element (the design reflects this perception). The 1-in. aluminum cube has two recesses in each face to house circular slugs. The recesses were positioned so that the slugs were retained in place axially by a wire passing through the cube attaching a pair of slugs on opposite cube faces. Pins spaced at 90-degree increments around each of the recesses were provided for anchoring the filaments, which were cemented to these pins and at the center of the slugs. Slugs were of four different weights: 6-1/4, 2-3/4, 1-1/4, and 9/16 grams. These four weights, in conjunction with two different strengths of filament, provided eight levels of "g" indication. Three of these fixtures were fabricated for impact testing. They were mounted in a row on the mechanical filter and their individual indications were compared to investigate the repeatability of the concept. The fixtures and slugs are shown in Figure 35.

5.4.3 Conical Slug Fixture

The conical slug test fixture was used for vibration, impact, friction, and transit packing testing of the final design. The fixture is shown disassembled in Figure 36. The functional elements were the aluminum body that housed the nine conical slugs and the threshold spring arrangement that provided adjustable spring pressure to the top of each conical slug. The aluminum body had nine cavities, arranged in three rows, to accommodate the slugs. Each cavity had four associated dimples which were anchor points for the sensing wires. These dimples were arranged so that one set for each slug size was oriented at 45 degrees to the other two matching sets (see sketch in Appendix E).

The slugs were manufactured from sintered tungsten stock. They closely resembled the final design that is intended to be produced in finished form by sintering. Three of each size were made. Their weights are 13.5, 5.8, and 2.0 grams. There are two threshold spring assemblies--one for the large slugs and the second for the medium and small slugs. Their spring pressure was provided by small wave washers. The washers were arranged individually on adjustable mounts so that the spring force on each slug could be regulated independently. This feature allowed the force applied to the slugs to be varied during the testing program and the optimum force to be derived empirically. The threshold spring assembly is illustrated in Figure 37.

5.5 ISOLATION FIXTURES

5.5.1 Compression Spring Fixture

During Phase I, a fixture was built to test the isolation properties of foam materials. This fixture was modified during Phase II and used for both compression and conical spring investigations. The modified design provided the functional features required by the PAD housing, a leak-proof 2-1/4-in. cubic

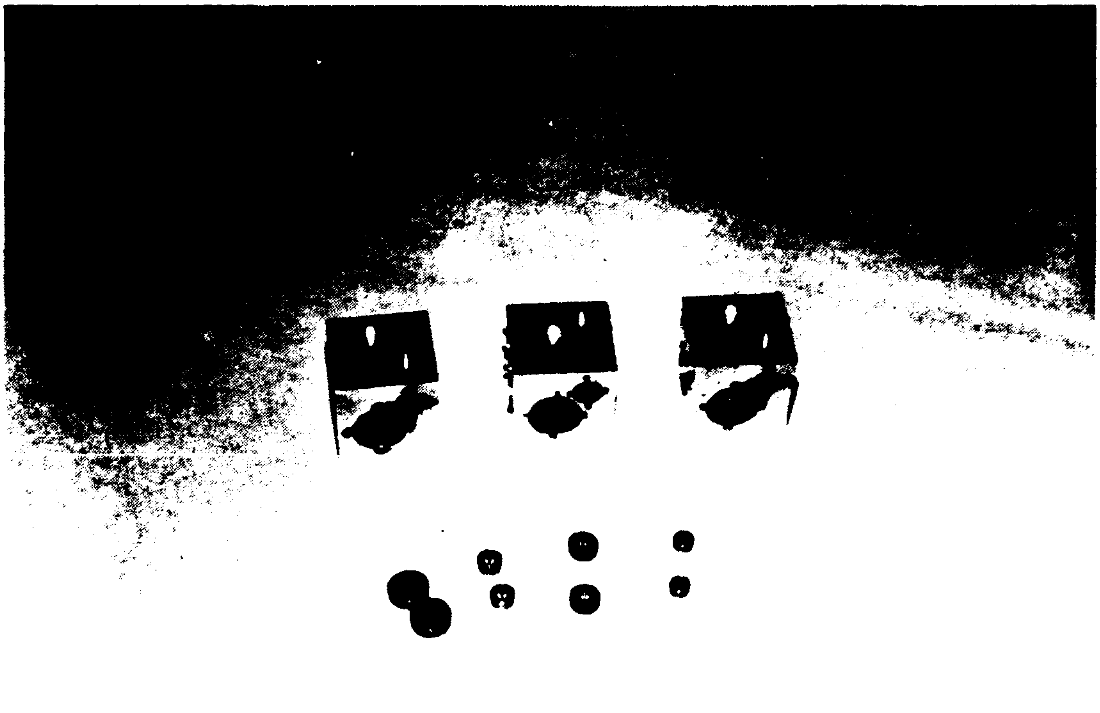


Figure 35. Dual-filament fixtures.

Figure 36. Conical slug test fixture.

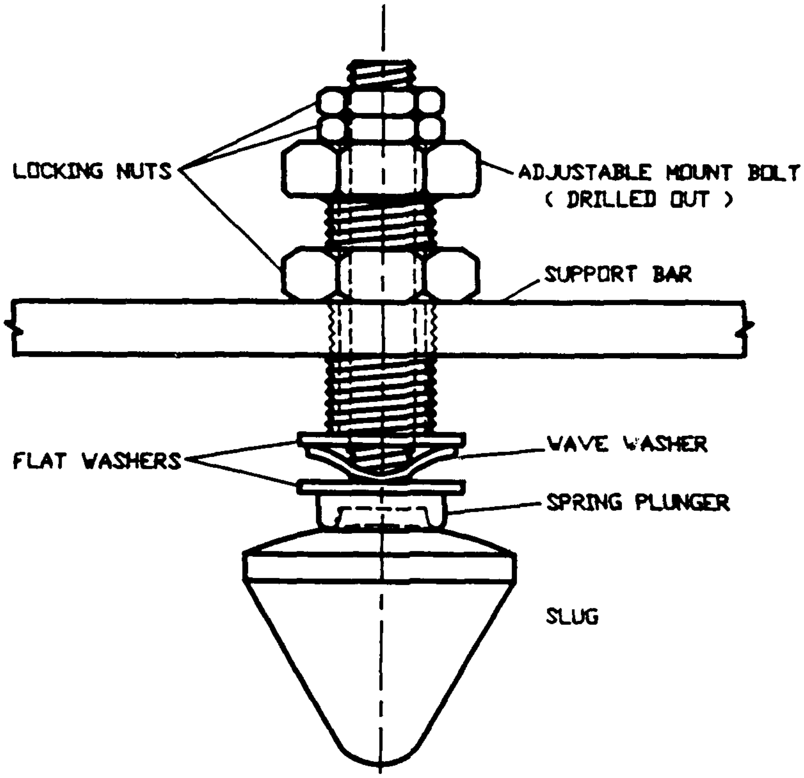


Figure 37. Conical test fixture, threshold spring assembly.

enclosure with a gasketed cover that could be clamped in place. An aluminum cube instrumented with an accelerometer could be suspended centrally within the box by springs which engaged locating pins in the box walls and cavities in the cube. With the cover in place, the interior could be filled with oil and the assembly mounted on the sled and impacted along both the Z and X-Y axes. The fixture arrangement for compression spring testing is shown in Figure 38.

A second accelerometer mounted on the sled platen provided a baseline vibration history for comparison with the data obtained from the isolated sensor. A block diagram of the data acquisition system is shown in Figure 39.

5.5.2 Conical Spring Fixture

The testing of the isolation characteristics of conical springs was conducted with the housing and data acquisition system previously used for testing compression springs. A smaller cube (1 inch) and a pair of special adaptor plates were used for locating and spacing the conical springs. Figure 40 shows the fixture.

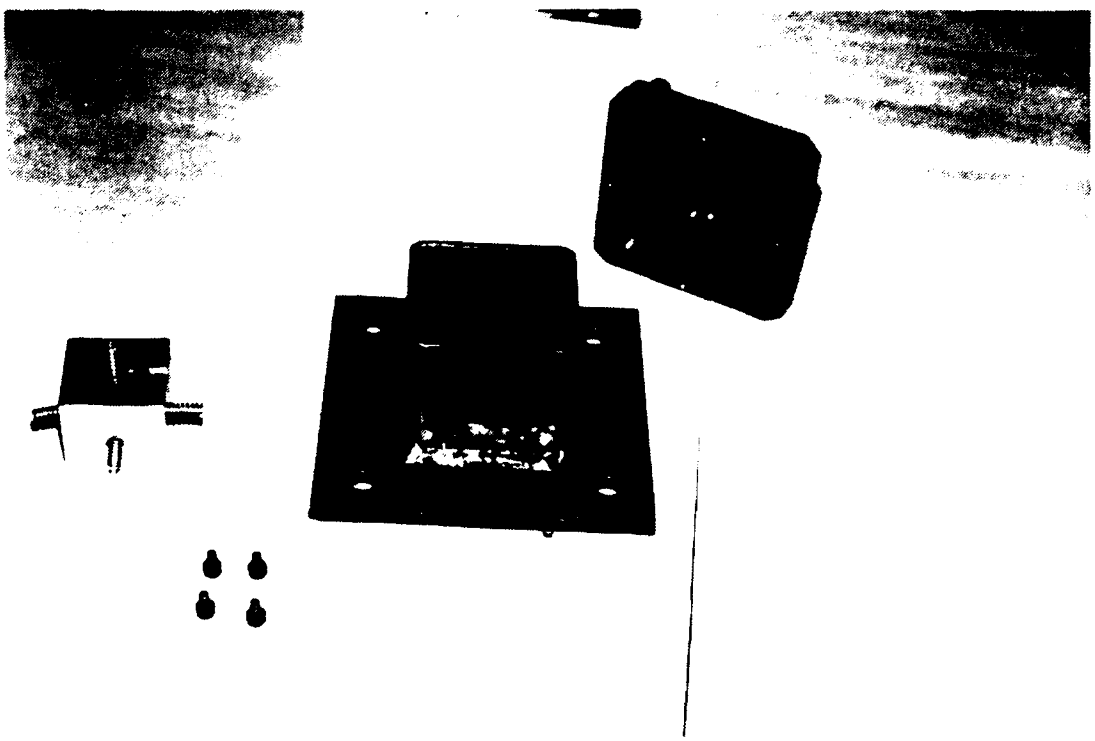


Figure 38. Isolation fixture.

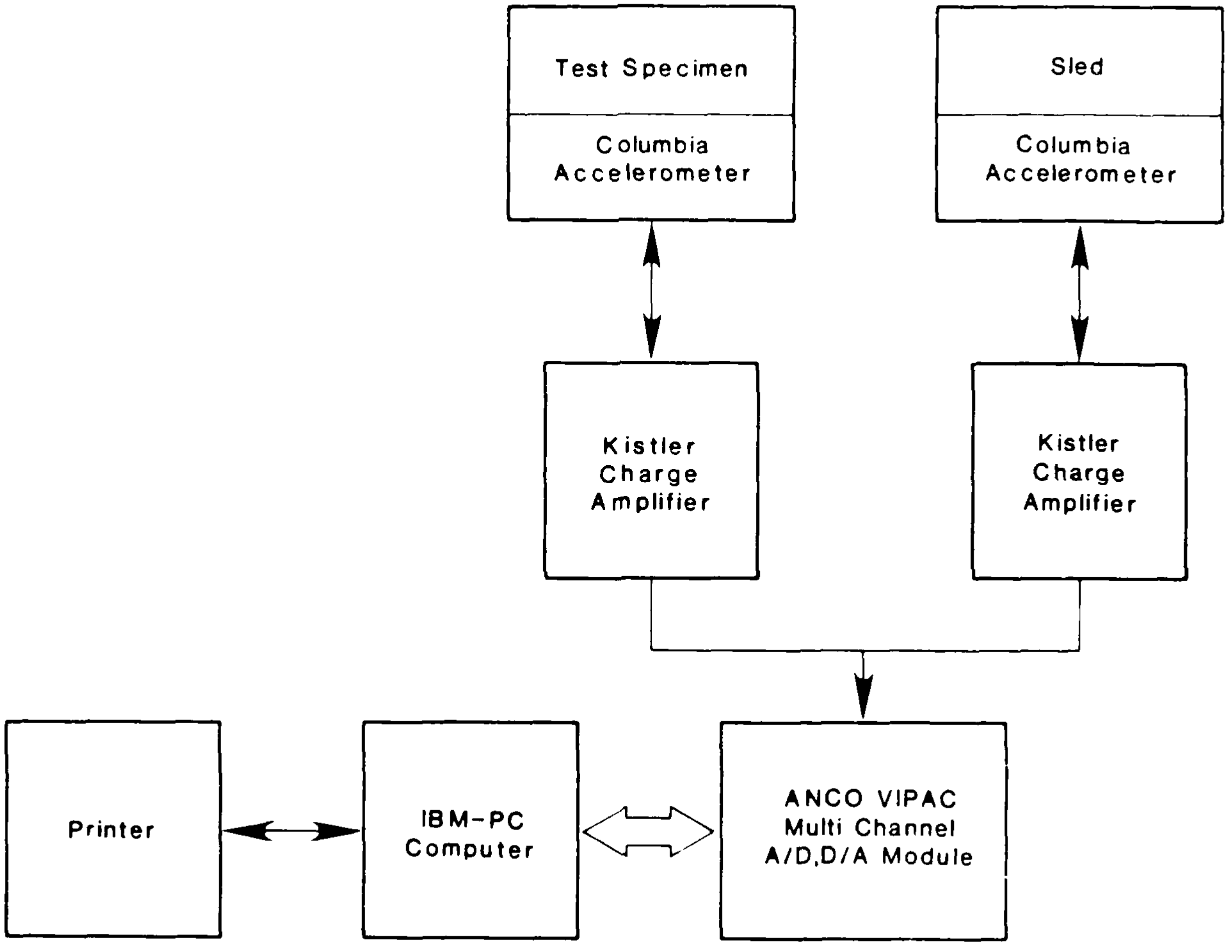


Figure 39. Block diagram of isolation testing system.

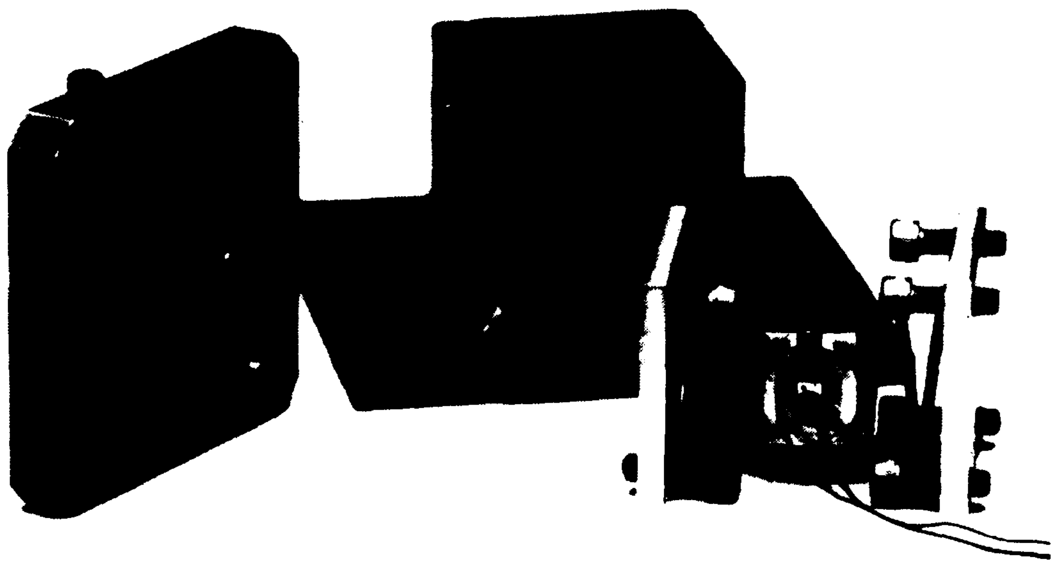


Figure 40. Conical spring test arrangement.

6.0 MANUFACTURING AND ASSEMBLY

The components necessary to construct a PAD were designed to be produced by conventional manufacturing practices. To produce these components economically, manufacturing tooling will be necessary. A projected list of tooling is given in Table 3.

The PAD sensor poses a number of unusual assembly requirements. The device is inherently susceptible to shock, and, consequently, extreme care will be necessary during the assembly process to ensure that the indicating mechanisms are not compromised. Correct cube orientation within the housing is another important functional requirement, and a rigorous inspection schedule will be necessary to guarantee integrity of the finished device, because after it is assembled into the aluminum housing, neither of these features can be verified visually.

The tools and fixtures listed in Table 4 are recommended as assembly aids. In addition, standard equipment, such as an arbor press or adhesive dispenser, is necessary.

TABLE 3. PROJECTED MANUFACTURING TOOLING REQUIREMENTS

Component Description	Part No.	Procedure and Tool
Case	166311-117-1	Drawing Die Piercing Die
Cover	166311-117-2	Drawing Die Piercing & Embossing Die
Slug (Large)	166311-119-1	Sintering Mold
Slug (Small)	166311-119-2	Sintering Mold
Spring Clip Spring Clip	166311-120-1 166311-120-2	Blanking Die Forming Die

Note: The orientation clip Part No. 166311-121-1 can be produced with standard tooling.

TABLE 4. PAD ASSEMBLY TOOLING REQUIREMENTS

Procedure	Tool
Assemble slugs into cube	Four-position fixture Slug spacers
Assemble orientation clip	Crimping die
Assemble tapered spring to cover	Positioning & crimping fixture
Assemble cube subassembly to cover subassembly	Orientation jig
Fill and assemble cover	Volumetric measure Holding fixture

7.0 COST ANALYSIS

Throughout the PAD development program, the need to develop an inexpensive device that could be produced in quantity has been a basic requirement. With the exception of the prototype quantity, which will be handmade and, consequently, expensive, cost analysis suggests that for reasonable production quantities, the unit selling price including amortized tooling charges should range between $86-$125.

Final components and their related tooling costs cannot be developed until the initial order quantity is established. Preliminary estimates based on production quantities of 1,000-10,000 have been prepared and are presented in Tables 5 and 6.

Assembly labor and tooling costs are also quantity dependent. Preliminary estimates for these costs, based on production quantities of 1,000-10,000 units, are presented in Tables 7 and 8.

The estimated cost summaries are presented in Tables 9 and 10.

TABLE 5. ESTIMATED COMPONENT COST

Item	Part No.	Description	Quantity Per Device	Cost ($) Production Quantity 1000 Unit	Ext'd	10000 Unit	Ext'd
1	166311-117-1	Case	1	-	2.64	-	2.30
2	166311-106-100	Cube Assembly	-	-	-	-	-
2A	166311-118-1	Cube	1	-	6.35	-	3.47
2B	166311-119-1	Slug	6	1.00	6.00	0.95	5.70
2C	166311-120-1	Spring Clip	4	0.60	2.40	0.42	1.68
2D	166311-120-2	Spring Clip	2	0.98	1.96	0.76	1.52
2E		No.0 x 1/8 LG, Type U Metallic Drive Screw	12	0.05	0.60	0.05	0.60
2F		42 gage Copper Wire	AR	-	0.10	-	0.10
2I	EA956AB	Dexter Hysol, Low Viscosity Adhesive	AR	-	0.10	-	0.10
3	TA2177	Tapered Spring Century Spring Co.	2	1.24	2.48	.11	2.22
4	166311-121-1	Orientation Clip	1	-	0.44	-	0.35
5	166311-117-2	Cover	1	-	1.28	-	0.89
6	2-030N674-70	O-Ring (1-5/8 dia.)	1	-	0.13	-	0.09
7		No.0 x 1/8 LG, Type U Metallic Drive Screw	6	0.05	0.30	0.05	0.30
8		Amsoil Silicone Oil (SAE80W-90)	0.8 oz.		0.02		0.02
9		Packing Case	1		1.50		1.50
10		Packing Case Inner	1		0.50		0.50
		SUBTOTAL			28.75		21.34
15% Finishing (Deburring, Plating, Painting)					4.31		3.20
		COMPONENT COST			33.06		24.54

TABLE 6. ESTIMATED COMPONENT TOOLING COSTS

Part No.	Description	Tool	Est. Cost ($)
166311-117-1	Case	Drawing Die Piercing Die	2,700.00
166311-119-1	Slug	Mold	3,500.00
166311-120-1	Spring Clip	Blanking Die	
166311-120-2	Spring Clip	Forming Die	2,375.00
166311-117-2	Cover	Drawing Die Piercing Die	950.00
		Misc Tooling	1,000.00
Total Estimate Component Tooling Costs			10,525.00

1,000 Qty amortized tooling cost $\frac{10,525}{1,000}$ = 10.52

10,000 Qty amortized tooling cost $\frac{10,525}{10,000}$ = 1.05

TABLE 7. ESTIMATED ASSEMBLY LABOR TIME

OP No.	Description	Quantity	Setup Man-hours	Labor (min.) Unit	Labor (min.) Ext'd
1	Assemble Slugs Into Cube Tool and Jigs: • Holding Fixture (4 position) • Adhesive Dispenser • Slug Spacers (8) • Arbor Press	6	16	1.5	9
2	Inspection	1			2
3	Assemble Orientation Clip and O-Ring to Cover Tools and Jigs: • Crimping Die • Arbor Press	1	8	3	3
4	Inspection	1			3
5	Assemble Tapered Spring to Cover Assembly Tools and Jigs: • Positioning and Crimping Fixture	1	8	3	3
6	Inspection	1			2
7	Assemble Cube Subassembly to Cover Subassembly, Assemble Second Tapered Spring	1	8	3	3
8	Inspection	1			2
9	Assemble Cover and Fill With Oil Tool and Jigs • Arbor Press • Holding Fixture	1	8	5	5
10	Inspection (Final)				5
11	Packing	1	8		5
	SUBTOTAL		54		42
	Contingency 20%		11		8
	TOTAL		65		50

TABLE 8. ESTIMATED ASSEMBLY TOOLING COSTS

Assembly Tooling (Special)

DESCRIPTION	ESTIMATED COST
Cube/Wire Holding Fixture (4 positions)	$2,000
Slug Spacers 8 @ $30.00	$ 240
Crimping Die, Positioning & Crimping Fixture	$1,000
Orientation Jig	$ 250
Assembly Fixture & Volumetric Measure	$ 500
Miscellaneous	$ 500
Subtotal	$4,490

Assembly Tooling (Standard)

DESCRIPTION	ESTIMATED COST
Adhesive Dispenser	$ 600
Arbor Press	$ 250
Miscellaneous	$ 250
Subtotal	$ 1,100

Total Assembly Tooling Costs (Special and Standard) $ 5,590

1,000 Qty. Amortized Tooling Cost $= \frac{5,590}{1,000} =$ $5.59

10,000 Qty. Amortized Tooling Costs $= \frac{5,590}{10,000} =$ $0.56

TABLE 9. ESTIMATED COST SUMMARY, PRODUCTION QUANTITY - 1000

MATERIAL COSTS:

Element	Ref		Unit Cost
Components	Table 5		$33.06
Amortized Component Tooling	Table 6		$10.52
Amortized Assembly Tooling	Table 8		$ 5.59
		Material Cost Subtotal	$49.17

LABOR:

Element	Ref	Man-Hours	Labor Rates	152% O.H.	Unit Cost
Set Up	Table 7	65/1000	$15.00	2.52	$ 2.46
Production	Table 7	0.83	$15.00	2.52	$31.37
		Labor Subtotal			$33.84
		Subtotal			83.00
		30% GA			24.90
		Total Cost			107.90
		10% Profit			10.79
	1,000 Quantity Selling Price				118.69

TABLE 10. ESTIMATED COST SUMMARY, PRODUCTION QUANTITY - 10,000

MATERIAL COSTS:

Element	Ref		Unit Cost
Components	Table 5		$24.54
Amortized Component Tooling	Table 6		$ 1.05
Amortized Assembly Tooling	Table 8		$ 0.56
		Material Cost Subtotal	$26.15

LABOR:

Element	Ref	Man-Hours	Labor Rates	152% O.H.	Unit Cost
Set Up	Table 7	65/1000	$15.00	2.52	$ 0.25
Production	Table 7	0.83	$15.00	2.52	$31.37
		Labor Subtotal			$31.62
		Subtotal			57.77
		30% GA			17.33
		Total cost			75.10
		10% Profit			7.51
	10,000 Quantity Selling Price				82.61

8.0 TRANSPORTATION, INSTALLATION AND IMPACT ANALYSIS

8.1 TRANSPORTATION

Items that are sensitive to shock are inherently difficult to transport without damage. The PAD sensor, by definition, falls into this category. During both the evolutionary and final design activities, the need to develop a device that could be transported with a minimum of problems was recognized and, consequently, was an important factor in the design process.

The interaction that occurs on impact between a mass and an associated restraining member has been the underlying principle that characterizes all of the PAD concepts considered. The possibility of preventing the mass from moving during transit by means of pins, clips, pads, or similar devices is clearly the most effective method of protecting against transit damage. Unfortunately, the spring-oil filter system which is necessary to provide isolation restricts access to the sensing members and, therefore, makes the utilization of these techniques impracticable.

For this reason, part of the testing program was devoted to identifying a packing arrangement that would protect the PAD sensor during transit. It was found that the resilient suspension of the box containing the sensor within a larger container would provide the needed protection to shocks associated with normal transporting methods. A commercial shipping sensor with a trigger value less than the threshold value of the PAD sensor will be installed on the inner box. This sensor will guarantee the integrity of the PAD sensor.

8.2 INSTALLATION

The mounting and overall dimensions of the PAD sensor are shown in Figure 6. The device may be mounted on any flat surface by means of four No. 6 diameter screws. It is insensitive to orientation, but for simplicity of data analysis, it should be mounted with its X, Y, and Z axes coordinated with those of the vehicle to which it is attached.

Extreme caution must be exercised during the installation to ensure that the sensor is not shocked or jarred. It is recommended that a standardized procedure, which minimizes handling of the device, be developed and that installation personnel undergo practical training with dummy sensors to achieve proficiency in the installation technique prior to installing "live" sensors in vehicles.

8.3 IMPACT ANALYSIS

The serial number, location in vehicle, and axis orientation of each PAD sensor should be recorded in the host vehicle's maintenance history documentation at the time of installation. Should the vehicle suffer an impact of 15 g magnitude or higher, it is recommended that this information be verified prior to removal of the PADs to ensure that their indications are interpreted correctly.

The sensing module of the PAD is enclosed in a riveted aluminum housing, as it is intended that impact analysis will be conducted only under laboratory conditions. Therefore, it will be necessary to transport the sensors to the examination site in shockproof packing, similar to that used for shipping the new device, to prevent the possible compromise of data. After carefully opening the case (and verifying that the sensing cube is correctly oriented within), the status of each slug must be estimated (as a percentage deflection) and recorded. Comparison of this information with calibration data originally supplied with the device will provide the approximate magnitude and line of action of the applied impact. The proposed arrangement of the slugs and sensing wires is shown in Figure 41. Each cube face and sensing wire is identified to provide for the orderly recording of slug deflections (FIA 100, F2A 60/40, etc.).

When the axis of impact is coaxial with one of the primary cube axes, the magnitude of the applied shock can be calculated directly from the maximum "g" and percentage deflection values.

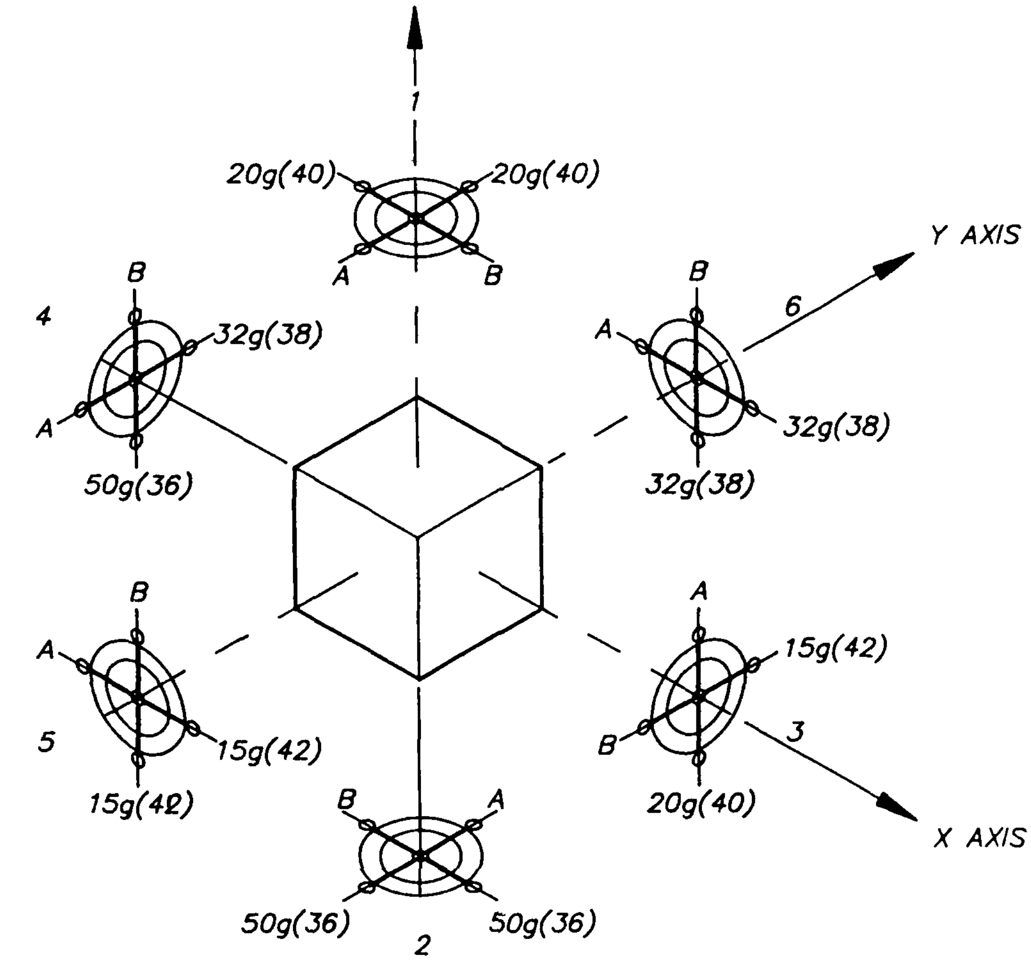
When the axis of impact bisects the primary axes of the cube, the magnitude and direction of the applied shock are recorded as component values. The component vectors can be resolved and the peak g and its line of action deduced by plotting the component values on Figure 42.

8.4 POTENTIAL APPLICATION

The ability of the PAD to capture the magnitude of peak acceleration in the 0-100 Hz frequency range and retain the value for future analysis is applicable to most passenger vehicles (in addition to the Army helicopter fleet). Early in the Phase II program a variety of agencies involved in the transportation industry were contacted and their interest solicited in the PAD concept. These potential customers included:

- Federal Aviation Administration (FAA).
- Helicopter Manufacturers (McDonnell Douglas Helicopter Company, Bell).
- Commercial Airplane Manufacturers (Boeing, Lockheed, Slovak Aviation).
- Automobile Manufacturers (Ford, GM, Chrysler).
- Federal National Highway Traffic Safety Administration.
- Bus Manufacturers (Greyhound--MCI).
- Railroad Transportation (Amtrak, Association of American Railroads).

Varying levels of interest were expressed by all of these potential customers, the general concensus being that further information and test evaluations of the final product would be necessary before specific applications within their sphere of operations could be identified.



Face	Sensing Wires Identity	Sensing Wires Gage	Axis	g Range Min.	g Range Max.	Percent of Deflection	Estimated Impact Force
F1	A	40	Y	20	32		
	B	40	X	20	32		
F2	A	35	Y	50	125		
	B	35	X	50	125		
F3	A	40	Z	20	32		
	B	42	Y	15	25		
F4	A	38	Y	27	70		
	B	35	Z	50	125		
F5	A	42	X	15	25		
	B	42	Z	15	25		
F6	A	38	X	27	70		
	B	38	Z	27	70		

Figure 41. Slug-sensing wire arrangement.

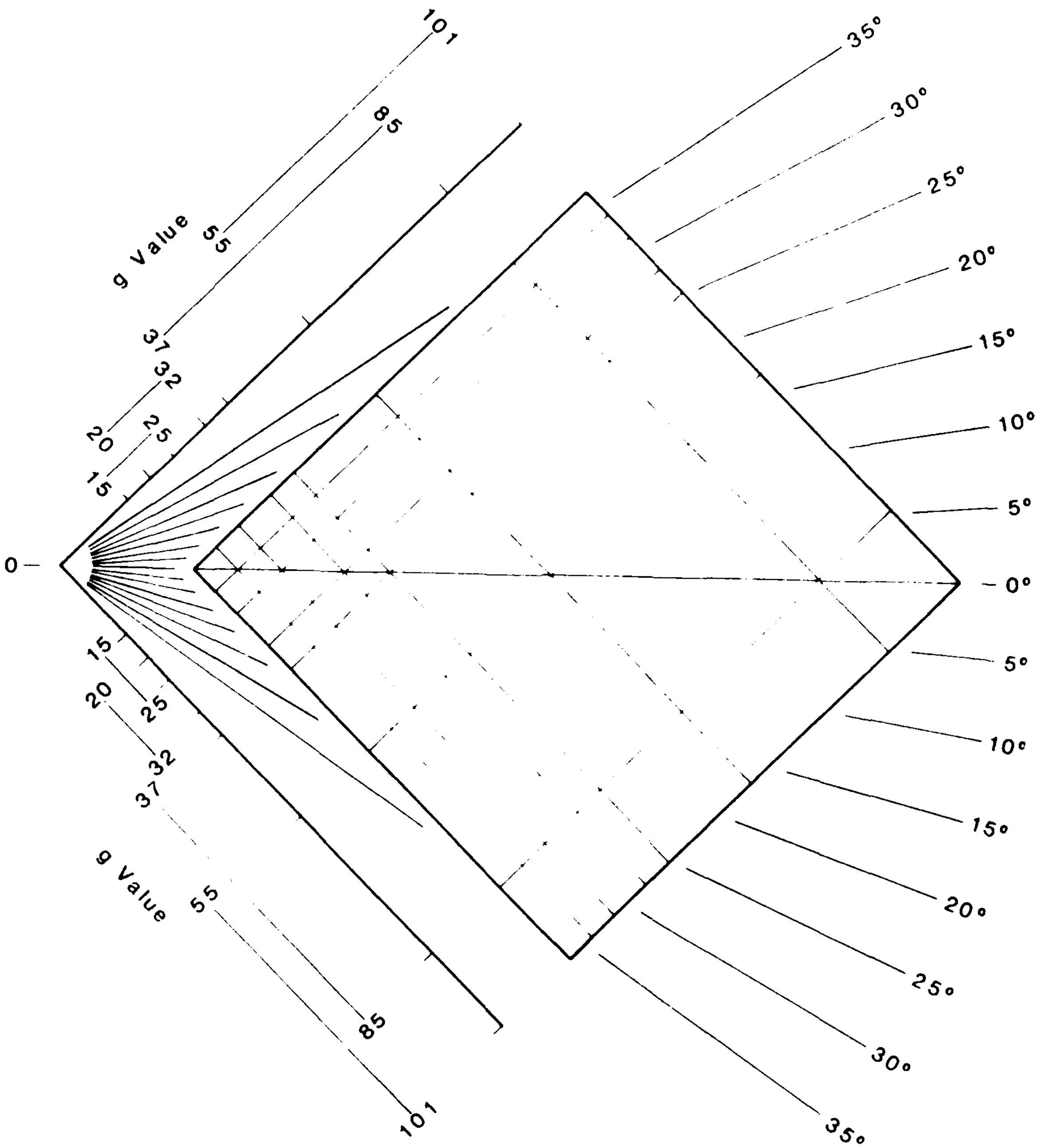


Figure 42. Peak g estimating chart.

APPENDIX A
PROGRESS REPORT NO. 1, DECEMBER 24 1985

Introduction

Work to date has concentrated on completion of the crash test sled and its calibration, design and preliminary evaluation of the isolation system for the cube, and a larger isolation system for the sled tests, design and manufacture of a special multi-test fixture, and preliminary evaluation of three possible "foam" materials. These are described in detail below.

Crash Sled and Its Calibration

The crash sled is complete as shown in the photographs in Figure 1. As previously described, a falling weight pully system is used to accelerate the sled at 3-4 g's over 15' run whereupon its impacts on a series of rubber bumpers and water trough. The initial acceleration (weights), length of run and number of bumpers can be varied to adjust the resulting crash history. Accelerations of up to 200 g's have been achieved with frequency content largely from 20 to 200 Hz. The sled is instrumented to measure terminal velocity and acceleration. Data acquisition is achieved using an IBM PC based ANCO "VIPAC" system (see Figure 2).

The sled has been calibrated so as to allow evaluation of the peak acceleration devices of their full range of operation. Figure 3 presents the achievable peak g's for a variety of weights/bumpers and run lengths. Figure 4 presents a typical time history while Figure 5 presents its Fourier transform. Figure 6 shows the nature of the time history if only signal below 100 Hz is considered.

Sled development and calibration is complete and it is now being used for the other program tasks.

Isolation System

As planned, the actual sensing device must be mounted in a mechanical filter (or isolation system) that makes it sensitive to frequencies below about 100 Hz and relatively insensitive to frequencies above 100 Hz. A method has been devised to instrument a sensing device as shown in Figure 5. Early tests indicated that a layer made of EAR C-3201-25 PSA Foam had the correct stiffness for the sensing device mass (3.5 oz) to achieve this filtering. Tests with impact at low acceleration (tap tests) confirmed this, as shown in Figure 6. However, at higher acceleration ($\sim$ 30 g on crash sled), the foam apparently is highly nonlinear or collapses and isolation is lost as the sensing cube collides with the container walls.

Efforts are now concentrating on finding other elastomers that will not collapse under the higher loads. Static tests are made at full travel to avoid a repeat of use of a highly nonlinear material.

In order to evaluate larger prototype systems (see later sections), a larger isolation system has been built to give a large isolated test platform on the crash sled. This device is shown in Figure 7. Its performance is still being evaluated.

Multi-Test Fixture

In order to evaluate many weight (slug) configurations and materials quickly, a multi-test fixture has been built. This is shown in Figures 7 and 8 and allows up to twenty simultaneous tests.

Foam Materials

Three materials have been obtained with potentially useful properties. These include two foams and the potential for use of a thin aluminum sheet instead of a foam. In this latter concept, the slug would penetrate through the aluminum sheet to indicate an acceleration level rather than imbed itself in the foam. All three materials are being tested. The foams are Union Carbide FPB-1, Carbon Foam, and Smithers BioMedical Systems BIOFOAM.

The aluminum sheets are being varied from .001" to .003" of 6061-T6 alloy. The benefit in an aluminum foil over a foam system is that of no concern for the environmental aging of the foam. A typical result with the BIOFOAM is summarized in Figure 9.

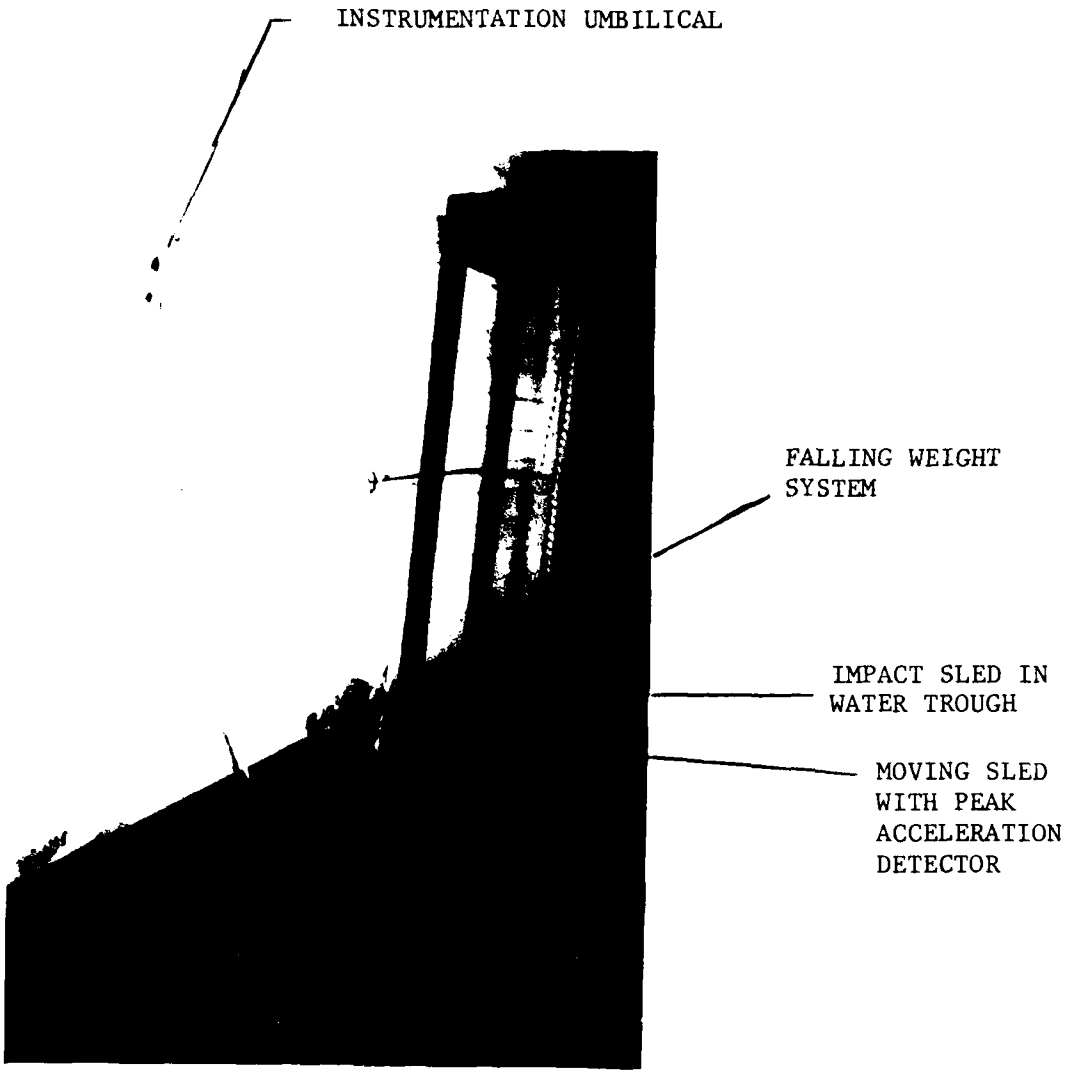


Figure 1. Overall view of crash sled system.

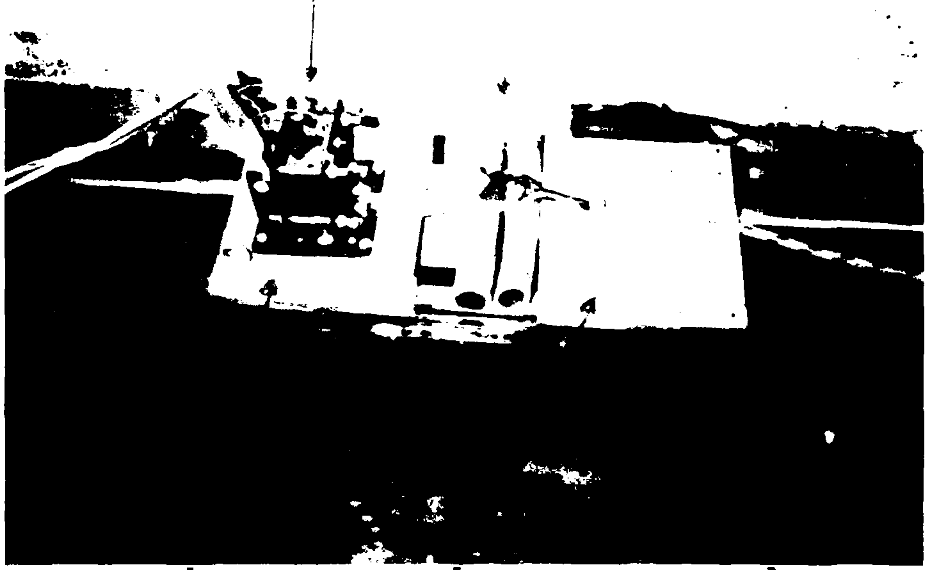


Figure 1. (Continued)

FALLING WEIGHTS AND PULLEYS

Figure 1. (Continued)

-5-

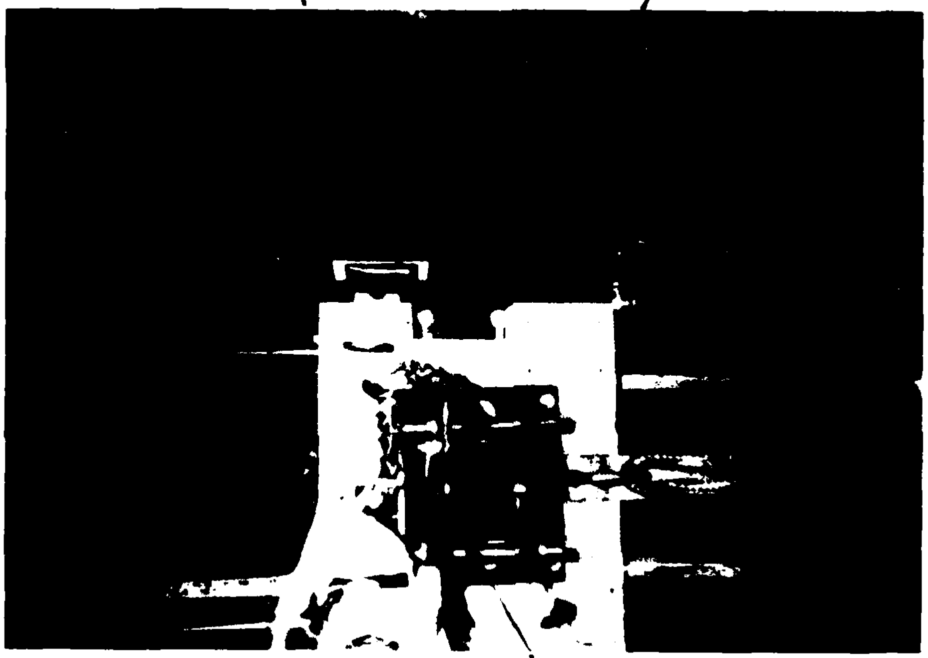


Figure 1. (Concluded)

VIPAC VIBRATION TESTING WORK STATION

CONTROL / DATA ACQUISITION / PROCESSING

VIPAC - A Uniquely Specialized Work Station Designed for the IBM-PC* and Compatibles

KEY FEATURES

HARDWARE SUPPLIED

- BNC terminated A/D, D/A with external trigger

SOFTWARE SUPPLIED

- FORTRAN compiler
- Graphics system
- VIPAC software:

TIME DOMAIN DATA ACQUISITION AND ANALYSIS

- 16-channel, A/D, 12-bit resolution, 30,000 samples/second (option to 80,000)
- 2-channel D/A, 12-bit resolution, 30,000 samples/second
- Calibration, baseline correction
- Integration
- Screen and hardcopy plots

FREQUENCY DOMAIN PROCESSING

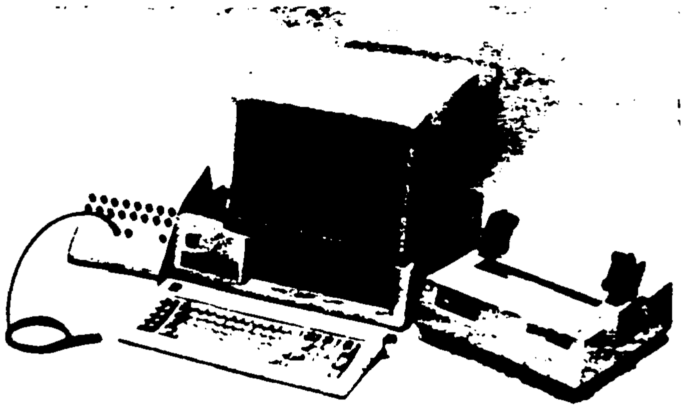
- Fourier analysis up to 4,096 points (direct and inverse)
- Digital filtering (high, low, bandpass, and band-reject)
- Screen and hardcopy plots

RESPONSE SPECTRA ANALYSIS

- Calculation and comparison
- Spectrum-compatible time histories
- Screen and hardcopy plots

MODAL MODEL DEFINITION

- Prediction of response to time histories
- Prediction of effects of structural modifications
- Calculation of participation factors from experimental data



VIPAC, an inexpensive vibration testing software and hardware system, was developed by ANCO Engineers. ANCO is a leader in laboratory and field testing of structures and equipment and in structural dynamic analysis. The system evolved from ANCO's perception of the need for an IBM-PC work station for vibration testing that would combine control with data acquisition and processing capabilities.

VIPAC is an ideal work station for IBM-PC (and compatibles) users. It drives external test equipment, such as a shake table, via a 2-channel digital-to-analog (D/A) converter. It enables the IBM-PC to acquire and process up to 16 channels of analog signals and to perform a variety of time and frequency domain processing. In addition to calculating the response of any modal model to time history excitation, the system predicts the effect of structural modifications and calculates participation factors from experimental data; and it provides full screen and hardcopy graphics.

* IBM-PC is a registered trademark of IBM Corporation

Figure 2

CONFIGURATION (100% LENGTH RUN, 4 BUMPERS)	VELOCITY ACHIEVED (FT/SEC)	PEAK ACCELERATION (G'S)	
		UNFILTERED	FILTERED*
0 Wts	28	32	19
4 Wts	36	45	28
8 Wts	44	58	36
12 Wts	45	85	49
16 Wts	52	128	60

*Filtered to remove energy above 100 Hz

Figure 3. Typical sled performance characteristics.

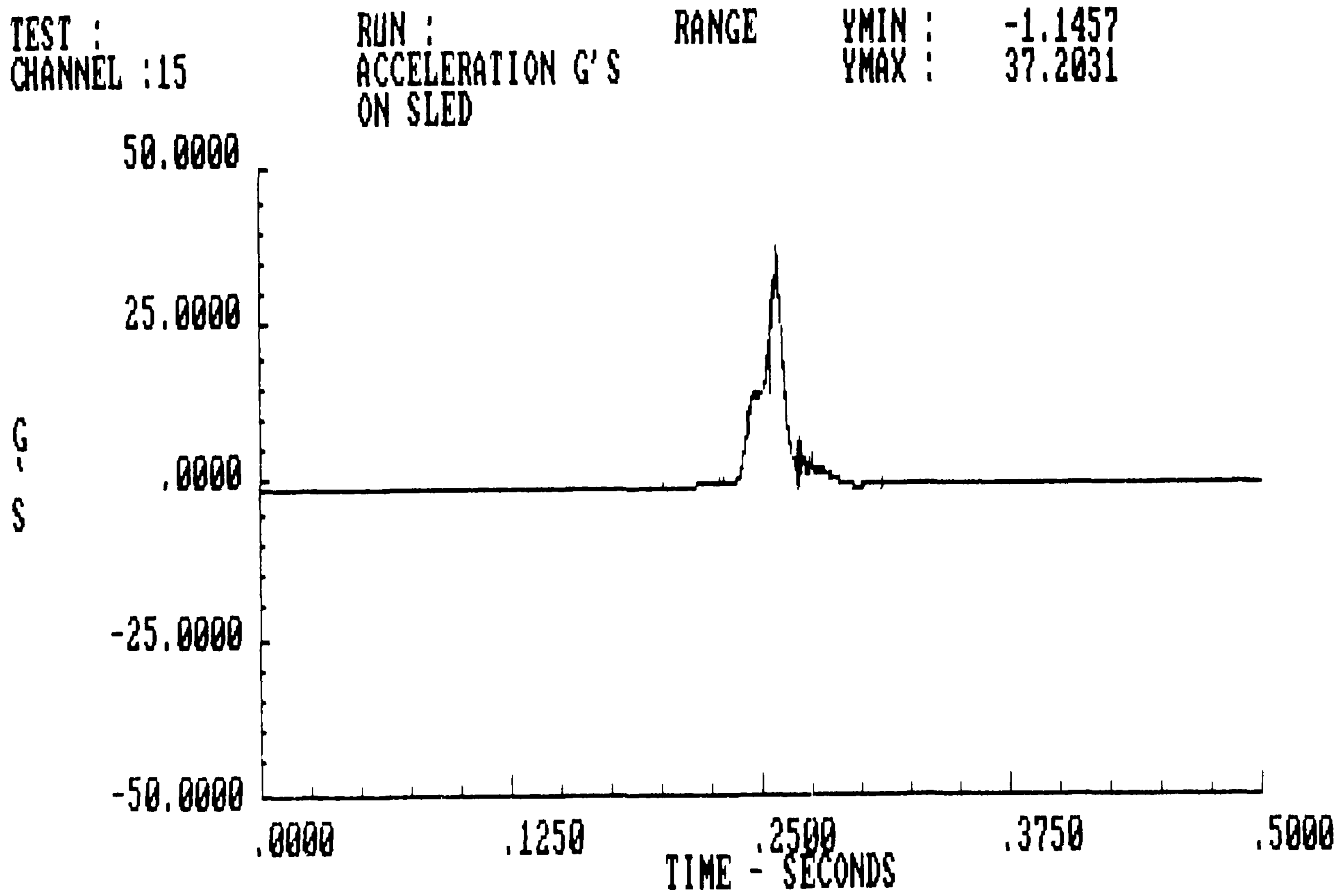

TEST :
CHANNEL :15
RUN :
ACCELERATION G'S
ON SLED
RANGE
YMIN : -1.1457
YMAX : 37.2031
50.0000
25.0000
.0000
-25.0000
-50.0000
G-S
.0000
.1250
.2500
.3750
.5000
TIME - SECONDS

Figure 4

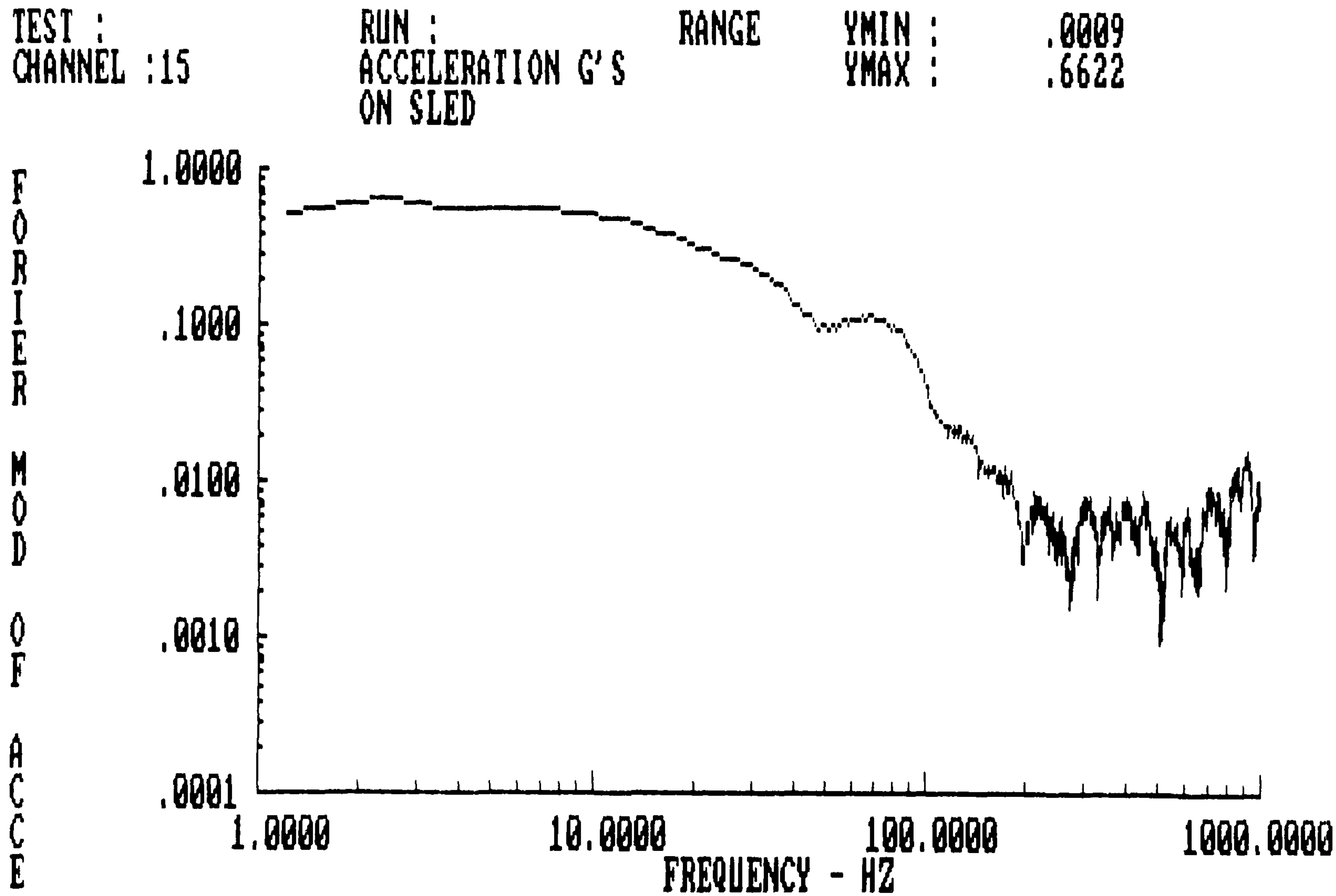

TEST :
CHANNEL :15
RUN :
ACCELERATION G'S
ON SLED
RANGE
YMIN : .0009
YMAX : .6622
FORIER MOD OF ACCE
1.0000
.1000
.0100
.0010
.0001
1.0000
10.0000
100.0000
1000.0000
FREQUENCY - HZ

Figure 5

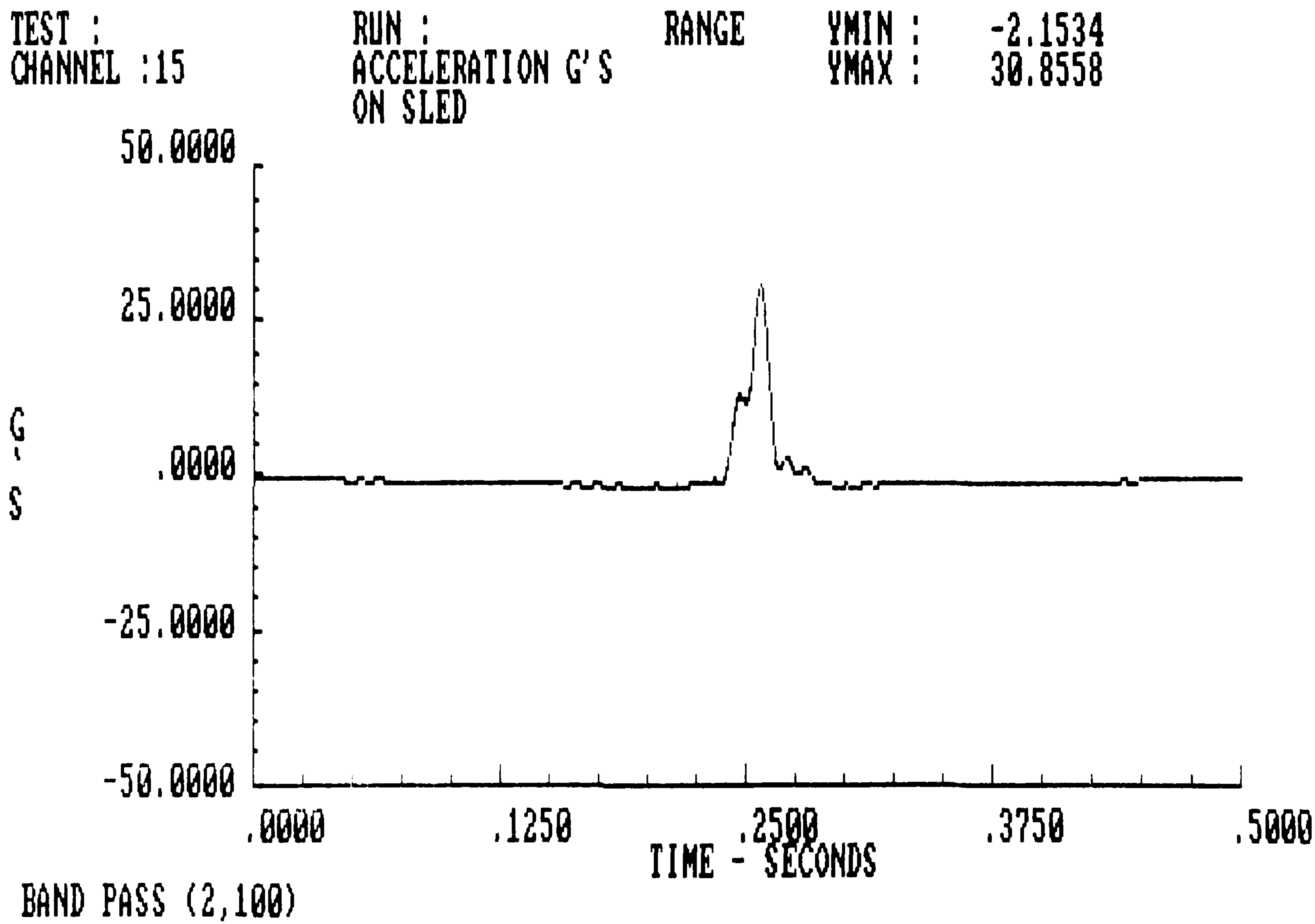

TEST :
CHANNEL :15
RUN :
ACCELERATION G'S
ON SLED
RANGE
YMIN : -2.1534
YMAX : 30.8558
50.0000
25.0000
.0000
-25.0000
-50.0000
G-S
.0000
.1250
.2500
.3750
.5000
TIME - SECONDS
BAND PASS (2,100)

Figure 6

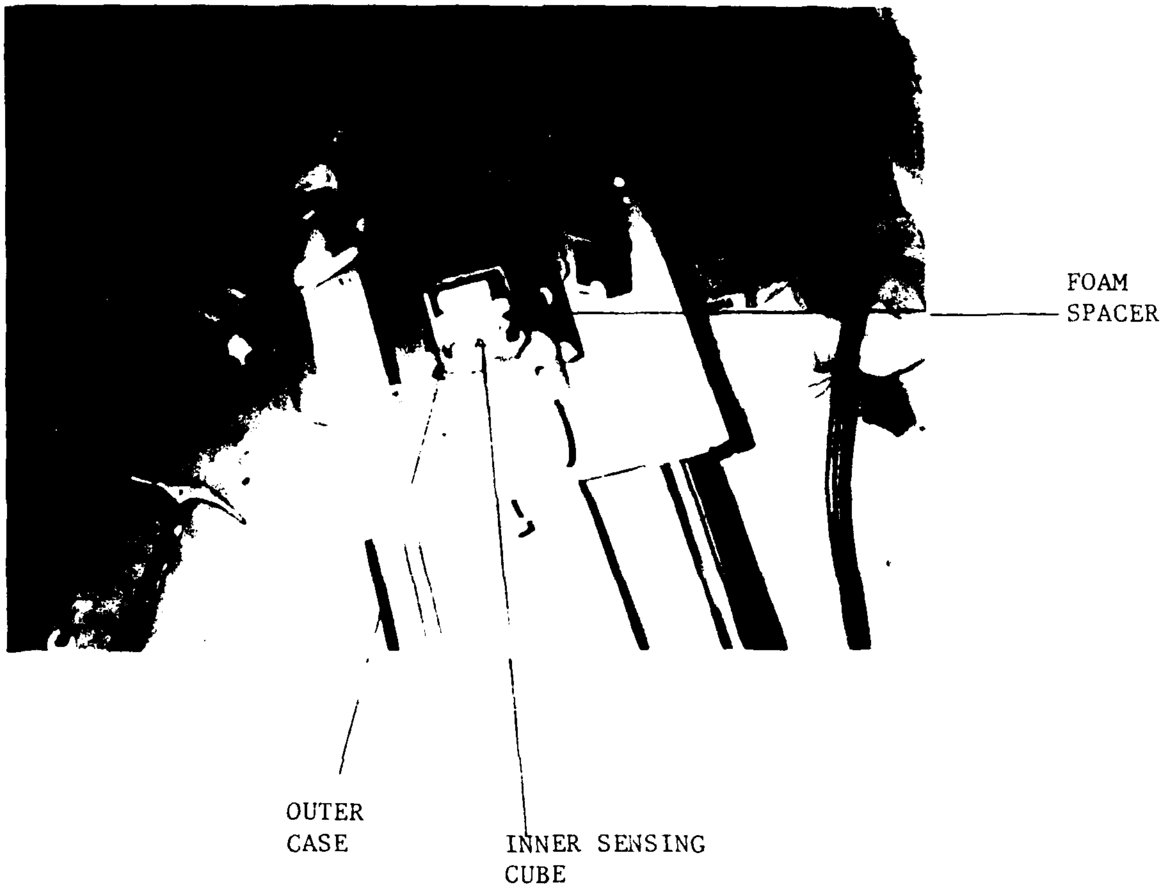


Figure 7. Peak acceleration device internals.

Low level impact
isolation results

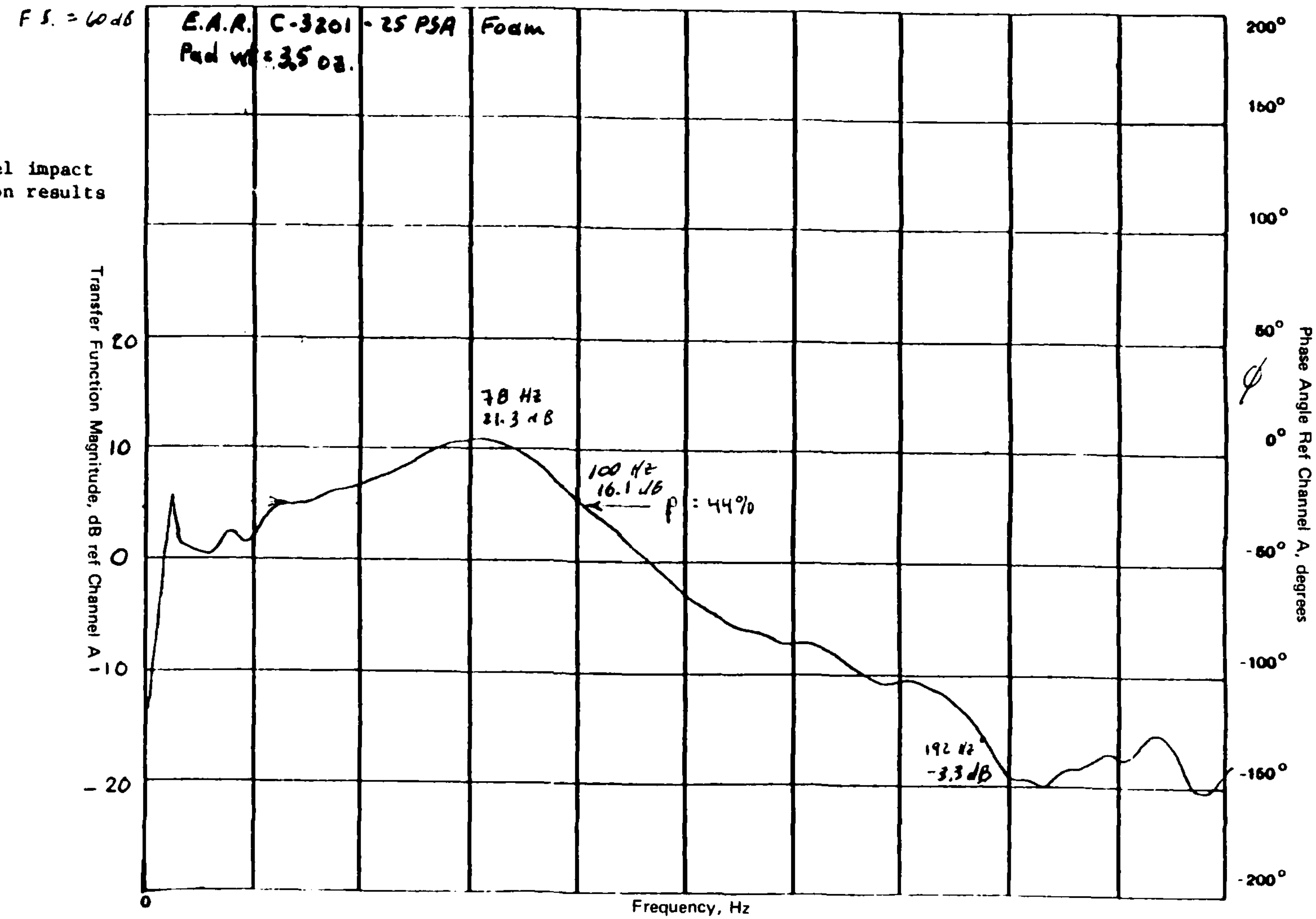


Figure 8.

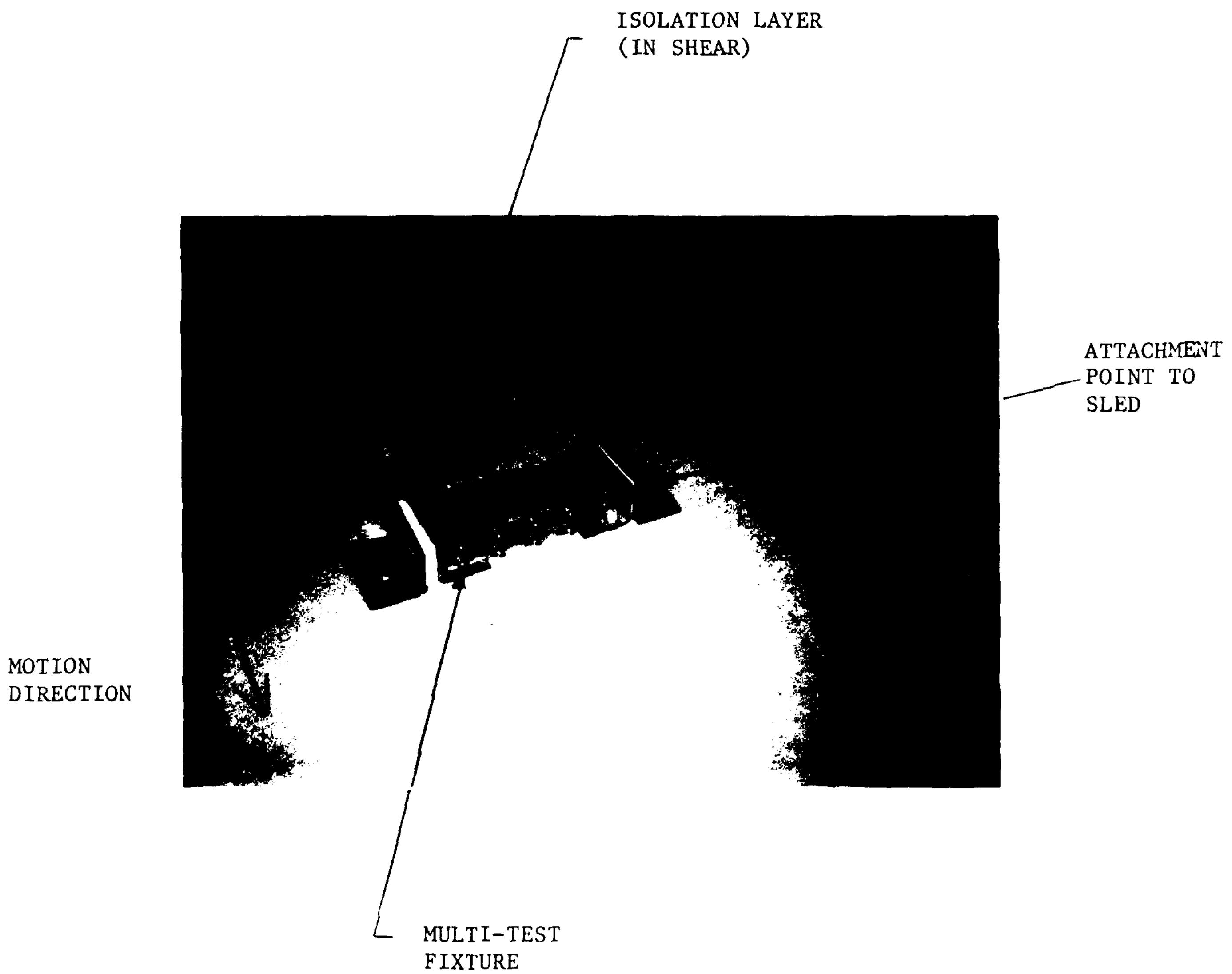


Figure 9. Large isolation platform and multi-test fixture.

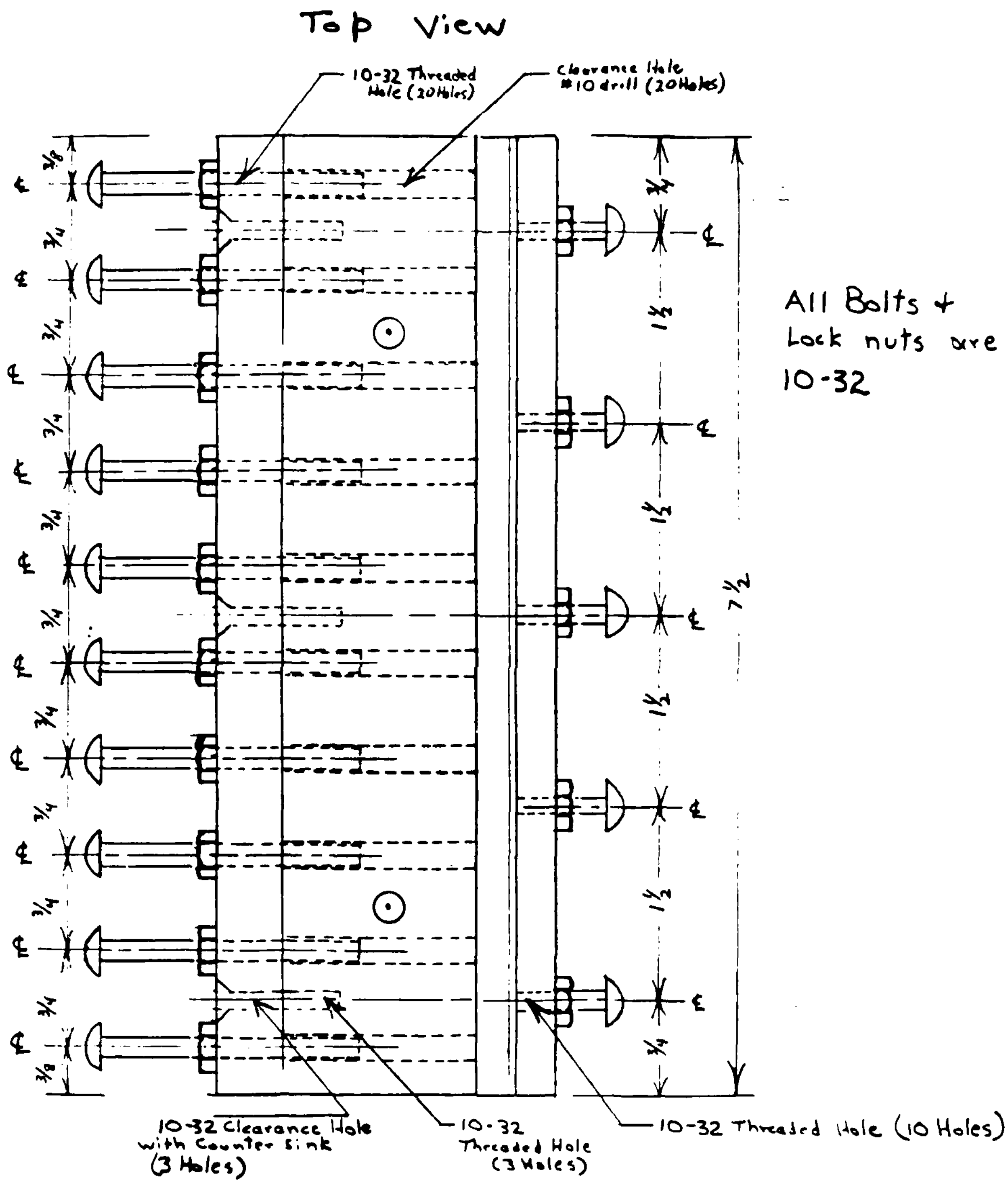


Figure 10. Drawing of multi test fixture.

-15-

END VIEW

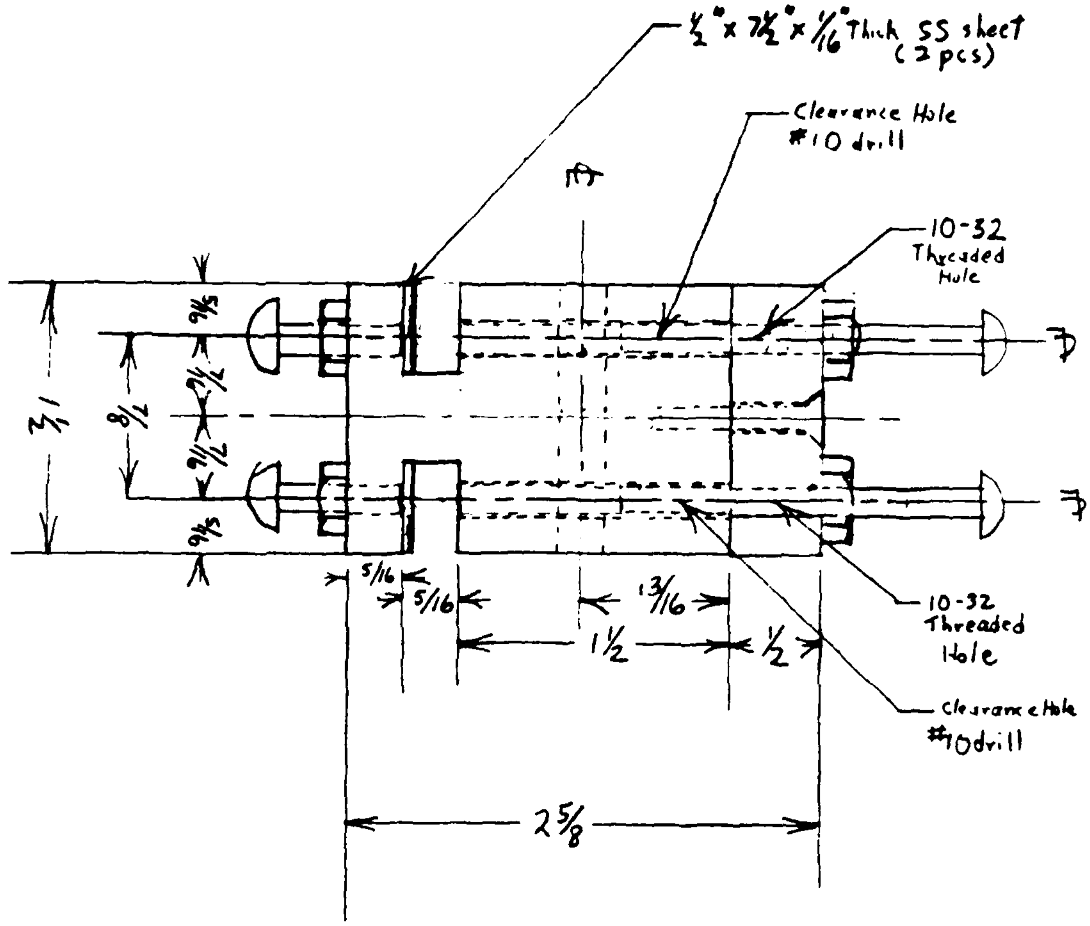


Figure 10. Continued.

-16-

The test fixture was affixed to the sled with high frequency shock absorbers in place. The sled was accelerated with the single weight with no additional lead weights added.

The weights above #14 were clearly displaced while all the weights up through #13 were not displaced (refer to table on next page). The acceleration data which was correlated with weight cross sectional area divided by its respective weight was taken from the Phase I final report. The resulting acceleration ranges for penetration of each weight in the test fixture are shown in the fourth column of the table. The predicted acceleration based on this data is 24 ± 4 g.

The actual acceleration of the sled during this test was measured with an on-board accelerometer which measured 37 g's (Figure 4). When filtered above 100 Hz, the acceleration is 31 g's (Figure 6). Thus the peak acceleration device is underpredicting the acceleration by about 15%. Further work will be used to improve the calibration of this device and reduce this error.

Figure 11. Peak G prototype test fixture test results.

ANCO ENGINEERS, INC
9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY Bruce Taylor DATE 1/3/86
CHECKED BY [illegible] DATE [illegible]

JOB NUMBER ______ PAGE ______ OF ______
DESCRIPTION Peak g [illegible] test fixture. Test Results

weight number	measured weight (gm)	Area/weight cm²/g ×100	Penetration Threshold[1] (g)
1	.155	115	140-150
2	.170	105	130-138
3	.175	102	125-134
4	.240	74.2	85-98
5	.280	63.6	70-84
6	.340	52.4	50-69
7	.390	45.7	40-60
8	.430	41.4	37-54
9	.470	37.9	35-50
10	.550	32.4	30-43
11	.660	27.4	25-36
12	.722	24.7	24-32
13	.850	21.0	22-27
14	.955	18.7	21-25
15	1.090	16.3	19-22
16	1.260	14.1	18-19
17	1.440	12.4	16-16.5
18	1.620	11.0	15±.5
19	1.820	9.79	13.5±.5
20	2.120	8.40	11.7±.5

– no failure
– failure

Predicted G Level: 24±.49

Area of pins = 0.178 cm²

1) ANCO Final Report 1663[3]
"An Inexpensive Peak Acceleration Indicator for Air Crash Monitoring[1]",
Aug, 1984, Page 5-14.

Figure 11. Continued.

-18-

APPENDIX B

PROGRESS REPORT NO. 2 - APRIL 7, 1986

Progress to date has been in three areas:

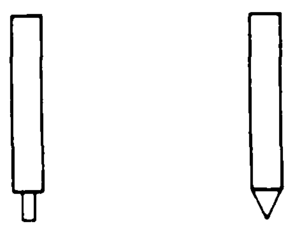
- o selection and testing of indicating media and masses
- o design and testing of mechanical filter
- o prototype design and costing of production unit

Indicating Media and Masses

Investigation of the properties of low strength foams have shown difficulties with the use of such materials. The low strength is difficult to achieve and control. Further, the environmental stability (time, temperature) is difficult to assure. While tests on the crash sled indicate such materials are basically suitable these consideration have led us to emphasize a slightly different approach. This concept is to use a thin metallic film instead of a foam media. Thus penetration (or non-penetration) thru the film is substituted for penetration (or not) into the foam media. The metallic film has reproducible properties and excellent environmental stability.

To date aluminum, brass, and stainless steel films varying in thickness between .0002 in. and .0030 in. have been investigated. The preferred film appears to be cold rolled stainless steel (T302) in the .0002 to .001 inch range owing to its availability in small sizes, and relatively low ductility.

To date, two types of mass penetrators have been investigated as shown below:



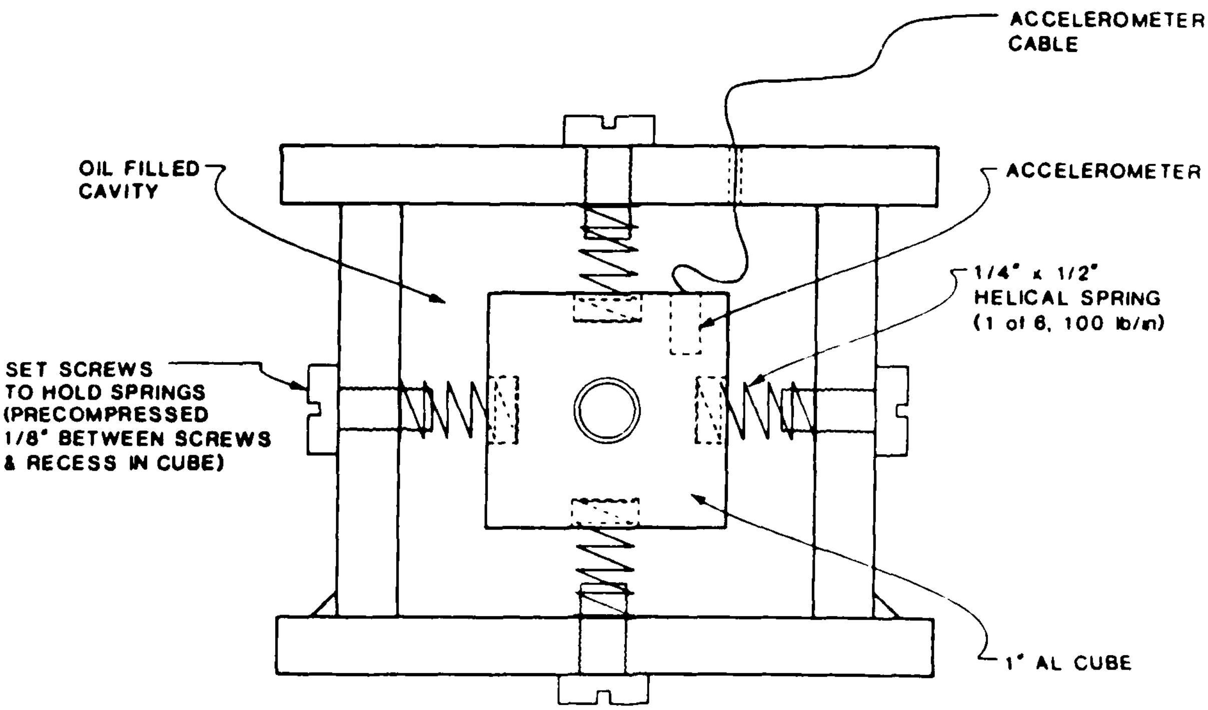
A B

The first (A) involves a blunt nose reduced diameter penetrator in which the reduced diameter is varied to adjust penetration sensitivity. In the second (B) a 90° or 120° point is used and the mass of the penetrator adjusted to adjust sensitivity. Using a 3/16 inch diameter, one inch long A-type with .018 inch reduced diameter, penetration on a .0002 inch foil occurs at about 50 g's.

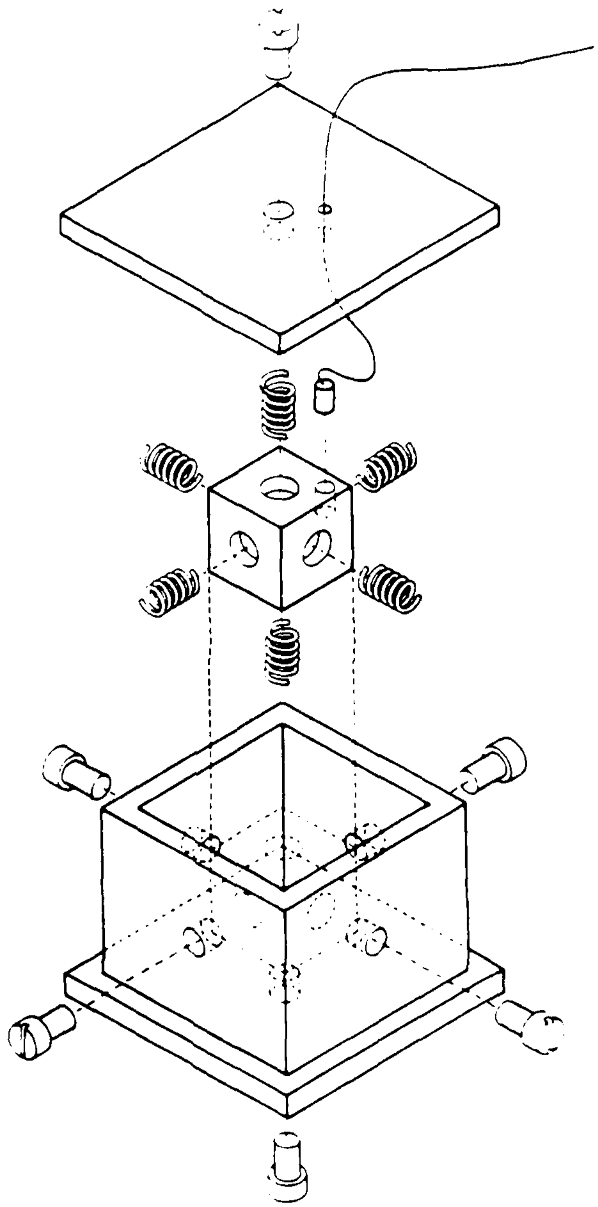
A similar sized B type penetrates at about 30 g's. The A type appears to have a great sensitivity to reduced diameter that may make its use prone to error. Static and dynamic tests are currently being performed to study sensitivity and reproducibility and relative merits of type A and B.

Mechanical Filter

For reasons, similar to those that have convinced us to use metallic films rather than foam media for indicating, we have decided to use a helical spring system for the mechanical filter. This eliminates the nonlinearities found with foams and the concern over their environmental properties and aging stability. The current test prototype is illustrated below. It has an unclamped resonance of 97 Hz. The response measured in the crash sled is shown in Figures 1 and 3 and clearly indicate the strong attenuation of response above 100 Hz, as desired. The damping is provided by filling the cavity around the cube with oil. In our current experiment 80 weight petroleum based oil is used. In the final design a silicone oil will be used with temperature insensitivity and documented aging stability. (Tentatively General Electric SF96 appears adequate.)



Cross Sectional View of Mechanical Filter Test Prototype



Exploded View of Mechanical Filter
Test Prototype
(Illustrating Triaxial Configuration)

Production Unit

A tentative production design has been made in order to focus on design options and prepare preliminary cost estimates. The design includes the use of 12 rather than 6 springs to provide more rotational constraint but is otherwise quite similar to the unit described in the previous section. It allows for eight levels of indication in each of three axis. Tentatively, the indication points would be at 10,14,20,28,40,56,80, and 112 g's. After a crash the investigator would retrieve the device, open the cover (held by 4 screws) drain the oil and remove the cube. The penetration (or non-penetration) of the masses can then be observed at the sides of the cube. The design is about 2 1/2 inches square and weights about 5 oz. Estimates from manufacturers estimate that in large quantities (>1000) per unit costs will be $ 40.00 to $ 80.00.

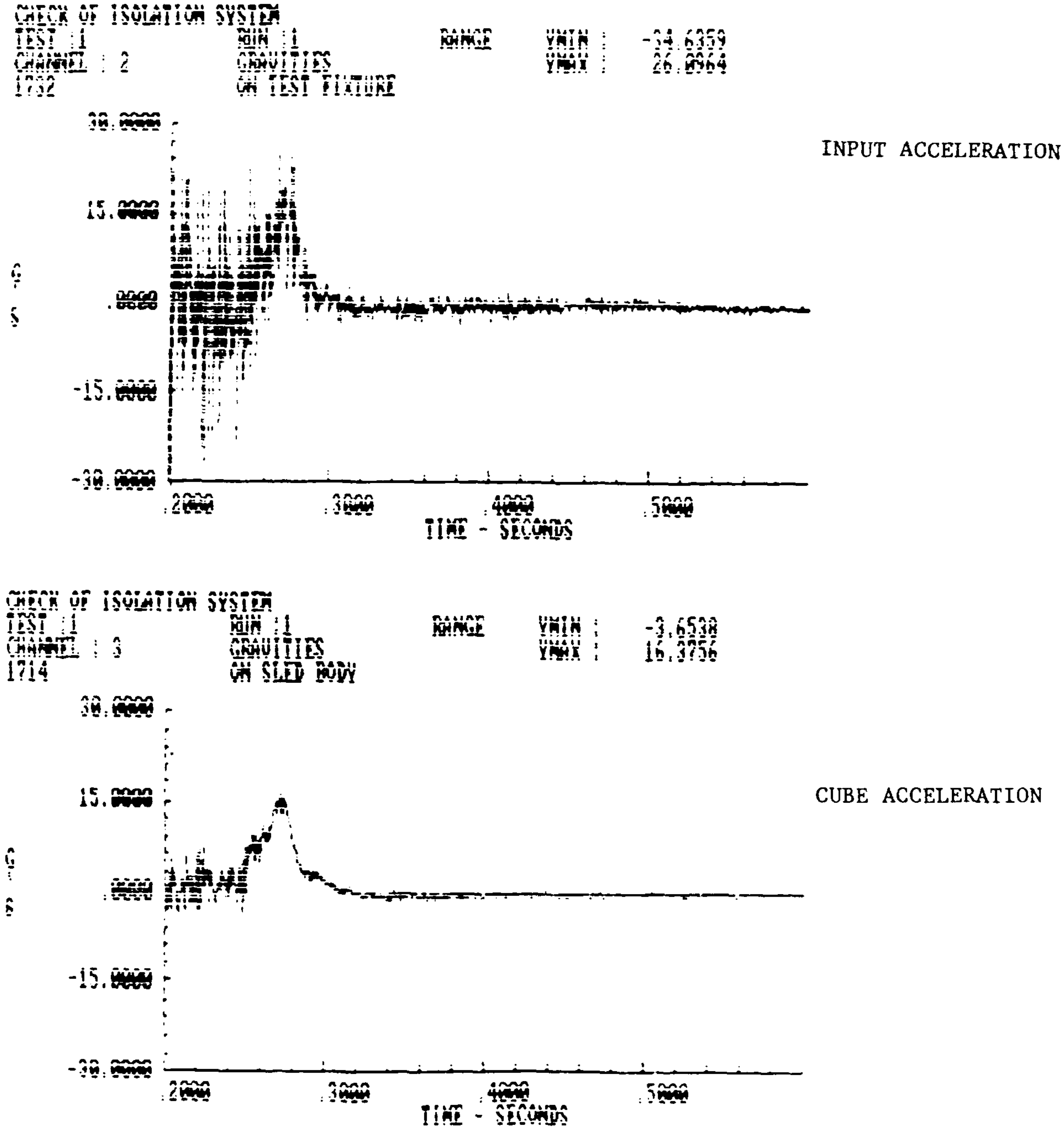
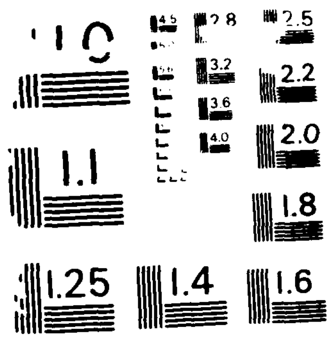


Figure 1.
Time Histories Showing
Reduction of High Frequencies

AD-A191 639 PEAK ACCELERATION DEVICE (PAD)(U) ANCO ENGINEERS INC 2/2
CULVER CITY CA P IBANEZ ET AL. OCT 87 ANCO-1663.11
USAAVSCOM-TM-87-D-3 DAAK51-85-C-0009

UNCLASSIFIED F/G 1/4 NL



TEST CHART
NATIONAL BUREAU OF STANDARDS

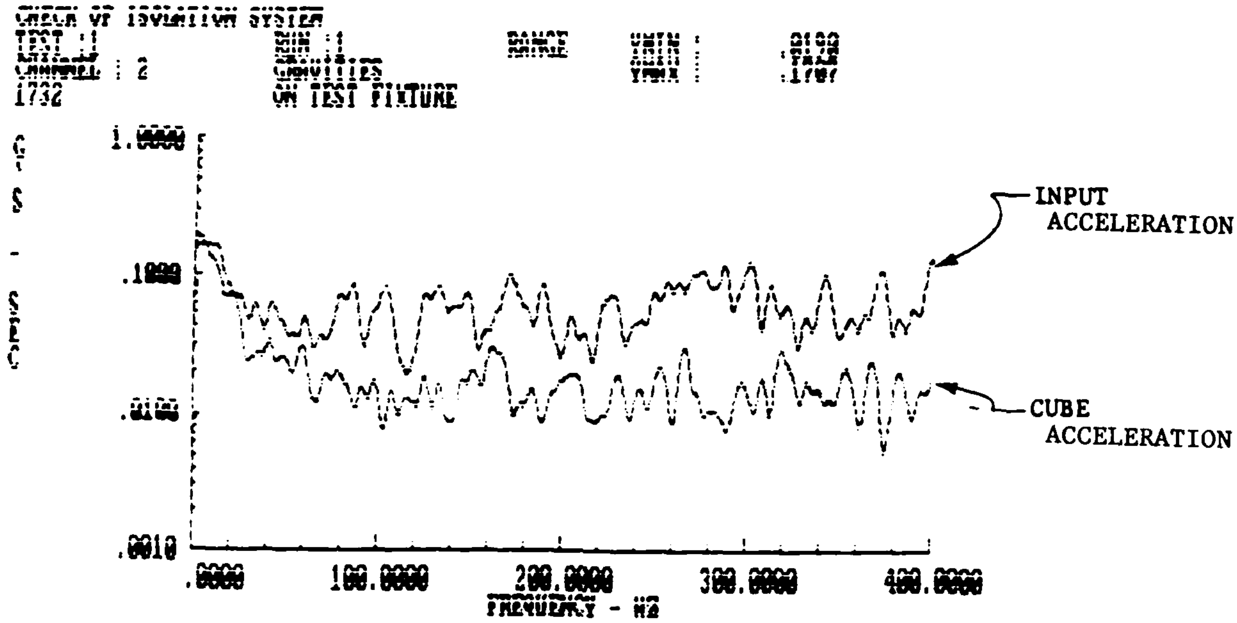
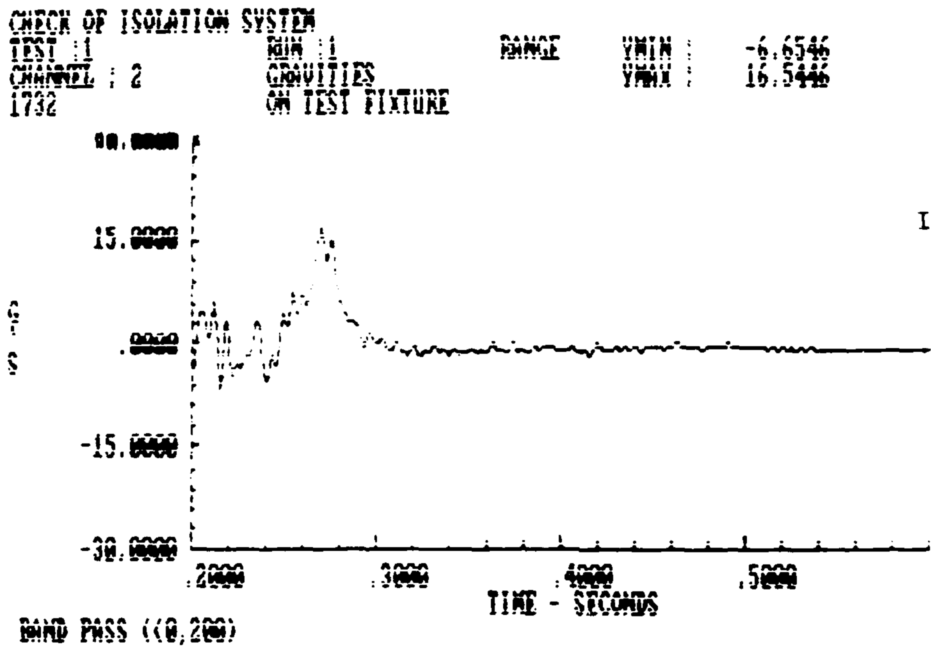
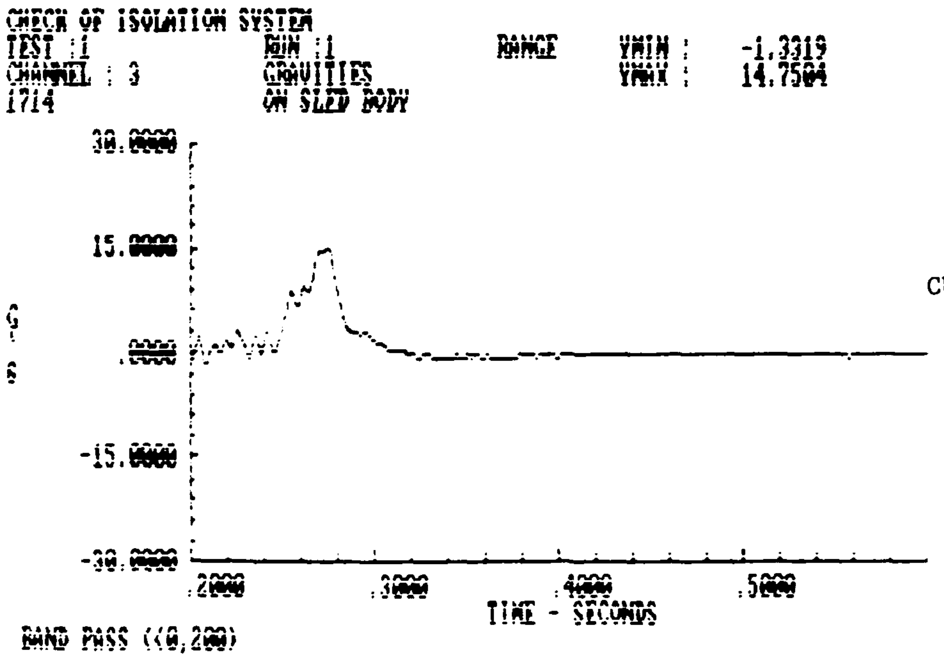


Figure 2.
Fourier Transforms Showing
Reduction of High Frequencies



INPUT ACCELERATION



CUBE ACCELERATION

Figure 3.
Time Histories Filtered at 200 Hz Showing
Similar Effect to Mechanical Filter

APPENDIX C

PROGRESS REPORT NO. 3 - June 1986

1.0 Progress to date has been in two areas:

- o final design and selection of indicating media and masses
- o preliminary design of production unit

2.0 Indicating Media and Masses

From project initiation the key factor in PAD design has been the choice of indicating media and mass. The initial concept was that of metal spheres of various diameters in a weak matrix. The weakest material identified (a phenolic foam) was still too strong to produce a PAD size that was acceptable (goal - 2 inch cube). The concept was then developed to use rods (slugs) instead of spheres, as their length could be increased and diameter decrease to achieve a more penetrating mass configuration while maintaining the same total weight of material. While this improved the situation to a point where an acceptable design was possible, the variability of the foam material and its questionable aging and environmental properties led us to substitute thin metallic foil as a measuring media. As discussed in our previous progress report (Appendix A) the key issues with this concept are the alloy, thickness, geometry and clamping of the foil and the size and point geometry of the slug.

To evaluate various design parameters a number of sled tests were performed (Experiment #1 in Appendix B). These tests indicated that the conical shape point and the blunt nose point (type A and B of the previous progress report) still required greater forces, even with the thinnest available foil (.0002 stainless steel), than are available within a design based on a 2 inch cube. More importantly, we found extreme sensitivity to point profile and also sensitivity to impact duration and foil clamping arrangement. To clarify these problems we conducted a test series (Experiment #3 in Appendix B) to investigate alternate point profiles and metal clamping techniques. These tests were conducted statically in order to measure penetration force independent of rate of loading. From these tests we concluded that minor variations in point geometry could cause significant variation in penetrating force. For example, a single light pass of a point over fine emery cloth could double the required penetrating force. As such variations in point geometry were were felt to be inevitable in any reasonable manufacturing process we concluded that slug penetration of foils was unsuitable as the basis of the PAD design.

Analysis of the results obtained during the foil tests suggests that the variability of the foil concept probably arises from complex stress concentrations at the point -foil contact. We concluded that a design based on a mechanism which relied on the primary stresses of a well defined member could yield the results desired. This member, of course, would have to have a strength appropriate to masses of the 3-12 gram range. This led us to the concept of a mass strung in a fine wire (see Figure 1.). Initial static tests showed that masses of an acceptable size would fail such wires if they were made of about .002 inch diameter copper wire. Dynamic tests on the sled (Experiment #4 in Appendix B) indicated that breaking or noticeable stretching of the wire was a reliable and reproducible indicator of acceleration level. It is apparent that the elastic limit force is somewhat greater dynamically than statically. It is also clear that the strain to failure is greater dynamically, that statically.

In order to investigate the influence of fatigue under normal operating conditions a series of tests (Experiment #5 in Appendix B) were performed. In this testing, a multi mass/wire fixture was attached to a programmable actuator and excited with random noise of 3 to 100 hz frequency with a broad peak at about 50 hz. These tests were run at 3-10 g levels to approximate worst case operating conditions. It was found that the more sensitive masses (i.e., those designed to indicate peak accelerations in the 10-30 g range) would fail at these lower accelerations. It was thus concluded that the design required a threshold device to prevent fatiguing the wire under operating conditions. A spring clip was incorporated in the prototype design (see drawing 166311-116). It will be evaluated during the prototype tests.

Once the wire/mass system was shown to be feasible we had to consider the packaging on the cube. In order to reduce size we were led to make dual use of each mass via a dual wire system (Figure 2). By attaching two perpendicular wires to

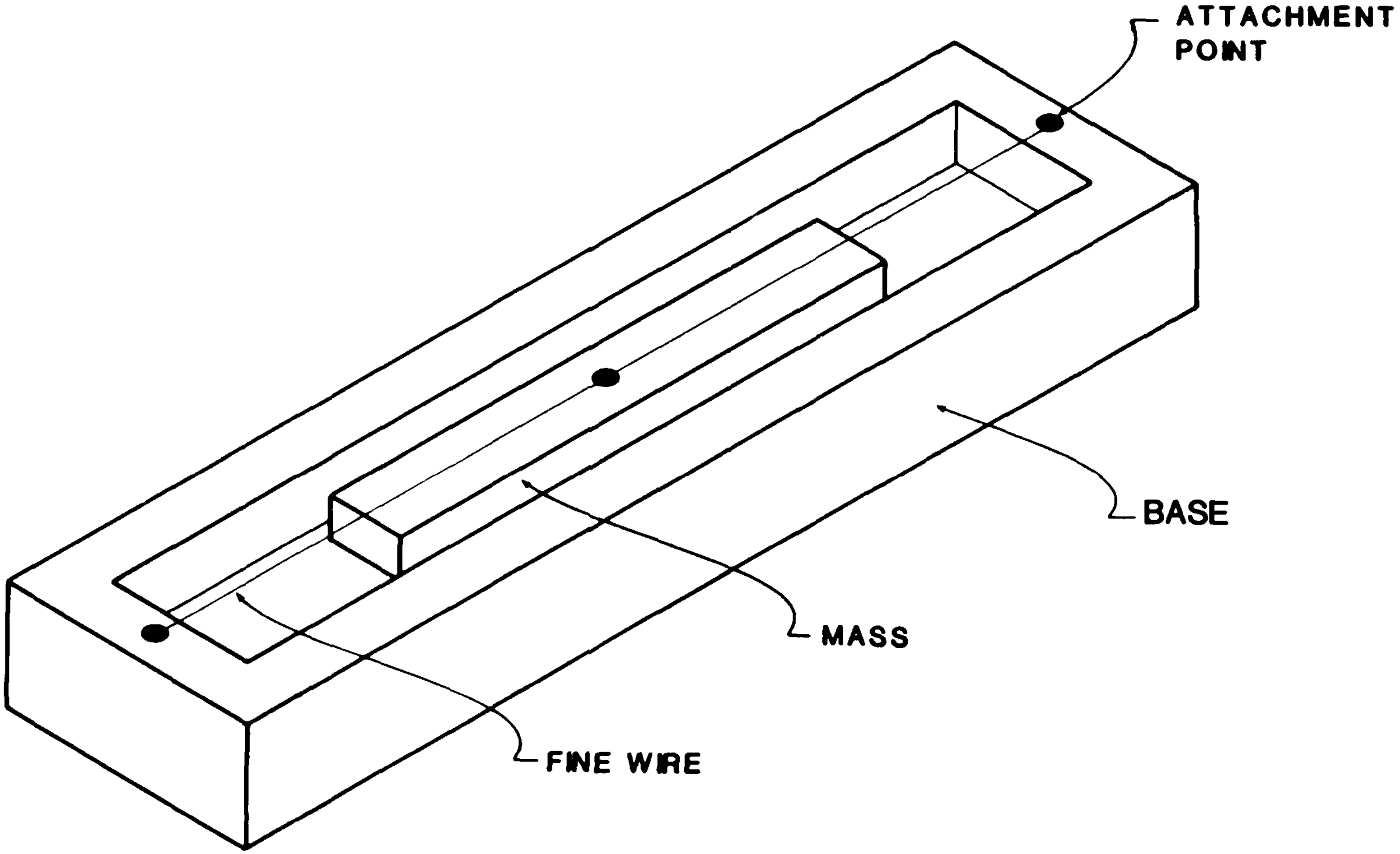


Figure 1. Mass - wire concept.

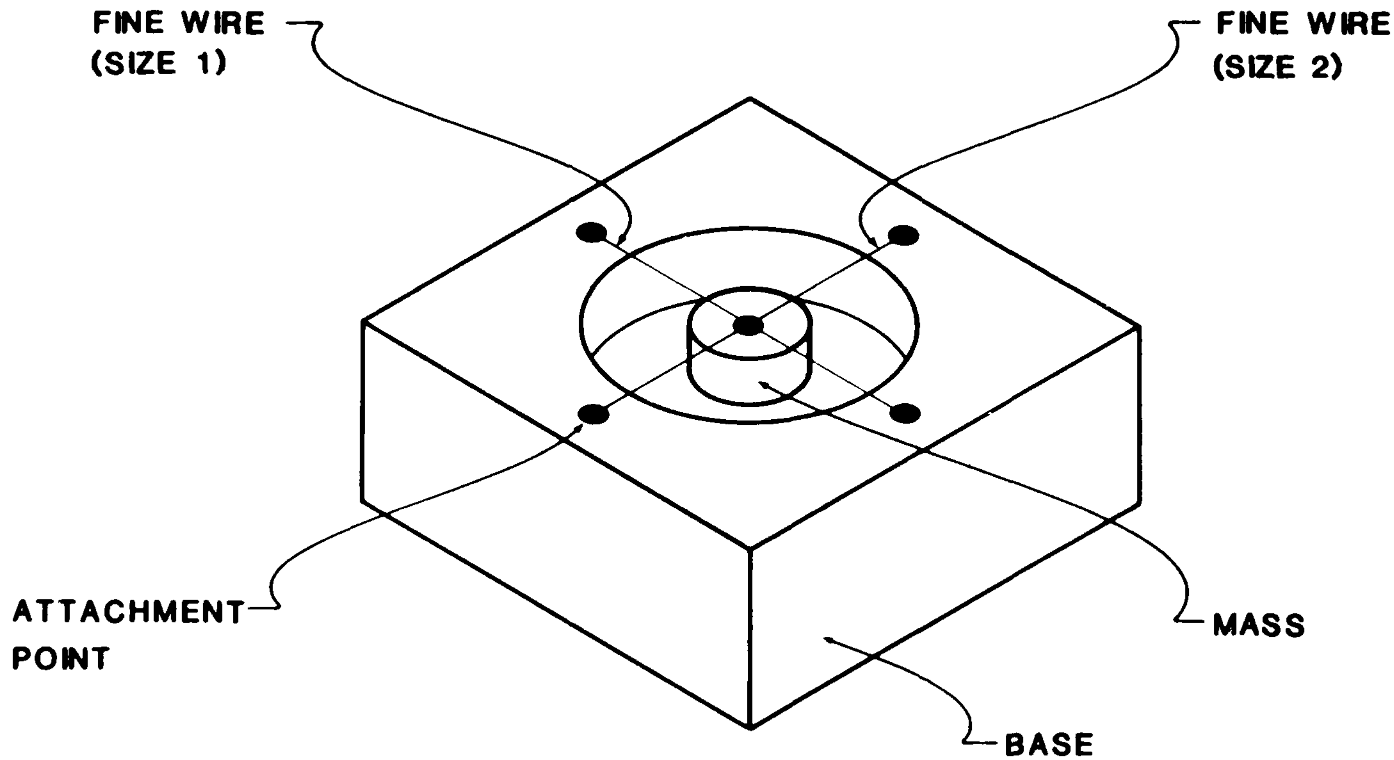


Figure 2. Dual mass wire configuration.

the same mass, a dual indication of acceleration was possible (of course in perpendicular directions). Our calculations indicated that the cross axis accelerations would not significantly interact. A series of dynamic sled tests (Experiment #6 in Appendix B) indicated that this was true and that suitable and reproducible results could be obtained from the dual wire design.

One remaining key questions is the attachment of the copper wire to the base. Solder or welding has been initially rejected due to the fineness of the wire and concern over the effect of the heat on wire properties. Results with epoxy glue has been promising and compatibility tests with the oil damping medium are now being conducted. (Experiment #7 in Appendix B).

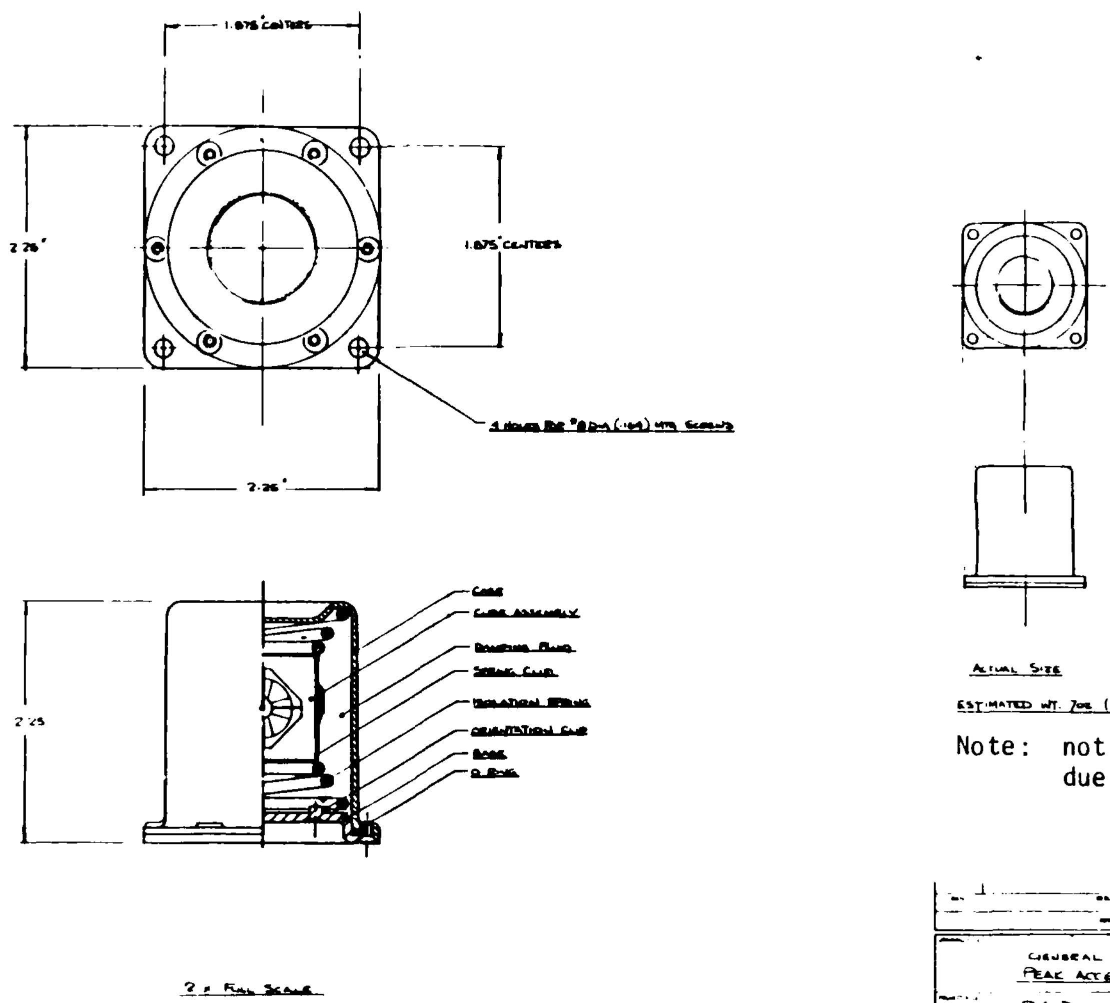
3.0 Production Unit Design

The various considerations discussed in section 2 have led to the design shown in the accompanying drawing #166311-115, General Arrangement of Peak Acceleration Device and #166311-116, General Arrangement of Cube Assembly. The mass consists of a conical centered tungsten slug placed in a larger conical hole in the cube face. The conical design allows the mass to be larger than a cylindrical design without increasing cube size. Two masses are placed on 3 of the cube faces and one mass placed on the remaining 3. This yields a total of nine masses each indicating two acceleration levels and hence provides 18 indication levels (six in each axis direction - for example 14, 21, 32, 47, 71, and 106 g's).

The masses are held in place by spring clips that provides both the spring tension used to threshold the mass (to obviate fatigue failure) and cube/case orientation. The spring clip will be mechanically attached to the cube and will facilitate the bonding of the copper wires to the cube.

The cube is held within the outer case by springs. Our earlier design which involved 6-12 helial springs has been refined to use two conical helical springs. This concept has been tested (Experiment #2 Appendix B) to establish that it offers significant attenuation in three axis at frequencies above about 100 hz. Silicone oil continues to be used to provide damping. As Shown in drawings #166311-115 the PAD envelope is 2 1/4 inches x 2 1/4 inches x 2 1/4 inches and is estimated to weigh about 7 ounces. Detailed cost estimates from manufacturers are now being obtained for both prototype and production quantities.

DRAWING 166311-15



ESTIMATED WT. 7oz

Note: not actual size due to reduction

GENERAL ARRANGEMENT OF PEAK ACCELERATION DEVICE

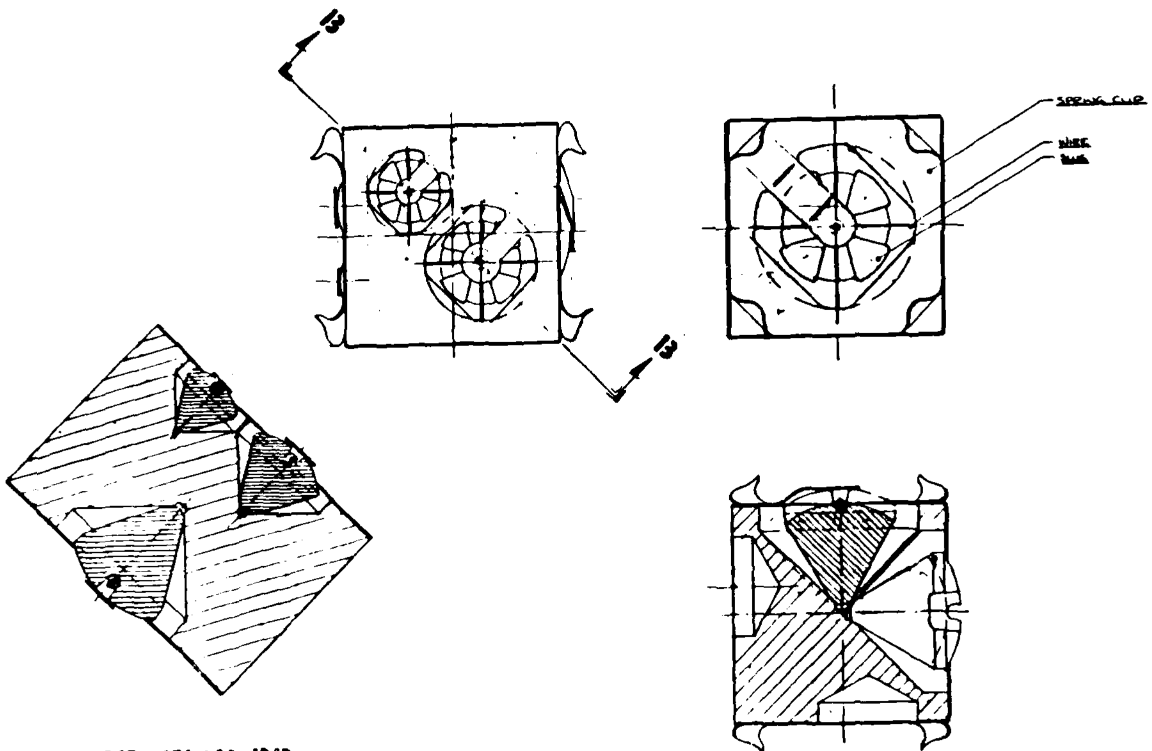
P.A.D.

AS NOTED

ANCO

ANCO Engineers, Inc

DRAWING 166311-16



SECTION BB

ACTUAL SIZE

Note: Not actual size due to reduction

GENERAL ARRANGEMENT OF CUBE ASSEMBLY

P & D

ANCO

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4.0 Schedule

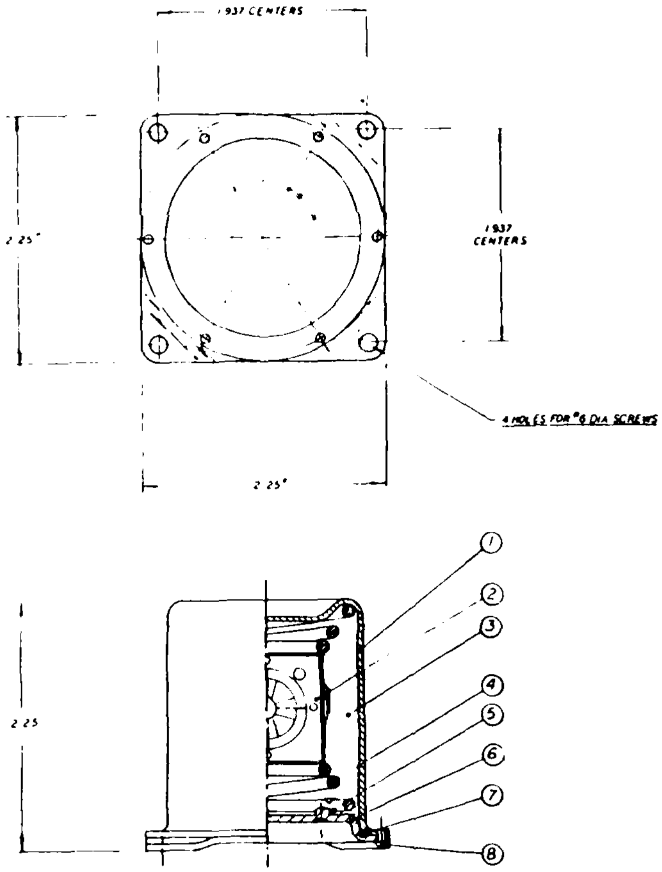
The schedule for completion of the project is shown in Table 1. This requires completion of the epoxy resistance test and evaluation of conical dual wire spring clip devices on the sled. Fatigue tests will be repeated. Final drawings and parts for 30-40 prototypes will be produced. About 30% will be used in evaluation and acceptance test. A final report will be prepared including cost estimates for mass produced items. Fifteen units will be delivered to AVSCOM for client evaluation.

APPENDIX D

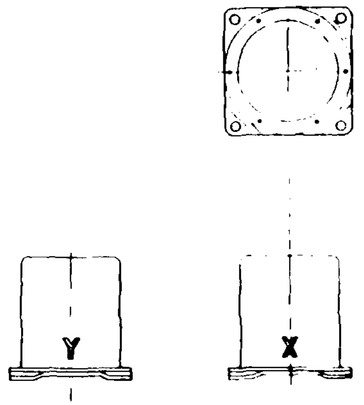
PRELIMINARY MANUFACTURING DRAWINGS

166311-115	General Arrangement PAD Device
-116	General Arrangement Cube Assembly
-117	Case and Cover
-118	Cube
-119	Slug
-120	Spring Clip
-121	Orientation Clip

QTY -100	ITEM	PART NO	DESCRIPTION	SOURCE
1	1	166311-H7-1	CASE	
1	2	166311-H6-100	CUBE ASSEMBLY	
	3		SILICONE OIL	AMSOIL
2	4	TA-2177	TAPERED SPRING	CENTURY SPRING CO
1	5	166311-121-1	ORIENTATION CLIP	
1	6	166311-H7-2	COVER	
1	7	2-030N674-70	O RING	PARKER SEALS
6	8		NO 0-80 L6 TYPE U DRIVE SCR	DUCOMMUN



2 x FULL SCALE



ACTUAL SIZE

ESTIMATED WT 79 (90 GRAMS)

6-30-86 A GENERALLY REVISED

REV

GENERAL ARRANGEMENT OF

PAD DEVICE

PEAK ACCELERATION DEVICE

AS NOTED

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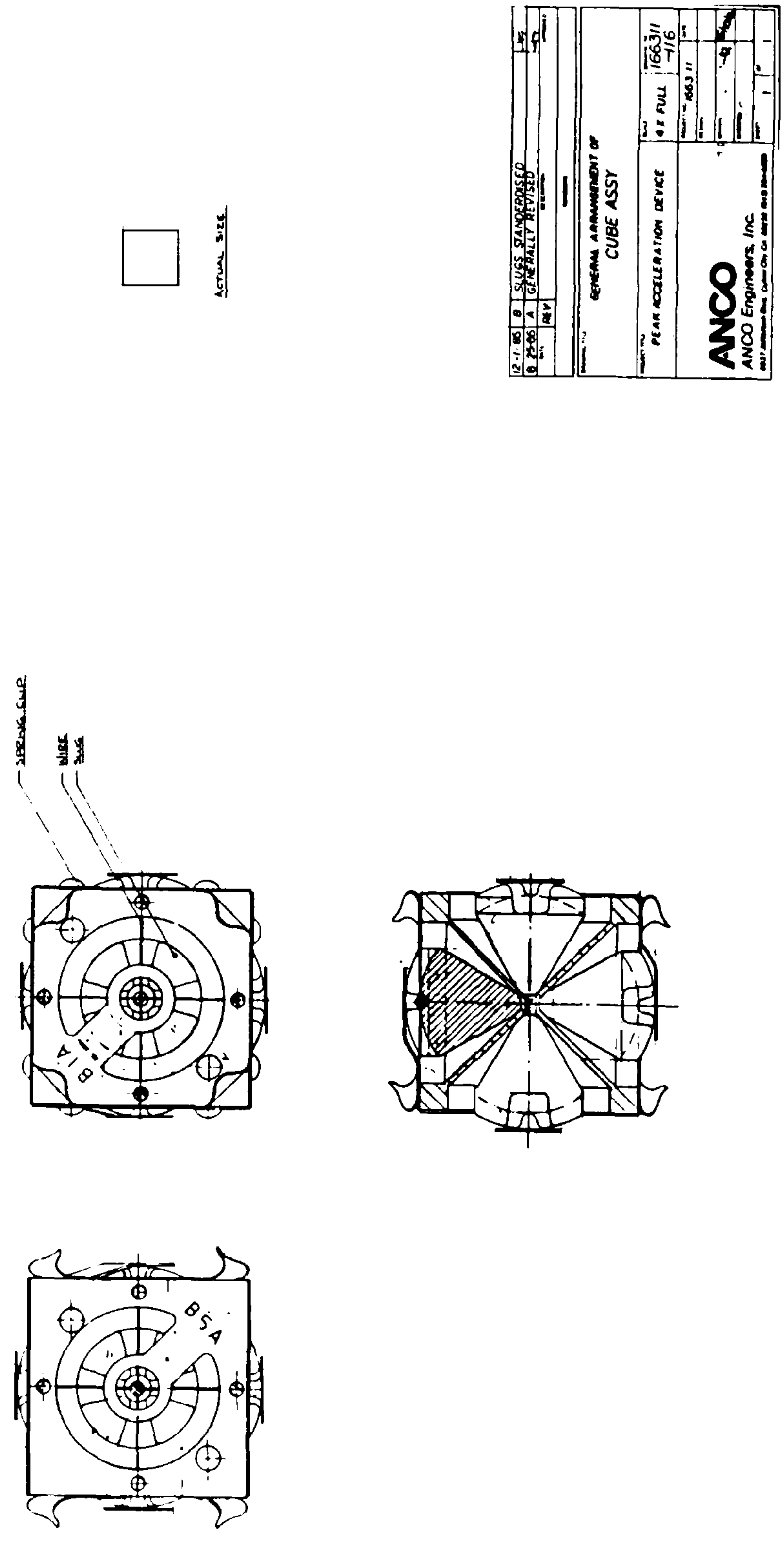
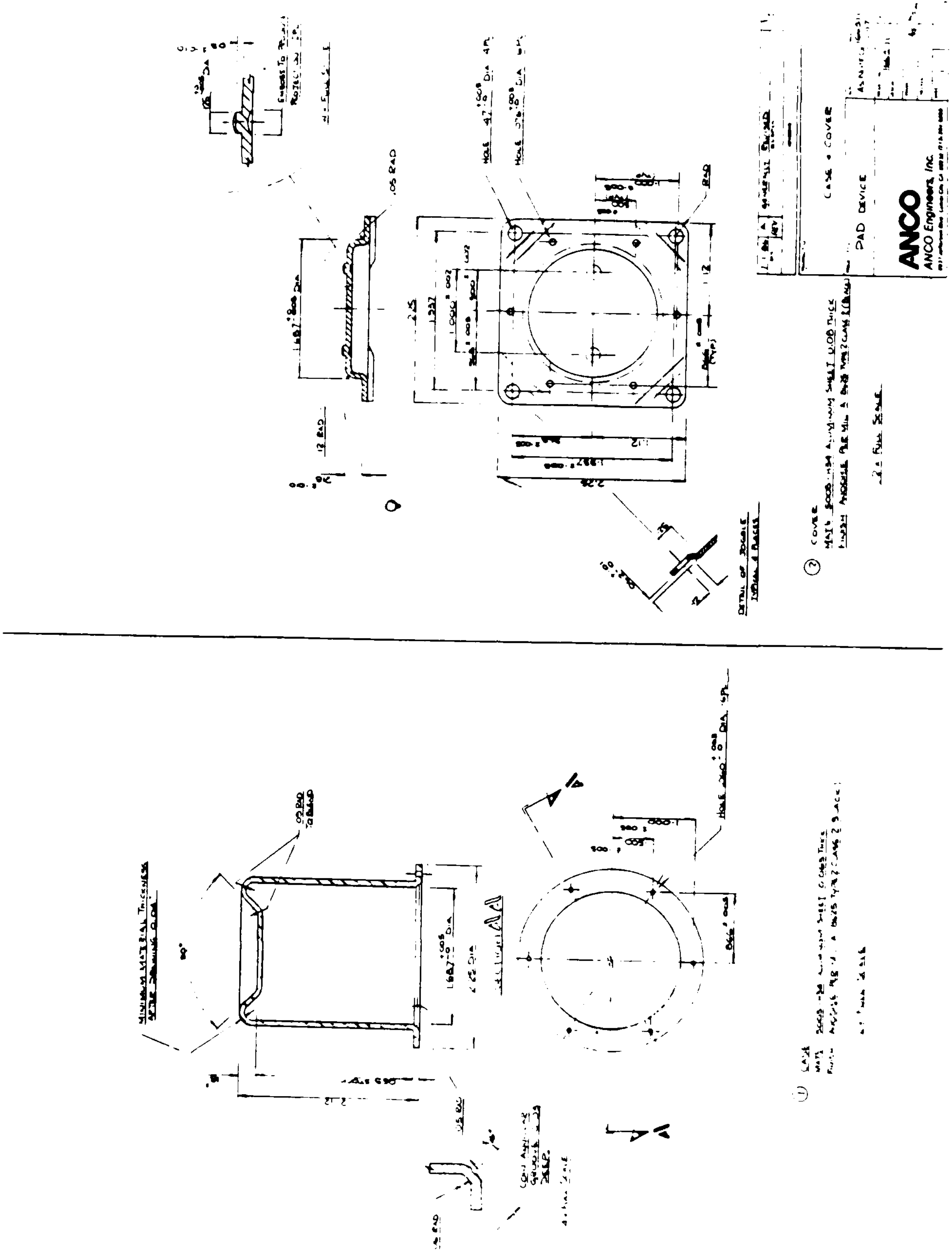
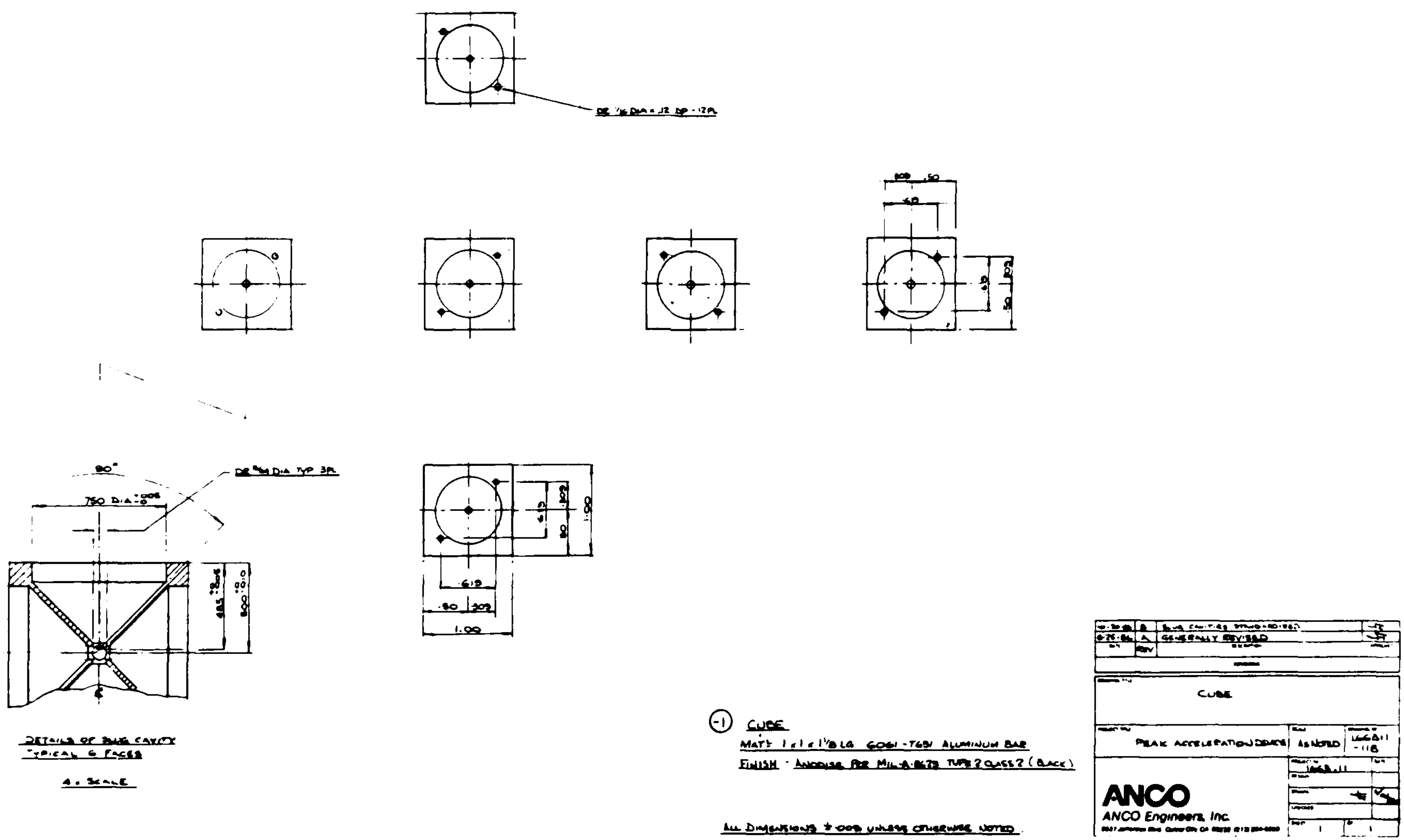
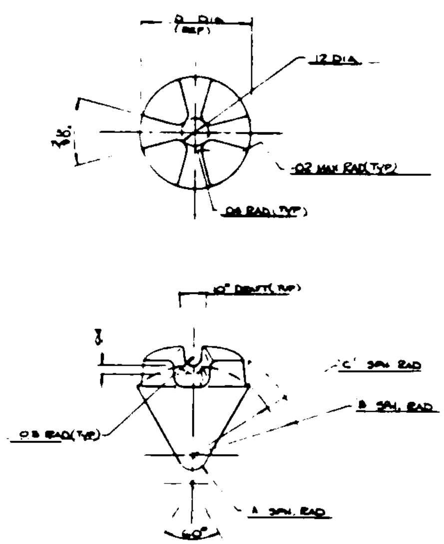
15
B


12-1-86 | B | SLUGS STANDERDISED
8-25-86 | A | GENERALLY REVISED
REV
GENERAL ARRANGEMENT OF
CUBE ASSY
PEAK ACCELERATION DEVICE
4 X FULL
166311-116
166311
ANCO
ANCO Engineers, Inc.
ACTUAL SIZE
SPRING CLIP
WIRE
SLUG
B1A
B5A


ANCO
ANCO Engineers, Inc
PAD DEVICE
CASE & COVER
DETAIL OF DOUBLE
TYPICAL 4 PLACES
COVER
CASE


DR 1/16 DIA x .12 DP - 12 PL
DR DIA TYP 3PL
90°
.750 DIA +.005 -0
.485
.800
.619
.80
.209
1.00
.50
DETAILS OF PLUG CAVITY
TYPICAL 6 FACES
4 x SCALE
-1 CUBE
MAT'L 1 x 1 x 1 1/8 LG 6061-T651 ALUMINUM BAR
FINISH - ANODIZE PER MIL-A-8625 TYPE 2 CLASS 2 (BLACK)
ALL DIMENSIONS ±.005 UNLESS OTHERWISE NOTED
B PLUG CAVITIES STANDARDIZED
6-25-84 A GENERALLY REVISED
REV
CUBE
PEAK ACCELERATION DEVICE
AS NOTED
-118
ANCO
ANCO Engineers, Inc.
1
1



ITEM	A	B	C	D	WEIGHT
-1	.06	.445	.400	.50	13.5 gm

SLUG
MATL SINTERED TUNGSTEN
FINISH NONE

NOT TO SCALE

12-1-86	B	-2 PART DELETED	
8-27-86	A	-3 PART DELETED	
DATE	REV	DESCRIPTION	APPROVED

SLUG

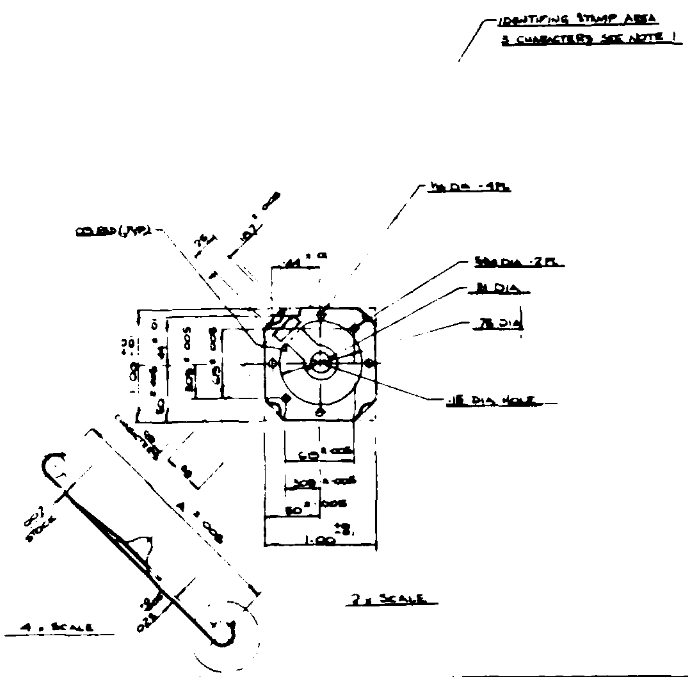
PEAK ACCELERATION DEVICE

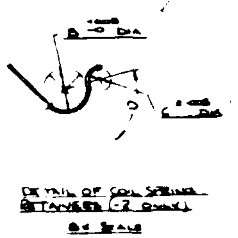
N.T.S

16631-115

1663.11

ANCO
ANCO Engineers, Inc.





ITEM	A	B	C	D
-1	-	-	-	-
-2	1.064	.05	.05	60°

SPRING CLIP
MAT'L .007 THICK C1095 SPRING STEEL (ANNEALED)
HEAT TREATMENT HARDEN & TEMPER TO 42 Rc
FINISH TUMBLE TO REMOVE SHARP EDGES PRIOR TO HARDENING

NOTES
1. MODIFY 166B11-120-2 STAMP - B1A
" " " -2 " - A2B
" " " -1 " - A3B
" " " -1 " - B4A
" " " -1 " - B5A
" " " -1 " - A6B

DATE	REV	DESCRIPTION
	B	DUAL DESIGN DELETED
7-9-86	A	GENERALLY REVISED

SPRING CLIP

PEAK ACCELERATION DEVICE

SCALE: AS NOTED
DRAWING NO.: 166B11 -120

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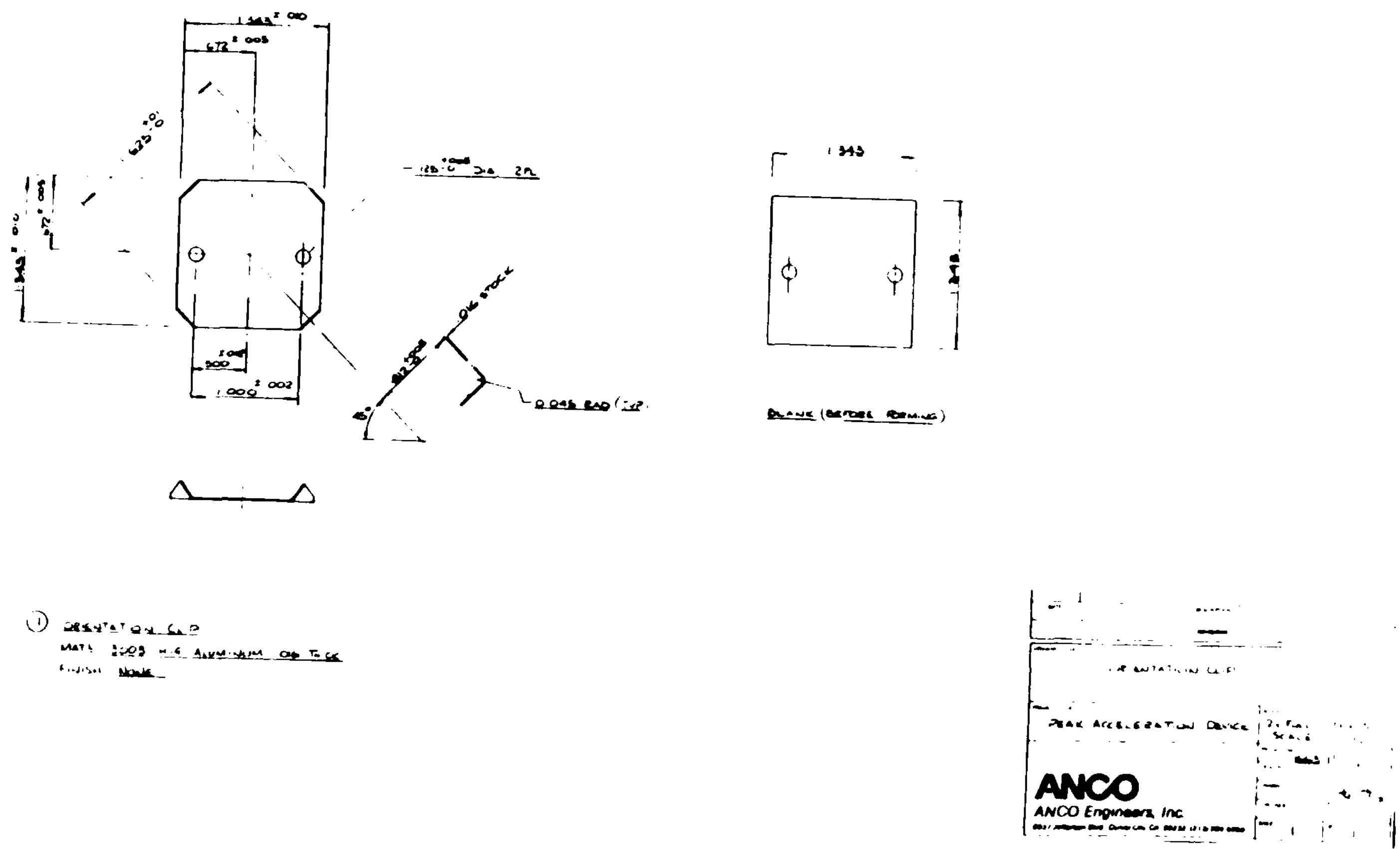
SHEET 1 OF 1


1.343
.016 STOCK
0.045 RAD (TYP)
BLANK (BEFORE FORMING)
FINISH NONE
PEAK ACCELERATION DEVICE
ANCO
ANCO Engineers, Inc

APPENDIX E
TEST RESULTS

CONICAL TESTING
TEST :21 RUN :1 RANGE YMIN : -1.4228
CHANNEL : 1 GRAVITIES YMAX : 11.0833
1734 ON TEST FIXTURE

16
F

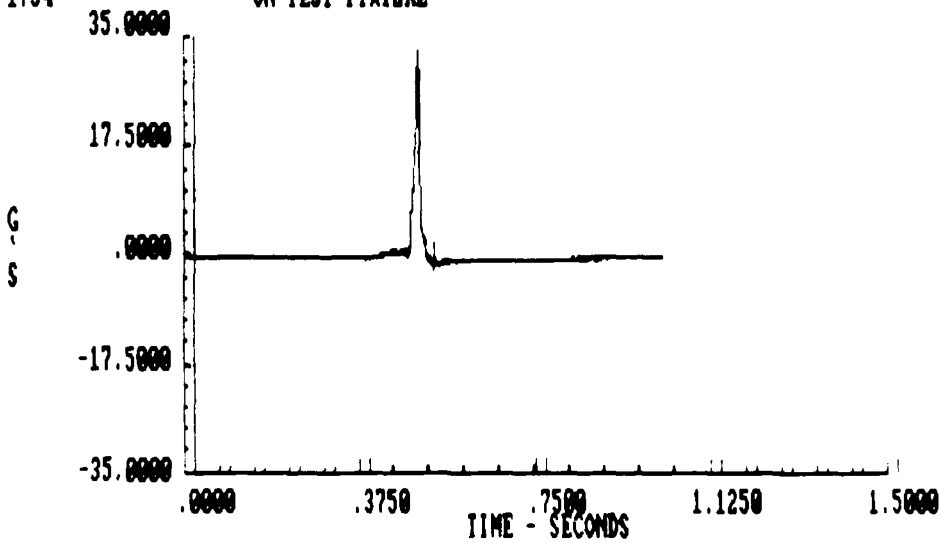
CONICAL TESTING
TEST :21 RUN :2 RANGE YMIN : -1.5677
CHANNEL : 1 GRAVITIES YMAX : 14.5534
1734 ON TEST FIXTURE

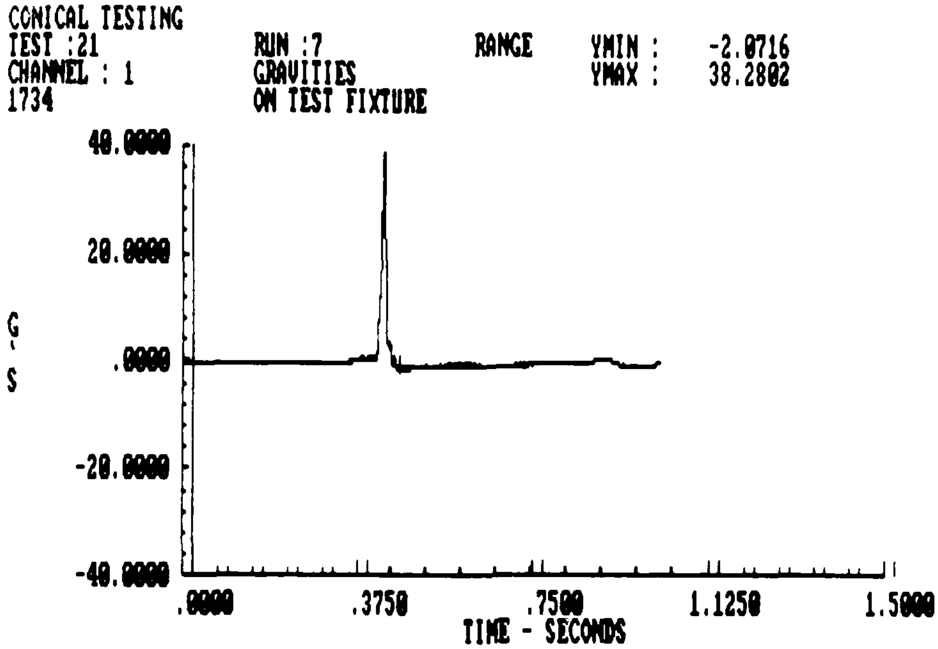
CONICAL TESTING
TEST :21 RUN :3 RANGE YMIN : -1.8226
CHANNEL : 1 GRAVITIES YMAX : 19.0860
1734 ON TEST FIXTURE

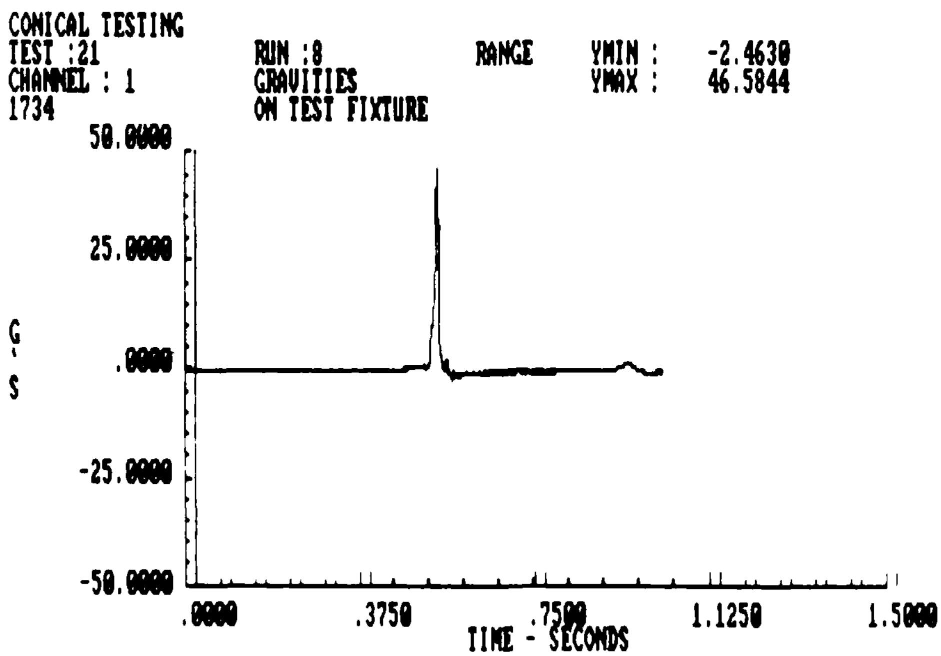
CONICAL TESTING
TEST :21 RUN :4 RANGE YMIN : -2.1493
CHANNEL : 1 GRAVITIES YMAX : 23.8400
1734 ON TEST FIXTURE

CONICAL TESTING
TEST :21 RUN :5 RANGE YMIN : -2.2052
CHANNEL : 1 GRAVITIES YMAX : 27.6922
1734 ON TEST FIXTURE

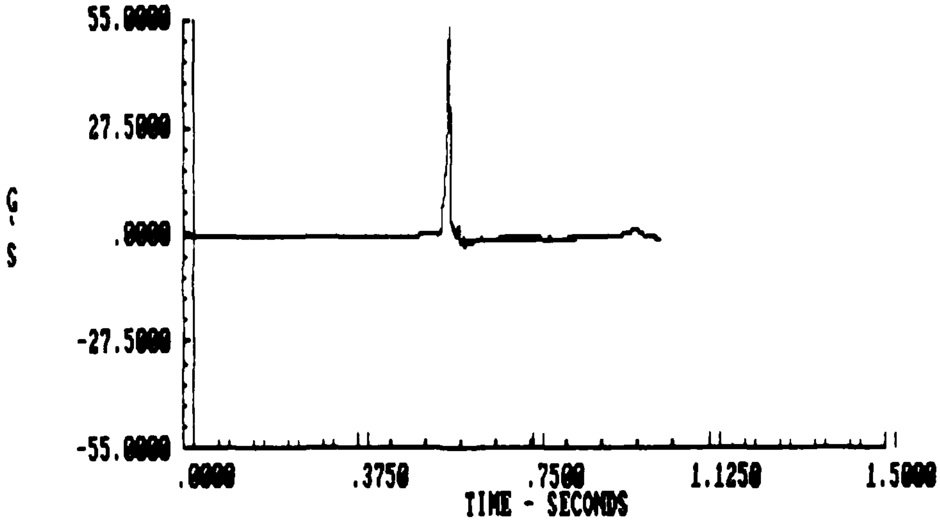
CONICAL TESTING
TEST :21 RUN :6 RANGE YMIN : -2.4466
CHANNEL : 1 GRAVITIES YMAX : 32.9223
1734 ON TEST FIXTURE




CONICAL TESTING
TEST :21
RUN :7
RANGE
YMIN : -2.0716
CHANNEL : 1
GRAVITIES
YMAX : 38.2802
1734
ON TEST FIXTURE
40.0000
20.0000
.0000
-20.0000
-40.0000
G'S
.0000
.3750
.7500
1.1250
1.5000
TIME - SECONDS

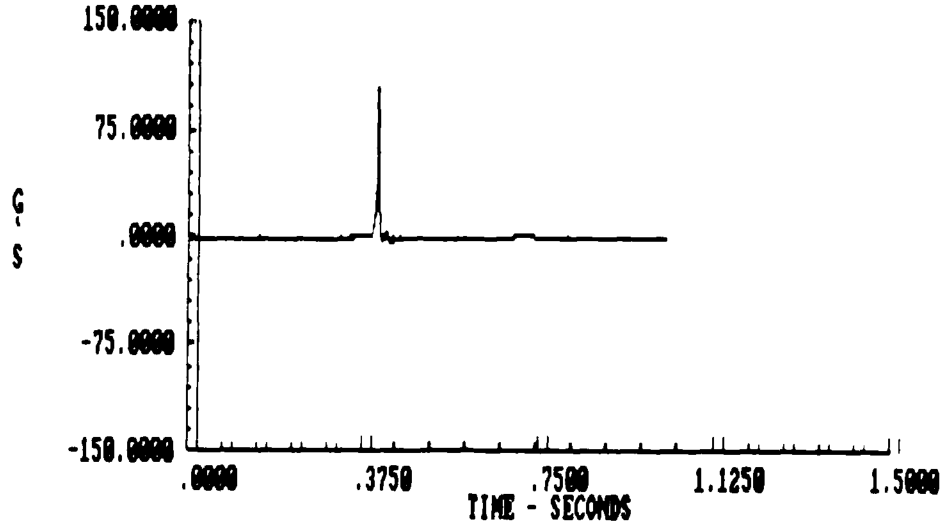

CONICAL TESTING
TEST :21
RUN :8
RANGE
YMIN : -2.4630
CHANNEL : 1
GRAVITIES
YMAX : 46.5844
1734
ON TEST FIXTURE
50.0000
25.0000
.0000
-25.0000
-50.0000
G'S
.0000
.3750
.7500
1.1250
1.5000
TIME - SECONDS

CONICAL TESTING
TEST :21 RUN :9 RANGE YMIN : -2.9666
CHANNEL : 1 GRAVITIES YMAX : 52.8224
1734 ON TEST FIXTURE

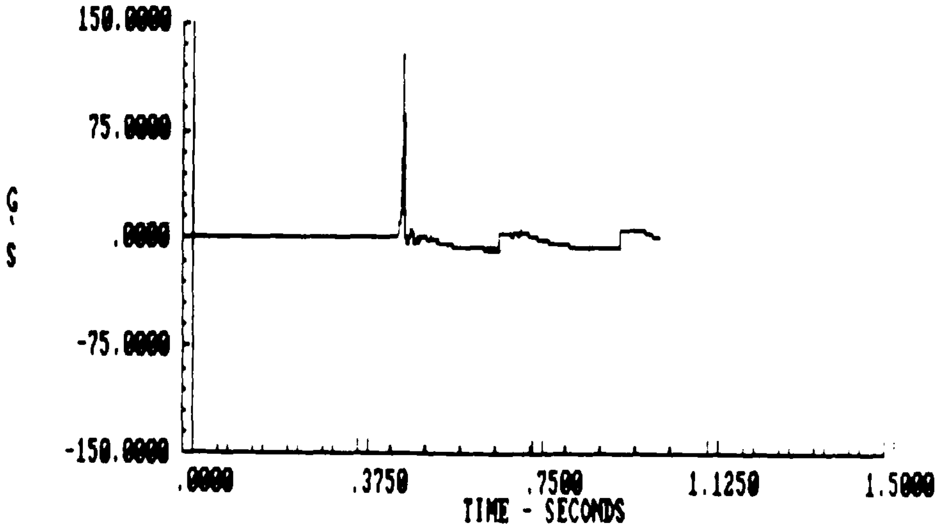


CONICAL TESTING
TEST :21 RUN :10 RANGE YMIN : -3.1392
CHANNEL : 1 GRAVITIES YMAX : 73.6561
1734 ON TEST FIXTURE

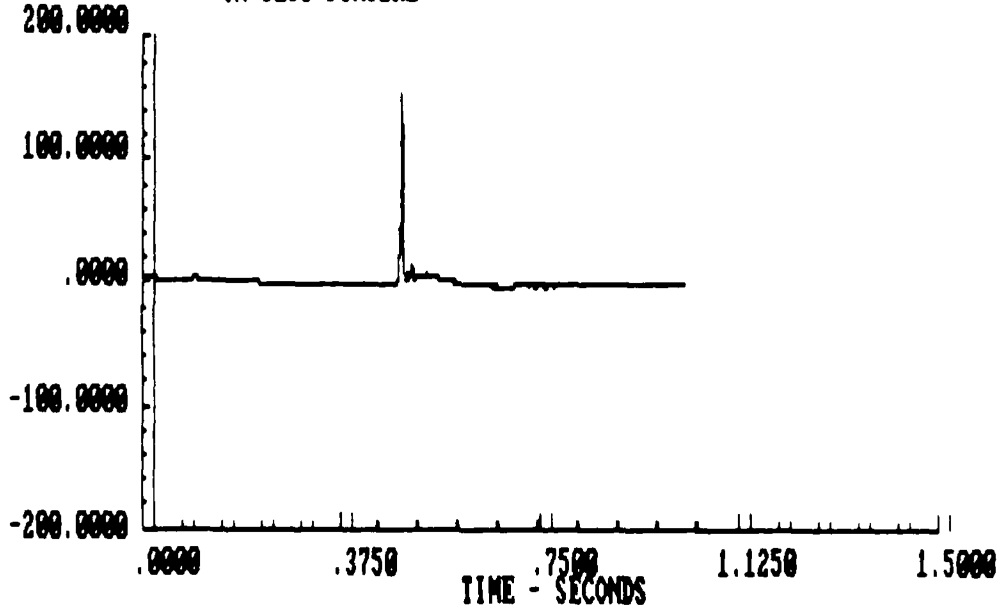
CONICAL TESTING
TEST :21 RUN :11 RANGE YMIN : -3.8798
CHANNEL : 1 GRAVITIES YMAX : 103.6923
1734 ON TEST FIXTURE



CONICAL TESTING
TEST :21 RUN :12 RANGE YMIN : -7.8407
CHANNEL : 1 GRAVITIES YMAX : 126.6976
1734 ON TEST FIXTURE



CONICAL TESTING
TEST :21 RUN :13 RANGE YMIN : -4.1248
CHANNEL : 1 GRAVITIES YMAX : 152.2015
1734 ON TEST FIXTURE



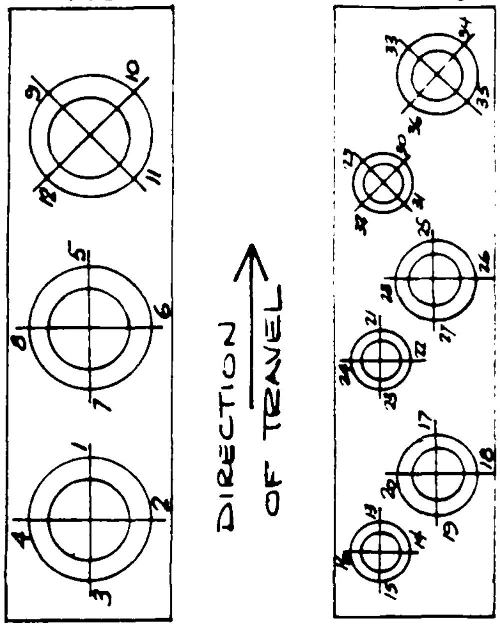
Tabulated Data, Conical #1 thru #22

Impact Time Histories Conical 21, Runs 1 thru 15

ANCO ENGINEERS INC	663.11
9937 Jefferson Boulevard	
MADE BY [illegible] DATE 6-10-86	EXPERIMENT NO #1
CHECKED BY [illegible] DATE 9/86	TITLE CONICAL

TOP VIEW

SIDE VIEW



RUN NO.	START POS.	BRICKS	BUMP	GS
1	28"	∅	2×1	11
2	29"	1	2×1	18.5
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

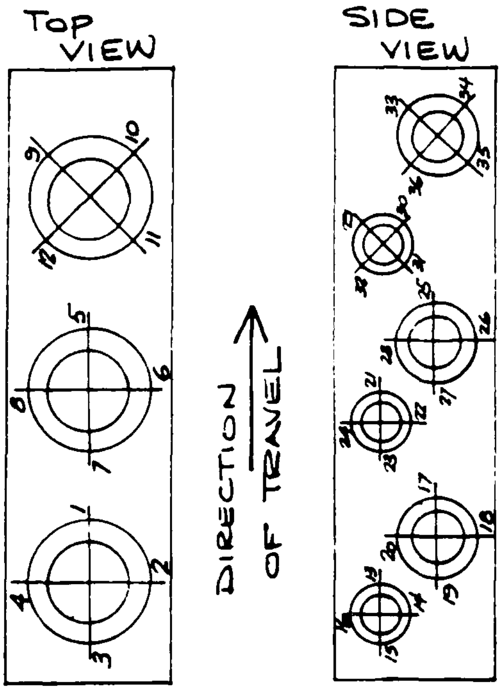
KEY: B - BROKEN
S = STRETCHED (100% DEFLECTION)

	WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS
	GAGE	40											40	
RUN	1		B											
	2	S		S	B					B				
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:

1. OIL FILLED.
2. 1, 20 + 28 WERE BROKEN AFTER 1ST RUN. SUSPECT MECHANICAL DAMAGE [illegible]
3. SLUGS LOADED WITH COMPRESSION SPRINGS. ESTIMATED LOAD [illegible] GRMS.

ANCO ENGINEERS, INC. 9937 Jefferson Blvd., Culver City, CA 90232	JOB NUMBER 1663.11 PAGE ____ OF ____
MADE BY [signature] DATE 6-10-86	DESCRIPTION
CHECKED BY [signature] DATE 9/86	EXPERIMENT No 2 TITLE CONICAL



RUN No.	START POS.	BRICKS	BUMP	G'S
1	28	8	2×1	44
2	28	14	2×1	187
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED (100% DEFL)

17
F

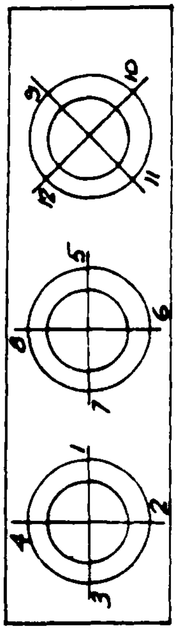
	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	40											40	
RUN	1	S	B	S	S					S	B			
	2	B		B	B	B	B	B	S	B		B	B	*20 ALSO BROKEN
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:

1. REQUIRED G'S ARE HIGHER THAN ANTICIPATED OTHERWISE TEST SATISFACTORY.
2. OIL FILLED.

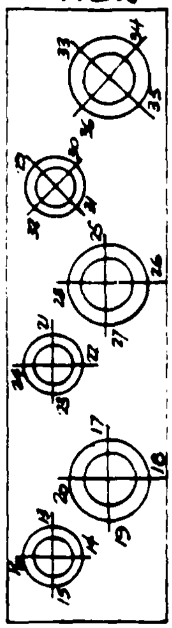
ANCO ENGINEERS, INC. 9937 Jefferson Boulevard Culver City, CA 90232	JOB NUMBER 1663.11 PAGE ____ OF ____
MADE BY JG DATE 6-13-86	DESCRIPTION
	EXPERIMENT No 3
CHECKED BY RL DATE 9-86	TITLE CONICAL

TOP VIEW



DIRECTION OF TRAVEL

SIDE VIEW



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	28	6	2x1	148.5
2	28	10	2x1	215.4
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED

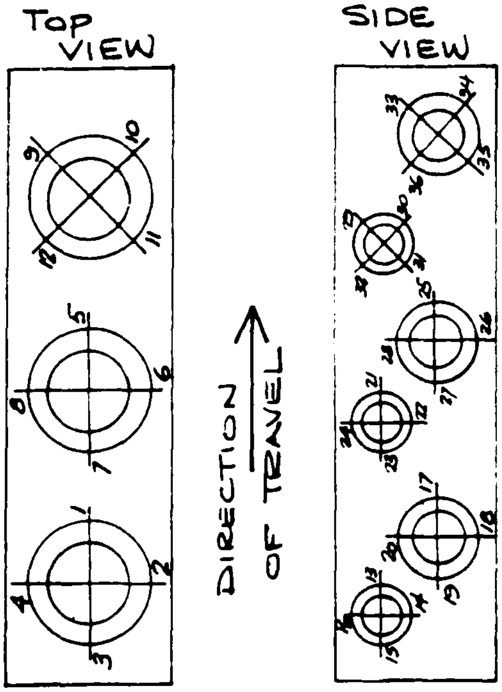
	WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE													
RUN	1	B	B	S	B		*			S	S			* QUESTION WIRE
	2					S				B				
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:

1. ACCELEROMETER RECALIBRATED - G'S MEASURED FOR TESTS 1 & 2 QUESTIONABLE.
2. STRETCHED INDICATES WIRES HAVE EXTENDED TO LIMIT OF TRAVEL WITHOUT FRACTURE
3. OIL FILLED

ANCO ENGINEERS, INC.

MADE BY [initials] DATE 6-16-86	JOB NUMBER 1663.11 PAGE ____ OF ____
CHECKED BY [initials] DATE 9-86	DESCRIPTION EXPERIMENT No 4
	TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G's
1	28	2	2x1	105
2	28	2	2x1	160
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED (100% DUF)
/ = APPROXIMATE DISPLACEMENT.

WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE	38	38	38	38	40							40	
RUN 1	B	B	70/30	70/30			B						
2			S	B	B				B	S			
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

NOTES:

1. OIL IMMERSED
2. SPRING TENSION ON SLUGS REDUCED BY 50%
3. 70/30 INDICATES APPROXIMATE SLUG DISPLACEMENT FROM ORIGINAL POSITION.

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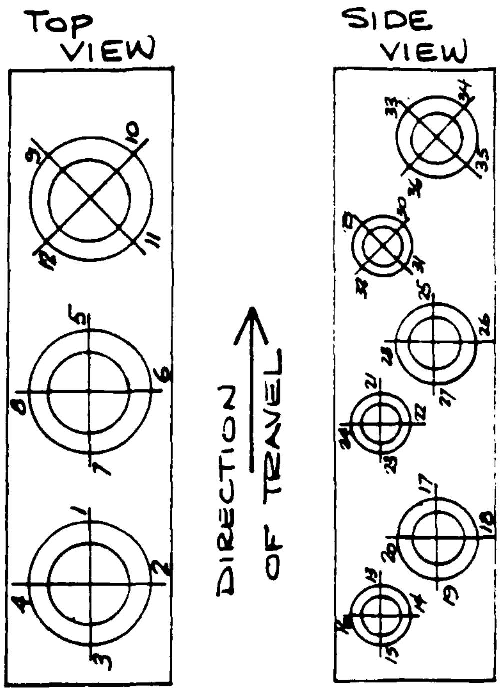
9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY	[illegible]	DATE	6-16-86
CHECKED BY	[illegible]	DATE	9-86

JOB NUMBER 1663.11 PAGE ____ OF ____

DESCRIPTION
EXPERIMENT No 5
TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1		2	2x1	130
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED

WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE	38	38	38	38	40							40	
RUN 1	B	*	S	S			SEE NOTES		S	S			* WIRE BOND FAILED
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

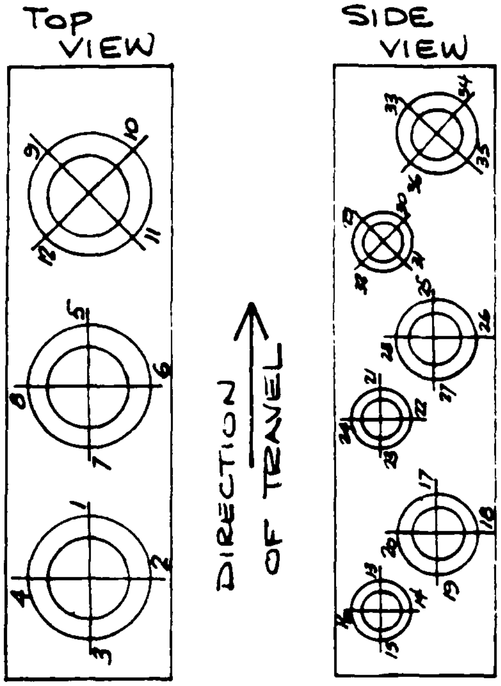
NOTES:

1. OIL IMMERSED
2. #31 WIRE PULLED THROUGH.
3. BECAUSE OF GLUE FAILURES - IGNORE TEST.

ANCO ENGINEERS, INC.
9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY [signature] DATE 6-17-86
CHECKED BY [signature] DATE 9-86

JOB NUMBER 1663.11 PAGE ____ OF ____
DESCRIPTION
EXPERIMENT No 6
TITLE CONICAL



RUN No.	START POS.	BRICKS	BUMP	G'S
1	42	Ø	2x1	82
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED (100% DEP)

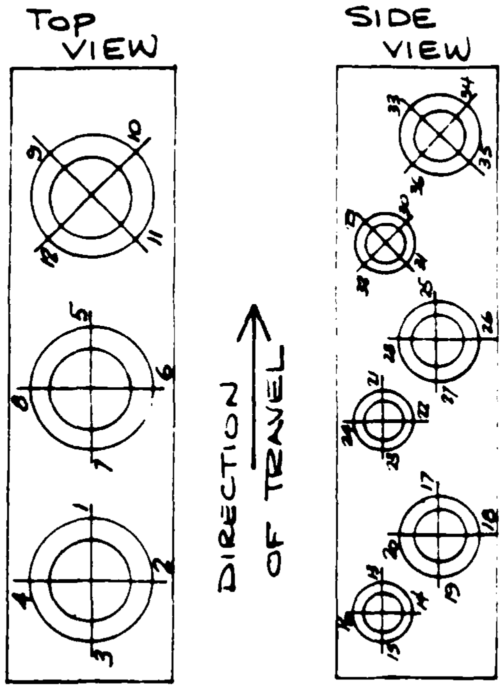
	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	38	=	=	38	40	=	=	=	=	=	=	40	
RUN	1	B	S											
	2													
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:
1. OIL IMMERSED.
2. FIXTURE MODIFIED BY ADDITION OF 'O' RINGS. SPRING SETTING .67
3. O' RING PRESSURE ON SIDE SLUGS TO GREAT TO PERMIT FRACTURES

ANCO ENGINEERS, INC.
9937 [illegible]

MADE BY [initials] DATE 6-19-86
CHECKED BY [initials] DATE 9-86

JOB NUMBER 1663.11 PAGE ____ OF ____
DESCRIPTION
EXPERIMENT No 7
TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	46	2	2x1	81.0
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED (100% DEFL)

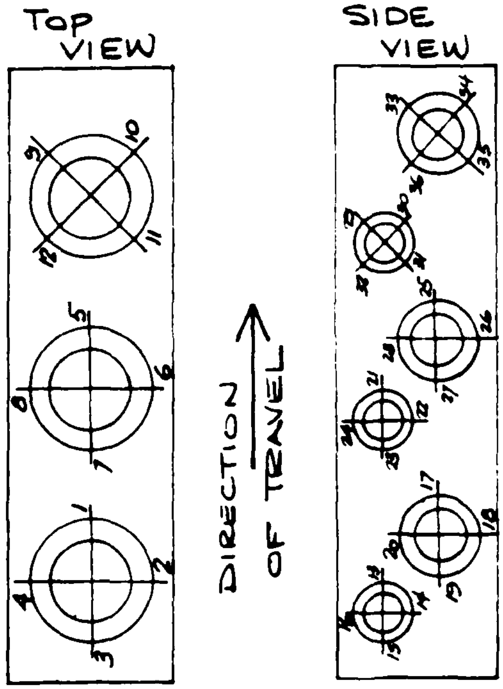
	WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	40	40	40	40	42							42	
RUN	1	B	B	S	B					B	B			
	2													
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:
1. NOT OIL IMMERSED

ANCO ENGINEERS INC

MADE BY [signature] DATE 6/20/86
CHECKED BY [signature] DATE 9/86

JOB NUMBER 1663.11 PAGE ____ OF ____
DESCRIPTION
EXPERIMENT No 8
TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	46	2	2×1	89.2
2	46	3	2×1	106.8
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED

	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS
	GAGE	40	40	40	40	42							42	
RUN	1	B	B	S	B									
	2									B	B			
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

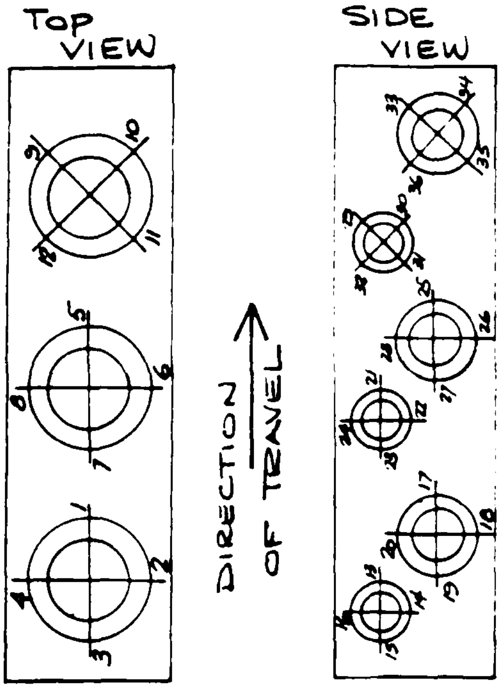
NOTES:

1. REPEAT OF TEST 7 OIL IMMERSED.
2. NOTE 19 & 27 WERE NOT STRETCHED IN 1ST RUN.
3. RUN AGAIN WITH 10% HIGHER G LEVEL.

ANCO ENGINEERS, INC

3937 Jefferson Blvd. ...

MADE BY [illegible] DATE 6-23-86	JOB NUMBER 1663.11 PAGE ___ OF ___
CHECKED BY Pel DATE 9-86	DESCRIPTION
	EXPERIMENT No 9
	TITLE CONICAL



RUN No.	START POS.	BRICKS	BUMP	G's
1	46	2	2x1	101.6
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED (100% DOF)

WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE	40	=	=	40	42	=	=	=	=	=	=	42	
RUN 1	B	B	S	S					B	B			
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

NOTES:

1. RERUN OF EXP #7 NOT OIL IMMERSED

ANCO ENGINEERS INC

9937 Jefferson [illegible]

MADE BY [signature] DATE 6-23-86

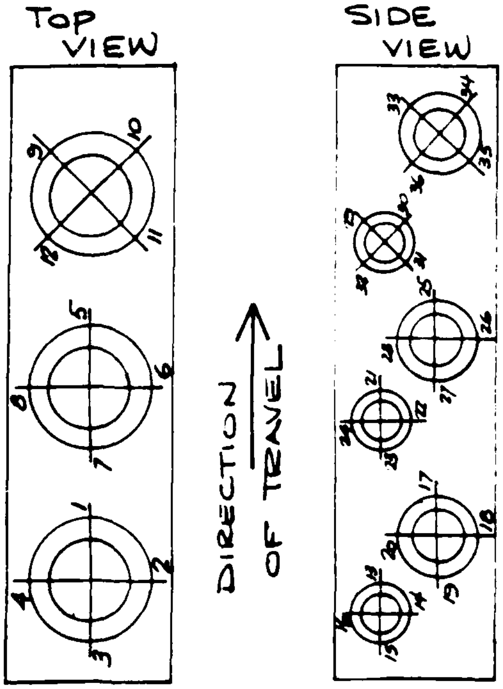
CHECKED BY [signature] DATE [illegible]

JOB NUMBER 1663.11 PAGE ____ OF ____

DESCRIPTION

EXPERIMENT No 10

TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	46	2	2x1	99.6
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED

	WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	40	═	═	40	42	═	═	═	═	═	═	42	
RUN	1	B	B	S	B					B	B			
	2													
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:

1. OIL IMMERSED RERUN OF EXPERIMENT #8
2. RESULTS ARE COMPARABLE WITH EXPER #8 WITHIN APPROX 10%

18
F

ANCO ENGINEERS, INC

[illegible] CA 90232

MADE BY [illegible] DATE 7-1-86

CHECKED BY [illegible] DATE 9-86

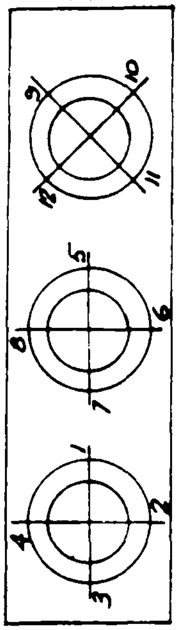
JOB NUMBER 1663.11 PAGE ____ OF ____

DESCRIPTION

EXPERIMENT No 11

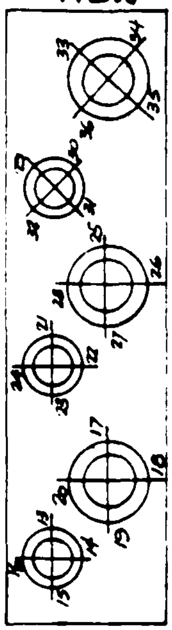
TITLE CONICAL

TOP VIEW



DIRECTION OF TRAVEL

SIDE VIEW



RUN No.	START POS.	BRICKS	BUMP	G's
1	61	∅	2×1	60
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED

	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	42	—	—	42									
RUN	1	B	S	S	S									
	2													
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:

1. NOT OIL IMMERSED.
2. ONLY LARGE SLUGS.
3. IMPACT TEST PRECEEDED BY A DRY ± 6 G VIBRATION TEST (10,000 CYCLES)

18
B

ANCO ENGINEERS INC

MADE BY [illegible] DATE 7-2-86

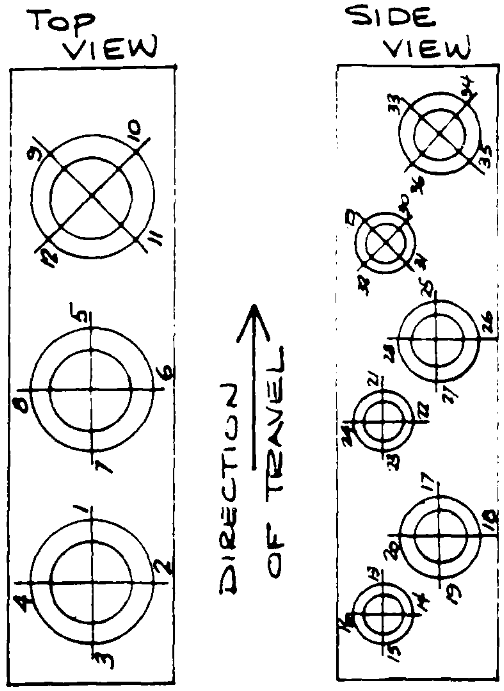
CHECKED BY [illegible] DATE 9-86

JOB NUMBER 1663.11 PAGE ____ OF ____

DESCRIPTION

EXPERIMENT No 12

TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G's
1	78	∅	2x1	34
2	68		2x1	43
3	63		2x1	44
4	57		2x1	46
5	52	∅	2x1	50
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED (100% DEFL)

WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE	42	42	42	42									
RUN 1	S	B											
2													
3													
4													
5			S	S									
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

NOTES:

1. ACCELEROMETER RELOCATED TO FIXTURE
2. NOT OIL IMMERSED
3. RERUN OF EXP #11
4. LARGE SLUGS ONLY.

ANCO ENGINEERS, INC

9937 Jefferson Blvd., Culver City, CA 90232

MADE BY [illegible] DATE 3-7-86

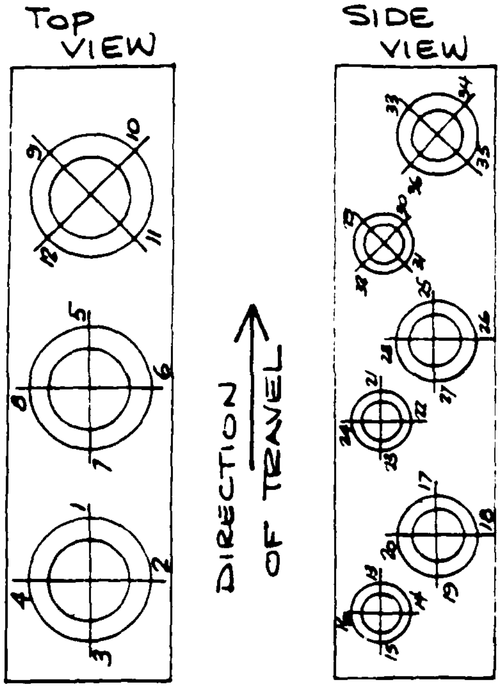
CHECKED BY [illegible] DATE 9-86

JOB NUMBER 1663.11 PAGE

DESCRIPTION

EXPERIMENT No 13

TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	96	∅	2×1	29
2	90	∅	2×1	32
3	84	∅	2×1	35
4		∅	2×1	39
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED

WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE	42	—	—	42									
RUN 1													
2	S												
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

NOTES:

1. NOT OIL IMMERSED
2. PRECEEDED BY VIBRATION TEST ± 6 G's (± 2 G's RMS) 100,000 CYCLES
3. WASHER DISTANCES 1/4 .040 – .064 5/8 .043 .062 7/12 .040 .062

ANCO ENGINEERS, INC

9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY Fz. DATE JULY 9th 86

CHECKED BY Pol DATE 9-86

JOB NUMBER 1663.11 PAGE ____ OF ____

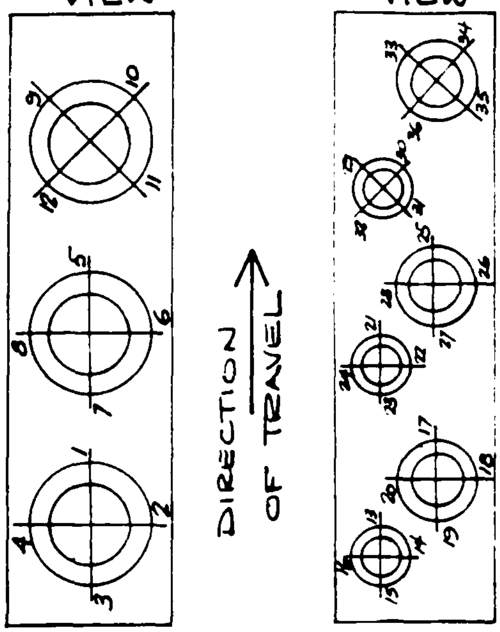
DESCRIPTION

EXPERIMENT No 14

TITLE CONICAL

TOP VIEW

SIDE VIEW



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	115	⌀	2×1	17.2
2	105	⌀	2×1	22.2
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED (100% DISPLACEMENT)
%/% = APPROXIMATE DISPLACEMENT

	WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	42	42	42	42									
RUN	1	70/30	70/30	*	*									* FAILED BY VIB. TEST.
	2	S	S											
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:

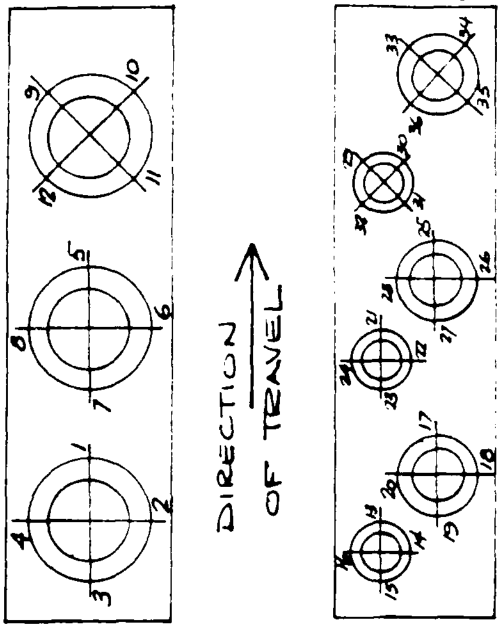
1. LARGE SLUGS ONLY
2. OIL IMMERSED FATIGUE TEST PRIOR TO IMPACT TEST
3. IMPACT TEST NOT OIL IMMERSED (ALTHOUGH RESIDUE FROM VIBRATION TEST REMAIN[illegible]
4. WAVE WASHERS USED INSTEAD OF 'O' RINGS

ANCO ENGINEERS INC

MADE BY: JG   DATE: July 9th 86
CHECKED BY: Pcl   DATE: 9-86

JOB NUMBER: 1663.11
DESCRIPTION:
EXPERIMENT No: 15
TITLE: CONICAL

TOP VIEW   SIDE VIEW



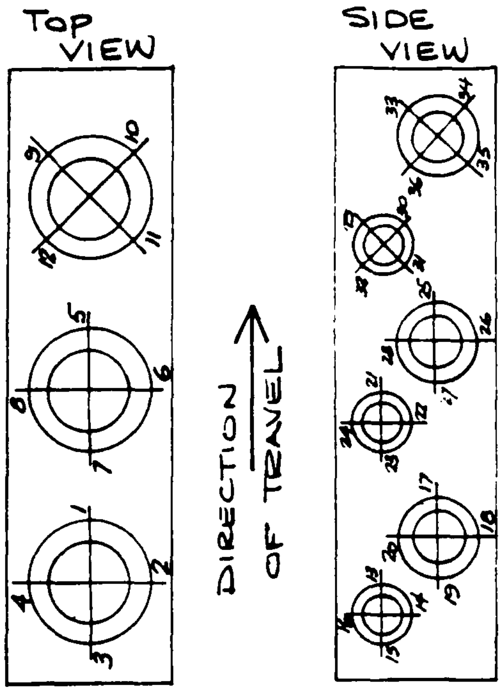
RUN NO.	START POS.	BRCKS	BUMP	G's
1	121	∅	2x1	10
2	121	∅	2x1	20
3	108	∅	2x1	23
4	102	∅	2x1	26
5	96	∅	2x1	29
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B - BROKEN
S = STRETCHED

WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE	42	42	42	42									
RUN 1													
2	70/30	70/30											
3	90/10	S											
4	S		70/30	70/30									
5			S	S									
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													

NOTES:
1. REPEAT OF EXP #14
2. PERSONNEL/ CABLE INTERFERENCE. LOW 'G' VALUE
3. IMPACT TEST NOT OIL IMMERSED. FATIGUE TEST RUN FOR 100,000 CYCLES AT 1.5 RMS = ±5 G's PEAK TO PEAK. STATIC TESTS WITH DEADWEIGHTS INDICATE FORCE ON SLUGS TO BE 120-140 GRMS SLUG WT 13 GRMS [illegible]

ANCO ENGINEERS, INC. 9937 Jefferson Boulevard Culver City, CA 90232	JOB NUMBER 1663.11
MADE BY [illegible] DATE 7/11/86	DESCRIPTION EXPERIMENT No 16
CHECKED BY [illegible] DATE 9-86	TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	121	Ø	2×1	SEE NOTE 2.
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED

	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE													
RUN	1													
	2													
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

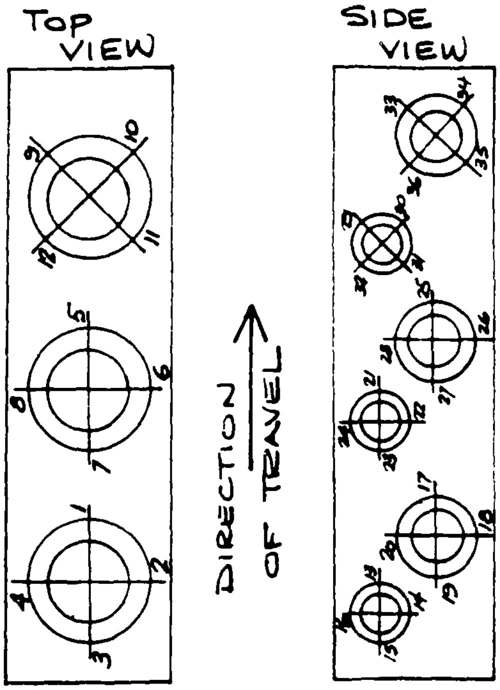
NOTES:

1. WITHOUT WIRES.
2. VIBRATED AT ±1.5G RMS = ±5G PEAK. IMPACT TEST DETERMINED THAT 7-8G'S DID NOT MOVE SLUGS (LARGE SLUGS USED). STATIC TESTING DETERMINED SIDE PULL OF 50-60 GRMS MOVED SLUGS. BOTH IMPACT & STATIC TESTS RUN UNIMMERSED BUT RESIDUAL OIL FROM VIBRATION TEST WAS PRESENT.

ANCO ENGINEERS, INC.
3937 Jefferson B[illegible] CA 90232

MADE BY [signature] DATE 7/16/86
CHECKED BY [signature] DATE 9-86

JOB NUMBER 1663.11 PAGE ___ OF ___
DESCRIPTION
EXPERIMENT No 17
TITLE CONICAL



RUN NO.	START POS.	BRCKS	BUMP	G's
1	117	∅	2x1	20.7
2	109	∅		25.7
3	102	∅		27.2
4	93	∅		33.7
5	84	∅		43.1
6	73	∅		45.9
7	52	∅		58.4
8	39	4	2x1	140.6
9				
10				
11				
12				
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED
#/# = APPROXIMATE DISPLACEMENT

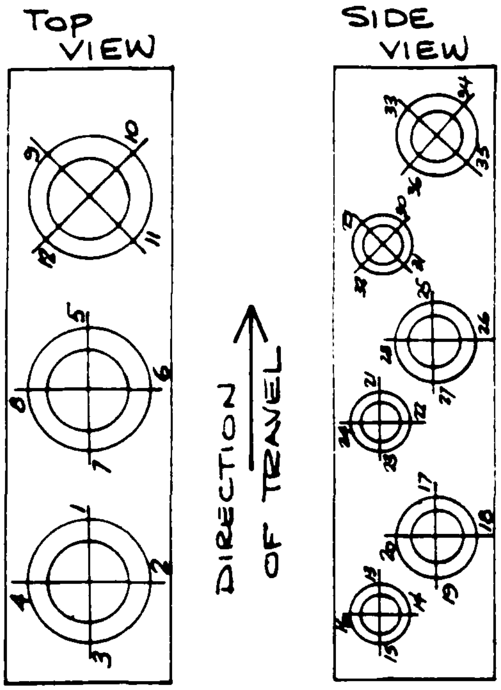
WIRE NO.		3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS
GAGE		42											42	
RUN	1	60/40												
	2	70/30												
	3	80/20												
	4	B	70/30	70/30	70/30									
	5		B	B	B								B	
	6									‡	60/40			‡ GLUE FAILURE BOTH 8 & 18
	7													
	8													
	9													
	10													
	11													
	12													
	13													
	14													
	15													

NOTES:
1. NOT OIL IMMERSED.
2. PR 2 TO IMPACT TESTS VIBRATED AT 1.4 - 1.6 RMS FOR 10 MINS. 4 & 8 STRETCHED TO 60/40. SHOULD NOT INFLUENCE RESULTS.

ANCO ENGINEERS, INC.
9937 Jefferson Boulevard Culver City CA 90232

MADE BY [signature] DATE 7/23/86
CHECKED BY [signature] DATE 9-86

JOB NUMBER 1663.11 PAGE ______ OF ______
DESCRIPTION
EXPERIMENT No 18
TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G'S
1	144	∅	2×1	10.6
2	132			14.1
3	125			16.3
4	116			19.6
5	107			24.2
6	97			28.6
7	86			38.2
8	74			45.2
9	62			56.0
10	50			70.4
11	40	∅		86.0
12	40	1		114.0
13	40	2	2×1	145.0
14				
16				

KEY: B - BROKEN
S = STRETCHED

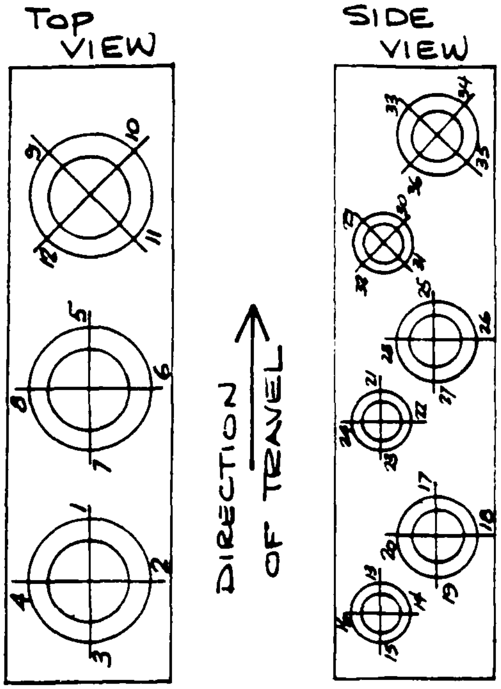
	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	42											42	
RUN	1	-	-	-	-	-	-	-	-	-	-		-	
	2	-	-	-	-	-	-	-	-	-	-		-	
	3	-	-	-	-	-	-	-	-	-	-		-	
	4	-	60/40	-	-	-	-	-	-	-	-		-	
	5	-	70/30	-	-	-	-	-	-	-	-		-	
	6	-	80/20	-	-	-	-	-	-	-	-		-	
	7	B	B	-	-	-	-	-	-	-	-			
	8			-	-	-	-	-	-	-	-		-	
	9			B	B	-	-	-	-	60/40	60/40		B	#18 GLUE FAILURE
	10					-	-	-	-	70/30	70/30			
	11					-	-	-	-	70/30	70/30			
	12					60/40	-	-	-	B	B			
	13					B	B	80/20	80/20					
	14													
	15													

NOTES:
1. NOT OIL IMMERSED
2. SUBJECTED TO 30 MINS. OF VIBRATION AT .04 - .05 RMS PRIOR TO SLED TESTS (TEST RUN IN 2 - 15 MIN. INCREMENTS)

ANCO ENGINEERS, INC.
9937 Jefferson Boulevard • Culver City, CA 90232

MADE BY	[initials]	DATE	7-24-86
CHECKED BY	[initials]	DATE	9-86

JOB NUMBER 1663.11 PAGE ______ OF ______
DESCRIPTION
EXPERIMENT No 19
TITLE CONICAL



RUN No.	START POS.	BRICKS	BUMP	G'S
1	131	∅	2x1	15
2	125	|	|	18
3	116	|	|	21
4	107	|	|	26
5	98	|	|	32
6	88	|	|	41
7	77	|	|	51
8	66	|	|	62
9	54	|	|	76
10	43	|	|	87
11	33	∅	|	144
12	33	|	2x1	154
13				
14				
16				

KEY: B = BROKEN
S = STRETCHED (100% DEFLECTION)
/ = APPROXIMATE DEFLECTION.

19
B

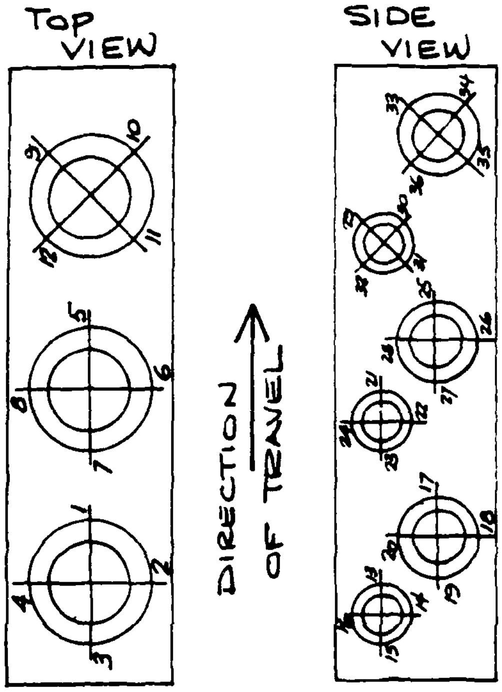
WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
GAGE													
RUN 1	-	-	-	-	-	-	-	-	-	-		-	
2	60/40	60/40	-	-	.	-	-	.	.	-		-	
3	70/30	70/30	-	.	.	-	-	.	-	-		.	
4	90/10	90/10	-	-	-	-	-	-	-	-		-	
5	B	B	70/30	70/30	-	-	-	-	-	-		-	#35 GLUE FAILURE
6			B	B	-	-	-	-	60/40	-		60/40	
7					-	-	-	-	60/40	60/40		70/30	
8					-	-	-	-	80/20	80/20		90/10	
9					-	-	-	-	S	S		S	
10					60/40	70/30	-	-					
11					80/20	70/30	60/40	60/40					
12							70/30	70/30					
13													
14													
15													

NOTES:
1. NOT OIL IMMERSED
2. VIBRATED AT .09 RMS FOR 20 MINS. PRIOR TO IMPACT TESTING.

ANCO ENGINEERS, INC.
9937 Jefferson Boulevard Culver City, CA 90232

MADE BY [illegible] DATE 7/28/86
CHECKED BY RR 9-86 DATE 9-86

JOB NUMBER 1663.11 PAGE ______ OF ______
DESCRIPTION
EXPERIMENT No 20
TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	G's
1	131	φ	2×1	8.2
2	124			11.1
3	115			12.8
4	105			14.5
5	98			16.4
6	91			19.2
7	82			22.7
8	71			26.0
9	60			30.9
10	48			38.1
11	39	φ		45.1
12	39			61.5
13	39	2		82.8
14	39	3		127.2
16	39	4	2×1	142.6

KEY: F (FAILED) { ~~B~~ = BROKEN; ~~S~~ = STRETCHED (100% DEFL). }
x/x = APPROXIMATE DEFLECTION

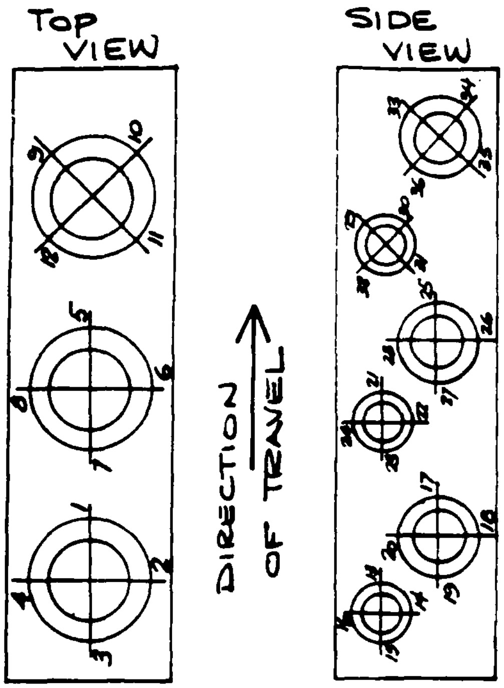
	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	COMMENTS.
	GAGE	42											42	
RUN	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	-	-	-	-	-	
	5	-	-	-	-	-	-	-	-	-	-	-	-	
	6	60/40	60/40	-	-	-	-	-	-	-	-	-	-	
	7	70/30	70/30	-	-	-	-	-	-	-	-	-	-	
	8	70/30	80/20	-	-	-	-	-	-	-	-	-	-	
	9	70/30	80/20	-	-	-	-	-	-	-	-	-	-	
	10	90/10	90/10	-	-	-	-	-	-	-	-	-	-	
	11	F	F	-	-	-	-	-	-	60/40	-	-	-	
	12			-	-	-	-	-	-	70/30	F	60/40	60/40	
	13			-	-	60/40	60/40	-	-	F		F	F	
	14			70/30	70/30	80/20	90/10	80/20	80/20					
	15			70/30	70/30									

NOTES:
1. NON-OIL IMMERSED
2. VIBRATED AT 0.09 RMS PRIOR TO IMPACT TESTING (20 MINS.)
3. BROKEN / STRETCHED = FAILED.

ANCO ENGINEERS, INC.
9937 Jefferson Boulevard · Culver City, CA 90232

MADE BY	[signature]	DATE	8-19-86
CHECKED BY	[signature]	DATE	9-86

JOB NUMBER 1663.11 PAGE ____ OF ____
DESCRIPTION
EXPERIMENT No 21
TITLE CONICAL



RUN No.	START POS.	BRICKS	BUMP
1	122	∅	2x1
2	112		
3	101		
4	87		
5	78		
6	66		
7	55		
8	46		
9	35	∅	
10	35	1	
11	37	2	
12	35	3	
13	36	4	2x1
14			
16			

KEY: F = FAILED (BROKEN OR 100% STRETCHED
#/% = APPROXIMATE SLUG DEFLECTION.

WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	G'S	COMMENTS
GAGE	42	═	═	═	═	═	═	═	═	═	═	42		
RUN 1	-	-	-	-	-	-	-	-	-	-	-	-	11.1	
2	60/40	60/40	-	-	-	-	-	-	-	-	-	-	14.6	
3	80/20	70/30	-	-	-	-	-	-	-	-	-	-	19.1	
4	F	F	60/40	60/40	-	-	-	-	-	-	-	-	23.8	
5			80/20	80/20	-	-	-	-	-	-	-	-	27.7	
6			F	F	-	-	-	-	-	-	-	-	32.9	
7					-	-	-	-	60/40	60/40	-	-	38.3	
8					-	-	-	-	70/30	70/30	-	-	46.6	
9					-	-	-	-	80/20	80/20	-	-	58.2	
10					-	-	-	-	90/10	90/10	60/40	60/40	73.7	
11					70/30	70/30	-	-	F	F	90/10	90/10	103.7	
12					90/10	90/10	60/40	60/40			F	F	126.7	
13					F	F	80/20	80/20					152.2	
14														
15														

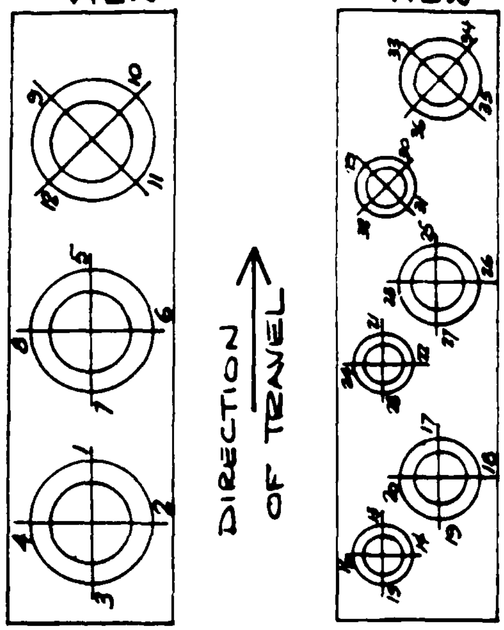
NOTES:

1. OIL IMMERSED FOR VIBRATION & IMPACT TESTS
2. VIBRATED AT ± 2.0g RMS FOR 100,000 CYCLES PRIOR TO IMPACT TESTS
3. WIRES ATTACHED WITH DEXTER HYSOL EA956 EXPOXY ADHESIVE.

ANCO ENGINEERS, INC 9937 Jefferson Boulevard, Culver City, CA 90232	JOB NUMBER 1663.11 PAGE
MADE BY [signature] DATE 8-21-86	DESCRIPTION
CHECKED BY [signature] DATE 9-86	EXPERIMENT No 22 TITLE CONICAL

TOP VIEW

SIDE VIEW



RUN NO.	START POS.	BRICKS	BUMP	
1	113	Ø	2±1	
2	102			
3	94			
4	83			
5	73			
6	64			
7	54			
8	47			
9	39	Ø		
10	39	1		
11	39	2		
12	39	3		
13	40	5		
14	40	6		
16	22	9		

KEY: F = FAILED (BROKEN OR 100% STRETCHED)
x/x = APPROXIMATE SLUG DEFLECTION.

	WIRE No.	3	7	11	12	15	23	31	32	19	27	35	36	G'S	COMMENTS
	GAGE	40											40		
RUN	1	-	-	-	-	-	-	-	-	-	-	-	-	15.6	
	2	60/40	60/40	-	-	-	-	-	-	-	-	-	-	20.6	
	3	70/30	70/30	-	-	-	-	-	-	.	-	-	-	23.2	
	4	90/10	F	-	-	-	-	-	-	-	-	-	-	28.6	
	5	F		60/40	60/40	-	-	-	-	-	-	-	-	34.7	
	6			90/10	90/10	-	-	-	-	-	-	-	-	41.1	
	7			F	F	-	-	-	-	-	-	-	-	55.0	
	8					-	-	-	-	60/40	60/40	-	-	56.4	
	9					-	-	-	-	70/30	70/30	-	-	69.1	
	10					-	-	-	-	F	F	60/40	60/40	101.0	
	11					60/40	F	.	-			80/20	80/20	130.2	
	12					70/30		-	-			F	F	147.3	
	13					F		-	-					182	
	14							-	-					203	
	15							70/30	70/30					258	

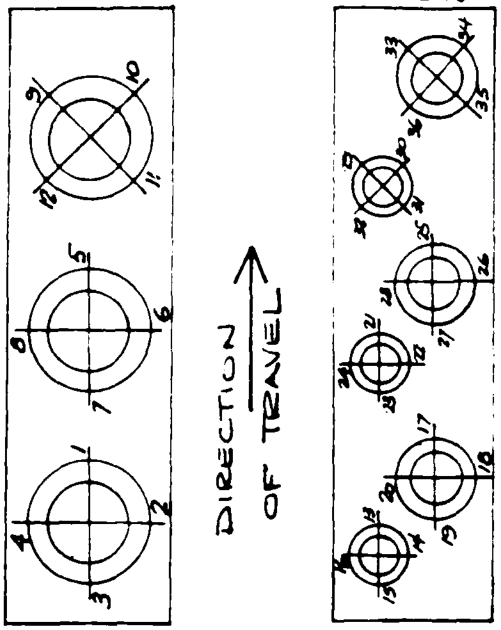
NOTES:

1. OIL IMMERSED FOR VIBRATION & IMPACT TESTS.
2. VIBRATED AT ± 2.0g RMS FOR 100,000 CYCLES PRIOR TO IMPACT TESTS.
3. WIRES ATTACHED WITH DEXTER HYSOL EA 956 EPOXY ADHESIVE.
4. SPRING PRESSURE SETTINGS AS EXPERIMENT #21.

ANCO ENGINEERS INC	JOB NUMBER 1663.11 PAGE ___ OF ___
MADE BY ___ DATE 11-20-86	DESCRIPTION
CHECKED BY RCL DATE 11-86	EXPERIMENT No 23
	TITLE CONICAL

TOP VIEW

SIDE VIEW



RUN NO.	START POS.	BRICKS	BUMP	
1	101	0	2x1	
2	91	0	2x1	
3	80	0	2x1	
4	60	0	2x1	
5	44	0	2x1	
6	25	0	2x1	
7	24	1	2x1	
8	25	2	2x1	
9	25	3	2x1	
10				
11				
12				
13				
14				
16				

KEY: F = FAILED (BROKEN OR 100% STRETCHED)
#/# = APPROXIMATE SLUG DEFLECTION.

	WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	G'S	COMMENTS
	GAGE	38	38	38	38										
RUN	1	-	-	-	-									11.8	
	2	-	-	-	-									13.2	
	3	-	-	-	-									15.2	
	4	-	-	-	-									17.1	
	5	-	-	-	-									21.7	
	6	60/40	-	-	-									27.6	
	7	70/30	70/30	-	-									36.8	
	8	80/20	80/20	70/30	70/30									49.3	
	9	F	F	F	F									77.6	
	10														
	11														
	12														
	13														
	14														
	15														

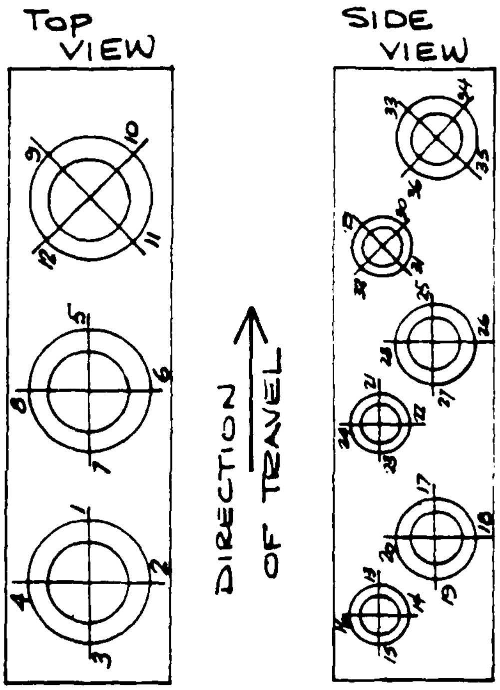
NOTES:

1. OIL IMMERSED IMPACT TEST
2. WIRES ATTACHED WITH DEXTER HYSOL EA 95[illegible] EPOXY ADHESIVE
3. SPRING PRESSURE SETTING AS EXPERIMENT #21.

ANCO ENGINEERS, INC.
9937 Jefferson Boulevard, Culver City, CA 90232

MADE BY	[illegible]	DATE	11-20-86
CHECKED BY	Pcl	DATE	11-86

JOB NUMBER 1663.11 PAGE ____ OF ____
DESCRIPTION
EXPERIMENT No 24
TITLE CONICAL



RUN NO.	START POS.	BRICKS	BUMP	
1	54	ø	2×1	
2	40	ø	2×1	
3	24	ø	2×1	
4	24	1	2×1	
5	24	2	2×1	
6				
7				
8				
9				
10				
11				
12				
13				
14				
16				

KEY: F = FAILED (BROKEN OR 100% STRETCHED)
x/x = APPROXIMATE SLUG DEFLECTION.

WIRE NO.	3	7	11	12	15	23	31	32	19	27	35	36	G'S	COMMENTS
GAGE	35	35	35	35										
RUN 1	–	–	–	–									28.8	
2	–	–	–	–									35.0	
3	60/40	60/40	–	–									51.3	
4	80/20	80/20	60/40	60/40									89.9	
5	F	F	90/10	90/10									126.4	
6			F	F									165.1	
7														
8														
9														
10														
11														
12														
13														
14														
15														

NOTES:
1. OIL IMMERSED IMPACT TEST
2. WIRES ATTACHED WITH DEXTER HYSOL EA 956 EPOXY ADHESIVE
3. SPRING PRESSURE AS EXPERIMENT #21.

4306-87

END
DATE
FILMED
6-1988
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