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REPORT NO. RS-TR-70-3

**EXPLODING FOIL TECHNIQUES  
INTERIM REPORT**

by  
**Erich H. Richert  
William S. Hodge**

April 1970

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## **EXPLODING FOIL TECHNIQUES INTERIM REPORT**

by

**Erich H. Richert  
William S. Hodge**

**DA Project No. 1L013001A91A  
AMC Management Structure Code No. 5016.11.844**

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**Missile Design Branch  
Structures and Mechanics Laboratory  
Research and Engineering Directorate  
U. S. Army Missile Command  
Redstone Arsenal, Alabama 35809**

### Abstract

This report discusses one new way to generate high pressure without using high quality explosives. Exploding foil techniques, the proposed method, results in a high pressure pulse of very short duration against a target. This phenomenon can be subdivided into three phases: the initial region at which the material heats up and explodes, the region of the dwell phase at which the vaporized material forms a low-conductivity vapor, and the region at which a resurge of current occurs in the vapor. Data applicable to rapidly exploded foils and wires are discussed, and the foils appear to be more suitable for simulating high pressure short duration shock waves because of the greater directionality achieved, and shorter heating time.

Exploding foil techniques could represent an applicable, inexpensive tool for simulation of high pressure short duration shock waves. The task here was to plan and design an apparatus for generating shock waves in the laboratory by exploding foil.

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## **I. Introduction**

At present very high pressure waves can be generated by a shock-wave technique using high quality explosives. This shock method of reaching high pressure is not very old (less than 15 years) and was made possible by the manufacture of high quality explosives and an explosive lens to produce very plane shocks. Various explosives are combined or the explosive chains are shaped in such a way that a detonation at a point is converted to the desired shock shape a short distance away from the initiation point.

The pressures that can be reached in a target depend on the pressure generated in the explosives which have a range from about 50 to 400 kilobars. The pressure generated in the material placed in contact with the explosive depends on its shock impedance. This means that the condition created thus in the material sample will depend on the product of the shock velocity and the initial density.

Unfortunately, the application of explosives is difficult and expensive. Underground facilities, away from populated areas, are necessary so that up to 100 pounds of explosives can be set off. Extraordinary safety measures are a must because of the danger to people involved. The operation expenses are considerable since each experiment destroys machined equipment necessary which must be replaced for the next test. This cost time could take weeks and would delay further experiments.

Therefore, researchers have tried to find a new way to generate high pressure without using high quality explosives. This new method had to be easier, much cheaper, less dangerous, and much faster, allowing repetition of experiments in a much shorter time.

As it appears, exploding foil techniques seem to be one answer to this demand. With the exception of a nuclear explosion itself, the highest energy density that can be obtained at a given point for a short time results from a wire or foil explosion when a sudden large pulse of electrical current is passed through it. A small piece of foil or wire, exploded by passing high electrical energy through it, creates a high temperature vaporization wave that results in a high pressure pulse of very short duration against a target.

This exploding phenomenon can be subdivided into three phases or regions which may be distinct or overlapping. The first phase is the initial conduction region where the material heats up and explodes. The second region is the dwell phase where the vaporized material forms a low-conductivity vapor. The third region is where a resurgence of current called post-dwell conduction occurs in the vapor. The time before the post-dwell phase is reduced if the

voltage is increased, and at sufficiently high voltages, the post-dwell and the initial conduction phase merge.

In the work on wires it was found that some type of relaxation process appears to take place at the onset of vaporization. This seems to be due to overheating in air. Overheating of above 20 electron volts per atom has been observed and even higher values appear attainable by using smaller wires and by going to faster circuits and higher voltages. Thus, large amounts of energy up to many times that of vaporization energy can be placed in the foil or also in the wire during the initial conduction phase. Therefore, if a capacitor bank triggers the foil and the electrical energy is supplied in such a short time that the foil is vaporized faster than it can get out of the way, and in addition, if the foil is confined in such a way to keep the metallic vapor back from immediate rapid expansion, the pressure can rise tremendously. (Pressures over 160 kilobars = 2.4 million psi were obtained.)

Although fewer data are presently available for rapidly exploded foils than for rapidly exploded wires, foils appear to be suitable for simulating high pressure short duration shock waves because greater directionality can be achieved. Also, the required heating time seems to be shorter than in the wire of the same mass per unit length, and because the foil explodes uniformly if the energy threshold for extensive vaporization is exceeded, the target is hit on all points simultaneously.

In summary, the exploding foil techniques could represent a very applicable, inexpensive tool for simulation of high pressure short duration shock waves. As investigations have shown, shock waves attenuate more rapidly than expected as they enter target material. This indicates a fundamental shortcoming of present theory regarding the behavior of material under shock. The point of failure under rapid dynamic tension is not the same as it is under static tension. If material is left under sufficient static load long enough, it will eventually come apart in a certain time, a week, maybe a month. For rapid loading, as it can be done with exploding foil, however, failure can happen almost instantaneously. Therefore, the exploding foil technique seem to represent a very applicable, inexpensive tool for gathering critical material property data which cause failures.

A thorough literature survey on research in this direction was undertaken but produced no results. Thus the task was to plan and design an apparatus for generating shock waves in the laboratory by exploding foil. This apparatus, in general, had to contain a power supply, the storage of energy, and the impulse or exploding device to which the stored energy had to be transferred in a timely manner. Means of monitoring of the applied current and voltage and also of the resulting peak pressure due to the foil explosion had to exist. Furthermore, a time history of the pressure of every test had to be obtained.

## 2. High Energy Discharge System

### a. General

The first part of this task mentioned above was therefore to design a storage system that would deliver at least 5000 joules of energy into a resistive type load such as the aluminum foil.

To sublime a foil - 1 in.  $\times$  1 in.  $\times$  0.001 in. = 0.001 in.<sup>3</sup> approximately 545 joules are necessary. For the intended area the volume of aluminum foil to be exploded -1.75 in.  $\times$  1.875 in.  $\times$  0.001 in. = 0.0033 in.<sup>3</sup> approximately 1800 joules would be enough for sublimation. The estimated range of 5000 joules for the energy storage system appears therefore sufficient at this time. The schematic and the component list of this high energy discharge system are shown in Figure 1.

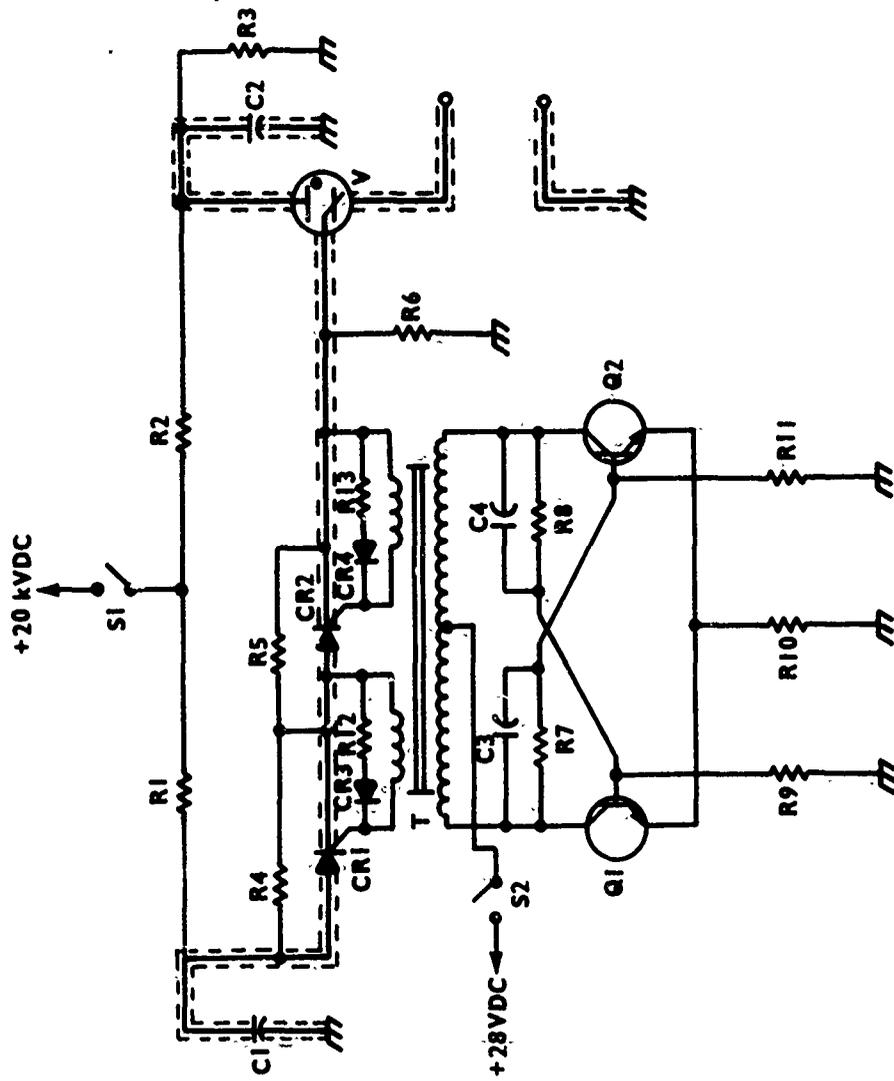
### b. Description of Operation

The operation of this system, described as follows, begins when switch  $S_1$  is closed. A 20-kVDC radar type power supply charges capacitor  $C_2$  to 8000 joules through resistor  $R_2$ . It takes about 32 seconds for  $C_2$  to charge to 8000 joules. At the same time, a trigger capacitor  $C_1$  charges to 240 joules through the voltage divider network comprised of the resistors of  $R_1$ ,  $R_4$ ,  $R_5$ , and  $R_6$ . It takes about 6.4 seconds for the trigger capacitor  $C_1$  to charge to 240 joules. When  $C_2$  reaches full charge, switch  $S_2$  is manually closed and a square wave inverter, comprised of the transistors  $Q_1$  and  $Q_2$ , triggers the control rectifiers  $CR_1$  and  $CR_2$  simultaneously through the transformer T. Capacitor  $C_1$  discharges through the ignitor electrode of the ignitron V and the foil load, and then to ground, thus igniting the ignitron V into conduction. Then  $C_2$ , the main energy storage capacitor, discharges through the ignitron into the foil load until the foil explodes. Diodes  $CR_3$  and  $CR_4$  in conjunction with resistor  $R_{12}$  and  $R_{13}$  prevent destruction of the SCR gates from high reverse voltages. Transistors  $Q_1$ ,  $Q_2$ , capacitors  $C_3$ ,  $C_4$ , resistors  $R_7$  through  $R_{10}$ , and transformer T comprise a free-running L-R inverter used to trigger the SCR's, the  $CR_1$  and the  $CR_2$  rectifiers.

## 3. High Energy Capacitor Discharge Unit

### a. General

During the design of the high energy discharge system (5000 joules) a portable high energy capacitor discharge unit (18,600 joules) was obtained from NASA on a loan basis. This unit was built for use in magnetic forming



COMPONENT LIST		
REF DESIG	VALUE	REMARKS
R1, R2	400 k, 2kW	
R3	400 k, 500W	
R4, R5	15k, 100W	
R6	10 k, 100W	
R7, R8	1.4 k, 1/2W	
R9, R11	11, 1/2W	
R10	10, 1/2W	
C1	15 $\mu$ f, 4kVDC	
C3, C4	0.002mf	
CR1, CR2	35RE100	IR
Q1, Q2	2N576A	GE
V	GL 7703	GE
T	P50T-CF-50T S2T-2T	DELTA MAX.5340-D1
CR3, CR4	1N849	
R12, R13	15, 1/2W	

FIGURE 1. HIGH ENERGY DISCHARGE SYSTEM

processes. Investigations showed that this unit could also be used for exploding foil.

b. Description of the Unit

The high energy capacitor discharge unit is a mobile source of low inductive electrical energy delivering rapid pulses of intense transient electrical currents to an impulse device. The power requirement is 115 volts, 60 cycles ac at approximately 20 amperes. The unit is rated at 18,600 joules and is approximately 3 feet wide, 5 feet long, and stands 3 feet high from the trailer bed (Figure 2). A Phenolite cover, equipped with four compartments, houses all

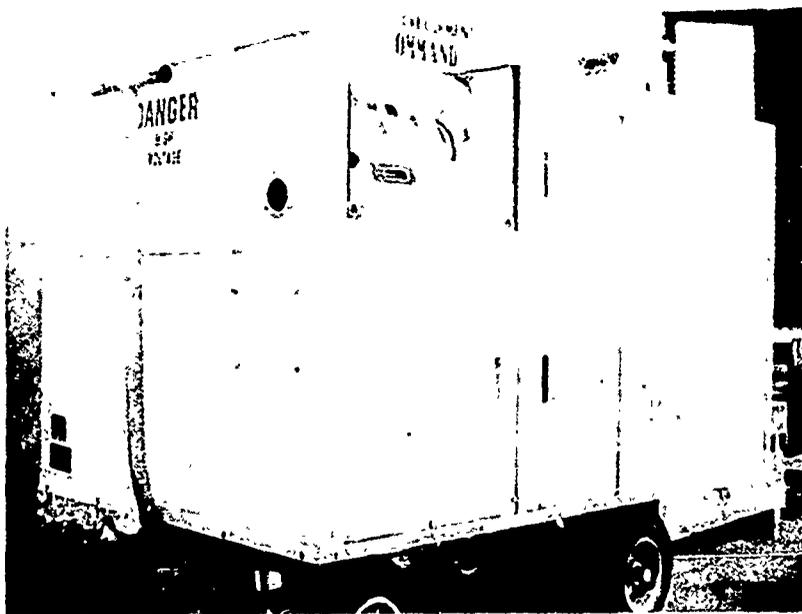


FIGURE 2. HIGH ENERGY CAPACITOR DISCHARGE UNIT (18,600 JOULES)

components. Access to the compartments is through eight doors. Each door, except the control door, opens a normally closed microswitch, shutting off the power to the shorting relay whenever a door is opened.

A more important safety feature, however, is isolation of the control circuit from the high voltage power circuit. This is accomplished with the use of six Raysistors (Raytheon Trade Name), each consisting of control (light source) and signal (photocell) circuits assembled in an insulated casing and operated by pushbutton switches on the operator's control panel. No electrical connections exist between the light sources and photocells, thereby completely isolating the control operator and control circuits from the high voltage circuits.

When the control light in the Raysistor is turned on, the resistance in the photo-cell is reduced enough so that it acts as a switch to energize a sensitive relay.

The shorting bar relay, a hand shorting switch, and a smaller relay in the trigger circuit are other safety devices. Appendix A describes these and other components of the high energy discharge bank. Appendix B gives a list of the major functional components.

c. Functional Operation of the Unit

The block diagram of high energy capacitor discharge bank is shown in Figure 3. The unit is operated from the operator's control panel (Figure 4). The control panel contains all the switches and indicators necessary for normal operation and emergency shutdown.

There are two other components not involved in the normal operation of the unit. One is the adjustable voltage control, or variac. This component (Figure 5) is used to set the input voltage to the triggering unit.

The second component (Figure 6), the hand-operated shorting switch, is always closed when the unit is not in operation and opened before operation.

The unit is energized from the operator's control panel through a key switch which turns on the power to the 6-volt power supplies, the ventilating fan, and the filament section of the high voltage power supply.

The key switch also turns on the standby light; the short light comes on when the shorting bank relay closes.

All relays in the high voltage compartment are energized by Raysistors which are operated by depressing applicable switches on the control panel. All switches are self-illuminated.

Adjacent to the control panel, the high voltage meter relay occupies a well (Figure 5) that has an electrically interlocked plexiglass door. The meter indicates the amount of charge on the capacitors. The control meter is a 50-microampere movement with a scale calibrated from 0 to 10 kilovolts. The meter relay shuts off the high voltage power supply when the predetermined meter setting is reached or when the stop charge switch is depressed.

When the on switch is depressed, voltage is applied to the remaining control switches.

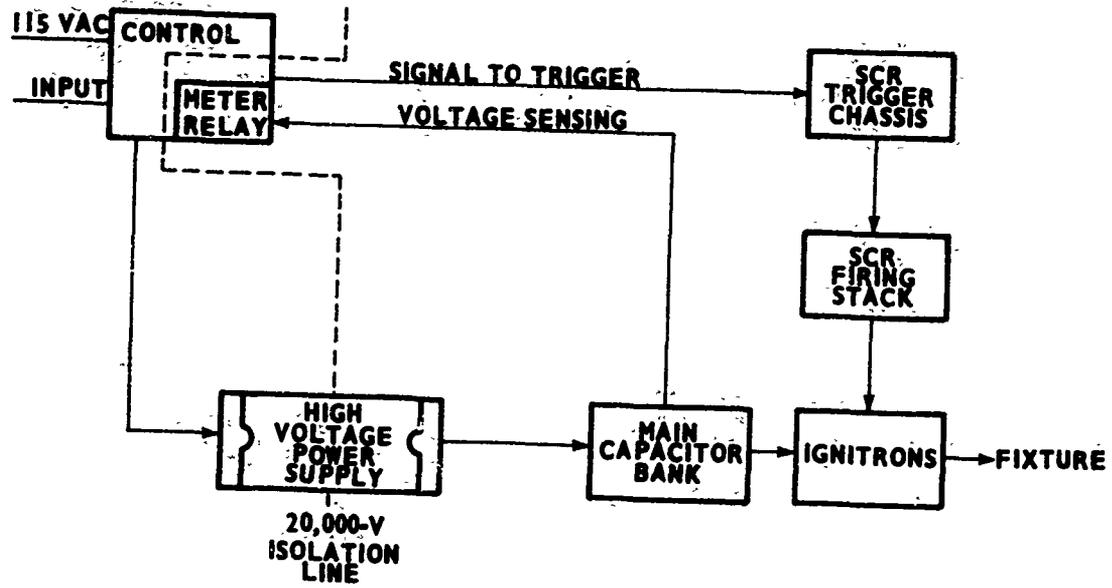


FIGURE 3. HIGH ENERGY CAPACITOR DISCHARGE BANK

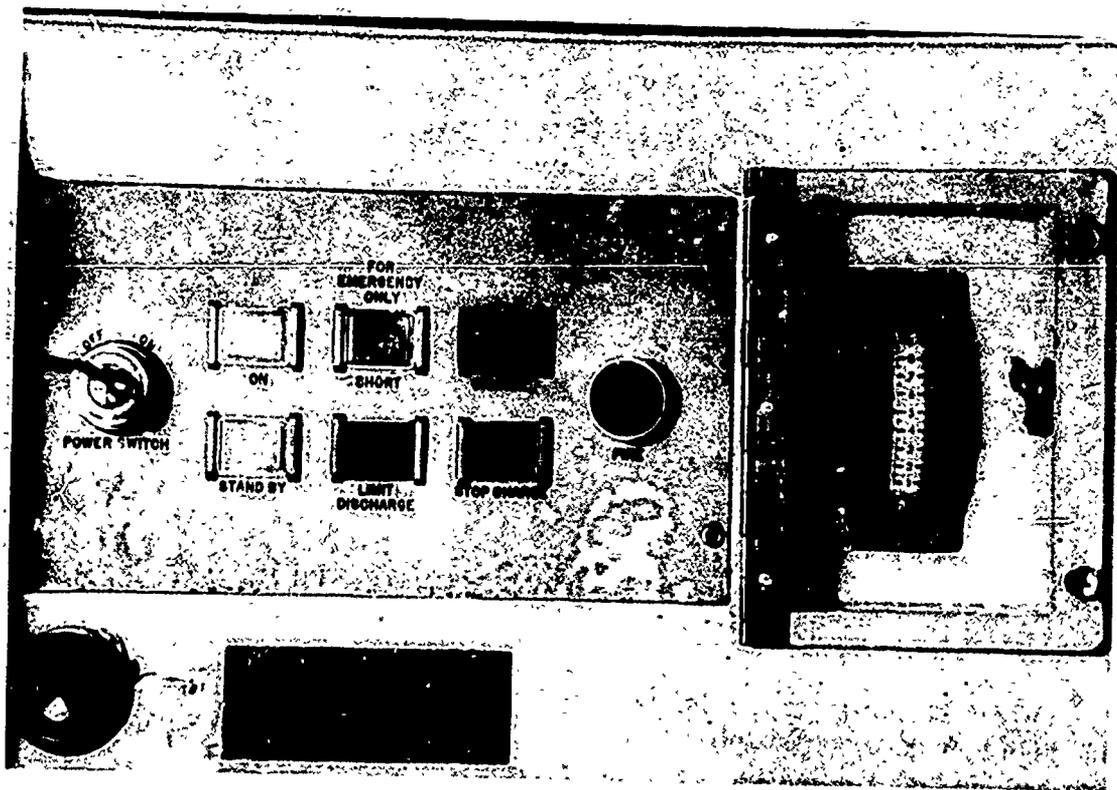
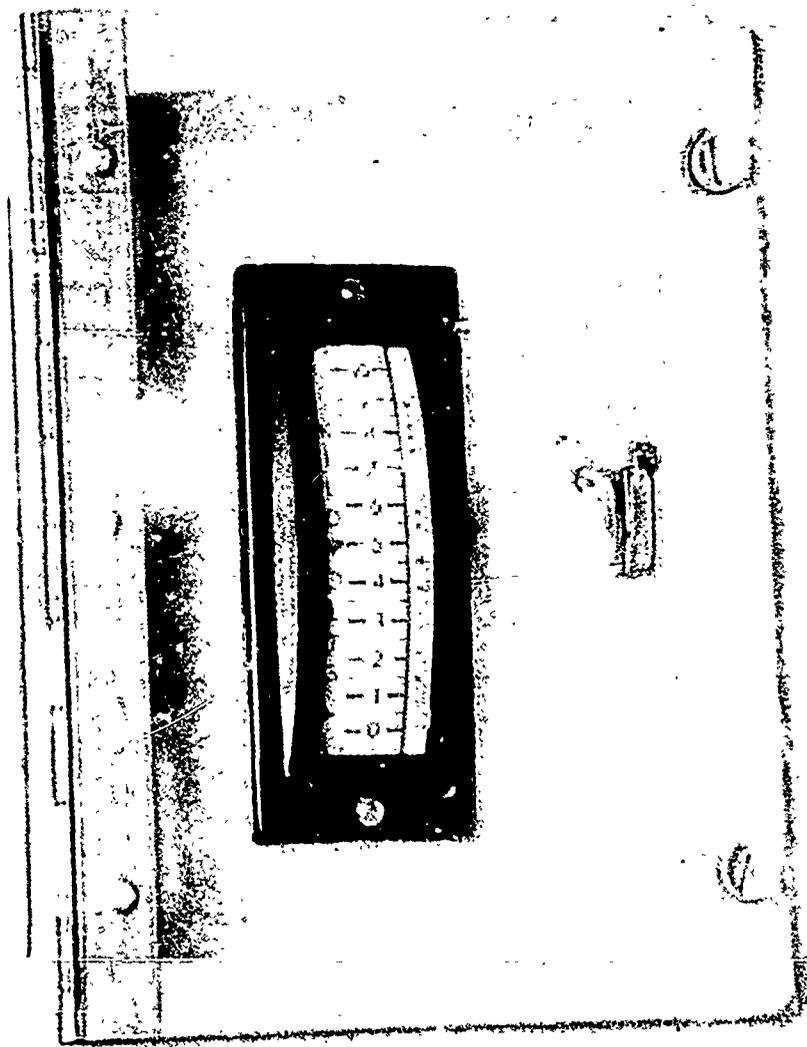


FIGURE 4. OPERATOR CONTROL PANEL



**FIGURE 5. ADJUSTABLE VOLTAGE CONTROL**

When the charge switch is depressed, 115 volts ac is sent to the primary of the high voltage power supply. The power supply charges the main capacitor bank when the high voltage vacuum relay operates.

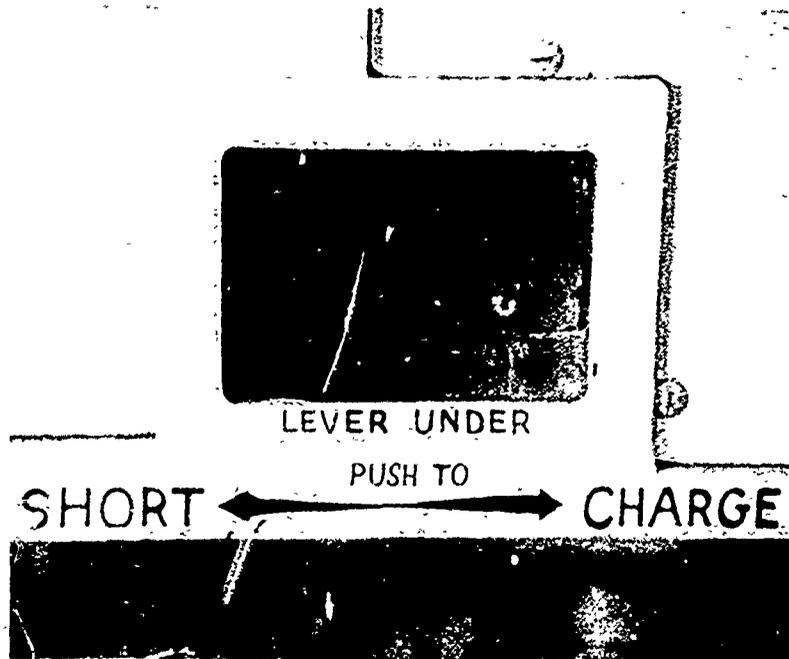


FIGURE 6. HAND-OPERATED SHORTING SWITCH

The main bank consists of six 60-microfarad capacitors in parallel, with a combined capacity of 360 microfarads.

The high voltage power supply is a conventional 115-volt primary, high voltage secondary unit using four 8020 tubes in a bridge rectifier circuit.

When it is desired to discharge the capacitor bank without firing, and no emergency exists, the limit discharge switch is used. Depressing the limit discharge switch de-energizes the high voltage vacuum relay, allowing the limit discharge resistor to be placed across the main capacitor bank and causing a safe discharge of the main bank.

Under normal operation, after the charge switch has been depressed and the unit has reached the desired charge, the ready light is illuminated. This happens when the charge has been stopped automatically by the meter, or the operator has actuated the stop charge switch.

When the fire switch is operated, the 300-volt relay closes and the firing unit sends a 300-volt pulse to the pulse transformer of the trigger circuit. The firing unit uses a voltage doubler operating from 115-volt ac line to provide the pulse. The pulse transformer reduces the voltage 60-to-1 or 5 volts and gates the silicon controlled rectifier of the trigger bank.

When the silicon controlled rectifier stack is fired, a positive going pulse is transmitted to the ignitors of the ignitrons driving them positive with respect to the cathodes.

The trigger bank is two 2 mf/2kV capacitors that store the charge for firing the ignitors of the ignitrons.

When the ignitrons conduct, the current flows from the main capacitor bank to the foil by way of the quick disconnect collector (Figure 7), through the 8 coaxial cables into the fixture, and then into the impulse device. By proper setting of the meter and by exceeding the threshold of vaporization of the aluminum foil, the foil will explode.

#### **4. Energy Transfer**

The eight Rex-Turbo low inductance coax cables, leading to the fixture (Figure 7 and 8) are fastened to the conductor block with special designed connectors. The cables are made short enough to make the discharge circuit initially critically damped.

#### **5. Fixture**

The fixture, which serves thus as cable collector but also as support for the impulse device, consists of four aluminum conductor blocks ( $2\frac{1}{4} \times 2 \times 11\frac{1}{4}$  in.), one cable plate, one plexiglass base plate, one plywood base plate, and two wooden supports. Figures 7 and 8 show the design of the fixture and the cable arrangements.

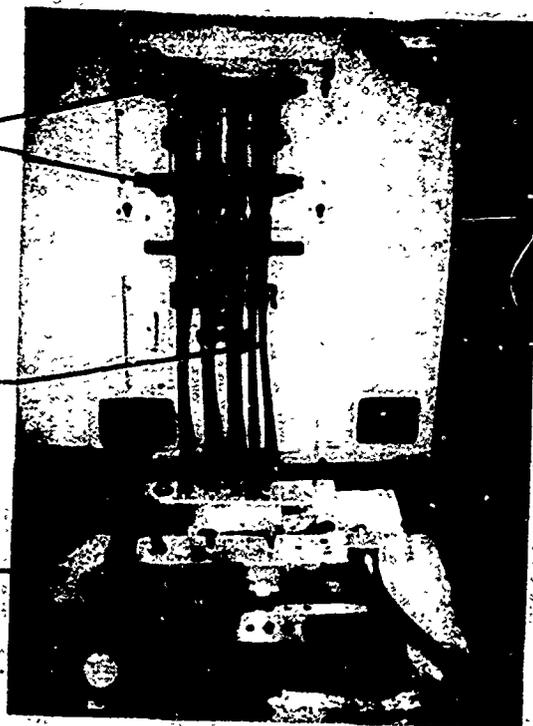
#### **6. Impulse Device**

The impulse device is located on top of the fixture and held in place by four bolts (Figure 7). The device consists of two aluminum-contact plates, the fiberglass spacer between the contact plates, the fiberglass backcover, two fiberglass front covers, the base plate with stiffeners, and the foil carrier (Figures 9 and 10). By incorporation of all experiences gained during development and checkout of the device (i. e., in general by changing contact plate and spacer configuration, covering the insulating spacer in the main portion of the impulse device and also in the foil carrier with 0.002-in. thick Mylar tape for protection against fast burnouts), and by increasing the tightness, it was possible to extend the use of the whole impulse device including the foil carrier with respect to the number of shots possible. In the beginning it was necessary

**QUICK DISCONNECT  
COLLECTOR**

**COAXIAL CABLES**

**FIXTURE**



**IMPULSE DEVICE**

**FIXTURE**

**CONNECTORS**

**FIGURE 7. ENERGY TRANSFER**

NO.	NAME	MATERIAL	QUANTITY
1	CONDUCTOR - BLOCK (UPPER)	AL	2x
2	CONDUCTOR - BLOCK (LOWER)	AL	1x
3	CONDUCTOR - BLOCK (LOWER)	AL	1x
4	CABEL PLATE	FIBERGLASS	1x
5	FIXTURE PLATE	PLEXIGLASS	1x
6	FIXTURE PLYWOOD PLATE	PLYWOOD	1x
7	SPACER	FIBERGLASS	2x
8	SUPPORT	PINE	2x
9	PLATE	FIBERGLASS	1x
10	CONNECTOR	AL	8x
11	SETSCREW 3/8	ST	8x
12	NUT	LS	8x
13	BOLT	LS	4x
14	WASHER	L2	8x
15	SCREW MACHINE (FLAT HEAD) HELIX 1/16"	LS	2x
16	WOODSCREW (1 1/2 lg)	LS	4x
17	WOODSCREW (1.8 lg)	LS	8x

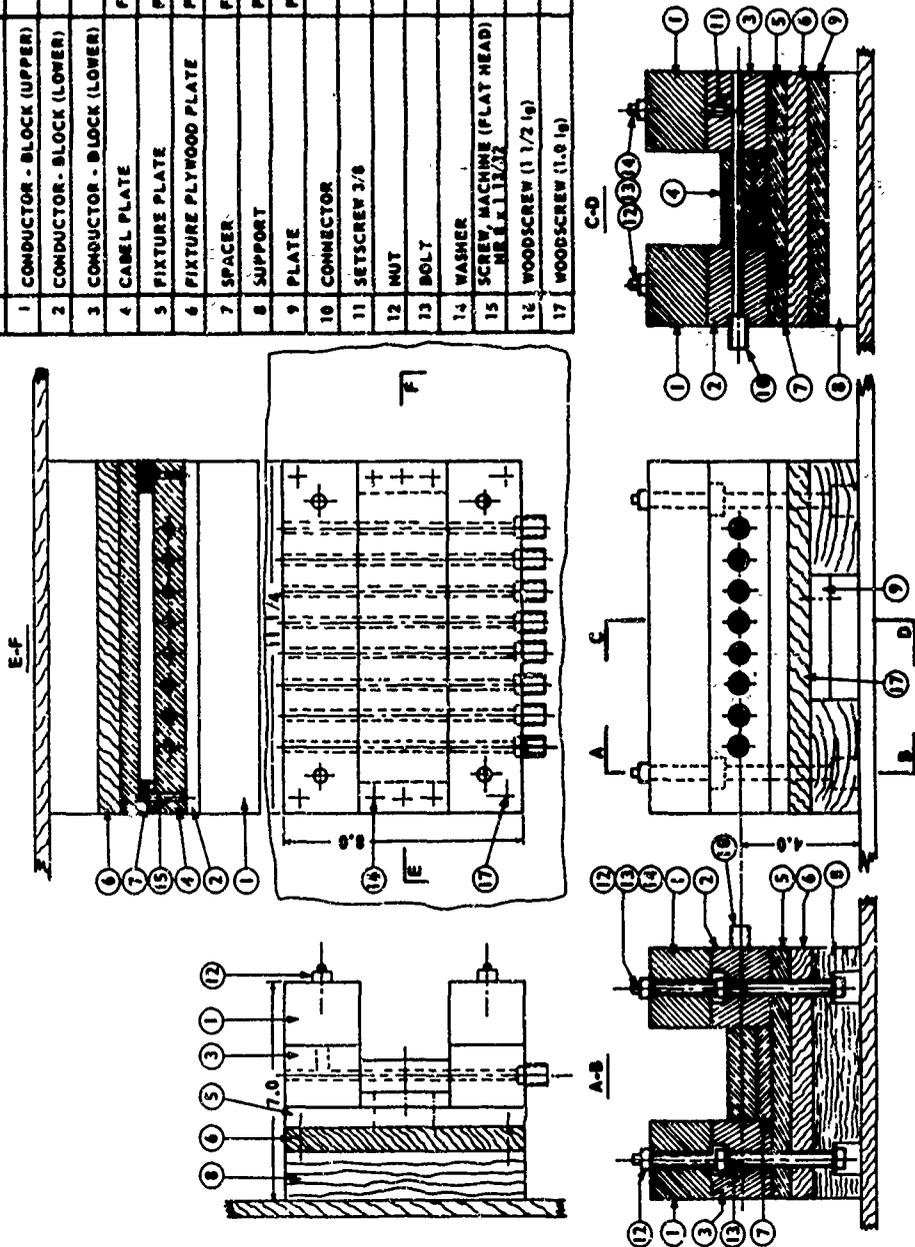


FIGURE 8. FIXTURE EXPLODING CONDUCTOR (PRELIMINARY)

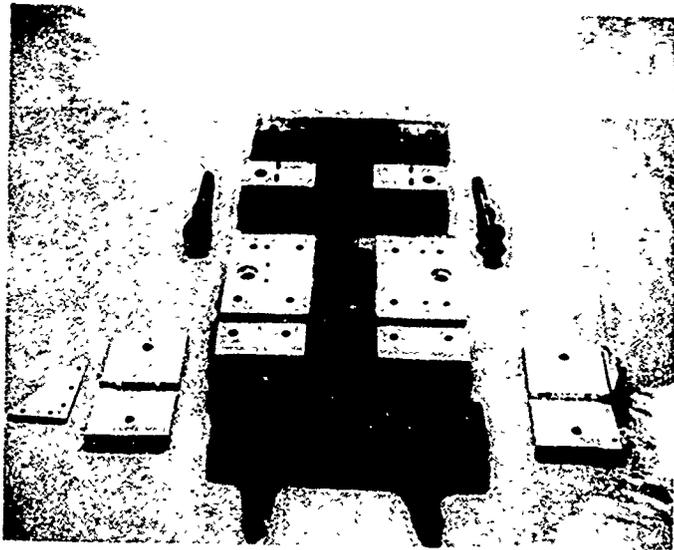


FIGURE 9. IMPULSE DEVICE, EXPLODED VIEW

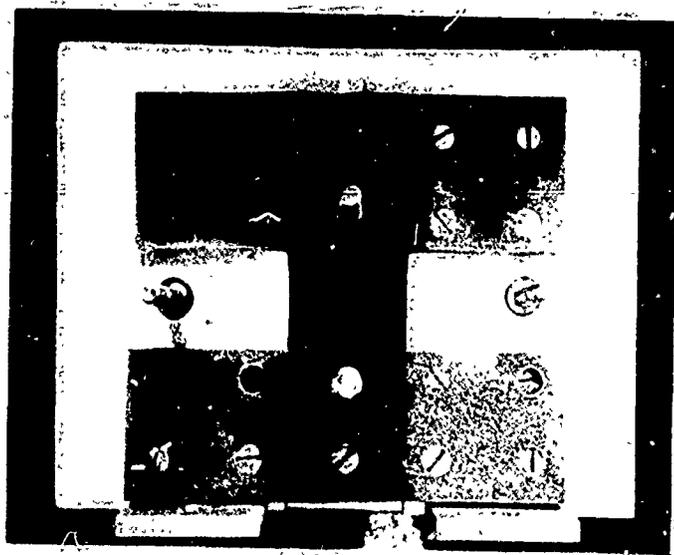


FIGURE 10. IMPULSE DEVICE, FRONT VIEW



FIGURE 11. FRONT COVER WITHOUT MYLAR TAPE AFTER FIRING

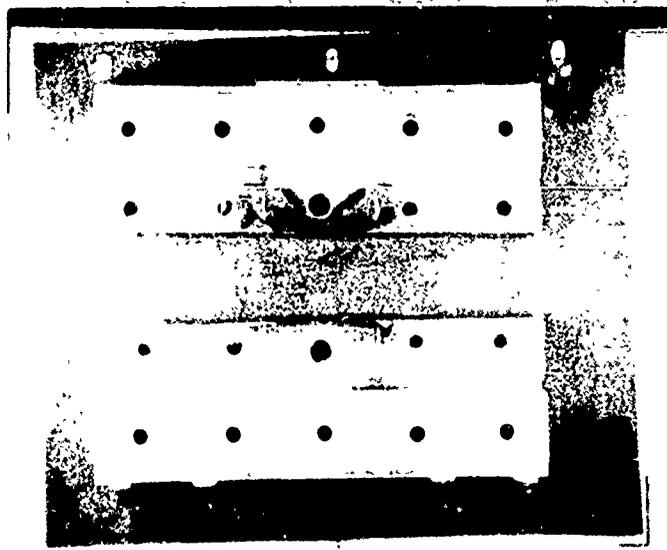


FIGURE 12. FRONT COVER WITH MYLAR TAPE AFTER FIRING

to rework the device after about five shots because of erosion, burning up of the fiberglass insulation in particular areas, and removal of accumulated aluminum particles in certain places to prevent short circuits (Figure 11 and 12).

In the present state of the device (Figure 13 through 17), especially after applying small foil holders to the foil carrier (Figures 18 and 19) with provision to keep the holders, two for each side, in position during reloading, reworking is a must only after 80 to 100 shots. The foil holders minimize the erosion of the main contacts and contribute to the seal-off of the explosion chamber to the side. The foil holders themselves instead of the main contacts erode now, and they have to be replaced after about 8 to 15 shots, which is much easier as a replacement or reworking of the main contacts. Also because of the holders, the reloading of the impulse device is now easier and faster. It is now possible to fire up to eight shots in 1 hour instead of previously only two shots per hour (Figures 20 and 21).

Other figures included here show some experiences gained during the development of the impulse device. The contact plates and the spacers were in the form as shown in Figures 22, 23, and 24.

No foilholder and tape covering were used at that time. The contact spacer (Figures 22, 23, and 24) in the form of two interlocking bushings suffered a tensile fracture after few shots. The immense pressure created by the foil explosion entered the very small gap (very tight fit) between the bushings and the contact plate and between the bushings themselves. The resulting damages are shown in Figures 25 through 29. Therefore, this configuration of the contact plates and spacers had to be changed, and in connection with other improvements as mentioned above the impulse device as designed (Figure 13) was suitable to undertake blastmeter tests.

## **7. Blastmeter and Blastmeter Tests**

### **a. General**

The objective of these tests was to determine the extent of the shock wave or blast effect produced by exploding foil.

Paper blastmeters measure the blast from the exploding foil by rupturing paper diaphragms of various diameters. The larger the diameter of the diaphragm, the more easily it will be broken. Therefore, for a weak blast, only the larger diaphragms will be broken; as the blast intensity increases, the size of the diaphragms broken becomes smaller. The strength of the blast as measured in this way can be indicative of the peak pressure in the blast. This use of the

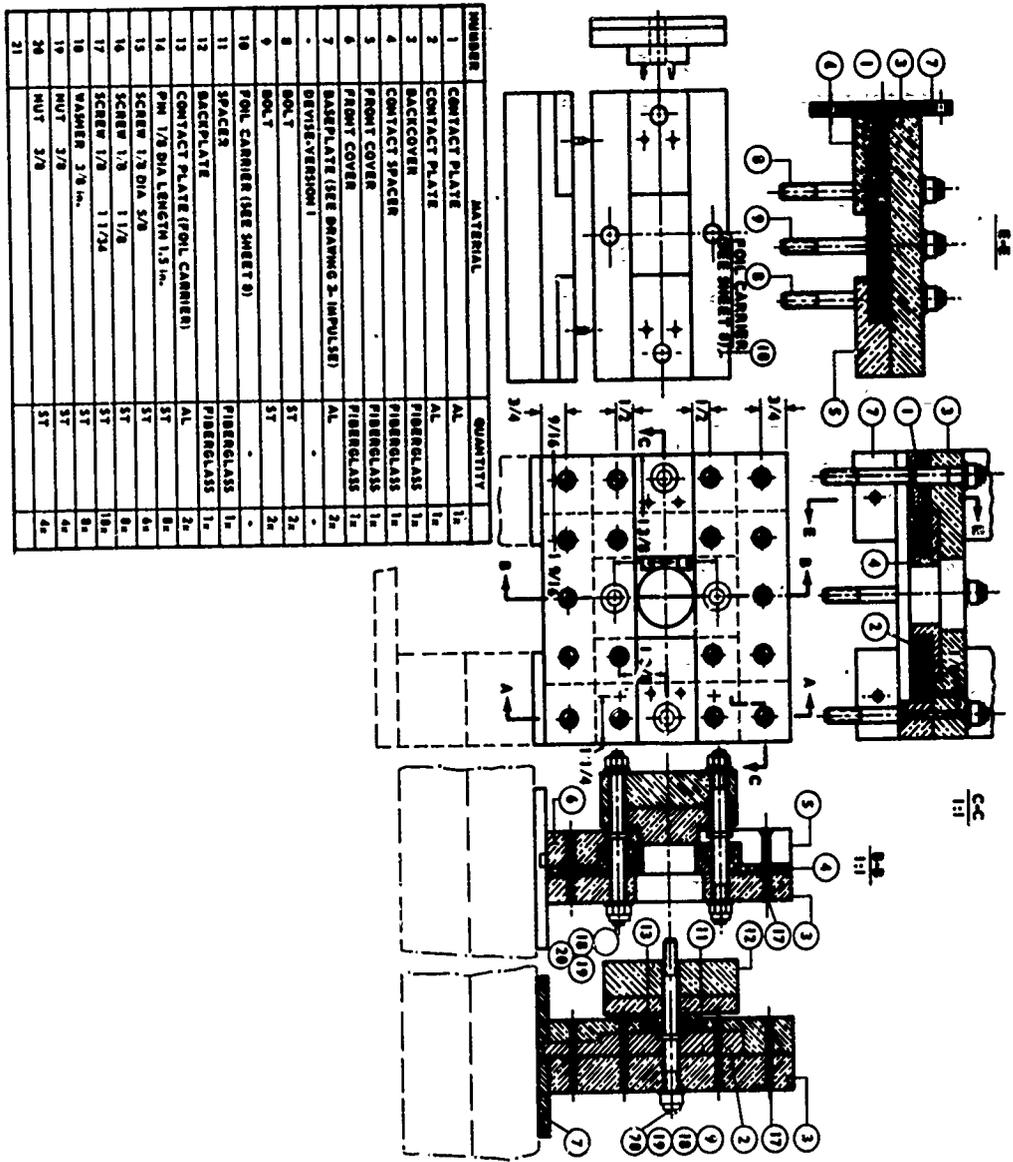


FIGURE 13. ASSEMBLY, IMPULSE DEVICE, VERSION III

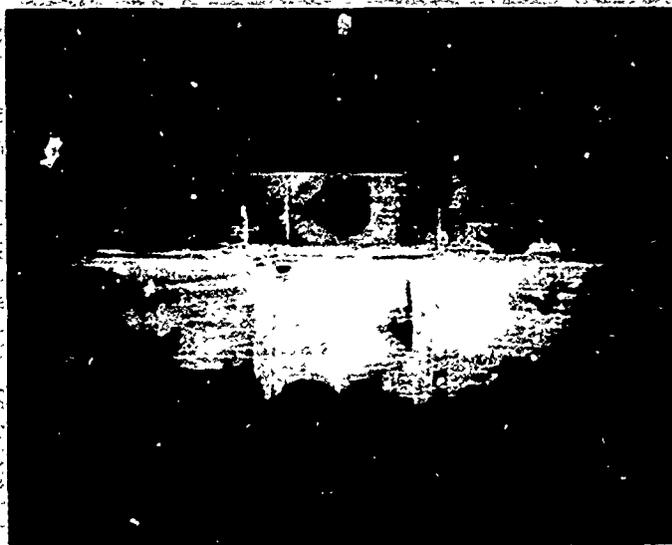


FIGURE 14. IMPULSE DEVICE, PRESENT STATE: VIEW 1

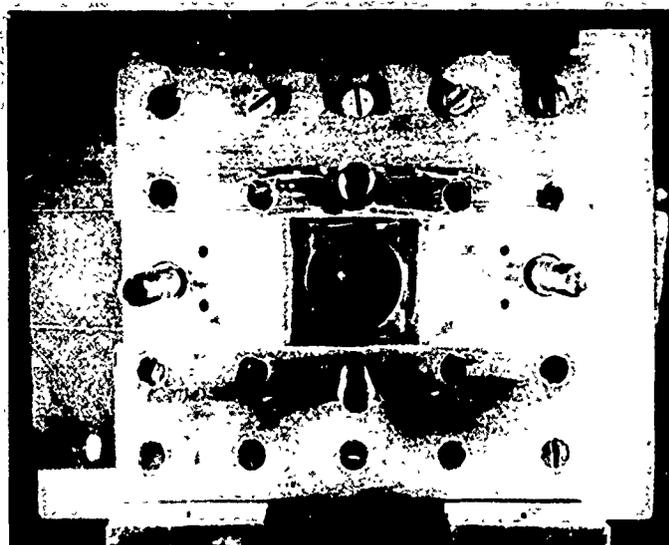


FIGURE 15. IMPULSE DEVICE, PRESENT STATE: VIEW 2

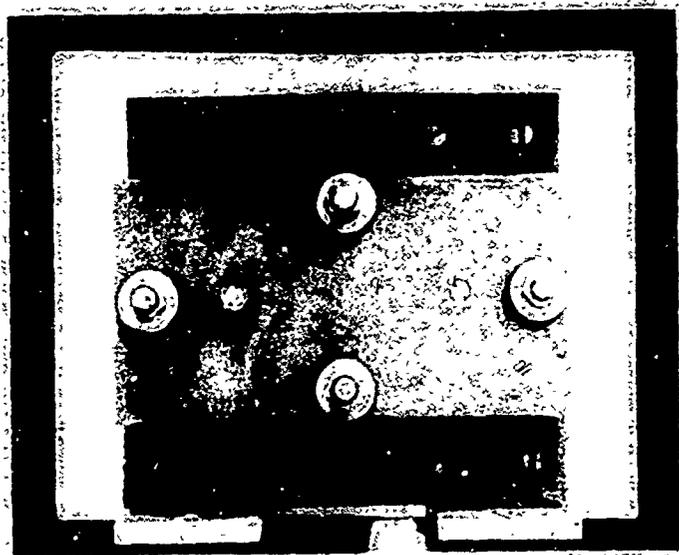


FIGURE 16. IMPULSE DEVICE, PRESENT STATE: VIEW 3

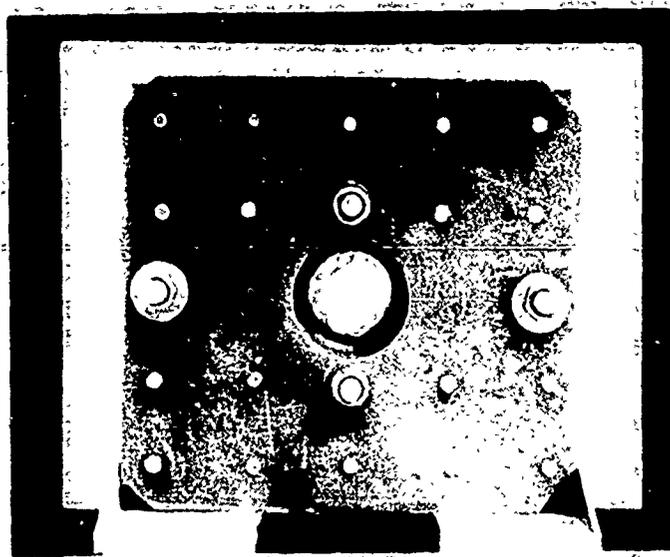


FIGURE 17. IMPULSE DEVICE, PRESENT STATE: VIEW 4

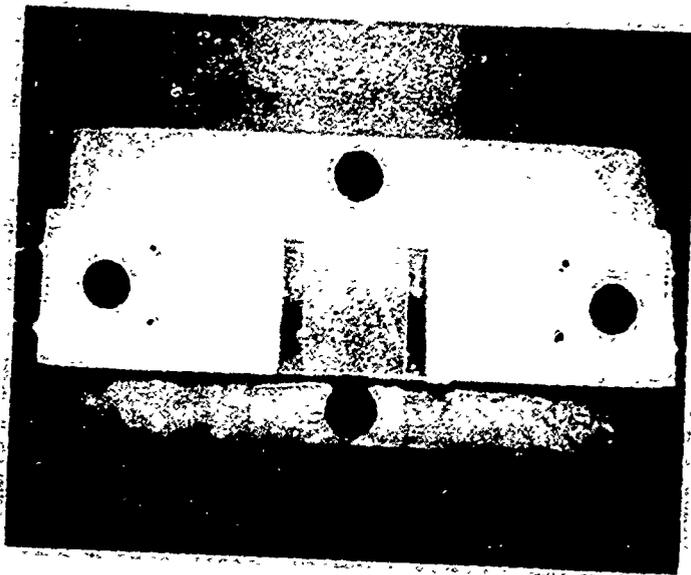


FIGURE 18. FOIL CARRIER, FOIL HOLDER, MYLAR TAPE PROTECTION  
BEFORE FIRING

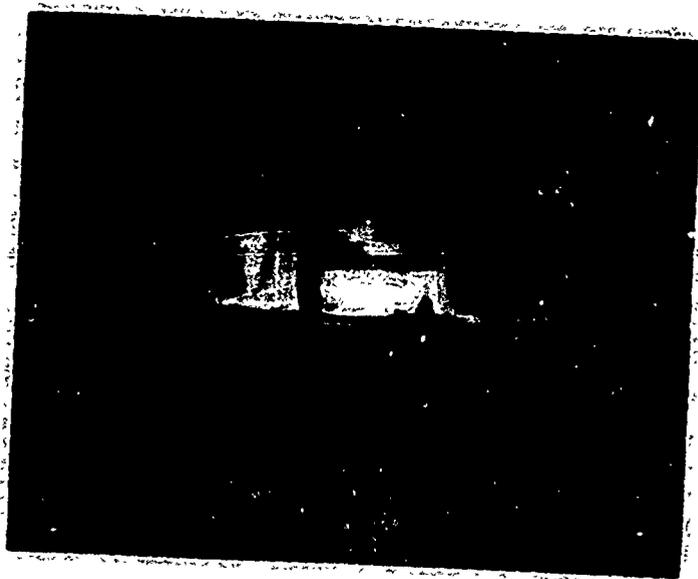


FIGURE 19. FOIL CARRIER, FOIL HOLDER, AND FOIL BEFORE FIRING

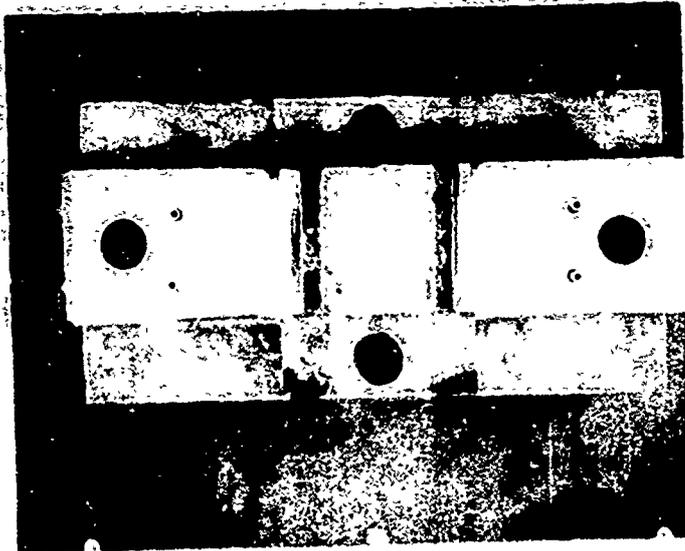


FIGURE 20. FOIL CARRIER AFTER FIRING



FIGURE 21. FOIL HOLDER AFTER FIRING

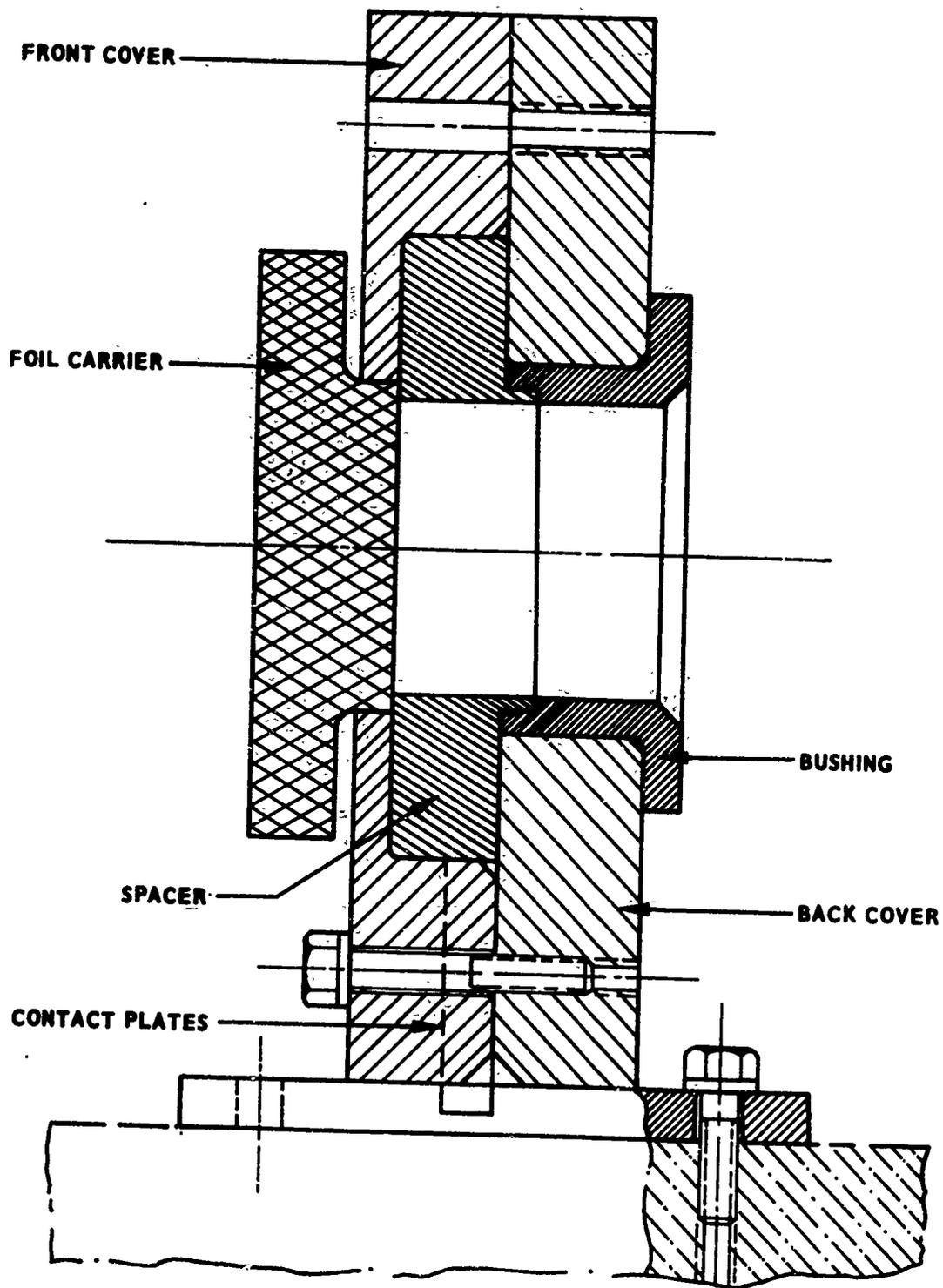


FIGURE 22. IMPULSE DEVICE, VERSION I

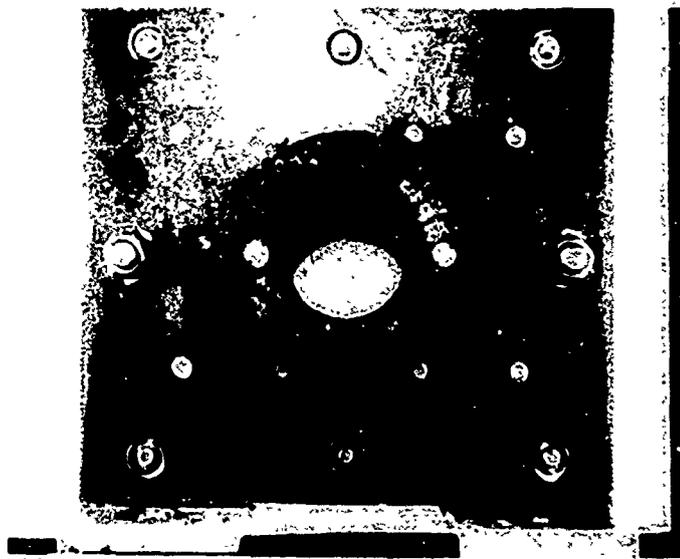


FIGURE 23. CONTACT SPACER: VIEW 1

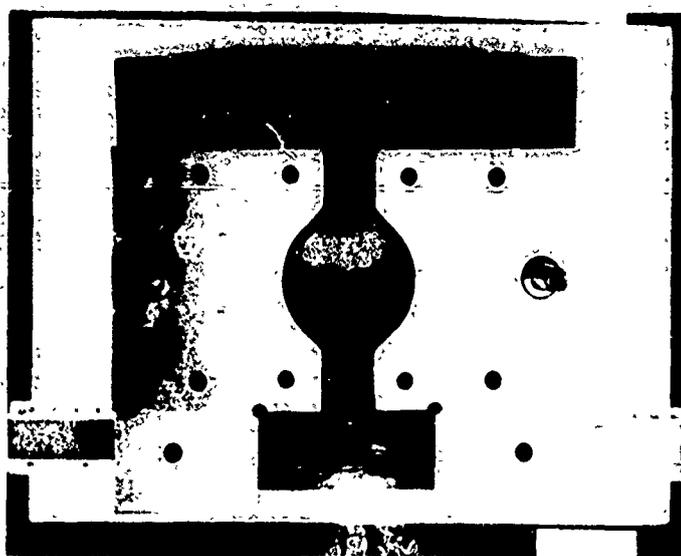


FIGURE 24. CONTACT SPACER: VIEW 2

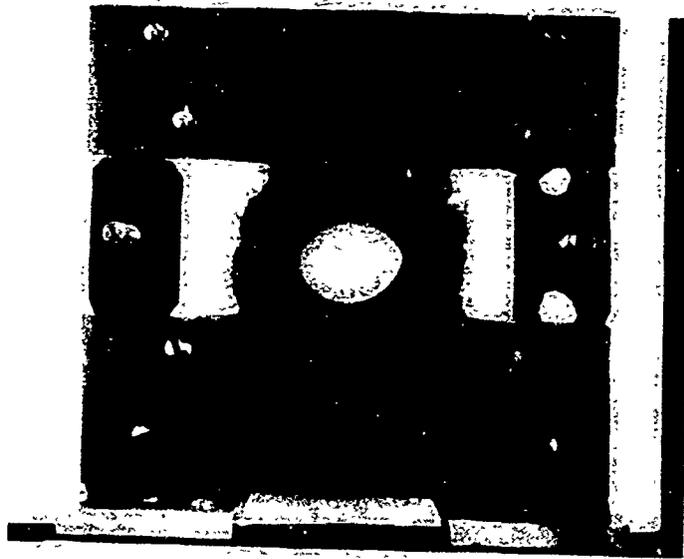


FIGURE 25. RESULTING DAMAGES: VIEW 1

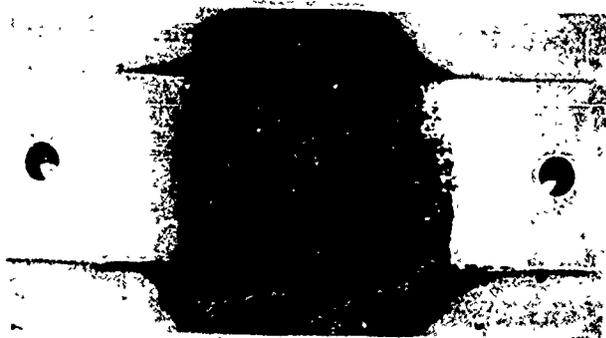


FIGURE 26. RESULTING DAMAGES: VIEW 2



FIGURE 27. RESULTING DAMAGES:  
VIEW 3



FIGURE 28. RESULTING DAMAGES:  
VIEW 4



FIGURE 29. RESULTING  
DAMAGES: VIEW 5

blastmeter is applicable to muzzle blast from guns, to the blast of high explosives, as well to the blast created by exploding foils. A rough calibration of the paper blastmeter, expressed in terms of peak pressure required to break a given diaphragm, is shown in Table I.

Figures 30 through 35, illustrate the test setup for the blastmeter tests.

b. Blastmeter

As the pictures show, the blastmeter device consists of two main parts, the tract and the sled (Figures 30, 31, and 32).

**TABLE I. PRESSURE REQUIRED TO BLOW OUT HOLES IN STANDARD PAPER BLASTMETER**

No. of Holes	1	2	3	4	5	6	7	8	9	10
Dia/ Inches	5-3/8	3-3/4	2-3/4	1-7/8	1-1/4	7/8	5/8	1/2	5/16	1/4
Area in <sup>2</sup>	22.96	11.04	5.93	2.76	1.22	0.601	0.306	0.196	0.076	0.049
Pressure psi	1.0	1.4	1.9	2.7	3.7	5.2	7.3	10.0	14.0	20.0

The track, fastened to the fixture with two bolts, is adjusted parallel to the axis of the exploding foil and marked off in 1-inch increments from 4 to 20 inches.

The sled functions as the holder of the diaphragms, and the design allows an easy and fast exchange of the nine different diaphragm holders.

The diaphragm holders, each one drilled in pairs of two simple sheets with a precise hole ranging from 1/4 to 3 3/4 inches in diameter, are holding the diaphragm paper (bond paper substitute 16) between the two sheets (Figure 32).

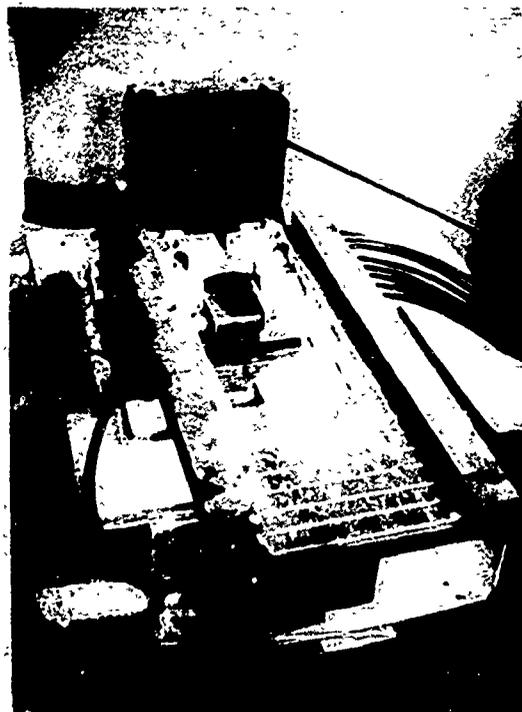
In this manner not only the exact diameter or area of a desired diaphragm is warranted but also the fast replacement of the diaphragm paper after rupture.

The center point of the diaphragm is in the axis and the diaphragm itself is parallel to the exploding foil. If the sled is fastened to the track on the increment line, assuming the 4-inch line, the diaphragm is exactly 4 inches from the foil. This can be extended to a maximum distance of 24 inches, thus permitting about 20 pressure measurements by adjusting the sled in 20 different places.

**c. Test Procedure**

The procedure used in the test was to start with the smallest diaphragm (1/4 in. diameter) and the shortest distance possible from the foil (4.0 inches). Then the sled was moved back in increments of 1/2 to 1 inch until the diaphragm remained intact. This indicated that the blast was not strong

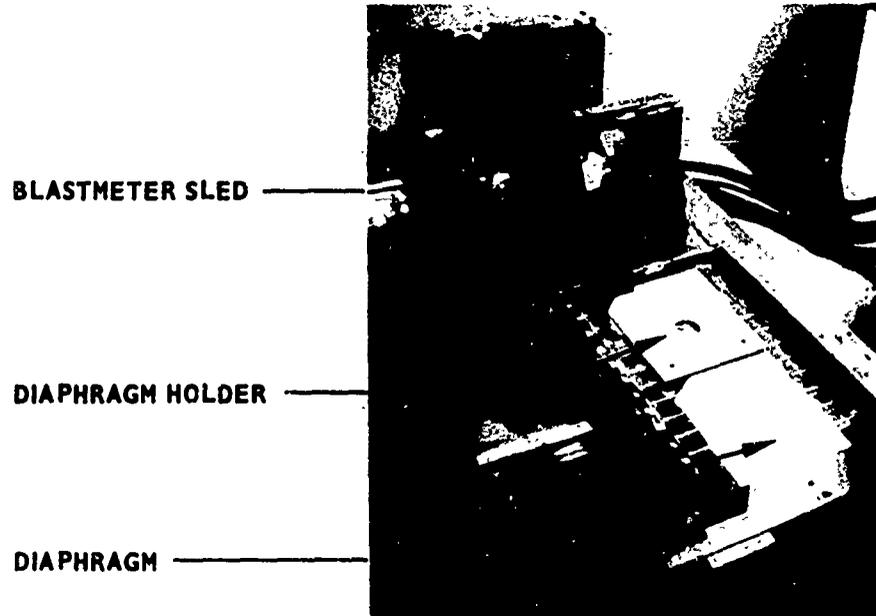




IMPULSE DEVICE

BLASTMETER TRACK

FIGURE 31. IMPULSE DEVICE AND BLASTMETER TRACK



BLASTMETER SLED

DIAPHRAGM HOLDER

DIAPHRAGM

FIGURE 32. BLASTMETER SLED, DIAPHRAGM HOLDER, AND DIAPHRAGM

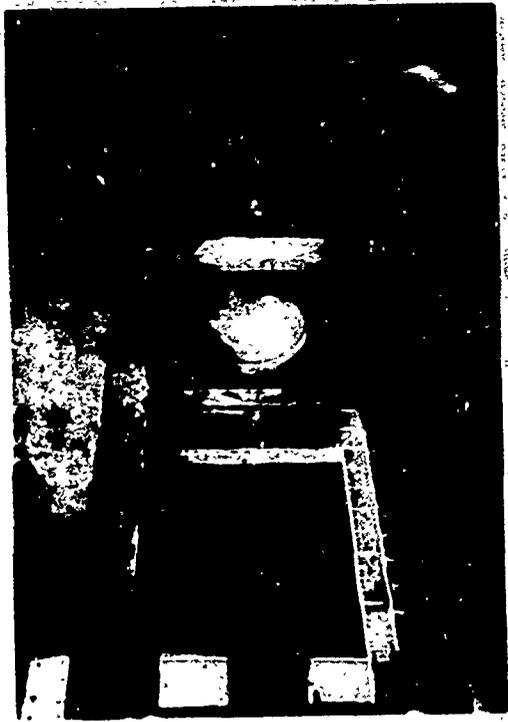


FIGURE 33. DIAPHRAGM,  
5/16-INCH DIAMETER



FIGURE 34. DIAPHRAGM,  
7/8-INCH DIAMETER

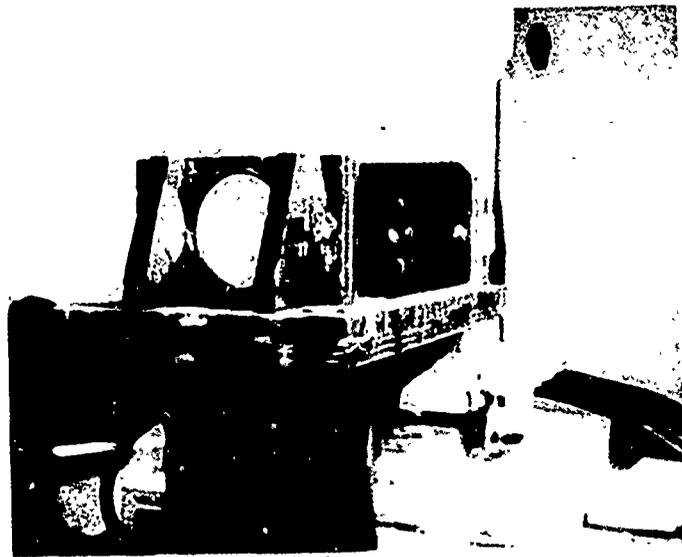


FIGURE 35. DIAPHRAGM, 1 1/4-INCH DIAMETER

enough to rupture the (1/4 in. diameter) diaphragm and the next bigger one had to be applied.

Two test runs were made. Test run No. 1 with a foil area of 3.0625 squared inch, 0.001 inch thick; and test run No. 2 with 3.28125 squared inch, 0.001 inch thick. In both runs the energy level was the same — 4560 joules (5.000 V). Theoretically 544.2 joules are necessary to vaporize an aluminum foil 0.001 inch thick with an area of 1.0 squared inch.

In test run No. 1 the energy applied was 2.8 times higher, and in test No. 2 2.6 times higher, as theoretically necessary. The voltage was in both cases 5000 volts.

#### d. Test Results

The results of the two test runs are shown in Table II and Figure 36. The graph shows that the resulting curve of pressure versus distance is a decreasing exponential. Maximum pressure at a 4-inch distance from the foil is 20 psi, and minimum pressure at a 24-inch distance from the foil is 2.7 psi. It appears further that the threshold for extensive vaporization was exceeded. No identifiable droplets of molten aluminum foil were found — only a dust-like powder.

The blastmeter tests were used to serve only as an indicator for the blast magnitude range. To determine pressure versus time accurately, a pressure transducer capable of measuring dynamic pressure was necessary. At the same time voltage and current had to be measured, too. All three time histories for each test had to be recorded in some manner. A fast response oscilloscope and an oscilloscope camera were used for these tests.

### 8. Pressure Transducers

After an investigation of commercially available transducers, the Kistler Piezotron Pressure Transducer Model 212X was selected. The transducer was installed in an aluminum plate similar to the diaphragm holder. This plate could be inserted into the sled in the same manner as the diaphragm holder used in the blastmeter test setup. Thus it was possible to use the whole setup for the blastmeter test and for the pressure transducer test without any change. Figure 37 shows the transducer plate installed in the sled.



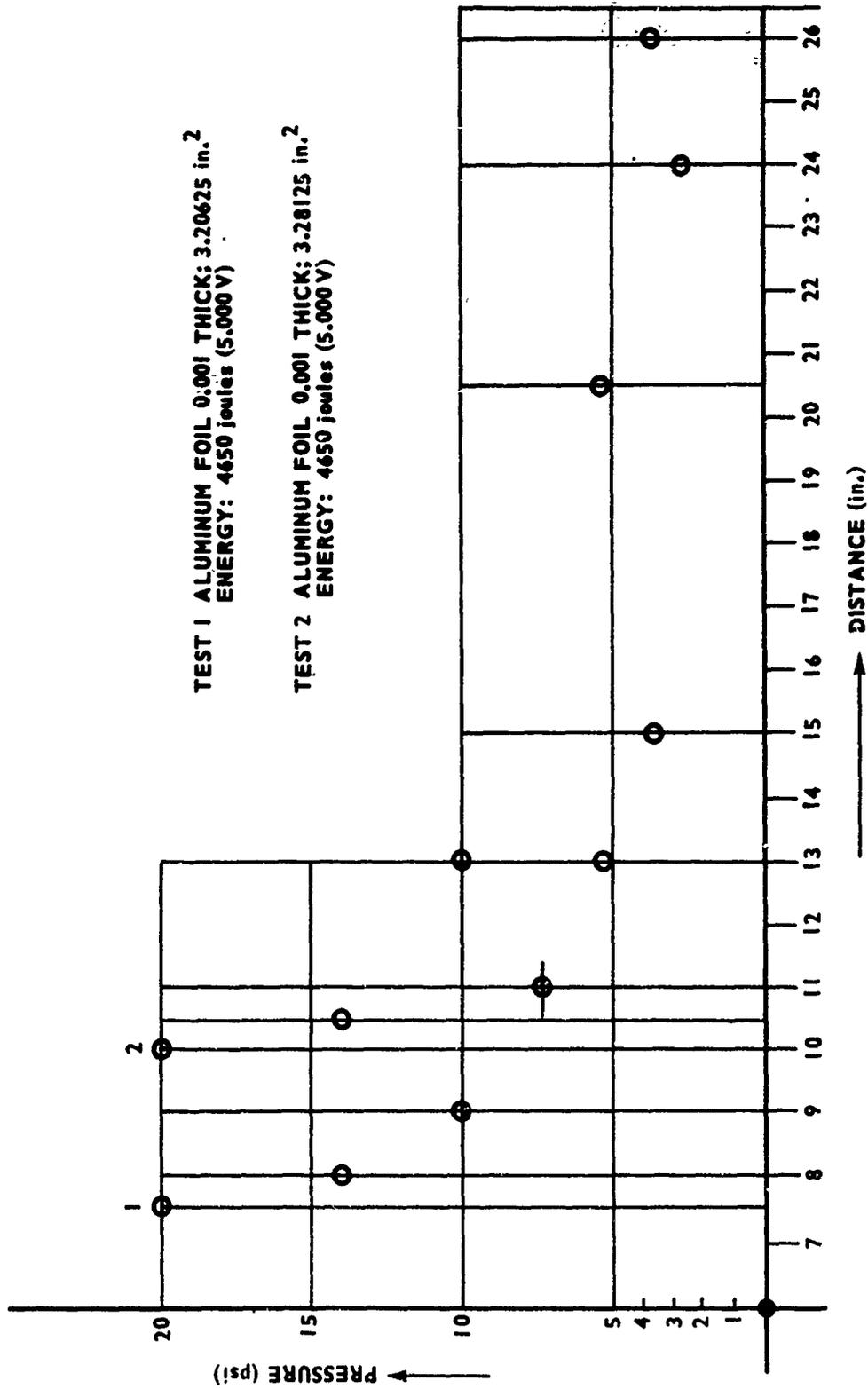


FIGURE 36. BLASTMETER TEST

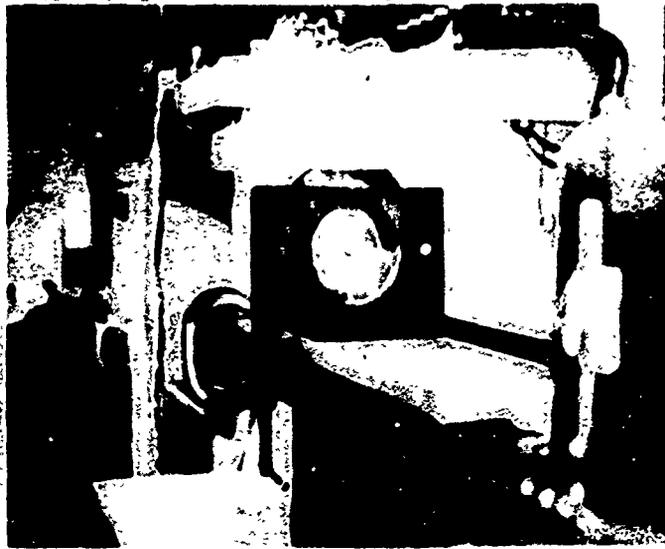


FIGURE 37. TRANSDUCER PLATE INSTALLED IN SLED

### 9. High Voltage Divider

To measure the voltage that appears across the foil load, it was necessary to reduce the voltage to a level that can safely be measured. Therefore, a high voltage divider was designed. The schematic is shown in Figure 38.

The high voltage divider consists of 20 1-megohm, 0.5-watt, 1-percent film type resistors connected in series, and a 1-kilohm resistor connected at the end to form an open loop. These resistors, insulated by a teflon tube, are inclosed in a large box composed of the baseplate, wood side walls, and a cardboard bottom plate (Figure 39).

The baseplate as well as the top plate of the box serves also as the carrier of the fixture and the impulse device. In this way, the connecting coax cable to the fixture could be kept very short. The input from the foil load is connected across the 100K resistor at one end. Both input and output leads are connected to an amphenol panel mount type coax connector. Since the amphenol type connector will not in general take more than 1000 volts, the phenolic insert in the connector on the high voltage side was removed and the center of the coax cable run directly to one end of the divider. Thus the high voltage integrity remained intact while the coax connector on the high voltage side served as a common connector and as a fastener. Figures 40 and 41 show the high voltage divider.

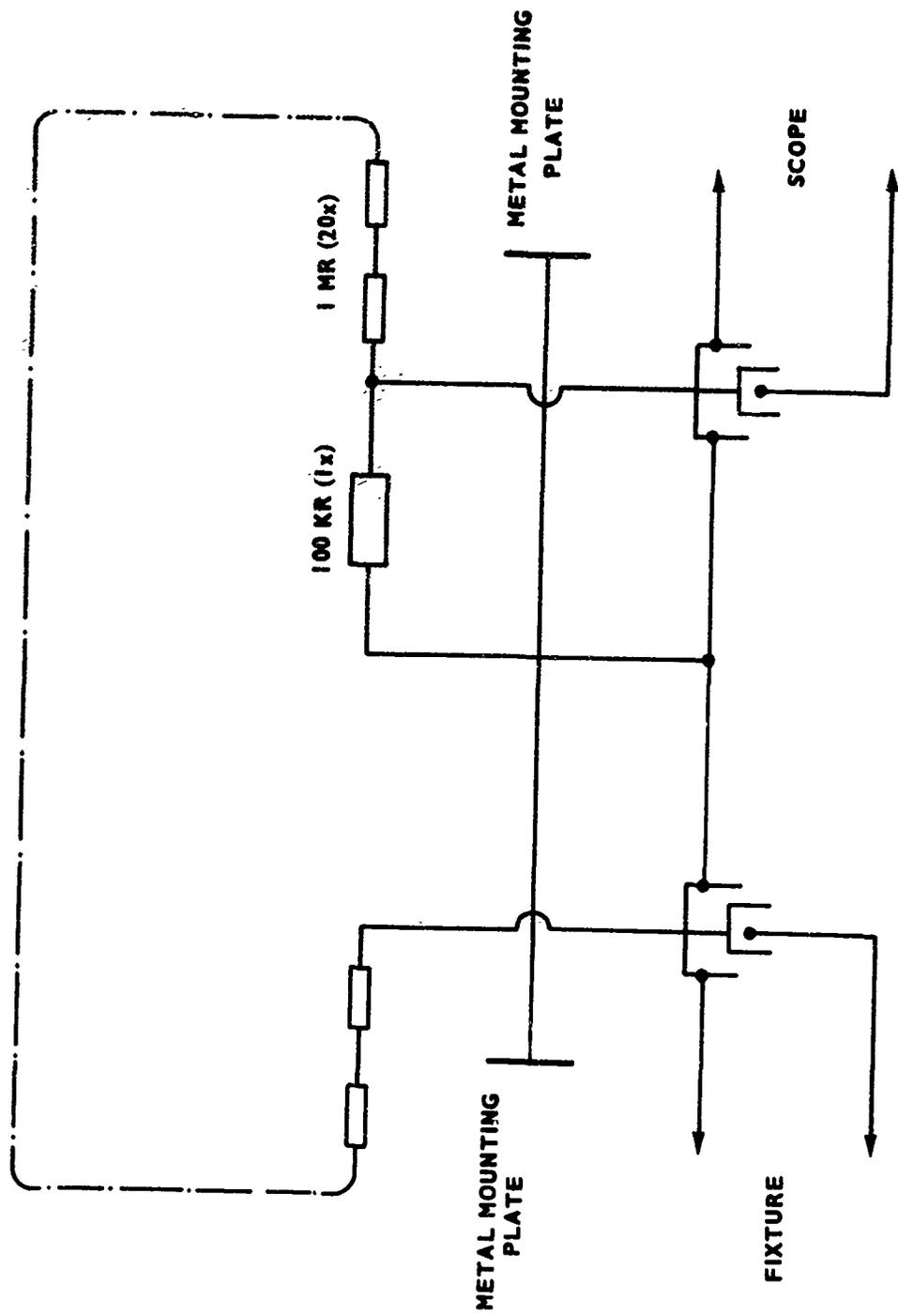


FIGURE 38. HIGH VOLTAGE DIVIDER, SCHEMATIC

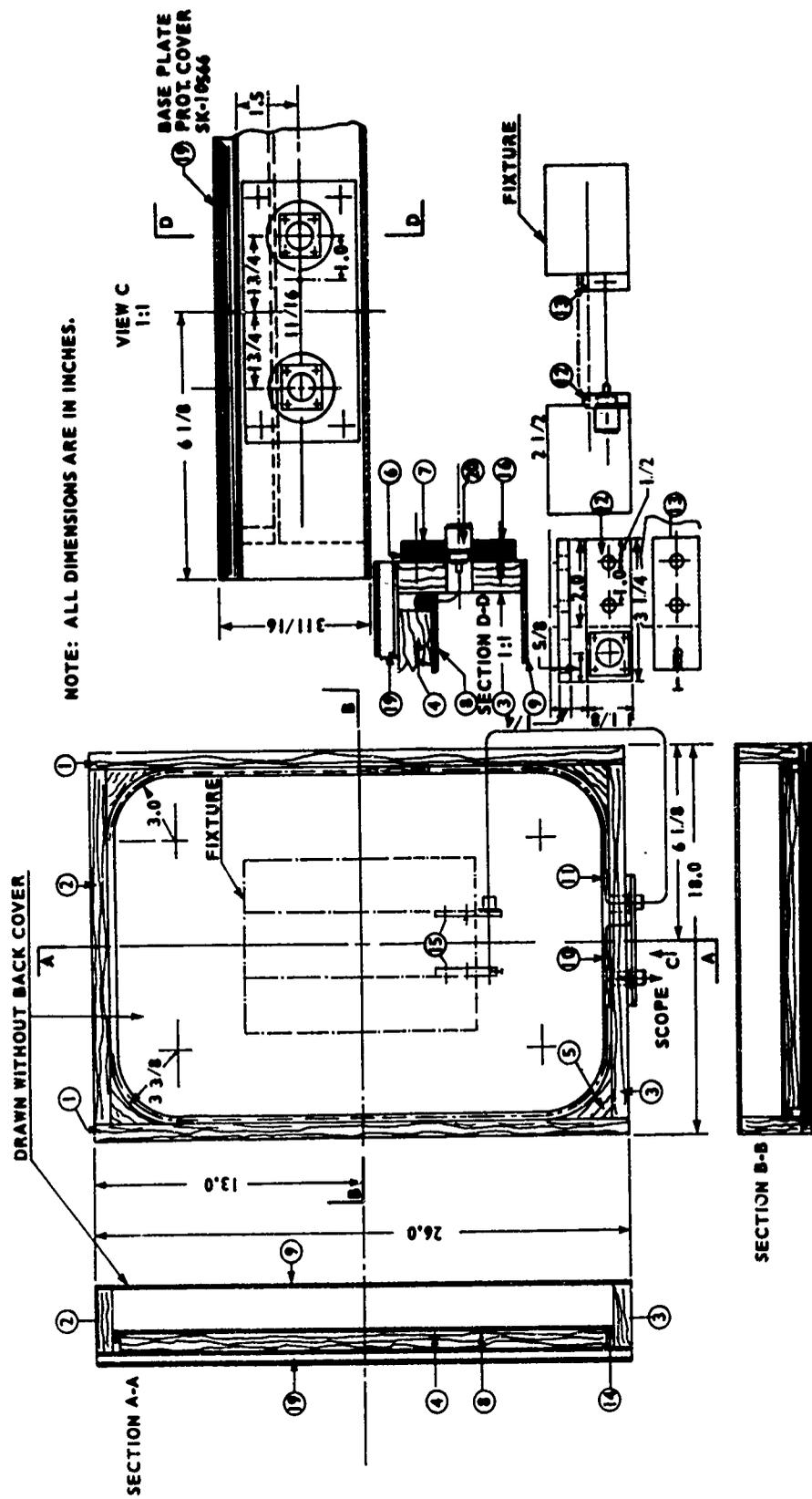


FIGURE 39. HIGH VOLTAGE DIVIDER



FIGURE 40. HIGH VOLTAGE DIVIDER, TOP VIEW



FIGURE 41. HIGH VOLTAGE DIVIDER, BOTTOM VIEW  
(WITHOUT BASEPLATE)

## 10. Current Shunt

The current shunt was designed as a means of measuring the current in the exploding foil output circuit from which a voltage can be measured that is proportional to the current flowing through the foil.

Two considerations are of primary concern:

- a. The resistance of the shunt must be small compared to the resistance of the foil (one-tenth or less), and jet large enough to get a measurable voltage level.
- b. Heat dissipation from the shunt must be rapid enough to prevent destruction of the shunt.

Copper was selected as the material for the shunt, since it was readily available and it has a resistance lower than that of aluminum. The current shunt and mounting is shown in Figure 42.

In designing the shunt care was taken in laying out the shunt dimensions not only in respect to resistance but also to capacitance and inductance since the shunt is in series with the foil load and will influence the discharge characteristics of the load circuit. (Figure 43).

The shunt consists of six basic parts (Figure 44):

- a) Part 1, a copper mounting plate
- b) Part 2, a copper outer shell
- c) Part 3, a copper inner shell threaded on the forward end to receive an amphenol 81-J double female type
- d) Part 4, a copper inner shell flange, threaded on the aft part to receive a 3/8-inch hexnut
- e) Part 5, a thin copper rod
- f) Part 6, a teflon bushing

Foil current enters the shunt through the aft end of the inner shell flange, Part 4 (Figure 44) and flows through the thin wall of the inner shell, Part 3, across the forward section of the inner shell to the forward section of the outer shell, Part 2, and back through the thick wall of the outer shell to the mounting plate, Part 1, and then out of the mounting plate. The voltage  $F_{out}$  to be measured appears across the thin wall section of the inner shell, Part 3. The voltage  $F_{out}$  appears + to - in polarity from the copper rod, Part 5, to the threaded section of the forward end of Part 3 respectively. The voltage  $F_{out}$  is connected

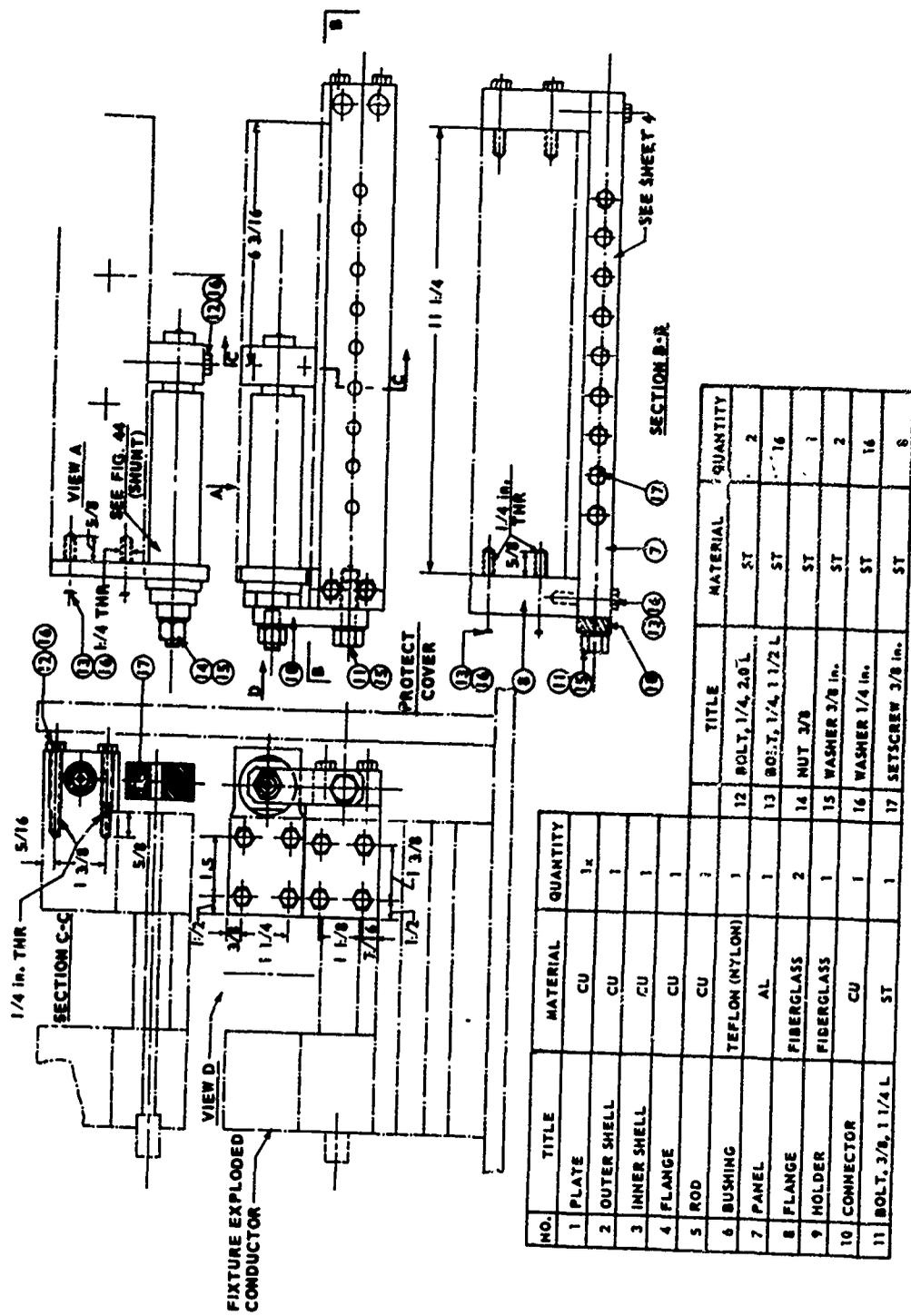


FIGURE 42. SHUNT (COAX CURRENT)

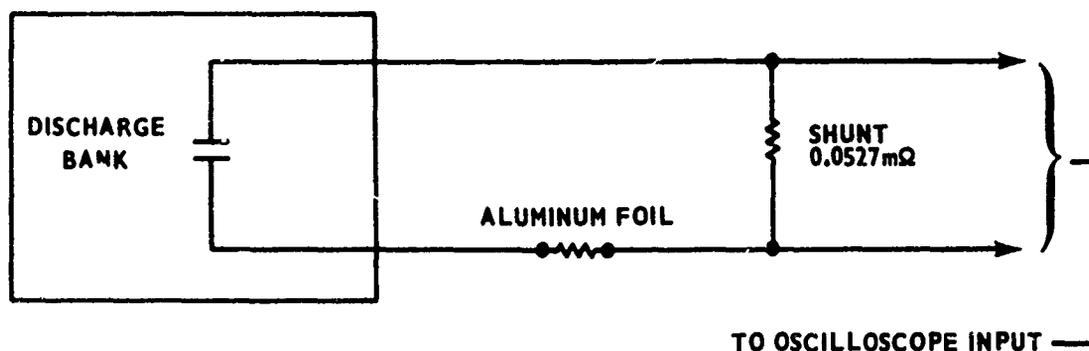


FIGURE 43. CURRENT SHUNT, SCHEMATIC

to the oscilloscope by the coax connector 81-J at the forward end of the inner shell, Part 3. The measuring device must present a large enough impedance to the shunt so that negligible load exists. The shunt resistance was measured at 0.0527 milliohms.

## II. Oscilloscope

The Tektronix Type 556 oscilloscope is a dual-beam type providing accurate voltage and time measurements in dc to 50-megahertz frequency range. Two complete horizontal and vertical deflection systems permit completely independent operation of the two beams.

In addition, there is a variety of special circuits in the oscilloscope to provide special functions such as continuously variable sweep-delay and trigger mode selection.

This oscilloscope was selected for:

- a) extremely fast rise time
- b) extremely wide band pass
- c) the two time bases and the two independent beams
- d) single-shot measurement capability and flexibility

The plug-ins used with the scope are a 1A4 unit for measuring current and voltage, and a 535<sup>4</sup> C unit for pressure measurements. The Tektronix Standard C27 Camera Package with a solenoid shutter actuator is used in conjunction with the scope for recording time histories for these tests (Figures 45 and 46).

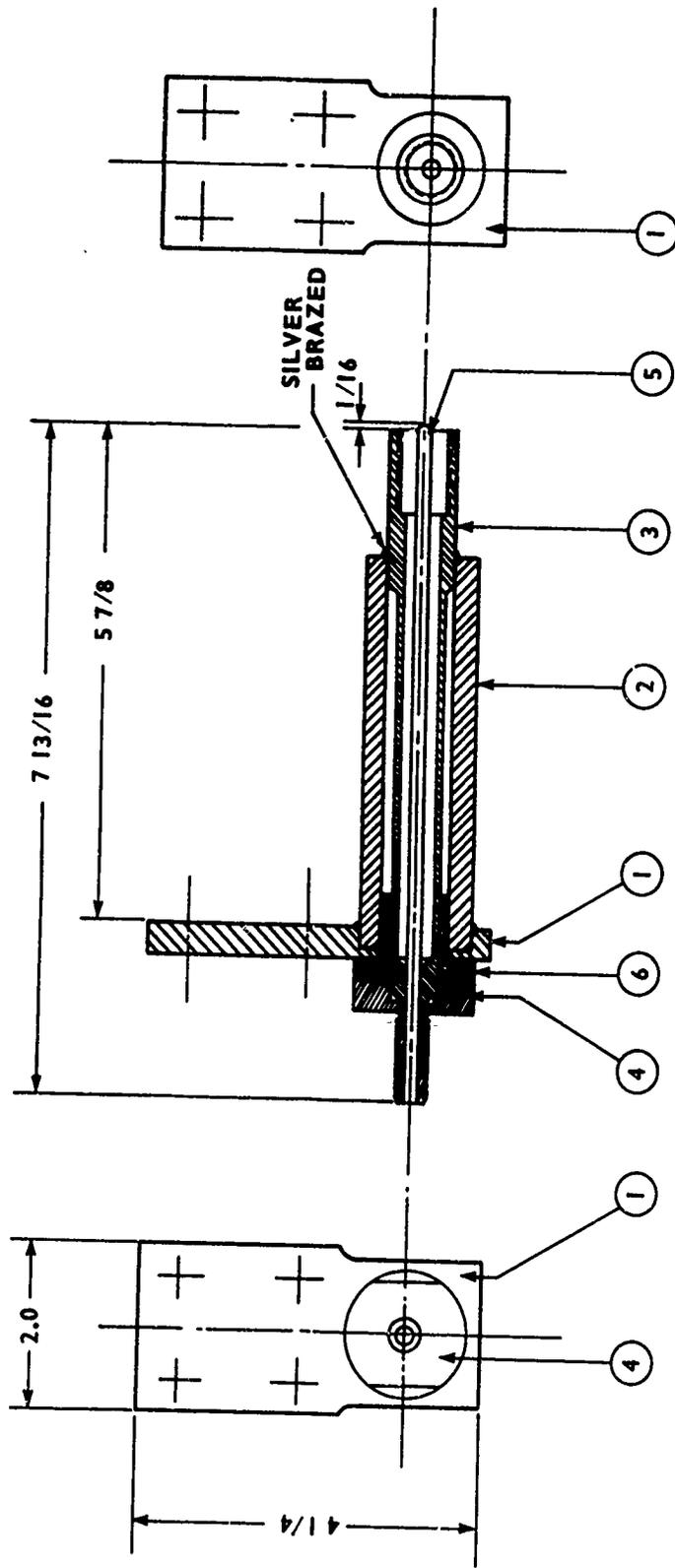


FIGURE 44. SHUNT ASSEMBLY (COAX CURRENT)

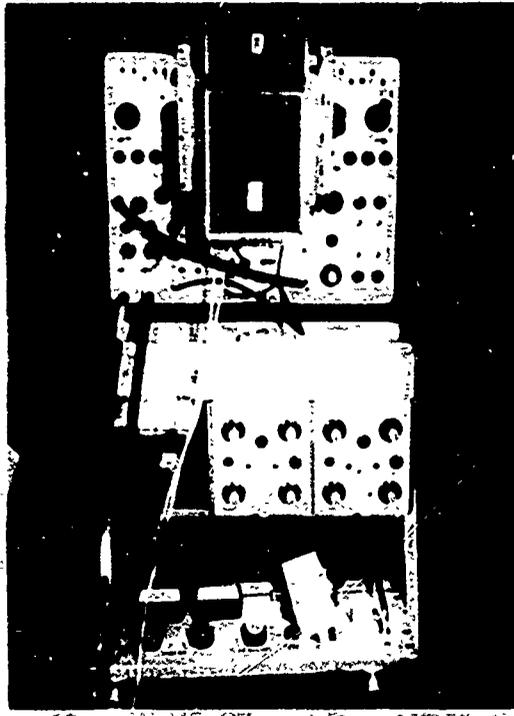


FIGURE 45. OSCILLOSCOPE

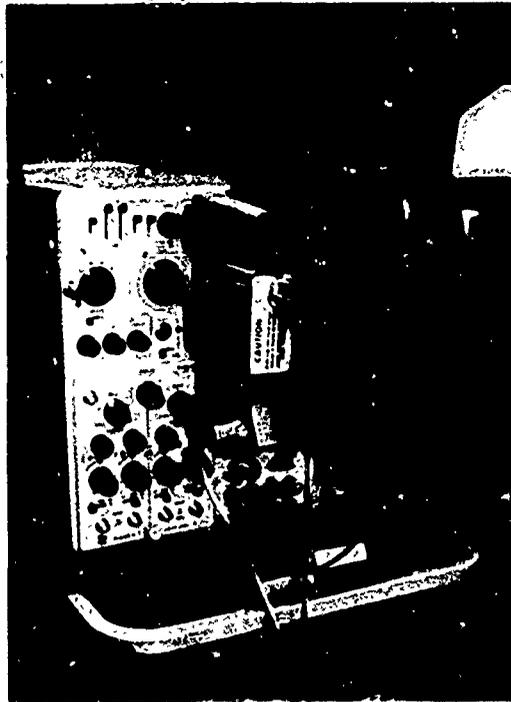


FIGURE 46. OSCILLOSCOPE CAMERA

## 12. Power Supply and Safety Feature for Oscilloscope and Camera

A separate 28-volt power supply provides the power to operate the camera solenoid and the shutter and discharge control device which is discussed later.

The power supply and the oscilloscope are isolated from the power mains for safety reason by a 1-kilowatt stancor P-6125 115-volt 60-cycle isolation transformer.

Figures 47, 48, and 49 show the block diagram with the overall arrangements, the isolation transformer and the power supply.

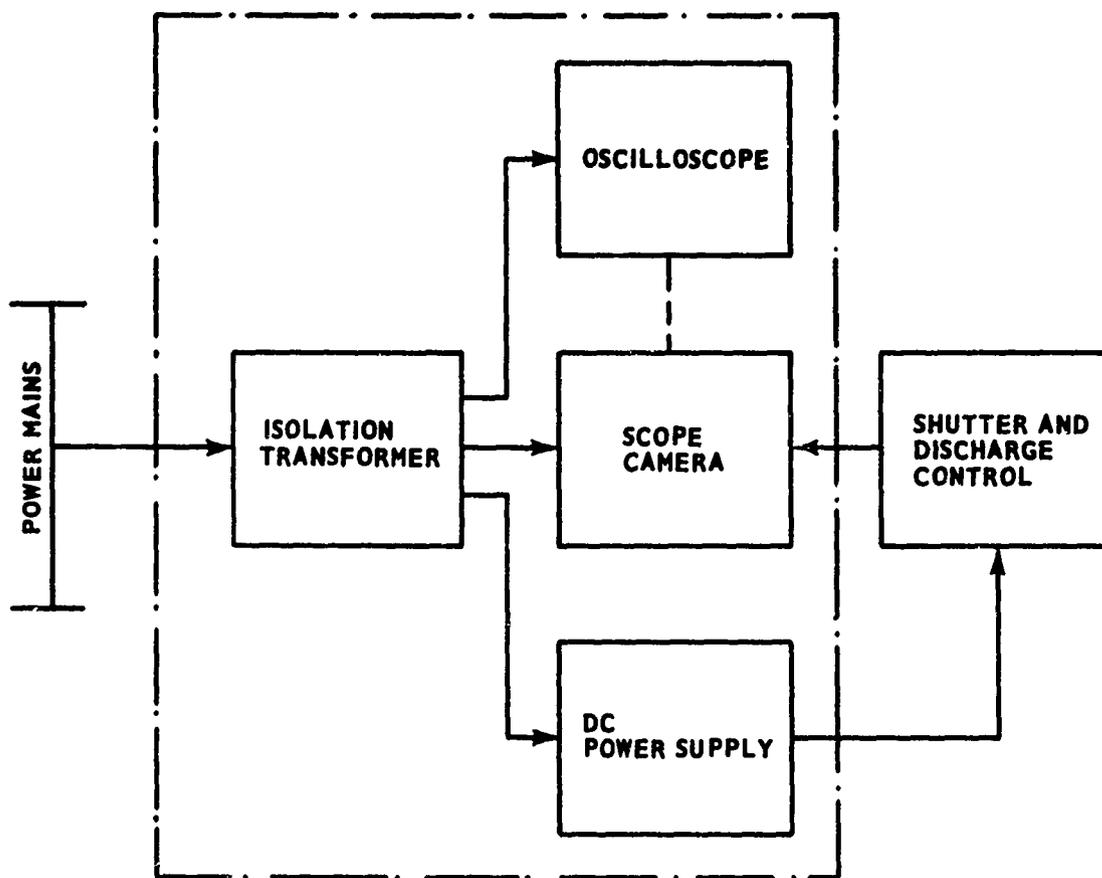


FIGURE 47. POWER SUPPLY AND SAFETY FEATURE, BLOCK DIAGRAM

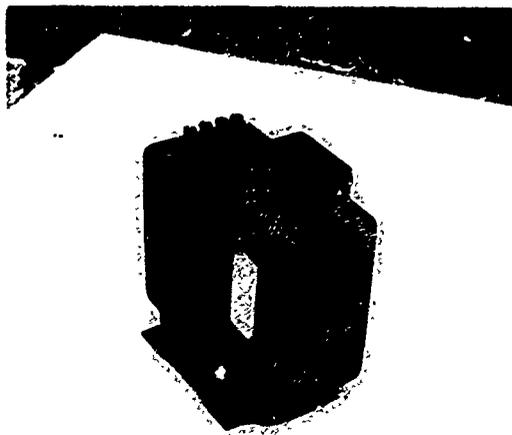


FIGURE 48. ISOLATION TRANSFORMER

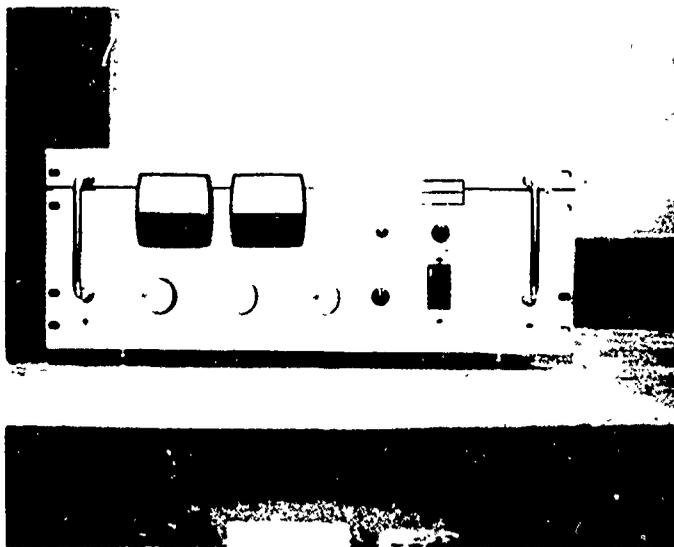


FIGURE 49. POWER SUPPLY

### **13. Shutter and Discharge Control Device**

The function of the shutter and discharge control device is to open a scope camera shutter for a predetermined length of time and delay the discharge of a high energy capacitor bank until the camera shutter has been opened. Figures 50 through 53 show the design, the schematic, and the printed circuit of the device.

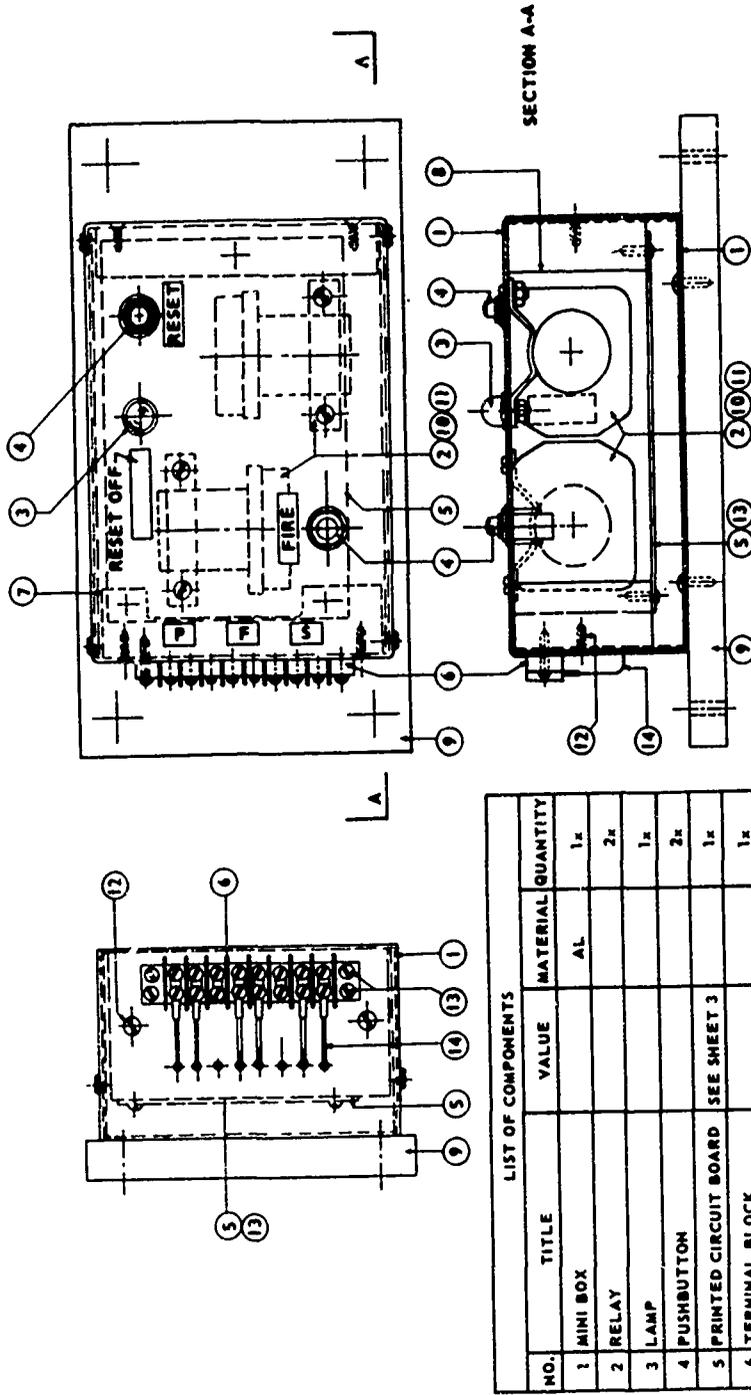
The circuit operation is as follows. When 30 volts dc is applied to the circuit, forward voltage is applied to CR1, CR2, and the UJT circuit containing Q1. At the end of a 2-second delay, Q1 sends a gate pulse to CR1 and CR1 turns on, Q1 deactivates, and commuting capacitor C charges to 30 volts dc. When S1 is closed, CR2 and CR4 are gated on, CR1 is turned off by the commuting capacitor, Q1 and Q2 begin to time out, and K1, the shutter relay, picks up. At the end of 50 milliseconds, CR3 is pulsed on by Q2, K2 picks up, and K3, the fire relay, picks up. After a 2-second delay, Q1 pulses CR1 on, commuting capacitor C turns CR2 off, and K1 drops out, closing the camera shutter. When S2 is opened, CR4 is turned off, K2 drops out, and the fire relay K3 drops out. The circuit is now ready for the next cycle.

### **14. Electronic Delay Circuit for Delaying Pressure Sweep**

A variable time delay circuit for triggering the pressure measurement sweep was necessary for the transducer tests. The delay circuit was constructed such that the delay circuit was initiated by the start of the discharge current pulse. Calibrated sweep delays from 0.5 to 2 milliseconds were obtainable with this circuit. Figures 54 through 57 show the device, the schematic, the overall arrangements and the printed circuit of the device. After extensive testing of this unit however, it was found that the delay circuit was not only very time-consuming in adjustment but also very critical as to centering the pressure trace on the scope. This is due to the high pressure sweep rate necessary. In addition, the delay had to be adjusted again after each discharge and/or voltage change. It was concluded, therefore, because of these complications, that another delay device method should be tried. This method is described in section 17, "Pressure Transducer Tests."

### **15. Collapsible Shielded Chamber**

To shield sensitive measuring equipment from radiation emanating from the exploding foil, a shielded chamber was necessary. This chamber had to be light enough to be moved easily from place to place, and it should exclude external radiation.



LIST OF COMPONENTS				
NO.	TITLE	VALUE	MATERIAL	QUANTITY
1	MINI BOX		AL	1x
2	RELAY			2x
3	LAMP			1x
4	PUSHBUTTON			2x
5	PRINTED CIRCUIT BOARD	SEE SHEET 3		1x
6	TERMINAL BLOCK			1x
7	CIRCUIT BOARD SUPPORT	SEE SHEET 5	WOOD	1x
8	CIRCUIT BOARD SUPPORT	SEE SHEET 5	WOOD	1x
9	BOX SUPPORT	SEE SHEET 4	WOOD	1x
10	SCREW	3/16 x 3/8	ST	4x
11	NUT	3/16 In.	ST	4x
12	WOODSCREW (FLATHEAD)	1/8 x 3/8	ST	4x
13	WOODSCREW (ROUNDHEAD)	1/8 x 5/8	ST	9x
14	HOOK UP WIRE	AWG NO. 20	VINYL INS	

FIGURE 50. SHUTTER AND DISCHARGE CONTROL ASSEMBLY

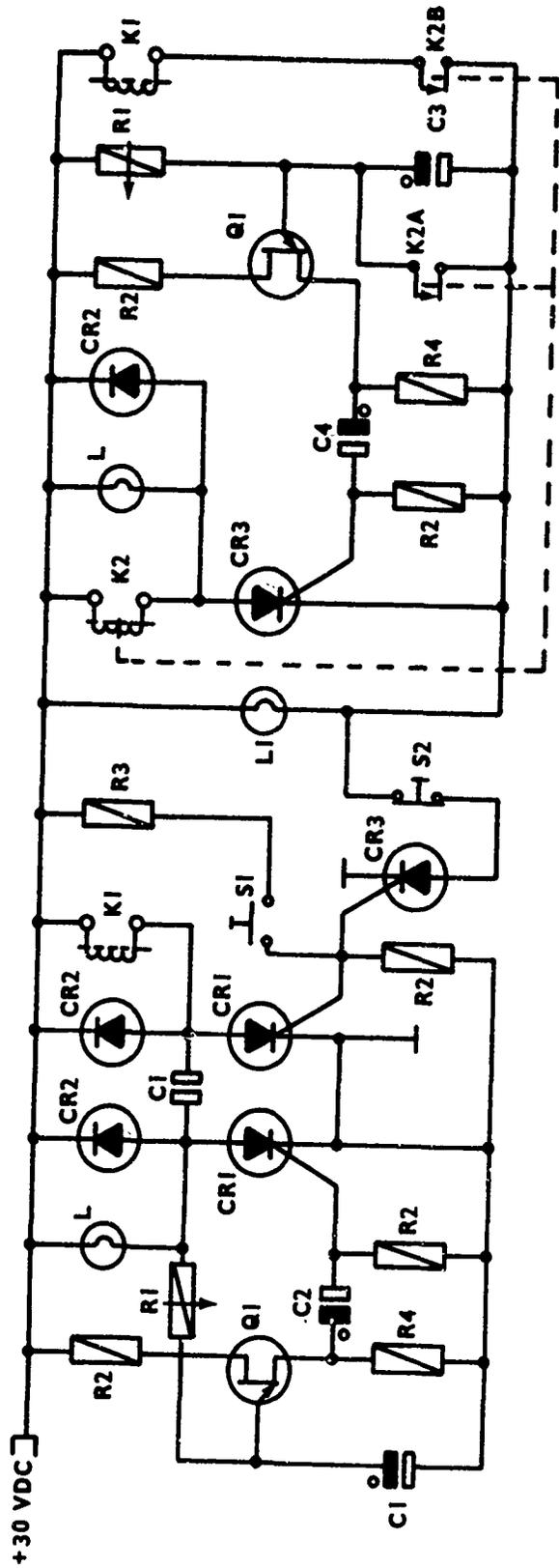
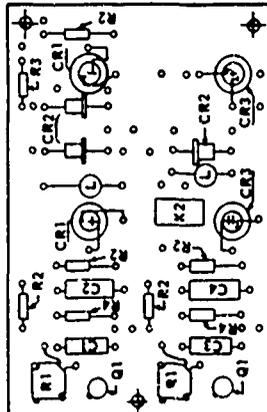


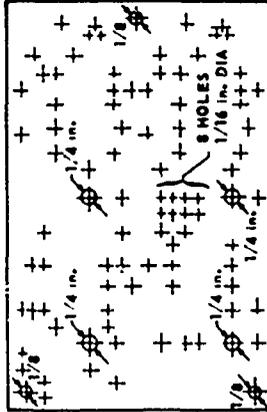
FIGURE 51. SHUTTER AND DISCHARGE CONTROL, SCHEMATIC

TOP VIEW

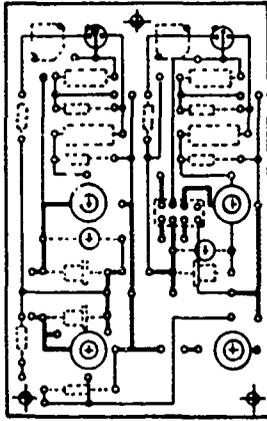


TEMPLATE

ALL HOLES DRILLED FROM COPPER SIDE ONLY



BOTTOM VIEW



LIST OF COMPONENTS

NO	TITLE	VALUE	REF DES	QUANTITY
1	POTENTIOMETER	1Ω, 1/2W - BOURNS TRIMPOT	R1	2x
2	RESISTOR	200Ω, 1/2W - OHMITE CARBON	R2	5x
3	RESISTOR	400Ω, 5W	R3	1x
4	RESISTOR	30Ω, 1/2W - OHMITE CARBON	R4	2x
5	LAMP	GE327	L	2x
6	CAPACITOR	10μF, 50VDC SPRAGUE TANTALUM, 1500 SERIES	C1	1x
7	CAPACITOR	10μF, 20VDC SPRAGUE TANTALUM, 130D SERIES	C2	1x
8	CAPACITOR	2 μF, 50VDC TMSCM-2 TANTALUM	C3	1x
9	CAPACITOR	6.8 μF, 35VDC SPRAGUE TANTALUM 1500 SERIES	C4	1x
10	TRANSISTOR	2N492	Q1	2x
11	DIODE SCR	2N1772A	CR1	2x
12	DIODE	1N540	CR2	3x
13	DIODE SCR	2N1772	CR3	2x
14	PC RELAY	LEACH M250 A1 - 112	K2	1x
15	PC BOARD	4 x 6 x 1/16 (0.001 COPPER CLAD FIBERGLASS)	K2	1x

ALL NOT DESIGNATED HOLES ARE 1/32 in. DIAMETER

NOTE: ALL NARROW PC-LINES ARE 1/32 in. THICK.  
 ALL WIDE PC-LINES ARE 1/16 in. THICK.  
 POTENTIOMETERS ARE MOUNTED ON BOARD BY U-BRACKETS (SOLDERED TO BOARD)  
 ALL RESISTORS ± 5% TOLERANCE.  
 ALL CAPACITORS ± 10% TOLERANCE.  
 DOT SHOWS POSITION OF RELAY.

FIGURE 52. SHUTTER AND DISCHARGE CONTROL, PRINTED CIRCUIT



FIGURE 53. SHUTTER AND DISCHARGE CONTROL DEVICE

This task was accomplished (Figure 58) by wood frames with reinforcing cardboard triangles at each corner. The walls for each frame were also cardboard, stapled to the frame and covered by 0.001 inch thick aluminum foil. The door, constructed like the frames, was hinged to the end frame and held closed by three spring-loaded wires attached to the door and to one of the side frames.

After final improvements like additional overlapping of all junctions with aluminum foil, radiation testing disclosed negligible amounts of external radiation (Figure 59).

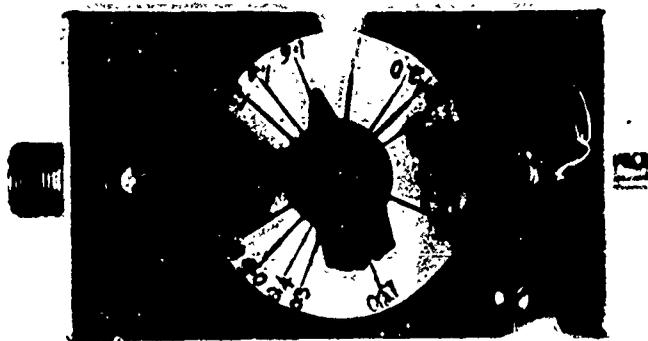


FIGURE 54. SWEEP DELAY

#### 16. Protective Cover

The cover for the impulse device and the supporting structure was designed as a safety feature for three reasons:

COMPONENT	SYMBOL
BATTERIES	B1, B2, B3
SWITCH	S
LAMP	L
UNIUNCTION	Q1
DIODE	CR1
SCR'S	CR2, CR3
CAPACITORS	C1 ÷ C4
RESISTORS	R1 ÷ R6

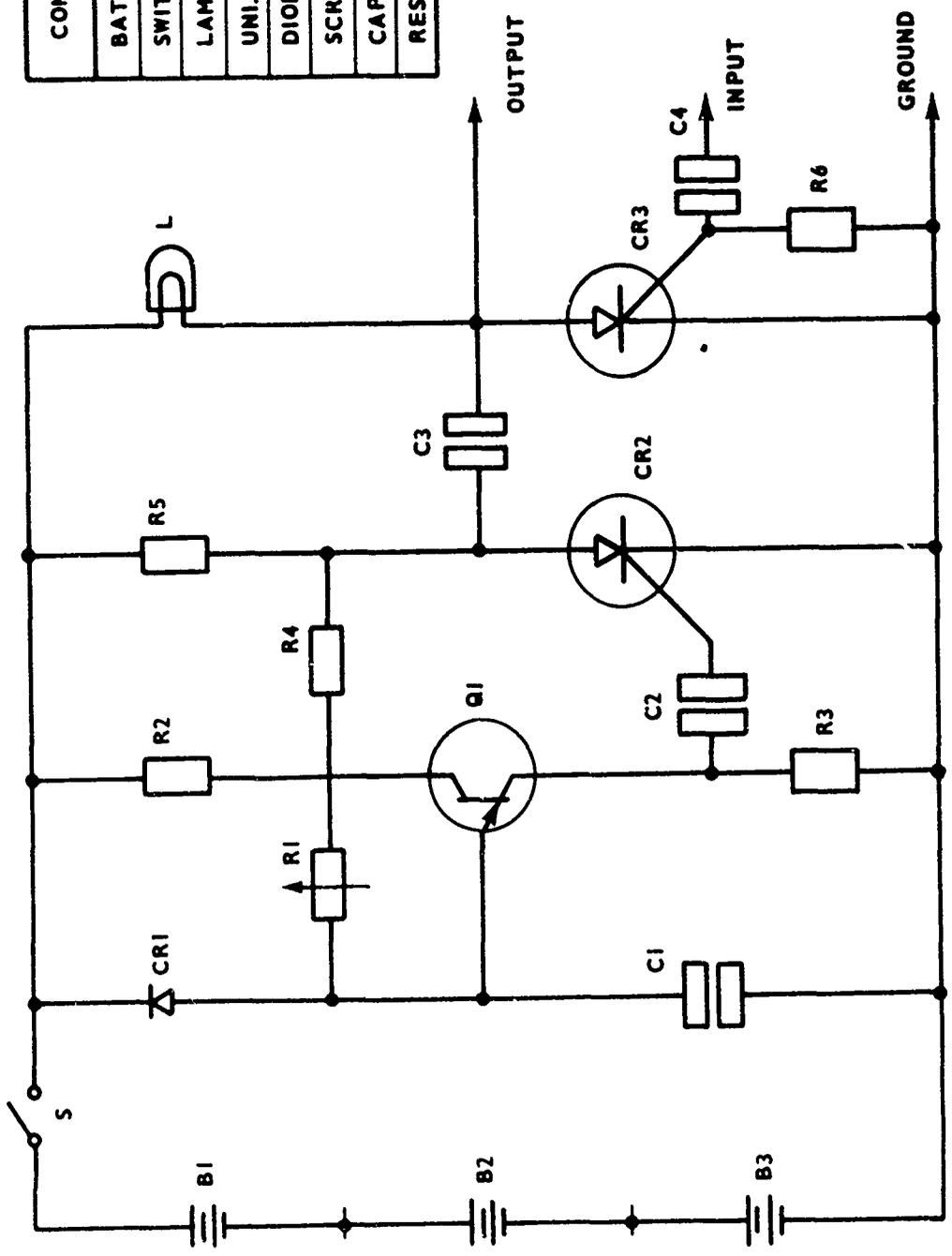


FIGURE 55. SWEEP DELAY CIRCUIT. SCHEMATIC

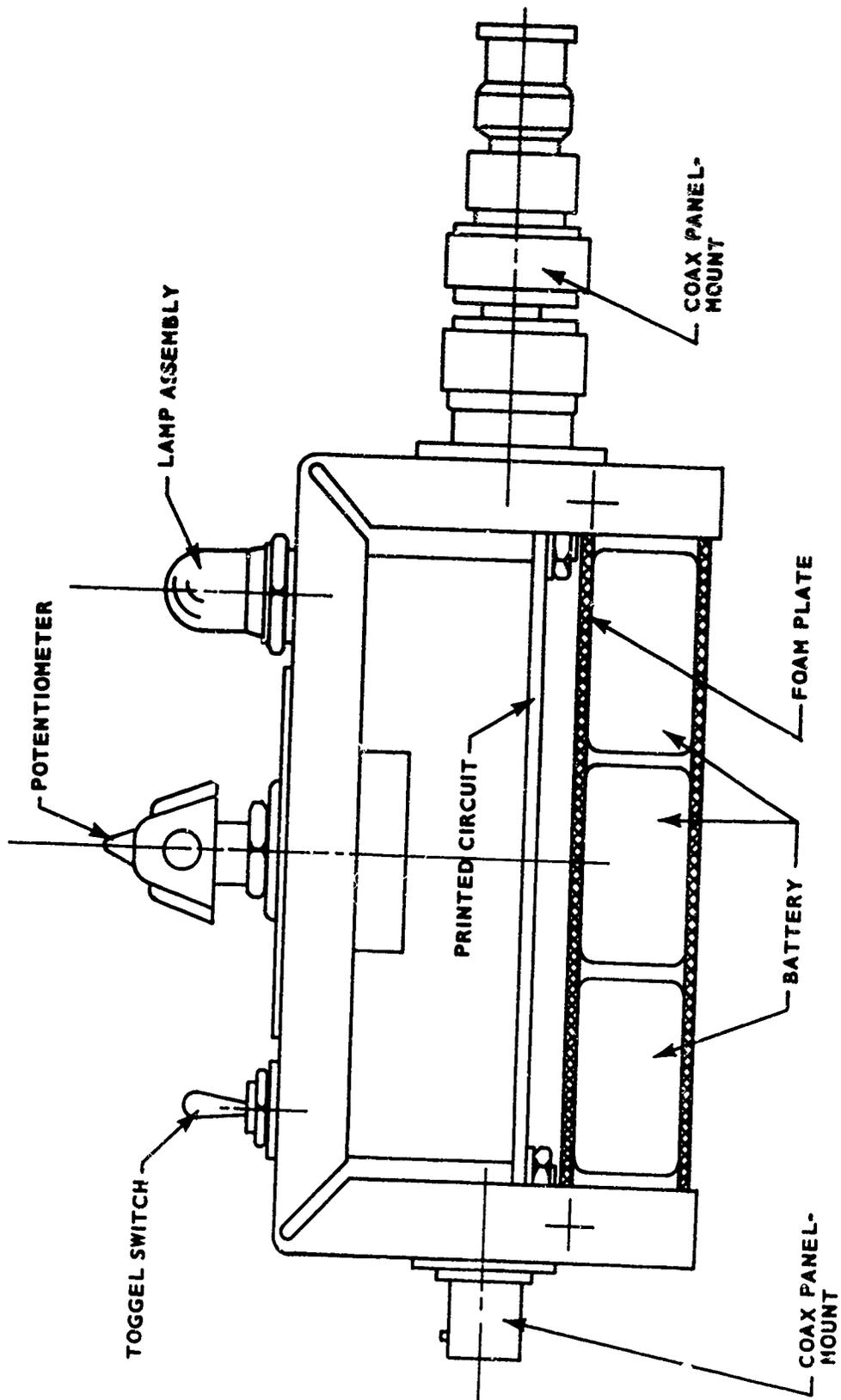


FIGURE 56. SWEEP DELAY ASSEMBLY

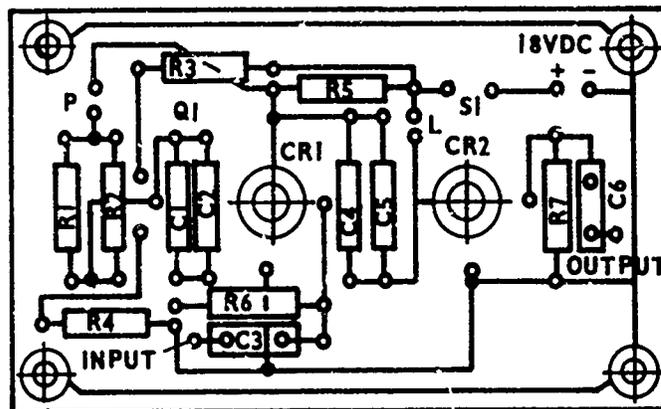


FIGURE 57. PRINTED CIRCUIT

- a) To prevent personnel from coming in contact with the high voltage present across the impulse device during the explosion period.
- b) To lower the sound intensity resulting from the explosion.
- c) To eliminate any flash that might be observed and to prevent accidental damage to the impulse device.

The cover is fabricated from plexiglass plates and is shown in Figures 60 and 61. To decrease extraneous radiation the inside of the cover is lined with aluminum foil.

## 17. Pressure Transducer Tests

### a. General

The objective of these tests was to establish a peak-pressure curve versus distance, and a pressure versus time curve in one of the locations of the pressure transducer. After tests with a previously designed electronic delay circuit for delaying pressure sweep had brought no satisfactory results, it was decided to experiment at this time with a self-triggering system. The same mechanical setup as that for the blastmeter tests was used. The electrical setup for these tests is described in the block diagram of Figure 62.

### b. Test Procedure

The pressure transducer, Kistler Piezotron Mod. 212X (Experimental), was used as signal and trigger transducer for these tests. The blast

NO.	TITLE	MATERIAL	QUANTITY
1	SIDEFRAME	WOOD/CARDBOARD	2x
2	TOP AND BOTTOM FRAME	WOOD/CARDBOARD	2x
3	FRONT AND BACK FRAME	WOOD/CARDBOARD	2x
4	DOOR FRAME	WOOD/CARDBOARD	1x
5	DOOR FRAME	WOOD/CARDBOARD	2x
6	SIGNAL AND POWER LEADBLOCK	WOOD	120 ft
7	WOODEN SUPPORT 1 in. x 1 in.	WOOD	160 ft <sup>2</sup>
8	FRAME COVER	CARDBOARD	20 ft <sup>2</sup>
9	CORNER REINFORCEMENT	CARDBOARD	160 ft <sup>2</sup>
10	SHIELDING	AL FOIL	10 ROLLS
11	TAPE	PAPER	170
12	WOODSCREW 1/8 x 1 1/2 L	BR	500
13	NAIL 1/32 - 7/16	BR	2
14	HINGE	BR	3
15	SPRING	ST	15 ft
16	WIRE 1/16 DIA	ST	

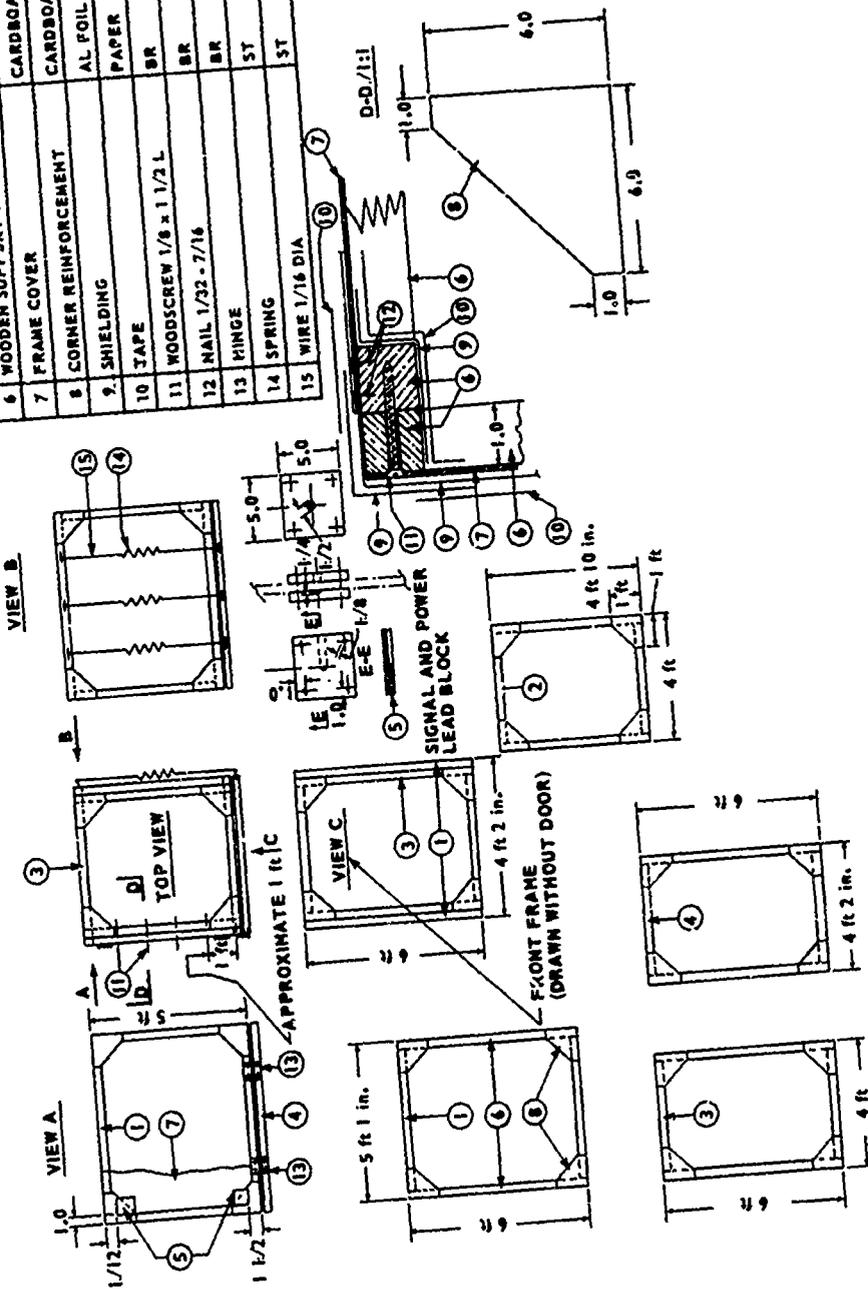


FIGURE 58. COLLAPSIBLE SHIELDED CHAMBER



FIGURE 59. SHIELDED CHAMBER

pressure signal was to trigger the scope in single sweep mode. The transducer plate with the transducer was inserted into the sled and clamped at the desired distance from the foil. Figure 63 shows the calibrated curve of the transducer and Figure 64 shows the transducer plate.

#### c. Results

##### (1) Test Runs 1 and 2.

The measurements given in Table III were taken, and a peak pressure curve (pressure versus distance) and also a pressure versus time curve for a distance of 10 inches from the foil were made (Figures 65 and 66). The scope pictures taken (Figures 67 and 68) revealed that the initial portion of the blast wave was missing because of a finite preset triggering level. Since the initial time duration, during which the blast was chopped, was

extremely short compared to the duration of the blast wave itself, linear extrapolation of the pressure versus time curve back to zero pressure was made.

#### d. Conclusions

In general, the scope pictures obtained were good. The initial portion of the blast wave was missing, the self triggering system could not be altered to obtain this portion, and therefore, another method of triggering was needed. The pressure transducer (Kistler Piezotron Mod. 212X Exp.) according to the calibration chart is accurate only up to 200 psi. This limitation was exceeded as the tests show. Measurements above this limit appear therefore questionable and of no true value. For this reason the transducer was replaced by a transducer of higher capability (4000 psi).



FIGURE 60. PROTECTIVE COVER, FRONT SIDE



FIGURE 61. PROTECTIVE COVER, BACK SIDE

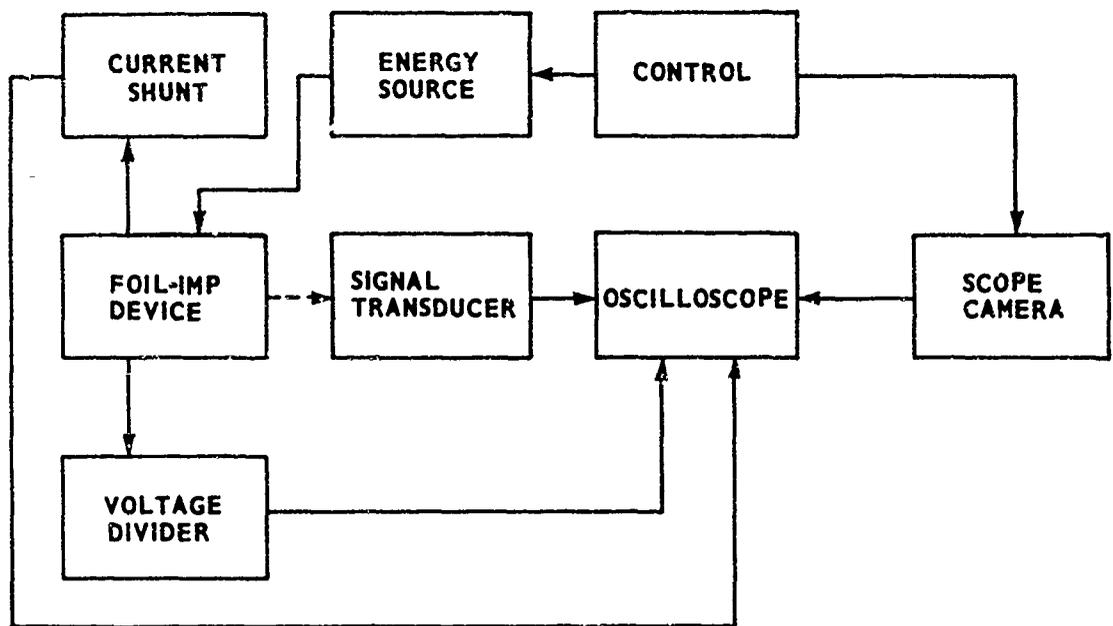


FIGURE 62. PRESSURE SURVEY, BLOCK DIAGRAM

## 18. Triggering Problem

### a. Part 1: General

The test of a self-triggering system had shown that good scope pictures were received but also that the initial portion of the blast wave was missing because of a finite preset triggering level. It became clear that triggering had to take place that very moment when the blast wave arrived at the signal transducer or shortly before.

In the assumption that the wave front would be a flat one and would travel in this configuration from the source of the blast wave until its complete dissipation, the triggering device had to be located ahead of the signal transducer.

If the wave front of the blast wave was not flat as assumed but slightly curved, the triggering device would have to be slightly farther ahead of the signal transducer. By placing the triggering device as close as mechanically possible to the signal transducer in the center of the blast wave, the extension variation of the triggering device would be at a minimum since the triggering device would still be in the region of the flat or less curved portion of the wave front.

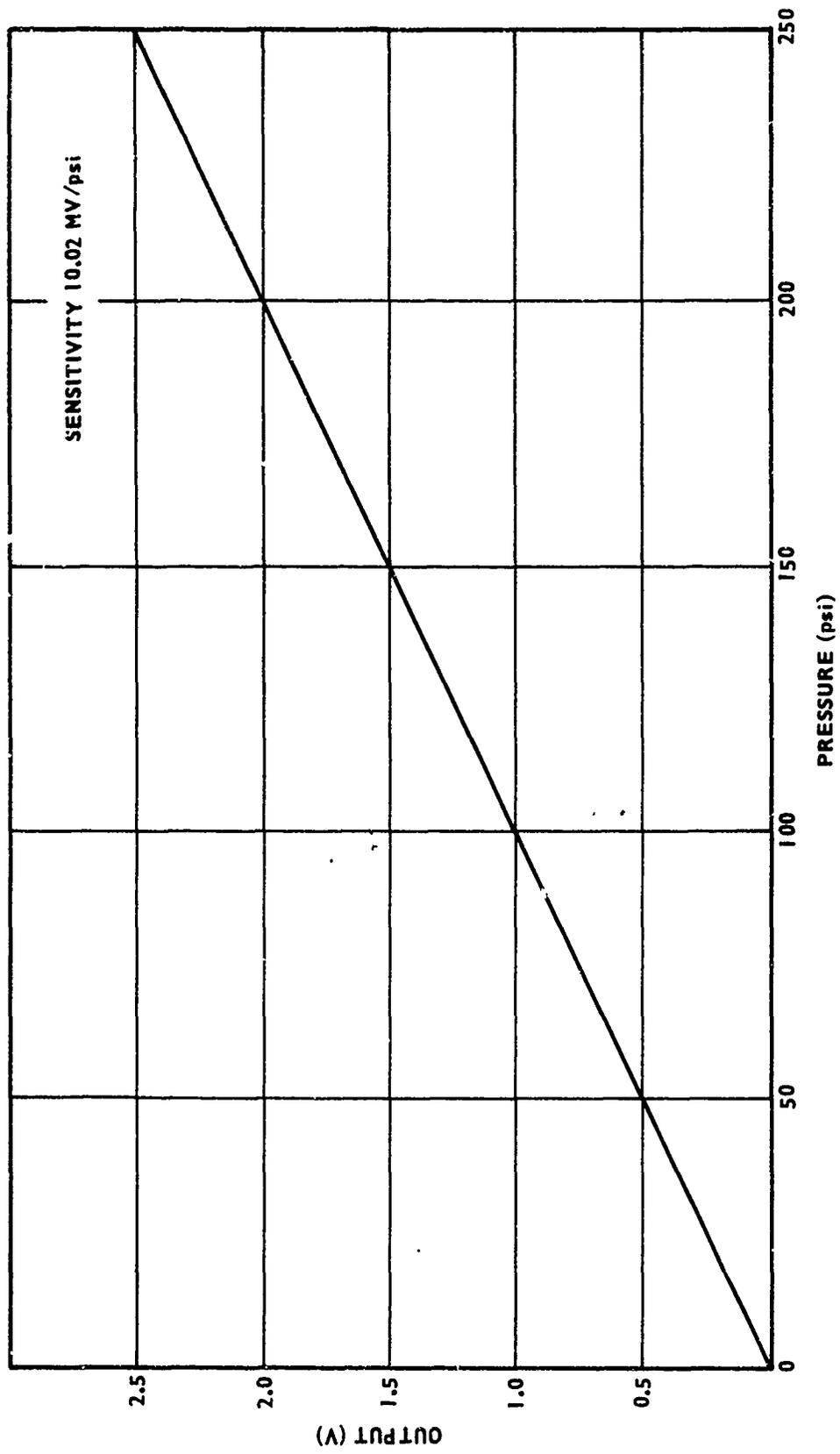
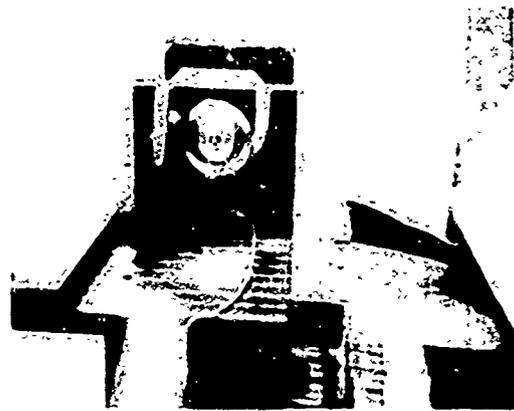


FIGURE 63. PRESSURE TRANSDUCER, KISTLER PIEZOTRON MOD. 212X EXP.



FRONTSIDE



BACKSIDE

FIGURE 64. TRANSDUCER PLATE

TABLE III. MEASUREMENT RESULTS

Distance from the Foil [in. ( $\Delta x$ )]										
4	6	8	10	12	14	16	18	20	22	24
Peak-Pressure [psi ( $\Delta P$ )]										
				70	48	49	41	36	28	28
400	330	140	100	78	58	51	43	36	32	28

However, assuming now that the blast spreads in a spherical wave, the condition would be as shown in Figure 69.

$$\text{Extension } S = d - \sqrt{d^2 - (0.625)^2},$$

where  $d$  is the distance of the signal transducer from the blast (from 4 in.  $\leq d \leq 24$  in.). For all values of  $d$ ,  $S$  is always near zero; therefore, the effect of the spherical blast wave front geometry has a negligible effect on the sweep triggering.

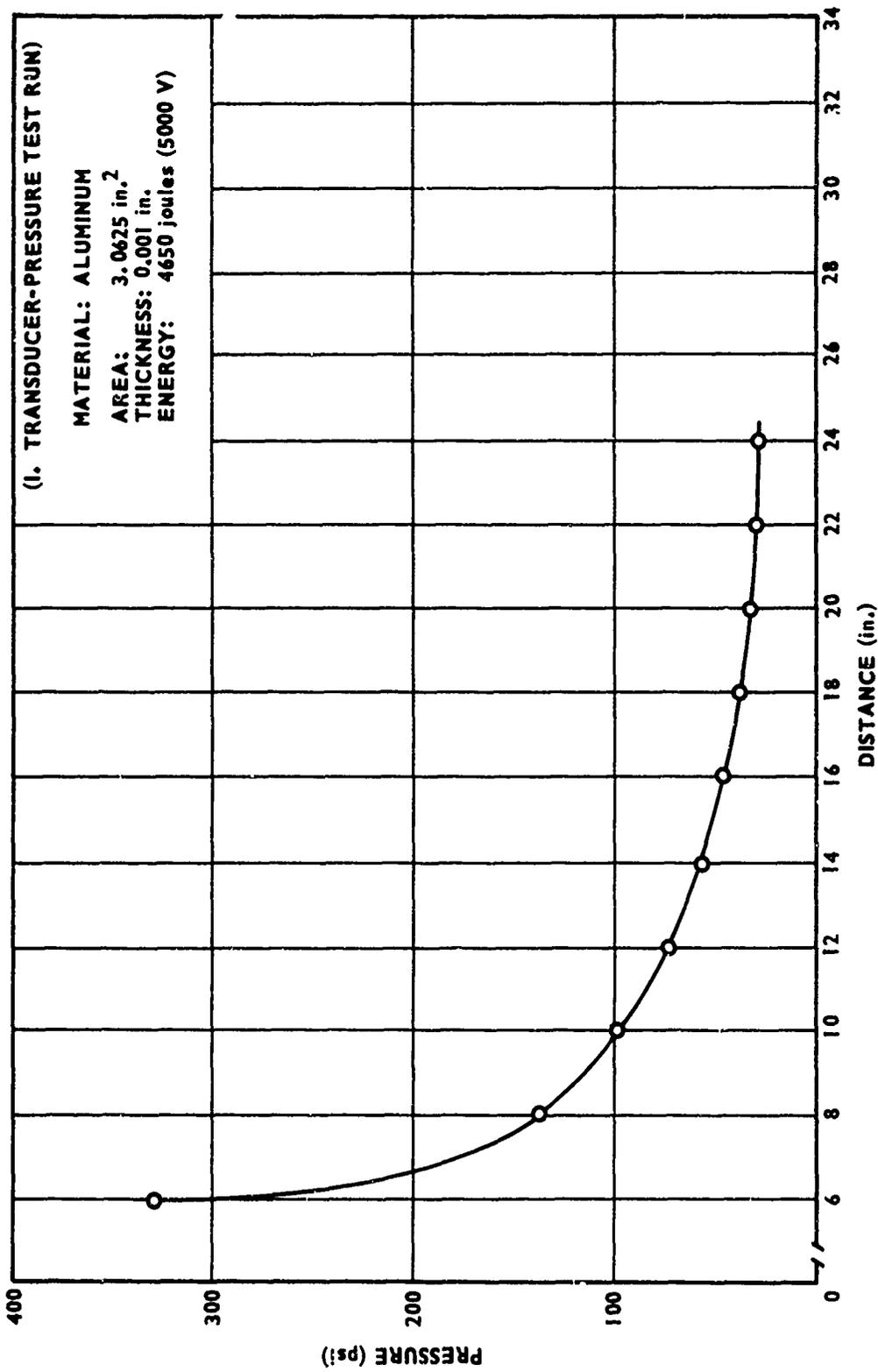


FIGURE 65. PEAK PRESSURE VERSUS DISTANCE

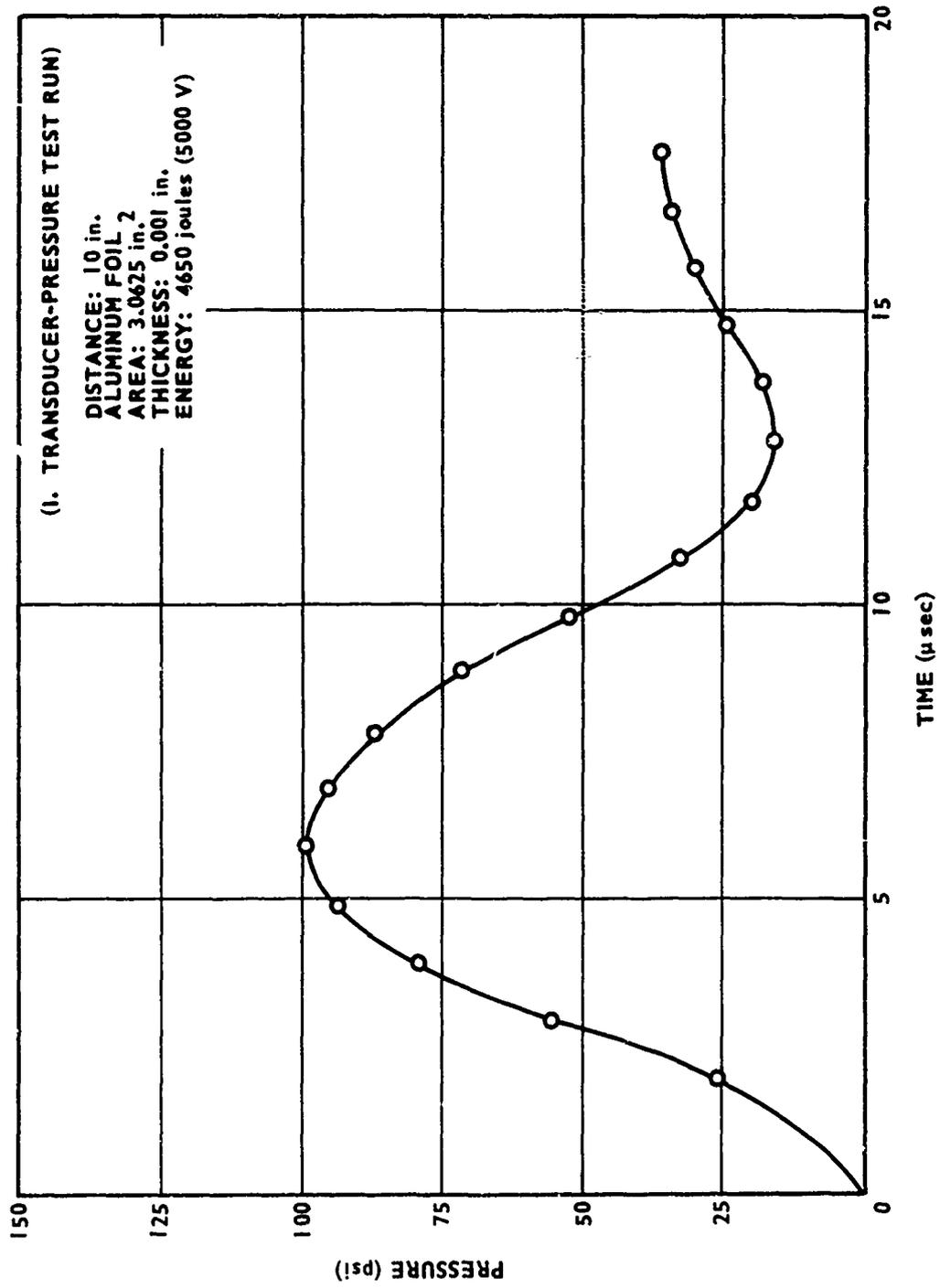


FIGURE 66. PRESSURE VERSUS TIME

As the transducer plate is moved closer to the blast, the amplitude of the blast wave increases in somewhat exponential fashion with decreasing distance from the foil. Therefore, for a given preset triggering level on the scope the extension  $S$  must be reduced accordingly to compensate for this fact in order to retain the blast wave in the desired location on the scope picture (first division).

The true extension cannot be calculated because the delay is influenced by the signal amplitude effect on the time base trigger. This effect is not directly measurable and can only be found experimentally.



$\Delta P = 20 \text{ psi/cm}$   
 $\Delta t = 2 \mu \text{sec/cm}$   
 $\Delta x = 10 \text{ in.}$   
PEAK PRESSURE = 100 psi

FIGURE 67. SCOPE PICTURE, 100-PSI PEAK PRESSURE



$\Delta P = 20 \text{ psi/cm}$   
 $\Delta t = 2 \mu \text{sec/cm}$   
 $\Delta x = 12 \text{ in.}$   
PEAK PRESSURE = 70 psi

FIGURE 68. SCOPE PICTURE, 70-PSI PEAK PRESSURE

b. Part 2: Procedure

These pressure transducer tests were made to find the true extension of the trigger device (in this case a pressure transducer) from the signal transducer in respect to the distance from the foil. The same mechanical setup as in the previous tests (self-triggering system) was used. As triggering

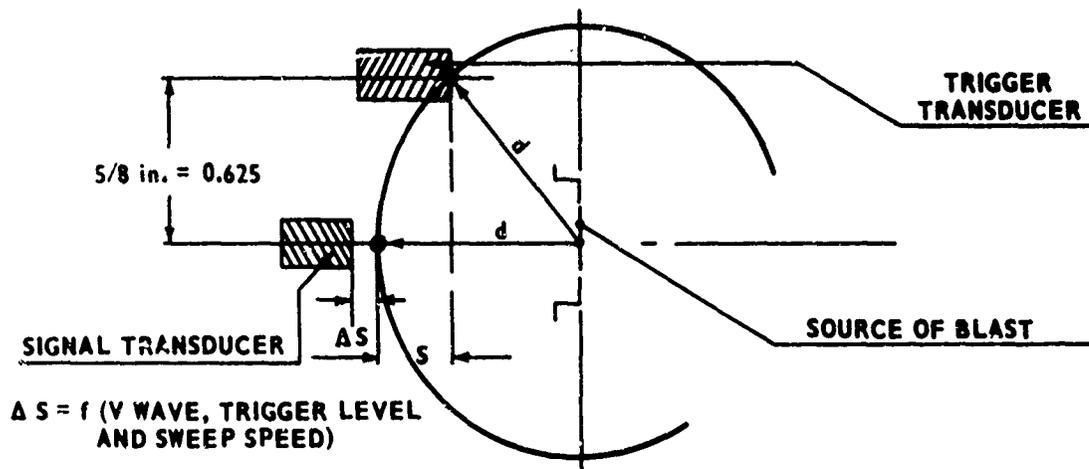


FIGURE 69. SPHERICAL BLAST WAVE

device the pressure transducer (Kistler Piezotron Mod. 213M 101) and as the signal transducer the pressure transducer (Kistler Piezotron Mod. 212X Exp.) were selected. A new transducer plate (Figure 70) for the trigger and signal transducer was designed and fabricated from nonconducting material (plexiglass) to avoid a ground loop. By removing one or more of the six 1/32-inch thick washers, it was possible to extend the trigger transducer from the signal transducer from 0 to 3/16 inch. Figure 71 shows the mechanical setup with the nonconducting plate with the two transducers and two battery couplers. The electrical setup is described in the block diagram of Figure 72.

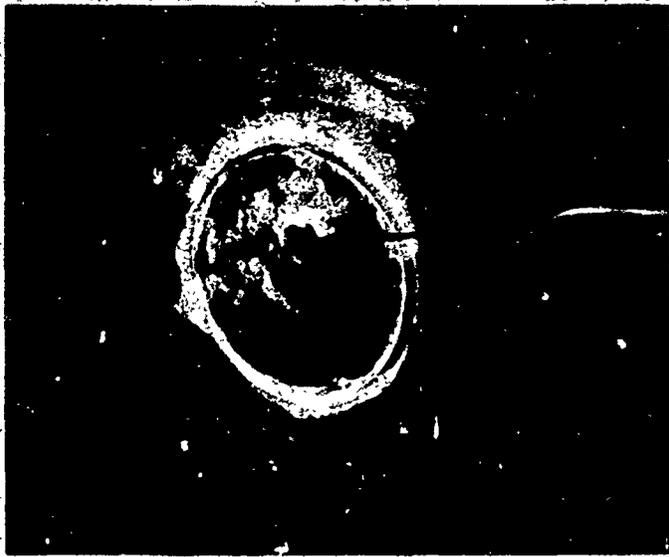
c. Results: Test Run No. 1

Scope pictures (Figures 73 and 74) taken in the test run showed that electromagnetic interference was present, and on some of the scope pictures it was observed as a superimposed wave that deflected the pressure trace off scale entirely.

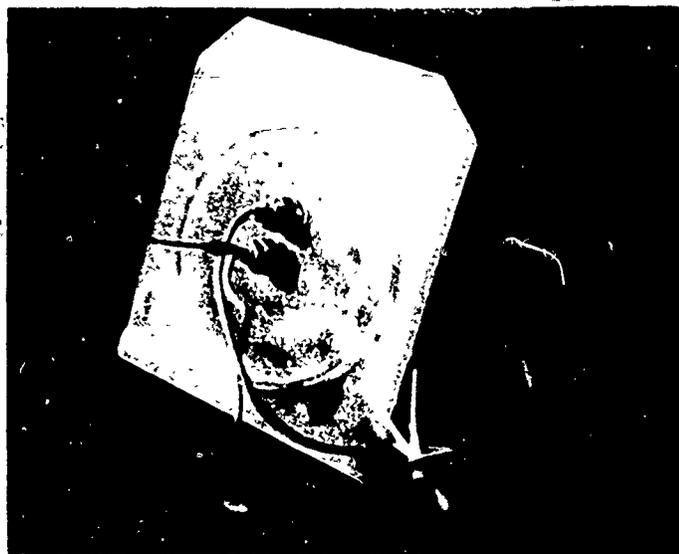
Poor electrical connections were observed too.

In conclusion, three results were noted:

- 1) Electromagnetic interference radiates from the discharge bank and from the impulse device during the test run.
- 2) Significant amounts of electromagnetic interference enter the measurement lines through either the transducer or the battery couplers.



TRIGGER TRANSDUCER



SIGNAL TRANSDUCER

FIGURE 70. TRANSDUCER PLATE

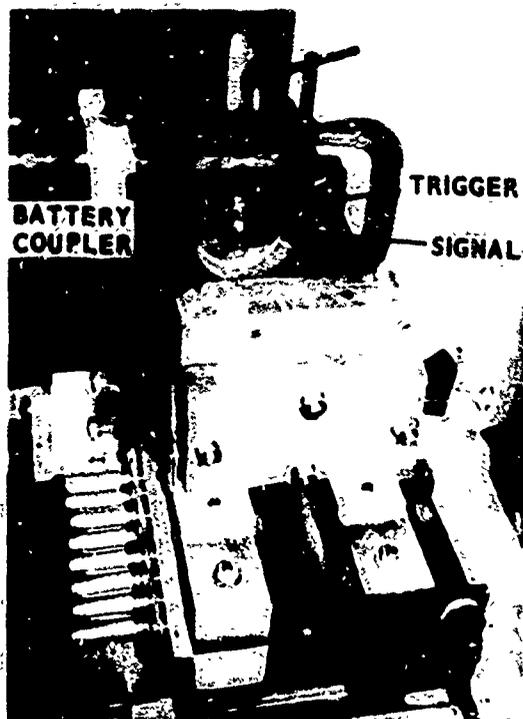


FIGURE 71. TRANSDUCER

- 3) Poor electrical connections at the measurement lines exist because of the rigidity of the coaxial cable used.

To solve these new problems and to proceed with the triggering test runs without much delay, it was decided to make a quick and simple check on the magnitude of the electromagnetic interference and on how much of it could be eliminated through the following provisional arrangements. Each battery coupler was individually wrapped in an insulating material and then completely shielded in aluminum foil. The shielded battery couplers were moved further from the impulse device and the capacitor bank.

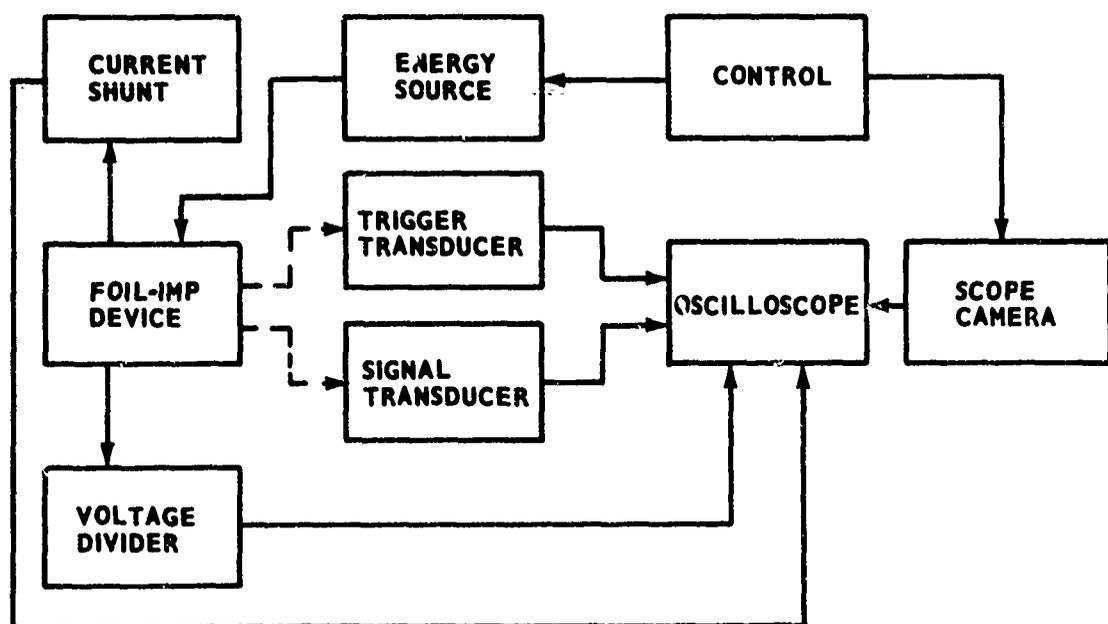
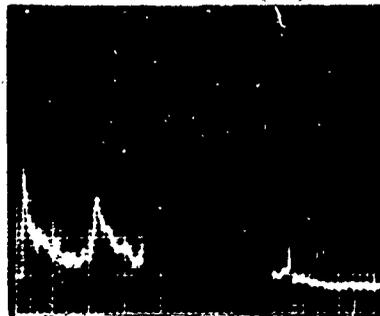


FIGURE 72. ELECTRICAL SETUP: BLOCK DIAGRAM



$\Delta P = 50 \text{ psi/cm}$   
 $\Delta t = 50 \mu\text{sec/cm}$   
 $\Delta x = 10 \text{ in.}$   
 $\Delta s = \text{TRIGGER EXTENSION}$   
 $= 3/16 \text{ in.}$   
**ENERGY = 4650 joules**

FIGURE 73. SCOPE PICTURE A

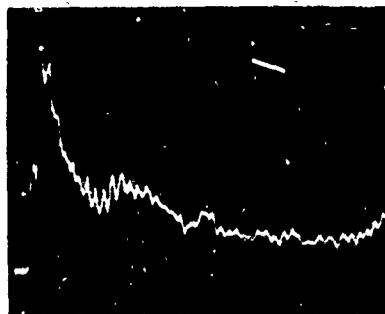


$\Delta P = 20 \text{ psi/cm}$   
 $\Delta t = 10 \mu\text{sec/cm}$   
 $\Delta x = 15 \text{ in.}$   
 $\Delta s = \text{TRIGGER EXTENSION}$   
 $= 3/16 \text{ in.}$   
**ENERGY = 4650 joules**

FIGURE 74. SCOPE PICTURE B

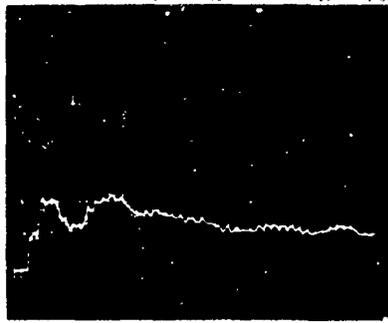
d. Results: Test Run No. 2

The improvement in elimination of electromagnetic interference can be seen on the scope pictures (Figures 75 through 78).



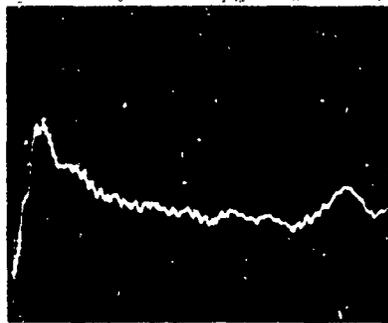
$\Delta P = 20 \text{ psi/cm}$   
 $\Delta t = 10 \mu\text{sec/cm}$   
 $\Delta x = 10 \text{ in.}$   
 $\Delta s = 1/8 \text{ in.}$   
**ENERGY = 4650 joules**

FIGURE 75. SCOPE PICTURE C



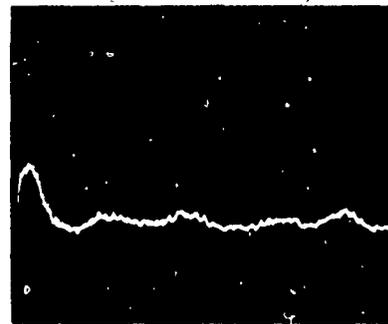
P = 20 psi/cm  
t = 10  $\mu$ sec/cm  
x = 15 in.  
s = 1/8 in.  
E = 4650 joules

FIGURE 76. SCOPE PICTURE D



P = 10 psi/cm  
t = 10  $\mu$ sec/cm  
x = 18 in.  
s = 1/4 in.  
E = 4650 joules

FIGURE 77. SCOPE PICTURE E



P = 10 psi/cm  
t = 10  $\mu$ sec/cm  
x = 20 in.  
s = 1/8 in.  
E = 4650 joules

FIGURE 78. SCOPE PICTURE F

As the scope pictures show the electromagnetic interference was almost completely eliminated by shielding the battery couplers completely and by moving the packages from their previous location on the track rail further from the electromagnetic interference source and setting the battery couplers 90 degrees to the impulse device and the capacitor bank.

The electromagnetic interference entering the lines through the transducers appeared now to be negligible.

By exchanging the very rigid and heavy Rex Turbo low inductance coax cable with the much lighter and much more flexible Supremant 5569 REV 3 coax cable, the electrical connection proved satisfactory.

Because of the necessity to disconnect the battery couplers after each test run to prolong the battery life the provisional insulating and shielding wrapping for the battery couplers was replaced by a permanent arrangement. The battery couplers were placed between styro foam plates and enclosed in aluminum miniboxes (Figure 79).

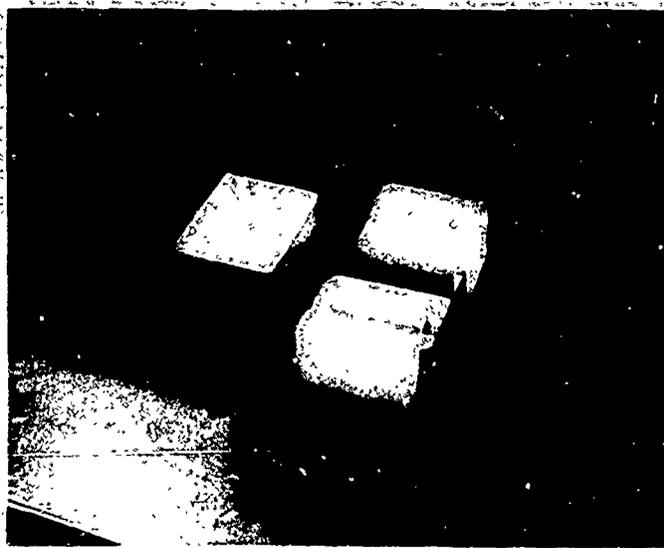


FIGURE 79. BATTERY COUPLERS

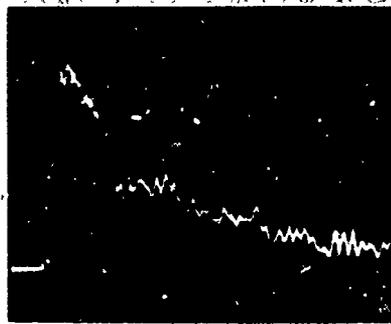
e. Results: Test Run No. 3

To check out these new arrangements in respect to electromagnetic interference, another test run was made. At the same time an attempt was made to determine a satisfactory location of the triggering transducer with respect to the signal transducer. The plexiglass transducer plate and the Kistler Piezotron transducer 213M 101 and 213M 103 were used. Both transducers were flush with the plate in the first test shot; no extension existed. As expected, no satisfactory pressure trace was recorded on the scope picture.

The trigger transducer, then, was extended 3/16 inch from the plate by removing all the washers, and the signal transducer was retracted 1/16 inch into the plate by adding two 1/32-inch washers. The total extension was thus now 1/4 inch.

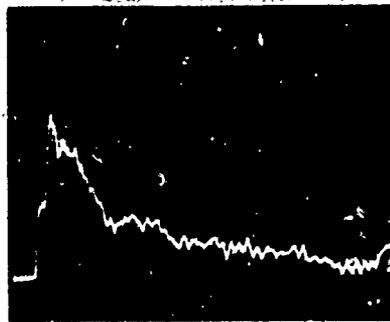
The next shot, and also the following ones, indicated that the proper delay was still not satisfactory because the pressure wave was not completely recorded on the scope picture. A further extension was not mechanically possible; therefore, it was decided instead of increasing the extension of the trigger transducer to reduce the triggering level at this time.

The following shots produced good pressure traces on the scope picture (Figures 80 and 81). However, the last shot at a 6-inch distance from the



$\Delta P = 20 \text{ psi/cm}$   
 $\Delta t = 10 \mu \text{ sec/cm}$   
 $\Delta x = 10 \text{ in.}$   
 $\Delta s = 1/4 \text{ in.}$   
**ENERGY = 4650 joules**

FIGURE 80. SCOPE PICTURE G



$\Delta P = 50 \text{ psi/cm}$   
 $\Delta t = 10 \mu \text{ sec/cm}$   
 $\Delta x = 8 \text{ in.}$   
 $\Delta s = 1/4 \text{ in.}$   
**ENERGY = 4650 joules**

FIGURE 81. SCOPE PICTURE H

exploded foil resulted in the fracture of the plexiglass transducer plate (Figures 82 and 83). The pressure level at this distance exceeded the calibrated pressure range of the signal transducer (200 psi) by about 400 psi. (Figure 84).

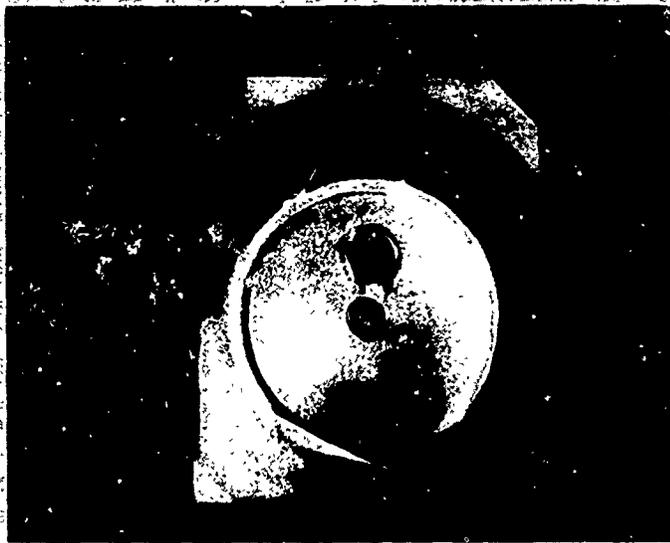


FIGURE 82. PLEXIGLASS TRANSDUCER PLATE FRACTURE, VIEW 1

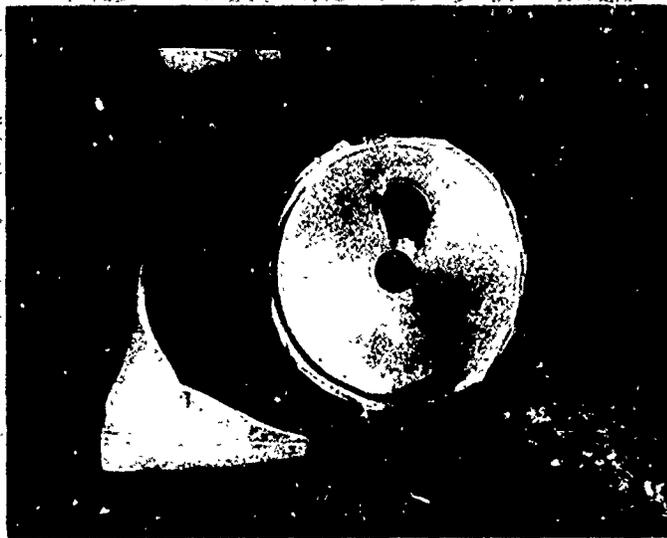
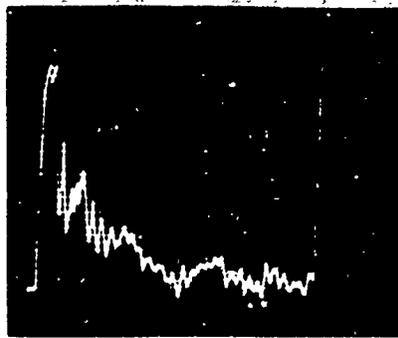


FIGURE 83. PLEXIGLASS TRANSDUCER PLATE FRACTURE, VIEW 2



$\Delta P = 100 \text{ psi/cm}$   
 $\Delta t = 10 \mu \text{ sec/cm}$   
 $\Delta x = 6 \text{ in.}$   
 $\Delta s = 1/4 \text{ in.}$   
ENERGY = 4650 joules (5000 V)

FIGURE 84. SCOPE PICTURE I

f. Conclusion

To find the true extension of the trigger device from the signal transducer in respect to the distance from the foil further tests are necessary. The latest scope picture were promising but not entirely conclusive, however, it seems to be the right approach.

To proceed with the tests a new stronger transducer plate must be fabricated for a new transducer with a much higher pressure range (4000 psi). The extension possibility of the trigger device should be increased to 3/8 inch.

**Appendix A**  
**Components: High Energy Capacitor Discharge Unit**

I. Operator's Control Panel

The operator's control panel (Figure A-1), located on the upper left-hand side of the unit, contains a switch panel, meter, a counter, and a potentiometer. The switch panel consists of the standby indicator and the power, on, short, limit discharge, charge, stop charge and fire switches. All switches, except the power switch, are equipped with an indicator that lights when depressed.

a. Power Switch

The power switch (Figure A-1) is a double-pole, key-operated switch with ON and OFF positions. Placing the switch at ON energizes the 6-volt power supply, turns on the high voltage power supply filaments, turns on the ventilating fan, and lights up the standby indicator. Placing the switch at OFF terminates power to the unit.

b. Standby Indicator

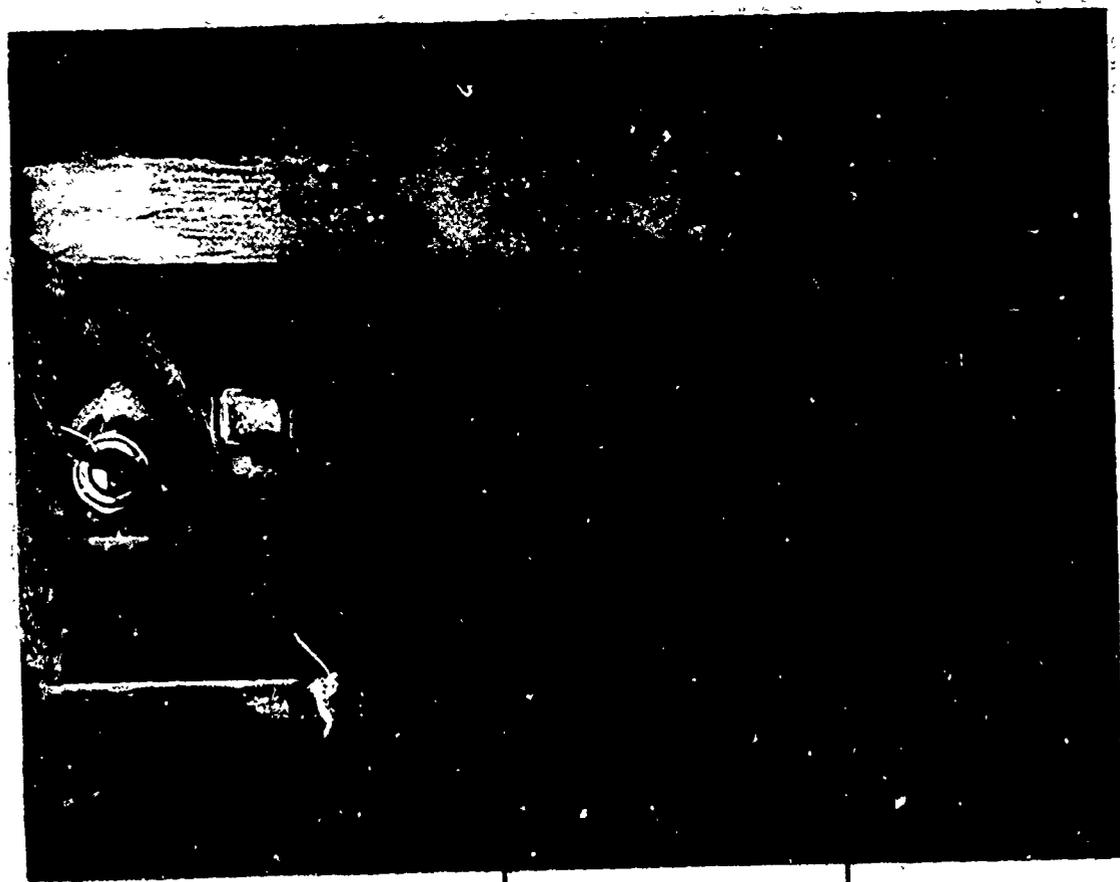
The standby indicator (Figure A-1) indicates that power is on the 6-volt power supply, the filaments of the high voltage power supply are on, and the ventilating fan is operating.

c. ON Switch

The ON switch (Figure A-1) is a momentary pushbutton microswitch equipped with a holding coil. When the switch is depressed, power is supplied to the switch panel and the charging cycle is ready to begin.

d. Short Switch

The short switch (Figure A-1) is a momentary pushbutton microswitch equipped with a holding coil. When depressed, the switch allows the shorting bar relay movable contact to drop, discharging the main bank through the relay.



CHARGE-CURRENT  
LIMITING POTENTIOMETER

COUNTER

CONTROL METER

FIGURE A-1. OPERATOR'S CONTROL PANEL

e. Charge Switch

The charge switch (Figure A-1) is a momentary pushbutton microswitch equipped with a holding coil. Depressing the switch starts the unit charging by lifting the shorting bar relay, operating the 30-ampere mercury relay, putting 115 volts, 60 cycle ac, on the primary of the high voltage power supply, and starting the timer that when timed out (1 sec) energizes the vacuum relay which switches the high voltage to the capacitor bank through the limiting resistor.

f. Stop Charge Switch

The stop charge switch (Figure A-1) is a momentary pushbutton microswitch equipped with a holding coil. Note: The unit is equipped to stop charge automatically at a preset level governed by the meter. However, the stop charge switch may be used as conditions warrant. When the switch is depressed, power is shut off to the high voltage power supply and the ready light comes on. The unit may be fired unless a new level of charge is desired. If a new level of charge is desired, after the unit has discharged and the short light homes on, the limit discharge switch must be depressed, and the charge cycle started again.

g. Limit Discharge Switch

The limit discharge switch (Figure A-1) is a momentary pushbutton microswitch equipped with a holding coil. When depressed, the switch allows the capacitor bank to bleed off through two parallel 50,000-ohm resistors.

h. Fire Switch

The fire switch (Figure A-1) is a momentary pushbutton microswitch without a holding coil. When the switch is depressed, the trigger fires the ignitrons discharging the capacitor bank into the foil.

i. Control Meter

The control meter (Figure A-1), located on the operator's panel, is a 50-microampere meter scaled from 0 to 10 kilovolts and registers voltage across the capacitors by taking a small proportional voltage off the meter multiplier. The meter is preset to a desired charging level and through a transistor amplifier operates the meter relay to cut off the charge at the preset level. The meter relay is part of the control meter.

j. Counter

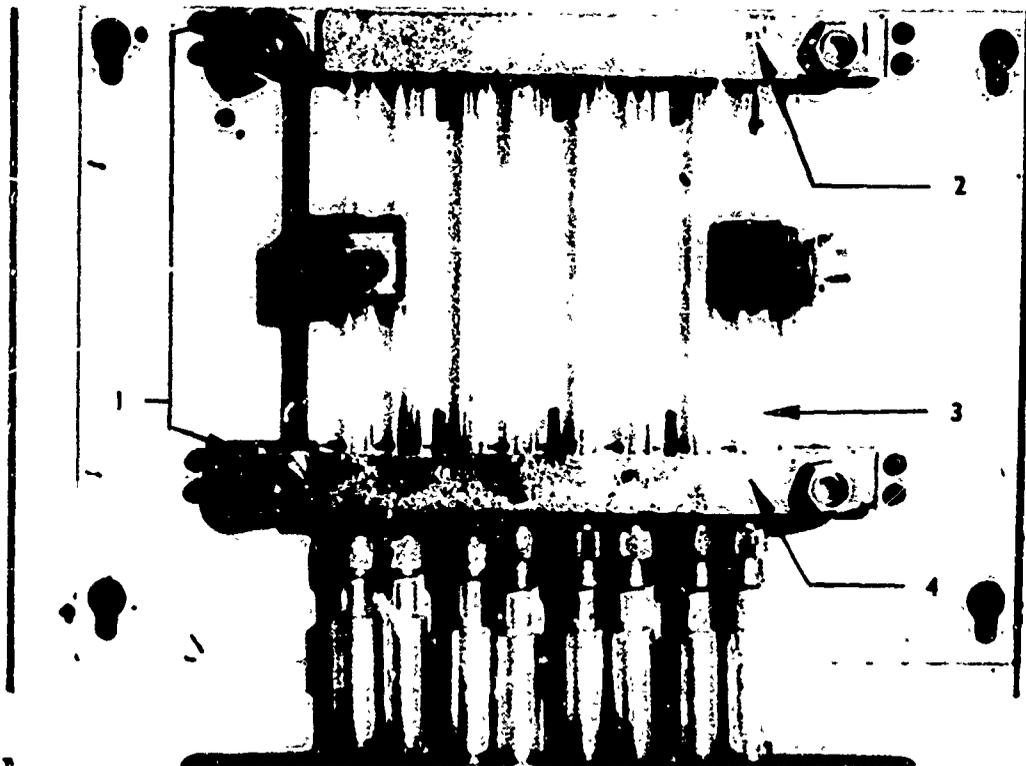
A counter (Figure A-1), located on the control panel, registers the number of firings performed by the unit.

k. Charge Current Limiting Potentiometer

The current limiting potentiometer (Figure A-1) is the variable control part of the charge current circuit. Its function is to set the bank capacitors' charging current to any desired value. This necessary since the power mains receptacles are ampere rated and the current drawn from them adjusted accordingly.

II. Quick Disconnect Collector

The quick disconnect collector (Figure A-2), located at the rear of the unit, is a high voltage terminal where the Rex Turbo low inductance coax cables leading to the fixture are connected and disconnected. The collector consists of a pair of positive bars, negative bars, and spacers mounted on collector bars. The inner disconnect is mounted in reverse of the outer disconnect.



1 COLLECTOR BAR                      3 SPACER  
2 POSITIVE BAR                      4 NEGATIVE BAR

FIGURE A-2. QUICK DISCONNECT COLLECTOR

### III. Shorting Bar Relay

The shorting bar relay (Figure A-3), is a solenoid-operated relay that discharges the main capacitor bank whenever the short switch is depressed, an interlocked door is opened, or the unit is shut down. A clear view window allows personnel to observe the position of the relay.



FIGURE A-3. SHORTING BAR RELAY

#### IV. Shorting Switch

The shorting switch (Figure A-4), mounted on the lower aft end of the unit, is a hand-operated knife switch with short and charge positions. It functions as a mechanical safety device and is a second positive means of insuring that the main bank is discharged. The shorting switch should not be used as a means to discharge the main bank because damage to the unit may result.

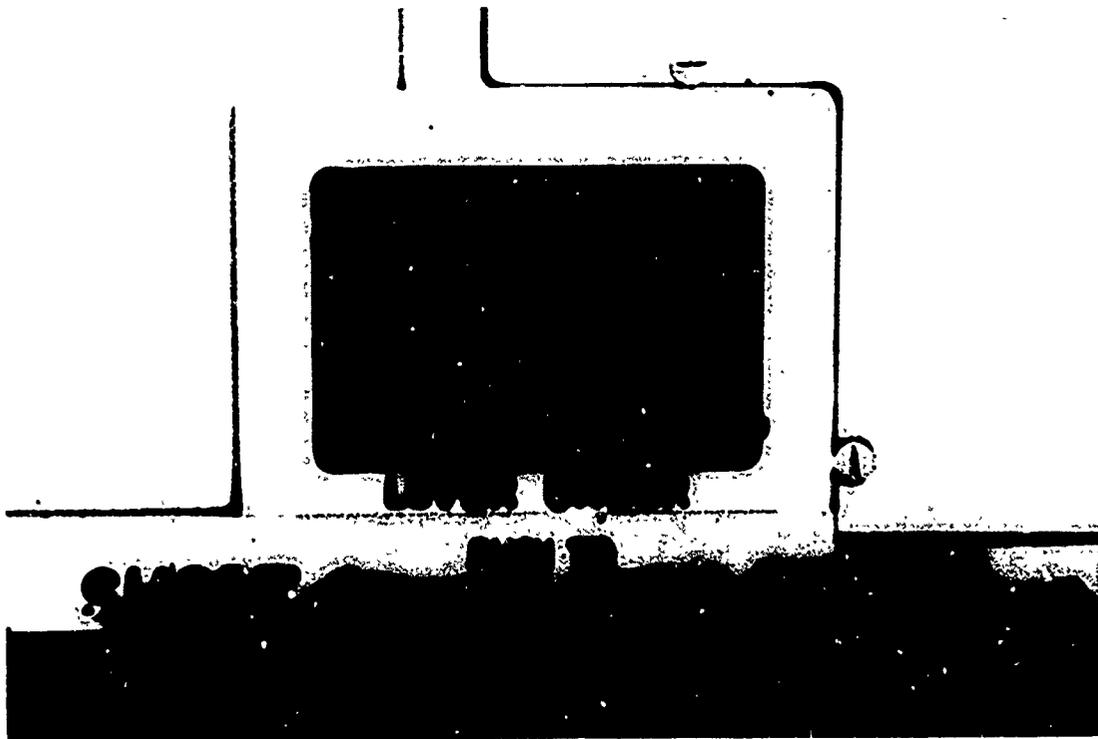


FIGURE A-4. SHORTING SWITCH

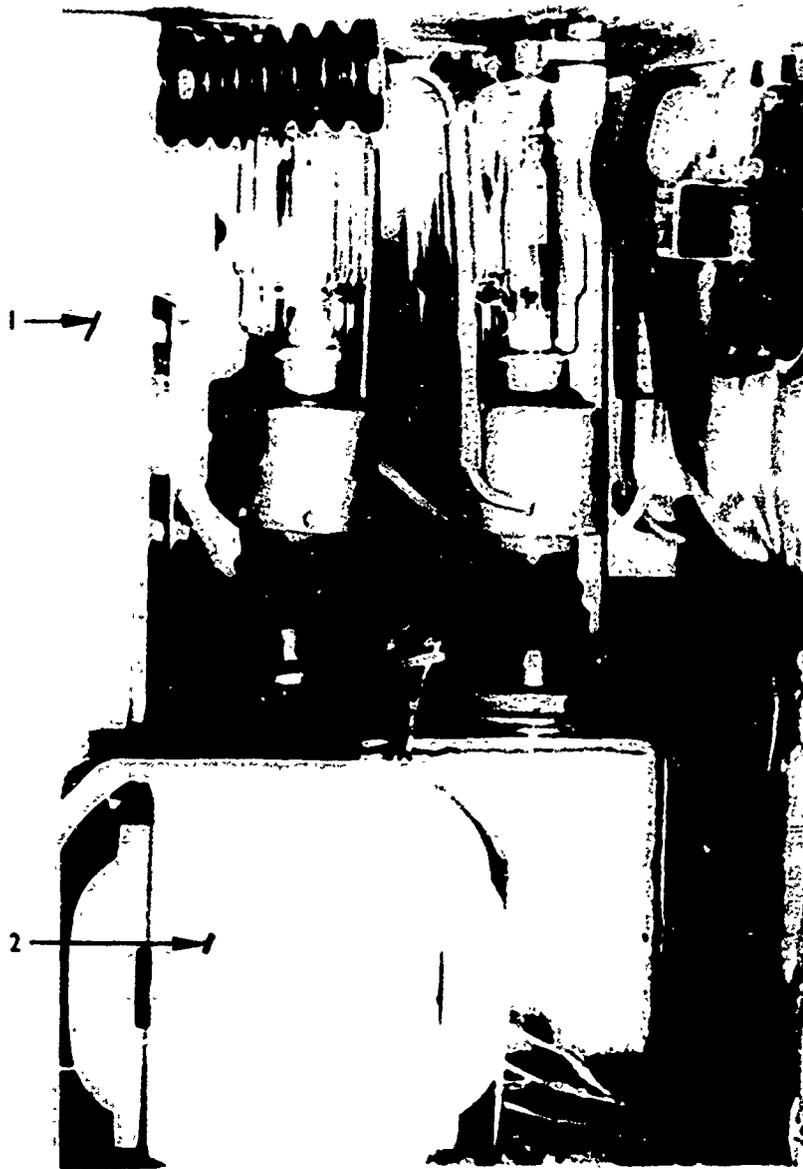
#### V. High Voltage Power Support

The high voltage power supply (Figure A-5), mounted in the forward lower compartment, is a General Electric Kenetron Bridge Rectifier with an output of 200 mils at 10 kilovolts. Its function is to charge the capacitor bank.

#### VI. Isolation Transformer

The isolation transformer (Figure A-5), located on the left-hand side of the high voltage power supply, is a one-to-one ratio transformer with 20,000

volts isolation safety feature isolating high voltage electrical components from the control circuit.



1-HIGH VOLTAGE POWER SUPPLY  
2-ISOLATION TRANSFORMER

FIGURE A-5. HIGH VOLTAGE POWER SUPPLY AND ISOLATION TRANSFORMER

#### VII. Sensitive Relays

There are six sensitive relays mounted on electrical boards located behind the operator's control panel and forward of the capacitor bank. Each relay functions to operate the control circuits, including the firing circuit.

#### VIII. Main Capacitor Bank

The capacitor bank, located in the aft compartment, consists of six low inductive, fast discharge capacitors, rated at a nominal capacity of 60 microfarads each and a working voltage of 10 kilovolts.

#### IX. Power Supply, 6- and 28-Volt

There is one 6-volt power supply mounted on an electrical board, located behind the operator's control panel. The other 6- and 28-volt power supplies are located on the electrical board in the aft compartment forward of the capacitor bank. The 6- and 28-volt power supplies are filtered bridge rectifier units with an input of 115 volts ac and a negative 6- and 28-volt dc output for the control and signal circuits.

#### X. Time Delay Relay

The time delay relay is mounted on the electrical board in the aft compartment forward of the capacitor bank. The relay delays the high voltage to the capacitor bank for 2 seconds, allowing the shorting bar relay to open and preventing possible arcing of the shorting bar relay contacts.

#### XI. Mercury Relay

The mercury relay, located in the lower forward compartment, controls 115 volts, 60 cycle ac, to the primary of the high voltage power supply.

#### XII. Vacuum Relay

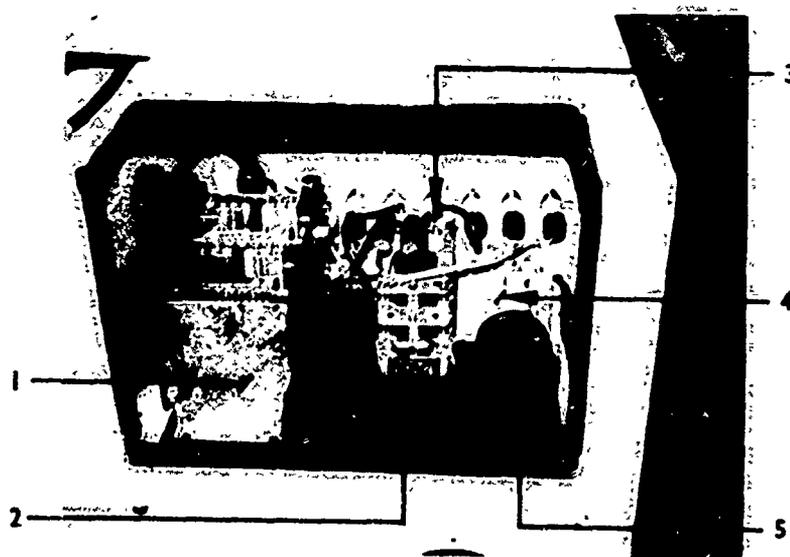
The vacuum relay, located in the lower forward compartment, controls the charging voltage from the high voltage power supply to the capacitor and discharges the main bank through the limiting resistors.

### XIII. Raysistor

Six Raysistors are located in the upper right-hand compartment behind the trigger chassis. The raysistors, an electro-optical device, consist of a control circuit (light source) and a signal circuit (photo cell) assembled in a casting. The Raysistors eliminate electrical connections between the control circuits and the high voltage circuits completely isolating the operator. A variation of the input to the light source changes the resistance of the photo cell resistor from 2 megohms to 160 ohms operating the applicable sensitive relay.

### XIV. Trigger Chassis

The trigger chassis (Figure A-6) is located in the upper right-hand forward compartment and consists of silicon control rectifier stack, shorting relay, capacitors, dc high voltage power supply, and variac as shown. The trigger chassis functions to ionize the ignitrons, causing them to discharge the main capacitors into the foil.



- 1-SILICON CONTROL RECTIFIER STACK
- 2-SHORTING RELAY
- 3-CAPACITORS
- 4-POWER SUPPLY
- 5-VARIAC

FIGURE A-6. TRIGGERING CHASSIS AND SILICON CONTROL RECTIFIER

a. Silicon Control Rectifier Stack

The silicon control rectifier stack (Figure A-6) consists of two 1300-volt silicon controlled rectifiers and equalizing circuits mounted in an aluminum heat sink. Its function is to discharge the trigger capacitors.

b. Trigger Chassis Shorting Relay

The shorting relay (Figure A-6) removes the charge from the trigger capacitors when de-energized. When energized, it turns on the 115 volts ac to the high voltage trigger supply and connects the trigger supply output to the capacitors to charge them through 400 kilohms of resistance.

c. Trigger Capacitors

The trigger capacitors (Figure A-6) are two parallel, two microfarad, 5-kilovolt capacitors that function to trigger the ignitrons.

d. DC High Voltage Trigger Power Supply

The power supply (Figure A-6) is rated at 115 volts ac input with an output of 5 kilovolts dc at 10 milliamperes. Its function is to charge the two parallel, 2-microfarad trigger capacitors.

e. Variac

The variac (Figure A-6), a transformer with a variable secondary, is used to set the trigger voltage by varying the input voltage to the 5-kilovolt dc power supply.

XV. Ignitrons

Four ignitrons, wired in parallel, function as a switch to deliver the main capacitor charge to the foil. When the ignitors are fired, mercury in the ignitrons become ionized, conducting the charge through the ignitrons.

**XVI. Ventilating Fan**

A ventilating fan, mounted on the power supply door, cools the high voltage power supply and limiting resistors.

**Appendix B**  
**Major Functional Components: High Energy Capacitor Discharge Unit**

**Major Functional Components: High Energy Capacitor Discharge Unit**

The major functional components of the high energy capacitor discharge unit are the following:

- 1) Capacitor bank
- 2) High voltage power supply
- 3) 28-Volt power supply
- 4) 6-Volt power supply
- 5) Firing circuit
- 6) Triggering circuit
- 7) Control panel assembly
- 8) Raysistors
- 9) Meter and meter relay

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Structures and Mechanics Laboratory Research and Engineering Directorate U. S. Army Missile Command Redstone Arsenal, Alabama 35809		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP N/A	
3. REPORT TITLE EXPLODING FOIL TECHNIQUES			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report			
5. AUTHOR(S) (First name, middle initial, last name) Erich H. Richert William S. Hodge			
6. REPORT DATE 23 April 1970		7a. TOTAL NO. OF PAGES 91	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO.		8b. ORIGINATOR'S REPORT NUMBER(S) RS-TR-70-3	
8c. PROJECT NO. (DA) 1L013001A91A AMC Management Structure Code No. 5016, 11, 844		8d. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AD	
9. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of this Command, ATTN: AMSMI-RS.			
10. SUPPLEMENTARY NOTES None		12. SPONSORING MILITARY ACTIVITY Same as No. 1	
13. ABSTRACT This report discusses one new way to generate high pressure without using high quality explosives. Exploding foil techniques, the proposed method, results in a high pressure pulse of very short duration against a target. This phenomenon can be subdivided into three phases: the initial region at which the material heats up and explodes, the region of the dwell phase at which the vaporized material forms a low-conductivity vapor, and the region at which a resurge of current occurs in the vapor. Data applicable to rapidly exploded foils and wires are discussed, and the foils appear to be more suitable for simulating high pressure short duration shock waves because of the greater directionality achieved and shorter heating time.  Exploding foil techniques could represent an applicable, inexpensive tool for simulation of high pressure short duration shock waves. The task here was to plan and design an apparatus for generating shock waves in the laboratory by exploding foil.			

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85

Security Classification

**UNCLASSIFIED**

**Security Classification:**

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Exploding foil techniques High pressure generator Rapidly exploding foils Short duration shock waves						

**UNCLASSIFIED**

**Security Classification**