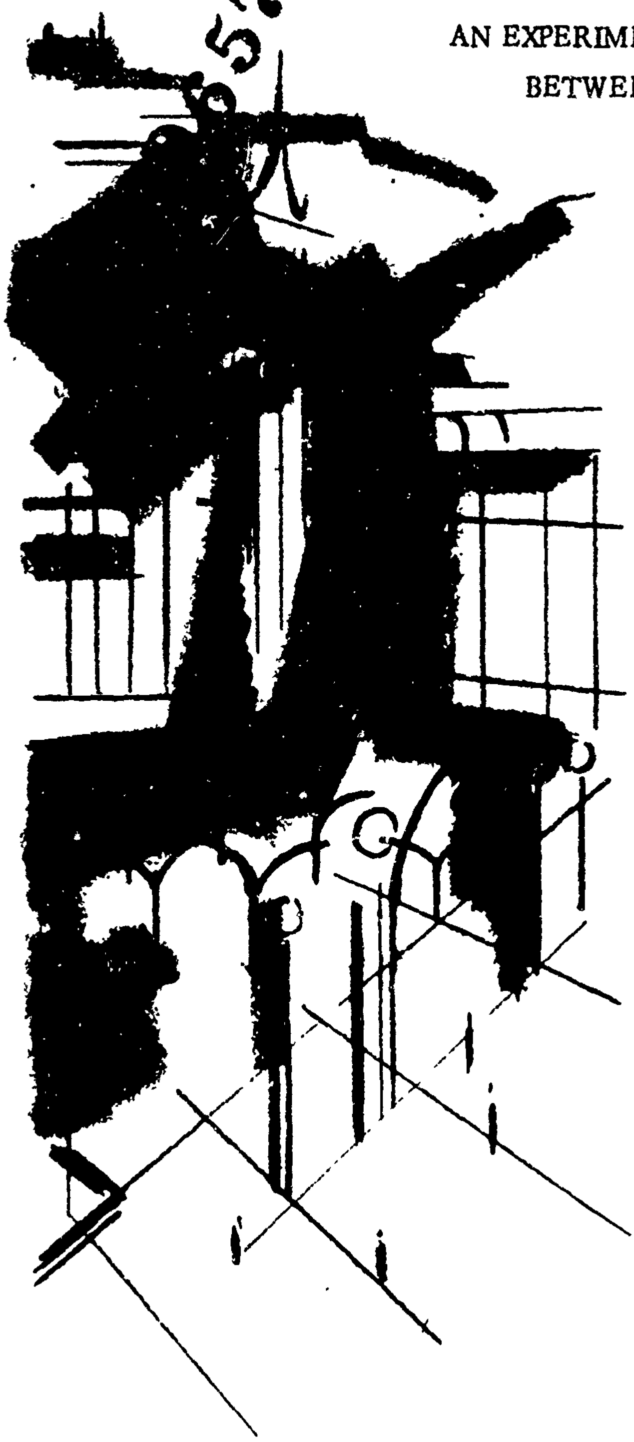

AN EXPERIMENTAL METHOD FOR THE STUDY OF INTERACTIONS BETWEEN DETONATION WAVES AND MAGNETIC FIELDS

By
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Technical Note No. 3-67
Grant AFOSR 129-67
Report No. AS-67-7

June 1967

COLLEGE OF ENGINEERING

UNIVERSITY OF CALIFORNIA, Berkeley

38

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ABSTRACT

Reported here is the design and construction of an experimental apparatus for the study of the influence of electromagnetic fields on the structure of detonation waves. The apparatus consists of a detonation tube having a 3/4 inch square test section with axial magnetic and transverse electric fields. The structure of the detonation wave is recorded by the use of the soot film technique.

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ACKNOWLEDGMENT

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INTRODUCTION

The first comprehensive study of the interaction between detonation waves and electric and magnetic fields was made by Bone, Fraser and Wheeler [1] in 1935. In their investigation a rotating drum camera was used to record changes in the velocity and spin in $CO + O_2$ detonations due to transverse magnetic, axial magnetic and axial electric fields. More recently the interaction between detonation waves and electromagnetic fields became a subject of numerous studies, notably those of Toong and his students at M.I.T. [2] who investigated some overall aspects of the process for a possible application as an energy conversion system.

In the meantime stroboscopic laser-schlieren photography has given detailed information on the multi-wave character of the detonation front [3]. Traces, left by the wave intersections on a soot covered wall of the detonation tube, have also provided a valuable means of obtaining a qualitative description of the evolution of the wave structure [4]. In addition, graphical methods have been formulated for the analysis of wave intersections associated with the detonation front [5].

In light of these developments it has become of interest to investigate the effects of the electromagnetic fields on the structure of the detonation wave. To this end an apparatus has been built, which utilizes the soot film technique, to study such effects in the case of axial magnetic and transverse electric fields.

The design and construction of this apparatus is presented here. Preliminary experiments have been performed in argon diluted acetylene-oxygen mixtures to test its operation, but no observation has been made yet of the effects of the interaction between the electromagnetic field and the wave structure.

APPARATUS

A schematic diagram of the entire apparatus is shown in Fig. 1. The detonation tube consists of a 4 foot stabilization section, which is connected to a 5 foot test section. In operation the driver is filled with a detonable mixture which is ignited at the closed end with a spark gap. The resulting explosion bursts the diaphragm, producing an overdriven detonation wave at the beginning of the stabilization section. This wave decays within 3 or 4 feet to a steady detonation which then propagates through the tube.

The test section is constructed out of 1/2 inch thick plexiglass to form a rectangular tube with internal dimensions of 60 x 1 1/4 x 3/4 inch. Two copper electrodes, 24 x 1 1/4 inches, are imbedded in opposite walls in the center of the tube. A removable 1/2 x 3/4 inch plexiglass bar runs the length of the tube and reduces its cross section to 3/4 x 3/4 inch. Before each experiment, the bar is covered with a thin film of kerosene soot. The test section is centered in the magnet so that the soot records the structure of the detonation wave in its original, perturbed and relaxing states. Shop drawings of the tube are enclosed in the Appendix.

A steady, wide kerosene flame is used to apply soot directly onto the plexiglass bar. To insure controllable soot thickness and consistency, a "soot machine" has been constructed, which consists simply of a rail-mounted movable support for the bar and an adjustable stand for the kerosene burner. This device permits the bar to be drawn smoothly through the flame. Photographs of the soot records are made by inserting the bar directly into a photographic enlarger and printing from it as from a negative.

Use is made of a recently developed continuous flow gas mixing device [6] to supply the required explosive mixtures for the driver and driven sections of the detonation tube. A schematic of the flow system is presented in Fig. 2.

In operation the needles are in a choked flow condition so that the flow rate depends only on the upstream stagnation pressure. The flow mixing system has been chosen for its versatility, ease of operation and relative safety, as compared to the conventional batch mixing chamber gas supply.

A magnet has been designed and constructed to produce an axial field that is uniform to within 5% over a distance of 10 inches along the tube. The field profile is displayed in Fig. 3. With the use of a 32kJ capacitor bank a maximum field intensity of 19kG has been obtained. As shown in Fig. 4, the magnet is composed of three separate coils wound on a single spool. The outer coils consist of 10 layers with 11 windings per layer and the inner coil consists of 8 layers with 8 windings per layer. This geometry allows the inclusion of two 3 inch ports for optical access across the tube in the interior of the magnetic field.

The magnet geometry was determined by means of a computer program which could vary the parameters of a trial coil configuration to provide a least squares fit of the field distribution to a uniform 10 inch field. Since optical measurements were anticipated, a trial configuration consisting of three coils was used. A compromise between field uniformity, field strength and available spool materials fixed the internal diameter of the coils at 8 3/4 inches. The computer then adjusted the coil sizes and spacings to provide the optimum field distribution.

The coils were wound with 1/4 inch square, cotton insulated copper wire, each winding being saturated with a mixture of 815 Epon epoxy resin and 11% by weight of agent D catylist. To insure against internal electrical breakdown, the layers of wire were separated by an epoxy saturated, double layer of fiberglass cloth. The magnet spool was made out of type G-10 epoxy fiber laminate, and the coils were held apart by braces of the same material. Shop drawings of the magnet spool are included in the Appendix.

The magnet was mounted in a large box as depicted in Fig. 5. The shaded areas represent 1/32 inch sheet metal which lines the interior and provides shielding for the magnetic field. The box is constructed out of 1/2 inch plywood and braced with angle iron; it is supported by a metal stand with adjustable legs that permit vertical alignment. As an added safety precaution, a compartment has been added to the box for the installation of most of the high voltage components.

The field has been calibrated by resonating the magnet with the capacitor bank and then measuring the voltage across a small 80 turn coil placed at various positions along the magnet axis. The time dependent behavior of the field during an experiment is monitored by integrating the voltage across another coil attached permanently to the magnet.

The modified crowbar circuit, shown schematically in Fig. 6, is used both to activate the magnet and to produce an electric field between the electrodes in the test section. With reference to Fig. 7, its operation is as follows. Initially the capacitor bank is charged to $-V_o$. The gas is ignited in the driver and the resulting detonation wave is detected by an ion gap which then triggers ignitron A. This discharges the capacitor bank through the magnet. At a later time, when the magnet voltage (V_m) has reversed polarity and field strength has just passed its maximum, ignitron B is fired. This switches the magnet current through the electrodes and the shunt resistor (R_s). On the time scale of the experiment the magnet acts as constant current source so that a large range of electrode voltages (V_e) may be obtained by adjusting the shunt resistor.

PRELIMINARY EXPERIMENTS

Preliminary experiments with this apparatus have been made using the mixture of $2C_2H_2 + 3O_2 + 11A$ at an initial pressure of 22mm at room temperature. It has been found that detonation waves propagating in the single mode (the equivalent of detonation spin in a square cross section tube) in this mixture make excellent soot records and are extremely stable and reproducible, so that any perturbations due to the electromagnetic field could be easily observed. A soot record of the unperturbed wave is shown in Fig. 8. The dark lines in the photograph correspond to the traces left by the wave intersections that occur in the detonation front which propagates from left to right. The unusual structure of this wave may be interpreted as a coupling between the spinning mode (7), usually found in a circular cross section tube, and the transverse waves of a rectangular tube (4).

Soot records from experiments with a magnetic field of 16kG and an electric field corresponding to a potential of 1kV imposed across the 3/4 inch width of the test section are shown in Fig. 9. Pictures of oscilloscope traces of the magnetic field strength, magnet voltage and electrode potential are displayed in Fig. 10. Although the oscilloscope records were obtained from different experiments, their repeatability was sufficiently good to establish the simultaneity of the results in Fig. 10. It is evident from the soot records that the wave structure of the detonation front has not been disturbed by the presence of the electromagnetic fields.

CONCLUSIONS

An apparatus for the study of the interaction between detonation waves and electromagnetic fields has been designed and constructed. It consists of a shock driven detonation tube and a magnet with a capacitor energy source and the auxiliary switching circuits.

Preliminary experiments have been performed to test the operation of the apparatus, but no effect of the electromagnetic field on the detonation wave has been, as yet, observed.

An interesting set of soot records of detonation waves in the single mode (the equivalent of detonation spin in a square cross section tube) has been obtained. Future plans call for experimentation with significantly higher electric and magnetic fields than the 2kV/cm and 16kG attained in the preliminary experiments, as well as for modification of the geometry of the interaction process by changing the direction of the magnetic field from axial to transverse.

REFERENCES

1. Bone, W. A., Fraser, A. P., Wheeler, W. H., Phil. Trans. Roy. Soc. (London), A, 235, 29-68, 1935.
2. Plett, E. G., "Joulean Heating and Lorentz Force Effects on Gaseous Detonation Flow Fields", Ph.D. Thesis, M.E. Dept., M.I.T., 1966.
3. Urtiew, P. A., Oppenheim, A. K., "Experimental Observations of the Transition to Detonation in an Explosive Gas", Proc. Roy. Soc., A, 295, 13-28, 1966.
4. Steel, G. B., "Experimental Study of the Wave Structure of Marginal Detonation in a Rectangular Tube", University of California, Berkeley, Rept. No. AS-66-4, January 1966.
5. Oppenheim, A. K., Smolen, J. J., "Vector Polar Method for the Analysis of Wave Intersections", University of California, Berkeley, Report No. AS-66-16, November 1966.
6. Kamel, M. M., Lundstrom, E. A., "Continuous Gas Mixing by the Use of Critical Flow Through Small Diameter Tubes", University of California, Berkeley, Rept. No. AS-67-3, March 1967.
7. Schott, G. L., "Observations of the Structure of Spinning Detonation", Phys. Fluids, 8, 5, 850-865, 1965.

FIGURE CAPTIONS

Fig. 1 Schematic Diagram of the Apparatus

Fig. 2 Schematic Diagram of the Flow Mixing Device

Fig. 3 Profile of the Magnetic Field Strength - The reference field strength, B_o, is given by the relation $B_o(kG) = .97V_o(kV)$, where V_o is the voltage across the 160 F energy storage capacitor bank.

Fig. 4 Assembly of the Magnet

Fig. 5 Magnet Enclosure

Fig. 6 Switching Circuits

Fig. 7 Detonation Wave Diagram with Plots of Magnet Field Strength (B), Magnet Voltage (V_m), and Electrode Voltage (V_e).

Fig. 8 Soot Records of Single Mode Detonation without Electromagnetic Fields - The detonation propagates from left to right in a mixture of $2C_2O_2 = 3O_2 + 11A$ at an initial pressure of 22mmHg and at room temperature. The record is taken from one wall of a 3/4 x 3/4 inch cross section tube.

Fig. 9 Soot Records of Single Mode Detonation with Electromagnetic Fields - The records have been taken under the same conditions as those shown in Fig. 8 under the action of an axial magnetic field of 16kG and an electric field corresponding to a potential of 1kV imposed across the 3/4 inch width of the tube.

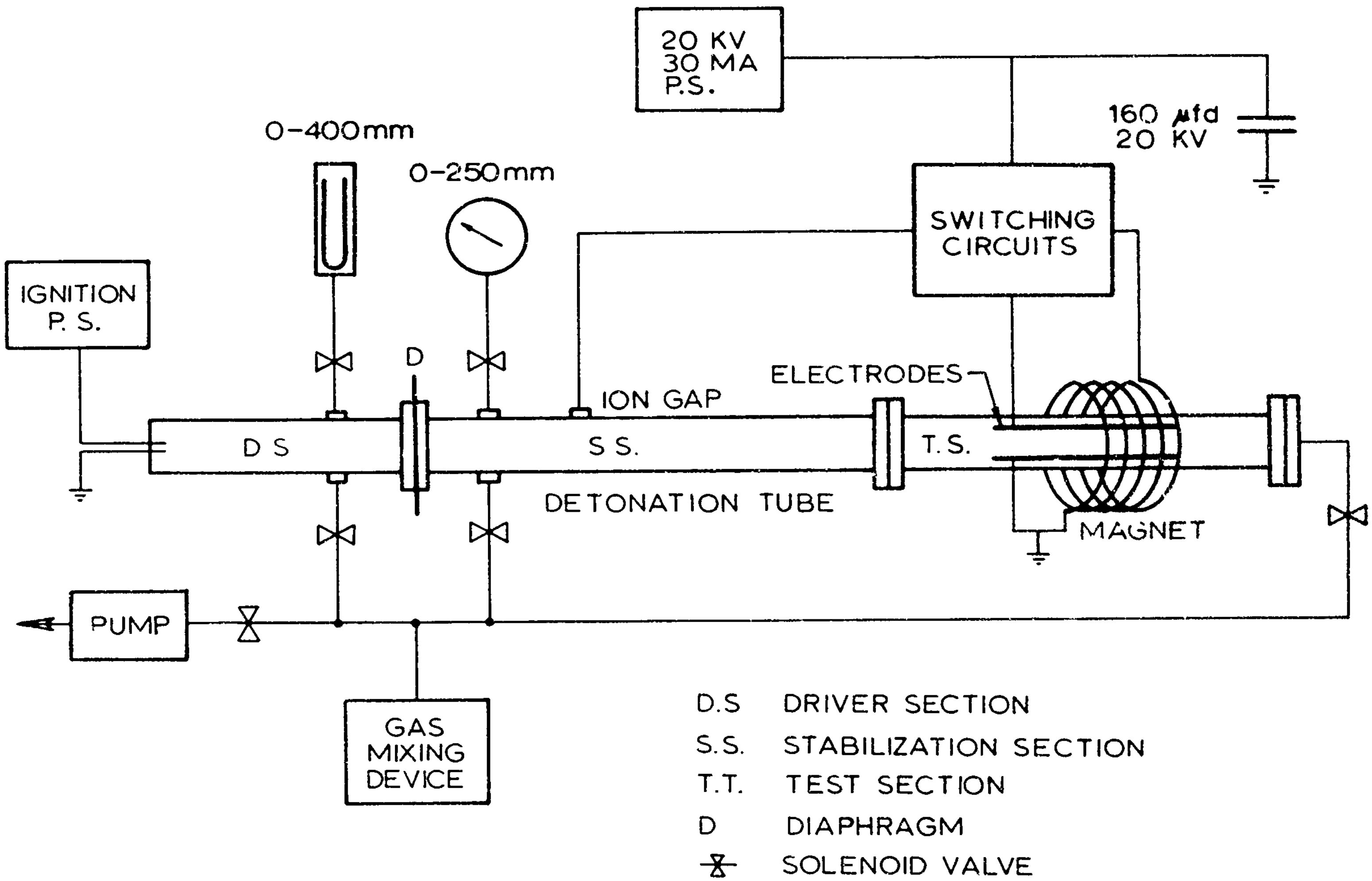
Fig. 10 Oscilloscope Records from Experiments with Single Mode Detonation and Electromagnetic Fields

a)	Magnetic Field Strength	Vertical scale:	1 division = 4.0kG
		Horizontal scale:	1 division = .5msec
b)	Magnet Voltage	Vertical scale:	1 division = 5kV
		Horizontal scale:	1 division = .5msec

c) Electrode Potential Vertical scale: 1 division = 200V

Horizontal scale: 1 division = .1msec

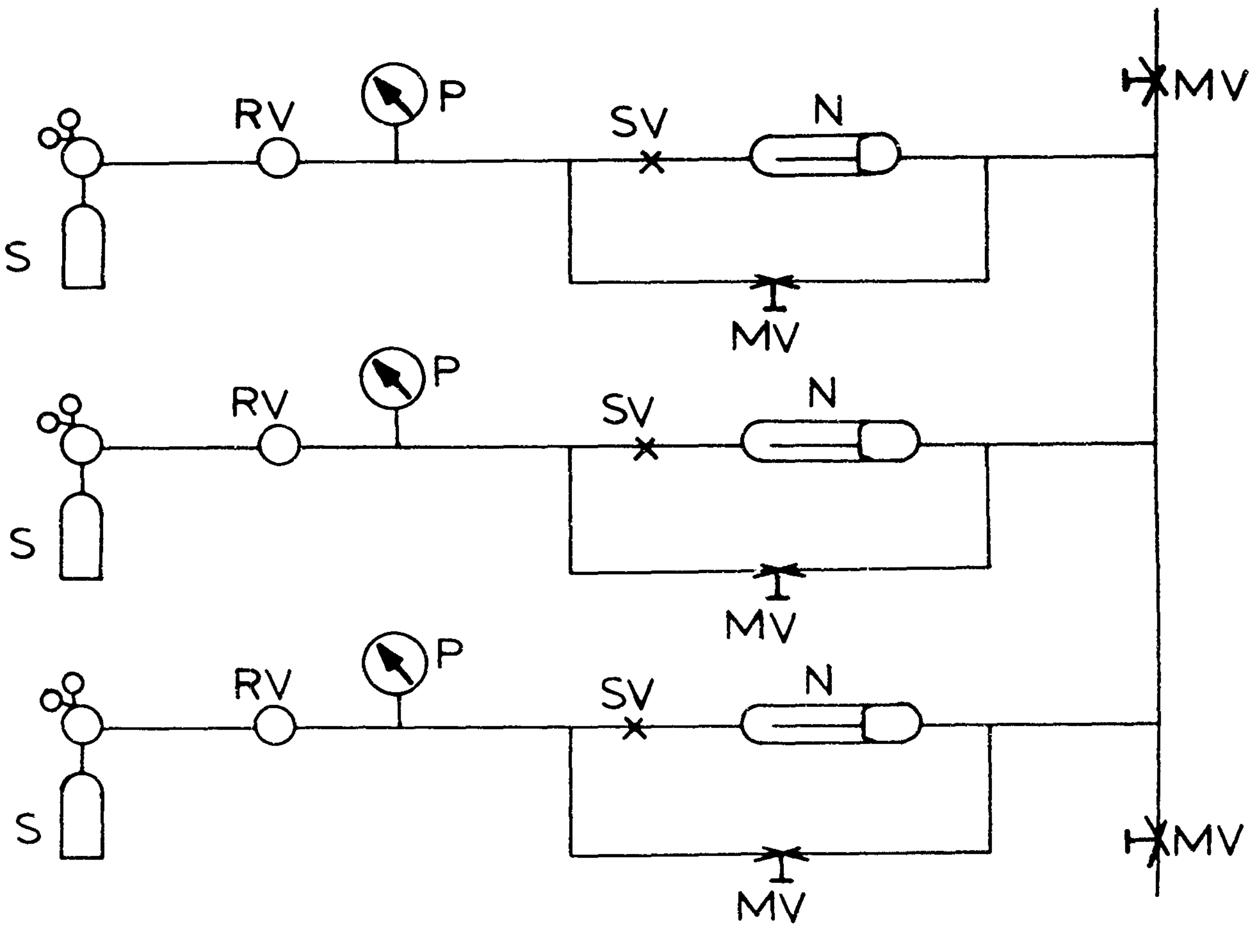
Ignitron A is fired at T_a and ignitron B is fired at T_b.



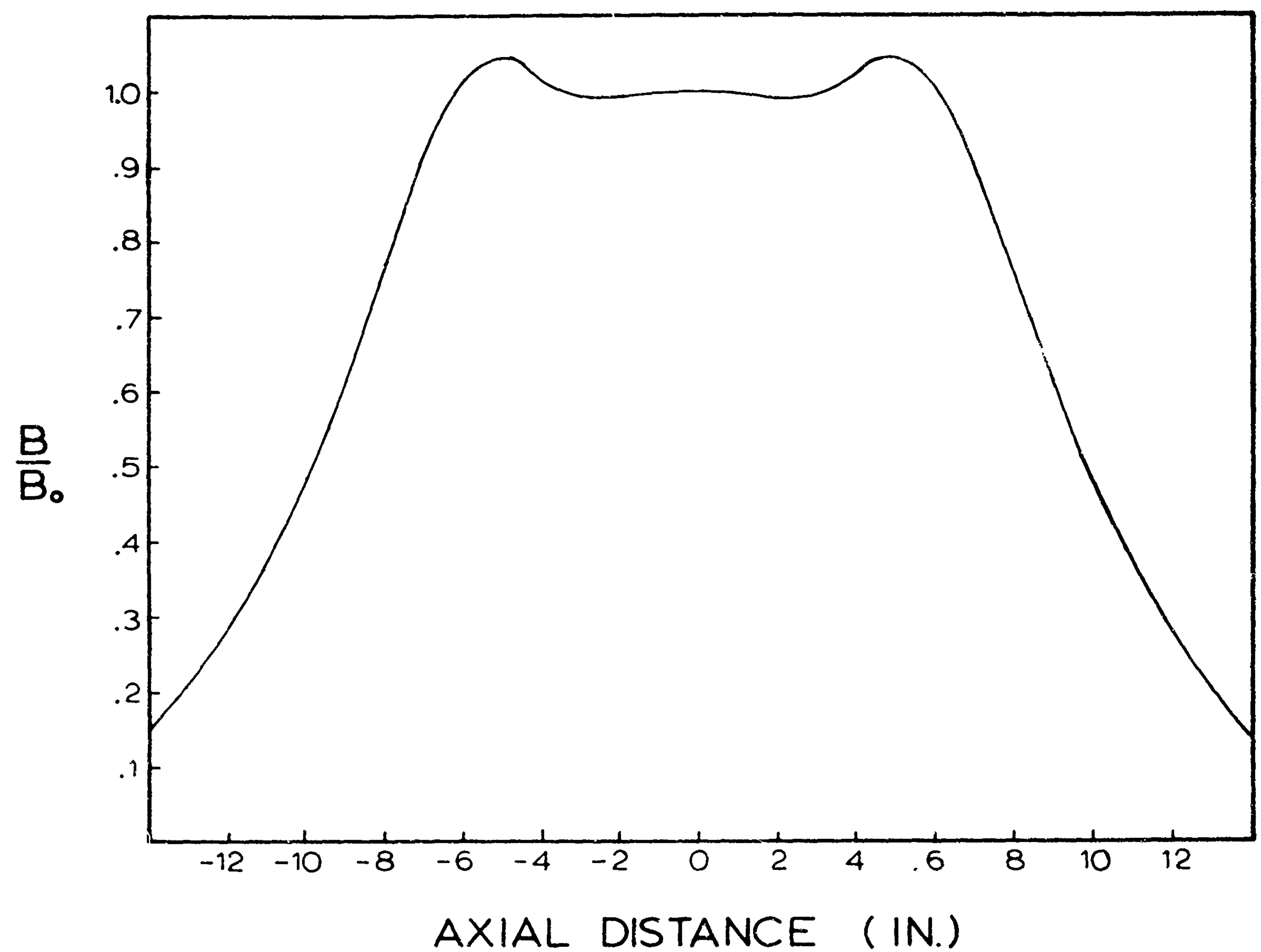
20 KV
30 MA
P.S.
160 μfd
20 KV
0-400mm
0-250mm
SWITCHING
CIRCUITS
IGNITION
P. S.
D
ION GAP
ELECTRODES
D S
S S.
T. S.
DETONATION TUBE
MAGNET
PUMP
GAS
MIXING
DEVICE
D.S DRIVER SECTION
S.S. STABILIZATION SECTION
T.T. TEST SECTION
D DIAPHRAGM
SOLENOID VALVE

1

SCHEMATIC OF FLOW SYSTEM



MV	Manual Valve	P	Pressure Gauge	S	Gas Supply
N	Needle Holder	RV	Regulating Valve	SV	Solenoid Valve


1.0
.9
.8
.7
.6
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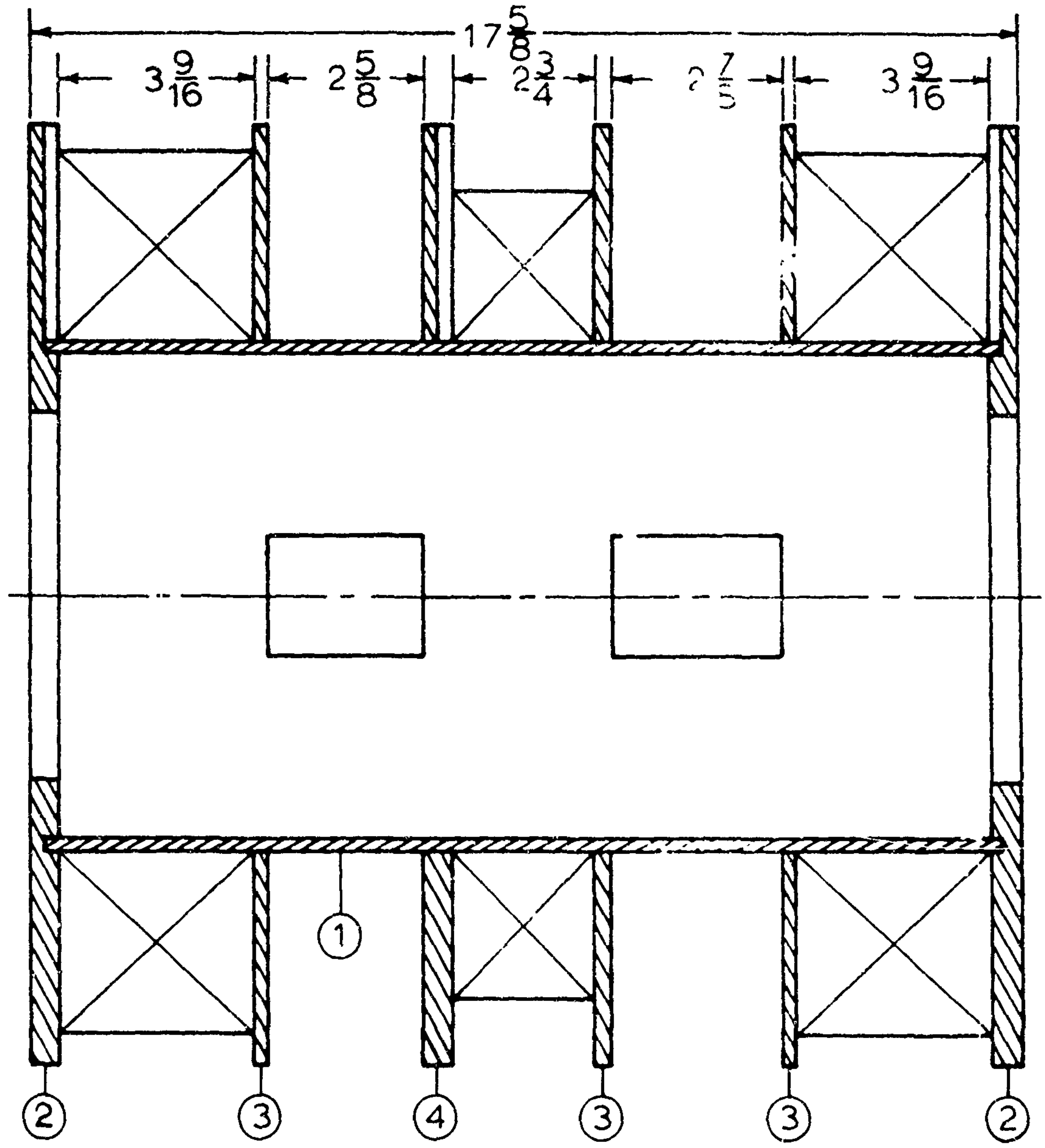
.4
.3
.2
.1
B/B₀
-12 -10 -8 -6 -4 -2 0 2 4 .6 8 10 12
AXIAL DISTANCE (IN.)



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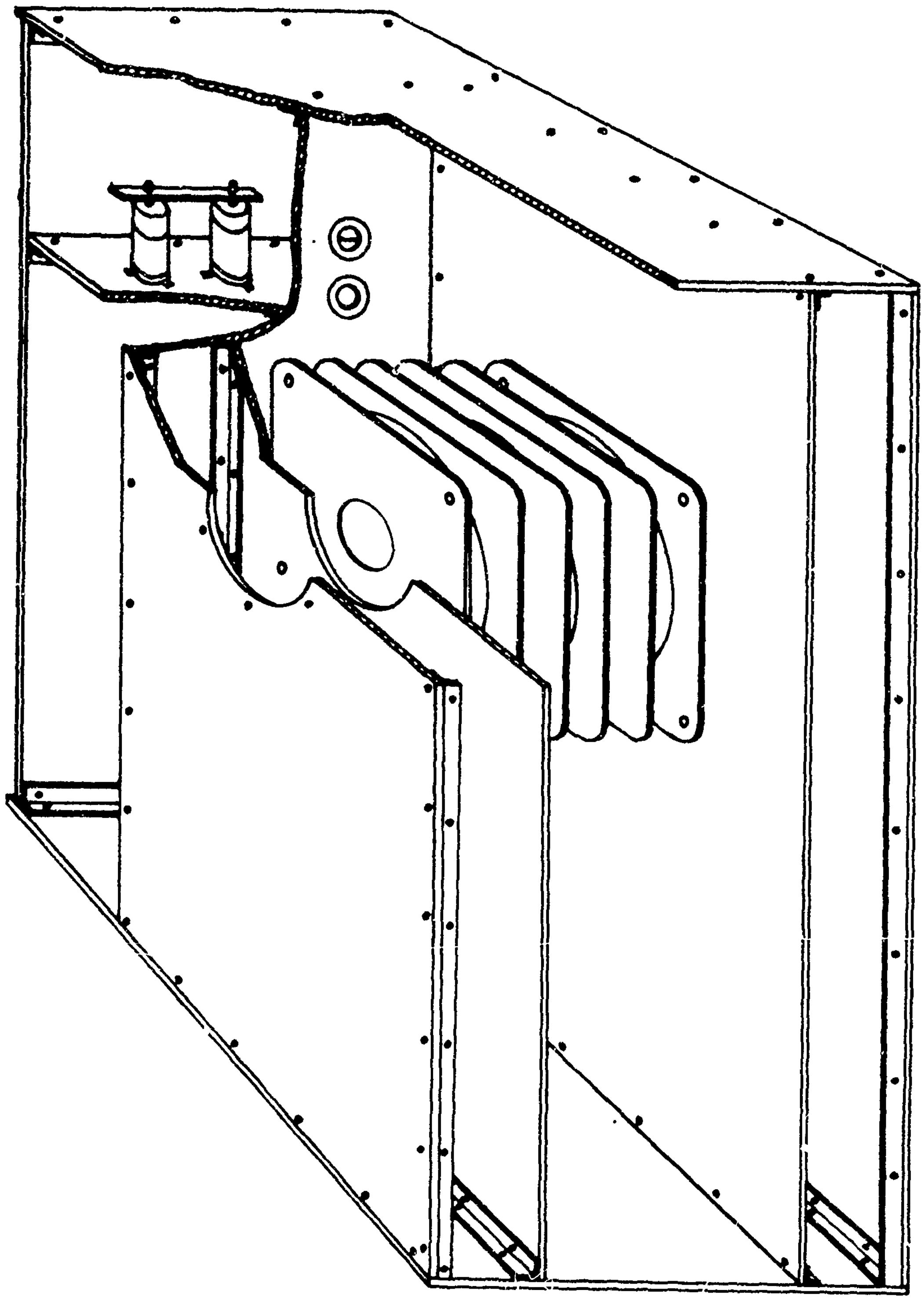

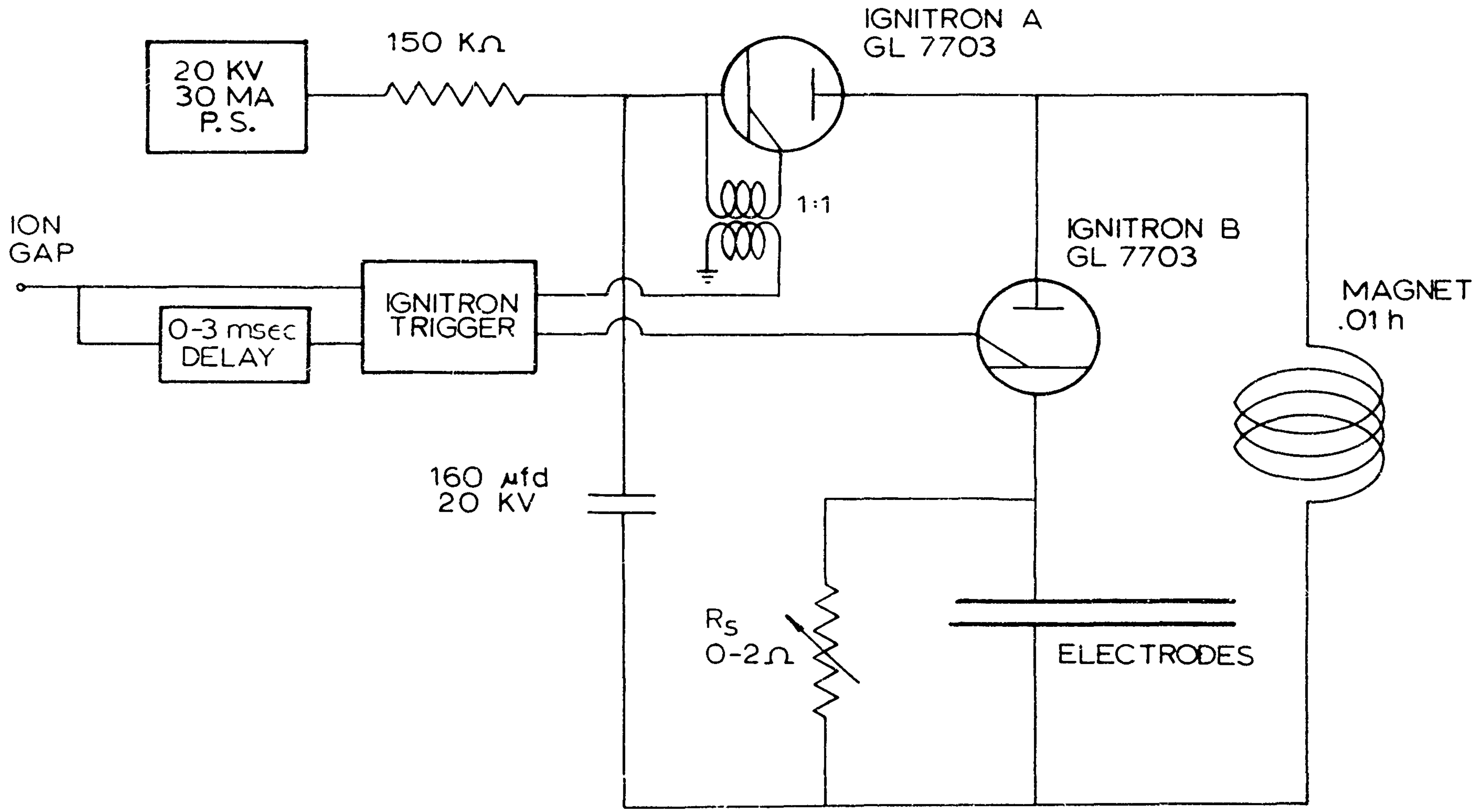
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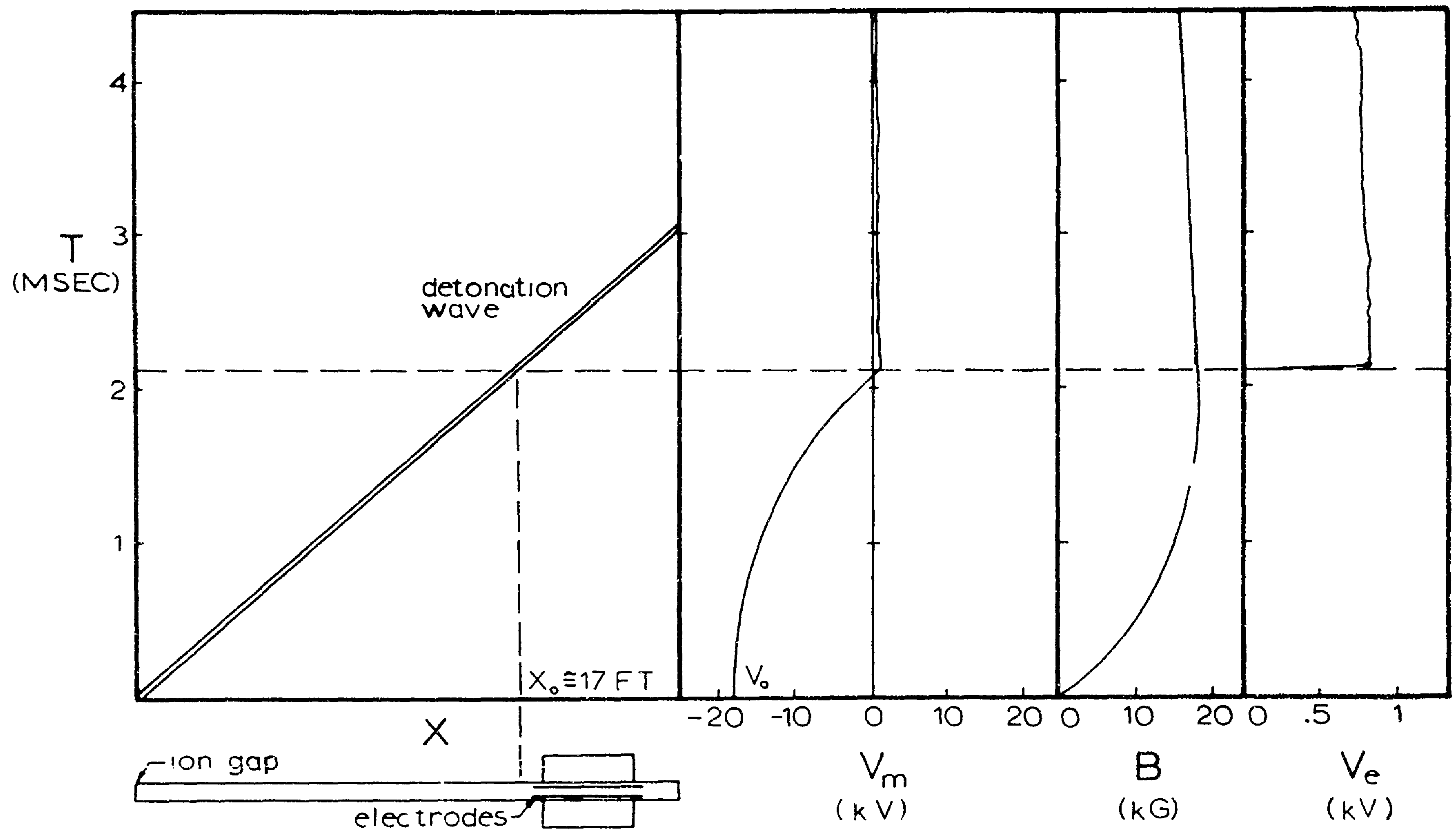
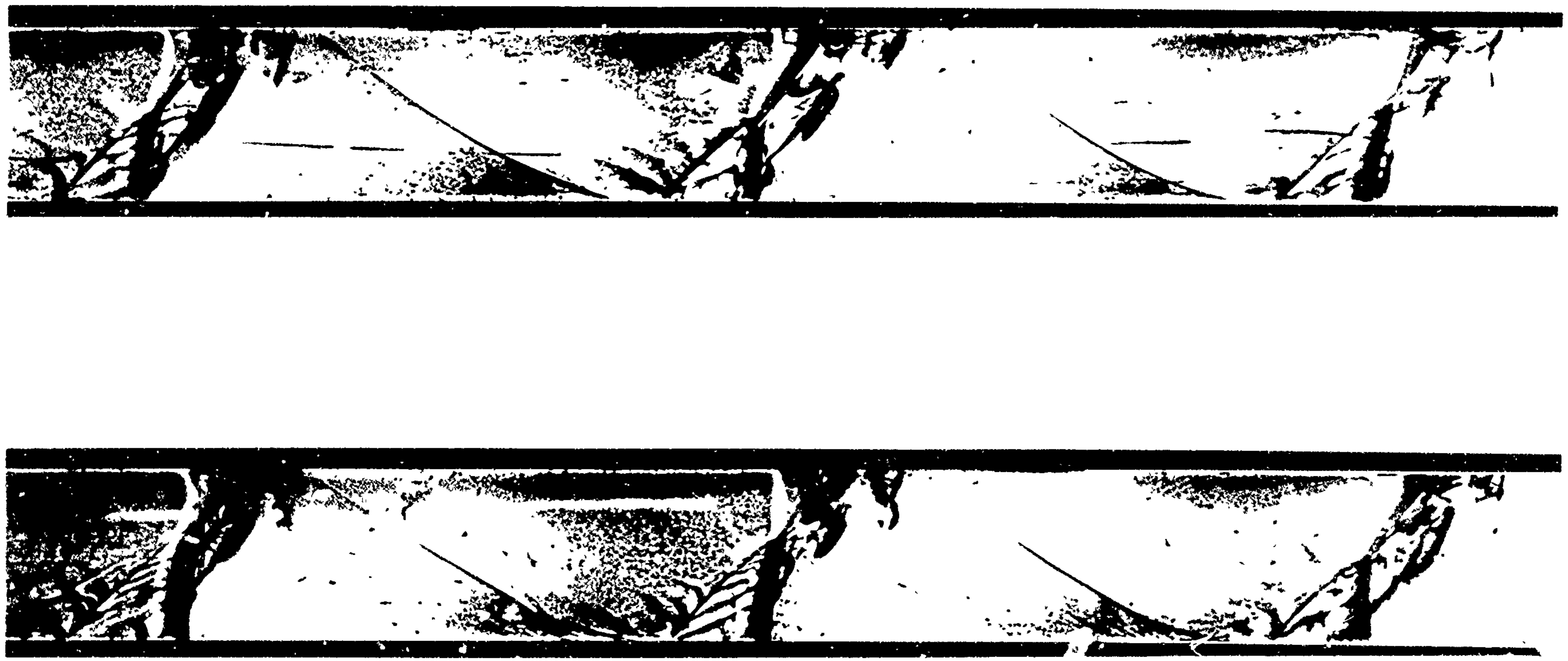
30 MA
P. S.
150 KΩ
IGNITRON A
GL 7703
1:1
ION
GAP
0-3 msec
DELAY
IGNITRON
TRIGGER
IGNITRON B
GL 7703
MAGNET
.01 h
160 μfd
20 KV
R_S
0-2Ω
ELECTRODES

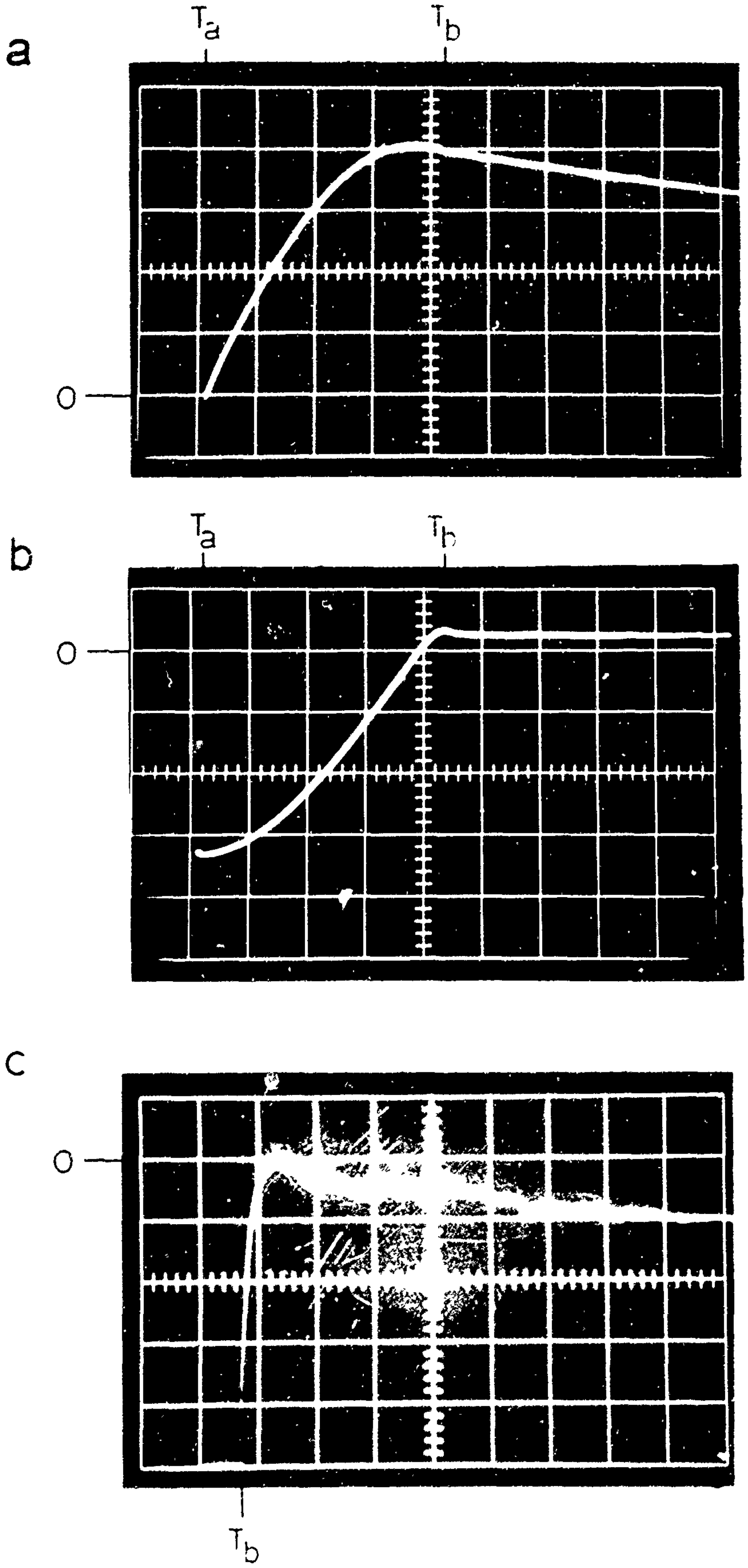
6


T
(MSEC)
4
3
2
1
detonation wave
$X_o \cong 17$ FT
X
ion gap
electrodes
V_o
-20 -10 0 10 20
V_m
(kV)
0 10 20
B
(kG)
0 .5 1
V_e
(kV)

7

6



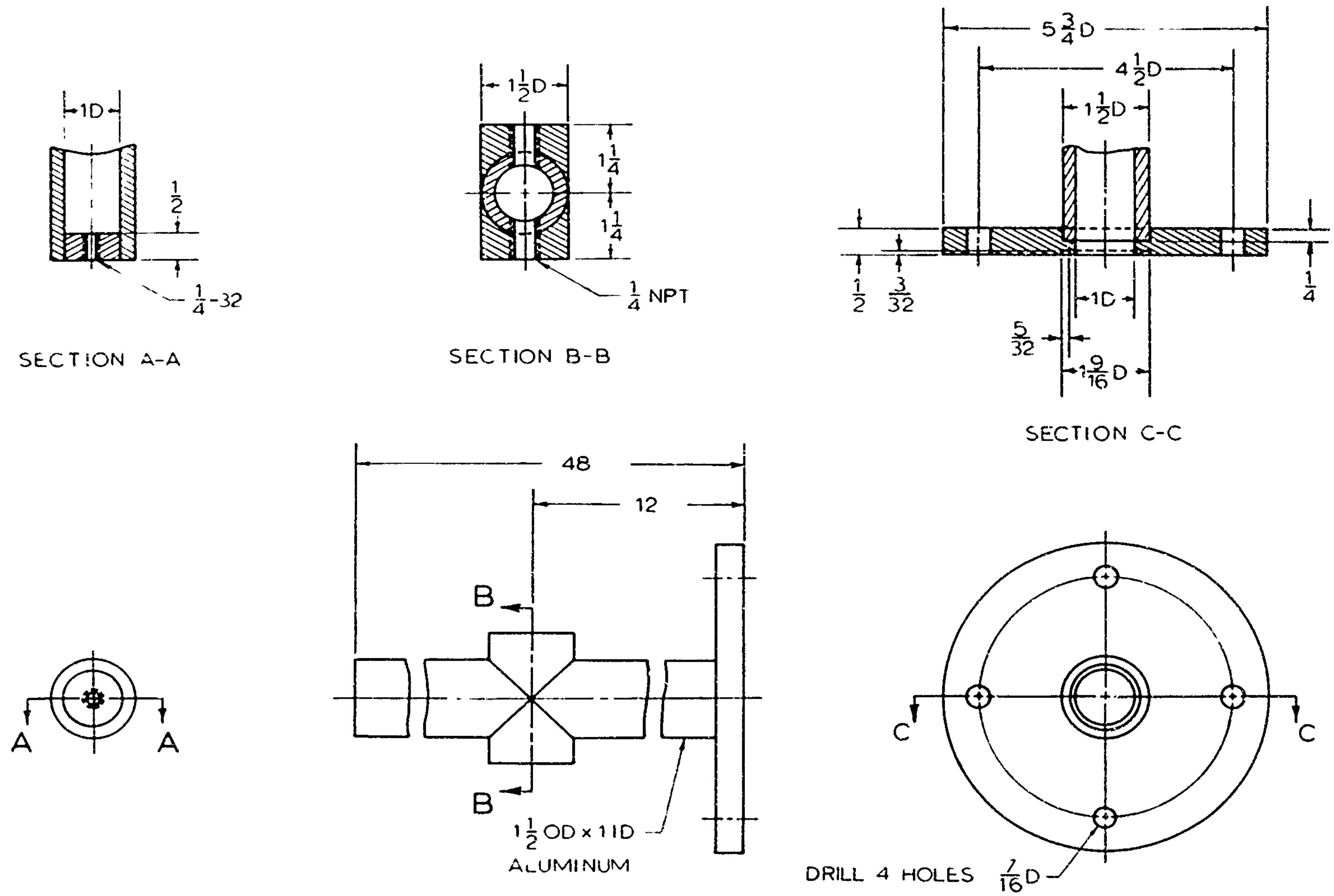


a
Ta
Tb
0
b
Ta
Tb
0
c
0
Tb

APPENDIX

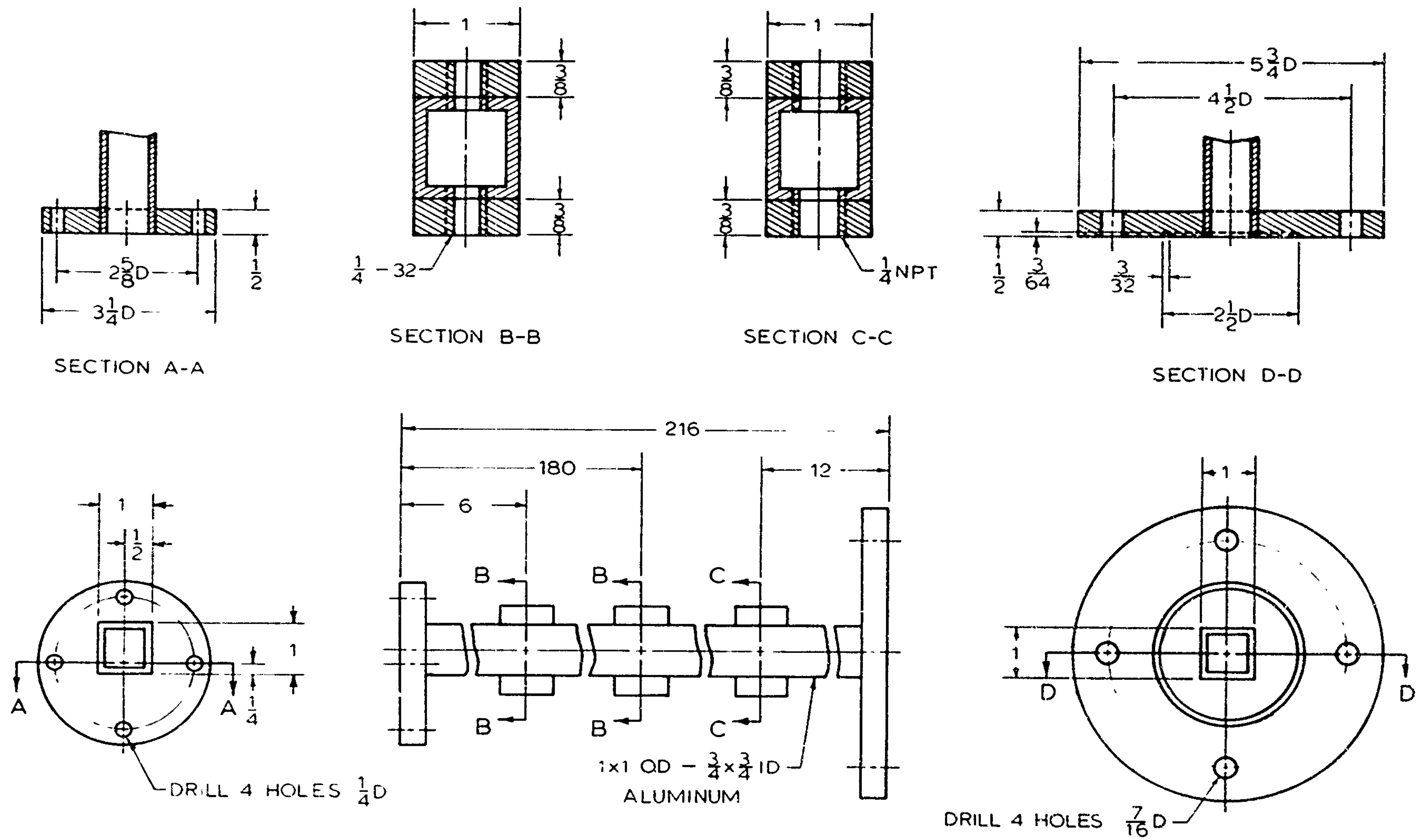
Shop Drawings

Fig. 1	Driver Section
Fig. 2	Stabilization Section
Fig. 3	Test Section Assembly
Fig. 4 - 7	Test Section Details
Fig. 8 - 11	Magnet Spool Details. An assembly drawing of the spool is shown in Fig. 4 of the text.



1D
1/2
1/4-32
SECTION A-A
1 1/2 D
1 1/4
1 1/4
1/4 NPT
SECTION B-B
5 3/4 D
4 1/2 D
1 1/2 D
1/2
3/32
1D
5/32
1 9/16 D
1/4
SECTION C-C
48
12
B
B
A
A
1 1/2 OD x 1 ID
ALUMINUM
C
C
DRILL 4 HOLES 7/16 D

A1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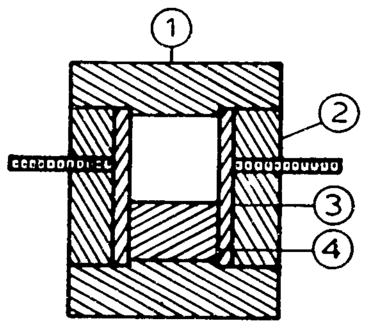
3/8
1/4 - 32
1/4 NPT
5 3/4 D
4 1/2 D
1/2
3/64
3/32
2 1/2 D
2 5/8 D
3 1/4 D
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
216
180
6
12
B
C
A
D
1/4
DRILL 4 HOLES 1/4 D
1x1 OD - 3/4x3/4 ID
ALUMINUM
DRILL 4 HOLES 7/16 D

A2



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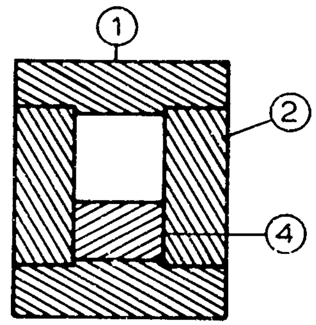

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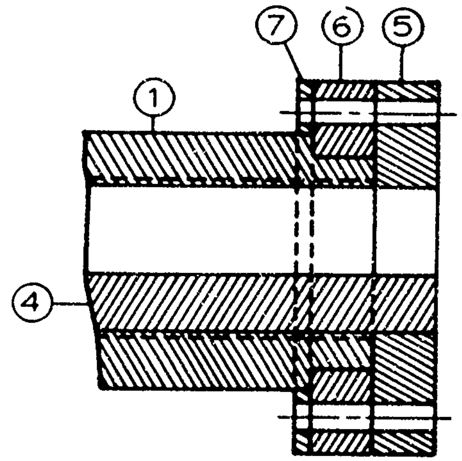

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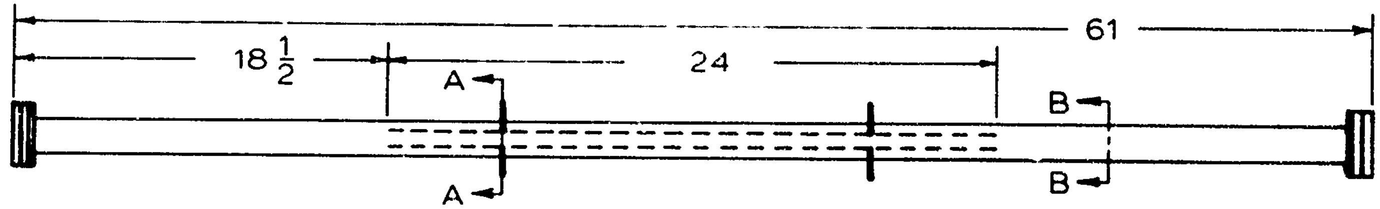

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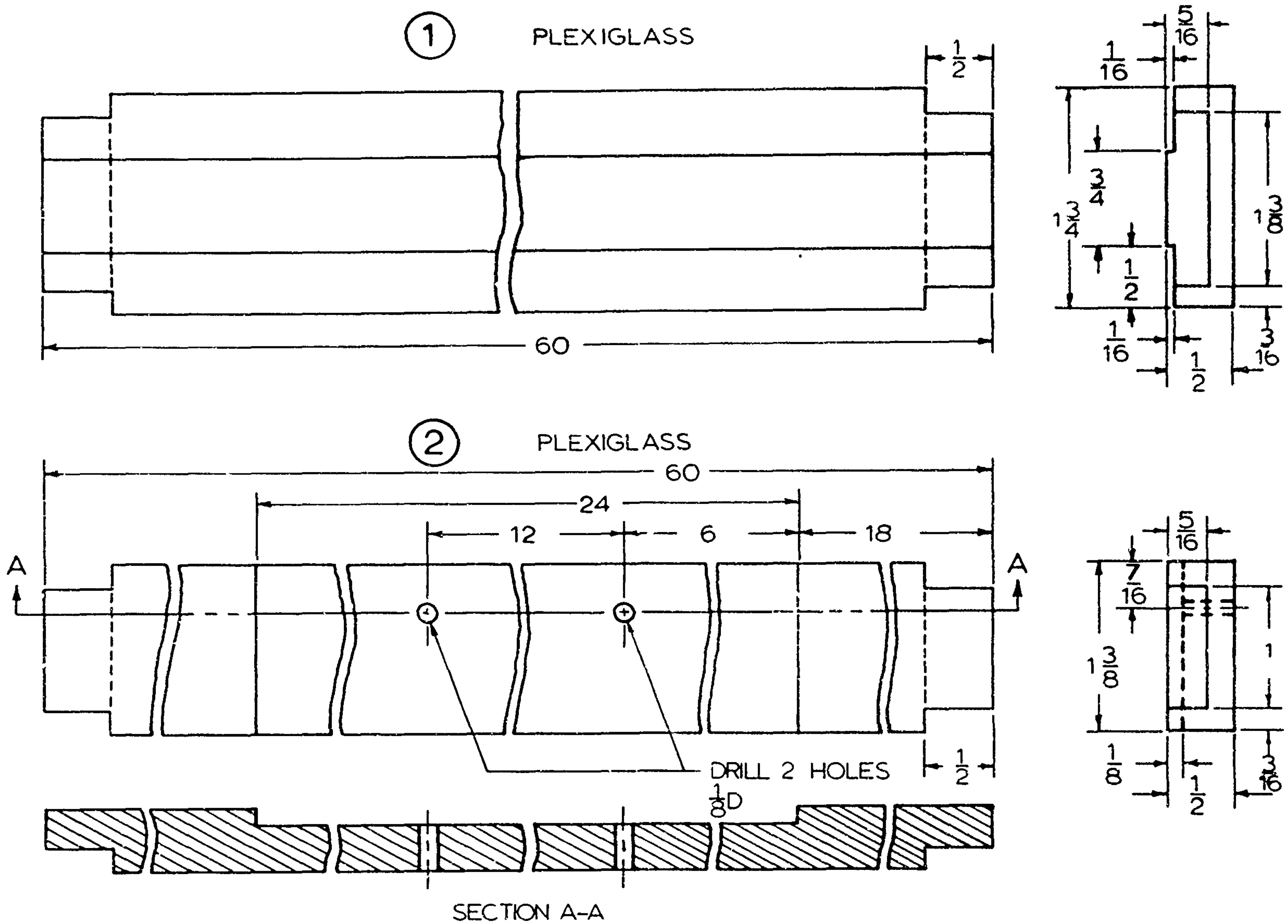

1
PLEXIGLASS
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2
PLEXIGLASS
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24
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6
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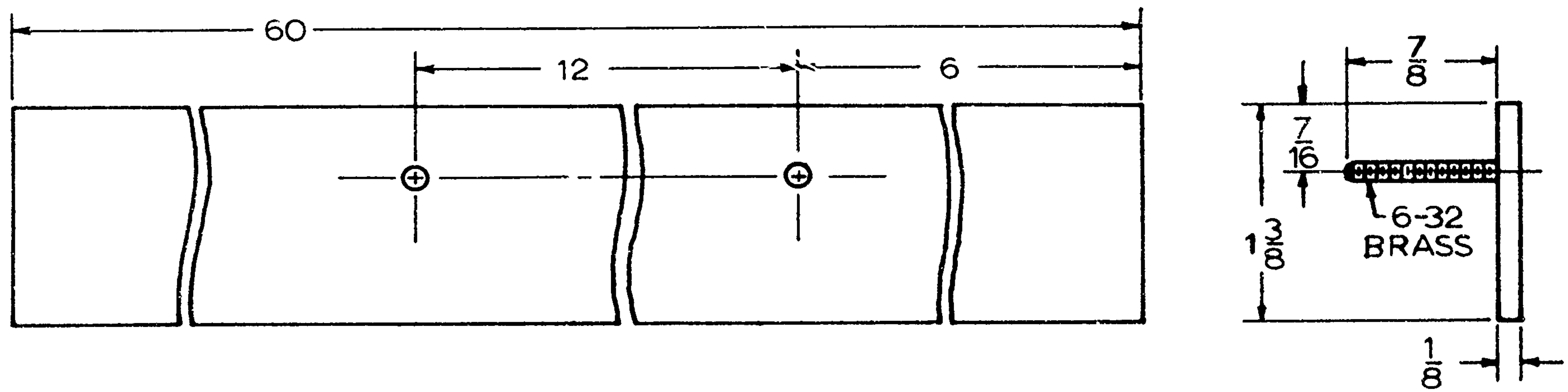
A
A
DRILL 2 HOLES
1/8 D
SECTION A-A

A 4

(3) COPPER



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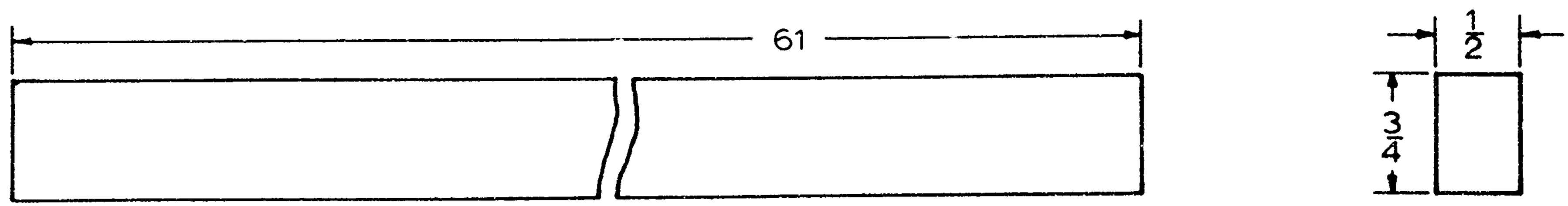

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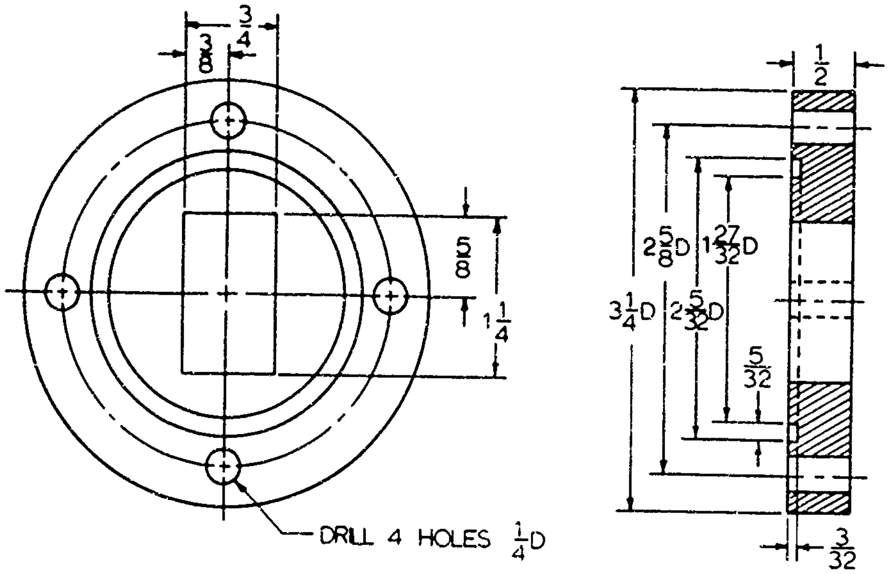

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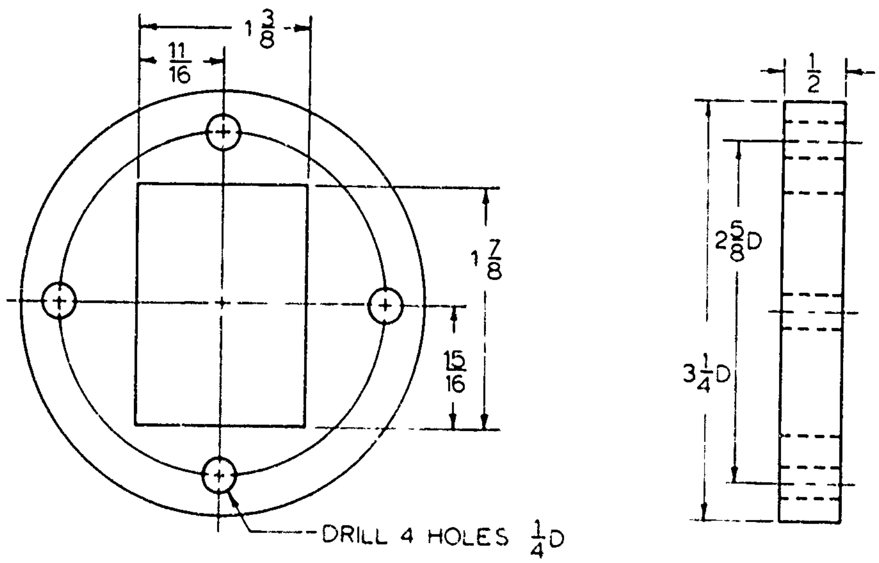

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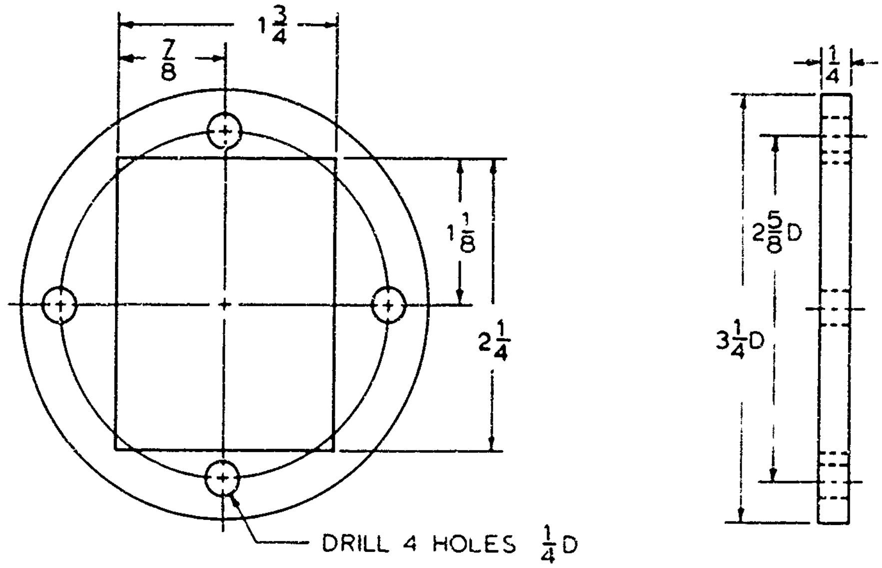

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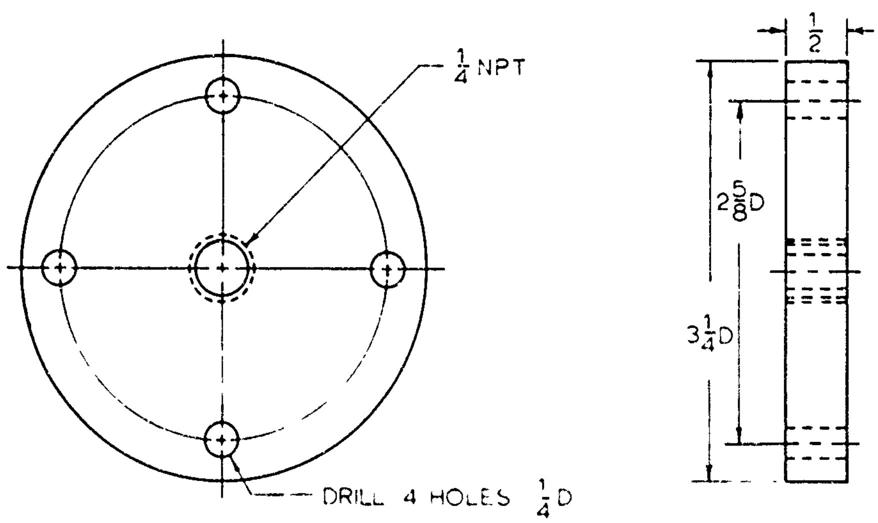

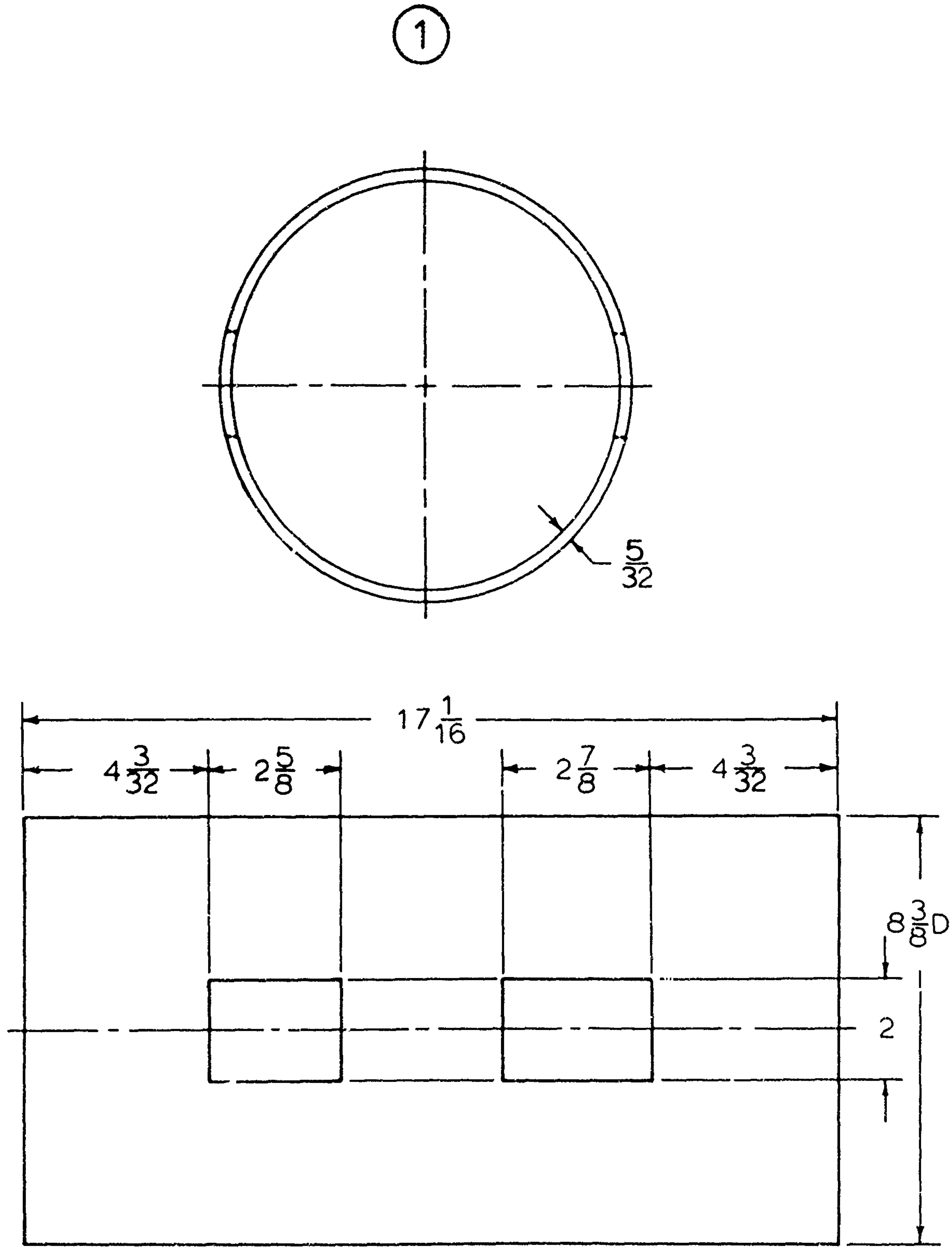

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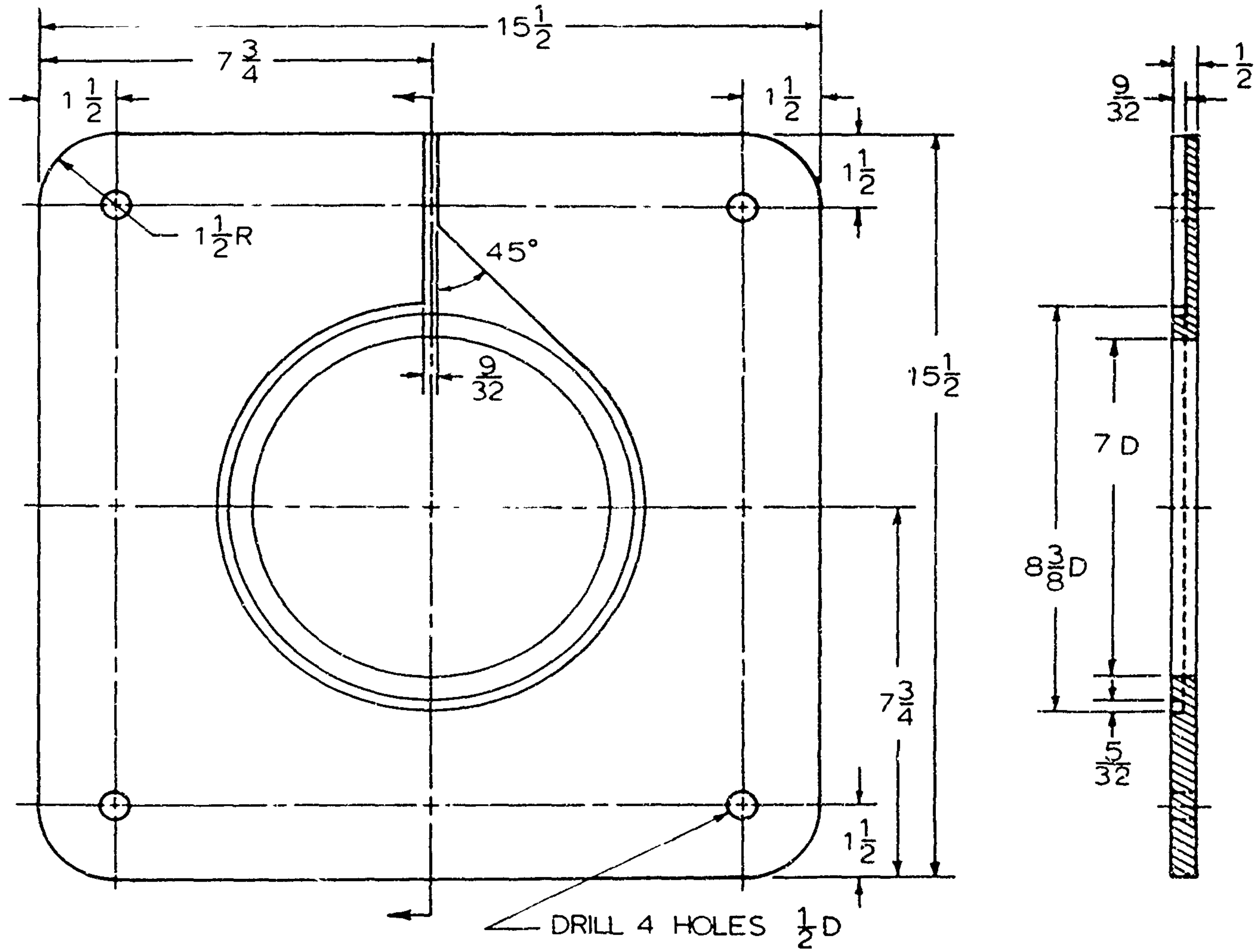
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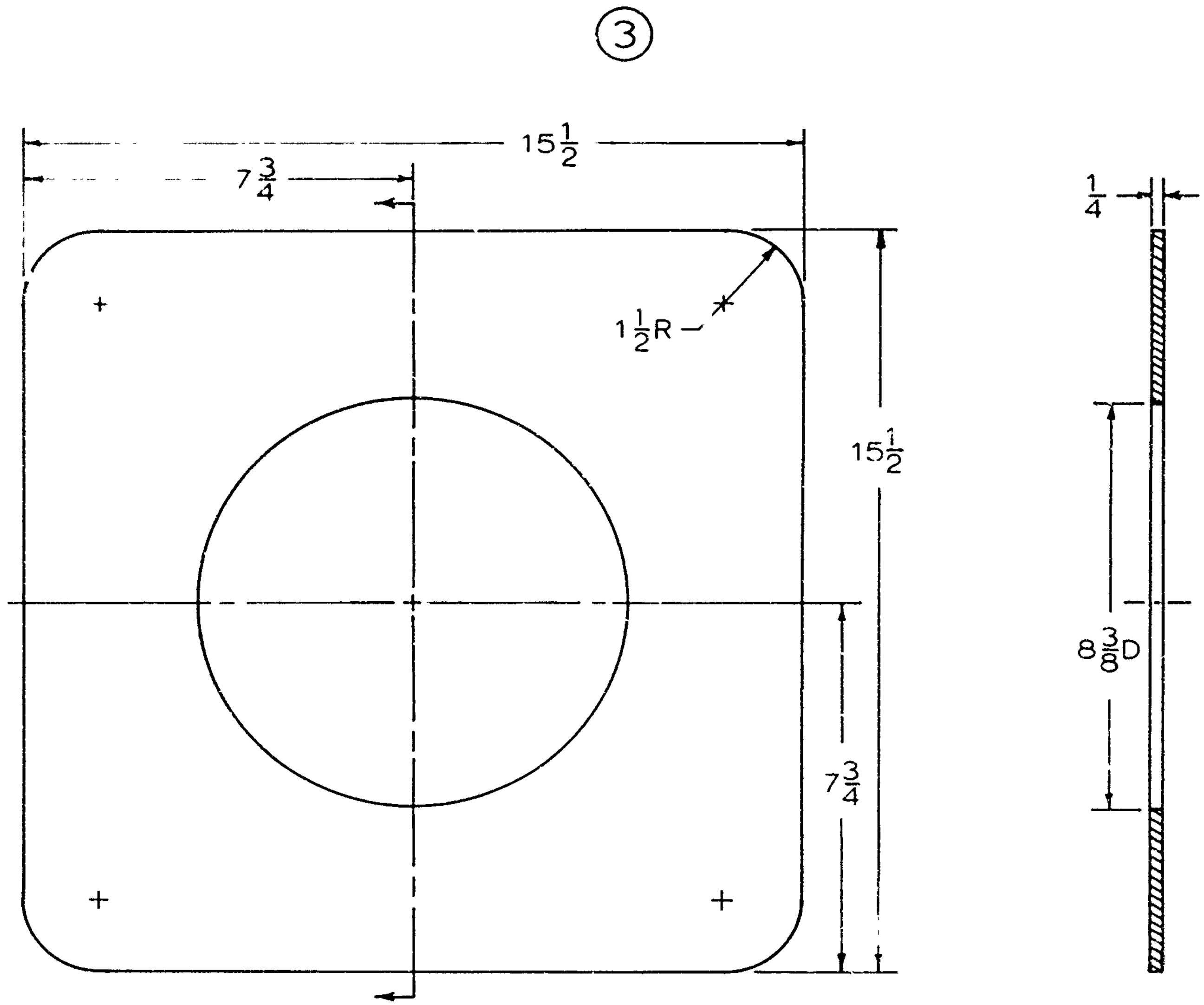
9/32
1/2
7 D
8 3/8 D
5/32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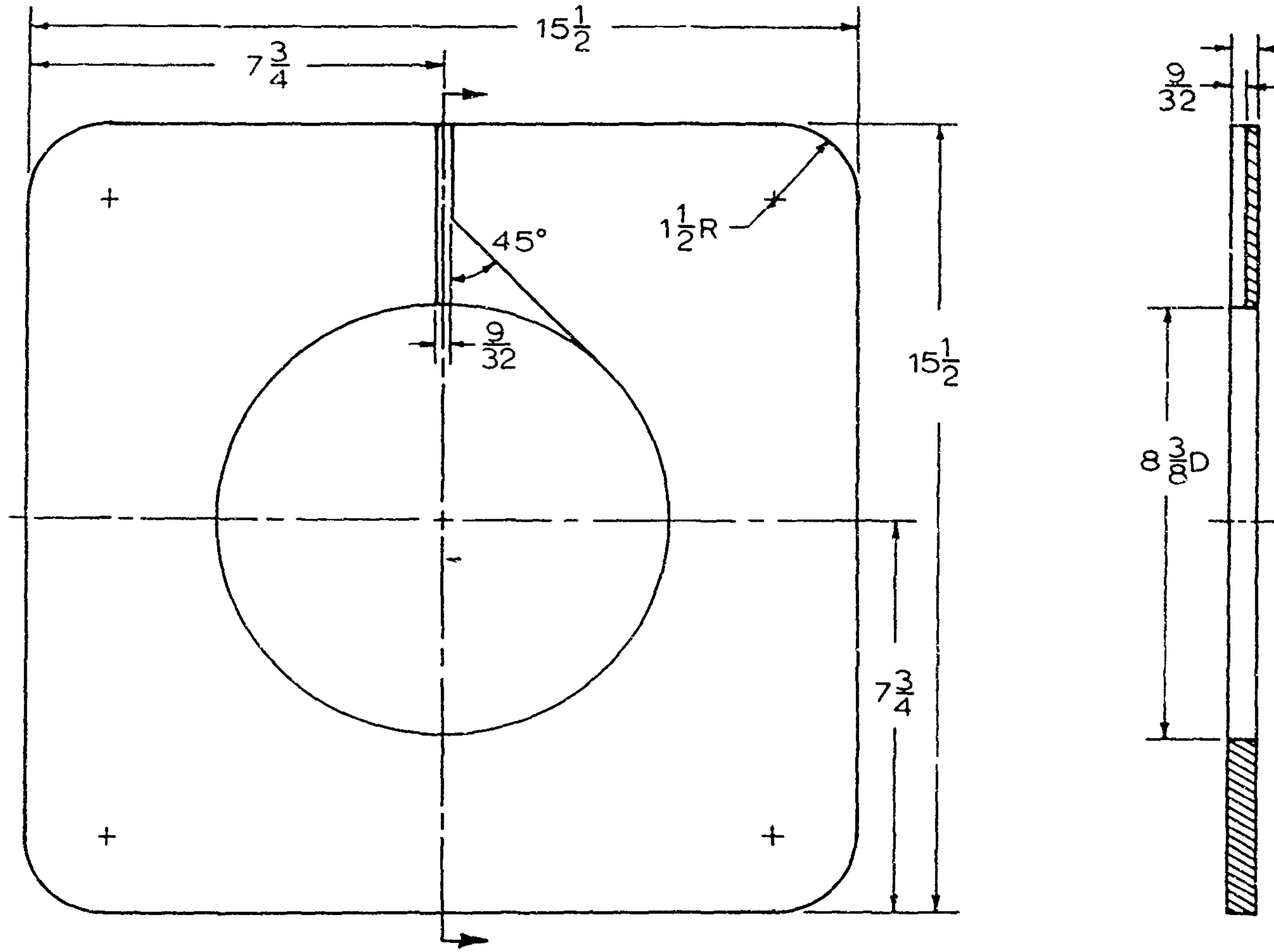
1/4
8 3/8 D

4



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13 ABSTRACT

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