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10 January 1944

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NAVY DEPARTMENT

Report of Hydrodynamic Shock Test

on

Submarine Underwater Electric Log Equipment

FR-2176

Submitted by

Pitometer Log Corporation  
New York, New York

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TABLE OF CONTENTS

<u>SUBJECT</u>	<u>PAGE</u>
Authorization for Test .....	1
Object of Test .....	1
Abstract of Test .....	1
(a) Conclusions .....	1b
Description of Material .....	2
Method of Test .....	8
Results of Test .....	11
Discussion .....	15

APPENDICES

PLATE

Pitometer Log Corp. Rotary Distance Transmitter and Control Unit, Covers removed, and Laboratory Manometer Control Panel.....	1
View of Log System Units having Hydraulic Components and Manometric Calibration Set-up.....	2
View of Hydrodynamic Pressure Wave Generator--NRL Drwg. F-556-A.....	3
View of Complete Laboratory Test Set-up for Calibration, Static Pressure Test, and Hydro-dynamic Shock Test of Ship's Log Systems.....	4
Air Cushion Chambers, One assembled and One disassembled, for Insertion in Rod Meter Pressure Lines.....	5
Typical Calibration Curves of Pressure Tank and Attached Rubber Tubing.....	6
Typical Calibration Curves of Pressure Tank and Attached Copper Tubing.....	7
Block Diagram of Pressure Recording Circuit.....	8
Typical Pressure-Time Records.....	9
Typical Pressure-Time Records.....	10
Photograph of Tourmaline Piezoelectric Pressure Gages and Fittings used in Test Apparatus.....	11
Pressure-Energy Plot (Observed VS Calculated).....	12

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### AUTHORIZATION FOR TEST

1. This problem was authorized by reference (a), and other references pertinent to this problem are listed as references (b) to (k) inclusive. As the tests lead to consideration of the phenomena of underwater explosions as presented in several confidential reports, and as it has been necessary to incorporate material given in some of them, this report has been classified "Confidential" although the problem was classified "Restricted" as authorized.

- References:
- (a) BuShips Ltr. SS/565-5(350) of 17 November 1942 to NRL.
  - (b) Specification SGS(65)-151a of 1 February 1937.
  - (c) NRL Test Report B-1631 of 3 July 1940.
  - (d) NRL Drwg. F-556-A- Hydrodynamic Shock Device.
  - (e) DTMB-Report No. 510, August 1943. (Confidential)
  - (f) DTMB-Report No. 480, October 1941. (Confidential)
  - (g) Excerpts from B.E.I. Nos. 20, 21, and 26 pages 32-35, 20-26, and 9-11 respectively.
  - (h) Division 8, OSD Report No. 1739 of 24 August 1943. (Confidential)
  - (i) Experiments on The Pressure Wave Thrown out by Submarine Explosions--H. W. Hilliar, Research Experiment 142/19, 1919.
  - (j) Multiple Pulses of Underwater Explosions, W.H.O.I., 9-21-41. (Confidential)
  - (k) I. C. Instruction Book No. 36 GG, Pitometer Log Corp.

### OBJECT OF TEST

2. The object of the present test of existing, currently approved and used, underwater electric log systems for submarines was to investigate the structural and functional ability of the equipment when operated:

- a. under conditions of increased static pressures imposed by increased depth of operation of new type submarines and
- b. when subjected to dynamic pressure pulses, superimposed on the maximum static pressures, as would be the case when a submarine is submerged in the vicinity of noncontact underwater explosions.

### ABSTRACT OF TEST

3. The units of the Pitometer Log Corporation's underwater electric log system, rotary balance type RB-25, supplied under contract NXSS-24953, were furnished for these tests. Those units of

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ABSTRACT OF TEST (Contd.)

this system which are hydraulically coupled to the sea and are directly affected by pressure changes due to depth of submergence and/or underwater explosions were set up at this Laboratory in a suitable manometric calibrating system where they were subjected to hydrostatic pressures up to 350 psi. upon which were superimposed dynamic pressure pulses of increasing magnitudes, until failure of any component part of the system was observed or until a maximum dynamic pressure pulse of 2000 psi. was attained.

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CONCLUSIONS

(a) The log system was undamaged by the increased static head applied. No accuracy or endurance tests were requested under conditions of simulated submergence. Accuracy tests under simulated submergence to a depth of one hundred (100) feet were reported in reference (c).

(b) The log system failed under 700 psi. dynamic pressure pulse superimposed on 350 psi. static pressure under a condition in which the lengths of rubber tubing connecting the rodmeter to the log system were omitted in order to subject the components to a high value of dynamic pressure, which could not be obtained with the rubber tubing in the system, and discover the weakest point in the hydraulic system.

(c) The pressure impulse  $\int p dt$  delivered by the test apparatus is considerably greater for an equivalent peak pressure than that resulting from the shock wave of an underwater explosion. Also the total value  $\sum_{1}^n \int p dt$  of the multiple impulses delivered by the test apparatus is probably much greater than the summation of all the impulses resulting from the 300 lb. TNT explosion considered exemplarily or a considerably heavier explosion. From this standpoint, when an equivalent peak pressure is applied, the pressure generating apparatus represents a much more severe test than a rather heavy noncontact underwater explosion. The greatest difference, as compared to the shock wave of an underwater explosion, lies in the relatively long period of the pressure pulse from the apparatus which would produce greater effect on components of an apparatus tested in this manner should they have relatively low frequency responses. It is thought that the secondary impulses from an underwater explosion, some of which carry considerable energy in a relatively low pressure wave of longer time duration than the shock wave, are more nearly approached by the type wave generated by the test apparatus than is the initial shock wave from an underwater explosion.

(d) The damage parameters considered significant at the present stage in attempting to correlate structural damage with the measurable quantities associated with underwater explosions are;  $P_{max.}$  (peak pressure),  $\int p dt$  (impulse),  $\frac{dp}{dt}$  (instantaneous slope of pressure time curve), and  $\frac{dp}{dx}$  (pressure gradient). Little is known about the effects of the last two parameters; but considerable correlation has been attempted using the first two parameters. The test apparatus approximates an explosion in that it reproduces  $P_{max.}$ , overproduces  $\int p dt$ ; but does not represent  $\frac{dp}{dt}$  and  $\frac{dp}{dx}$ .

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CONCLUSIONS (Contd.)

(e) The rubber tubing and the proposed air chambers in the log system installation have considerable effect in absorbing pressure changes in any form. Provision of an air pad in the system will absorb, with relatively small overall changes in pressure, large pressure fluctuations of practically any frequency in the range considered. The difficulties attending the use of air chamber snubbers were pointed out in the body of this report. Further difficulties were experienced with the submitted air chambers which were functionally imperfect in that the apex seals leaked air under the pressures developed and the major part of the air was contained in the bleeder lines and attached rubber hoses and pinch clamps. The apex seal should be made more effective, the rubber hose and pinch clamp discarded, and the bleeder line shortened to the minimum length necessary for use of a positive acting, pressure-proof stop cock or small valve. Installation in the log system should be made such that the air chambers can be isolated by bypasses during "blow-off" procedures, to avoid loss of air or introduction of air from the chambers into other components of the system, and a drain cock should be provided for each chamber to permit drainage of excess water from the chambers so that the initial "charge" of air may be obtained. No method was incorporated for ascertaining the amount of air in the snubber chambers. Some means of determining the water level in the chamber, such as a pressure proof window, would have to be provided.

(f) For greater protection of the log system components, rubber tubing should be used throughout in connecting the system to rod meter and in interconnecting the units. This tubing should be securely clamped to prevent blowing off of any connection.

JAN 19 1944

## DECLASSIFIED

### DESCRIPTION OF MATERIAL

4. The components of the Pitometer Log Corporation's underwater electric log system submitted for test were the rod meter and sea valve assembly, rotary distance transmitter, submarine control unit, and two air cushion chambers for insertion in the dynamic and static pressure lines connecting the rod meter to the remainder of the system.

5. The purpose of the log system is to indicate the speed of the ship and the total distance traveled. Speed and distance are derived from the changes in the velocity head of the flowing water around a rod projected from the ship's hull. This rod meter contains a pitot tube arrangement of orifices which transmit the dynamic and static pressures to the log mechanism. The pressure transmitted by the dynamic orifice, which is located at the stagnation point at the leading edge of the rod meter, is proportional to the square of the velocity of the water and the pressure head due to depth,

$$V_o^2 = \frac{2}{\rho} (P_s - P_o) \quad (1)$$

The static orifice or orifices are located on the surface of the streamlined rod tip as nearly as possible at positions giving zero or constant pressure differences with speed and transmit only the static head.

6. The difficulty of rod meter design is encountered in placing these static orifices at the best locations so as to have no pressure change effective at these points over the speed range covered, avoidance of cavitation and effects due to change in type of flow, and minimum effects due to small angles of yaw between rod meter axis and ship's line of travel. Difficulties with the dynamic orifice in addition to errors due to small angles of yaw, arise from frictional losses of pressure making it necessary to insert a correction factor or "rod coefficient", into the basic relationship, so that:

$$V_o^2 = C \frac{2}{\rho} (P_s - P_o) \quad (2)$$

In all cases experimental calibration of the rod meter is necessary to determine C, its constancy, the effects of yawing the rod, cavitation, and the maintenance of a constant pressure, proportional only to depth, at the static orifices. The log mechanism responds to the difference in pressures transmitted by the static and dynamic orifices, i.e. that part dependent on  $V^2$ .

7. Connection from the static orifice of the rod meter is made to a pressure-tight cast bronze chamber contained in the control unit. A bellows, its open end sealed to the top of the chamber, divides the chamber into two hydraulically isolated sections. The bronze movable head of the bellows is coupled to a lever which rotates (through small angles) a shaft passing through the walls of the chamber and supporting externally a long lever arm which carries

DESCRIPTION OF MATERIAL (Contd.)

contacts at the far end. Pressure from the static orifice is applied to the exterior of this bellows; and pressure from the dynamic orifice is applied to the interior. Motion of the bellows resulting from differences in those pressures is restricted by two studs, one internal to the bellows and one projecting from the base of the chamber, that act against the bellows head.

8. The dynamic orifice of the rod meter is connected, through a pump chamber in the transmitter unit containing a centrifugal impeller, to the interior of the bellows in the control unit. The control unit and rotary distance transmitter are thus functionally interdependent. Thus, when there is no forward motion causing a velocity head at the leading orifice, the pressures inside and outside the bellows are equal and equal to the static head due to depth only. Under these conditions the contact arm is located centrally between two contacts which control a variable speed d.c. motor driving the centrifugal impeller. Whenever there is a difference in pressure between interior and exterior of the bellows, the bellows moves. Any motion of the bellows is magnified by the contact arm which closes a circuit through either of two windings on a reversible follow-up motor which positions contacts on a continuously variable auto-transformer. This auto-transformer supplies a.c. voltage to the armature rectifier of the d.c. motor driving the centrifugal impeller. The centrifugal pump rotates in such a manner as to at all times produce a pressure opposing the dynamic pressure set up at the leading orifice of the rod meter. Any difference in pressure between interior and exterior of the bellows unit will cause the follow up motor to drive, through a gear train, the contacts on the auto-transformer to a position such that the pump speed causes the impeller to balance this pressure difference. The balancing process at a constant speed is one in which the transformer contacts continually hunt slightly about the true point of equilibrium.

9. The pressure developed at the dynamic orifice of the rod meter is proportional to the square of the ship's velocity. Likewise the pressure developed by the centrifugal pump is proportional to the square of the speed of the pump. The speed of the pump is, therefore, directly proportional to the speed of the ship. Indicated speed and total distance are derived from a second output shaft on the pump motor, operating through a gear reduction, the speed of which is a linear function of ship's speed. This shaft drives, through suitable gear ratios, an odometer distance indicator and self-synchronous transmitters in the rotary distance transmitter unit which transmit to auxiliary indicator units revolutions proportional to distance traveled. The entire control unit assembly is gimbal mounted to prevent introduction of errors due to pitching and rolling of the ship. These units are shown by photographs, Plates 1 and 2. Details of the equipment are covered by previous Laboratory reports and the manufacturer's instruction books.

DECLASSIFIED

DESCRIPTION OF MATERIAL (Contd.)

10. Only the two units described, the submarine control unit and the rotary distance transmitter, are hydraulically interconnected and coupled to the sea. The relationship between these and other units in the system is purely electrical. The interdependence of these two units is such that complete or partial hydraulic failure in either results in excessive errors or complete failure of the entire system.

11. Two air cushion chambers were submitted for insertion in series with the hydraulic lines from the rod meter. These experimental chambers were proposed by the manufacturer as a possible means of obtaining a pressure snubbing action due to the provision of air pads. As shown by photograph, Plate 5, each consists of a cylindrical chamber provided with inlet and outlet close to the base and bleeder line at the apex of the cover.

12. The rod meter and sea valve assembly was provided with a cast bronze chamber which was bolted to the sea valve base in the position corresponding to the skin of the ship. The rod meter tip could be projected into this chamber which it was proposed would be hydraulically coupled to a dynamic pressure producing device.

13. As requested in BuShips ltr., reference (a), a hydrodynamic pressure generator tank, similar to the type employed in testing condenser tubes by hydrodynamic shock, reference (g), was designed. The details of construction and assembly are given by drawing, reference (d). Changes found necessary on trial tests are also shown by drawing, reference (d). The assembled unit is shown by photographs, Plates 3 and 4.

14. The testing system can be considered as a rigid tank with a piston at one end. The piston is suddenly advanced at a velocity,  $v$ , for a time,  $dt$ , when the falling weight strikes the striking head on the piston. This compresses the fluid, causing a decrease in volume of the water in the system. If the walls are sufficiently strong so that expansion of the enclosure can be neglected, the pressure built up in the system adiabatically will ultimately depend on the volume change and the modulus of elasticity of the fluid medium.

$$\frac{1}{K} = E = - \frac{\Delta P V}{\Delta V} \quad (3) \quad \begin{array}{l} E - \text{elastic modulus} \\ K - \text{compressibility} \\ \text{coefficient} \end{array}$$

15. For the present system employing water as a medium, and having a volume of app. 50 cu.in. and a piston area of 0.307 sq. in. (5/8" D), the volume change to produce the desired 2000 p.s.i. dynamic pulse is, taking  $E = 3 \times 10^4$ ,

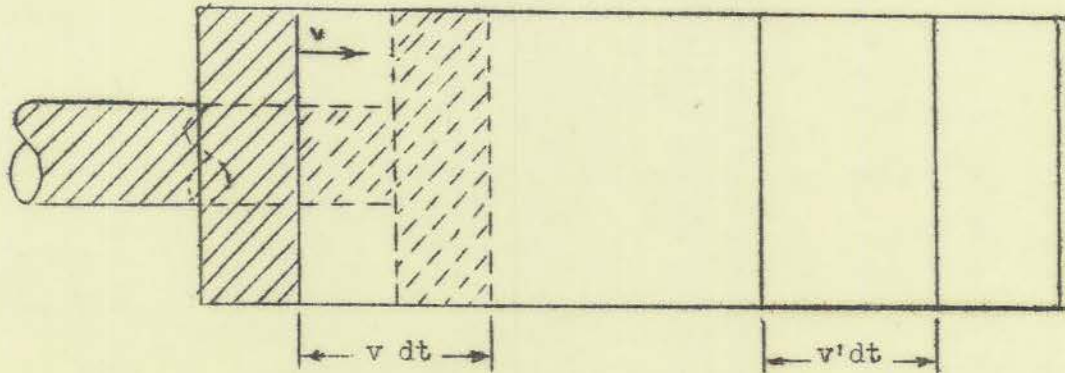
$$\Delta V = \frac{-v \Delta P}{E} = \frac{50 \times 2000}{-3 \times 10^5} = -.33 \text{ cu. in.}$$

The necessary stroke of the piston is then .33/.307 or 1.08 inches.

JAN 19 1944

DESCRIPTION OF MATERIAL (Contd.)

16. The sudden motion of the piston sends a pressure wave through the medium.



While the piston moves a distance  $vdt$ , the pressure wave travels a distance  $v'dt$ . (Refer to illustrative diagram.) Since the total mass of the medium is constant, through any time interval,  $dt$ , the mass of the fluid displaced by the piston must equal the gain in mass, due to the increase in density, of the volume transversed by the pressure wave,

$$A \rho v(dt) = A v' (dt) (d\rho) \quad (4)$$

Where,  $A$ , is the area of the piston and,  $\rho$ , is the density of the fluid. From the law of conservation of momentum, it follows that

$$FT = Mv_1 - Mv_2 = d(Mv) \quad (5)$$

or in terms of the present system

$$A (dp) (dt) = v' (dt) A \rho v \quad (6) \quad \begin{array}{l} Adp = \text{force} \\ v' dt A \rho = \text{mass} \end{array}$$

From (4)

$$v' = v \frac{d\rho}{\rho} \quad (7) \quad \text{and from (6)} \quad v' = \frac{dp}{\rho v} \quad (8)$$

Combining (7) and (8)

$$(v')^2 = \frac{dp}{d\rho} \quad (9)$$

Since  $E = \frac{-dp}{\frac{dV}{V}}$  by definition and  $\frac{-dp}{\frac{dV}{V}} = \frac{dp}{\frac{d\rho}{\rho}}$ , it follows

DESCRIPTION OF MATERIAL (Contd.)

that  $E = \frac{dp}{\frac{d\rho}{\rho}}$  and  $\frac{dp}{d\rho} = \frac{E}{\rho}$  (10)

Substituting for  $\frac{dp}{d\rho}$  from (10) into (9) and solving for  $v'$  it

obtains that  $v' = \left(\frac{E}{\rho}\right)^{\frac{1}{2}} = \left(\frac{dp}{d\rho}\right)^{\frac{1}{2}}$  (11), or that the velocity

of the travelling pressure wave is a function of the modulus of elasticity and density of the medium in which propagated.

17. The tank system was designed for flexibility in the magnitudes of pressures that could be produced. The hydrodynamic shock tank consists essentially of a rigid closed tank, of app. 50 cubic inches volume, with a tightly packed piston on which a weight is dropped.

18. The pressure produced in the tank is directly proportional to the weight and the height of fall of the weight and inversely proportional to the area of the piston for a constant volume of the liquid container. By equating the energy of the mass to the work done on the system,

$$\frac{1}{2} P_{\max} ASA = Wh$$

$$P_{\max} = \frac{2Wh}{\Delta SA} = \frac{2Wh}{\Delta V}$$

From (3)  $\Delta V = \Delta PVK$

hence  $V_1 - V_2 = KV (P_2 - P_1)$  or

$\Delta V = KVP$  if  $P_1 = 0$  or is the

reference boundary.

thus:  $P_{\max} = \frac{2Wh}{KVP}$  ;  $P^2 = \frac{2Wh}{KV}$  or  $P_{\max} = \sqrt{\frac{2Wh}{KV}}$  (12)

For a given system at constant temperature, K and V may be considered constant and the fundamental relationship becomes

$$P = Cu^{\frac{1}{2}} \quad (13) \quad \text{where, } C = \left(\frac{2}{KV}\right)^{\frac{1}{2}}$$

C = constant  
u = energy

$$u = (Wh)$$

where: W = Weight  
h = Height of fall  
A = Area of piston  
 $\Delta S = \frac{\Delta V}{A}$  = Piston displacement  
K = compression per unit vol. per p.s.i.  
V = total volume  
P = maximum pressure developed

DESCRIPTION OF MATERIAL (Contd.)

19. The equation,  $P_{\max.} = \sqrt{\frac{2Wh}{KV}}$ , applies only if all the energy from the falling mass is transferred to the medium, assumes rigid container, uniform pressure throughout liquid at any instant, and constant volume of container. It neglects frictional losses in the system, piston, weight guides, etc., and the variation of K with P. Also, since all of the energy will not be transferred at the initial contact, a series of pressure pulses of decreasing magnitudes will be expected since the weight will bounce several times due to the elasticity of the water and the steel. The governing factor that enters into the maximum pressure generated for a system of constant volume change and rigid confinement, assuming frictional losses reduced to a minimum, is then the amount of the total available energy transferred from the weight on contact with the piston. The design of the system was such that the stroke of the piston could be varied from 1 to 4 inches in one inch increments and a 50 lb. weight dropped from a maximum height of 32" or a maximum weight of 80 lbs. dropped from a height of 30.5" with the piston set for maximum travel of 4 inches. The maximum theoretical pressures generated are then 4520 and 5630 p.s.i. respectively using a value of

$$K = 3.08 \times 10^{-6}$$

(decrease in unit volume per p.s.i.).

20. The above calculations are applicable only for the case where the enclosure can be considered rigid and its expansion neglected. The expansion of the tank walls was neglected because sufficiently thick walls were employed. However, when external systems are coupled onto the tank, the pressure generated will be decreased whenever there is any expansion of the system. Also, when the volume of the water in the system is increased the pressure will be less as seen from equation (12). Thus as different systems are coupled onto the tank, there will be different pressures generated for the same energy input. Using the analytical expression

$$P = \frac{2Wh}{\Delta_s A} \text{ for rigid system and } P = \frac{2Wh}{\Delta_t A} \text{ for expansive system.}$$

Where:  $\Delta_t = \Delta_s + \Delta_r$

piston travel,  $\Delta_s = \frac{\Delta V_1}{A}$

where  $\Delta V_1$  is volume change due to compression of water at a given pressure.

piston travel,  $\Delta_r = \frac{\Delta V_2}{A}$

where  $\Delta V_2$  is volume displacement due to expansion of system (tank and attachments) at the same pressure.

DESCRIPTION OF MATERIAL (Contd.)

Therefore,

$$P = \frac{2Wh}{A(\Delta_s + \Delta_r)} = \frac{2Wh}{\Delta V_1 + \Delta V_2}$$

Thus the external system, when non-rigid, limits the pressure generated for a given weight and height of fall.

21. The pressures were measured by tourmaline crystal units, described in reference (h), supplied by N.D.R.C. These crystal units are shown in their mountings in Plate No. 11. The crystals were calibrated by the N.D.R.C. group and mounted in moulded rubber enclosures. The e.m.f. applied to the oscillograph by a piezoelectric gage is

$$E = \text{KPA/C or } Q = \text{KPA}$$

Q = charge in coulombs

P = pressure in p.s.i.

A = effective area of crystals

C = total capacity of cable and amplifier input condenser

K = piezoelectric constant =  $1.0 \times 10^{-11}$  coulombs/lb. for tourmaline.

Since it is very difficult to determine A accurately, the ratio  $\frac{Q}{P} = \text{KA}$

is generally determined experimentally and called the "sensitivity" of the gage. The sensitivity given for the crystals was  $1.3 \times 10^{-12}$  coulombs per pound per square inch. This gives a value of approximately 1.63 millivolts per 100 pounds per sq. in. for the particular input coupling condenser of the pre-amplifier used for these measurements.

METHOD OF TEST

22. It was necessary to calibrate the tank for the several different systems connected to it. The calibration was accomplished using the tourmaline crystal, piezoelectric units described in paragraph 21.

23. The calibration of the crystal units as furnished by the N.D.R.C. group was checked by using a pressure relaxation method. A crystal unit was sealed into a system in which the pressure was raised to a value read on an accurately calibrated Bourdon gage and the pressure was then released by puncturing a copper diaphragm disc in the side of the pressure chamber by driving a cutter through the disc. The volume of the tank was large enough and the area of the cutting surface small enough so that there was no appreciable pressure increase during the instant of cutting the copper. The crystal unit output was fed through the preamplifier to a cathode ray oscilloscope where the deflections were checked against calibrating voltages fed through the same circuit. The pressure-voltage values obtained agreed with those

METHOD OF TEST (Contd.)

calculated from the sensitivity given by the N.D.R.C. group.

24. For the pressure measurements made herein, the crystals were mounted in metal adapters, one of them directly in the face plate of the pressure tank and the other in a small rigid chamber at the end of the system that was coupled to the tank. The output of the crystals was fed into the pre-amplifier, and then into the cathode ray oscilloscope. The deflection of the oscilloscope beam was recorded photographically. By calibrating the deflection on the screen, the voltage generated by the pressure pulse could be scaled from the photograph. After the photographic recordings were made, it was found more convenient and time saving where many observations were to be made to omit the camera and visually observe the deflection produced on a tube having a long persistence screen and equipped with a reference scale.

25. As pointed out previously, the losses in the system are the friction of the piston rod in the cylinder, the retardant friction of the weight against the guide rods, and the energy losses in the water and steel piston. During the construction of the cylinder, which was designed for a lapped seal, a satisfactory lap seal between the piston and the cylinder wall was not obtained. To prevent a delay in the test program, a packing gland was inserted with which it was possible to attain a watertight seal up to the 350 p.s.i. static pressure required and up to the maximum dynamic pressures obtained but at the expense of increasing the friction, slowing the time for the piston displacement, and decreasing the maximum pressures obtainable.

26. The initial calibration curve was run with one gage mounted in the closed tank. The curve was uniform and is as shown in Plate 6. Because it was realized that different systems coupled to the tank would change the maximum value of pressure generated, four more calibration curves for other systems were run. The first of these systems consisted of two 8 foot lengths of 1/4 inch copper refrigeration tubing, one coupled to each outlet of the orifice plug which was designed to simulate the dynamic and static orifices of a rodmeter and was fitted into the face plate of the tank, Plate 11. The pressure was measured both in the tank and at the end of each of the tubes. The calibration curves obtained are shown in Plate 7. The next system coupled to the hydrodynamic shock tank consisted of two 8' lengths of rubber pressure tubing supplied by the manufacturer and normally used to connect the rodmeter to the log system and for the interconnection of the other hydraulic components. The pressure generated was measured both in the tank and at the end of the rubber tubing. The calibration curves of pressure generated vs. energy input are given in Plate 6.

27. The pressure generated using rubber tubing and copper tubing were measured since both types of tubing are employed in an underwater log system installation. The capacity of the pressure generating system is a direct function of the load on the tank. Therefore, for final tests of the log equipment, during which the other

hydraulic components were necessarily included in the load, the applied pressure could be only approximately predetermined from known tank pressures for an equivalent load, and the attenuation of pressure for different types of connecting tubes. The pressure generated was therefore necessarily measured for each blow to the tested equipment.

28. To further check the pressure pulse generated by the hydrodynamic shock tank, the wave form of the pressure wave was determined. The pre-amplifier output was applied to the horizontal deflection plates of the oscillograph tube and a 200 c.p.s. timing wave was applied to the Z axis. The timing signal appears as a minute break in the oscillograph trace every two hundredth (1/200) of a sec. The timing frequency was obtained from an audio oscillator accurate to  $\pm 1/2\%$ . The timing wave was fed from the frequency generator into a "Chronometric Pulser." The pulser consists of a thyatron input and a single amplifier stage. The timing voltage at input is a sine wave variation. The output is a sharply peaked periodic pulse, the duration of which is determined by the circuit constants, and the period of which is equal to the timing input frequency. This periodic pulse is coupled to a grid of the C.R.O. tube to cut off the electron beam periodically. The time of cut off is less than 0.1 the period of the pulse. The pressure wave trace when recorded photographically appears on the 35 mm. film strip of the camera as a function of time. Traces were obtained for wave form in the closed tank, wave form in tank and at tube end for copper tubing coupled to the tank, and wave form in tank and at tube end for rubber tubing coupled to the tank. These wave form traces are included, together with a calibrating trace, as Plates 9 and 10.

29. It was first attempted to apply the hydrodynamic wave to the log system through the rod meter furnished by coupling the chamber surrounding the rod tip (bolted to sea valve base) to the pressure tank. This proved to be rather cumbersome and impracticable since it was difficult to relieve the sea valve assembly of air. The dynamic pressure wave caused all seals in the sea valve to leak momentarily. This leakage, together with the near doubling of the volume of water in the system, lowered the maximum dynamic pressure that could be obtained to about 1000 p.s.i. For the final shock test of the log system the rod meter was discarded and the pressure applied to the log system through two 8' lengths of 1/4" copper tubing simulating the rod meter length attached to the orifice plug in the face plate of the pressure tank, as shown in Plate 3. These tubes were connected to the manometer system, which could be isolated by valves, as shown in Plate 2 (two tubes coming up from lower right of picture) and to the log system units, which were interconnected with high pressure rubber tubing (approx. 6' total). The required 350 p.s.i. static pressure was maintained in the pressure tank and consequently in the underwater log system by means of a pump which was isolated from the system before the dynamic wave was generated.

JAN 19 1944

METHOD OF TEST (Contd.)

30. The manometers are calibrated up to equivalent speeds of 40 knots, a water manometer being used for speeds up to 8 knots, in order to increase the accuracy of setting at low speeds, and a mercury manometer for speeds up to 40 knots. The manometers are calibrated on a basis of water having a density of 1.000 gm/ml and a rod meter having a 0.957 coefficient. A 40 knot master speed indicator (not furnished by the manufacturer) was used for continuous speed indications during the tests.

31. Following initial calibration, the log system was subjected to a 350 p.s.i. static pressure for a period of one half hour. A check of calibration, removal of air cushion chambers, and connection of the log system to the pressure generator tank as described in Paragraph 29, prepared the system for the hydrodynamic shock test. The hydrodynamic pressures delivered were measured in the shock tank by observing deflection of C.R.O. beam on a long persistence screen provided with calibrated scale.

32. The performance of the pressure snubbers was tested by measuring the pressure applied to the snubber and that transmitted through the snubber, when the snubber was coupled directly to the tank through the dynamic orifice. The snubber was supplied with varying amounts of water at atmospheric pressure, then the hydrostatic pressure was brought up to 350 p.s.i., and varying amounts of energy imparted to the system. The snubbers were tested under the following conditions, the pressure being measured both in the tank and at the end of the copper tubing on the outlet snubber line:

- (1) snubber half full of water (air jet hose on)
- (2) snubber half full of water (air jet hose removed)
- (3) snubber full of water (air jet hose on)
- (4) snubber full of water (air jet hose removed)
- (5) no snubber unit but with a length of rubber hose on line equivalent to rubber coupling supplied with the snubber unit.

RESULTS OF TESTS

33. The accuracy check of the log system before hydrostatic test and hydrodynamic-hydrostatic tests gave values of error within the limits set by specification, reference (b). The 350 p.s.i. static pressure test which was maintained for 1/2 hour, caused no apparent damage to the equipment. During this period there was no velocity head applied to the system and the log system speed indicator operated satisfactorily, with only slight hunting of the indicator and pump. There was no observed leakage of the system. The results of an accuracy check of the system following the hydrostatic test were satisfactory.

RESULTS OF TEST (Contd.)

34. The hydrodynamic shock test conducted in the manner described in para. 29 yielded the following results:

<u>Static Pressure</u> psi	<u>Superimposed Dynamic</u> <u>Pressure psi (in tank)</u>	<u>Accuracy Check at a few</u> <u>chosen points</u>
350	250	No observed effect.
350	425	No observed effect.
350	700	Bellows housing leaking around external contact arm shaft. Pump speeding up to maximum speed.

35. It was found, following the failure under the hydrodynamic shock test, disassembly, and examination of the bellows housing in the control unit, that one of the rubber sleeves for shaft sealing gland (piece no. 46 of drawing 6-1A Alt. 1, of reference (k)) had been punctured. This allowed water to leak from the enclosure surrounding the bellows causing a large differential to be felt by the control unit and the pump speed to reach the maximum allowed by the auto-transformer limit switches. The differential felt by the control unit would probably be less if a similar failure occurred in Service since there would be available an unlimited volume of water at the static orifice to replace that which leaked out, providing that the leakage did not become too rapid, whereupon the bellows would expand and be permanently deformed or ruptured. In the present system, since the pressure built up was in a confined system, the leakage resulted in successively lower pressures. The pressure was released as soon as the indicator reached maximum speed.

36. New rubber sleeves for the shaft seal were supplied by the manufacturer. These were installed, the control unit reassembled, the contact arm centered between contacts, and the log system recalibrated. Since the master speed Indicator was no longer available, it was necessary to check the system against time with a constant velocity head applied. The following results were obtained:

<u>Manometer setting in</u> <u>equivalent knots - values</u> <u>approached by accelerating</u>	<u>Odometer Nautical</u> <u>Miles</u>	<u>Time</u> <u>Minutes</u>	<u>% Deviation</u> <u>From</u> <u>True Distance</u>
5.00	182.60 <sub>0</sub>	00:00	---
	183.12 <sub>5</sub>	06:00	---
	183.64 <sub>7</sub>	12:00	+ 4.7
	184.95 <sub>5</sub>	27:00	---
	185.74 <sub>0</sub>	36:00	+ 4.7
	186.96 <sub>0</sub>	50:00	---
	187.83 <sub>5</sub>	60:00	+ 4.7

RESULTS OF TEST (Contd.)

Manometer setting in equivalent knots - values approached by accelerating	Odometer Nautical Miles	Time Minutes	% Deviation From True Distance
10:00	192.90 <sub>0</sub>	00:00	---
	193.90 <sub>3</sub>	06:00	+ .3
	194.90 <sub>2</sub>	12:00	+ .1
	195.90 <sub>4</sub>	18:00	+ .13
	196.90 <sub>5</sub>	24:00	+ .12
	197.90 <sub>5</sub>	30:00	+ .1
15:00	199.00 <sub>0</sub>	00:00	---
	200.00 <sub>0</sub>	04:00	0.0
	201.00 <sub>2</sub>	08:00	+ .1
	202.00 <sub>4</sub>	12:00	+ .13
20:00	224.00 <sub>0</sub>	00:00	---
	224.99 <sub>7</sub>	03:00	- .3
	225.99 <sub>8</sub>	06:00	- .1
	226.99 <sub>5</sub>	09:00	- .2
	227.99 <sub>7</sub>	12:00	- .1
	228.99 <sub>7</sub>	15:00	- .06

Values  
Approached by decelerating

15:00	230.00 <sub>0</sub>	00:00	---
	231.00 <sub>0</sub>	04:00	0.0
	232.00 <sub>0</sub>	08:00	0.0
	233.00 <sub>5</sub>	12:00	+ .2
	233.99 <sub>5</sub>	16:00	- .1
10:00	236.00 <sub>0</sub>	00:00	---
	237.00 <sub>5</sub>	06:00	+ .5
	238.00 <sub>5</sub>	12:00	+ .3

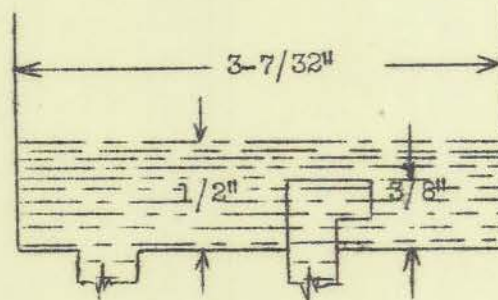
The above results indicate that the system was undamaged except for failure of shaft seal sleeve.

37. The effect of the air cushion chambers in reducing the transmitted pressure pulse was in proportion to the original volume of air present before its compression under 350 p.s.i. The pressure at the end of the line in which the chamber was inserted, when originally half full of water and with the supplied length of rubber hose attached to bleeder line cut off, differed from that with the chamber full of water originally by less than 5%. Air bubbles escaped, as shown by applying soap solution, around cap of cylinder and from bleeder line when the pressure surge was applied.

RESULTS OF TEST (Contd.)

38. A simple analysis of the snubber chamber between the pressure operation limits set, shows that the volume of air in the chamber at 350 p.s.i. is small, even with the minimum original volume of water, and that most of it will most likely be in the cap and bleeder tube (copper), or taken up in the expansion of the short length of rubber hose attached to the bleeder tube. The minimum initial water level for the chamber is considered to be at least 1/2", or 1/8" above the outlet pipe which projects approximately 3/8" above the base. The minimum volume of water then would be

$$V = \pi \frac{3.218^2}{8} = 4.07 \text{ cu. in. or } 66.7 \text{ ml.}$$



The volume of the cylinder, bleeder tube and attached rubber tube were measured and found to be approximately:

Cylinder	- - - - -	475 ml.
Cu tube	- - - - -	2.5 ml.
Rubber tube	- - - - -	10 ml.

The volume of air present at one atmosphere is then 487.5 - 66.7 or 420.8 ml. Increasing the pressure to 350 p.s.i. decreases this volume, if the ideal gas law is applied, to app.

$$V_2 = V_1 \frac{P_1}{P_2} = \frac{420.8 \times 15}{365} = 17.3 \text{ ml.}$$

Of this volume at least 12.5 ml. is in the rubber and copper tubes of the bleeder line, or at most app. 15 ml. of air remains in the chamber if the rubber tube on bleeder line is of minimum length.

39. The approximations of air volume at 350 p.s.i. in the air chamber for minimum water fill neglect effects of temperature changes since the temperature ranges of operation are not known. Decrease in temperature will operate to decrease the volume of air for two reasons; (1) the volume of the gas varies directly as temperature and (2) the partial pressure of water vapor in air decreases with temperature. The latter effect is small and can be neglected but the volume coefficient of temperature is 1/273.1 per degree centigrade. Calculation of volume change with temperature and pressure can be made from the following:

$$V_2 = \frac{P_1 V_1 T_2}{T_1 P_2}$$

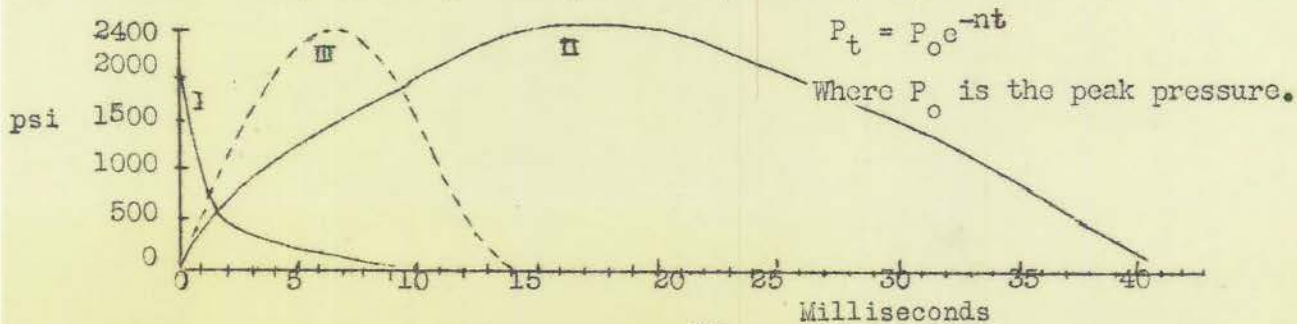
In any event it is most likely that the volume of air in the chambers would be less than that calculated because of difficulty in maintaining the proper fill of water under operating conditions. The present bleeder line arrangement should be mechanically improved to prevent loss of air and to take up the minimum volume of the compressed air.

#### DISCUSSION OF RESULTS

40. The dynamic pressure producing apparatus employed in the present investigation was similar to the final apparatus built for hydraulic shock test of condenser tubes. The first method used, (Reference (g)), was based on the retardation of a water column moving at a velocity,  $v$ , by quick closure of a valve in time  $dt$ . This produced the pressure surge by means of waterhammer. Later the water column was accelerated by compressed air. The pressure built up in waterhammer is dependent upon the rate at which the velocity of the water column is extinguished, the deceleration of the water.

41. The type travelling pressure waves expected from paragraph 16 were observed superimposed on the pressure time trace in all cases with the gage located in the tank; but were absent in the pressure-time records taken at the ends of the copper and rubber tubing. The waves are rapidly dissipated in passing through media confined by non-rigid boundaries such as the copper and rubber tubing, so that in all cases the pressure wave applied to the log system can be considered as a smooth wave without the rapid oscillations observed in the tank. (This holds within the range of frequencies effectively visible at the film speeds employed, up to 100 in/sec.) The present apparatus has been described in some detail with respect to the wave form, amplitude, and time duration of the pressure pulse produced. There remains to be attempted a comparison with the damaging effect of the shock wave produced by an underwater explosion. To this end the amplitude, form, and time duration of the shock wave from an underwater explosion is approximately described.

42. The complete experimental and theoretical picture of what occurs during an explosion is not precisely known. Conclusions made by Hilliar, reference (i), have been largely substantiated and found to be generally accurate by subsequent investigations on large numbers of explosives with various measuring means. The amplitudes and general shape of the shock waves from brisant explosives is characterized by an abrupt rise of nearly infinite slope and logarithmic decay or wave tail described in general by the empirical equation (Diagram Curve I)



DISCUSSION OF RESULTS (Contd.)

43. The shock wave originates from the initial expansion of the gas globe <sup>following</sup> conversion of the solid mass of explosive to gaseous combustion products. The time constant of the wave (the time for the pressure to decrease to 1/e of its peak value) the length of the wave, and the peak pressure, for a given explosive, will be governed by the dimensions and mass of the explosive charge. The intensity of the pressure wave decreases approximately as 1/r when the distance, r, from the charge center exceeds app. 10 times the initial radius of the solid charge. The length of the impulsive wave is of the order of 10 times the radius, reference (i), of the original mass. The wave eventually travels at the speed of sound, the initial velocity being greater due to increases in density of the medium near the charge. The spherical symmetry of the wave about the charge will be governed by the symmetry of the charge and the point of initiation of the detonation in the explosive mass. If the linear dimensions of a given explosive are changed in the ratio X, the pressure curve previously appearing at a distance r from the center of the charge will be obtained at a new distance Xr at time also changed in the ratio X. The energy carried by the wave will also be X times as great and since the wave covers a spherical surface X<sup>2</sup> times as great, the total energy is, therefore, proportional to X<sup>3</sup> or the weight of the charge. If a mass W of a given explosive produces pressure and velocity distributions, p = C (r,t), v = C' (r,t), (t measured from the initiation of the explosion) then a mass W<sub>2</sub> of the same explosive will produce distributions

$$P = C \left[ r \left( \frac{W_1}{W_2} \right)^{\frac{1}{3}}, t \left( \frac{W_1}{W_2} \right)^{\frac{1}{3}} \right] ; v = C' \left[ r \left( \frac{W_1}{W_2} \right)^{\frac{1}{3}}, t \left( \frac{W_1}{W_2} \right)^{\frac{1}{3}} \right]$$

The shape of the charge must remain the same. The peak pressures occurring from TNT explosives (TNT, Amatol, Minol, etc.) can be predicted by the empirical relationship

$$P_o = \frac{KW}{r^3} \text{ where } K = 1.3 \times 10^4$$

if W in lbs. and r is ft. p in p.s.i. within the range where p varies as 1/r.

44. Subsequent motion of the gas bubble, which retains something more than half the initial energy, after generation of the shock wave, gives rise to a series of impulses generated by alternate contractions and expansions of the gas globe. The interval between successive impulses for a given explosive charge (mass and dimensions constant) varies with the depth of submergence. The time interval between the (n-1) and the n-th pulses for large amplitude oscillations of the globe, is given by Willis' formula. (References (e and j))

$$T_{(n-1)} = 1.14 \rho^{\frac{1}{2}} P_o^{-\frac{5}{6}} W_n^{\frac{1}{3}} \text{ where } \rho \text{ is the}$$

density of water, p pressure and W the maximum energy of the gas at

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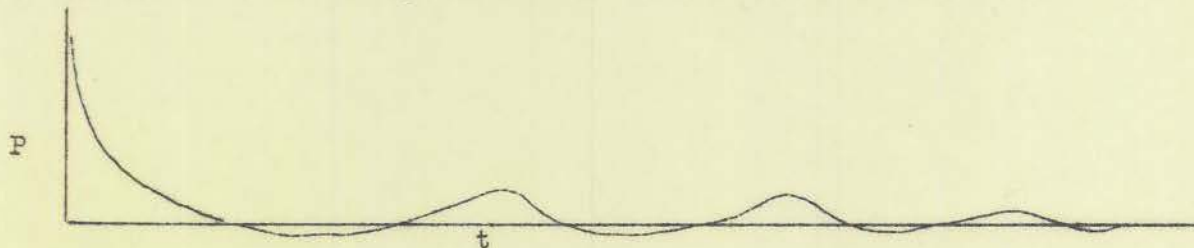
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DISCUSSION OF RESULTS (Contd.)

the end of the n<sup>th</sup> oscillation. W will be less than the total energy released by the explosion and may be expressed in terms of the maximum radius of the gas globe

$$W = \frac{4}{3} \pi r_{\max}^3 P_0 \quad \text{or} \quad T_{(n-1)} = 1.83 \rho^{\frac{1}{2}} P_0^{-\frac{1}{2}} r_{\max}$$

The relation of the initial and successive impulses passing a point at distance r from the explosion will then be somewhat as follows:



It is thought that each of those successive impulses will carry less energy than the shock wave and be more or less rounded (without steep fronts) because of lesser amounts of energy transmitted to the water after the initial loss of energy.

45. The pressure wave generated by the test apparatus employed in this investigation is fairly symmetrical except when rubber tubing, which has a low spring constant and consequent long recoil period is coupled to the system, and rises relatively slowly due to the finite time required by the accelerated piston to compress the water in the system. The general shape of the wave, compared to that of TMT is shown by diagram, paragraph 42, Curve II, and oscillograms, Plates 9 and 10. The time of rise was undoubtedly slowed by the friction between piston and packing gland and the compression of liquid in a small cylinder (immediately below the piston) feeding into a larger chamber. A free piston would give a much steeper rise as would a larger diameter piston working in the present system. The test conditions, which necessitated maintaining a 350 p.s.i. static pressure, required a tight seal between piston and cylinder. The overall efficiency of the system as a peak pressure generator is about 45% as used with tight seal. (See comparison of calibration curve and theoretical curve for the system, Plate 12.) Efficiencies as high as 62%, corresponding to pressures up to 3500 p.s.i. were obtained with well lubricated guide rods and minimum friction between piston and packing gland.

46. Waves having much steeper fronts can be obtained by experimenting with a rigid cylinder of water in which the piston area and column length can be varied. In order to avoid practical difficulties in the laboratory due to excessive heights of fall necessary to obtain high impact velocities of the falling mass, the mass might be accelerated by compressed air or springs. Waves approaching

JAN 29 1944

DISCUSSION OF RESULTS (Contd.)

the slope of the front of the explosion shock wave, (Curve III diagram paragraph 42) could be obtained in this manner. In this connection, however, duplication of the decay form and impulse values of explosion shock waves would probably not be obtained practicably. Paragraph 5 of reference (f) states " - - - the precise shape of the steep front of the pressure wave is probably of no practical interest. Nor should the effects of the secondary impulses be altered much by the mere fact that they probably have no steep fronts at all. The general form of the pressure wave may, however, be of importance, in some cases because of resonance effects." A series of impulses is generated by the bouncing mass in the test apparatus. One record in which four pulses were recorded is shown by Plate 9.

47. The dimensions of the rod meter are such that it would be small relative to the length of the pressure wave from a 300 lb. TNT depth charge and an approximation of conditions at the target (rod meter) can be obtained by treating the flow as non-compressive and the pressure as static. At 50 feet from such a charge the pressure would be

$$P_{\max} = \frac{1.3 \times 10^4}{50} (300)^{\frac{1}{3}} = 1740 \text{ psi.}$$

The results given by the above equation based on data obtained with mechanical gages are thought to be low by 10 to 15% considering data obtained from piezoelectric gages as more representative of the true pressures. For a linear small amplitude wave,

$$p = \rho c u$$

(p the excess pressure above normal, c velocity of sound in the medium, u the particle velocity and  $\rho$  the density) using

$$\rho c \text{ as } 68.2 \frac{\text{lb. sec.}}{\text{ft. in}^2} \text{ for sea water, } u = .176 \text{ in/sec per psi.}$$

pressure differential. Then the particle velocity at 50 ft. from the depth charge will be 25.4 ft/sec. Integration of Hilliar's curve for a 300 lb. TNT charge, reference (f), gives an equivalent of the maximum pressure acting for .85 milliseconds or an impulse of 1.48 lb. sec. per sq. in. Typical curves for the pressure tank were integrated roughly by tracing from the film on a good grade of graph paper, cutting out the curves and weighing them accurately and weighing a piece (a unit square) of graph paper corresponding to the time axis and maximum amplitude of the pressure-time curve. The areas are in proportion to the weights of the graph paper sections.

DISCUSSION OF RESULTS (Contd.)

Curve	$P_{max}$ psi	Impulse #sec/in <sup>2</sup>	Equiv. Time of Peak Pressure Acting Milliseconds
Plate 9 Closed Tank	2400	77.5	32.3
Plate 9 Closed Tank	1650	52.0	31.6
Plate 9 Closed Tank	1120	31.8	28.4
Plate 9 Closed Tank	660	23.6	28.0
Plate 9 at end of 16' of Cu tube	2100	71.5	34.0
Plate 9 at end of 16' of Cu tube	1250	37.8	30.2
Plate 9 in tank with 16' of Cu tube	1800	60.8	33.8
Plate 10, at end of 16' of rubber tubing.	280	15.4	5.5
Plate 10, in tank, with 16' of rubber tubing	510	17.5	3.4

48. Considering the pressure as static when the wave front arrives at the rod meter, the peak pressure of 1740 p.s.i. acting for .85 milliseconds, (the time for which an equivalent impulse of the wave would be obtained if the peak pressure of 1740 p.s.i. acted alone) and the diameter of the rod orifices as  $\frac{3}{32}$ " , the total amount of water that could enter the system through any one orifice of this diameter can be estimated roughly from Torricelli's Theorem, neglecting the coefficient C (which is one (1) theoretically).

$$V = C \sqrt{2gh}$$

Using the density of sea water as  $64 \frac{lb}{ft^3}$  , the equivalent head of water is 3920 ft. The velocity of efflux through an orifice of  $\frac{3}{32}$ " diameter under this head would be

$$V \text{ in/sec} = 12 \sqrt{2g3920} = 6029$$

$$\text{The quantity of water/sec, } Q = VA = 6029 \times \pi \left( \frac{3}{32} \right)^2 = 41.5 \text{ in}^3 / \text{sec.}$$

and that in  $.85 \times 10^{-3}$  seconds

$$Q_t = VAt = .85 \times 10^{-3} \times 41.5 = .035 \text{ in}^3.$$

Such small volume changes would be readily absorbed, without appreciable rise in pressure, by the rubber tubing and particularly the air pad provided in snubber chamber; provided of course, that a volume of air comparable to that calculated in paragraph 38 is present.

CONCLUSIONS

49. The log system was undamaged by the increased static head applied. No accuracy or endurance tests were requested under conditions of simulated submergence. Accuracy tests under simulated submergence to a depth of one hundred (100) feet were reported in reference (c).

50. The log system failed under 700 p.s.i. dynamic pressure pulse super-imposed on 350 p.s.i. static pressure under a condition in which the lengths of rubber tubing connecting the rod meter to the log system were omitted in order to subject the components to a high value of dynamic pressure, which could not be obtained with the rubber tubing in the system, and discover the weakest point in the hydraulic system.

51. The pressure impulse  $\int p dt$  delivered by the test apparatus is considerably greater for an equivalent peak pressure than that resulting from the shock wave of an under water explosion. Also the total value

$$\sum_{1}^{n} \int p dt$$

of the multiple impulses delivered by the test apparatus is probably much greater than the summation of all the impulses resulting from the 300 lb. TNT explosion considered exemplarily or a considerably heavier explosion. From this standpoint, when an equivalent peak pressure is applied, the pressure generating apparatus represents a much more severe test than a rather heavy moncontact underwater explosion. The greatest difference, as compared to the shock wave of an underwater explosion, lies in the relatively long period of the pressure pulse from the apparatus which would produce greater effect on components of an apparatus tested in this manner should they have relatively low frequency responses. It is thought that the secondary impulses from an underwater explosion, some of which carry considerable energy in a relatively low pressure wave of longer time duration than the shock wave, are more nearly approached by the type wave generated by the test apparatus than is the initial shock wave from an underwater explosion.

52. The damage parameters considered significant at the present stage in attempting to correlate structural damage with the measurable quantities associated with underwater explosions are;  $P_{max}$  (peak pressure),  $\int p dt$  (impulse),  $\frac{dp}{dt}$  (instantaneous slope of pressure

time curve), and  $\frac{dp}{dx}$  (pressure gradient). Little is known about the

effects of the last two parameters; but considerable correlation has been attempted using the first two parameters. The test apparatus approximates an explosion in that it reproduces  $P_{max}$ , overproduces

$\int p dt$ ; but does not represent  $\frac{dp}{dt}$  and  $\frac{dp}{dx}$ .

53. The rubber tubing and the proposed air chambers in the log system installation have considerable effect in absorbing pressure

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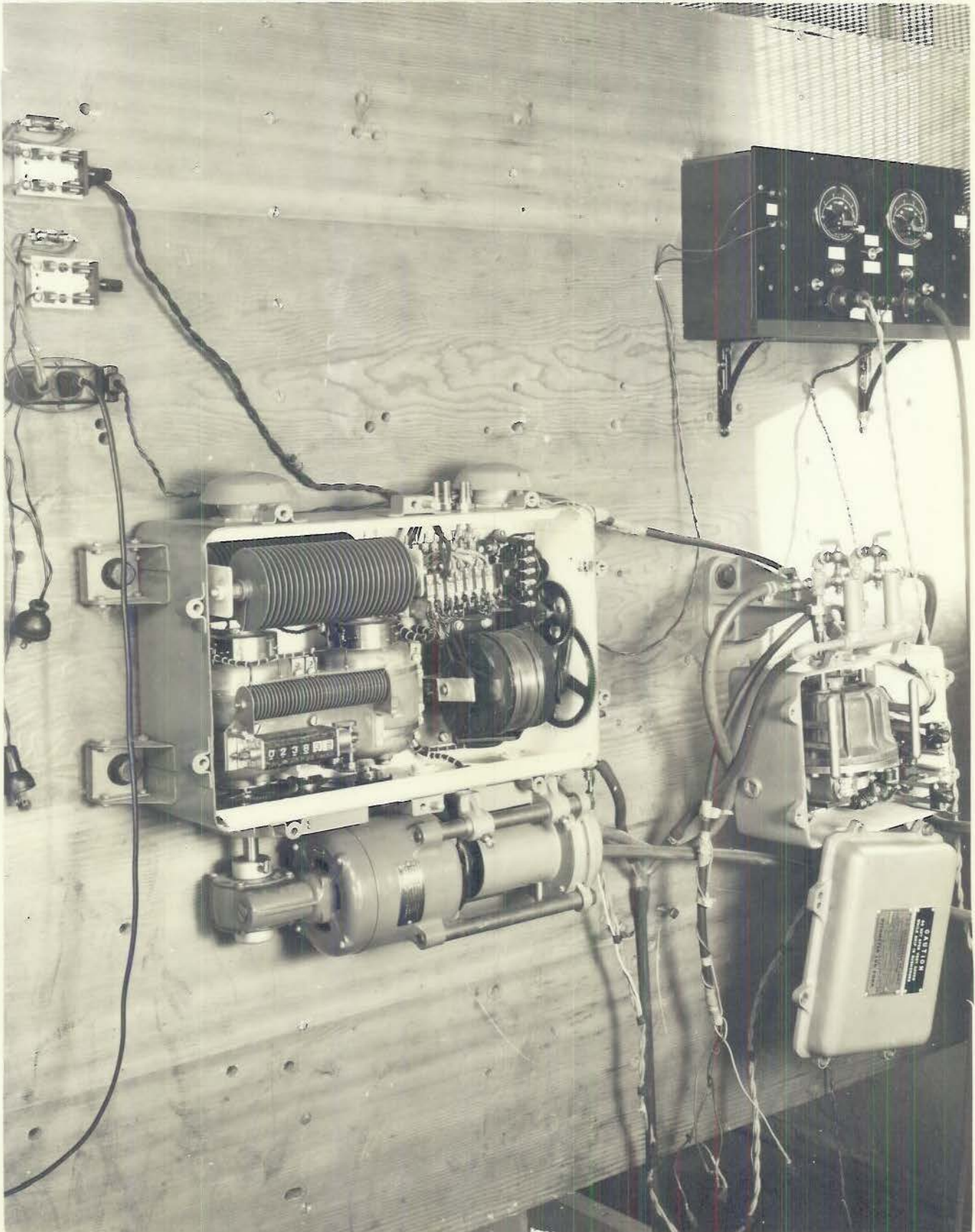
CONCLUSIONS (Contd.)

changes in any form. Provision of an air pad in the system will absorb, with relatively small overall changes in pressure, large pressure fluctuations of practically any frequency in the range considered. The difficulties attending the use of air chamber snubbers were pointed out in the body of this report. Further difficulties were experienced with the submitted air chambers which were functionally imperfect in that the apex seals leaked air under the pressures developed and the major part of the air was contained in the bleeder lines and attached rubber hoses and pinch clamps. The apex seal should be made more effective, the rubber hose and pinch clamp discarded, and the bleeder line shortened to the minimum length necessary for use of a positive acting, pressure-proof stop cock or small valve. Installation in the log system should be made such that the air chambers can be isolated by bypasses during "blow-off" procedures, to avoid loss of air or introduction of air from the chambers into other components of the system, and a drain cock should be provided for each chamber to permit drainage of excess water from the chambers so that the initial "charge" of air may be obtained. No method was incorporated for ascertaining the amount of air in the snubber chambers. Some means of determining the water level in the chamber, such as a pressure proof window, would have to be provided.

54. For greater protection of the log system components, rubber tubing should be used throughout in connecting the system to rod meter and in interconnecting the units. This tubing should be securely clamped to prevent blowing off of any connection.

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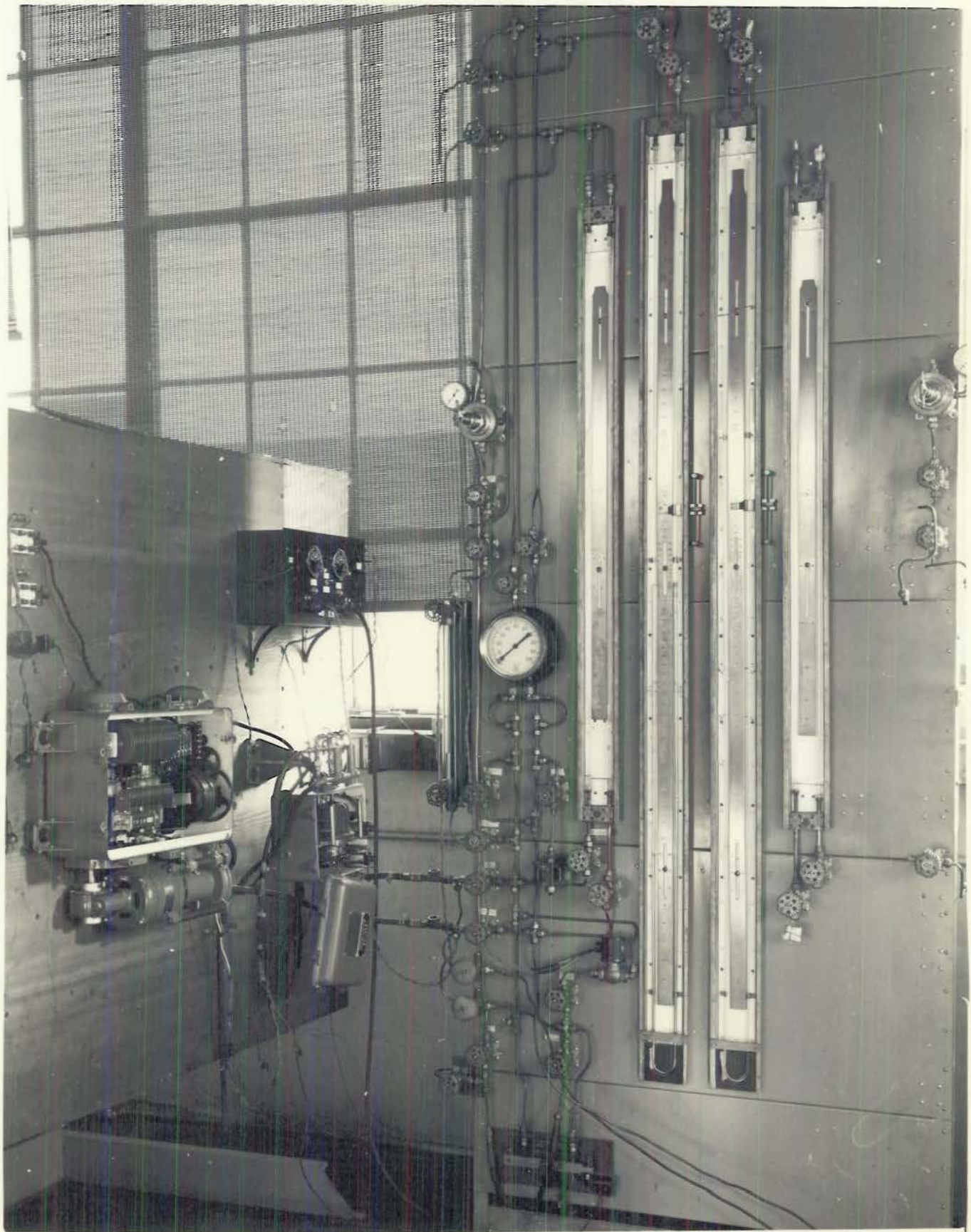
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PLATE I

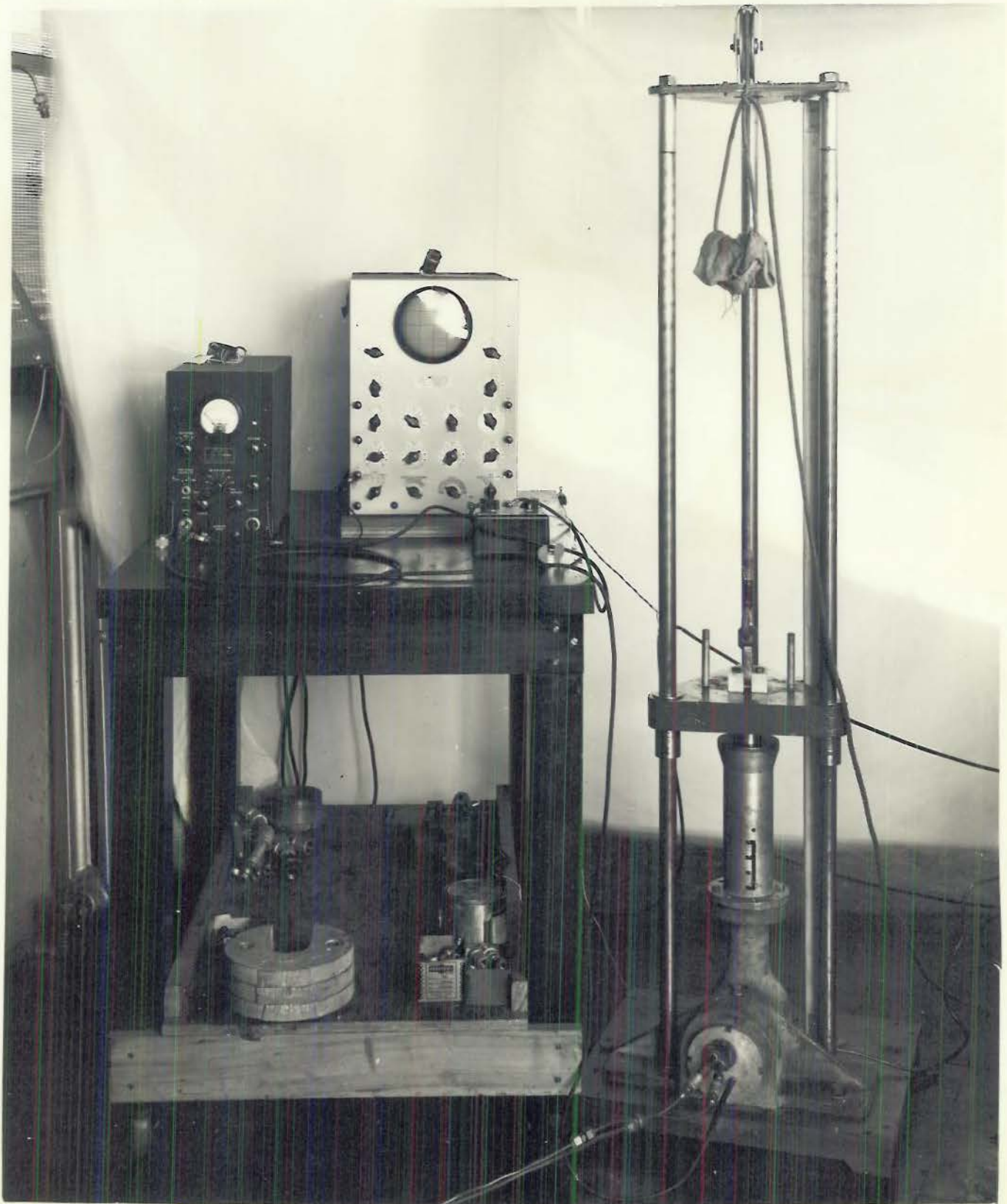
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PLATE 2

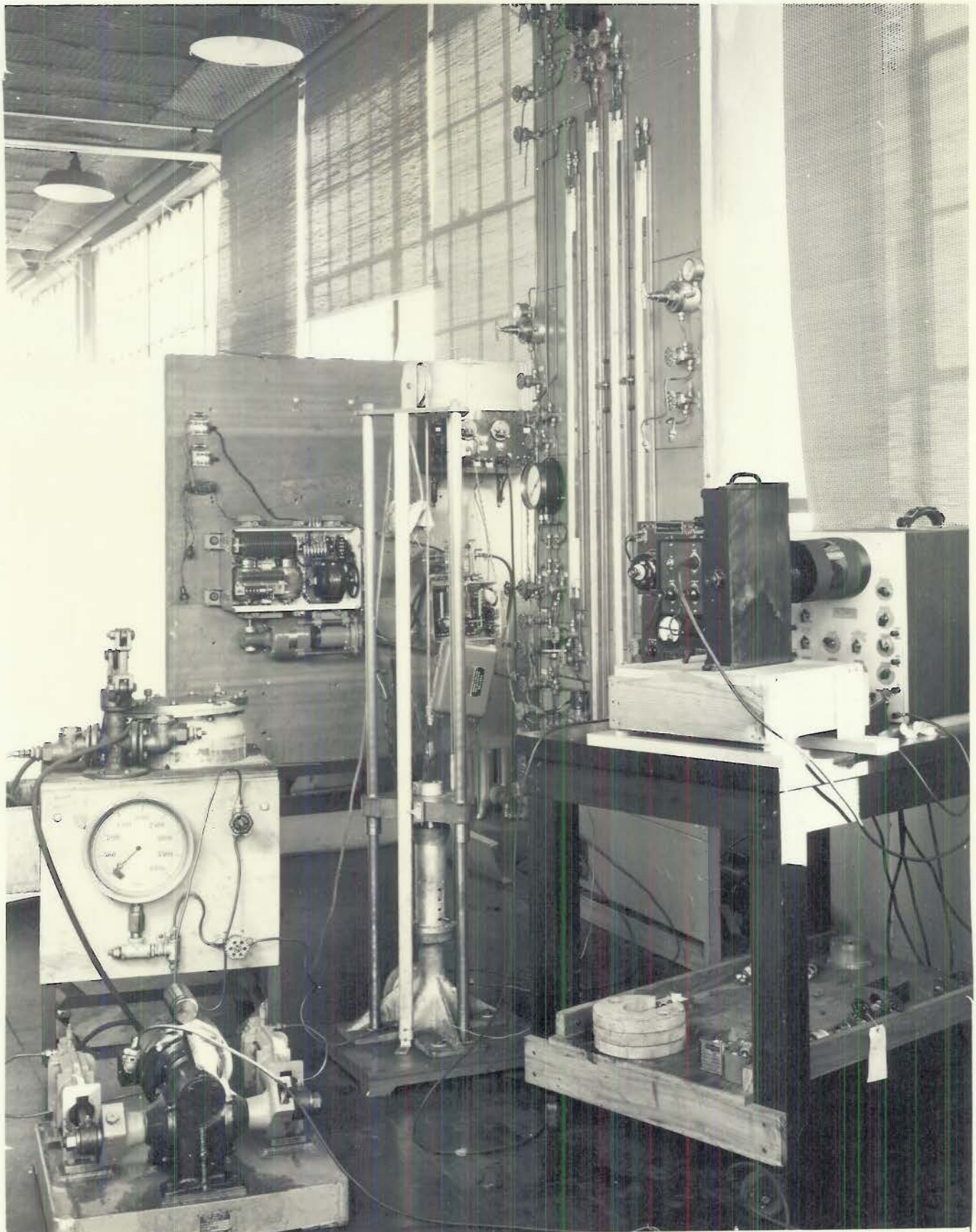
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PLATE 3

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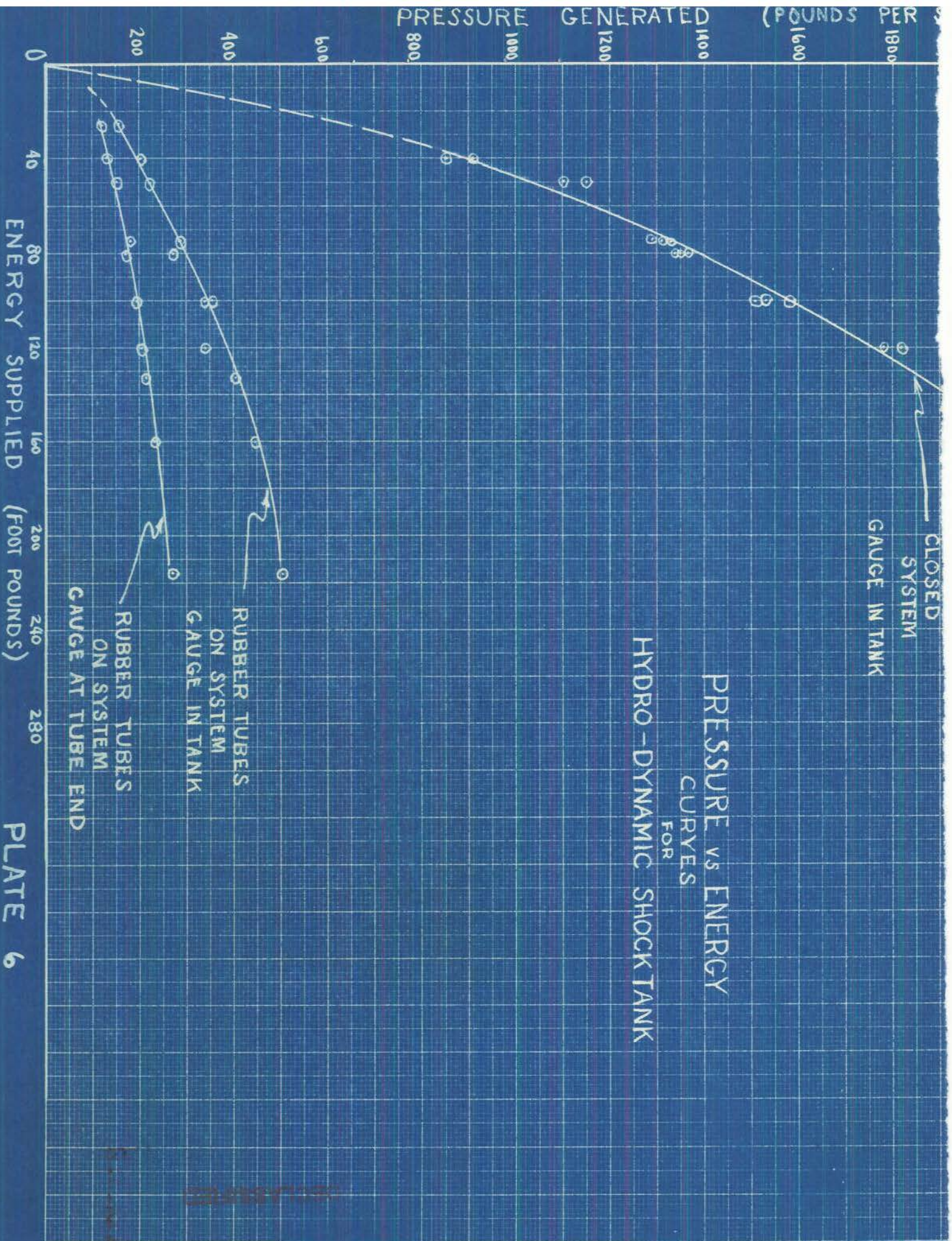
PLATE 4

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PLATE 5

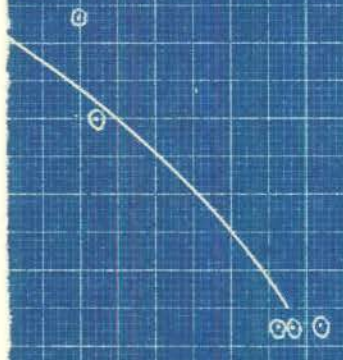


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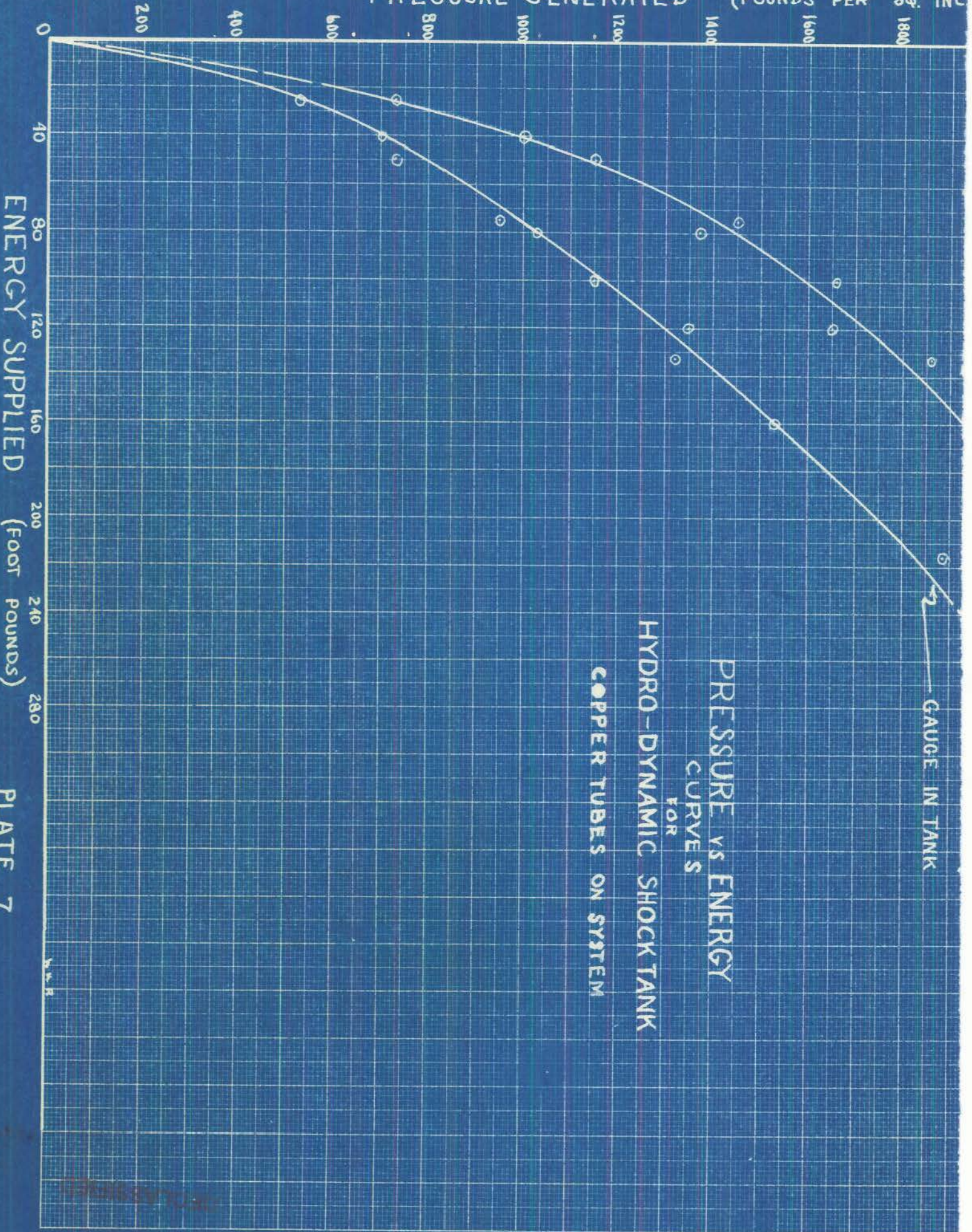
Q. INCH.)  
2000

2200

2400



PRESSURE GENERATED (POUNDS PER SQ. INC)



GAUGE IN TANK

PRESSURE vs ENERGY  
CURVES  
FOR  
HYDRO-DYNAMIC SHOCK TANK  
COPPER TUBES ON SYSTEM

ENERGY SUPPLIED (FOOT POUNDS)

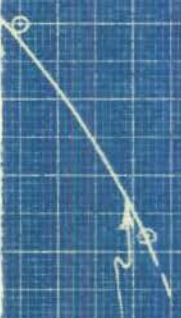
PLATE 7

TEST 45818

2400

2200

2000



GAUGE AT TUBE END

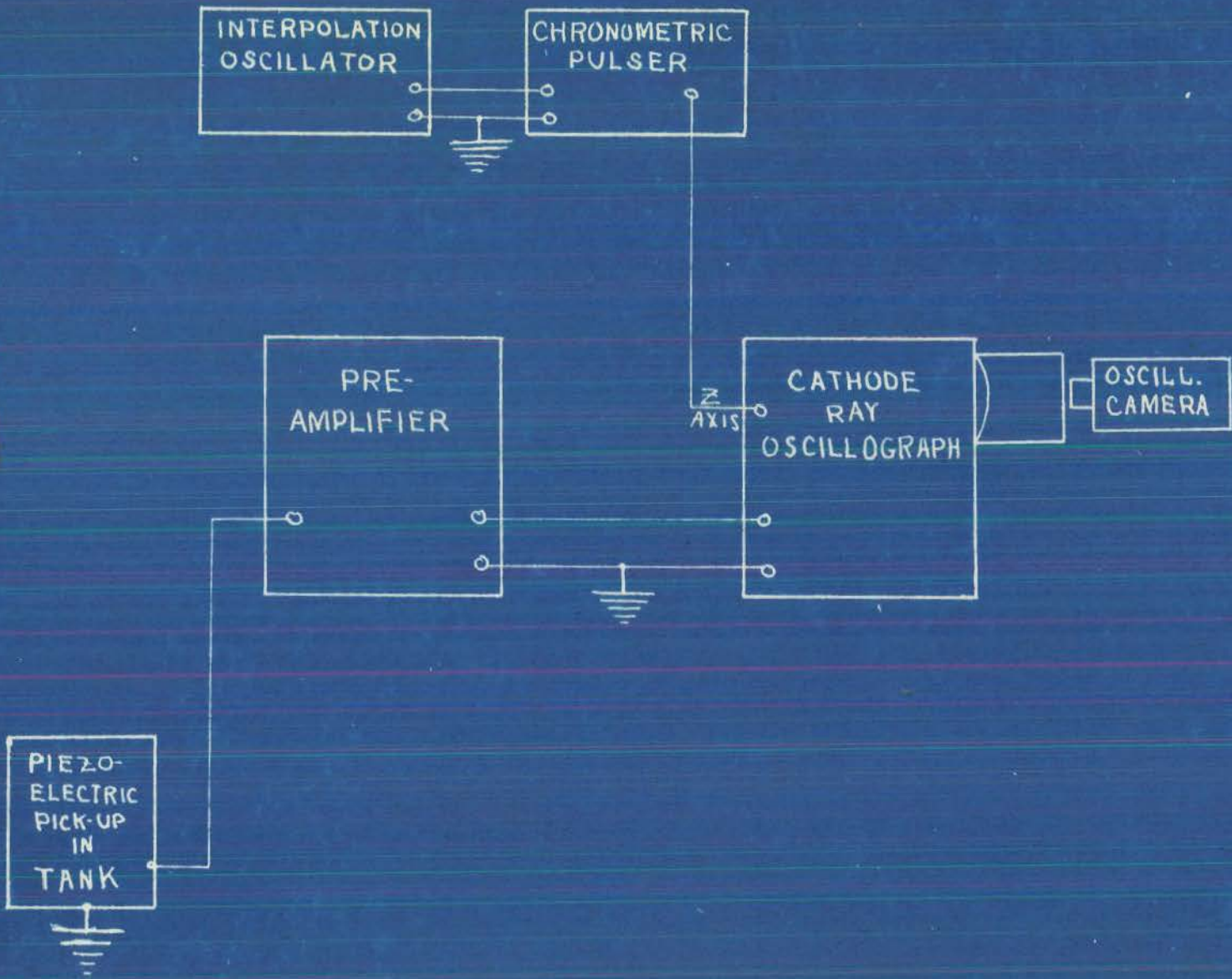


PLATE 8

ORIGINAL SPEED  
PRESSURE WAVE IN  
A CLOSED TANK

0

.025

P, MAX. = 2400 P.S.I.

PRESSURE WAVE WITH  
16 FEET COPPER TUBE  
ON TANK GAUGE  
AT TUBE END.

0

.025

P, MAX. = 2100 P.S.I.

ORIGINAL SPEED  
PRESSURE WAVE WITH  
16 FEET COPPER

TUBE ON TANK GAUGE  
IN TANK

0

.025

P, MAX. = 1800 P.S.I.

.05

SP K 004  
TOTAL ENERGY INPUT TO TANK = 216 FT. LBS.

.050

.595

N 7 7 9 E 0 3

ENERGY INPUT = 216 FT. LBS.

.055

PAR

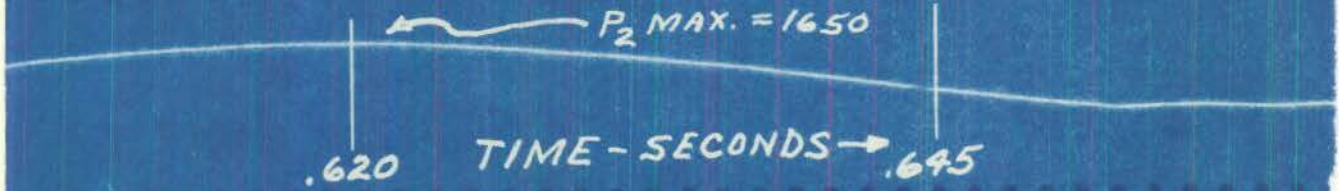
(L) (R) (A) (T) (J)

DA

SP K  
ENERGY INPUT = 216 FT. LBS.

.55

N 0 0 3 5 6



N. 7 = 7.5 E

TIME - SECONDS →

MAP

REVERSE

MAP

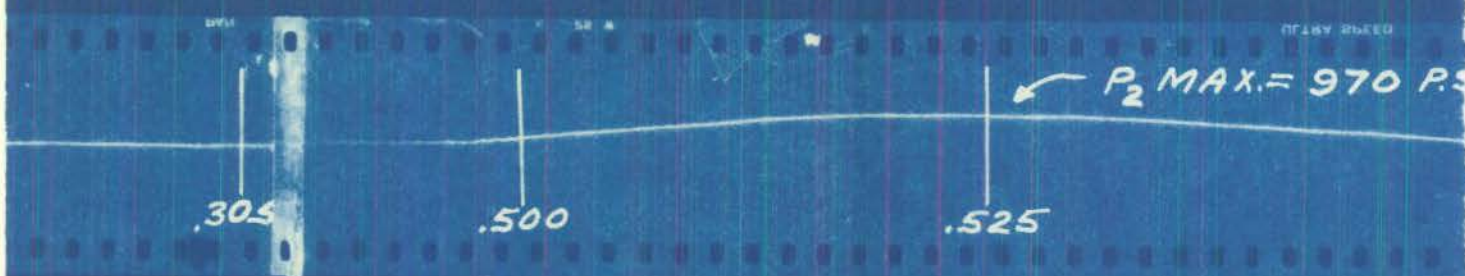
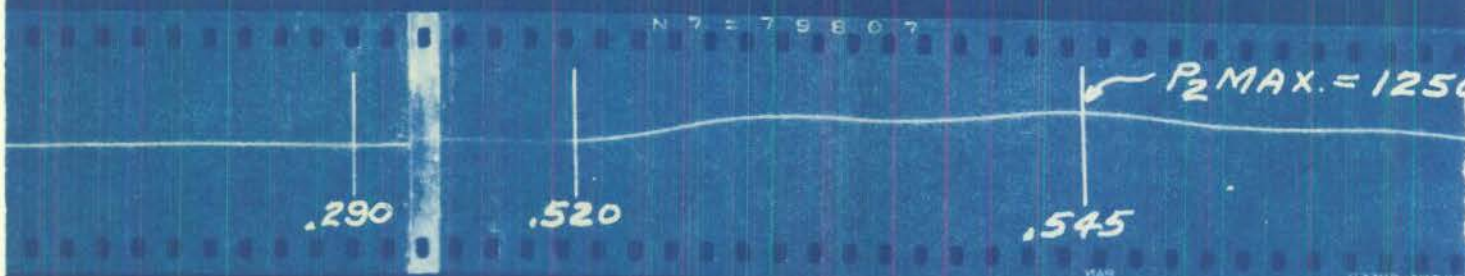
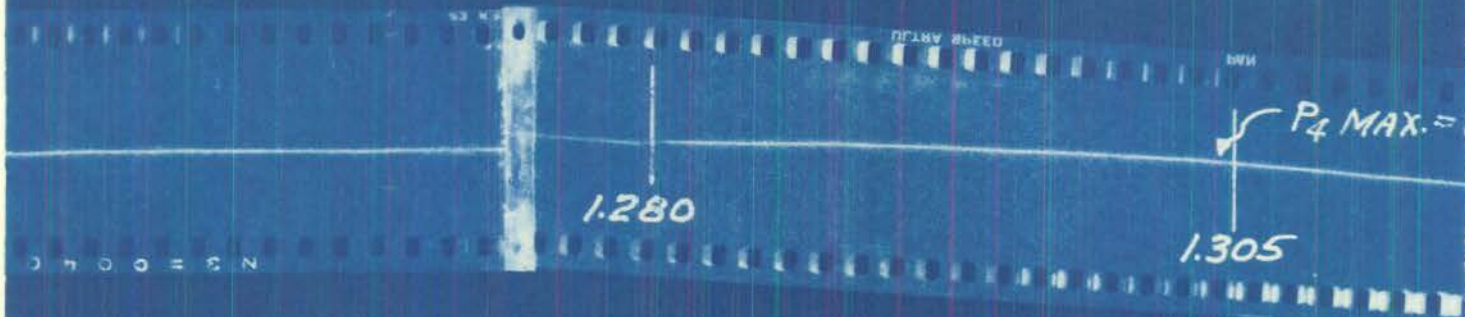
TIME - SECONDS →

N. 2 E. 10. 7. 0. N

030

$P_3 \text{ MAX.} = 1120$   
1.055

1.110



DECLASSIFIED

660

1.330

P.S.I.

.575

S.I.

PLATE 9

NOV 1971

DECLASSIFIED

PRESSURE WAVE WITH  
16 FT. RUBBER TUBE ON TANK  
GAUGE AT TUBE END

$P_{MAX.} = 280$

ENERGY IN

0

.015

5 6 8 6 L = L N

PRESSURE WAVE WITH  
16 FT. RUBBER TUBE ON TANK  
GAUGE IN TANK

$P_{MAX.} = 510$

ENERGY INPUT = 2

0

.015

PAN

ULTRA SPEED

X 05

REEL SPEED

5000

INPUT = 216 FT.LBS.

TIME-SECONDS → .100

N 7 = 7 9 8 2 9

216 FT.LBS.

TIME-SECONDS → .100

N 2 = 5 8 4 4 8  
CALIBRATING WAVE

(FULL SCALE DEFLECTION)

44

ULTRA SPEED X 50



ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

ULTRA SPEED X 50

PLATE 10

DECLASSIFIED

.200

N 7 = 7 8 8 3 3

3 0

.200

ULTRA SPEED PAN

DECLASSIFIED

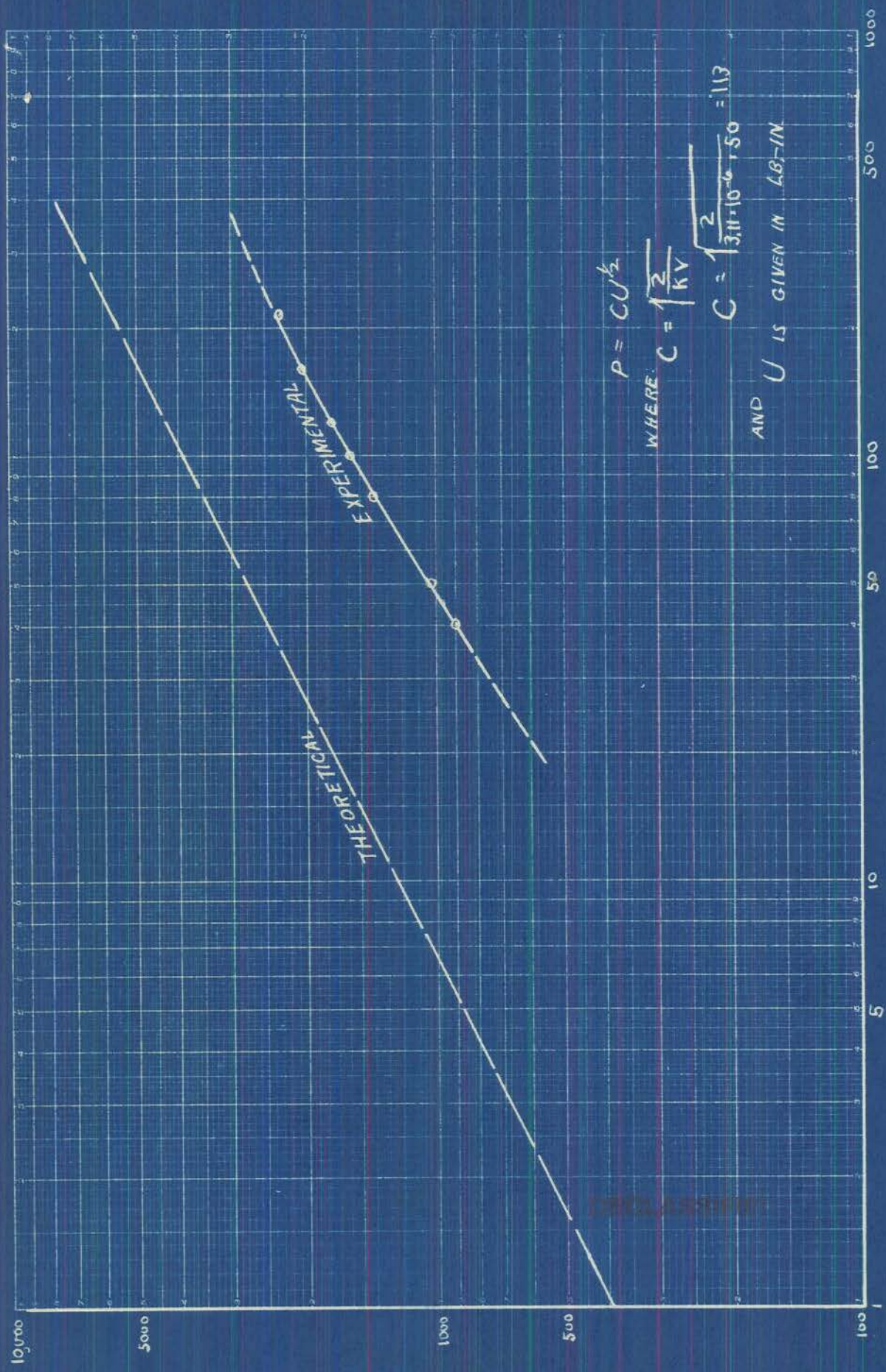
DECLASSIFIED



DECLASSIFIED

PLATE II

PRESSURE PRODUCED (P.S.I.)



$$P = CU^{1/2}$$

WHERE  $C = \sqrt{\frac{2}{KV}}$

$$C = \sqrt{\frac{2}{3.11 \cdot 10^{-6} \cdot 150}} = 113$$

AND U IS GIVEN IN LB-IN

ENERGY INPUT (FOOT LBS.)