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28 November 1942

HIGH IMPACT SHOCK INSTRUMENTATION AND MEASUREMENTS-FIRST PARTIAL REPORT

By
Irwin Vigness

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NAVY DEPARTMENT

REPORT ON

High Impact Shock Instrumentation and Measurements

First Partial Report

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ABSTRACT

The nature of high impact shock characteristics and methods of measurement are discussed. An outline is included of types of apparatus used for shock measurements, together with the apparatus considered essential. Methods and circuits used for acceleration measurements are considered in detail. Quartz crystal type accelerometers are considered the best means for measuring high impact accelerations. Measurements of maximum acceleration obtained on an old cracked striking plate and a new striking plate of the Naval Research Laboratory Shock Stand are compared. Differences are small. Measurements of maximum acceleration for top and end blows obtained on the shock stand at the Naval Research Laboratory are considerably higher than corresponding values determined by Westinghouse and General Electric for the machines at Schenectady, Philadelphia and East Pittsburgh. Probable reasons for this are discussed. An appendix is included in which motions of an elastically mounted weight, subjected to simple shock, are discussed in the light of the ordinary approximate theory of elasticity, and, more briefly in the light of elastic theory involving traveling stress waves.

[redacted]

INTRODUCTION

(a) Authorization

1. This work was authorized by Bureau of Ships project 1438/42.

(b) Statement of Problem

2. The principal problems of this report are the measurements of factors associated with shock. These measurements are made for the following reasons:

(1) To insure that the shocks imposed by devices, such as the HI (high impact) shock machine, are comparable to those suffered in action.

(2) To insure that the performances of different shock machines are standardized and that equipment mounted in an identical manner on similar shock machines receive similar shocks for specified machine settings.

(3) To determine the accelerations, displacements, and strains, of shock tested apparatus and of shock mounts in order that points of weakness may be discovered and the design improved.

(c) General Discussion of Shock

3. A shock is the result of one or more closely spaced mechanical impulses. These impulses consist of very large forces that are applied for very short times. The velocities and displacements associated with shock are usually quite small. Usually the velocities are less than 50 feet per second (20 ft/sec for the shock machine) and the displacements are not more than a few inches. The velocities are acquired nearly instantaneously. The accelerations associated with shock are enormous, values to about 6000 g have been measured. They are limited only by the strengths of the materials subjected to shock. Because of the inherent flexibility of structual materials the magnitudes of the acceleration fall to much lower values at short distances from the part that receives the impulse. Shock usually consists of a series of impulses of varying magnitude. This is particularly true when caused by underwater explosions. Conditions may be further complicated because of collisions caused by relative displacements of various parts subjected to shock. The acceleration-time curves following the impulses are extremely complicated in nature. Frequently definite predominate frequencies can be observed, but more often they consist mainly of non periodic transients that do not resolve themselves into any pattern of standing waves.[19] The definite frequencies often do not appear until some short time after the impulse has elapsed. Both the definite frequencies and the non periodic transients must be considered as a function of the geometry and elastic properties of the object, and supports of the object, in which they occur, together with the nature of the impact.

[redacted]

4. It is impossible, as yet, to define the mechanical effect of shock in terms of any simple numerical quantities. Curves showing the time relations of either acceleration, velocity or displacement, of all points on an apparatus should contain all the information necessary for a complete description of shock. In practice, however, it has not been possible to derive satisfactorily either a velocity or a displacement curve from an acceleration curve, or to derive an acceleration curve from a displacement curve, except for short intervals of time. (see plate 10-12).

5. If shock is to be described by numerical values these values should be descriptive principally of the following factors:

(a) Extremely large accelerations of high frequency associated with small displacement amplitudes.

(b) Lower magnitude acceleration of lower frequencies associated with larger displacement amplitudes.

(c) Maximum specific impulses. A specific impulse is here defined an impulse per unit of mass and is equal to the integral of the acceleration over a time interval considered, or:

$$\text{Specific impulse} = \int_{t_1}^{t_2} a\,dt$$

Several suitable time intervals, $t_2 - t_1$, may be chosen. A maximum value of the above integral, for a given time interval spaced at any location along the time axis of the acceleration curve, is a maximum specific impulse. It is equal to the velocity change between points t_1 and t_2 as derived from the acceleration curve. This method of describing shock is given in reference 19.

(d) Maximum displacement.

(e) Time required to attain the maximum displacement and the time for the displacement cycle.

(f) Deformation and bending. The effects of distortion of members on which apparatus is mounted can be sufficient to break attached apparatus even with no other associated shock.

6. As knowledge of the subject is increased it may be possible to ascribe certain numerical quantities as descriptive of the severity of shock. It has been customary to give the maximum acceleration and sometimes the maximum displacement in describing the severity of shock. It is apparent that the relative importances of the various factors associated with shock depend upon the nature and mounting of an object for which protection is desired. The extremely high accelerations are of principal importance when brittle materials are rigidly connected to stiff heavy structural parts, while flexibly mounted apparatus is affected mainly by lower, longer acting, accelerations involving large displacements.

[redacted]

7. For the design of shock mounts the important factors are the maximum displacements and the time of the displacement cycle. If large amplitude oscillations occur the negative amplitude must, of course, be considered. With these data a shock mount capable of limiting apparatus mounted thereon to some suitable value of g, and with a lowest natural period above some specified minimum value, can probably be constructed. Little is known as to the transmission of traveling stress waves by the shock mounts. (See Appendix I).

8. Shipboard shock may be the result of

- (a) Shell impact
- (b) Contact explosion
- (c) Internal explosion
- (d) Underwater explosion that is not a contact explosion
- (e) Reactions caused by firing of large guns

9. Shocks from underwater non-contact explosions are believed to represent the principal shock problem. Shocks from direct shell impacts become small at short distances from the impact. External or internal explosions cannot be protected against in the immediate vicinity of the explosion or where an air blast of the explosion occurs. Shocks caused by these explosions are usually small outside of the barriers confining the explosions. Thus within the confinement, apparatus cannot be protected, outside the confinement it usually is not necessary. Reactions caused by the firing of large guns are small compared to the shocks here considered.

(d) Apparatus used for Shock Measurements

10. To obtain complete information as to the nature of a shock it has been customary in this country to obtain curves representing the acceleration-time and displacement-time relations. In addition to these measurements, attempts have been made to measure various factors that might be an index of shock severity. These latter attempts have included simple, practical instruments for measuring maximum acceleration, such as the many types of spring weighted peak accelerometers, impact gages, crusher gages, and similar type instruments, that depend upon deformation of material and that require displacements to obtain this deformation. These are expected to give only an index of shock severity. This index of severity can only be correct for comparing shocks of similar natures.

11. The apparatus listed in the following outline contains most of the types used for high impact shock measurements. Some older methods used for underwater pressure work, such as the copper crusher gage, the copper diaphragm gage, and the spray method, have not been included.

1. Accelerometers
    - a. Crystal
        - Quartz
        - Tourmaline
        - Rochelle Salt

[redacted]

        b. Wire Strain Gage (Bonded Metalectric)
            Cantilever
            Longitudinal
        c. Condenser
        d. Carbon Pile
        e. Mass-Spring
        f. Mass-Plug
2. Velocity meters
        a. Moving coil in uniform magnetic field
            (Vibration -velocity detectors)
3. Displacement meters
        a. Rotating Drum
        b. Inductive
        c. Resistance
        d. Photoelectric
        e. Lead Maximum displacement gage
        f. High Speed Moving Pictures
        g. String Traveling Wave
4. Shock Intensity
        a. Lead Impact gage
5. Strain gages
        a. Wire (Metalectric)
        b. Magnetic
        c. Electronic

12. Only a brief description, sufficient to show the basic principles of operation, will be given of the above apparatus. Full description may be found in the references listed at the end of the report.

a. Crystal accelerometers.[1, 2, 7, 8, 9, 11, 13] In the quartz crystal accelerometer a mass is pressed against quartz crystals with a force greater than that expected to be developed by any acceleration of the mass. The changes of pressure caused by acceleration of this mass are measured by the piezo-electric charges developed. Tourmaline is mainly used to measure underwater pressure changes as it is sensitive to hydrostatic pressure whereas quartz is not. Rochelle salt crystals are about 1000 times as sensitive as quartz or tourmaline, but they are weak mechanically and unstable chemically and are unsuited for high intensity shock work.

b. Wire Strain Gage Accelerometers[3, 16, 20] (Metalectric). The resistance of a wire changes slightly as the wire is strained. If this strain is small compared to displacements caused by accelerations then this resistance change can be made to vary directly as the acceleration for suitably designed apparatus. A wire strain gage accelerometer, if made of good sensitivity, has a low natural period of vibration. If the period is made high (0.00005 sec) the sensitivity is reduced. The type of instrument is dependable and should probably be developed in parallel with the quartz accelerometer in order that independent checks over uncalibrated regions of acceleration might be obtained. At the present time the quartz accelerometer is the more convenient and accurate instrument. A description of a strain gage type accelerometer, developed at this Laboratory, is included in this report.

[redacted]

c. Condenser type accelerometers. This type has not been developed for practical use. The name of this accelerometer is descriptive of its mode of operation. A principal difficulty encountered in this type would be changes of capacity of cable connection during shock.

d. Carbon Pile type Accelerometer.[10] The probable instability of a carbon pile under high impact shock does not warrant the development of this instrument.

e. Mass-Spring type Peak Accelerometers and Mass-Plug type Peak Accelerometers. In the mass-spring type accelerometer a mass is held in place by a spring. When a force caused by an acceleration became greater than the counteracting spring force there is a motion of the mass. This motion is detected by either optical or electrical methods. In the mass-plug type a mass is held in place by a bakelite plug of a given cross section. When the acceleration exceeds a certain value the force exerted by the mass on the bakelite plug causes the plug to break. These methods may be calibrated by centrifugal means.

f. Velocity meters. These consist, generally, of a coil moving in a uniform radial magnetic field, in the same manner as the coil of a dynamic loud speaker. It is difficult to construct a practical instrument with a long (5 or 6 inches) uniform magnetic field. It is thought better, in this country, to measure both acceleration and displacement rather than to derive them from a velocity-time curve.

g. Rotating Drum Displacement Meter.[1] A drum rotating at a known speed is placed with its axis parallel to the motion of a part whose displacement is desired. A pencil is attached to this part so as to write on the drum.

h. Inductive type Displacement Meter.[1, 3] The displacement of a part of an apparatus is measured by the change of inductance of a coil. An iron plunger penetrates into the coil a distance dependent on the displacement of the apparatus part.

i. Resistance type Displacement Meter. A uniform fixed resistor of fine wire is placed across an electrical potential. A sliding contact, the position of which depends directly on the displacement, taps off a potential that is directly proportional to the displacement.

j. Photoelectric Displacement Meters. The displacement of a part is measured by the shadow cast as the part moves across a light beam. A photoelectric cell measures the light.

k. High Speed Moving Pictures.[2] Displacement of all exposed parts of an apparatus can be determined with reasonable accuracy by high-speed moving pictures (1000 or more frames per second).

l. String Traveling Wave. If an end of a suspended string is displaced perpendicularly to the string axis a traveling wave

[redacted]

is initiated that will move with a definite velocity along the length of the string. This velocity depends upon the string tension. If the string is assumed perfectly flexible and air friction is neglected the shape of the traveling wave is preserved until altered by end reflections. Edgerton has recorded the shape of these traveling waves by photographic methods. The shape of the wave is a direct plot of the displacement-time curve of a part to which the string is attached. The time axis is along the length of the string and the displacement axis is perpendicular to the string.

m. Lead Impact Gage.[1, 12] The lead impact gage is intended to provide an index to the "severity of shock". It consists of a weighted ball in contact with a piece of lead. An acceleration in a suitable direction causes the ball to indent the lead. The diameter of the indentation is a measure of the severity of shock. The device cannot compare shocks of different nature. It may be used to compare similar shocks.

n. Wire Strain Gages.[2, 16] Baldwin-Southwark type SR-4 strain gages, or other gages of a similar nature, can be used directly to determine the strains of materials to which they are attached. These are more suitable than any other type strain gage of this time as they are light, linear, and will follow frequencies through the range concerned (30,000 cycles per second).

(e) Essential Measuring Apparatus

13. For shock measurements it is essential that acceleration-time and displacement-time curves be obtained. The British have, in some cases, substituted velocity measurements for the above two from which they derive the acceleration and displacement. It is necessary that relative motions, distortions and strains of many parts of an apparatus be observed. To make these measurements with the greatest ease and accuracy the following equipment is preferred:

a. Quartz Crystal Accelerometer. The auxiliary equipment required is given later in this report.

b. High Speed Moving Pictures (See paragraph 39). Gross displacements and deformations are pictured as a whole by high speed moving pictures (1000 or more frames per second). The high speed moving pictures are expected to combine displacement measurements of all points in the field of view together with observations of the apparatus as a whole, whereas other displacement methods record the motion of a single point. The moving pictures are not expected to show the small displacements and deformations caused by the high frequency accelerations. They are expected to show only gross displacements.

c. Wire Strain Gages. These gages are not expected to be used routinely, but in cases where the above measurements do not give sufficient information.

[redacted]

d. Lead Maximum Displacement Gage. This is a rough and ready gage that requires no skill and little cost or time. It can give valuable information. (See paragraph 37 and plate 20).

METHODS AND APPARATUS USED AT THE NAVAL RESEARCH LABORATORY

(a) Electrical Circuits for Strain Gages and Accelerometers

14. A block diagram of the electrical circuits used for quartz and wire strain gage type accelerometers, and for wire type strain gages, is shown in figure (1).

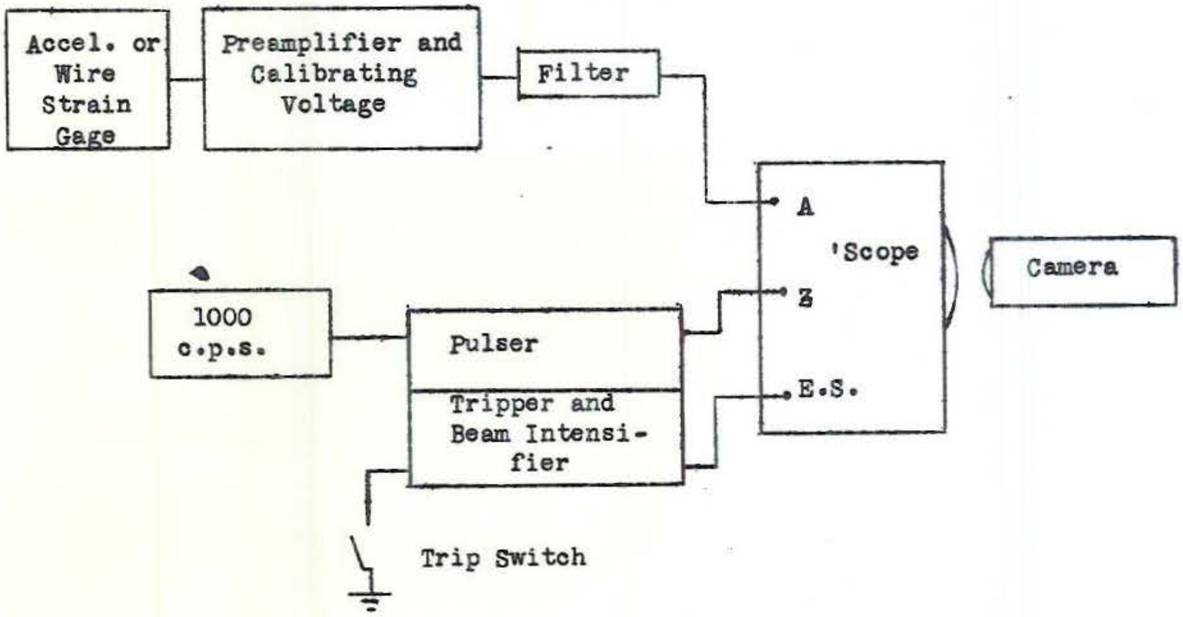

Figure (1). Block diagram of apparatus used in acceleration or wire strain gage measurements. The oscillograph is a Dumont #175A which has "Z" axis modulation and single sweep features.

15. Because the crystal accelerometer has a high impedance electrical circuit and the wire strain gage has a low impedance electrical circuit (the latter usually less than 1000 ohms) some advantage is obtained by using different types of preamplifiers in the two cases. At the present time a commercial instrument (RCA type 319-A) is used with the crystal accelerometer. It was found necessary, because the cable connected to the crystal accelerometer changed capacity during shock, to remove the grid bias cell and 100 megohm resistor of the first tube of this amplifier. In their place a small 1.5 volt dry cell was attached directly to the grid of the tube and a 1 megohm resistor was placed connecting the opposite side of the dry cell to the ground. This removed, to a large extent, the potential across the accelerometer and so minimized the effect of changing cable capacity. The amplification curve was flat to below 20 cycles per second with these changes. It dropped about 15 percent at 15,000 cycles. This amplifier can also be used with the wire strain gages, but it is better to use a battery operated amplifier as the A.C. hum is objectionable when small signals are

[redacted]

encountered. Battery operated preamplifiers designed for crystal accelerometers and for wire strain gages are described in a Taylor Model Basin report[18]

16. Three low pass filters have been constructed with cut-off values at about 12,000, 5000, and 1000 cycles per second. The circuits and their transmission curves are given in plates 1, 2 and 3.

17. An examination of plates 4 to 9 show that the oscillograph trace is interrupted by a very narrow blank space at regular time intervals. A Dumont oscillograph type 175A is used. In this oscillograph it is possible to control the intensity of the electron beam by changing the potential of a grid of the cathode ray tube. This intensity control is the so called "Z" axis. A short persistance, blue, cathode ray tube is necessary for moving film recordings. The output of a 1000 cycle tuning fork (G.R. type 813-A audio oscillator) is fed to a pulser (see plate 14 for circuit diagram). The pulser changes the amplified tuning fork input into a sharp electrical impulse. One pulse occurs for every positive cycle of input voltage so in this case the pulses are 0.001 second apart. These provide a negative bias on the aathode ray tube grid at 0.001 second intervals which extinguishes the beam during the duration of the pulse.

18. A trip switch is provided that initiates a long positive pulse on the cathode ray tube grid, and at the same time starts the oscillograph sweep circuit so that a single sweep is obtained. The intensity of the cathode beam is adjusted so that the fluorescence is just visible before the transient occurs. The cathode spot is then adjusted to a position off the screen. This prevents fogging the camera film. Care must be taken that the positive pulse be not of too great amplitude as this may cause a slight vertical displacement of the cathode ray beam. Plates 4 and 5 were taken in this manner. The thousand cycle timing pulse is on continuously and is of sufficient amplitude to extinguish the beam even though superimposed on the long positive pulse. A 1/2 mfd. 2000 volt condenser was added in parallel with the cathode ray grid coupling condenser within the Dumont oscillograph in order to increase the time constant of the "Z" circuit.

(b) Cameras for Oscillograph Recordings

19. Two types of cameras are used. A stationary film camera using 4.5 x 6 cm film and having a fl:8 lens is used when a long time axis is not required. A moving film camera (G.R. High Speed camera type 651A-E) is used when a long time axis is desired. This latter camera is well suited for this type of work. When it is used the beam intensifier is eliminated. The camera can be tripped by hand or by suitable relays. About 10 feet of 35 mm. film, with a leader or trailer or both, are required for hand tripping.

(c) Quartz Accelerometer

20. The quartz accelerometer used was constructed by Westinghouse and is well described in a report[17] written by that company. Plates

15 and 16, taken from this report, show the construction of the instrument. On these figures, parts 17 are the quartz crystals, parts 3, 6, and 7 constitute the mass (see paragraph 12 part a). Parts 9 are disc springs that force the mass against the crystal. A sensitivity of 0.0079 millivolts per unit of gravity, g, as given by Westinghouse checks with the value determined at this Laboratory (see paragraph 44).

(d) Wire Strain Gage Type Accelerometer

21. The strain gage type accelerometer constructed at this Laboratory is shown in plate 17. It consists of a thin walled seamless steel tube, one end of which is hard soldered to a base containing a mounting stud, the other end is hard soldered to a bronze mass. Tubes of several wall thicknesses (0.0084", 0.0114", and 0.0252") have been used. The outside diameters were all approximately 0.5". A strain gage, made of 1 mil diameter cupron wire wound on one surface of an onion skin paper, figure 2, is cemented to the tube. The wires of the strain gage run in the direction of the tube axis, they cover the complete circumference of the tube. This latter is necessary in order that bending stresses may cancel out. The gage resistance is about 600 ohms.

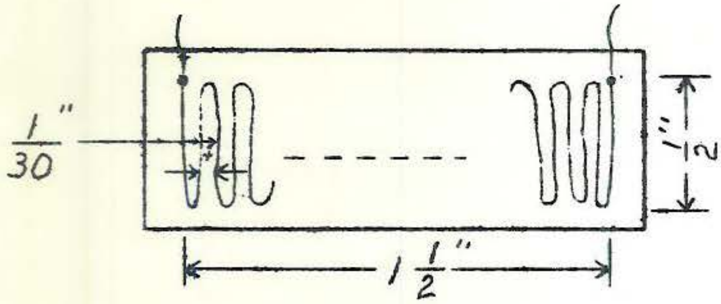

Figure (2) Wire Strain Gage for accelerometer.

22. After the wire is wound as illustrated a second thin sheet of onion skin paper is cemented (with duco and acetone) on the gage so as to sandwich the wires. Care must be taken not to move the gage and paper with respect to each other before the cement has hardened or the gage wires will be moved from their positions.

23. A good procedure for cementing (with duco and acetone) the gage wire to the tube is to put a liberal amount of cement on the tube and the back of the wire gage. The wire gage is then put in position on the tube and a medium cotton thread is wound around the tube over the wire gage. Winding should begin over the leads and should be wound closely and uniformly forcing the excess cement out the bottom. Only one layer of winding is necessary. After this layer has been wound more windings should be placed over the leads, these windings should be saturated with duco. The complete gage should now be baked for several days at temperatures between 50°C and 100°C.

[redacted]

24. The gage base is threaded so that a protecting cover tube can be used. Attempts have been made to damp the natural period by connecting the top of the cover tube and the top of the gage mass with a lead (1/8" thick) washer.

25. The following section on wire strain gages applies also to this type accelerometer, which in essence, is a strain measurement.

(e) Wire Strain Gages

26. A wire strain gage may be used as one arm of a bridge circuit (see figure 3). R_8 of this circuit should be adjusted to equal the gage resistance. It consists of a small wire wound resistor of slightly less resistance than the gage plus a variable resistor for balancing. R_6 and R_7 are fixed wire wound resistors of about 5000 ohms each. R_6 and R_7 should be very close to the same value, but it does not make much difference what that value is. Small slow changes of unbalance do not effect the oscillograph signal.

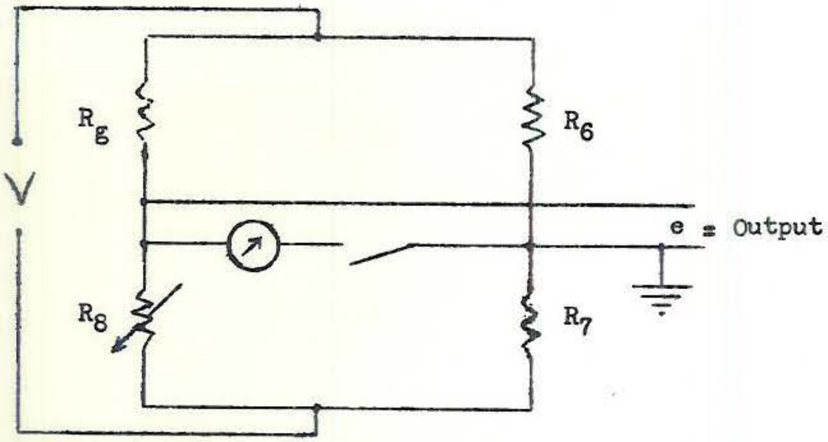

Figure (3) Bridge circuit for wire type strain gages.

27. An alternative circuit is shown in figure 4. While this circuit is more simple it was found that the large steady state voltage across the output polarized a blocking condenser (a 1 mfd. paper condenser) in the preamplifier circuit and caused some delay in reaching steady state conditions.

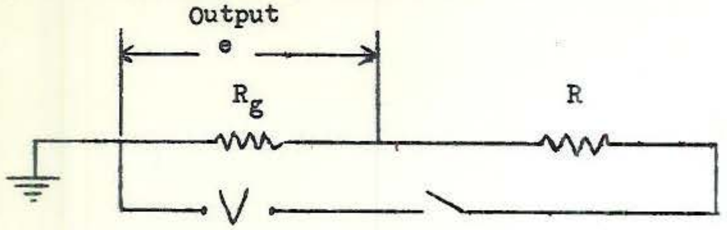

Figure (4) An alternative circuit for wire type strain gages.

28. If R is made equal to R_g, in the above circuit, V is the applied voltage, and if ΔR_g denotes the change of strain gage resistance, then it can easily be shown that the change of output voltage is

[redacted]

(1)
$$\Delta e = \frac{V \Delta R_g}{4 R_g} .$$

This same equation also holds true for the circuit shown in figure (3). It is assumed that ΔR_g is small and that the impedance of the circuit into which the output feeds is very high compared to the values of the above circuits.

The change of resistance of a wire strain gage is

(2)
$$\frac{\Delta R}{R} = G \frac{\Delta \ell}{\ell}$$

Where $\frac{\Delta \ell}{\ell}$ is the strain and G is the so called gage factor.

The output voltage from equation (1) is therefore

(3)
$$\Delta e = \frac{GV}{4} \frac{\Delta \ell}{\ell}$$ or the strain is

(4)
$$\frac{\Delta \ell}{\ell} = \frac{4 \Delta e}{GV}$$

29. This last equation means that a strain can be measured by using the calibrating voltage with the preamplifier as shown on figure (1). The gage factor, G, is known. An alternative method of calibrating is to change the resistance of the gage circuit by a known small amount and noting the change of signal resulting. The change of resistance is usually accomplished by adding a high resistance in parallel with the gage and shorting a small section of this resistance to produce the change. For the wire strain gage type accelerometer the acceleration is determined below:

If r = accelerometer tube mean radius
t = accelerometer tube wall thickness
W = weight of bronze mass of accelerometer
E = modulus of elasticity of the tube (mild steel)
a = acceleration
g = acceleration of gravity
$n = a/g$

then by ordinary mechanics

(5)
$$n = \frac{8 \pi r t E}{WG} \frac{e}{V}$$

where

(6)
$$a = ng$$

30. Equation (5) determines the theoretical value of acceleration. This can be checked by calibrations and from results given later (paragraphs 41 through 43). It will be found that the check is very satisfactory. This equation will not be valid in the

[redacted]

vicinity of the resonant point of the mounted accelerometer.

Calibration of Accelerometers

31. A bar, if held in position so that is restricts the flow of air from a suitable orifice, can be made to vibrate at its natural frequency. This can be explained qualitatively by assuming that the escape of air is proportional to the displacement of the bar from the orifice and that the departure from average air pressure is proportional to the integral of the difference between the air flow and the average value of flow. In figure (5) the solid curve represents the displacement of the bar from the orifice, or the flow of air from the orifice, and the pressure is assumed to be represented by the broken curve. When the displacement, or flow, is greatest the pressure is falling with greatest rapidity. If these are sinusoidal functions the pressure will be below average while the bar is moving away from the orifice. This will increase the amplitude of vibration until some steady state condition is reached.

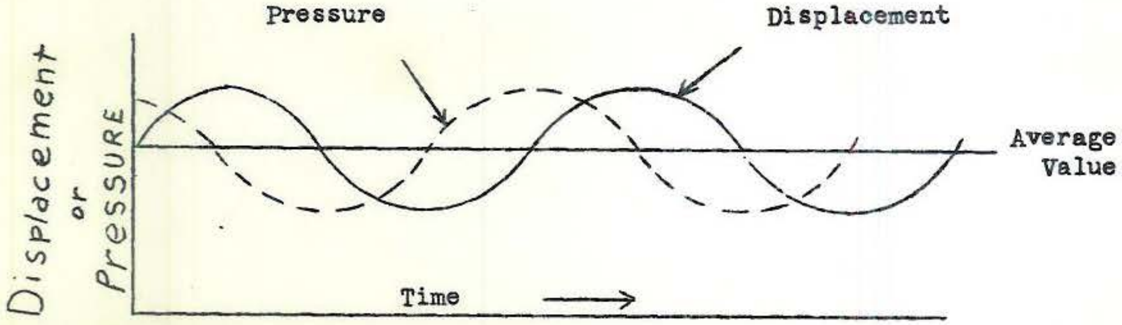

Figure (5)

32. Figure (6) shows roughly such a bar and orifice. Plate 18 illustrates a laboratory set-up used in making measurements included in this report. The bar illustrated in this plate is of cold rolled steel 2" thick, 2-1/2" wide, and 21" long. It is not advisable to use a bar of square cross-section because of lateral vibrations. The bar is kept from moving in a horizontal plane by pins held against its fundamental nodal points. The bar is allowed to move slightly in a vertical direction so as to float freely on the film of air between the orifice and bar. When there is no air pressure the bar rests solidly on the wide lips of the cup containing the orifice. Spring supports are sometimes an advantage to remove part of the weight of the bar from the air column.

33. The bar will not vibrate if there are any loose objects, or if any object that subtracts much energy, is mounted upon it. Thus the crystal accelerometer with the regular cable attached prohibits bar vibrations as the cable absorbs too much energy. Good vibrations can be had if a short flexible wire is used to connect the accelero-

[redacted]

meter to the cable. The maximum of acceleration obtained by this method has been about 450g. This was with a wire strain gage type accelerometer attached. With some development work it is possible that this maximum can be considerably increased.

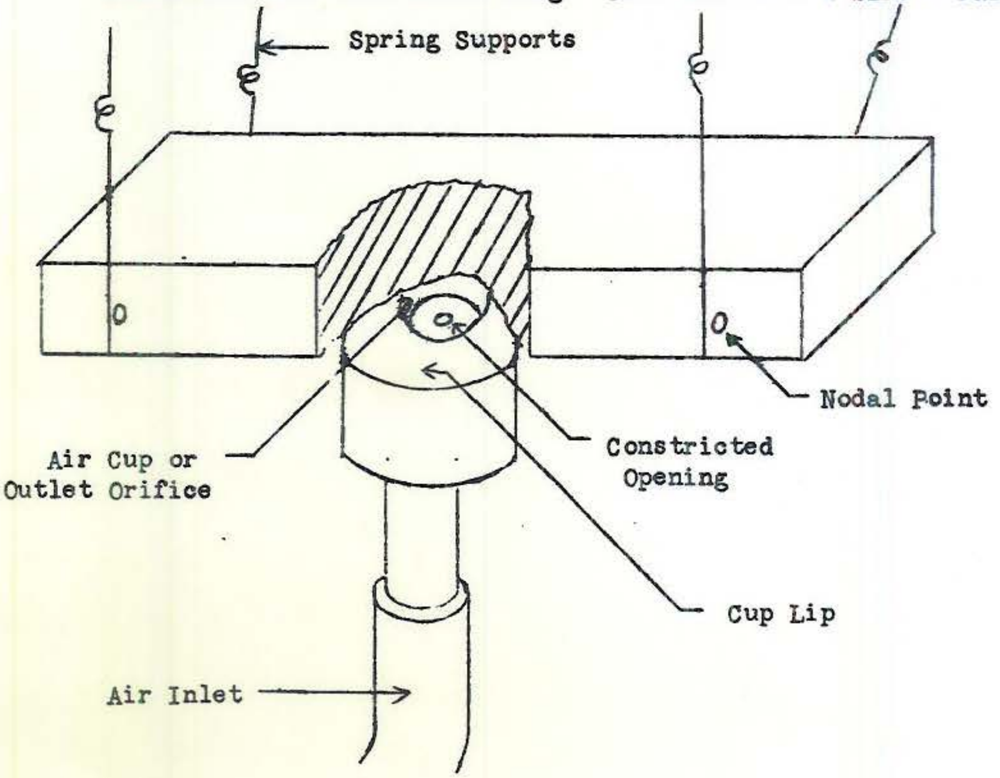

Figure (6) Compressed air excited vibrating bar. The sectioned part is cut away to show the air orifice.

34. To calibrate an accelerometer it is attached by means of a stud to a tapped hole in the center of the bar (See plate 18). The accelerometer is illuminated with a strobotac (GR type 631-B) and the excursions of a scratch or spot, as it moves in slow motion, is measured with a traveling microscope. The excursions can be measured in non-intermittant light by observing the length of a streak made by a moving scratch, but care must be taken not to include the width of the spot in the measurements. When the strobotac is used the frequency of the bar can also be easily obtained.

35. The maximum acceleration of a sinusoidally vibrating body is

(7)

$$a_{max} = 4\pi^2 f^2 D$$

where

f is the frequency and
D is the maximum displacement

[redacted]

from an average position.

or

$$(8) \qquad n = \frac{4\pi^2}{g} f^2 D$$

where

$$a = ng$$

Which is thé acceleration in terms of the number of gravity units. It corresponds to equation (5). Equation (8) determines the experimental, or measured, value of acceleration which is used for calibration determinations.

Impact Gages

36. Two similar types of impact gages are in use. One constructed by General Electric and another of more economical design constructed at this laboratory. An unassembled view of the latter is shown on plate 19. The laboratory model is made from standard hexagonal cold rolled steel stock and the lead discs are punched from selected 1/8 inch thick sheet lead. As no weight is added to the ball (3/8 inch dia. ball bearing) the instrument is not as sensitive as the General Electric model. It is emphasized that these gages can only be used to compare similar type shocks and under no circumstances can they be expected to give indications as to the magnitude of high frequency accelerations.

Lead Maximum Displacement Gage

37. General Electric[1] has described this gage. The gage is constructed of a tapered lead angle, made of about 1/32 inch thick sheet lead, that is soldered to a brass, or iron, base. (See plate 20). This gage is mounted so as to be partly crushed by a displaced part. The displacement is measured by the amount crushed. The gages can be straightened and used many times.

Displacement Meters

38. A resistance type displacement meter, has been used at this Laboratory. It is expected that the high speed moving picture camera will be used in its stead for the determination of displacement.

High Speed Moving Pictures

39. The delivery of a high speed moving picture camera to the Naval Research Laboratory has been delayed. This camera is expected to take up to 3000 frames per second on 16 mm film. The equivalent time of exposure per frame at this speed is said to be 1/12000 second. It was expected that the performance and suitability of this method of measurement would be evaluated in this report, but in order to expedite the dissemination of other

[redacted]

information from this Laboratory, its performance will be indicated in a later report.

MEASUREMENTS

(a) Accelerometer Characteristics

40. A free acclerometer, i.e., an accelerometer that is not mounted on any mass, has been found to exhibit different characteristics than when mounted on a mass. There are several reasons why this should be so, one of which can be explained in the following manner: An accelerometer consists of a mass that resists a change of motion. This mass is connected elastically to a mounting base. The mass and the base will, in the unmounted case, vibrate about the center of mass of the system. If the accelerometer is mounted the mass will vibrate about the base. In this latter case the accelerometer will have a longer natural period. The change of natural period may be expected to be greater in the wire strain gage type accelerometers, either cantilever or tubular type, than in the quartz type where the weight of the mass is considerably smaller than the weight of the base. Changes of natural frequency, due to this cause, are clearly shown on plates 4 and 5. The changes for the quartz accelerometer are difficult to evaluate as several different modes of vibration are introduced when the accelerometer is mounted. These different modes of vibration introduced by mounting an accelerometer on a heavy base (the base usually consisted of a steel block, approximately cubical and about 2-1/2 inches on a side) make it probable that the high frequency components (about 10,000 c.p.s.) appearing in most records are but a local and unimportant manifestations. It is considered important that an accelerometer, when mounted on a small relatively heavy steel block, should exhibit natural frequencies below 12,000 cycles per second.

(b) Accelerometer Calibrations

41. Wire Strain Gage Type. The constants of gages #1 and #4 are (see paragraph 29).

	#1	#4
r	0.235	0.24 inches
t	0.0114	0.0252 inches
E	29×10^6	29×10^6 lbs/in^2
W	0.109	0.116 lbs
G	2.1	2.1

Equation (5) of paragraph 29 becomes therefore

$$n(\text{gage } \#1) = 0.00855 \times 10^3 \frac{e}{V}$$

$$n(\text{gage } \#4) = 0.018 \times 10^3 \frac{e}{V}$$

42. Calibration was performed on a vibrating bar for which, (from equation (8) paragraph 35)

$$n = \frac{4\pi^2 f^2 D}{g}$$

[redacted]

For gage #1

$e_{max} = 1.14 \times 10^{-3}$ volts (not R.M.S. value)

$V = 21.7$ volts

$D = 6.5 \times 10^{-3}$ inches

$f = 820$ cycles per second

So

$$a = ng = \frac{4\pi^2 f^2 D}{g} g = \underline{448g}$$

$$a = ng = 0.00855 \times 10^3 \frac{e}{V} g = \underline{450g}$$

Thus the value of acceleration as measured by an uncalibrated accelerometer agrees with the value as determined by displacement and frequency.

For gage #4

$e_{max} = 0.26 \times 10^{-3}$ volts

$V = 21.4$ volts

$D = 3.52 \times 10^{-3}$ inches

$f = 824$ cycles per second

So

$$a = ng = \frac{4\pi^2 f^2 D}{g} g = \underline{243g}$$

$$a = ng = 0.018 \times 10^3 \frac{e}{V} = \underline{220g}$$

43. The value of acceleration as measured by an uncalibrated accelerometer is in fair agreement with the measured value of acceleration.

44. Quartz Crystal Type. The quartz crystal accelerometer was mounted on a bar that vibrated with a frequency of 896 c.p.s. The sensitivity, as given by Westinghouse, is 0.0079 millivolts per unit of gravity with a capacity of 0.0987 mfd. in parallel with the unit. For any other capacity across the unit the sensitivity is:

$$s = \frac{0.0079 \times 0.0987}{C} \text{ millivolts/g}$$

where C is the capacity in parallel with the unit. The capacity of the lead cable used was 40 micro micro farads per foot (single conductor microphone cable). Two capacities were used

[redacted]

in parallel with the crystals, either 0.0109 mfd. or 0.0809 mfd. These result in sensitivities of

$$s_B = 0.0716 \text{ millivolts/g}$$

or

$$s_A = 0.00966 \text{ millivolts/g}$$

Check 1 (C = 0.0109 mfd.)

Accel. measured from frequency and displacement	= 222g
Accel. measured with accelerometer	= 225g

Check 2 (C = 0.0809 mfd.)

Accel. measured from frequency and displacement	= 189g
Accel. measured from accelerometer	= 171g

The lower crystal of the accelerometer broke about August 24th. With a new crystal installed the following check was obtained. (C = 0.0809 mfd.)

Accel. measured from frequency and displacement	= 198g
Accel. measured from accelerometer	= 211g

These values all check within 10 percent and must be regarded as satisfactory.

(c) HI Shock Machine Measurements

45. Measurements of the HI Shock Machine characteristics as reported here are limited to acceleration measurements with the crystal accelerometer.

46. Acceleration Measurements. Plates 6, 7, 8, and 9 show typical acceleration curves. Plate 9 contains three records made under similar conditions. The gain ratio between the preamplifier and the oscillograph amplifier was changed for the different runs in order to determine if overloading occurred in the preamplifier. This did not occur so the three records can be regarded as identical. The similarity between the records is remarkable and point to point comparison can readily be made.

47. Plates 6, 7, and 8 give characteristics of the bare striking plate at position #6. (See plate 21 for diagrams showing position locations.) These are for a new undeformed striking plate. Very similar records were obtained for an old cracked and deformed striking plate. A comparison of maximum accelerations as obtained from the old and the new striking plates is shown in table I. Neither from the table nor from the oscillographic records do any significant differences appear between the old and the new striking plate. The accelerations at position 6 were, on the average, more severe for the cracked plate than for the new plate. It is possible that the average of the maximum accelerations of all points on the surface of the new more rigid striking plate would be greater than that of the old plate, and it is to be expected that variations from the average would not be as great in the new striking plate as in the old. It is not believed that their characteristics are greatly different. It is also seen from these plates that for the back blow a first rebound occurs after about

[redacted]

0.02 seconds. This is probably bottoming of the springs of one of the holding bolts. For the end blow it requires about 0.04 seconds for the rebound blow, the backstop must be hit in this case. For the top blow there is no sudden reversal of the plate, but after 0.08 seconds the plate has traversed its maximum distance and is thrown back against the hammer. A relatively long time later the hammer will fall back and strike the plate.

TABLE I

Comparison of the maximum accelerations as obtained at striking plate location #6 of a cracked, deformed striking plate and a new striking plate at N.R.L. and values[5] obtained by Westinghouse and General Electric for the HI Shock machines at East Pittsburgh, Schenectady, and Philadelphia.

Direction of Impact	Hammer Energy ft. lb.	Detector Location	Accel. on HI Shock Stand at				
			Schenectady	Phila.	East Pitts.	NRL Cracked	New
Back blow	2000	6	4300g	3300g	4200g	4500g	3700g
Top blow	2000	6a(9)	1130	1190			
		6C(10)	1500		930	1900	2300
End blow	2000	6e(11)	1375	1290			
		6d(12)	1060	1340		2700	2300

48. It is believed that the measurements, made by Westinghouse and General Electric for the top and end blows, are low because of the design of the accelerometer mounting block. A different design of block was used at the Naval Research Laboratory. A rough calculation indicates that an acceleration of 2000g would subject the 3/4" holding bolts of the Westinghouse or General Electric model to about 40,000 lbs/in^2 tensile stress in addition to their drawing up stress. Plate 21 shows the detector locations on the striking plate and the accelerometer mounting block used at this Laboratory.

49. All of the 12,000 cycle low pass filter records show a high frequency component of acceleration of about 10,000 to 12,000 cycles per second. As, has been mentioned in paragraph 40 it is possible that some of these are characteristic of the mounted accelerometer. Whether they be real or not, it is probable that they are of little significance except for brittle materials. An attempt should be made to experimentally determine the damaging effect of these high frequency accelerations. It is probable that more reliable information can be obtained when 5000 cycle low pass filteration is used rather than the 12,000 cycle low pass filter.

50. Plates 10 through 12 show that it is possible to integrate the acceleration curves for several thousandths of a second, with

[redacted]

either a 5000 or a 12,000 cycle low pass filter, and get reasonable results of velocity and displacement. This is a good method of checking the performance of the accelerometer as slight false changes in zero, (see plate 6 of reference 19) caused by the shock, quickly give rise to unreasonable values of velocity and displacement. The results also show that high frequency accelerations contribute little to the impulse. The first few milliseconds of the velocity and displacement can be regarded as of fair accuracy, but as the total area under the acceleration curve becomes large, and as the difference between the positive and negative areas becomes small, the results become inaccurate. It is interesting to note how negligible are the changes of velocity due to the high frequency components of acceleration. Changes of displacement due to these components are still smaller and cannot be noticed on the scale used.

SUMMARY AND CONCLUSIONS

51. High impact shock can be measured in terms of accelerations and displacements as a function of time. As it is impractical to determine these values at all points on an apparatus, measurements of distortion and strain are of considerable value for additional shock description.

52. Measurements of acceleration can best be obtained by means of a quartz crystal accelerometer. The acceleration-time curves are extremely complicated and cannot be sufficiently described by a few numerical values. When definite frequencies appear in these curves they should be included in its numerical description. When additional values are desired for its description a method, in which the maximum average value of acceleration for various short intervals of time, is suggested. This method has been used in a previous report.[19] A graphical representation of maximum shock characteristics is given on plate 23.

53. Many methods are available for measuring displacements, but it is expected that high speed motion pictures may well be used, as they are expected to provide additional information on distortion together with an overall view of the apparatus. Only gross displacements are expected from motion picture analysis. Velocity and displacement charges over periods of a few milliseconds can usually be obtained from acceleration records.

54. Acceleration measurements on the Naval Research High Impact Shock Stand have shown that the maximum accelerations of the bare anvil (striking) plate to be about twice as great for the back blow as for the top or end blows. Measurements made on this machine by the described methods show good agreement with measurements made by Westinghouse and General Electric for similar machines at Schenectady, Philadelphia, and East Pittsburgh for the back blow, but differ considerably for the top and end blows. It is believed that the accelerometer mounting block may cause this difference.

[redacted]

55. Little differences in maximum values of acceleration were observed for corresponding shocks when an old cracked striking plate was used. (see plate 22) and when a new striking plate was used.

56. A method of accelerometer calibration has been described. This method together with other methods of calibration should be further developed so that a quick, convenient, and reliable calibration can be obtained for various frequencies of vibration with magnitudes up to at least 1000g.

57. Natural frequency components, observable at about 10,000 to 12,000 cycles per second, are introduced by mounting the quartz crystal accelerometer on a small heavy base. It is probable, therefore, that some of the accelerations recorded in this frequency range are not real. It is believed that the records obtained with the 5000 cycle low pass filter are accurate within about 10 per cent. It would be most valuable to know the relative damaging effects of different acceleration frequencies on different types of apparatus.

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APPENDIX I

Motions of an Elastically Mounted Weight Subjected to a Simple Shock

The motions of an object subjected to a single impulse may, if determined exactly, be extremely complicated. When a force is applied to a body waves of stress radiate through the body from the point of application of the force. Those waves, like sound waves in a room, reverberate back and forth within their confines reflected and transmitted in various degrees at the boundaries of their confines. Superposition of the radiated and reflected waves at any point in the body gives the resultant stress at that point at some instant of time. If, however, the body is small, so that a stress wave traverses its length in a negligible time, then the ordinary theory of elasticity can be applied. The ordinary theory assumes the stress to be instantly transmitted through the body.

When the exact theory is used, the appearance of high frequency high magnitude accelerations in an elastically mounted material becomes reasonable while in many such cases the ordinary approximate theory indicates that these accelerations should be negligible. The approximate theory cannot be regarded as sufficiently correct if the impulse intensity changes appreciably during the time required for the stress wave to traverse the length of the supports of the apparatus.

Literature on longitudinal stress wave transmission is quite extensive. The references at the end of this appendix give good bibliographies for further study. Thornton(1) and Rayleigh(2) give the more elegant treatment of the subject while Donnell(3) gives an excellent and more simple description of a restricted field. DeJuhasz(4) has a series of articles. His bibliographies are quite extensive. Little work has been done on the propagation of transverse vibrations by stiff beams although the first two above references contain the general theory. A discussion of the approximate theory somewhat similar to that of this appendix is included in a recent Taylor Model Basin report(6).

A brief description of the propagation of longitudinal stress waves and of the propagation of transverse vibrations by stiff beams will be given. A more complete description, determined by the approximate theory, is presented on the action of an elastically mounted material. Additional material by this theory can be found in most texts on the subject(5).

A. Longitudinal Stress Waves

If a force, F, is applied to the end a bar (Fig. 1) for a time t then a pressure wave of length, $L = pt$, will be initiated, where p is the velocity of propagation.

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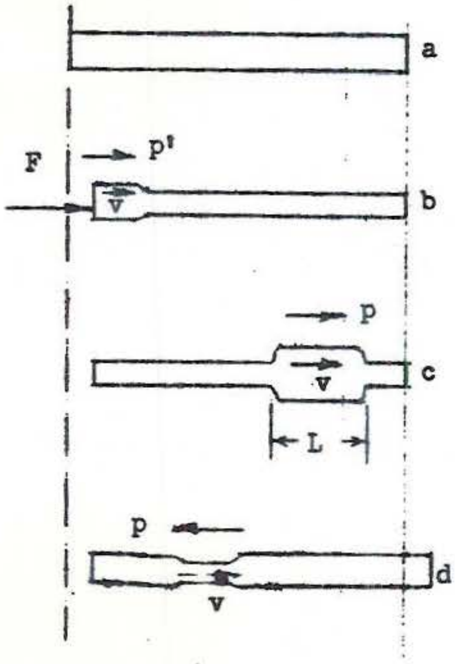

Figure 1. Short time impact on a bar. A force F is applied a short time at one end of a bar. The velocity of the traveling stress wave is p. The velocity of the particles within the disturbed section is v. An increase of bar diameter indicates compression, a constriction indicates tension.

When the force is applied the first infinitessimally thin layer at the end of the bar will start moving with a velocity, v. The acceleration of this layer can be regarded as infinite. If the force applied remains uniform for a time, t, then all of the parts of a bar section of length, L, will have a velocity, v, as indicated in the figure. The section L will move along the bar with the velocity of sound in that material and will be reflected and transmitted by varying degrees by changes of bar section. The bar as a whole will move in discontinuous steps as only one section of the bar is moving at a given time.

Some interesting features are included in the equations of motion and stress for the above case. The layer, or particle, velocity is

$$(1) \quad v = p\sqrt{\frac{g}{E\rho}}$$

where p = pressure
E = Modulas of elasticity
ρ = density
g = acceleration of gravity

For a mild steel material yielding will begin at $p = 30{,}000$ lbs/in^2. The factors E, ρ, and g are constants of the material.

[redacted]

For a steel bar

$$E = 30 \times 10^6 \times 144 \text{ lbs/ft}^2$$

$$\rho = 480 \text{ lbs/ft}^3$$

$$g = 32.2 \text{ ft/sec}^2$$

$$p = 30{,}000 \times 144 \text{ lbs/ft}^2$$

then from equation (1)

$$v = 17.3 \text{ ft/sec}$$

Therefore, if the bar is struck a blow of short time duration by a hard material, and if the velocity of the striking material is greater than 17.3 ft/sec, permanent deformation will result. If the blow is of a longer time duration a lesser striking velocity is required to result in permanent deformation. Impacts of intensity necessary to cause permanent deformation will not be transmitted great distances because of excessive energy losses, therefore, it may be concluded that a high velocity impact of a given momentum provides little more shock a distance from the impact than a low velocity impact of the same momentum. Low velocities are considered between 17 ft/sec and about 100 ft/sec. High velocities are considered as over 100 ft/sec.

If a body is mounted on the right end of the bar (Fig. 1) the amount of energy it can receive is at most equal to the energy of the traveling wave. This energy, half kinetic and half potential, is

$$(2) \qquad W = \frac{p^2}{E} V$$

where V is the volume of the strained section.

Assume the maximum stress to be 30,000 lbs/in^2 and E to be 30×10^6 lbs/in^2 then

$$(3) \qquad W_{max} = 30V \text{ in-lbs}$$

A mounted body may receive a relatively large impulse of energy in a very short time. A pulse one foot long would last about 1/17000 second. A small, light, mounted body would immediately (nearly) attain the velocity, v.

B. Propagation of Transverse Vibration by Stiff Beams.

Figure 2a shows a stiff beam fixed at one end. The fixed end is moved upwards quickly, compared to the natural period of the bar, and brought to rest. The beam will have a bend as shown in Figure 2b. This kink will travel along the length of the beam at a velocity that is dependent not only on the physical properties of the beam, but also on the shape of the kink. It will be reflected and transmitted in varying degrees at changes of bar section. If the fixed end of the beam is displaced harmonically in the vertical direction the velocity of the waves have been shown to vary inversely as the wavelength(1).

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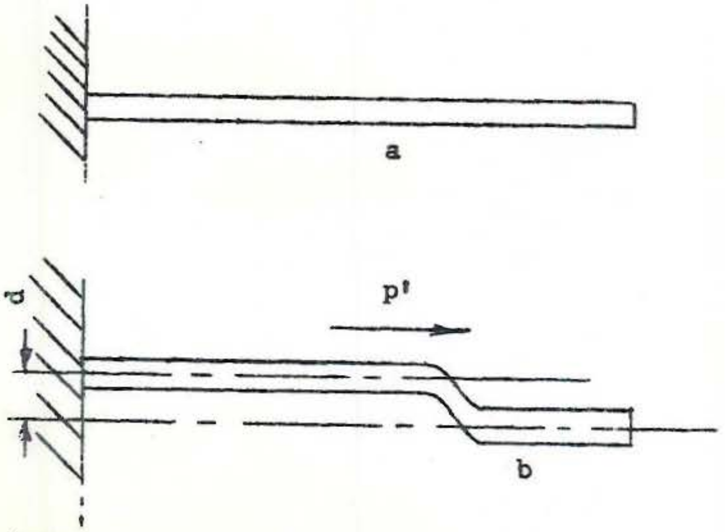


Figure 2. Part a shows a stiff bar supported at its left end. Part b shows the bar a short time after the support had been displaced quickly upward a distance d. The bend in the bar travels with a velocity p'.

It is probable that this type of wave causes many high frequency accelerations recorded on the H. I. shock machine. It is understood that ordinary transverse resonant vibrations of beams are standing waves resulting from these types of traveling waves.

The amount of energy transmitted by the kink in the bar is the sum of the kinetic energy (velocity upward in this case) and potential energy of bending. It is obvious that a wave of this kind traveling along a heavy ship's structure may impart severe high frequency impulses to relatively light materials that are mounted on the structure even though the structure has a long fundamental natural period of vibration.

C. Approximate Theory - Action of Elastically Mounted Materials Under Signal Impulses of Various Shapes

This section does not consider aspects of propagation of stresses. Judgment and reservations are, therefore, necessary in applying the derived results. The results should apply quite well for the analysis of materials of small dimensions and for materials on mounts incapable of transmitting much energy by traveling stress waves. This is generally true if the mounted material is heavy compared with its supports. Action of elastically mounted materials subjected to harmonic vibrations is amply covered by texts(5).

Consider a base (see Fig. 3) to which a weight, W, is elastically mounted. X_b and X_W represent the displacement of the base and the weight from an initial equilibrium position.

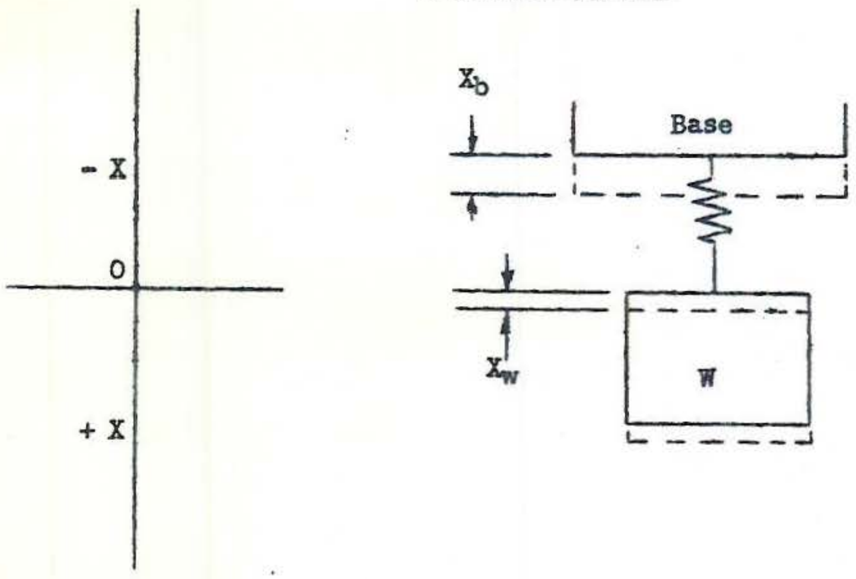


Figure 3. Elastically mounted weight.

If the base is displaced the spring will exert a different force on the weight. This force will be equal to the spring constant times their relative displacement or

(4) Force $= k\ (X_b - X_w)$ and this is equal to the acceleration times the mass of weight, so

$$(5)\quad \frac{d^2X_w}{dt^2} + \frac{gk}{W} X_w = \frac{gk}{W}\ X_b$$

or

$$(6)\quad \frac{d^2X_w}{dt^2} + p^2X_w = p^2X_b$$

The base is given a displacement as a function of time, i. e.,

$$(7)\quad X_b = Af(t)$$

A variety of simple pulses can be had by making $f(t) =$

(8) $\epsilon^{-a_1 t} - \epsilon^{-a_2 t}$ and adjusting parameters, a_1 & a_2.

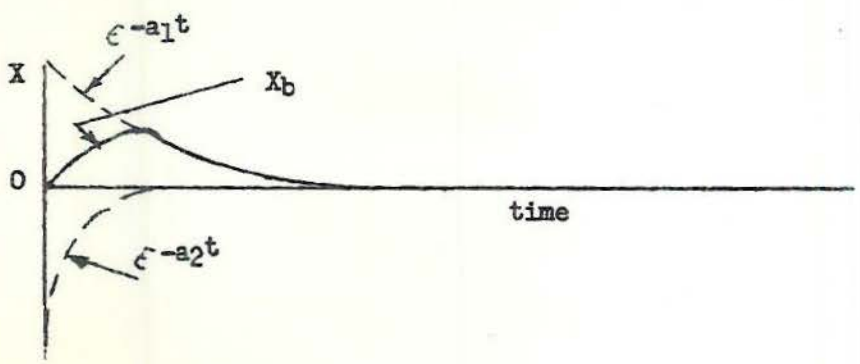


Figure 4. Displacement of the base to which the weight is mounted.

[redacted]

Assume therefore that

$$(9)\quad d^2X_W + p^2X_W = Ap^2\left(\epsilon^{-a_1t} - \epsilon^{-a_2t}\right)$$

A complete solution for this equation is

$$(10)\quad X_W = C_1 \sin pt + C_2 \cos pt + Ap^2\left[\frac{\epsilon^{-2_1t}}{a_1^2 + p^2} - \frac{\epsilon^{-a_2t}}{a_2^2 + p^2}\right]$$

Where C_1 and C_2 are arbitrary constants to be determined by boundary conditions which are

$$(11)\quad \text{When } t = 0 \text{ then } X_W = 0 \text{ and } \frac{dX_W}{dt} = 0$$

From these conditions

$$(12)\quad C_2 = Ap^2\left[\frac{1}{a_1^2 + p^2} - \frac{1}{a_2^2 + p^2}\right]$$

$$(13)\quad C_1 = Ap\left[\frac{a_1}{a_1^2 + p^2} - \frac{a_2}{a_2^2 + p^2}\right]$$

$$(14)\quad X_W = Ap\left[\frac{a_1}{a_1^2 + p^2} - \frac{a_2}{a_2^2 + p^2}\right]\sin pt - Ap^2\left[\frac{1}{a_1^2 + p^2} - \frac{1}{a_2^2 + p^2}\right]\cos pt + Ap^2\left[\frac{\epsilon^{-a_1t}}{a_1^2 + p^2} - \frac{\epsilon^{-a_2t}}{a_2^2 + p^2}\right]$$

Case I - Assume the base is displaced suddenly to a maximum position and returns slowly to zero as shown in Fig. 5.

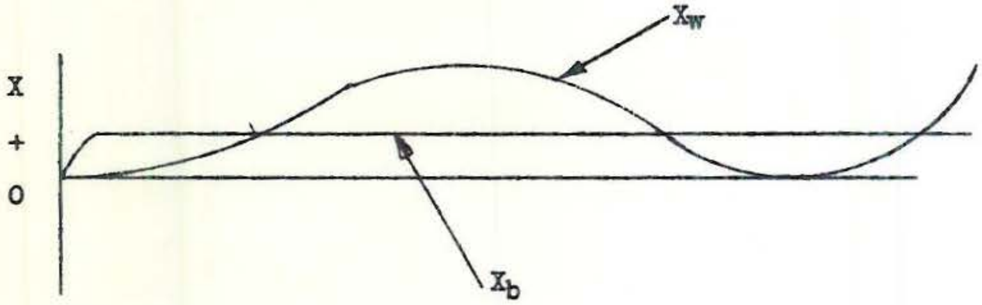


Figure 5. Sharp pulse of long duration.

In the above case it has been assumed that

$$(15)\quad a_2 >> p >> a_1 \qquad (a_1,\ a_2 \text{ and } p, \text{ have the dimensions } t^{-1})$$

[redacted]

under these conditions X_w of equation (14) reduces approximately to

$$(16) \qquad X_w = A\,(1 - \cos pt)$$

which is merely an oscillation about the displaced position with an amplitude equal to the displacement. It should be noted that the rapidity of the initial displacement of the base does not affect the displacement of the weight as long as the displacement is quick compared to p. Therefore, the maximum value of acceleration of the base has no relation to damage to the weight. In this case it is only the displacement that is of importance. (when traveling waves are considered this wave front may be important).

Case II - Assume the base moves slowly compared with the natural period of weight. (See Figure (6).

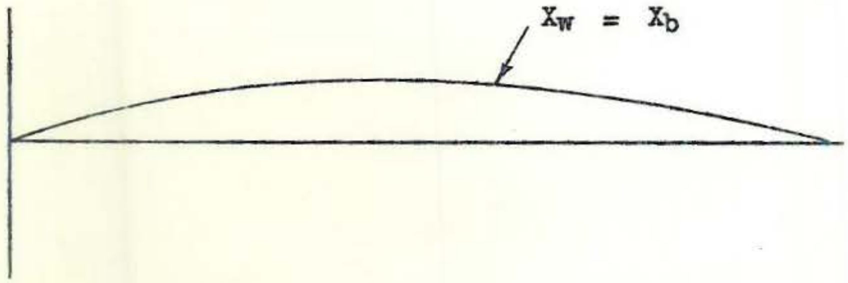


Figure 6. Pulse long compared to natural period of weight.

In this case it has been assumed that

$$(17) \qquad p \gg a_1 \text{ and } p \gg a_2$$

Under these conditions X_w of equation (14) reduces approximately to

$$(18) \qquad X_w = A\,(\epsilon^{-a_1 t} - \epsilon^{-a_2 t})$$

When the duration, and the time of rise or decay, of the pulse is long compared to the natural period of the weight, then the base and weight move as a unit and the maximum acceleration is the principal damaging agent.

Case III - Assume that the base is displaced to a maximum and returns to its initial position in a time short compared to the natural period of the mounted weight. (See figure 7).

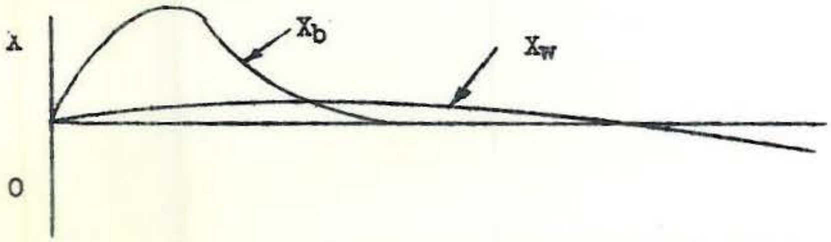


Figure 7. Pulse short compared to the natural period of the weight.

[redacted]

In this case it has been assumed that

$$(19)\quad a_2 \gg p \text{ and } a_1 \gg p \qquad a_2 > a_1$$

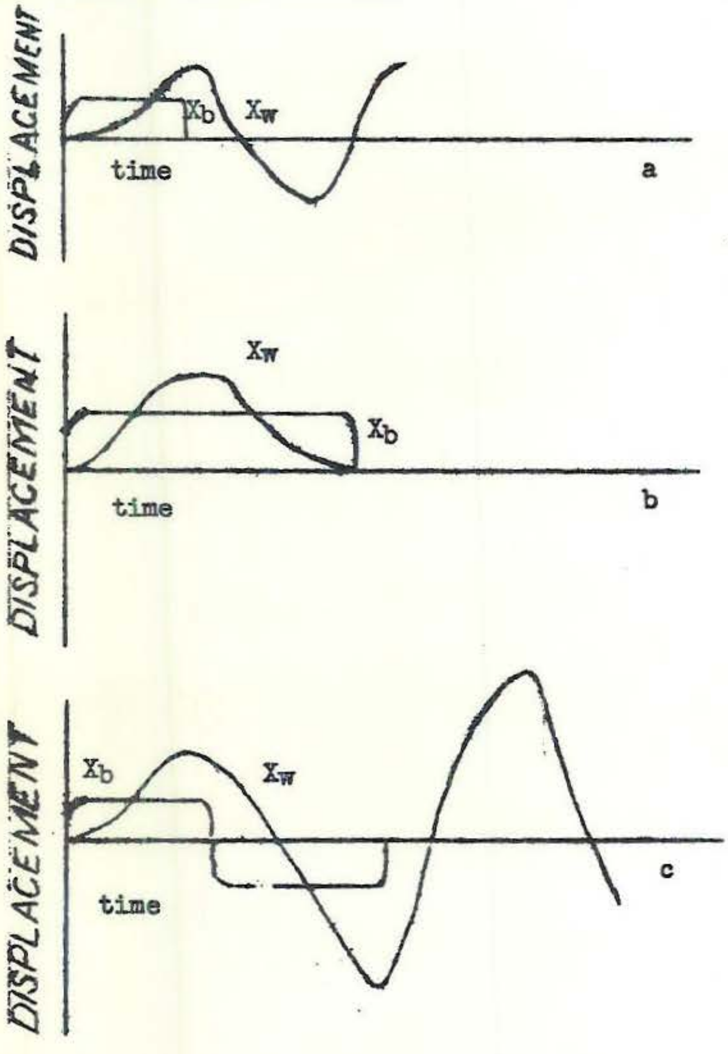
Under these conditions X_W of equations (14) reduces approximately to

$$(20)\quad X_W = Ap \left[\frac{1}{a_1} - \frac{1}{a_2} \right] \sin pt$$

Again it is noted that the initial displacement can be very rapid or the initial acceleration can be very high, without greatly affecting the results.

Case IV -

Assume the base to move in pulses, as illustrated below, having period of the same order of duration as the weight. No attempt is made to show the general case exactly, but from Case I the following quantitative results can be derived.



Sinusoidal Curves

Figure 8. Qualitative effect of displacement of the base for duration in the same order of magnitude as the period of the weight with respect to the base.

[redacted]

Figure 8 shows that the weight may suffer high amplitudes of displacement if the period of the base displacement cycles is of the same order of duration as the period of the weight with respect to the base. Figure 8a illustrates a single nearly square wave pulse of duration equal to one half the weights natural period. This is a first step in building up resonance. Part 8c shows a second step in building up resonance. Part 8b gives an ideal relation between the base and weight. Here the pulse lasts a full cycle and the weight executes but one cycle. From the above illustrations it is apparent that dangerous amplitudes of displacement may result if the period of the mounted weight is near that of the displacement. Collisions between the weight and the mounting plate are probable. From a study of displacement curves of submarine hulls caused by underwater explosions, and of plate 22, it is observed that a displacement cycle is usually greater than 1/25 second. As it is not recommended that mounted apparatus have periods longer than 1/25 second, because of possible resonance with ship machinery, it is advisable that mounts be constructed of sufficient stiffness so that apparatus (the weight) will approximately follow the low frequency displacement curve as shown on Figure 6. In order to minimize the effect of the higher frequency accelerations the mounted apparatus should have as long a period as possible. With the limit of 1/25 second as the longest period permissible it is suggested that periods be between 1/25 second and 1/100 second when possible. Plate 13 shows the reduction in magnitude of high frequency harmonic accelerations and displacement by an elastic mount.

CONCLUSIONS

The following statements are indicated by this appendix. The statements cannot be regarded as facts for all cases but must be considered with respect to the dimensions and nature of the structures subjected to shock.

1. Traveling stress waves, both longitudinal and flexual, may exist in structures having long natural periods of vibration. The existence and the reflections of these waves may give rise to high frequency high magnitude accelerations.

2. The maximum energy that can be transmitted in a traveling stress wave increases as some function of the mass and stiffness of the material through which the wave travels. A heavy object mounted on light supports will, therefore, be little affected by the traveling waves. A light object mounted on a heavy base will be greatly disturbed by traveling waves in the base. These waves may cause high magnitude high frequency accelerations even though the base has a long natural period.

3. If the effects of traveling stress waves are neglected then high frequency components of acceleration (above 5000 c.p.s.) and frequency components of a steep acceleration wave front, are not of importance to apparatus that, as mounted on a base, has natural frequencies below several hundred cycles per second.

[redacted]

4. To decrease damage, caused by deaccelerations, it is not advisable to have the period of vibration of the mounted apparatus near the time of a displacement cycle. If the apparatus mounting base is stopped when the apparatus is at the end of its swing (See Fig. 8a and 8c) the shock, as measured by displacement and low frequency components of acceleration, may be more than doubled. As the period of the apparatus cannot practically be made long enough to soak up the gross displacement cycle, it is suggested that in most cases the period be made short enough so as to follow this gross displacement cycle. (See Fig. 6). A period of 1/25 second would in most cases be short enough for this purpose. Exceptions to this rule are expected for many specific cases.

5. To decrease the effects of high and medium frequency accelerations the mounted apparatus should have natural periods, as long as possible. A compromise with part 4 must be attained.

6. The more exact theory of shock predicts extremely high values of acceleration near points of impact. In this theory only an infinitely thin lamina is initially assumed accelerated. This lamina may immediately acquire a given velocity, which requires infinite acceleration, without violating energy principles. Traveling stress waves may thus have extremely high accelerations near a point of impact. These values are of extremely short time duration and decrease rapidly in magnitude away from the point of impact. Certain types of maximum reading accelerometers may respond to these values and may therefore indicate higher values of acceleration than indicated by the crystal type accelerometer with its filtered output.

[redacted]

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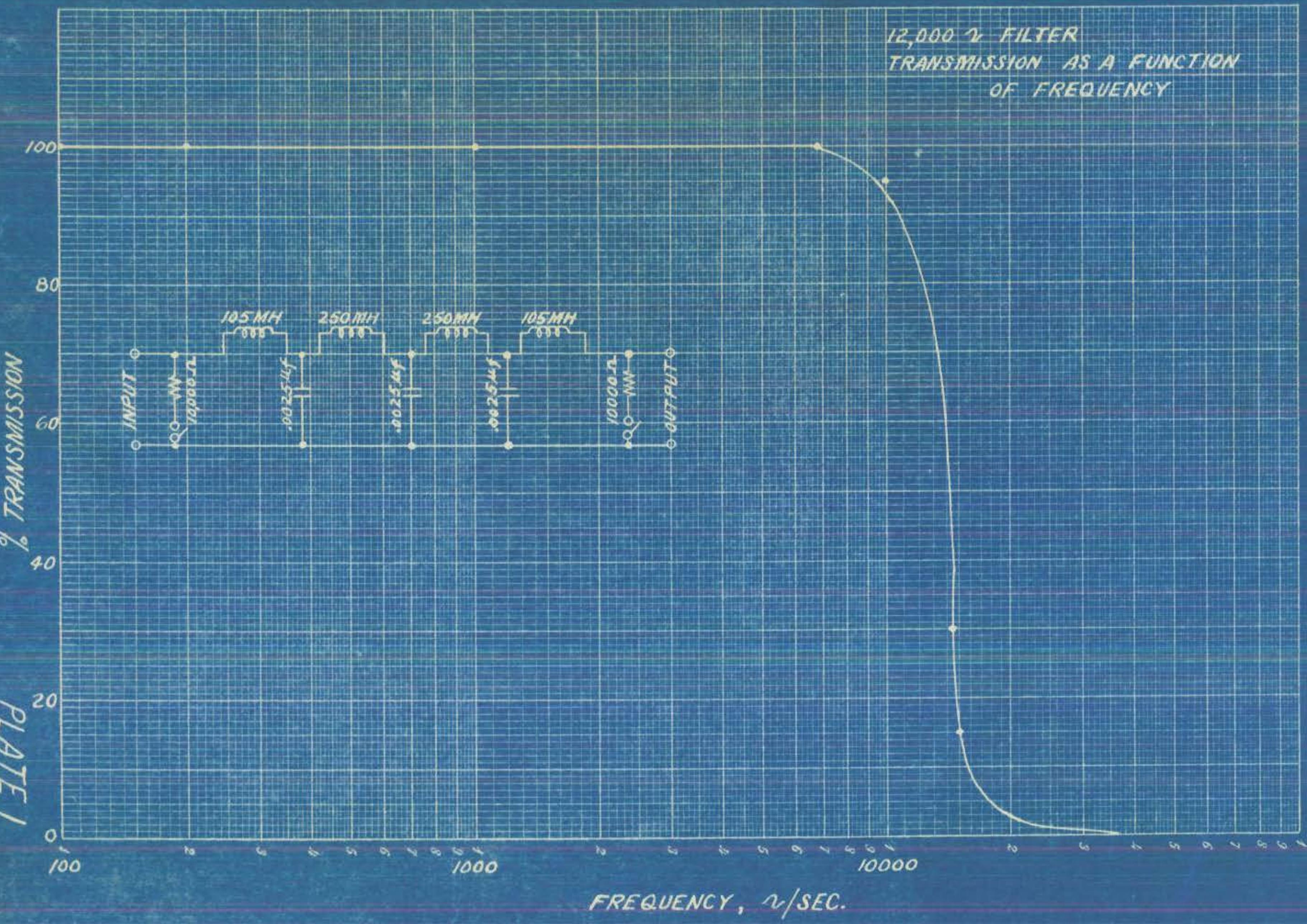
[redacted]



12,000 ν FILTER
TRANSMISSION AS A FUNCTION
OF FREQUENCY

PLATE I

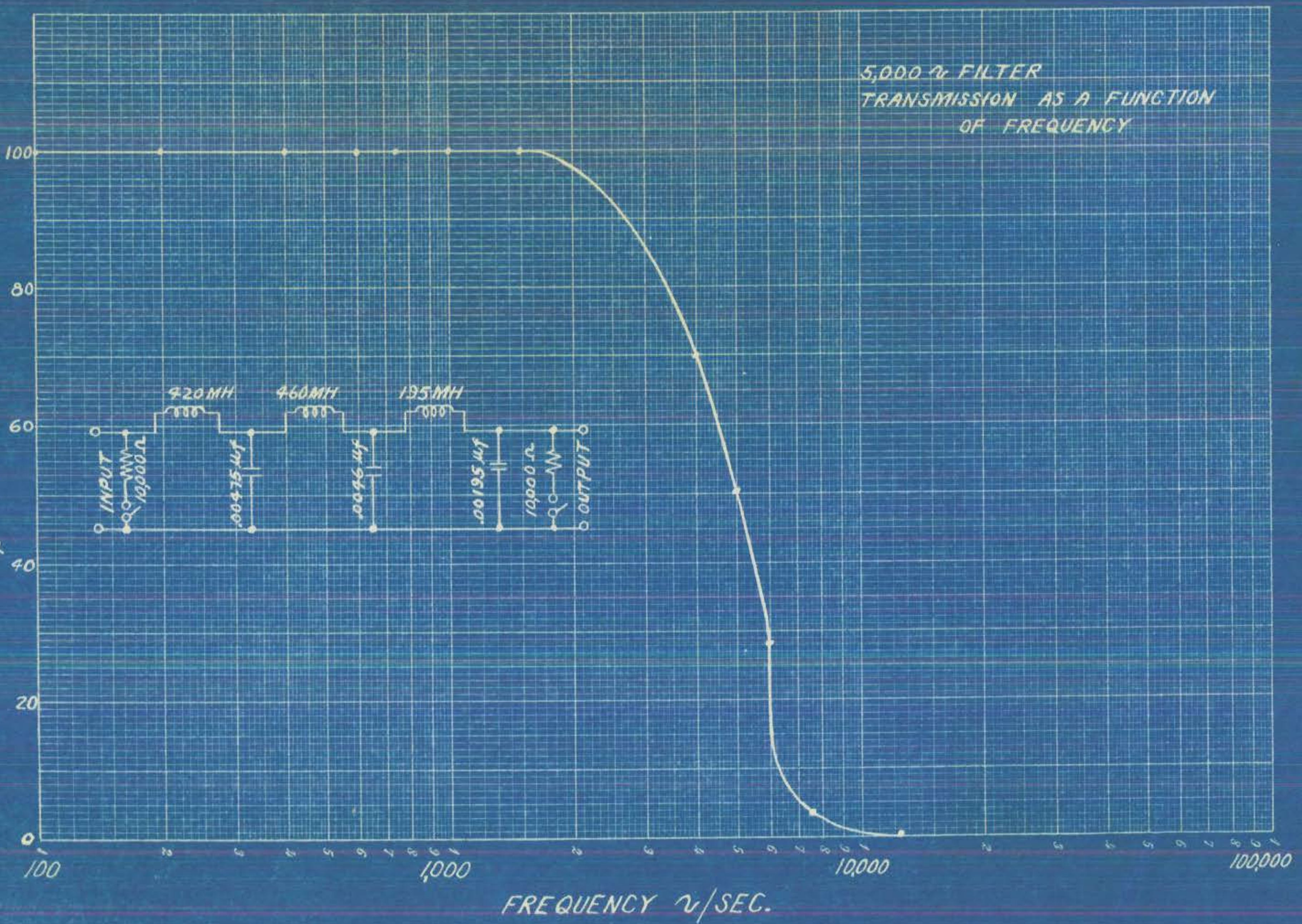

5,000 ν FILTER
TRANSMISSION AS A FUNCTION
OF FREQUENCY

PLATE 2

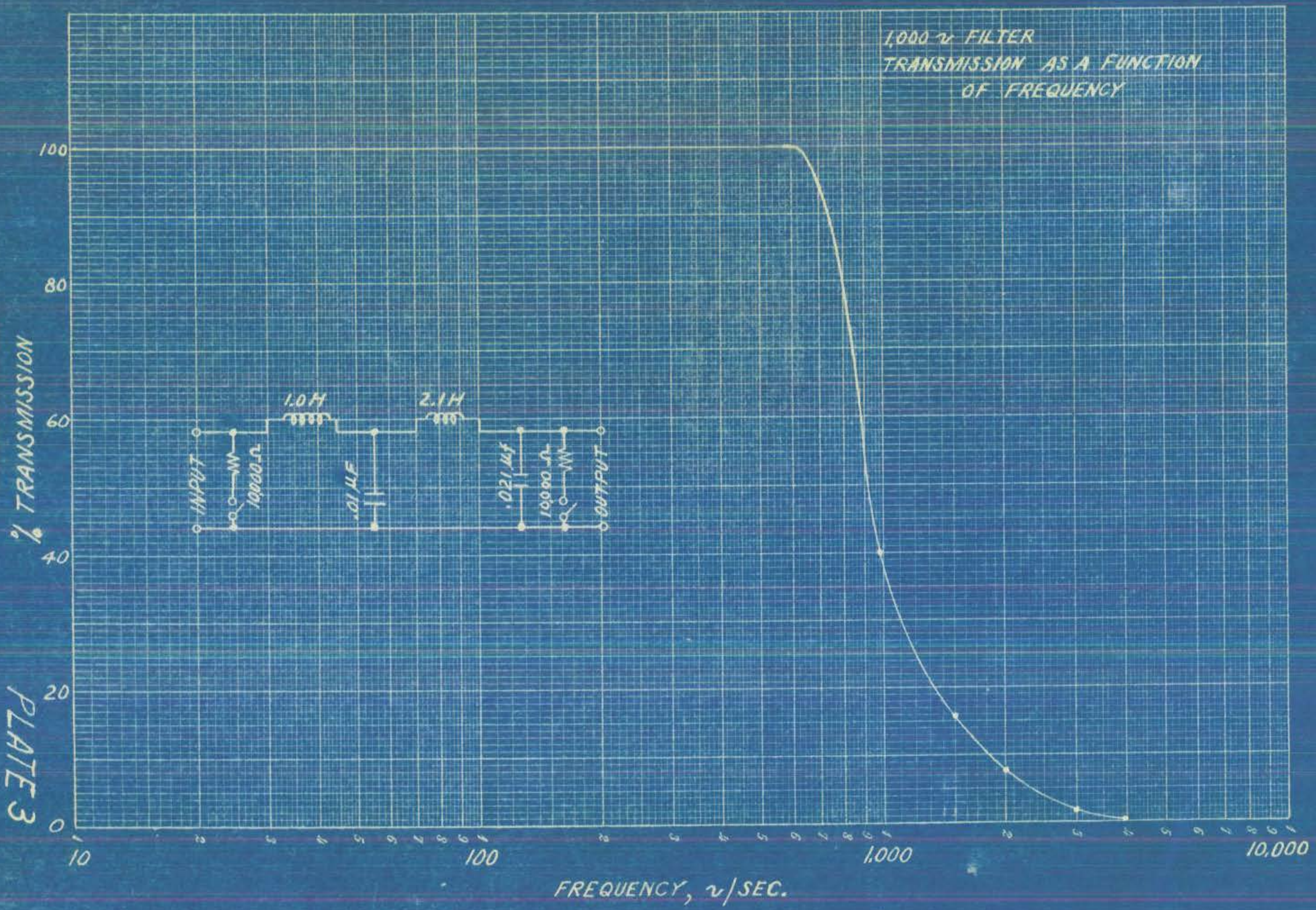
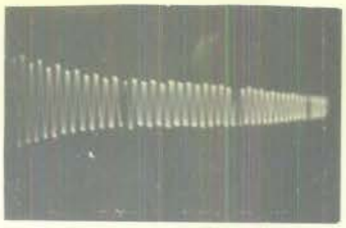
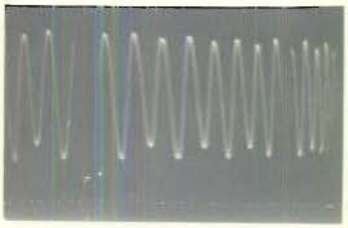

1,000 ν FILTER
TRANSMISSION AS A FUNCTION OF FREQUENCY
% TRANSMISSION
100
80
60
40
20
0
FREQUENCY, ν/SEC.
10
100
1,000
10,000
INPUT
10000 Ω
1.0 H
.01 μf
2.1 H
.021 μf
10,000 Ω
OUTPUT

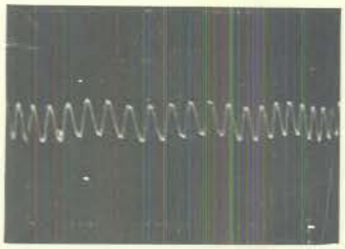
PLATE 3



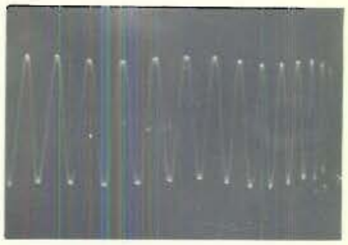
#4 GAGE - FREE
13000 ~/SEC.



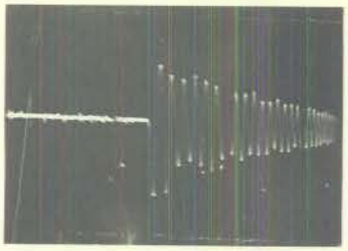
#1 GAGE – FREE
8500 ~/SEC.



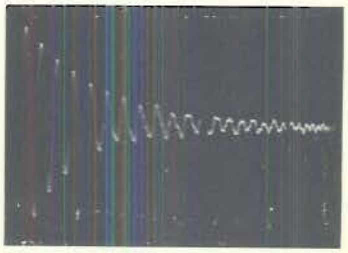
#4 GAGE -HEAVY BASE
9200 ~/SEC.



#1 GAGE -HEAVY BASE
6000~/SEC.
(CALCULATED 7500~/SEC.)



#4 GAGE -HEAVY BASE
$\frac{1}{8}$ INCH LEAD DAMPENER
9800~/SEC.

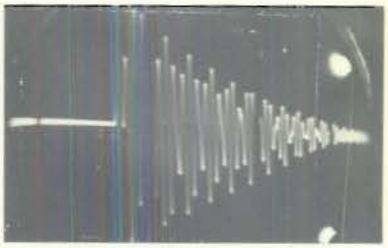


#1 GAGE - HEAVY BASE
$\frac{1}{8}$ INCH LEAD DAMPENER
7500 ~/SEC.

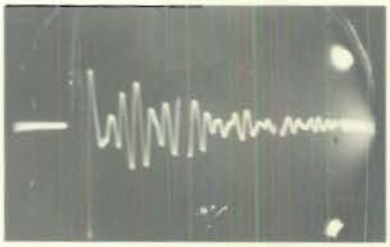
WIRE STRAIN GAGE TYPE ACCELEROMETER. GAGES #4 & #1 HAVE TUBE WALL THICKNESSES OF 0.025" & 0.011" RESPECTIVELY. EXCITATION INITIATED BY LIGHT HAMMER BLOWS. TIMING SPOTS ARE 0.001 SECONDS APART.

PLATE 4

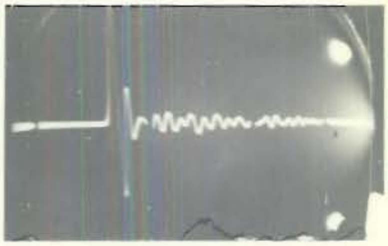
(A) FREE – NO FILTER
20000~/SEC.



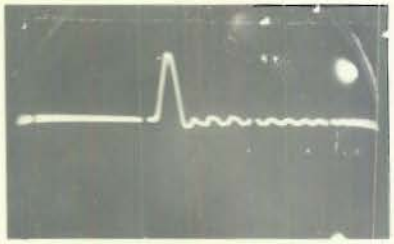
(B) HEAVY BASE - NO
FILTER



) HEAVY BASE
2 000~LOW PASS FILTER



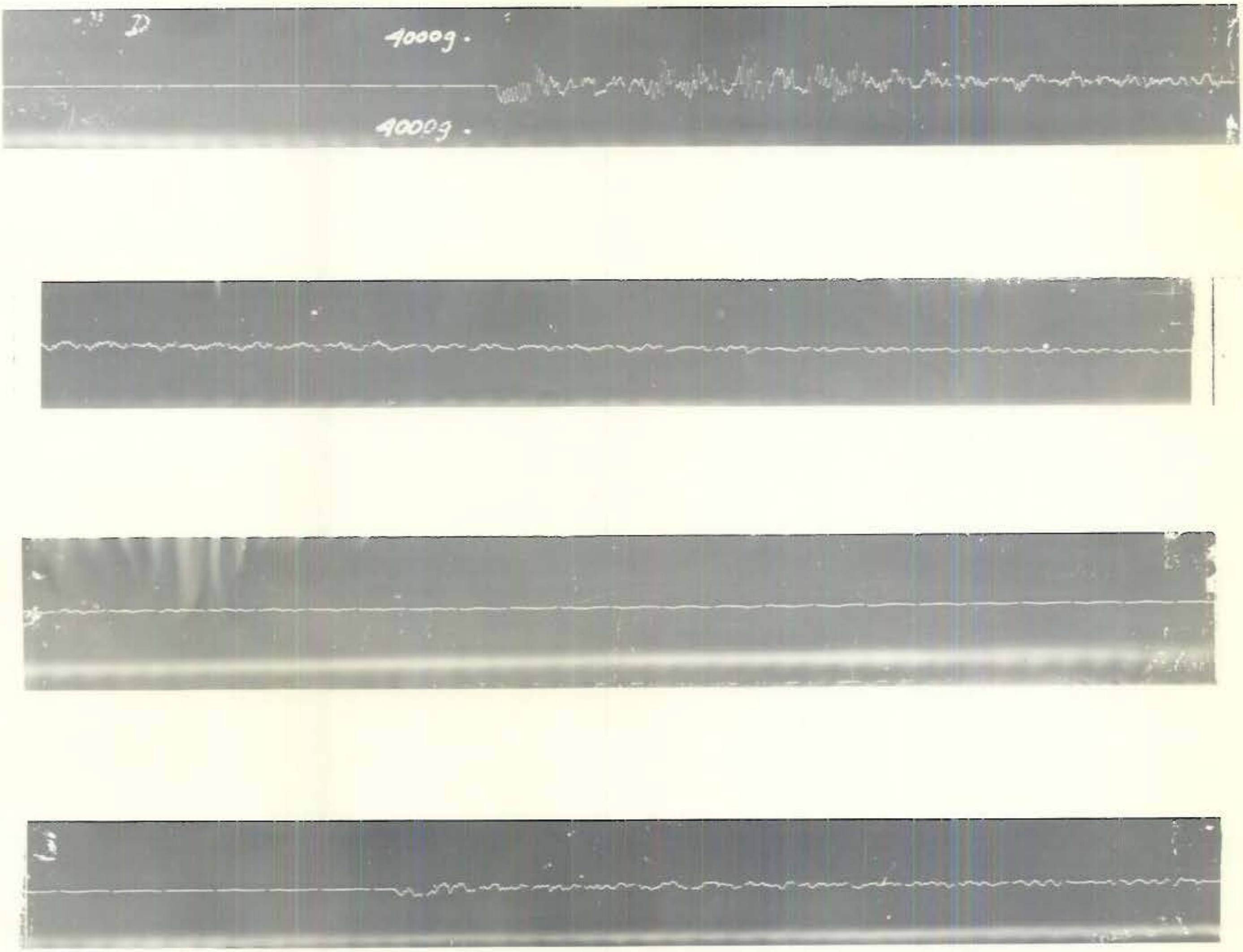
(D) HEAVY BASE
12000 ~LOW PASS FILTER



(E) HEAVY BASE
5000~LOW PASS FILTER

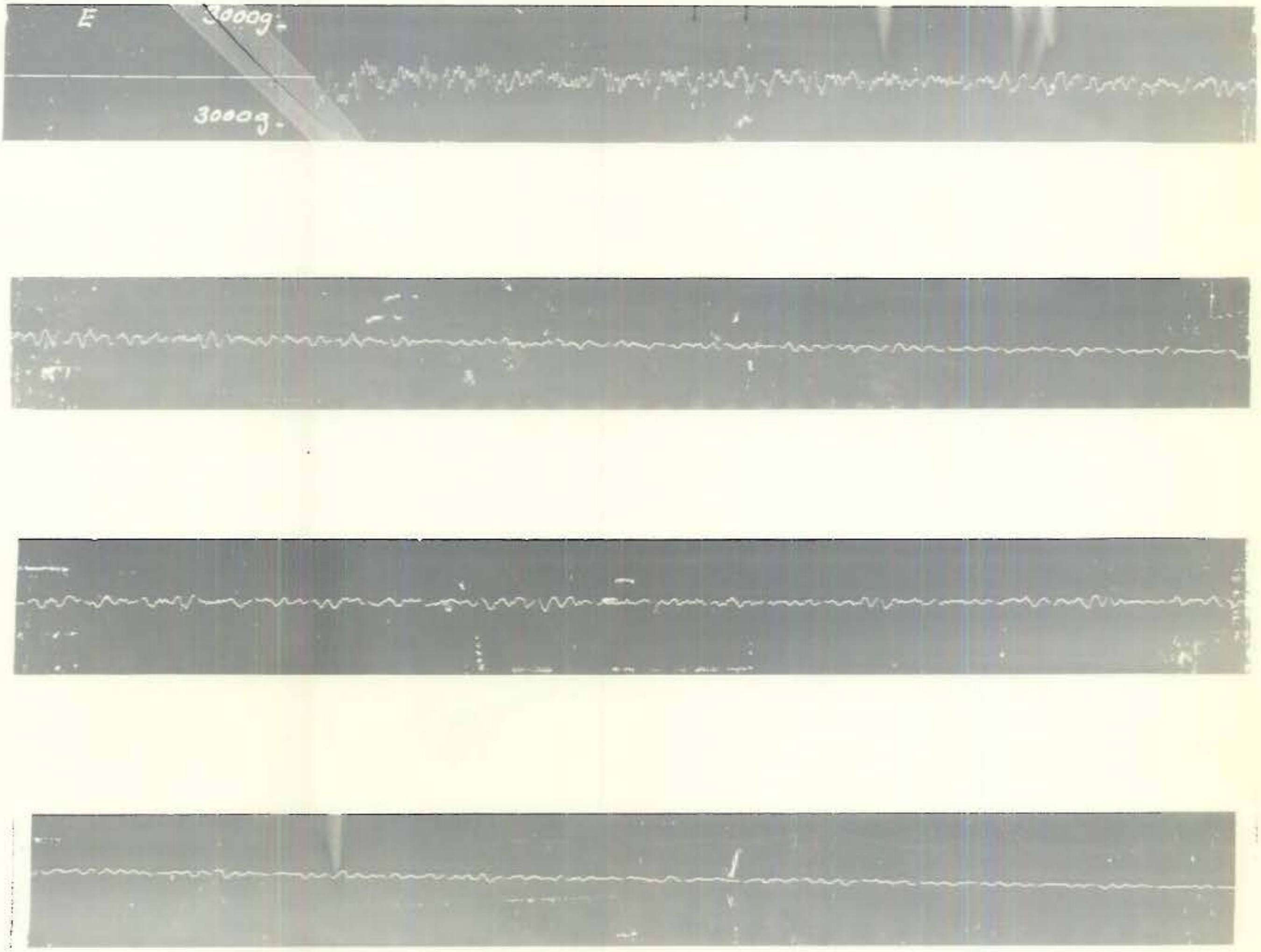
WESTINGHOUSE QUARTZ CRYSTAL ACCELEROMETER CHARACTERISTICS. ON ALL OSCILLOGRAMS EXCEPT (A) THE ACCELEROMETER WAS MOUNTED ON A STEEL BLOCK OF SEVERAL POUNDS WEIGHT. THE UNIT WAS HELD BY HAND DURING EXCITION BY LIGHT HAMMER BLOWS. TIMING SPOTS ARE 0.001 SECONDS APART.

PLATE 5



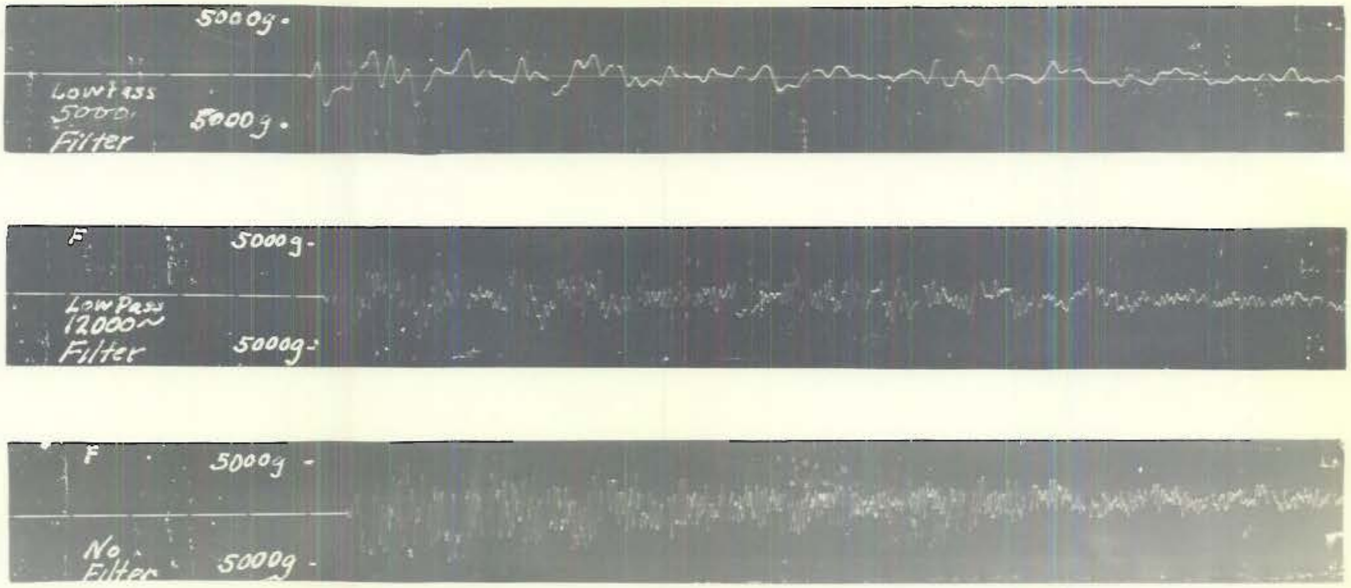
CRYSTAL ACCELEROMETER OSCILLOGRAM. TOP BLOW, 2000 FT.-LBS. POSITION 6C BARE PLATE, 12000 CYCLE LOW PASS FILTER. TIMING SPOTS 0.001 SECONDS APART. THE LOWER CURVES ARE CONTINUATIONS OF THE UPPER CURVES.

PLATE 6

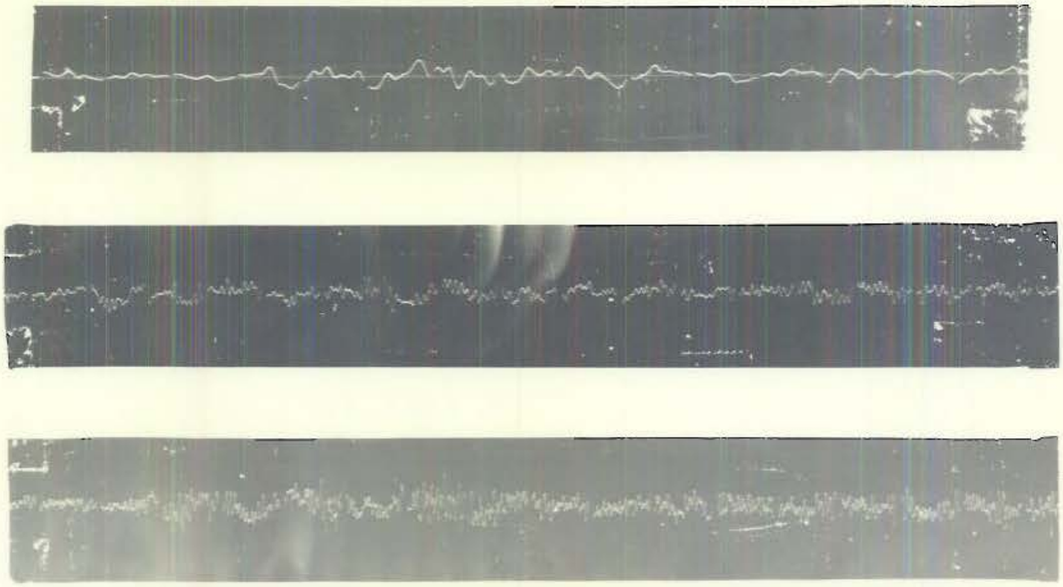


CRYSTAL ACCELEROMETER OSCILLOGRAMS. END BLOW, 2000 FT.-LBS., POSITION 6D BARE PLATE, 12000 ~ LOW PASS FILTER. TIMING SPOTS 0.001 SECONDS APART. THE LOWER CURVES ARE CONTINUATIONS OF THE UPPER CURVES

PLATE 7

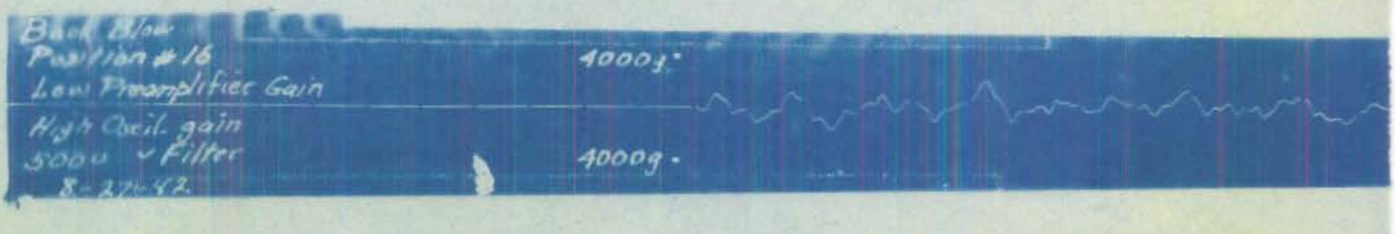


BACK BLOW, 2000 FT.-LBS., POSITION #6, BARE PLATE TIMING SPOTS 0.001 SECONDS APART. THE LOWER CURVES ARE CONTINUATIONS OF THE UPPER CURVES.

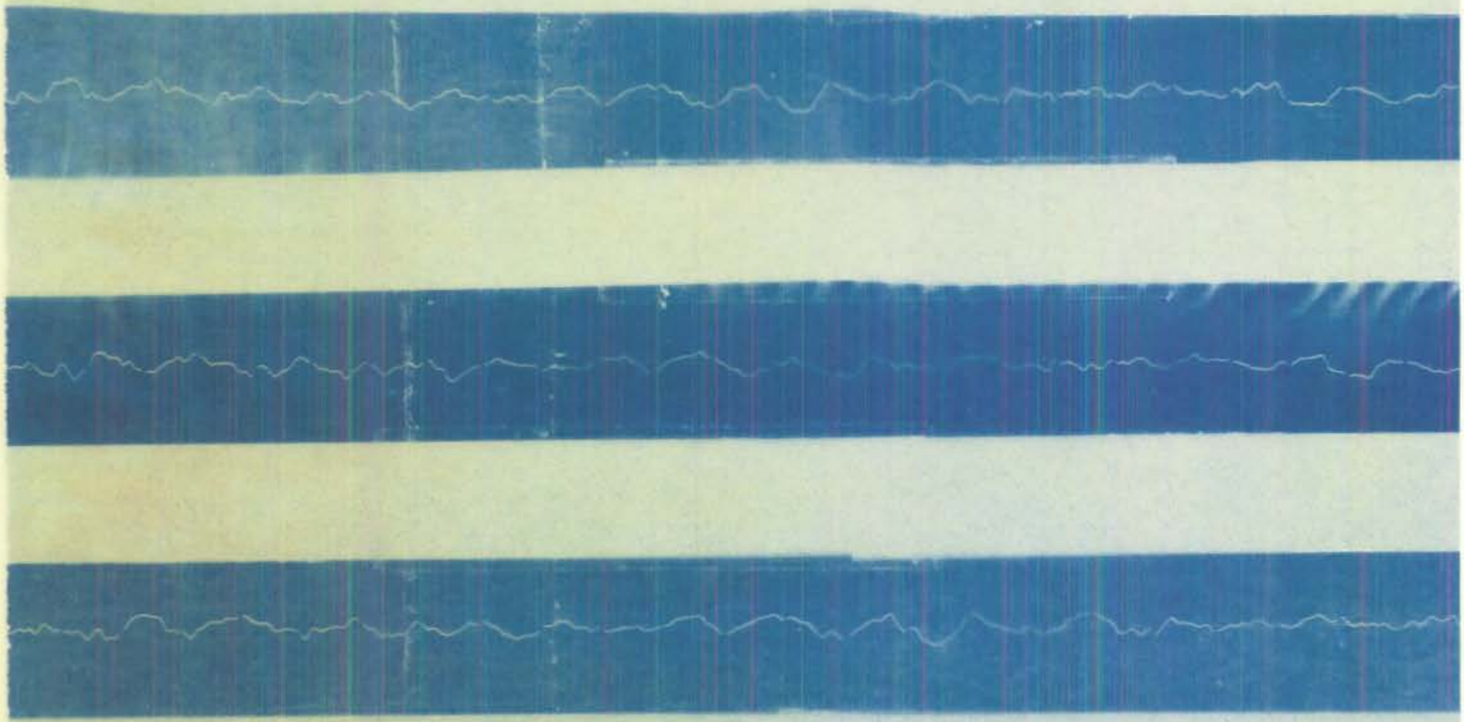


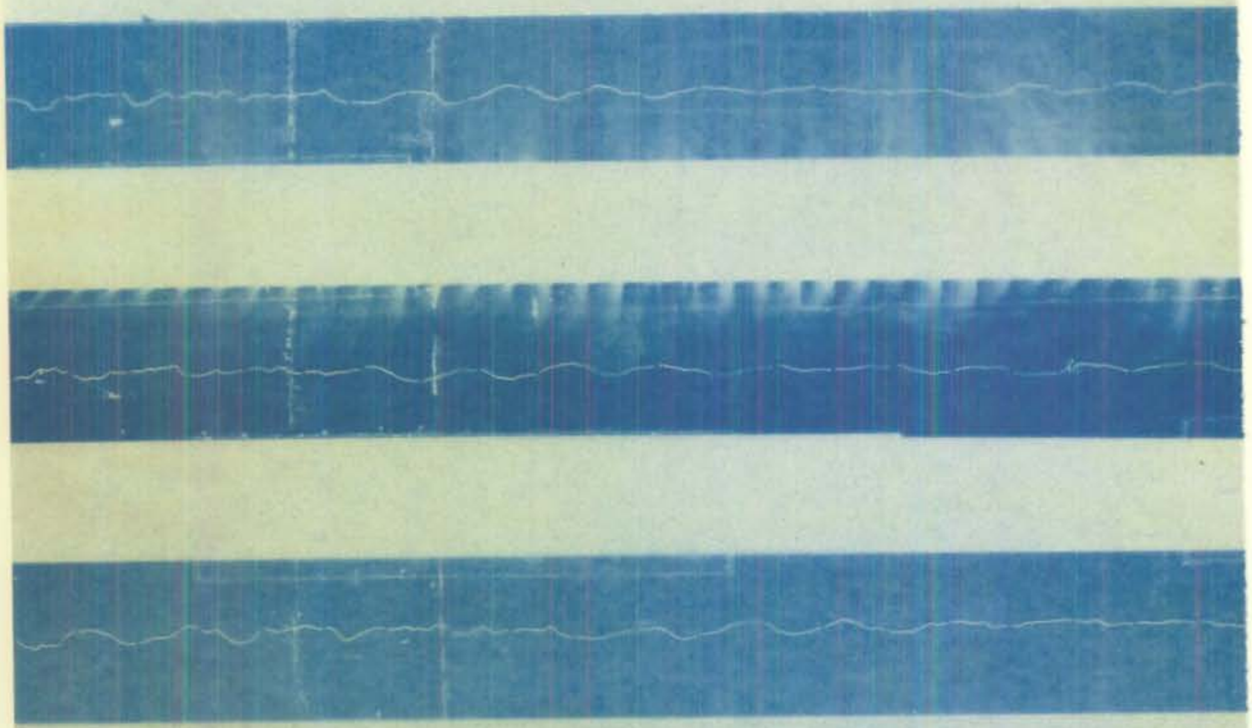
CRYSTAL ACCELEROMETER CURVES. CONDITIONS ARE IDENTICAL FOR THREE CURVES EXCEPT FOR FILTRATION.

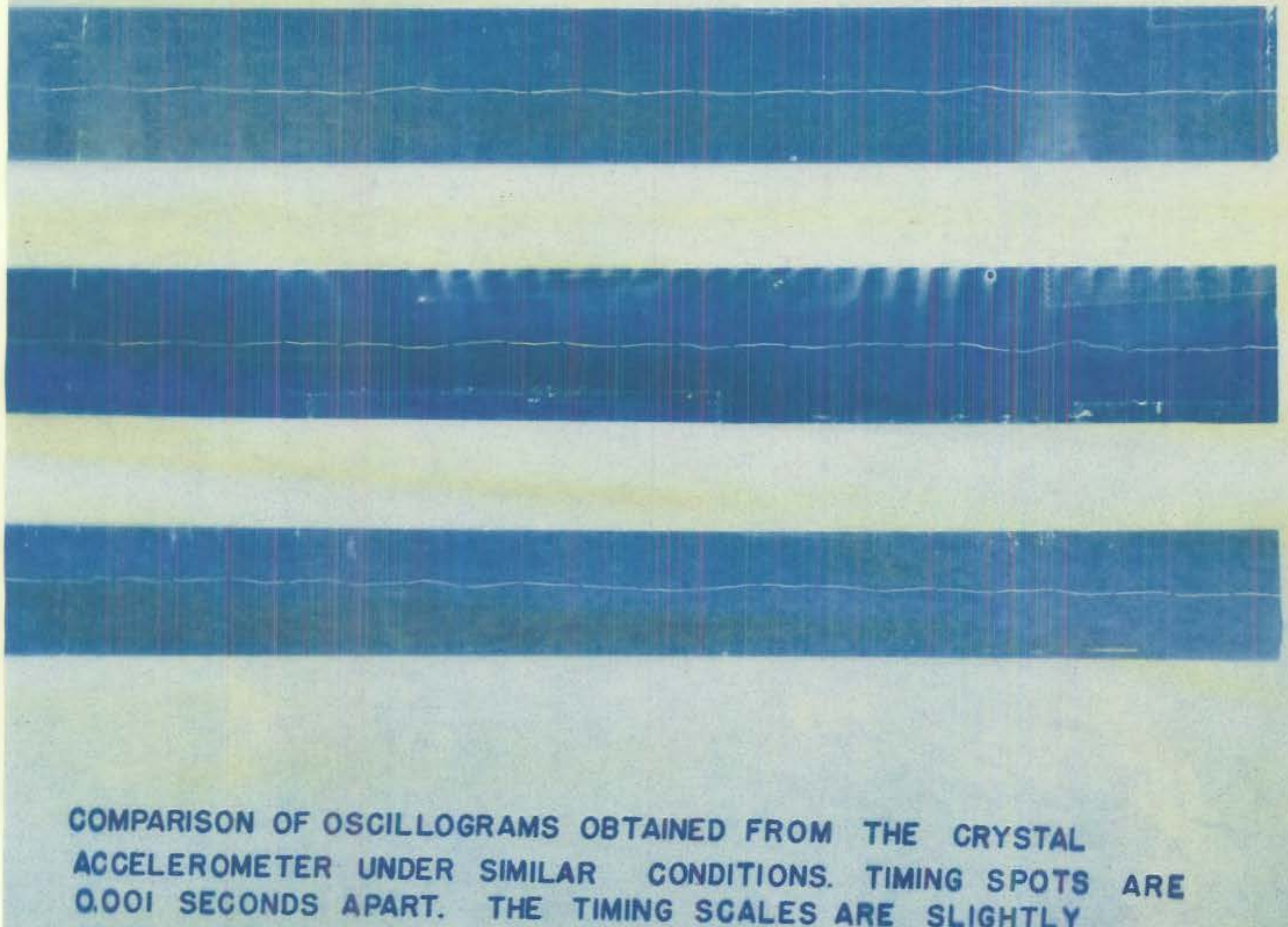

Back Blow
Position # 16
High Preamplifier gain
Low Osc. Ampl. gain
5000~ Filter
4000g
4000g


Back Blow
Position # 16
Low Preamplifier Gain
High Oscil. gain
5000 ~ Filter
8-27-42
4000g
4000g


Back Blow
Position # 16
High Preamplifier Gain
Low Osc. Gain
5000 ~ Filter
8-27-42
4000g
4000g







COMPARISON OF OSCILLOGRAMS OBTAINED FROM THE CRYSTAL ACCELEROMETER UNDER SIMILAR CONDITIONS. TIMING SPOTS ARE 0.001 SECONDS APART. THE TIMING SCALES ARE SLIGHTLY DIFFERENT.

PLATE 9

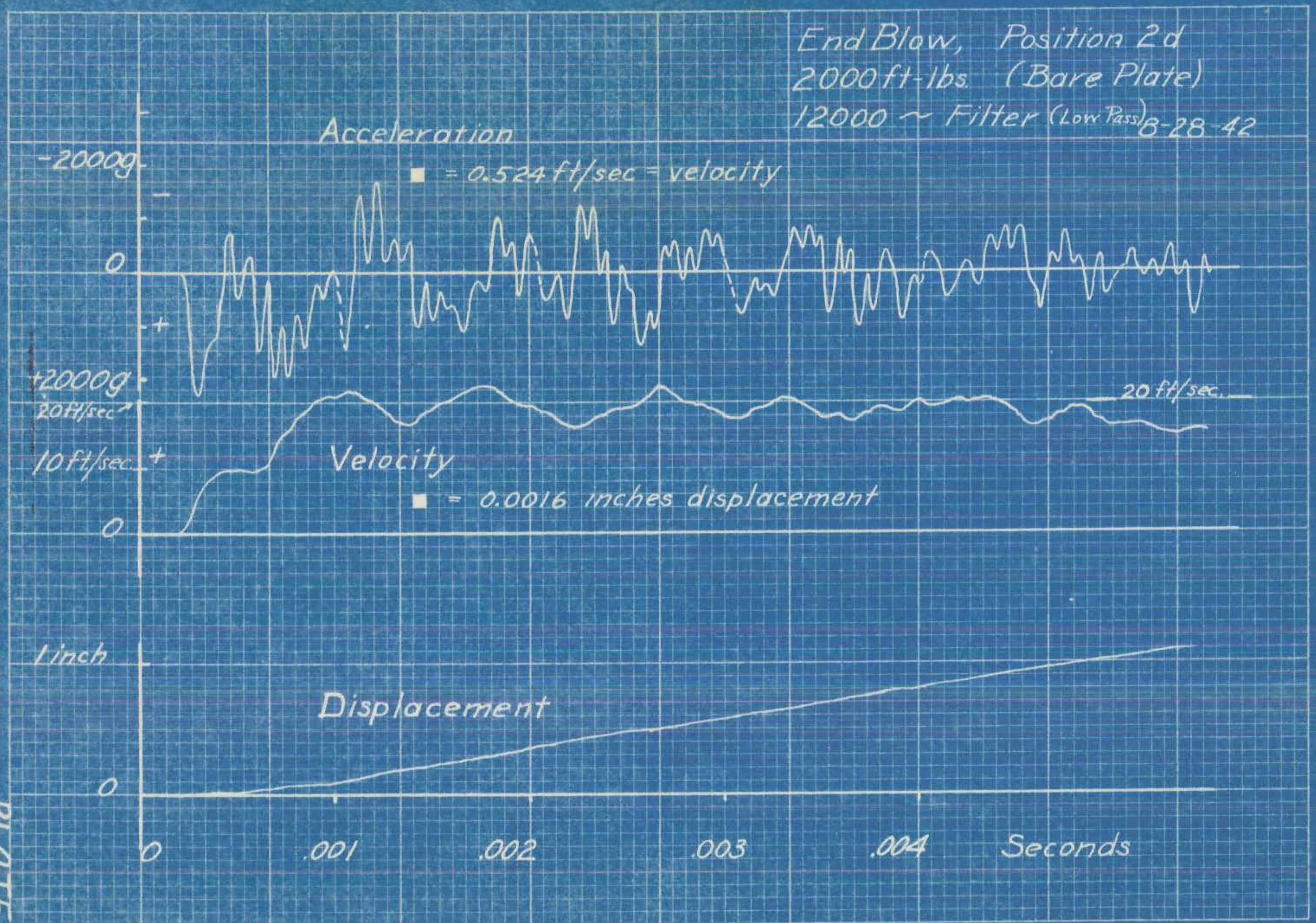

End Blow, Position 2d
2000 ft-lbs. (Bare Plate)
12000 ~ Filter (Low Pass) 8-28-42
Acceleration
■ = 0.524 ft/sec = velocity
-2000g
−
0
+
+2000g
20 ft/sec
20 ft/sec.
10 ft/sec.
+
Velocity
■ = 0.0016 inches displacement
0
1 inch
Displacement
0
0
.001
.002
.003
.004
Seconds

PLATE 11

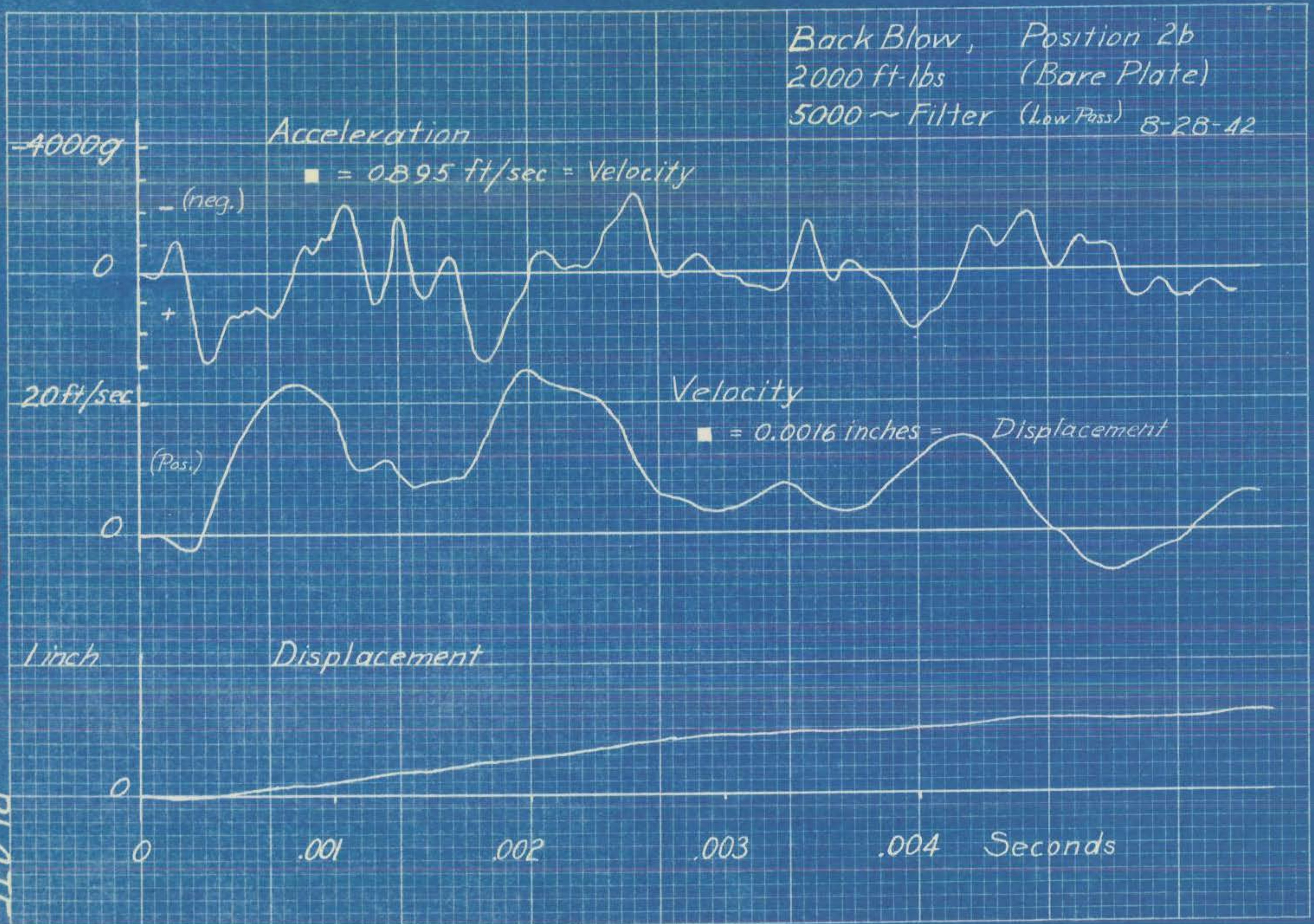
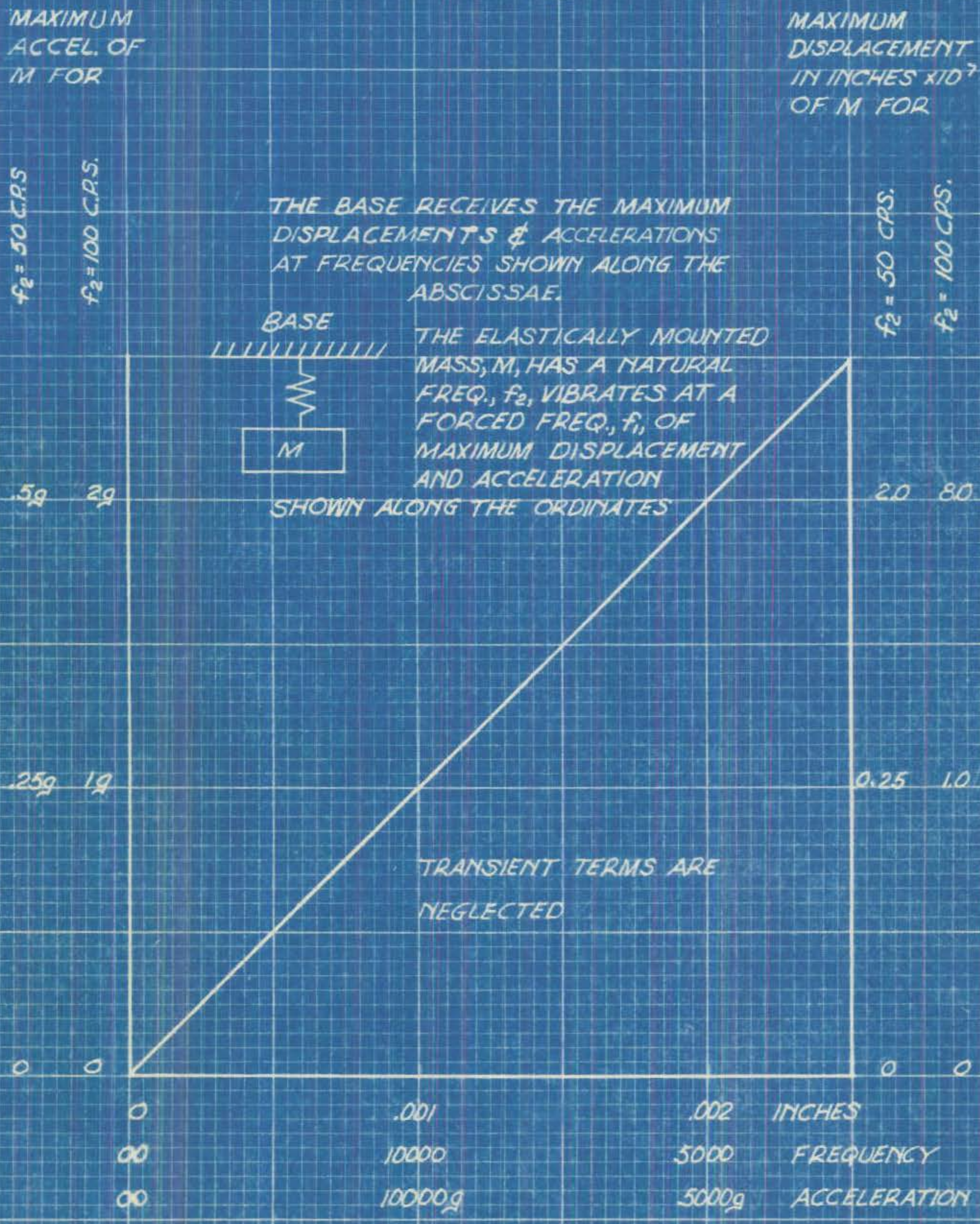
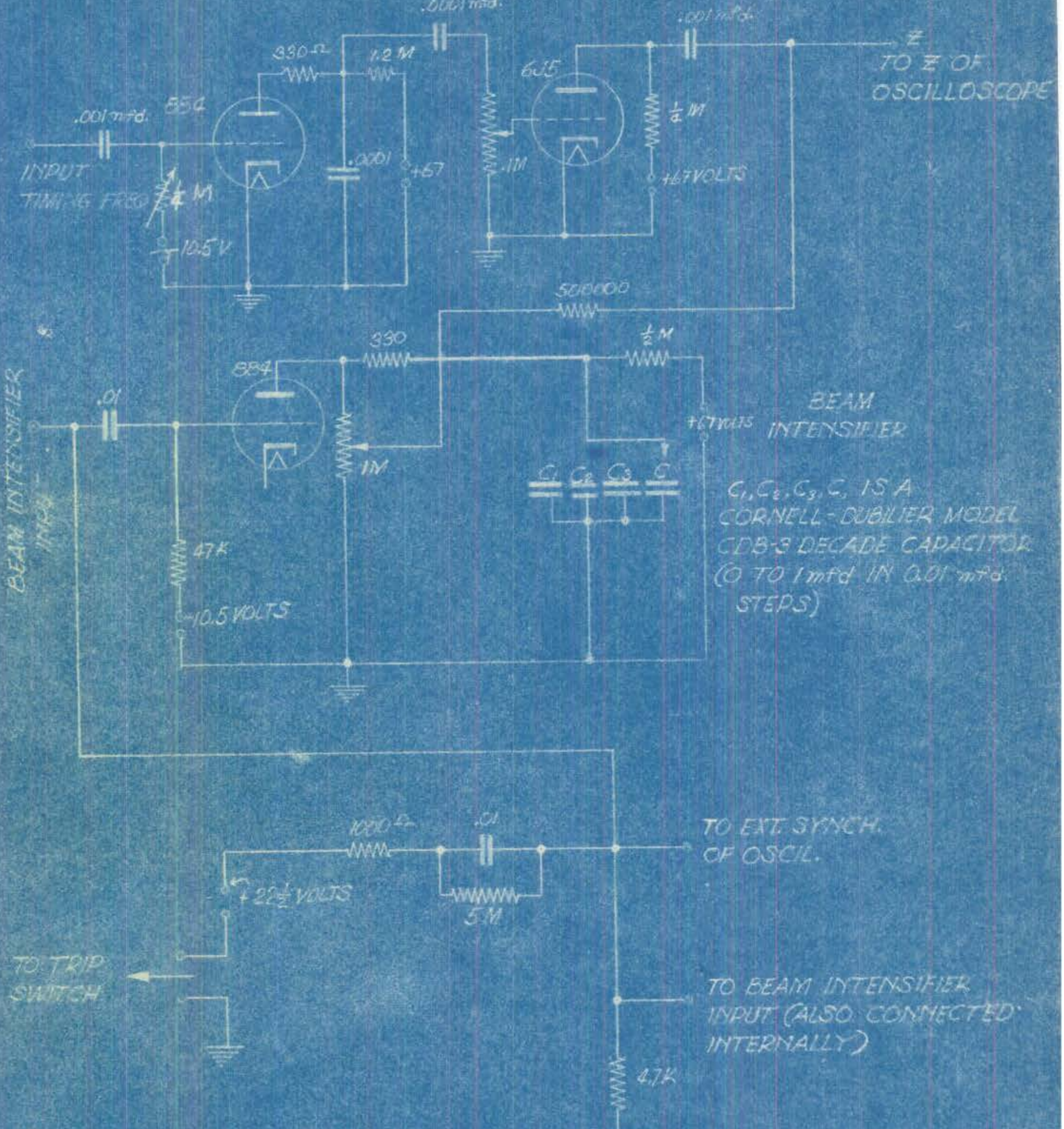

Back Blow, Position 2b
2000 ft-lbs (Bare Plate)
5000 ~ Filter (Low Pass) 8-28-42
4000g
Acceleration
■ = 0.895 ft/sec = Velocity
– (neg.)
0
+
20 ft/sec
Velocity
■ = 0.0016 inches = Displacement
(Pos.)
0
1 inch
Displacement
0
0
.001
.002
.003
.004
Seconds

PLATE 12



DISPLACEMENTS AND ACCELERATIONS SUFFERED BY A BODY ELASTICALLY MOUNTED TO A VIBRATING BASE.

PLATE 13



C_1, C_2, C_3, C, IS A CORNELL-DUBILIER MODEL CDB-3 DECADE CAPACITOR (0 TO 1 mfd IN 0.01 mfd STEPS)

TIMING FREQUENCY PULSE MAKER &
BEAM INTENSIFIER

PLATE 14

MECHANICAL DETAILS OF WESTINGHOUSE CRYSTAL ACCELERATION DETECTOR

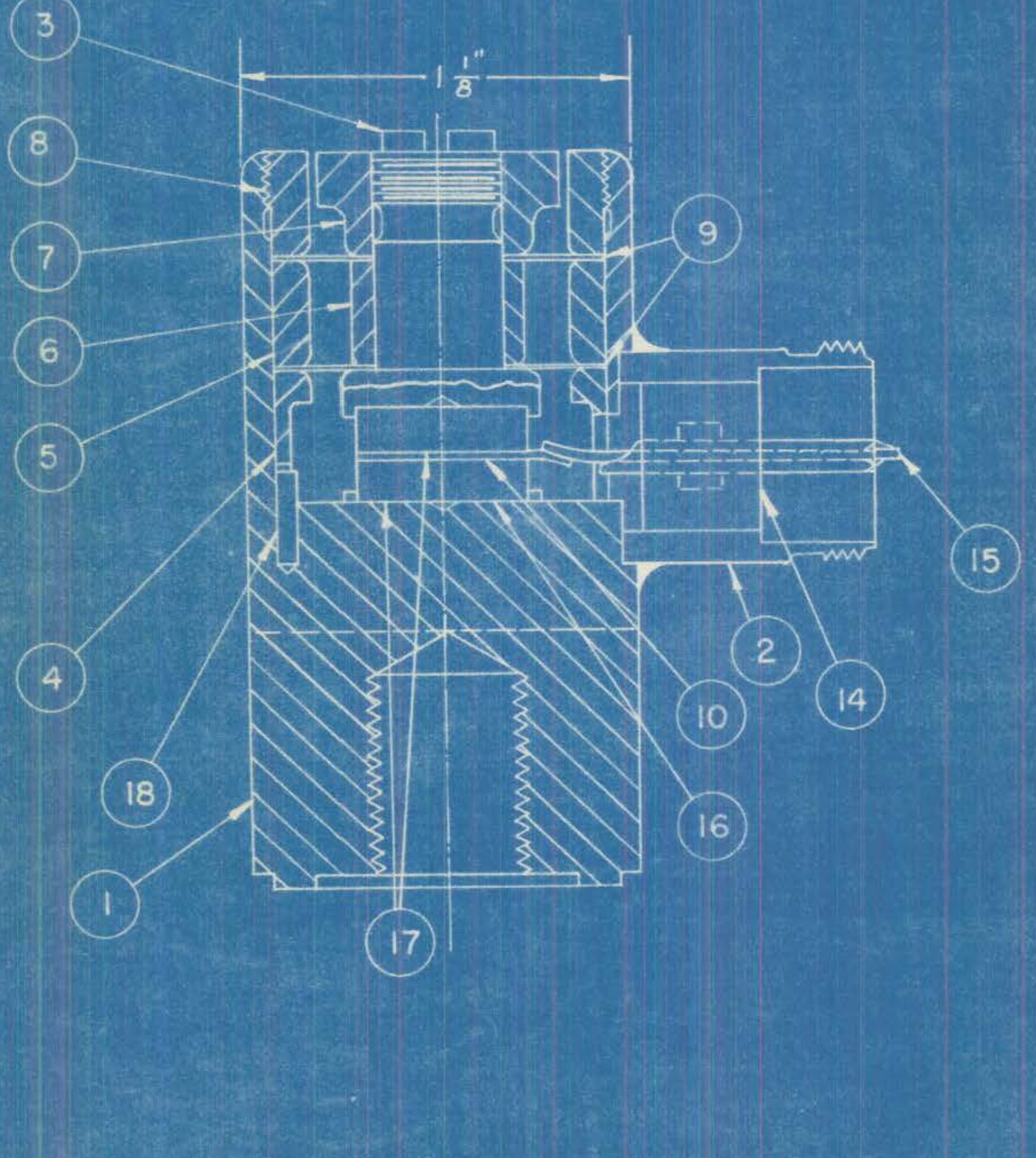
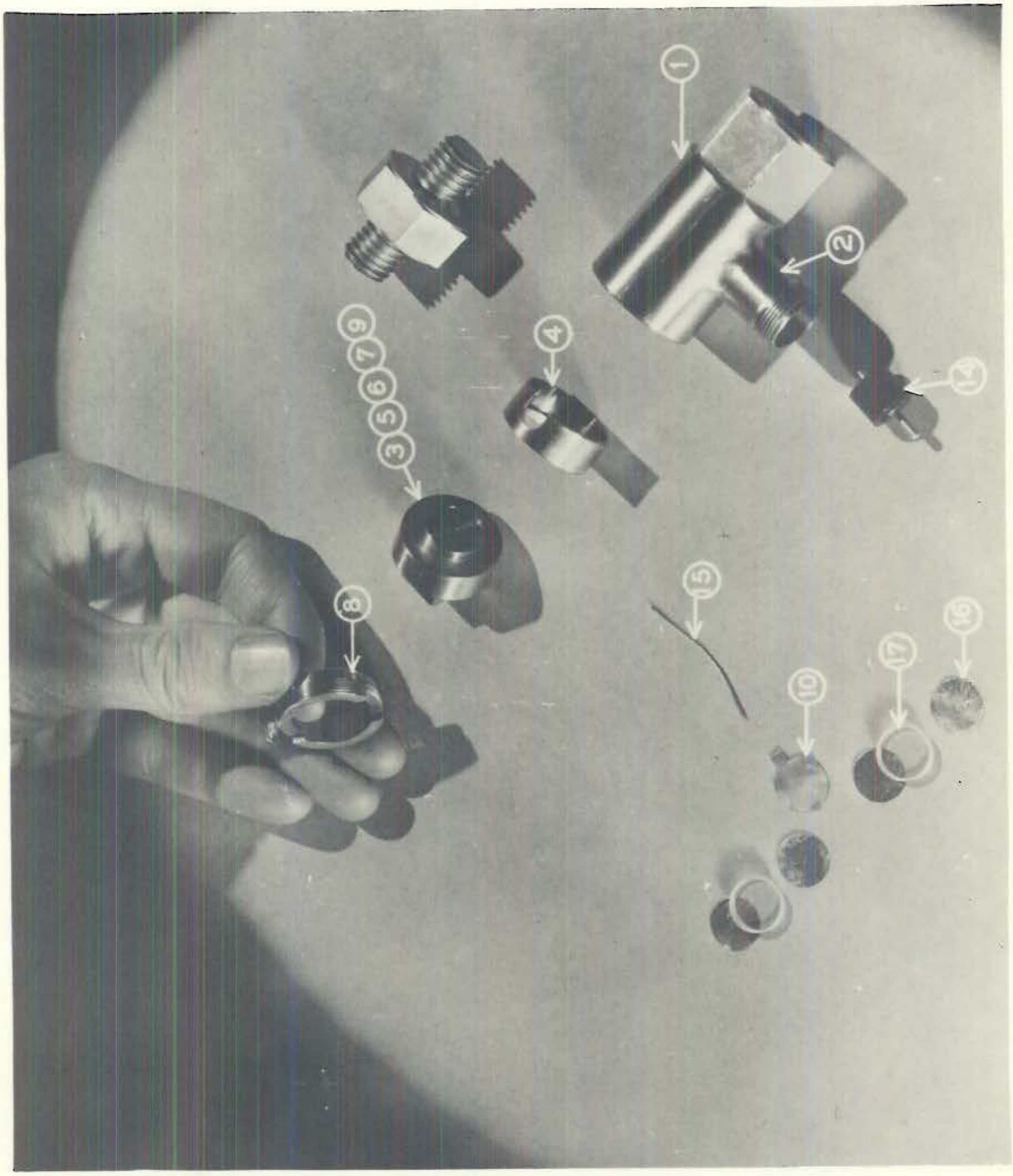


PLATE 15



WESTINGHOUSE ACCELEROMETER PARTS

WIRE STRAIN GAGE TYPE ACCELEROMETER

PLATE 17


ACCELEROMETER MOUNTING HOLE
STEEL BAR
24 INCHES LONG
AIR TUBE
COMPRESSED AIR EXCITED VIBRATING BAR

PLATE 18

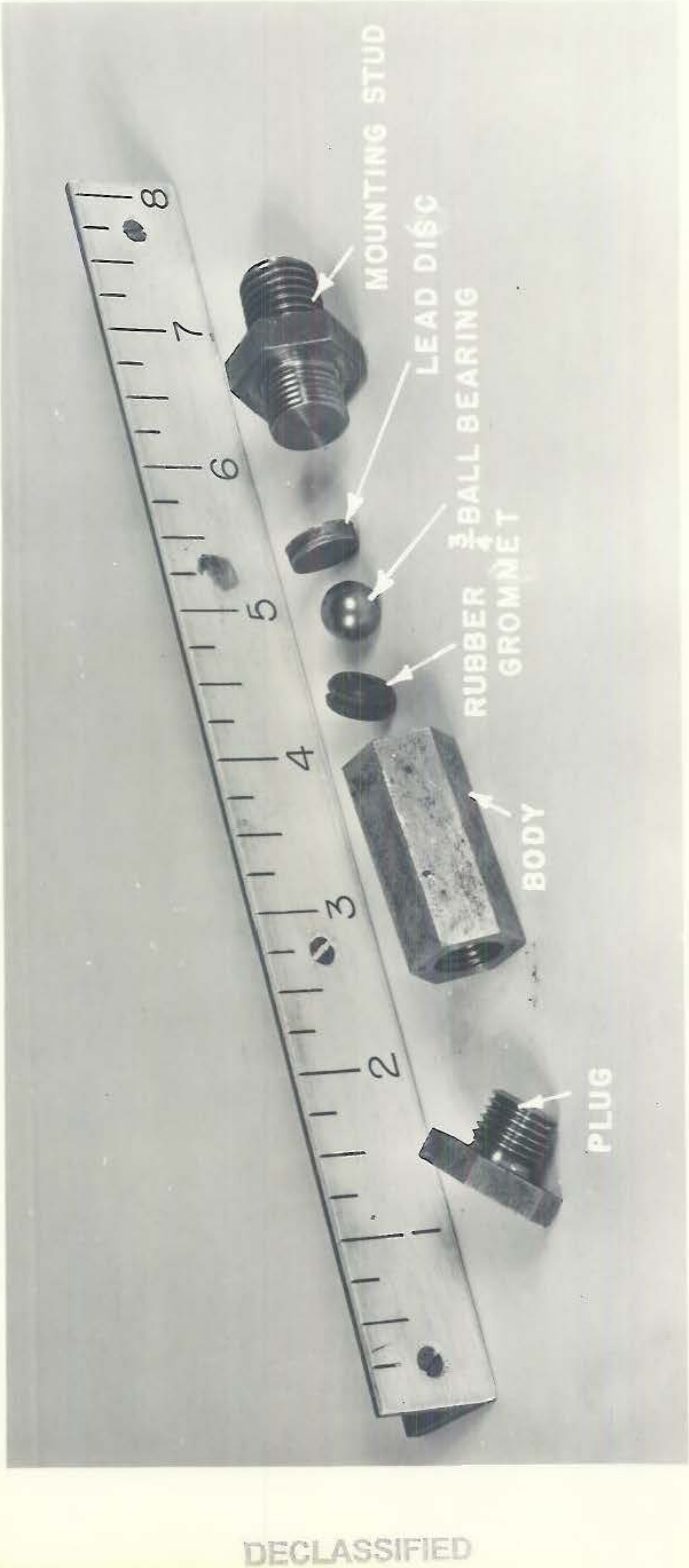
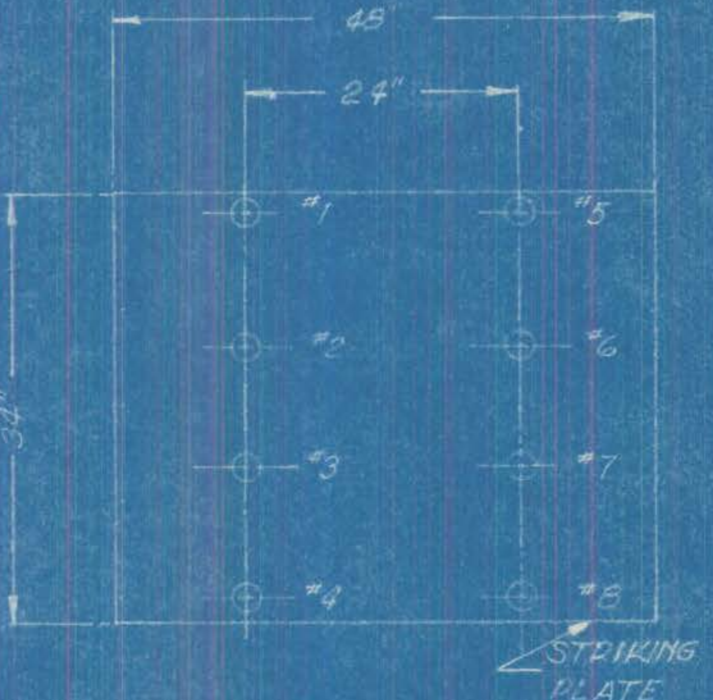
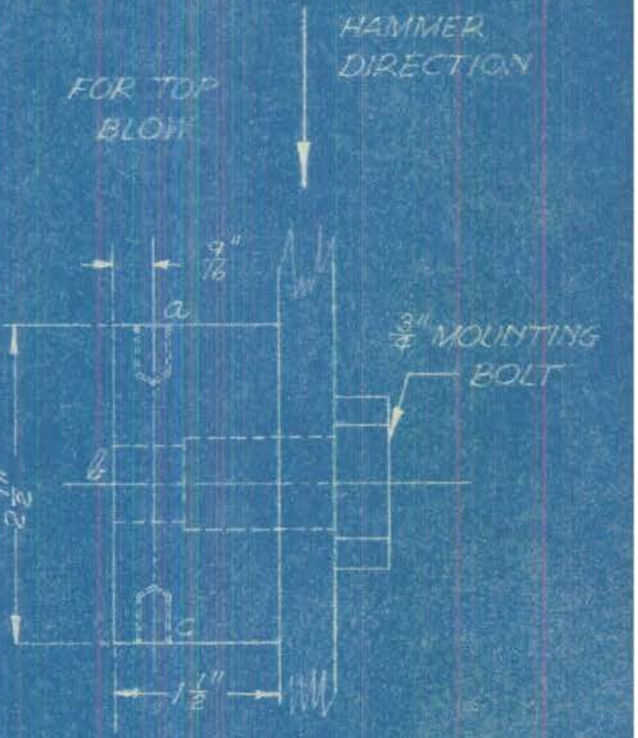

MOUNTING STUD
LEAD DISC
3/4 BALL BEARING
RUBBER GROMMET
BODY
PLUG
2
3
4
5
6
7
8

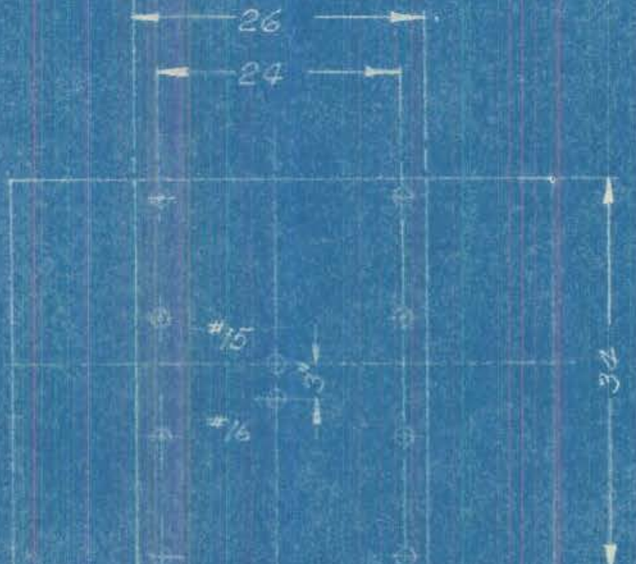
PLATE 19



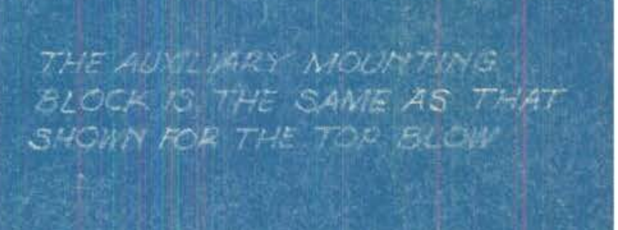


AUXILIARY MOUNTING BLOCK

AUXILIARY BLOCK FOR ACCELEROMETER. BLOCK IS 1/2" THICK PERPENDICULAR TO PAPER.



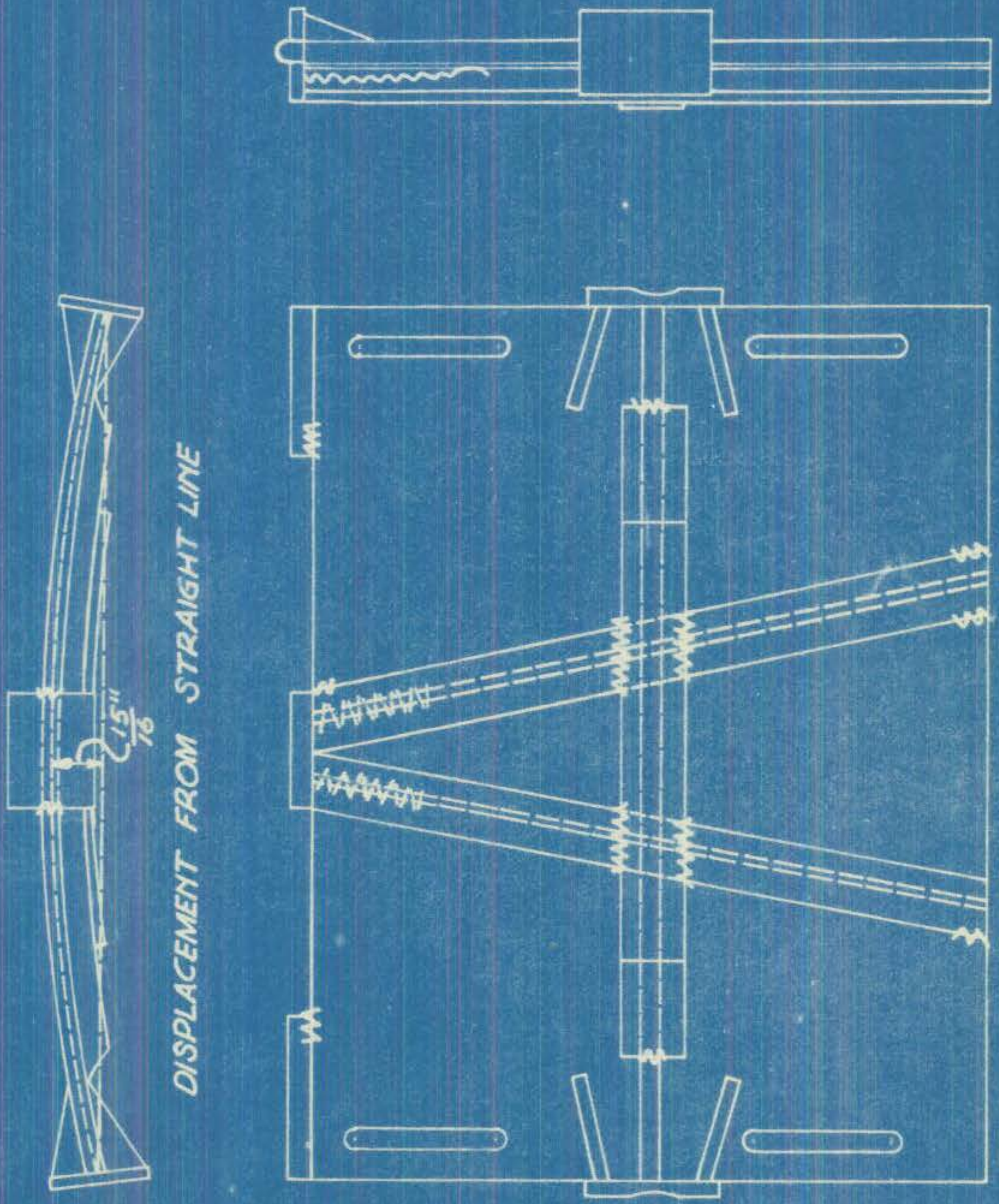
STRIKING PLATE WITH SUB-MOUNTING PANEL



THE AUXILIARY MOUNTING BLOCK IS THE SAME AS THAT SHOWN FOR THE TOP BLOW

POSITIONS OF ACCELEROMETER LOCATION NUMBERS

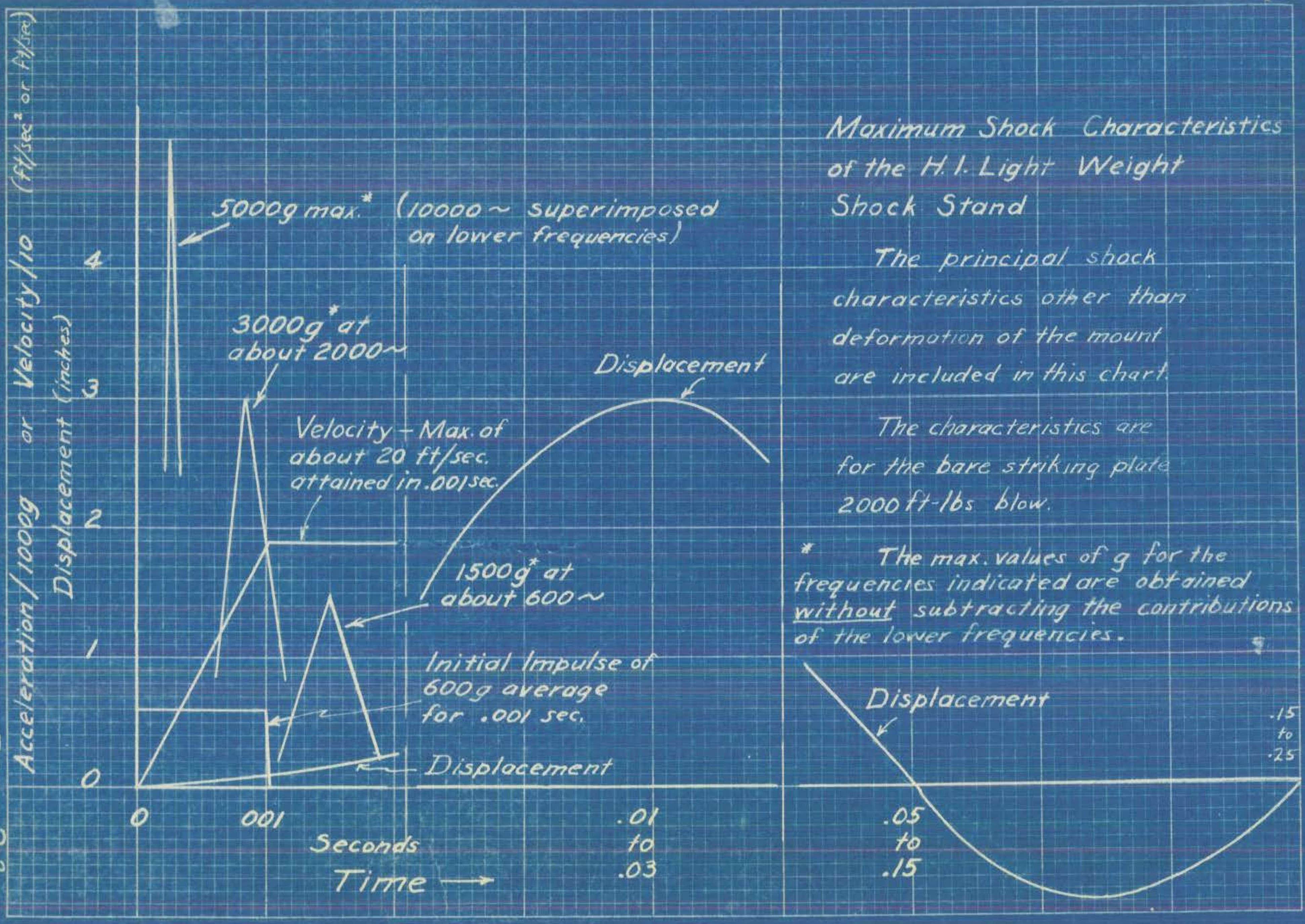
PLATE 21



CRACKS ARE SHOWN BY WAVEY LINES

DEFORMATIONS & CRACKS IN OLD STRIKING PLATE

PLATE 22



Maximum Shock Characteristics
of the H.I. Light Weight
Shock Stand

The principal shock characteristics other than deformation of the mount are included in this chart.

The characteristics are for the bare striking plate 2000 ft-lbs blow.

* The max. values of g for the frequencies indicated are obtained *without* subtracting the contributions of the lower frequencies.

Plate 23