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NAVY DEPARTMENT
Washington, D.C.

Report

on

Magnetic Search Coil Explorations and Ball-Punch Hardness Measurements for Bain Steel Piping.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
Washington, D.C.

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ABSTRACT

A magnetic search coil was constructed that is equivalent to two differentially connected pick-up coils equally spaced from a centrally wound exciting coil. The coils are wound on a bakelite tube and are constructed so that the tube and coils can be opened along a direction parallel to the axes of the tube, and placed around a pipe. The voltage induced in the pick-up coils by the exciting coil is rectified by a mechanical rectifier and indicated on a d.c. galvanometer both in magnitude and direction. This gives a measure of the space change of magnetic permeability along the length of the pipe. Hard spots in piping give indications corresponding to an area of low permeability. Sections along the pipe that are found to have low permeability contain hard spots that might be in the pipe. A ball-punch hardness tester, constructed from an automatic center punch, is used to test the areas of low permeability for hardness. An abstract of operational instructions is appended to this report.

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APPENDICES

INTRODUCTION

(a) Authorization

1. This problem was authorized by Bureau of Engineering letter JJ46-1/L5(12-15-SS) of 16 December 1939.

(b) Statement of Problem

2. A number of failures have occurred in steel tubing on recently constructed destroyers. These failures have been associated with local hard spots in the steel tubing and have occurred in high pressure feed water piping. The hard spots were responsible for the failures. It became necessary, therefore, to determine a method for the location of these hard spots in the steel tubing. The method used should be capable of application without removal of the pipe tested from its position in the ship.

(c) Known Facts Bearing on the Problem

3. The hard spots are, as the name indicates, small areas, usually of several inches average diameter, in otherwise normal pipe. They are caused (in Bain steel tubing) by the rapid cooling of these areas either in air or by water. The local heating of these small areas could have occurred either in the fabrication of the pipe bends or in the installation of the pipe. It is apparent that the hard spots were introduced following the heat treatment necessary after bending these pipes.

4. When a small area of a section of pipe is heated, this area will expand and will therefore be placed under considerable compression by the rest of the pipe. If the temperature of this local area is increased to a sufficiently high degree, the metal in this area will become upset. If this area is then cooled, it will tend to occupy less area than before it was heated and will be under tensile stress. When the cooling is very rapid, this tensile stress will be very large and will be aggravated by the increased hardness of this area which is also caused by the rapid cooling. The hardness is associated with decreased ductility and creep. Thus the mechanism for the natural relief of these stresses has been, to a large extent, removed. These stresses, together with those normally encountered, bring about the failure in this area.

5. It has been found impractical to explore a large number of pipes by conventional hardness methods. As hard areas differ magnetically from the normal areas, it was believed a method that measured the change of magnetic reluctance along the axis of the pipe would point out the sections containing the hard areas. The points along the axis that were indicated as probably hard would then be tested by some portable hardness tester to determine the actual hardness in some conventional units.

6. It must be emphasized that many conditions may affect the magnetic properties of a piece of steel besides the hardness of the material, and therefore no magnetic device can be used actually to measure hardness unless all these other factors are controlled. In the steel tubing concerned, hard spots were but one of several causes that increased the magnetic reluctance of various sections of pipe. A magnetic device can be made to point out sections of piping where there is a change of permeability as compared to other sections of the pipe or some standard material.

If there are hard sections present, they will be included as one of the sections where the permeability has changed to a small value. All of the sections of small permeability must be tested for hardness, for if hard spots are present, they will be included among these sections.

7. Considerable work has been done on electrical and magnetic testing of materials. No attempt will be made to cite the various methods used. A quite complete survey of this field is given by A.P.M. Fleming and B.G. Churcher[1], R. Berthold[2], H.H. Lester, R.L. Sanford, and N.L. Mochel[3].

METHODS AND APPARATUS

Magnetic Search Coil

8. From the schematic diagram, figure A of Plate 1, it can be seen that the search coil is equivalent to three coils. These coils are wound on a bakelite tube. An exciter coil, E, is wound on the center of this tube. A pick-up coil, P, is equivalent to a coil wound on each end of the tube equidistant from the exciter coil. These equivalent pick-up coils are connected in electrical opposition so that when the voltage induced in each is the same, in regard to both magnitude and phase, the voltage across the terminals, P-P, will be zero.

9. One of the search coils constructed is shown on Plate 2. As the coils must be made to slip around a pipe, without having access to the ends of the pipe, it was necessary that a break be made in the bakelite tube and coils. The exciter coil, 12 turns of #16 B&S gauge stranded copper wire, is broken by having the turns terminate in regular six prong plugs and sockets of the type used in radio work. These are arranged so that when the break is closed the plugs penetrate the sockets only a short distance (one-quarter inch). This eliminates binding. The pick-up coil, 200 turns of #34 B&S gauge D.S.C. copper wire, must be wound in different manner. The principle is best illustrated in figure 1. Plate 2 shows the construction of the pick-up coil. The coils are all wound in grooves machined in the bakelite tube. The coils must remain firmly in place within these grooves so that their relative positions do not become changed. All coils are passed out of their grooves over a piano-type hinge which is placed externally on the bakelite tube opposite the break. Guide screws

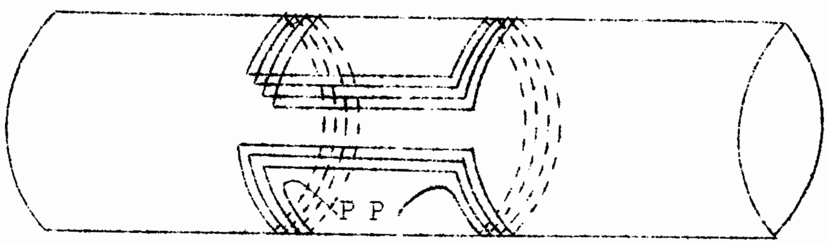


Figure 1.
Principle of winding of the pick-up coils.

are placed in the bakelite tube so that the tube may be kept centered as it is moved from one position to another along a pipe. Search coils have diameters of approximately 6 inches, 8 inches, and 10 inches. The length of the bakelite tubes is in all cases approximately 6 inches.

Mechanical Rectifier

10. The voltage generated across the two pick-up coil terminals, P-P, (Diagram A, Plate 1) can be measured with a D.C. instrument if this voltage is rectified. It is a very important advantage, however, that information is obtained as to which of the two (equivalent) pick-up coils generate the greater voltage. This can be accomplished quite simply if a mechanical rectifier (Creed relay type 1927 or similar instrument) is used in conjunction with a D.C. instrument capable of reading in either positive or negative directions. This rectifier allows the current to flow by mechanical contact for nearly one-half of every cycle. The exciter coil of the rectifier is connected in series with a resistance (r of figure C, Plate 1) which is adjusted to allow sufficient current to go through the exciter coil to operate the relay properly, when connected to 115 volts, 60 cycles, and also to help adjust the phase of rectification. With a high impedance Creed relay of 1600 ohms, about 10,000 ohms were placed in series. Additional means of adjusting the part of the cycle during which the electrical circuit is completed are provided with this relay.

Clipboard Panel

11. A panel mounting galvanometer, capable of reading from a negative 60 microamperes to a positive 60 microamperes and supplied with an Aryton type shunt to reduce its sensitivity when necessary, is mounted on a panel as illustrated in Plate 3 and diagrammatically shown in B of Plate 1. The change in sensitivity due to different shunt positions should be measured. This can simply be done by connecting the apparatus, obtaining full scale deflection with the galvanometer having highest sensitivity, and observing by what factor the galvanometer reading is reduced at the lower sensitivity. All plotted galvanometer readings should be in terms of maximum sensitivity. A radio filament transformer capable of supplying 10 amperes at 2.5 volts is also mounted on this panel. For convenience this panel is mounted directly on a clipboard to which could be attached paper for the recording of data.

Connections

12. Instructions for connections are given on Plate 1. Multi-conductor cables can be used to connect the different parts of the apparatus. The conductors connecting the exciter coil of the search coil to the clipboard panel should be equivalent to #14 B&S gauge copper wire or larger. Care must be taken that the mutual inductance between the exciter leads and the pick-up coil and its leads is small. This will be true if the conductors are twisted about each other within the cable. It has been found convenient to make the cable connecting the search coil to the clipboard about 12 feet long. The cable connecting the clipboard to the relay should be about 25 feet long. Then it will not be necessary to move the relay during a pipe exploration. A lamp cord about 25 feet long may be used to connect the apparatus to a 115 volt, 60 cycle supply source. A receptacle for this is provided on the mechanical rectifier box.

Typical Curve for a Small Hard Area

13. The data obtained by the search coil method consist of galvanometer readings as a function of the position of the search coil on the pipe being explored. The position of the search coil is defined as the distance between the center of the search coil, along its length, and a reference point on the pipe.

14. The exciter coil may be considered as the primary of a transformer, and the pick-up coil may be considered as two secondary coils. The pipe is equivalent to the iron core of the transformer. The pick-up coils are connected in opposition, i.e., when the flux is changing the same amount in both coils, the voltage generated by the one will be equal and opposite to that generated by the other; and the net voltage will be zero. The galvanometer will then read zero. This will be true when the search coil is in air away from metallic materials or over a pipe that is homogeneous and distant from magnetic disturbances (flanges, hangers, end of pipe, etc.). Whenever there is a difference in the voltage generated by these two coils, the net voltage will not be zero, and the galvanometer will read a positive or negative value depending on which coil generates the greater voltage. It is obvious that important phase shifts occur between the two pick-up coils, but due to lack of information concerning them, they will not be considered in this discussion.

15. Many changes may occur in piping that affect its magnetic properties. From experience it can be said that magnetically homogeneous pipes, as found installed in ships, are non-existent. The hardness of a pipe is one of the many factors that affect its magnetic properties. The hard areas are less permeable than "normal" areas. Thus, as a hard spot is approached, the leading pick-up coil will have less flux than the trailing coil, and the galvanometer will register both the magnitude and direction of this unbalance. When the center of the search coil (or center of the exciter coil) is directly over the center of the hard spot, the magnetic paths through both pick-up coils will be the same. They will be balanced and no current will flow through the galvanometer. Similarly, as the search coil goes by the hard spot, the trailing coil will generate less voltage and the galvanometer will read in the opposite direction from that read when the leading coil was over the hard area. If the center of the search coil is taken as the point of reference for its position on the pipe, the graph of the galvanometer readings as a function of the position of the search coil as it passed over a hard area on a pipe is of a type shown below in Figure 2.

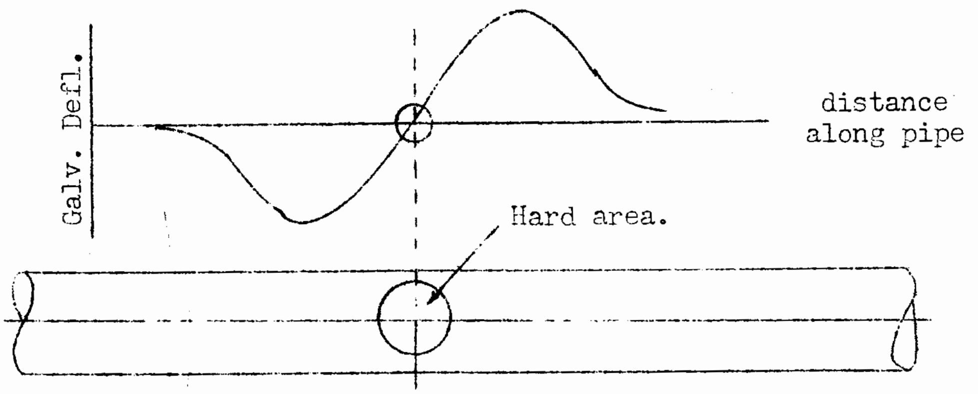


Figure 2.
Typical Curve for a Small Hard Area.

For a small hard spot, the distance measured along the axis of the pipe between the negative and positive maxima is about 6 inches. This is the width of the search coil. For a large hard spot, this distance will be greater than 6 inches. If this distance is of the order of 3 inches, it is due to external objects passing near to the coil (see Plates 5, 11, and 12).

16. Wherever there is a hard area, there will be a change of galvanometer reading of the type as idealized in the above graph. This does not mean that there is a hard spot where a curve of this type occurs, as many other changes in metals beside hardness affect its magnetic properties. A graph containing variations of this kind merely indicates suspicious areas. Each of these areas must be tested for hardness by other means such as the ball-punch. This instrument will be discussed under hardness measurements. Usually only a small proportion of the suspicious areas is hard. It is believed that every hard area having an average diameter greater than one-third the diameter of the pipe will be clearly indicated on the graph. It should be clear that the search coil does not measure hardness, but merely points out suspicious areas that will have to be tested by other means, and if hard areas are present they will be included among the suspicious areas.

17. The suspicious area will be at some point between the negative and positive maxima as one goes from negative to positive if the following procedure is followed. A piece of iron should be placed under the leading pick-up coil and the direction of motion of the galvanometer noted. This direction is taken as positive. The leading pick-up coil is that coil which is the greatest distance from the initial, or starting, end of the pipe.

Causes of Variation of the Typical Hardness Curve

18. In actual working conditions the idealized hardness curve shown above will be distorted by many disturbing factors. The principal ones of these are enumerated below:

(1) The dimensions of the hard area may be large compared with the length of the search coil.

(2) The search coil may not be in electrical balance. The search coil is in balance if the galvanometer reads zero when in operation on a homogeneous pipe, distant from the pipe end or magnetic interference. An unbalance is due in part to unequal spacing between the pick-up coils and the exciter coil. If the search coil is not in balance, it is sufficient to estimate the electrical "zero" by judging its position so that approximately the same area is enclosed by the curve above this zero line as below (see Plate 7). This shift of zero will remain constant for any properly constructed search coil. Because of the difference in magnetic paths of the many leads in the vicinity of the coil break, the coil may be balanced when operating with an air core, but not balanced when on a uniform pipe.

(3) The typical hardness curve may be superimposed on variations due to other magnetic inhomogeneities (Plates 8 and 10). This will be discussed more fully under probable errors.

Hardness Measurements

19. The search coil locates positions along the axis of a pipe that have less magnetic permeability than other sections of the pipe. The magnitude of the galvanometer reading indicates the change of difference of magnetic reluctance between the two ends of the coil (differences due to eddy current effects are neglected). At every position along the axis of the pipe, where it is indicated that the permeability is low, a hardness test must be made. If the exact location of this suspicious area is uncertain, hardness tests should be made along the length of the uncertain area at about 2-inch intervals. As the search coil gives no information as to the location of a hard spot about the circumference of a pipe, tests for hardness should be made at about 2-inch intervals around the circumference of the pipe at suspicious areas.

20. Hardness measurements are most conveniently made by means of a ball-punch of special construction. The punch consists of a large size automatic center punch (Brown and Sharpe automatic center punch #770, style 3, has been used) the tip of which has been replaced by an eighth-inch diameter steel ball. A standard Rockwell steel ball of this diameter may be used. This ball is held in place against a hardened steel seat by a collar, through which the ball partially protrudes. The collar is screwed to the rod on which the seat is located. This section is then screwed to the center punch. This section is illustrated in Figure 3 below. Mr. Noah Kahn, of the Brooklyn Navy Yard, has constructed some excellent ball-punches.

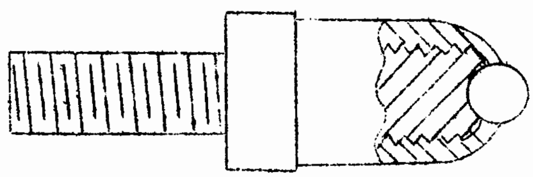


Figure 3
Ball-point Attachment for Automatic Center Punch. (Enlarged about 3 diameters)

21. A small area of pipe must be cleaned of scale and made to present the smooth appearance of clean iron for each location of ball-punch measurements. The preparation can be started with a flat file of medium coarseness and finished with a fine flat file. Corners or edges of files should never be used on high pressure piping. The ball punch impressions are made by holding the punch perpendicularly to the surface with the ball against a clean section of metal and applying pressure until the spring mechanism trips. This applies a blow of quite definite energy against the ball, thus making an impression in the material being tested, the diameter of which is a function of the hardness of this material.

22. The measurement of the diameters of the ball punch impressions should be made with a Brinell microscope whenever possible. If this is impractical, it may be sufficient to judge by visual inspection whether or not the diameters are normal. If the impression appears smaller than normal, additional efforts for measurements should be made, or other means of measurement should be devised. Impressions that are not circular should not be used. If a hard area is found, several impressions should be made to determine its extent.

Calibration of Ball-Punch

23. The ball-punch hardness tester must not be regarded as a precision instrument; however, with some care, readings can be obtained plus or minus 20 Brinell numbers. An idea of the accuracy obtained under good conditions can be seen from the spread of the points on the calibration curve (Plate 4).

24. The calibration should be carried out preferably on a piece of piping. It is immediately noted, in the use of a ball punch instrument, that impressions made on a small piece of material while placed on a non-rigid support, such as a wooden table top, are smaller in diameter than impressions made on the same piece of material when the material is placed on a heavy iron support. As the kinetic reaction determines to some extent the size of the impression, it is better that the calibration be carried out according to the conditions encountered in use. Each punch used should be numbered and have its own calibration curve. The calibration should be checked at frequent intervals.

EXPERIMENTS AND RESULTS

Types of Experiments

25. The experimental work falls into three general classes:

(1) Experiments designed to test the ability of the magnetic search coil method to locate hard spots in steel tubing. In these experiments the location, Brinell values for hardness, and in most cases the average diameters of the hard areas were known. Some of these data are shown on Plates 6 and 7.

(2) Experiments carried out to find the effect on search coil measurements of lagging on pipes during measurement and the effects of magnetic materials either attached to the pipe or in its vicinity (see Plates 5 and 14).

(3) Experiments that applied the method on board ship. In this last case the lagging and all magnetic obstructions that could reasonably be removed were removed from the pipe and vicinity, and the search coil was used to explore the pipe while the pipe was in its position on board the ship. Galvanometer readings were, in all cases, taken for positions of the search coil at two-inch intervals along the axis of the pipe.

26. The graphs (Plates 6 through 14) illustrate the types of curves obtained for a few of the pipes studied. After the search coil data were plotted, the suspicious areas were indicated on the graph, and the corresponding places on the pipe were tested for hardness with the ball-punch. The results of the hardness tests (the diameters of the ball-punch impressions) were then placed on the graph, as are shown on Plates 8 to 12 (see paragraph 30 below) in such a manner as to indicate the hardness values both with regard to positions along the axis and around the circumference of the pipe. The locations of magnetic interferences and bends in pipe were noted on the graph.

27. Pipes, with hard spots at known locations, have been explored at the U.S. Naval Engineering Experiment Station, at the Kellogg plant in Jersey City, and at the Naval Research Laboratory. Bain steel high pressure feed water pipes were explored for hard spots on board the U.S.S. destroyers ANDERSON, SIMS, and MUSTIN, at New York, Boston, and Norfolk Navy Yards, respectively. Twelve pipes were explored on the MUSTIN. No hard spots were found, although there were several border line cases. Between thirty and forty pipes were explored on the ANDERSON and SIMS. Slightly less than 50 per cent of the pipes explored were found to contain hard spots. Two feed water and one steam pipe were explored on board the USS HAMMANN at New York. One hard spot was located in a feed water pipe.

Curves and Data

28. Only a few typical curves are included in this report. These were selected to illustrate certain principles and not to serve as records of the information collected. These curves are discussed in other sections of this report.

29. External objects that come close to the coil often make quite characteristic curves. The horizontal distance between the negative and positive maxima is of the order of 3 inches (see end of paragraph 15 and Plate 5). Plate 11 shows such variations due to a pipe hanger. Plate 12 shows such a variation due to a rectangular ventilator that had one side parallel to the pipe for 20 inches.

30. Ball-punch hardness measurements are shown on Plates 8 to 12. The location of the test along the axis of the pipe is indicated by a number placed within a small circle. The location of the test around the circumference of the pipe is indicated by the radial lines terminating at this circle. The numbers at the opposite ends of these radial lines represent the diameters in millimeters of the ball-punch impressions at the respective locations.

Discussion of Errors

31. Errors may occur in assigning the correct location of a hard spot. These are due to the superposition of magnetic changes caused by the hard area on magnetic changes which are due to other causes. Plate 8 represents two pipes. Pipe #325 has very uniform magnetic structure, but because of its short length, the shape of the curve is determined by the end effects. Pipe #301 is about the same length between obstructions of similar magnetic nature. The curve for this pipe has variations due to border line hard areas. These are superimposed on a curve of a type as shown for pipe #325. The most probable location of a hard spot is at

a location corresponding to a point midway between the negative and positive maxima of the hardness type curve. If the position is in doubt, hardness measurements several inches on either side of this position along the axis of the pipe should be taken. It is not necessary that the hard area be located at the point where the curve intersects the zero galvanometer axis.

32. All hard spots cause variations in the exploration curves. However, if the pipe is uniformly hard, no variations of the exploration curve will indicate this condition. For this reason, at least one position on every pipe should be tested for hardness. However, this is usually not sufficient. Cases are encountered where variations of the exploration curve, because of causes other than hard spots, are greater than the variations due to some hard spots. It is necessary to test at several suspicious areas, even if the area that appears most indicative of hardness is found normal. It is believed that there will be no hard areas (1.5 inches average diameter or larger) missed if the three most suspicious areas of each pipe, per 10 feet of length, are tested for hardness.

33. Ordinary variations of pipe wall thickness will not cause much variation of the exploration curve due to magnetic skin effects when alternating currents of these types are used.

34. Errors associated with the ball-punch are discussed under "Hardness Measurements". Many conditions are encountered where, due to obstructions, no hardness measurements can be taken over part of the circumference of a pipe. This is the most likely cause of missing a hard area.

CONCLUSIONS

Facts Established

35. Hard spots over 1.5 inches in average diameter will be pointed out as a suspicious area by data obtained from search coil measurements. The verification of a suspicious area as a hard spot can be accomplished by a ball-punch method of hardness testing. These determinations can be accomplished with the pipe in position on ship, but the lagging and hanger straps should be removed in all cases, and other magnetic obstructions in the near vicinity of the pipe should be removed when practical.

36. End effects are encountered within 10 to 15 inches of the end of the pipe of flange. These are of such magnitude as to mask other variations that may occur from 8 to 12 inches from the flange so that no information can be obtained by the magnetic search coil method in this region.

37. No attempt should be made to correlate the degree of hardness with the magnitude of the galvanometer variation caused by the hard spot. This magnitude depends not only on the hardness of the material, but also on the shape, size, and rate of change of hardness of the hard area.

38. Many suspicious areas do not contain hard spots. These

suspicious areas are sections in the piping where there are rapid changes in the magnetic properties. They are in part associated with the heating necessary in fabrication of the pipe bends.

39. Hanger straps and other magnetic materials that come in contact with the pipe cause large galvanometer deflections when the search coil comes within 10 inches of the obstruction. Magnetic materials that are 1.5 inches or more from the search coil, when the search coil is between this magnetic material and the pipe studied, will cause negligible variations of galvanometer readings. Magnetic materials that come closer to the search coil than 1.5 inches will cause appreciable galvanometer deflections.

40. The most sensitivity and least interference from external sources will be had if the diameter of the search coil closely approximates that of the pipe being explored. Therefore the smallest size search coil that can be placed around the pipe and moved easily around the pipe bends should be used.

SUMMARY

41. Magnetic search coil methods can be used to point out areas of low permeability in piping. If hard sections are present in the piping, they will be included among the areas of low permeability. All areas in which the permeability is markedly lower than nearby sections are regarded as suspicious areas and must be tested for hardness with a hardness tester.

42. A ball-punch hardness tester has been found accurate to plus or minus 20 Brinell numbers and is convenient to use. This punch was constructed from a large size automatic center punch by replacing the regular point by an eighth-inch steel ball held by a collar against a hardened steel seat.

REFERENCES

1 - The Non-destructive Testing of Materials by Electrical and Magnetic Methods, A.P.M. Fleming and B.G. Churcher, Vol. 84, page 519 (May 1939) Journal of Institution of Electrical Engineers.

2 - Non-destructive Testing, Based on Magnetic and Electrical Principles, R. Berthold, Vol. 84, page 529 (May 1939), Journal of Institution of Electrical Engineers.

3 - Non-destructive Testing in the U.S.A., H.H. Lester, R.L. Sanford, and N.L. Mochel, Vol. 84, page 565 (May 1939) Journal of Institution of Electrical Engineers.

APPENDIX

Instructions for Operation of Search Coil and Ball-Punch Apparatus.

The following procedure has been found convenient in conducting inspections of installed pipes: (Numbers in parentheses refer to paragraphs in report.)

1. Remove all lagging, hangers, grating steps, and other magnetic obstructions (39) as far as practicable.

2. Mark each pipe with chalk at 2-inch intervals beginning at the hub of a flange or other convenient fixed reference point.

3. Place the search coil around the pipe with the heavy brass plug and socket connectors in the lowest position (9). Use adjusting screws to center the coil. Use the smallest diameter search coil that can easily be moved around the pipe bends.

4. Make the electrical connections (12) as shown on Plate 1.

5. Place the search coil at some distance, 15 inches, from a flange and close all switches. If the galvanometer is off scale with the switch (11) in position for greater sensitivity, move the search coil to some position where the galvanometer indicates a small value and standardize (17) the typical hardness curve. Follow procedure outlined in paragraph 17 whenever connections of any part of the apparatus are changed.

6. Adjust the galvanometer to greatest sensitivity and move the search coil toward the starting flange until a value of 30 (full scale) is indicated. Throw the switch below the galvanometer to the middle position and note the reading to the nearest tenth of a division. Determine (or check) the sensitivity factor by dividing the low reading into the high reading (11). The galvanometer should be adjusted to zero when the power is off.

7. Take galvanometer readings with the galvanometer in its most sensitive condition, being careful to reduce the sensitivity if "off scale" values of current are encountered.

8. Record values of galvanometer readings and the corresponding locations of the search coil on the pipe. The search coils are 6 inches long. If the search coil position is such that the trailing side of the coil is placed on zero, then the recorded position of the coil is three, which is the position of the center of the coil. Similarly for any position the recorded position of the coil is 3 inches greater than the position of the trailing coil.

9. Plot the data of galvanometer readings (all converted to scale of maximum sensitivity) against search coil location along the pipe axis in a manner as shown on Plates 8 through 13.

10. Mark at least 3 of the most suspicious areas for each 10-foot length of pipe (see paragraphs 15 through 19).

11. Test the marked suspicious areas with a ball-punch hardness tester (see paragraphs 19 through 22) and record (30) the results on the graph.

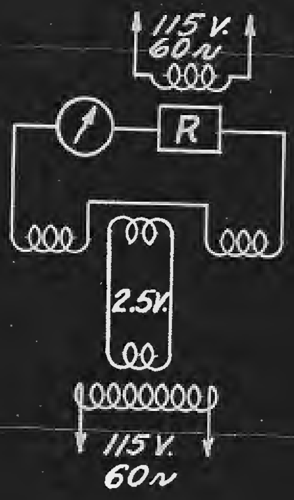
Personnel Required

The inspection work is accomplished most rapidly and effectively with a four-man group. This group should be under the supervision of a metallurgical laboratory or other laboratory of this type. It is desirable to have a fifth man from this laboratory in constant contact with this work in providing this supervision. The group of four may consist of an electrician, an electrician's helper, and two draftsmen (assistant marine engineers), although other good personnel may be used. Members of the ship's crew should be available for the removal of hangers or obstructions.

Performance Check of Search Coil and Ball-Punch.

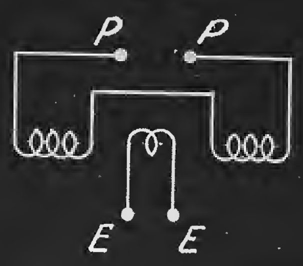
The supervising laboratory should have a "standard" pipe at least 6 feet in length and about 4 inches in outside diameter. The pipe should be seamless steel tubing, Bain steel if possible. Hard spots should be made in this pipe and measurements of their hardness should be made. This pipe should be used to check the performance of the search coil and ball-punch.

SCHEMATIC DIAGRAM



R – CREED RELAY
(A - MECHANICAL RECTIFIER)

A



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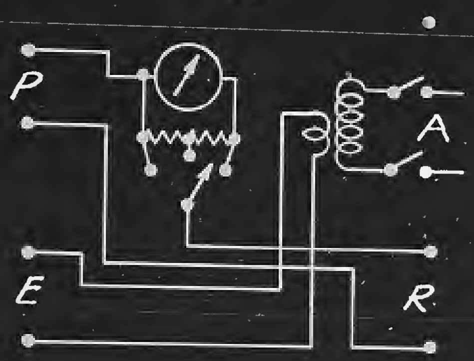

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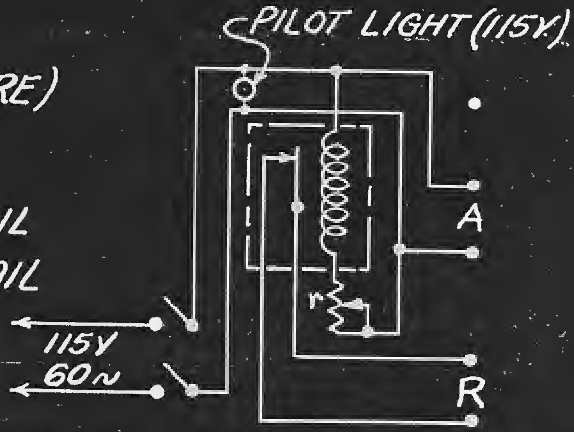
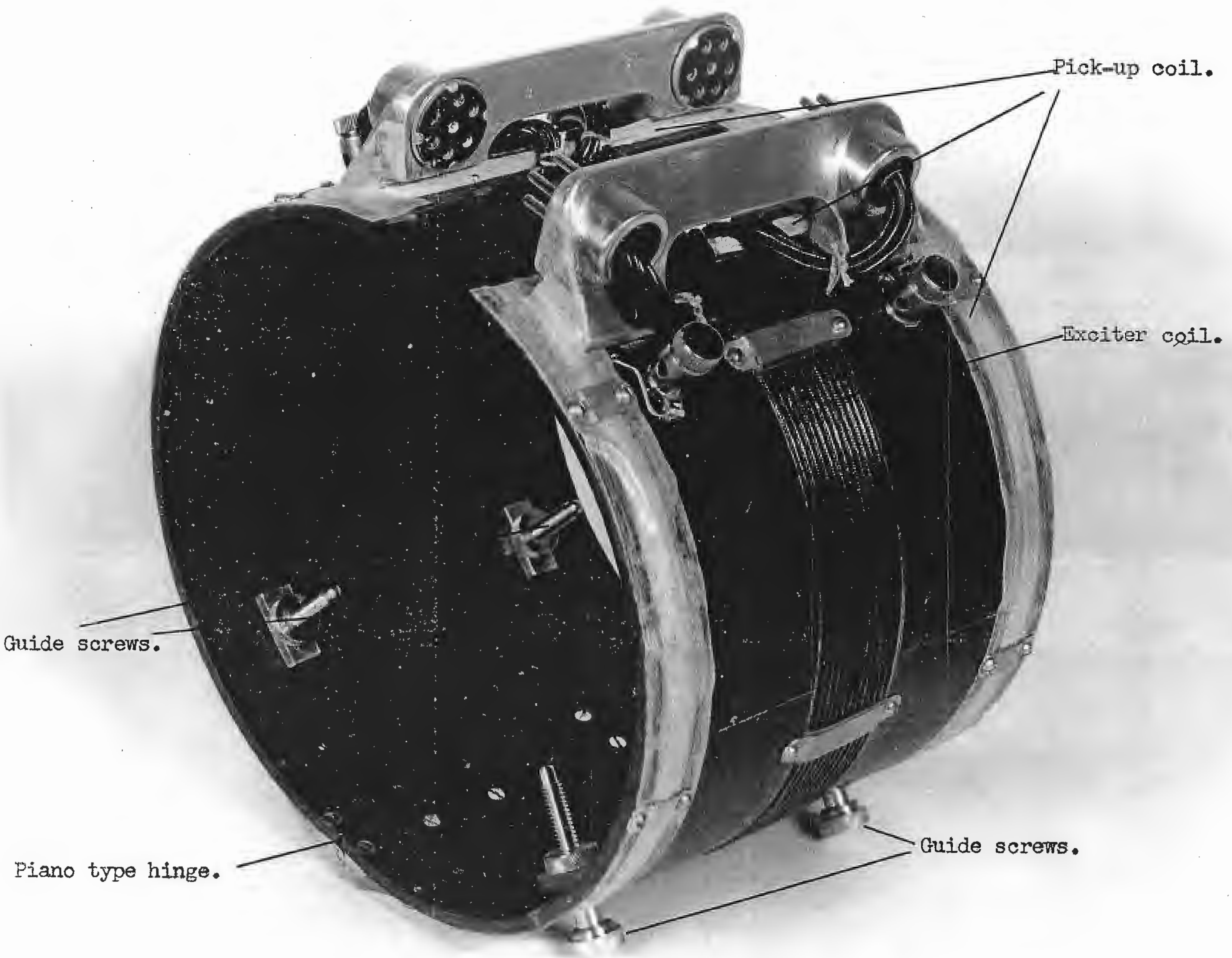


A — SEARCH COIL
P - PICK-UP COIL
E - EXCITER COIL (HEAVY WIRE)

B — CLIP BOARD PANEL
P – CONNECT TO PICK-UP COIL
E – CONNECT TO EXCITER COIL

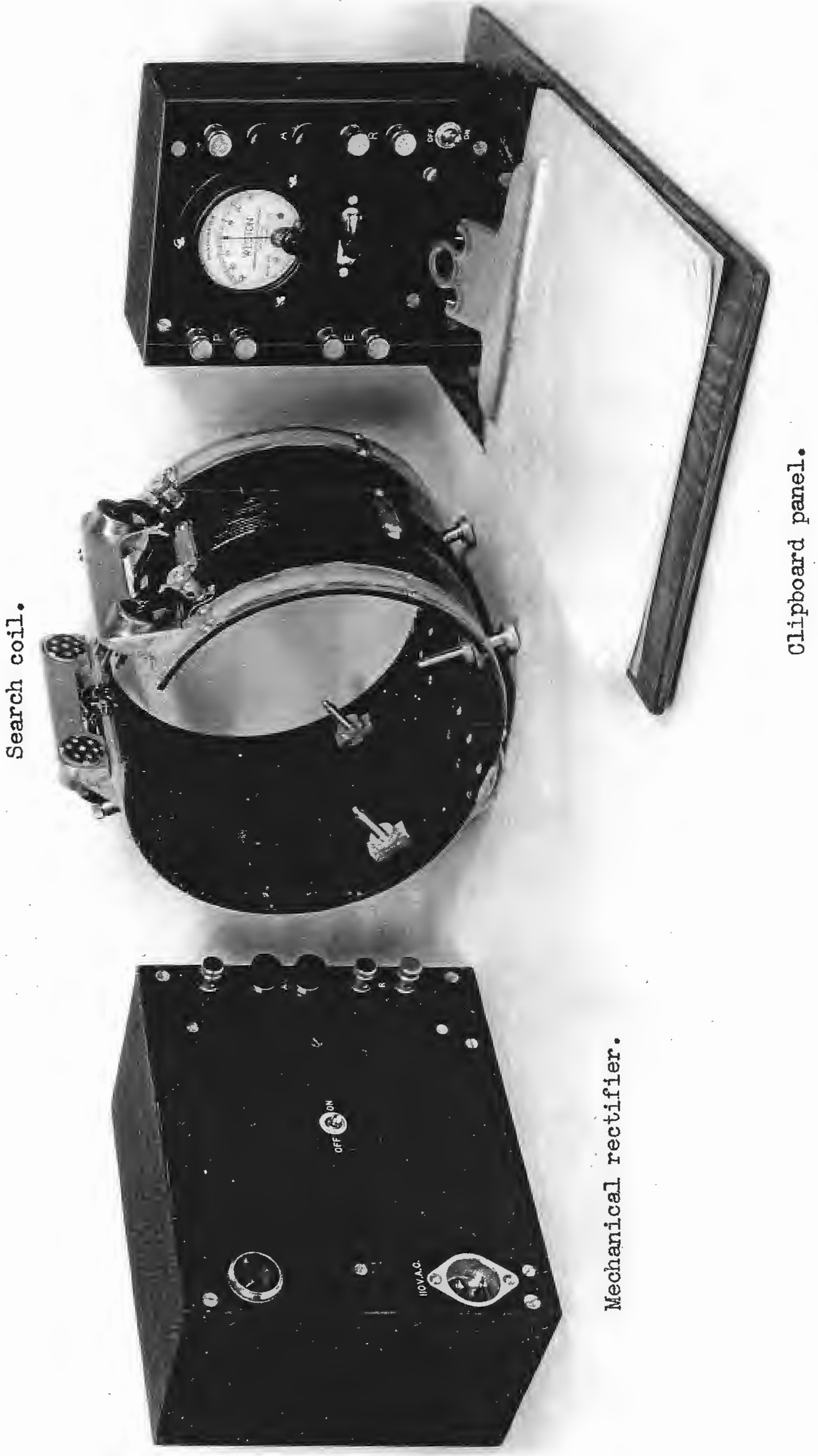
C — MECHANICAL RECTIFIER
(CREED RELAY)
CONNECT "A" OF CLIP BOARD PANEL TO "A" OF MECHANICAL RECTIFIER
CONNECT "R" OF " " " " "R" " " "

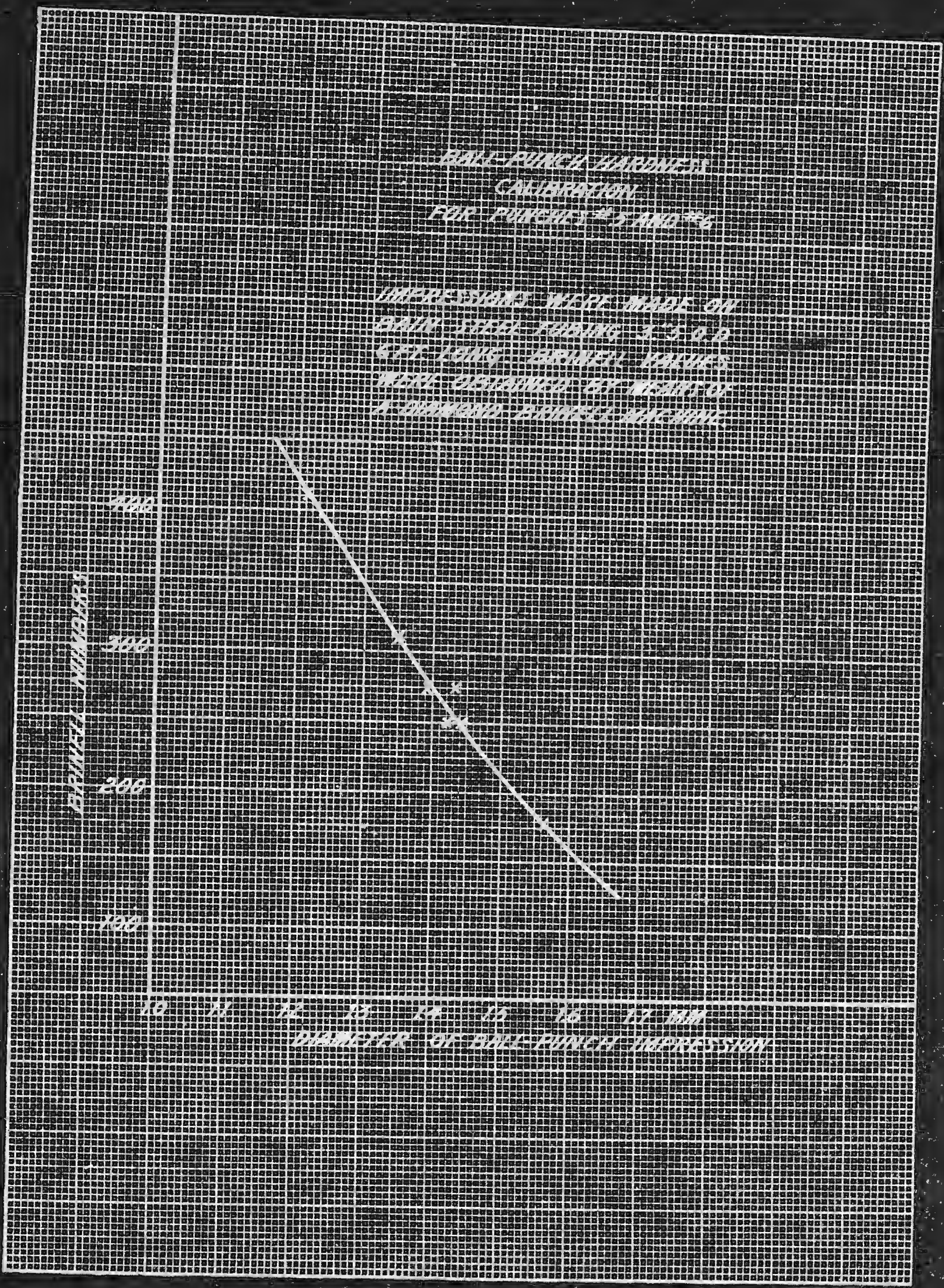
PLATE I.



SEARCH COIL

PLATE 2


Search coil.
Clipboard panel.
Mechanical rectifier.


BALL-PUNCH HARDNESS
CALIBRATION
FOR PUNCHES #5 AND #6
IMPRESSIONS WERE MADE ON
BRINELL NUMBERS
400
300
200
100
10
11
12
13
14
15
16
17 MM
DIAMETER OF BALL-PUNCH IMPRESSION

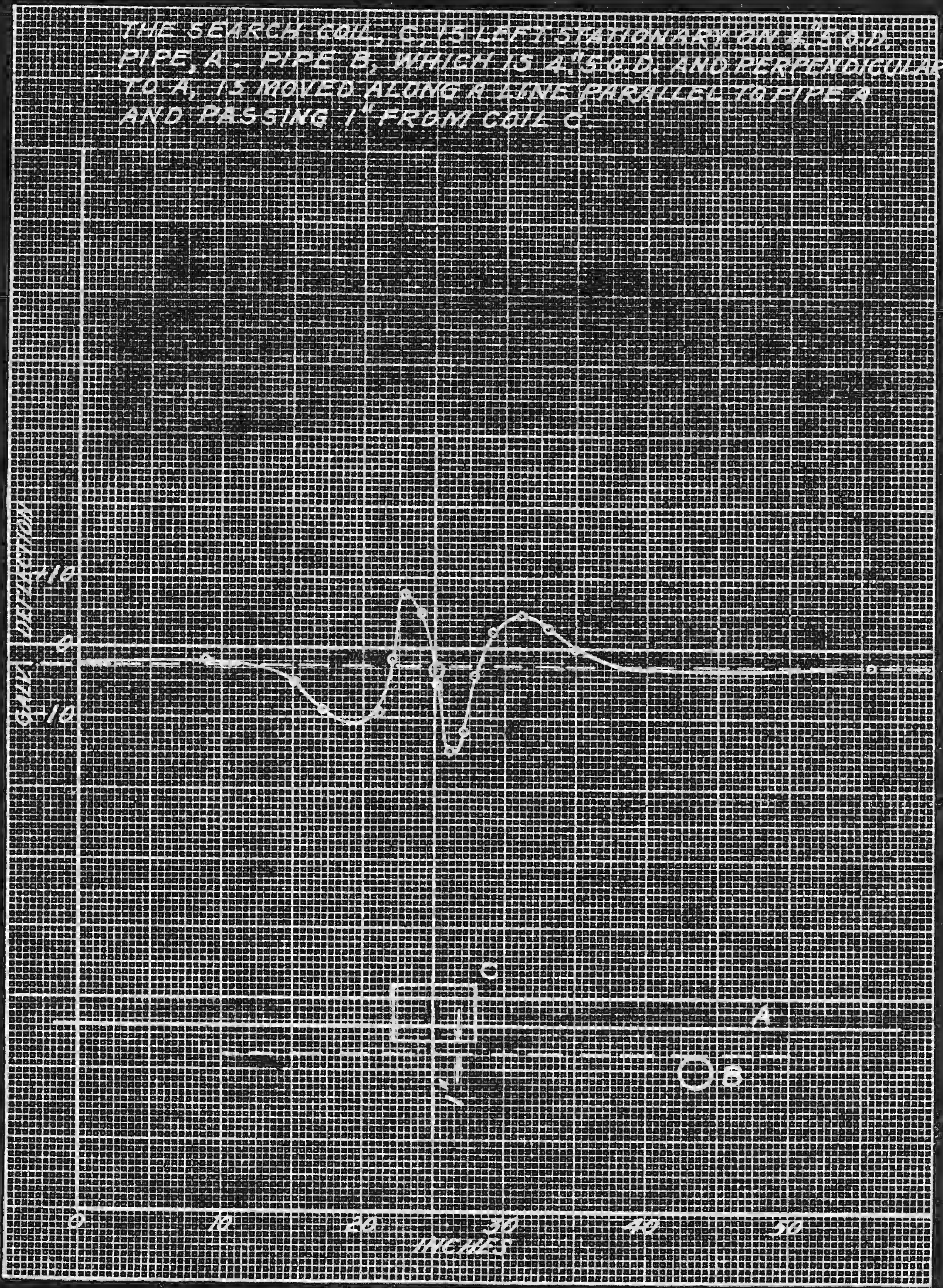

THE SEARCH COIL, C, IS LEFT STATIONARY ON 4"5 O.D. PIPE, A. PIPE B, WHICH IS 4"5 O.D. AND PERPENDICULAR TO A, IS MOVED ALONG A LINE PARALLEL TO PIPE A AND PASSING 1" FROM COIL C.
GALV. DEFLECTION
+10
0
-10
C
A
B
0
10
20
30
40
50
INCHES

PLATE 5

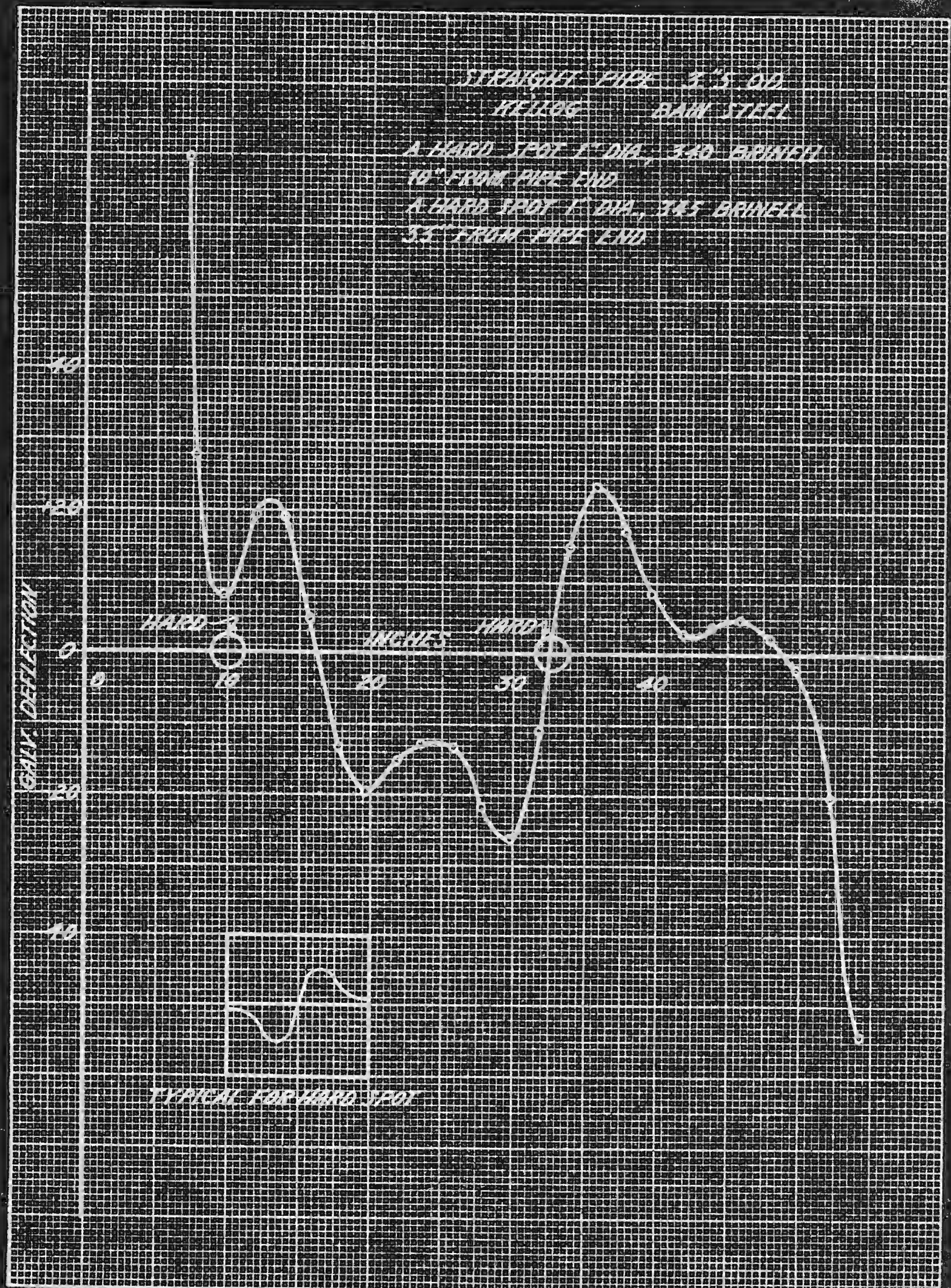

STRAIGHT PIPE 3.5 O.D.
A HARD SPOT 1" DIA, 340 BRINELL
10" FROM PIPE END
A HARD SPOT 1" DIA, 345 BRINELL
33" FROM PIPE END
GALV. DEFLECTION
INCHES
HARD
HARD
0
10
20
30
40
40
20
0
20
40
TYPICAL FOR HARD SPOT

PLATE 6

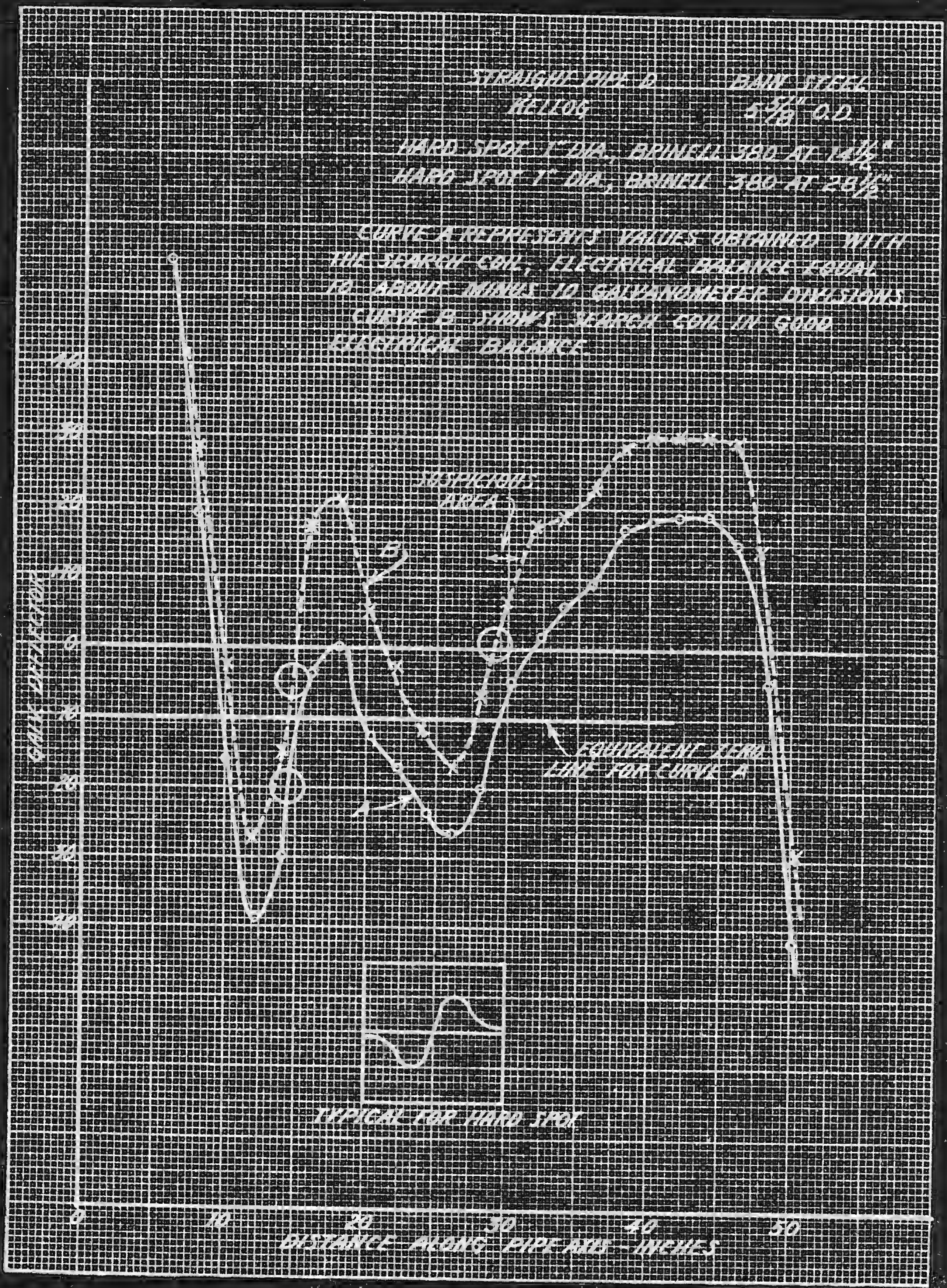

STRAIGHT PIPE D
BAIN STEEL
KELLOG
5 5/8" O.D.
HARD SPOT 1" DIA., BRINELL 380 AT 14½"
HARD SPOT 1" DIA., BRINELL 380 AT 28½"
CURVE A REPRESENTS VALUES OBTAINED WITH THE SEARCH COIL, ELECTRICAL BALANCE EQUAL TO ABOUT MINUS 10 GALVANOMETER DIVISIONS
CURVE B SHOWS SEARCH COIL IN GOOD ELECTRICAL BALANCE
SUSPICIOUS AREA
B
A
EQUIVALENT ZERO LINE FOR CURVE A
TYPICAL FOR HARD SPOT
GALV. DEFLECTION
40
30
20
10
0
10
20
30
40
0
10
20
30
40
50
DISTANCE ALONG PIPE AXIS - INCHES

PLATE 7

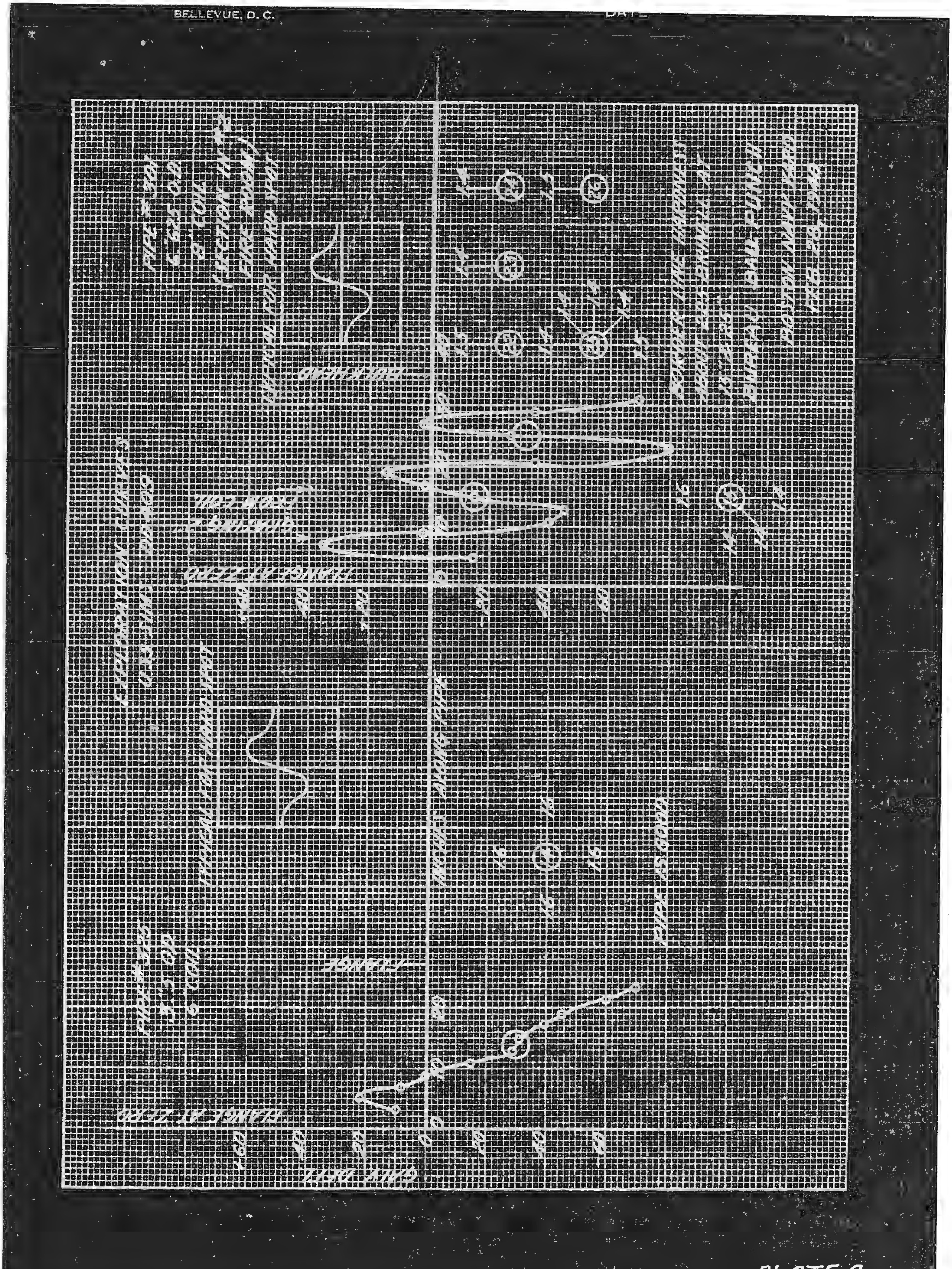


PLATE 8

BELLEVUE, D. C.

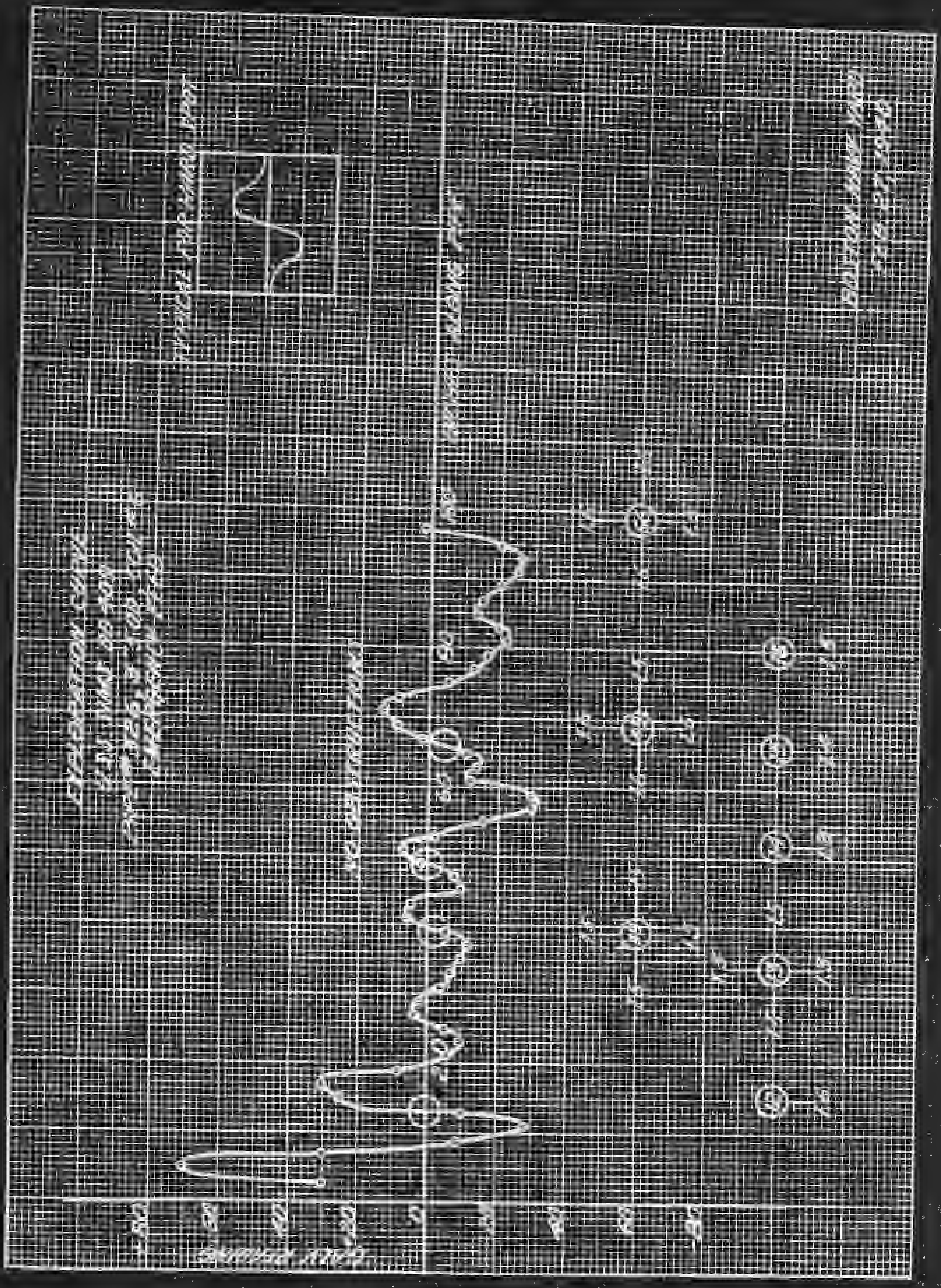


PLATE 9

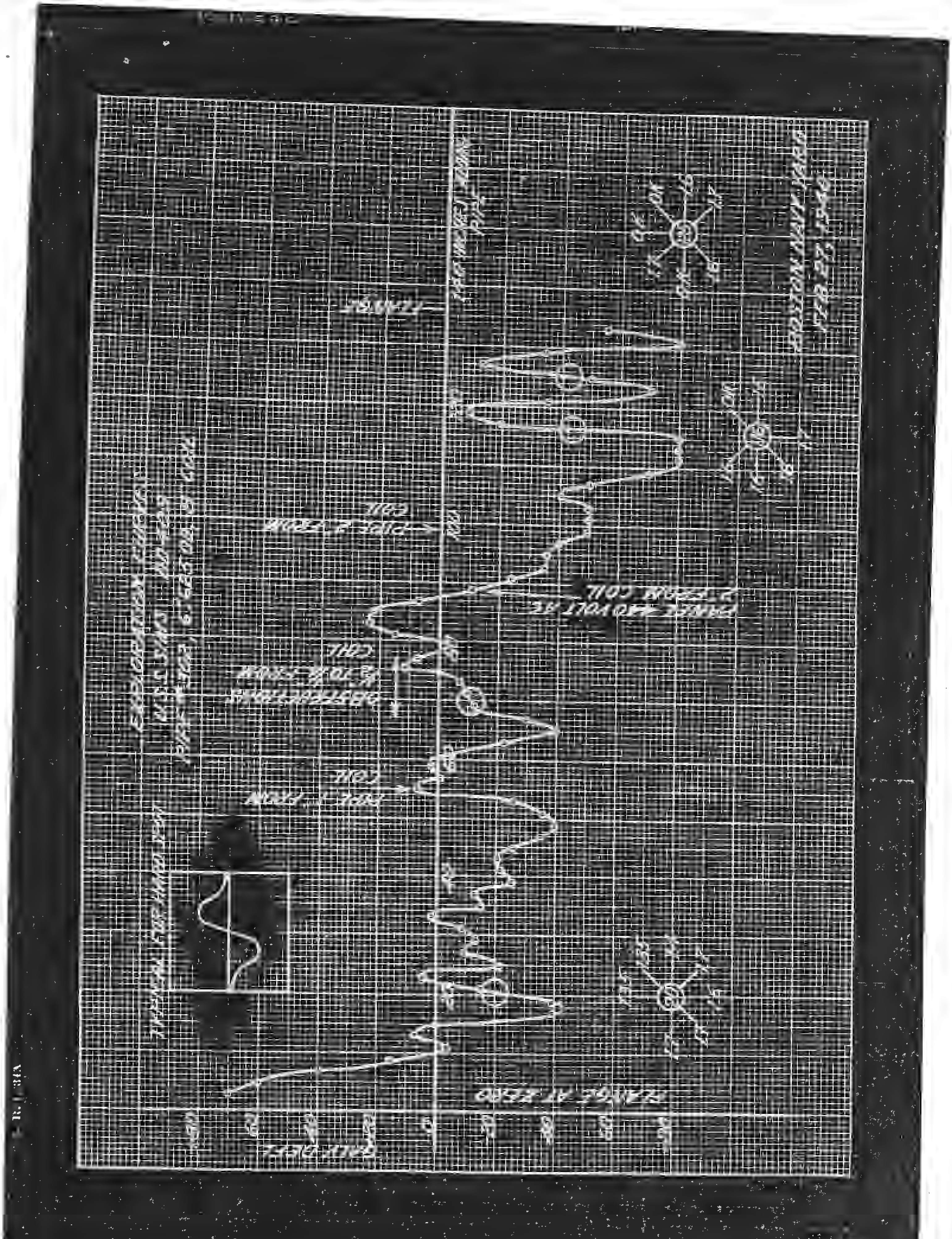
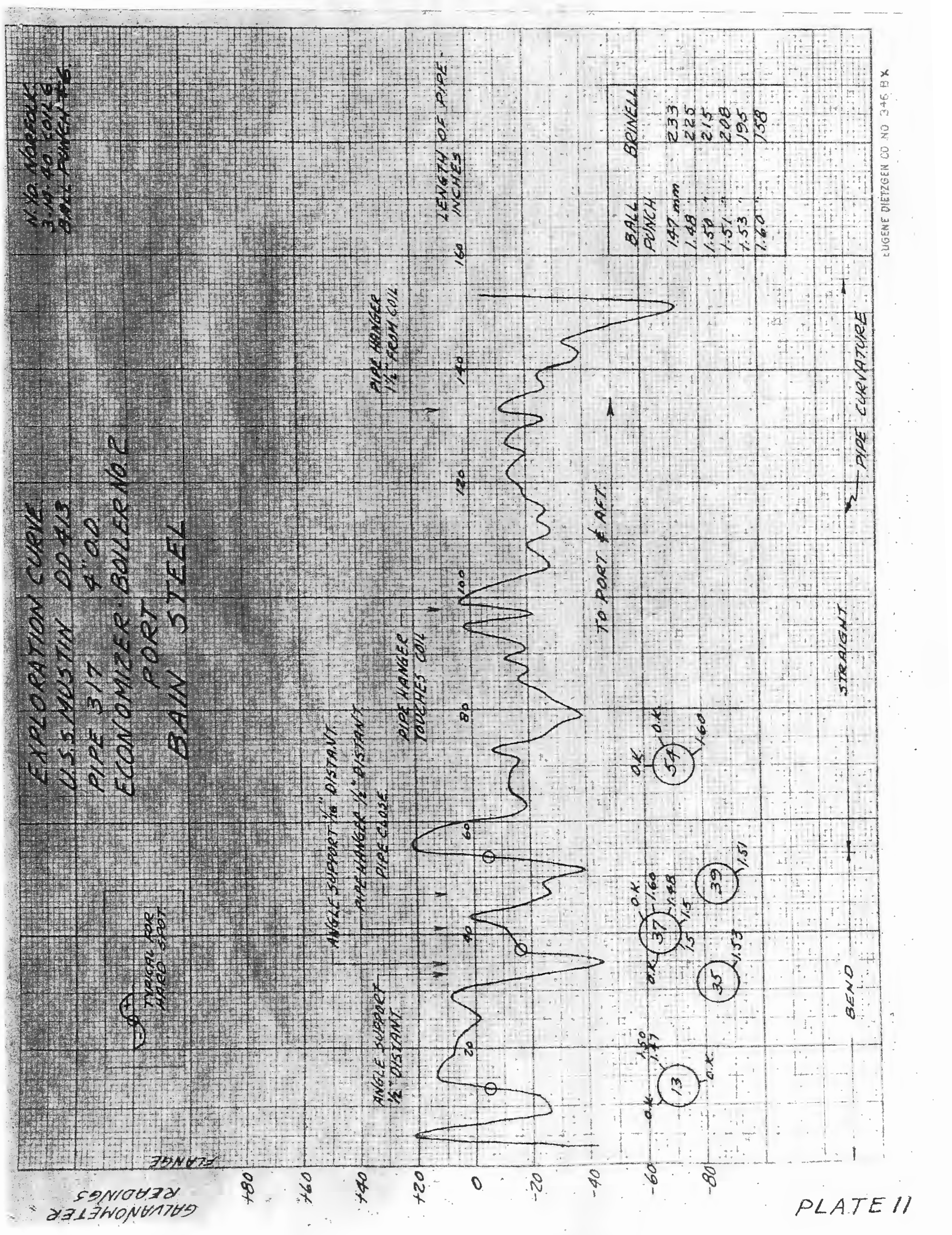


PLATE 10



EXPLORATION CURVE
U.S.S. AUSTIN DD #15
PIPE 317 4" O.D.
ECONOMIZER BOILER NO 2
PORT
BAIN STEEL
N.Y. NORFOLK
3-14-40 COIL 6
BALL PUNCH #6
TYPICAL FOR HARD SPOT
ANGLE SUPPORT 1/2" DISTANT
ANGLE SUPPORT 1/16" DISTANT
PIPE HANGER 1/2" DISTANT
PIPE CLOSE
PIPE HANGER TOUCHES COIL
PIPE HANGER 1 1/2" FROM COIL
LENGTH OF PIPE - INCHES
TO PORT & AFT.
BEND
STRAIGHT
PIPE CURVATURE
FLANGE
GALVANOMETER READINGS
BALL PUNCH
BRINELL
1.47 mm 233
1.48 225
1.50 215
1.51 208
1.53 195
1.60 158
EUGENE DIETZGEN CO. NO. 346 BX

PLATE 11

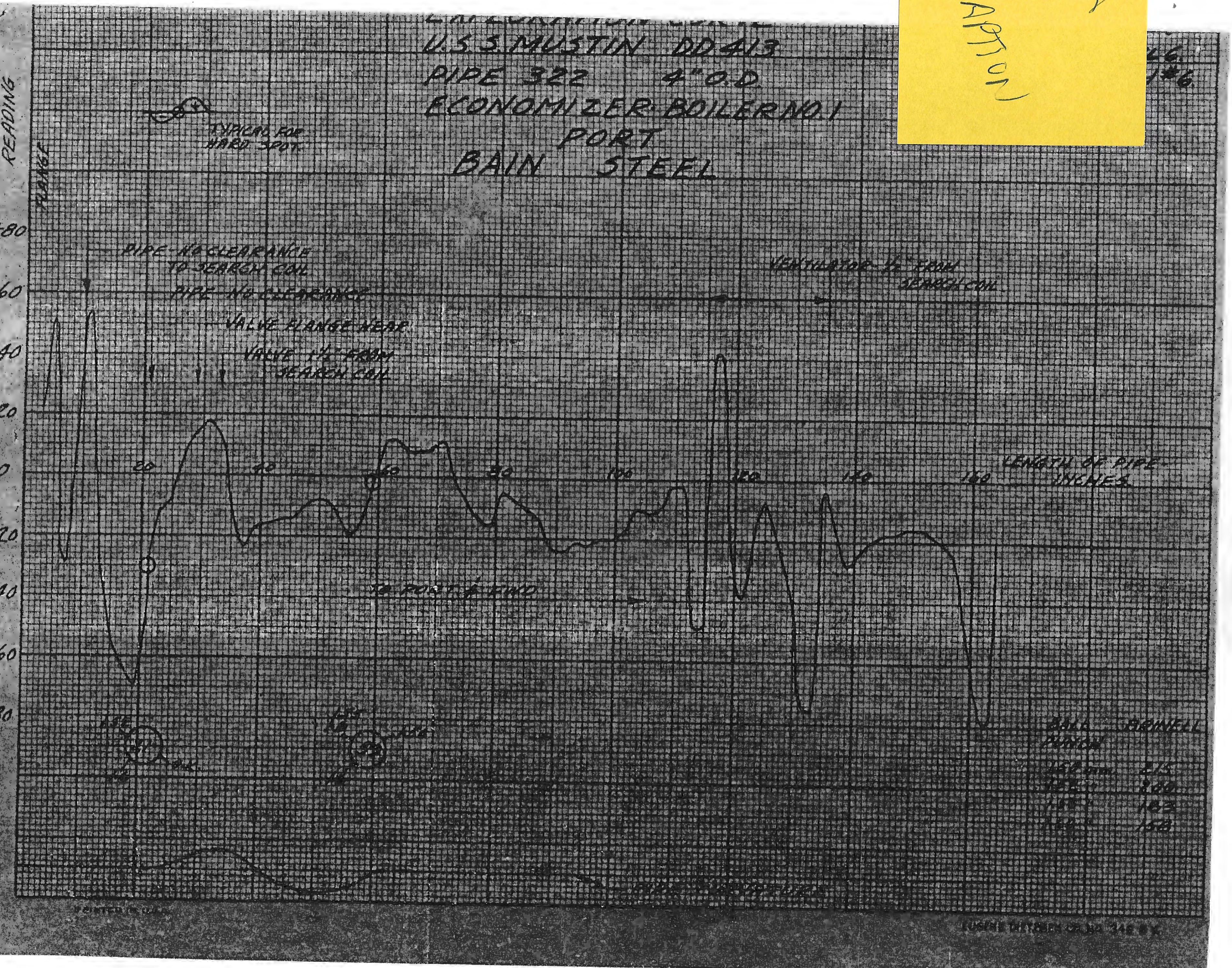

U.S.S. MUSTIN DD 413
PIPE 322 4" O.D.
ECONOMIZER BOILER NO. 1
PORT
BAIN STEEL
TYPICAL FOR HARD SPOT
GALVANOMETER READING
FLANGE
+80
+60
+40
+20
0
-20
-40
-60
-80
PIPE-NO CLEARANCE TO SEARCH COIL
PIPE-NO CLEARANCE
VALVE FLANGE NEAR
VALVE 1½" FROM SEARCH COIL
VENTILATOR ½" FROM SEARCH COIL
20
40
60
80
100
120
140
160
LENGTH OF PIPE INCHES
TO POST. & END
BALL
BRINELL

PLATE 12

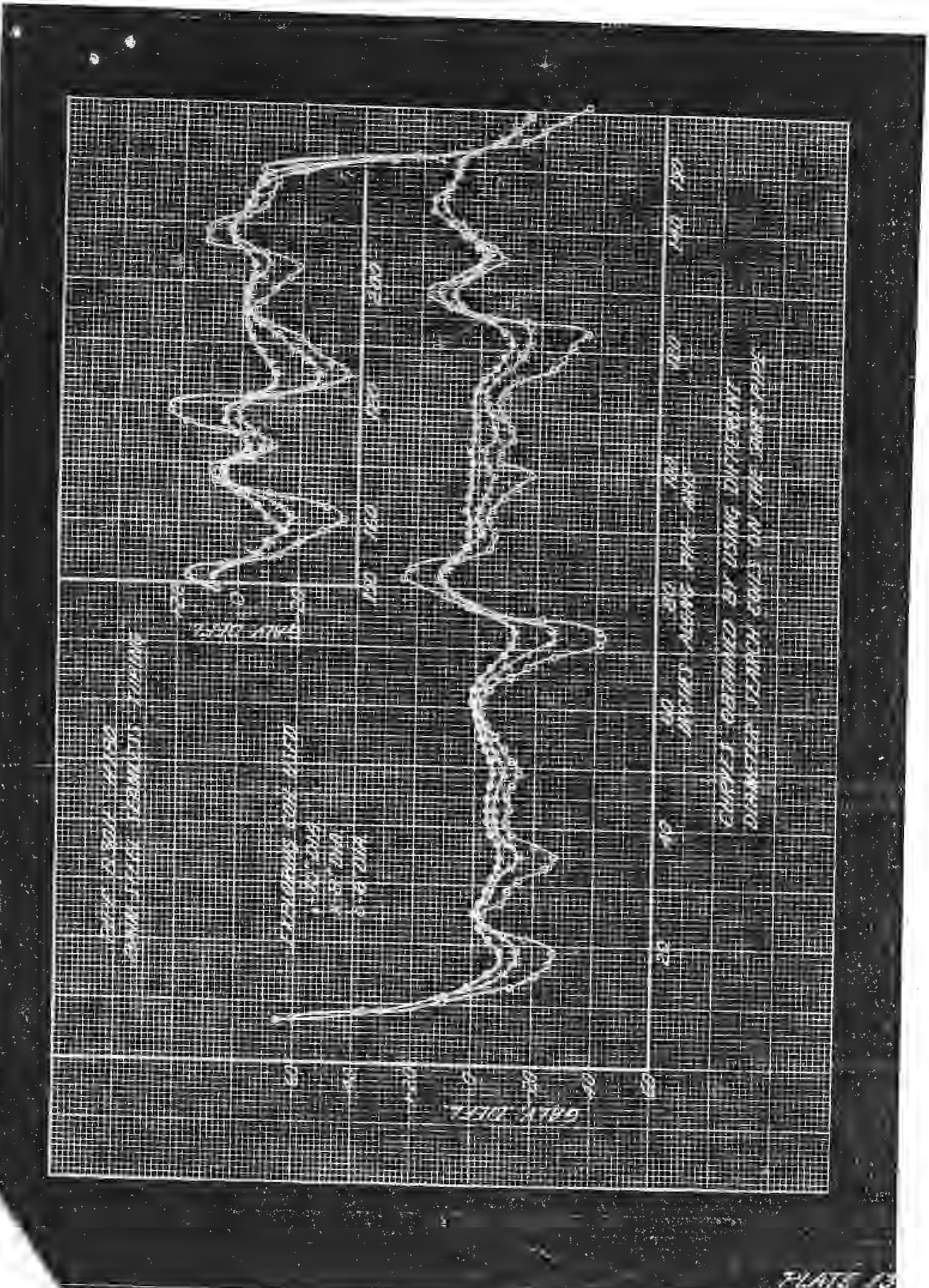

CURVES OBTAINED BY USING DIFFERENT
DIAMETER SEARCH COILS ON THE SAME PIPE

PLATE 13

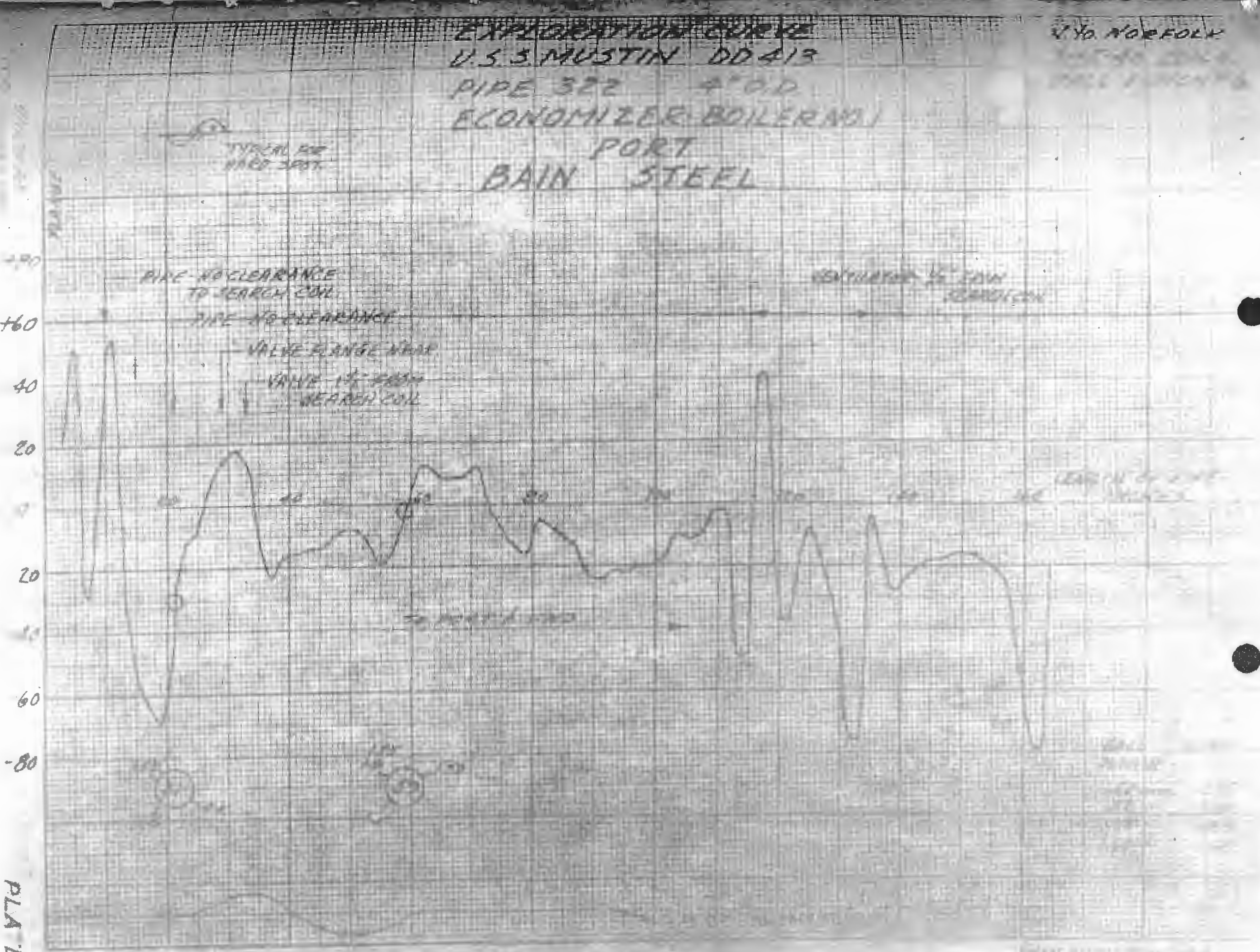


PLATE 12

1605