UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 196

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AN ELECTRONIC DETECTOR FOR LOCATING REINFORCING BARS EMBEDDED IN CONCRETE

By

C. R. Daum

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Denver, Colorado

February 23, 1946

HYD 196

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division

Laboratory Report No. 196
Hydraulic Laboratory
Circuits Designed by:
L. T. Cleaver and
C. R. Daum
Constructed by:
L. T. Cleaver
Written by: C. R. Daum
Reviewed by: D. J. Hebert

Denver, Colorado
February 23, 1946

Subject: An electronic detector for locating reinforcing bars embedded in concrete.

Introduction. In the construction of outlet works for various dams, it has been a complicated operation to drill grout holes through the concrete lining of the diversion tunnels because of heavy reinforcement steel embedded therein. To avoid this complication in the outlet tunnel at Anderson Ranch Dam, it was suggested by the project that consideration be given to the procurement of equipment capable of locating the reinforcing bars prior to the drilling operation. As a result of a conference between D. S. Walters, Acting Construction Engineer at Anderson Ranch Dam, and R. F. Blanks, Chief, Engineering and Geological Control and Research Division, Denver office, the problem of developing an electronic detector was assigned to the electronics section of the hydraulic laboratory.

Summary. Several different methods for locating metal were investigated before one was found which was suitable for use in locating reinforcing bars at the required depths. A satisfactory instrument was developed.

Laboratory tests on two concrete blocks with embedded reinforcing bars demonstrated that the instrument will locate bars at a depth of 4-3/4 inches and will distinguish bars 6 inches apart at that depth. It was also established that the condition of the concrete had no effect.

The instrument proved to be very satisfactory in field tests in the diversion tunnel at Anderson Ranch Dam. Despite fluctuation in the

supply voltage and the high level of noise in the tunnel, reinforcing bars at a depth of 5 inches and a spacing of 6 inches were easily located to the satisfaction of the field personnel. The possibilities of the instrument were demonstrated by locating a few bars at a depth of 18 inches, using signal overtone variations. This use of signal overtone variations required careful adjustment of the cut-off control. Two locations, one at 5-inch and one at 18-inch depth, were actually checked by drilling.

The field tests indicated that several minor changes in the equipment would be desirable. These changes, which will be discussed subsequently, will be made when the equipment is returned to the Denver office.

Operation. After receiving the apparatus, remove the chassis from the cabinet and inspect the wiring for loose connections. Insert the tubes in their designated sockets. Replace in the cabinet and attach the magnet-pick-up cable to its designated socket. Attach the power cord to its socket, and connect to 110-120 volts A.C. Throw the "off-on" switch on the front of the chassis to the "on" position. The pilot lamp should light. Allow about 10 minutes for the set to warm up and stabilize. Rotate the control knob on the front of the panel to the right. A strong signal should be heard in the earphones. Rotate the control knob slowly to the left until only a very weak signal is heard in the phones. Move the electro-magnet across the face of the concrete in a direction perpendicular to the axis of the bars to be located and with the magnet parallel to the bars. As the magnet passes over the bar, an increased signal will be heard in the earphones. The point of maximum signal indicates the position of the reinforcing bar. A photograph of the separate components is shown in figure 1A and figure 1B shows the equipment in operation.

Maintenance. No maintenance should be attempted in the field except the replacement of tubes and inspection for loose connections. If the equipment fails to operate properly, it should be returned to the Denver laboratory for repair.

Development Procedure. There are three fundamental principles used to locate buried wires and metals; namely,

1. Change in frequency of an electronic oscillator due to the presence of metal.

A - Component parts

B - Set in operation

ELECTRONIC DETECTOR FOR LOCATING STEEL IN CONCRETE

2. Application of an alternating current to energize the metal.

3. The effect of distorting the field around an electromagnet.

The last-named principle was found to be the most practicable and adaptable for the subject apparatus.

The first principle involves the use of an electronic oscillator which acts as a source of energy that varies in frequency from 100 kilocycles to as high as 3 megacycles per second. If a piece of metal is introduced into the field of the oscillator coil, the frequency of oscillation will change. There is a decided advantage to this type of detector in that any metal will affect the frequency. Magnetic metals will increase the effective inductance of the coil and will thus decrease the frequency of oscillations. A non-magnetic metal will have the inverse effect. The change of frequency can be detected by comparing this oscillator output with another fixed oscillator of approximately the same frequency. In the laboratory, the frequency used was 140 kilocycles. The range of this type of instrument is directly related to the diameter of the coil used; i.e., to have an approximate range of 6 inches, a coil 6 inches in diameter would have to be used to realize even a slight change of frequency. A coil of this size would spread out over too large an area and so would not differentiate between bars 6 inches apart.

A variation of this method using an audio-oscillator with a small, open-field, iron-core inductor for tuning was also tested. The frequency was approximately 10,000 cycles per second. The presence of iron within the field of the inductor increased the effective inductance and thereby decreased the frequency of oscillation. The field, however, did not extend out far enough. The range for the instrument was only about 2 inches.

In applying the second principle, the metal itself is energized. One procedure is to pass a current through the metal and use a small exploring coil to detect the radiated field. It would be impractical to pass a current through the network of reinforcing bars, so this adaptation was not tested. It is used for locating single buried telephone cables.

A test was made using a procedure in which a voltage was applied between the bars and the surface of the concrete. The equipment was designed to indicate changes in current and indirectly detect variation of resistance between the bars and the surface of the concrete. The position of minimum resistance would indicate the location of the embedded bar. The method was abandoned when it was found that variations in water content of the concrete gave incorrect results.

The third principle, which utilizes the distortion of a magnetic field, was applied in two ways. The first method used 1,000-cycle voltage to drive a small laminated-core electro-magnet connected into one leg of an inductance bridge. Approximately five watts of power was available for energizing the bridge. The sensitivity was high to small movements of the order of one inch. It would have been a good instrument for the comparison of paint thickness on sheet iron but did not have enough range for the present.

Equipment designed according to the third principle demonstrated a need for several changes. The power for driving the electro-magnet was increased to obtain more sensitivity. A longer magnet was built to increase the penetration. The bridge circuit was eliminated because it was tedious to adjust for balance. High sensitivity required silence in the earphones, which could not be attained due to stray 60-cycle pick-up from extraneous sources.

Ample power for driving the electro-magnet was obtained by converting to the power frequency of 60 cycles. That change simplified the problem of eliminating stray fields. The length of the magnet core was increased from 4 inches to 36 inches. In the case of the magnet entirely in air, the magnetic path included approximately 36 inches of iron and 22 inches of air. With an iron bar 6 inches from the pole faces of the magnet, a new path was created with 60 inches of iron plus 12 inches of air. The effective decrease in the length of the magnetic path produced an increase in the lines of magnetic force cutting the pick-up coils and induced an increased voltage.

The revised electro-magnet was built of approximately 50 layers of 30-gage hot-rolled iron cut into strips 3/4-inch wide and 36 inches long. The individual strips were dipped in a lacquer paint and dried before assembling into a core, to eliminate eddy current losses. A layer of friction tape was wrapped around the laminated core as a binding and insulating medium. Three layers of insulated wire of approximately 600 turns each were then wound over the friction tape. The three layers of windings were connected in parallel to a 6-volt secondary of a transformer, from which nearly 30 watts was supplied. The windings were approximately 22 inches long. A bend was made in the laminations (figure 1A) about 7 inches from each end to form a long "U" for the exploring probe. The faces were cut square and filed smooth. To complete the probe, a coil of 500 turns of small wire was scramble wound near each end of the lamination, each to serve as a pick-up coil. The voltage induced in these coils was fed into the first amplifier, a 6AC7 electronic tube. The combined voltage was too large, in that the grid of the first stage was overdriven and full amplification could not be realized. To correct this feature, another winding of 50 turns was added near the center of the activating coil and connected in phase opposition to the two pick-up coils. The field near the center of the activating coil remains quite constant and thus the 50-turn coil voltage does not impair the sensitivity of the instrument.

The final circuit is shown in figure 2. The output of the first stage is resistance-capacity coupled into the grid of a 6J7 stage. This stage is different from an ordinary amplifier in that the negative grid bias voltage may be increased to such a value that all plate current is cut off, or such that only the positive peaks of the input signal will cause the tube to conduct. This is represented in figure 3. Curve "a" represents the plate current plotted against grid voltage. Point "P" represents the cut-off potential for the grid, or, the voltage at which the plate current is zero. If a signal is superimposed on the steady grid voltage, and the steady voltage is adjusted more negative, a voltage may be found such that only the positive peaks of the signal will cause the plate circuit to conduct. The curve "b" represents the steady state for grid voltages and curve "c" gives the plate current. If the input signal is increased, as curve "d" signifies, the plate circuit will conduct more current and for a longer period of time, as indicated in curve "e." The harmonics, or overtones, added to the signal by this stage make it easier for the ear to distinguish differences in noise level in the phones. The output signal

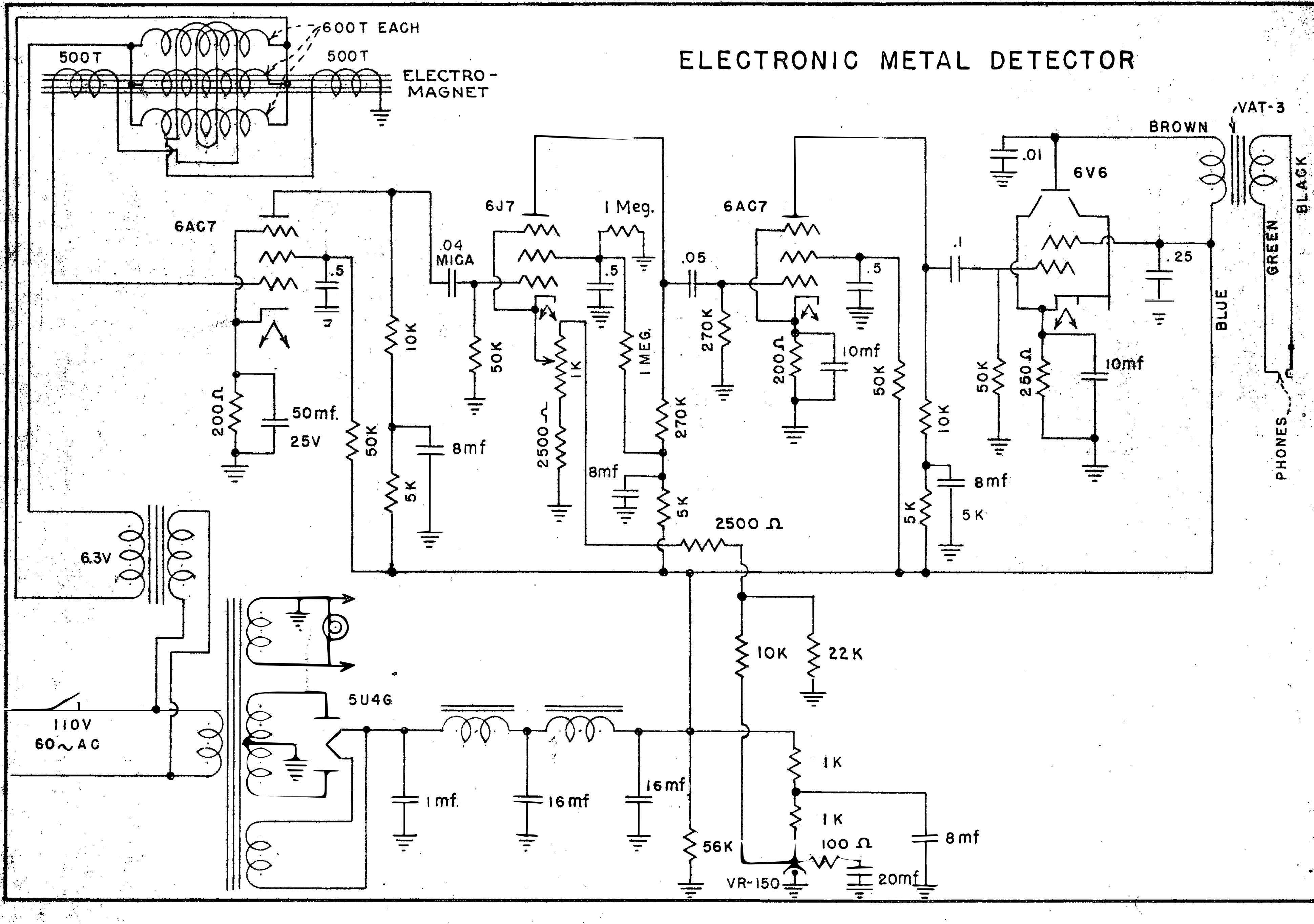

ELECTRONIC METAL DETECTOR
600T EACH
500T
500T
ELECTRO-
MAGNET
6AC7
6J7
1 Meg.
6AC7
6V6
.01
BROWN
VAT-3
BLACK
GREEN
BLUE
PHONES
.5
.04
MICA
.5
.05
.5
.1
.25
200Ω
50mf.
25V
50K
10K
5K
8mf
50K
1K
2500Ω
1 MEG.
270K
8mf
5K
2500 Ω
270K
200Ω
10mf
50K
10K
8mf
5K
5K
50K
250Ω
10mf
6.3V
5U4G
110V
60~AC
1mf.
16mf
16mf
10K
22K
1K
1K
8mf
100 Ω
56K
VR-150
20mf

FIGURE 3

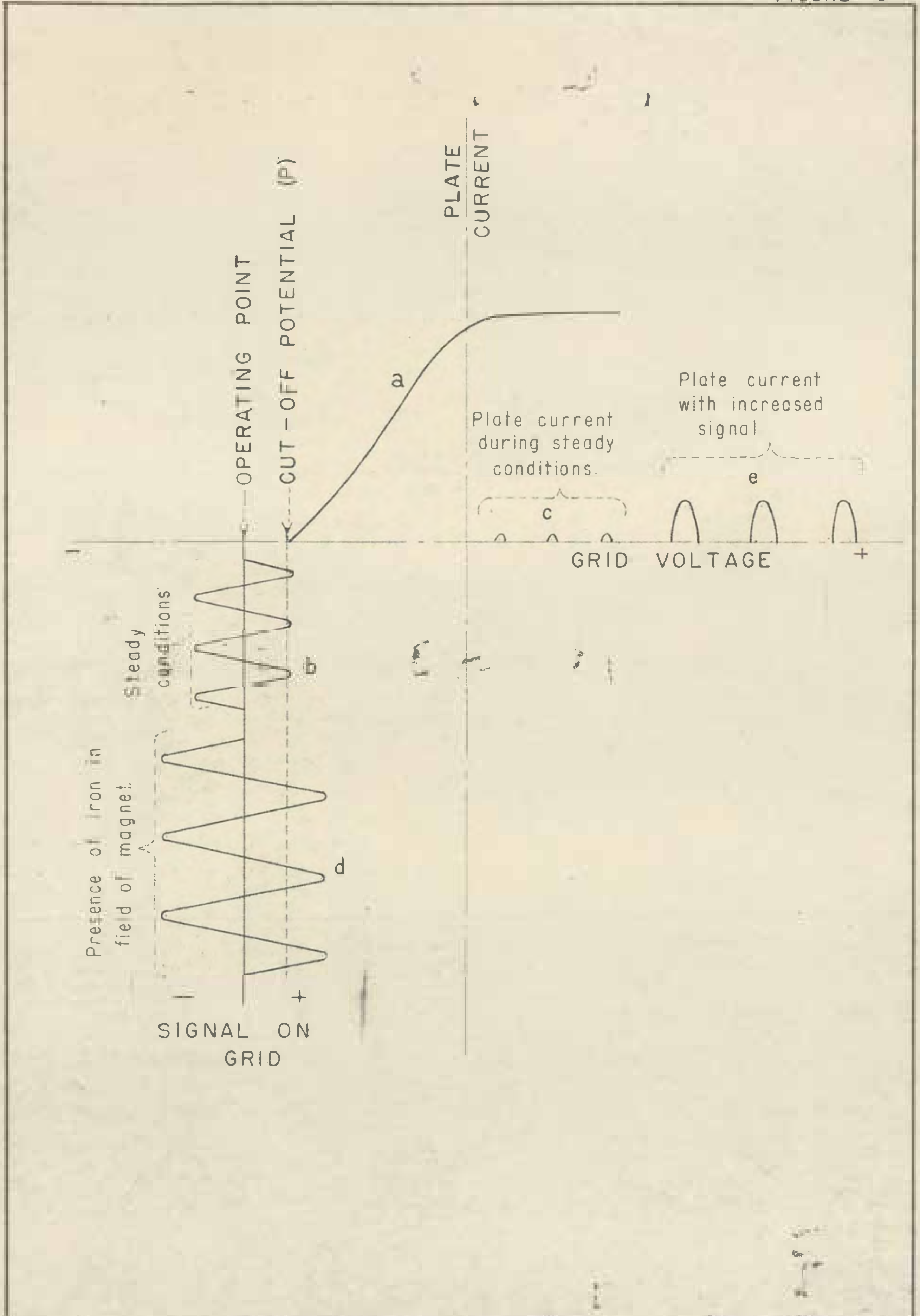


PLATE CURRENT
OPERATING POINT
CUT-OFF POTENTIAL (P)
a
Plate current during steady conditions.
c
Plate current with increased signal
e
GRID VOLTAGE
Steady conditions
b
Presence of iron in field of magnet.
d
SIGNAL ON GRID

from this stage is further amplified by a 6AC7 stage and coupled to a 6V6 power output stage and to the earphones.

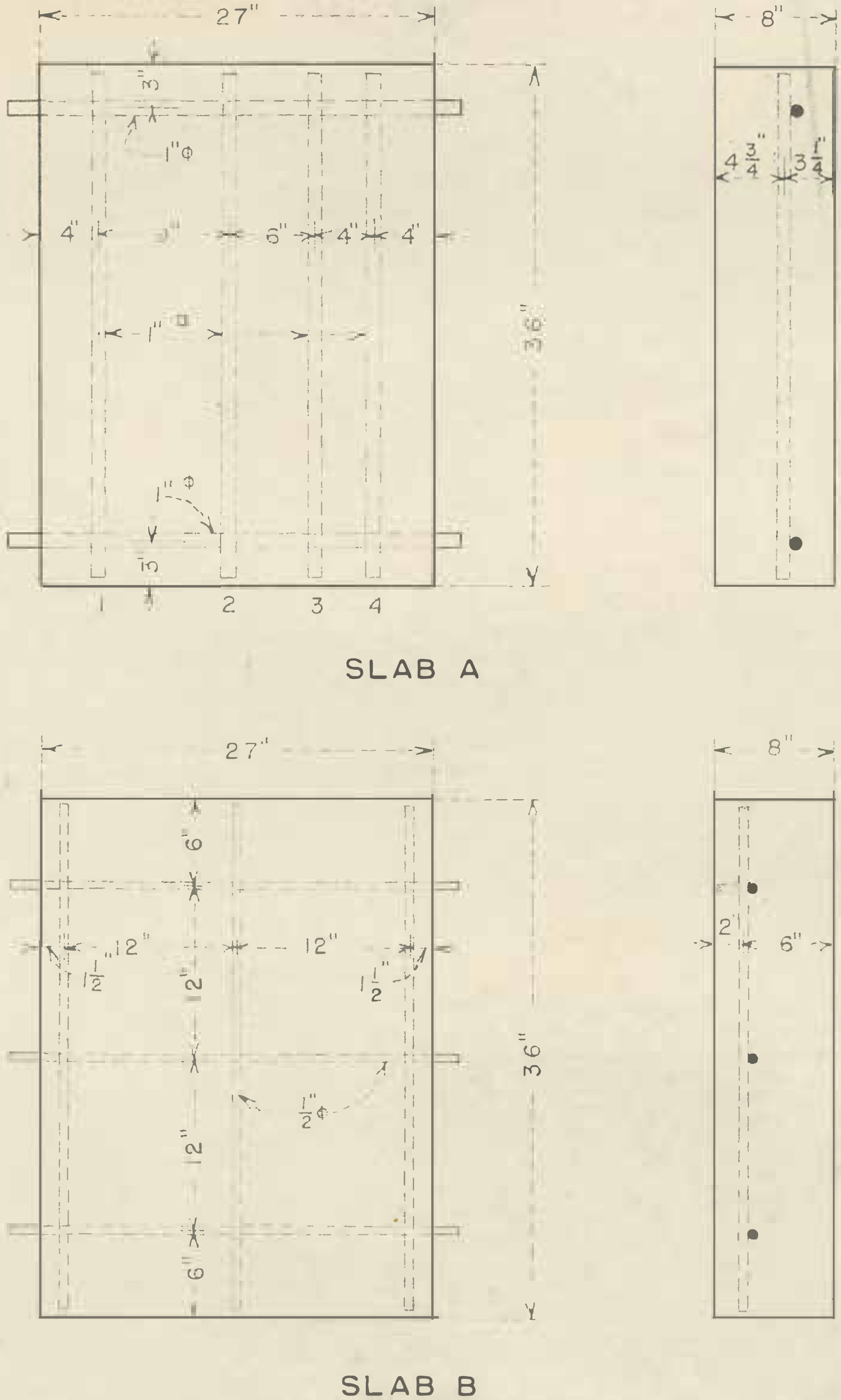
The windings on the magnet are connected to the chassis through two-conductor shielded cables approximately 10 feet long, and another pair is brought from the chassis for connection to the earphones. All cables are taped together for convenience.

A suggestion was made that a higher frequency be substituted for the power frequency to drive the electro-magnet. There would be an advantage in that the ear is more sensitive to a signal of 1,000 cycles than one of 60 cycles. An audio-signal generator and amplifier were connected to the electro-magnet, and several frequencies were tried. The results were negative since the sensitivity was decreased probably due to increased eddy current loss in the core. In addition, the pick-up of stray 60-cycle field in the laboratory was still too strong. The tests showed that the building of additional equipment for driving the magnet at a higher frequency was not warranted.

Laboratory Tests. Two concrete blocks 3 feet by 2 feet 3 inches by 8 inches were prepared in the concrete laboratory, with embedded reinforcing bars arranged to form a grid. The actual location of the bars is shown in figure 4. The reinforcement bar pattern was determined by use of the apparatus and compared with the designed location. In block A, bars 1 and 2 were located within an error of 1 inch, but bars 3 and 4 gave a continuous indication in the earphones. Close agreement in the location of bars 1 and 2 was realized from either side of the concrete. The bars in block B were located quite easily from the surface closest to the bars within an error of one-half inch. To locate the $\frac{1}{2}$-inch bars from the more distant surface required considerable care in adjusting the control on the apparatus. The increase in intensity of the signal in the earphones was slight.

Field Tests. On January 29 and 30, 1946, L. T. Cleaver, Engineering Aid, conducted field tests on the equipment in the diversion tunnel at Anderson Ranch Dam. A preliminary check of the equipment disclosed two loose connections due to shipment, which were repaired.

The lining of the diversion tunnel is approximately 24 inches thick with a layer of 1-1/4-inch reinforcing bars at 5 inches and one at 18-inch



LOCATION OF REINFORCEMENT BARS
IN CONCRETE TEST SLABS

depth from the face of the concrete. The bars were laid on approximately 6-, 8- and 12-inch centers at different locations in the tunnel, but may have shifted from these positions when the concrete was poured.

The bars at the 5-inch depth, with an original spacing of approximately 6 inches, were located quite easily by signal strength variations. Some bars at the 18-inch depth were located by signal overtone variations, and the locations were checked by actually drilling into the tunnel walls for a bar at each depth. The use of signal overtone variation required extremely careful adjustment of the cut-off control and was a tedious operation. A variable tap transformer with range of 6 to 12 volts used to energize the electro-magnet would give control over the field of the probe and would increase the sensitivity for locating the deeply embedded bars.

The reinforcing bars overlapped in two areas, one near the top of the tunnel on the south side and the other near the bottom of the tunnel on the north side. The lap area is 50 bar diameters wide or, in this case, approximately 6 feet wide. Within the lap area, the effective distance between the bars is approximately 2-3/8 inches, 4-3/8 inches and 9 inches, respectively, in the 6-, 8-, and 12-inch space areas due to the double bar effect.

In the lap areas where the original spacing was 6 and 8 inches, a continuous indication was obtained as predicted from the laboratory tests and the bars could not be separated. Some variation in the signal could be detected over the area with an original spacing of 12 inches, but it was not definite enough for accurate location.

One of the difficulties encountered was that of voltage fluctuations in the 110-volt, 60-cycle, alternating-current power supply serving the tunnels. Intermittent use of machinery connected to the same line caused voltage variations of as much as 50 volts. Power fluctuations could be minimized by having a separate line for the detector equipment or by using a voltage stabilizing transformer. The addition of a transformer would increase the weight by an objectional amount. In the location tests, the fluctuations were offset by working over a small area several times.

The noise made by the operation of jackhammers and other machinery interfered with the perception of signal variation in the earphones. This interference could be minimized by using rubber cups on the earphones. Better still, a visual indicator such as a 6U5 electron-ray tube (tuning eye), could be substituted for the earphones. This tube, incorporated into the circuit, would be rugged and quite sensitive. It would not be injured by an over-voltage, which would burn out a sensitive meter.

The field tests served to demonstrate also the need for some rearrangement in the equipment. As built, it is too heavy for one operator to move conveniently. It can be built in two parts and connected by a cable. It was suggested at the project that the division be made in such manner that the part containing only the lighter and more fragile components, such as vacuum tubes, could be carried as a pack on the operator's back. The part containing the heavier components, such as transformers, would be more rugged and could be handled with less care. The necessity of supplying high voltage to the tubes makes this particular arrangement inadvisable because it would expose the operator to the danger of shock. Use of the equipment at Anderson Ranch Dam is expected to develop suggestions which will help in determining the final arrangement.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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OPERATION AND USE OF ELECTRONIC DETECTOR FOR LOCATING REINFORCING BARS.

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ANDERSON RANCH DAM
BOISE PROJECT, IDAHO

March 14, 1947

HYD-196

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Anderson Dam, Idaho

March 14, 1947

To: Denver Office - Attention: Chief Engineer

From: Construction Engineer

Subject: Report on the operation and use of Electronic Detector for locating reinforcement bars - Anderson Ranch Dam, Boise Project.

1. Specifications No. 965, covering construction of Anderson Ranch Dam and Power Plant, provided for drilling and grouting the rock surrounding the outlet tunnel. It was originally planned to do this drilling and grouting work in the spring of 1942 after the lining was completed. Because of the delay in concreting operations and the desire for early river diversion to allow dam foundation work to proceed, the Contractor was given permission to defer the drilling and grouting to a later date.

2. Since several rings of grout holes were to be drilled in a section of tunnel the lining of which was very heavily reinforced, it was thought desirable to provide some means of locating the reinforcement bars so the grout holes could be drilled between them. Anticipating that drilling and grouting in the tunnel would be started in January 1946, an inquiry was made of The Goldack Company of Glendale, California in October 1945 to determine if they had, or could manufacture, an electronic instrument by means of which the reinforcement could be located. The Goldack Company started some experiments and reported they could furnish equipment on the basis of a full approval by the Government of its performance. These facts were called to the attention of Mr. R. F. Blanks in the Denver office and he suggested that suitable equipment could be developed in the Bureau's Denver laboratory.

3. The development of the detector was started in December 1945 and was completed in January 1946. Mr. L. T. Cleaver, who worked on the development of the instrument, brought it to Anderson Ranch Dam on January 28, 1946 for field trials. These tests were conducted in the tunnel under the most adverse conditions possible. Noise from the different types of air drills made it almost impossible to carry on a conversation. Also there was extreme variation of power line voltage. Several tests were made and it was found that the instrument would perform satisfactorily. Mr. Cleaver then returned to Denver leaving the instrument on the project together with complete instructions for its use.

HYD-196

4. Other necessary work caused considerable delay in the starting and progress of the grouting operations, and by the middle of January 1946 it became apparent that the program for grouting in the heavily reinforced section of the tunnel would be delayed a year. Hence the need for the detector was not acute, but it remained on the project throughout the year 1946.

5. When grouting was resumed in the tunnel in January 1947, the detector was used to accurately spot the location of some 84 drill holes. A few of these holes were spotted before the noisy operations were started, but most of them were spotted under very noisy conditions. The voltage of the electric power line was more uniform than it had been during preliminary field testing of the detector.

6. Mr. A. V. Lane, a Bureau employee on the project who was at one time a professional radio repair man, assisted Mr. Cleaver with the field testing of the detector in January 1946; and has operated the equipment at all times during its use for spotting grout holes in the tunnel. Mr. Lane had a decibel meter of his own which he tried out in place of the head phones. In his opinion the use of the meter was much preferred because visual observation was much more reliable than auditory observation. This was especially true when the noise of the drills was present.

7. It was found that the location of the inner curtain of reinforcement steel could be determined at all times. In the area where spacing was eight inches or more the use of the instrument proved valuable, and only in a few instances (when the outer bars were not directly behind the inner ones) was the reinforcement encountered by the drills. Where the bars were spaced on six inch centers the use of the instrument was of little value. The bars could be located, but very often there was not enough space between them to allow room for the three inch percussion bits that were used to drill through the concrete lining. When the bit found room in the inner curtain it generally encountered reinforcement in the outer curtain. In one instance thirteen holes were drilled in an area of about one square foot before successfully passing the reinforcement. However, in several instances the spotting was successful even where the reinforcement bars were spaced at 6-inch centers. In the area having only one curtain of steel with 8 inch minimum spacing, the instrument proved satisfactory.

8. It can be reported that the instrument performs the work for which it was designed. It is somewhat heavy and bulky, and its usefulness would be enhanced if it could be constructed so as to be more portable. If it were equipped with a visual indicator, and one man could carry and operate the instrument, it would be more practical. As now constructed two men are required to operate it. On several occasions it was necessary to delay the start of drilling operations until an extra Government employee was available.

9. Attached hereto are two photographs showing the electronic detector being used in the tunnel.

10. The detector was returned to the Denver office on February 26, 1947.

11. The development of the electronic detector is covered in Hydraulic Laboratory Report No. 196, An Electronic Detector for Locating Reinforcing Bars Embedded in Concrete, By C. R. Daum, dated February 23, 1946.

D. J. Walter

In dupl. w/- encls.

CC—Reg. Dir.,
Boise, Idaho w/- encls.

—Distr. Manager,
Boise, Idaho w/- encls.

3702 - ELECTRONIC DETECTOR - Inspectors A. V. Lane and C. A. Jungquist are operating the electronic detector to accurately determine the location of imbedded reinforcement in the outlet tunnel concrete lining, and thereby determining locations for drilling grout holes.

L. R. Murphy January 13, 1947

HYD-196

AD7-2 - ELECTRONIC DETECTOR - Use of a decibel meter instead of headphones with the electronic detector, as shown, is believed by the operator to be more satisfactory in the noisy tunnel.

L. R. Murphy January 13, 1947