An experimental closed-loop degaussing system: trials on HMCS "Cowichan" (MCB 162), Esquimalt, B.C., Aug. and Sept. 1959

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273292
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB); no. ERB-531, 1959-12

ERB-531

SECRET

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

AN EXPERIMENTAL CLOSED-LOOP DEGAUSSING SYSTEM

TRIALS ON HMCS "COWICHAN" (MCB 162)
ESQUIMALT, B.C. AUG. AND SEPT. 1959

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OTTAWA

DECEMBER 1959

ABSTRACT

An experimental closed-loop degaussing system was installed on the minesweeper HMCS "Cowichan." Trials which were conducted to determine its performance under static and dynamic conditions and to compare it with the ship's open-loop degaussing system are described. The system itself functioned satisfactorily and adequate gain and stability of the closed loop were achieved. However, the positioning of the gradiometers used as magnetic gradient error detectors in the closed-loop system, was a major problem which was not completely solved during these trials. As a result the closed-loop degaussing achieved was inferior to the best open-loop degaussing.

Important auxiliary results were obtained: open-loop degaussing was improved; the degaussing of the magnetic clutch was found to be satisfactory; the ship's eddy-current field was found to be unchanged since launching; a new ranging technique was developed using a rolling machine introduced by the Royal Canadian Navy.

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- R.M. Morris B.O. Pedersen O. Petersons -

INTRODUCTION

A "closed-loop" or self-monitoring degaussing system proposed earlier [1] was installed and tested on the Canadian Minesweeper HMCS "Cowichan" at Esquimalt, B.C. The system was designed to null the resultant of the opposing fields of the ship and the ship's degaussing coils, at detector positions just above the deck. For symmetrical fields above and below the ship, this should result in zero field under the ship as well, thereby producing the desired degaussing effect. The closed-loop control was applied to the ship's "M" and "A" systems only, the existing (open-loop) controller providing "L" degaussing.

It had been found in previous trials [2] that the ship's open-loop degaussing control worked correctly, but that the ship's coiling could not effectively compensate the non-symmetrical signature. For the present trials it was planned to correct this non-symmetry by installing local degaussing coils and to adjust the open-loop system to its optimum performance. The open-loop system would then provide a good reference with which the closed-loop system could be compared.

TRIALS PROGRAM

Trials were carried out during a six-week period in August and September 1959. During the first two weeks of this period, the closed-loop system and test equipment were installed on the ship, and the magnetic measuring range was set up in the RCN dock. In the following two-week period, system trials were carried out in this dock with the ship on a 180° magnetic heading. The magnetic measuring range was then moved to the Department of Public Works (D.P.W.) dock (incorrectly called "Department of Transport Dock" in previous reports). Trials were continued in this dock during the fifth and sixth weeks on headings of 61° and 241° magnetic. Dock trials were followed by one day of sea trials, a part of which was spent in ranging the ship on the RCN shallow magnetic range (depth about 26').

OPEN-LOOP DEGAUSSING SYSTEM

In an open-loop system the output of the controller depends only on the input quantities and the calibration of the control mechanism. A block diagram of the open-loop degaussing system installed on the "Cowichan" is given as Fig. 1. The input quantities to the controller are: heading information, supplied by the ship's gyro compass; roll and pitch information supplied by a vertical gyro stabilizer; and earth's field information supplied through manually adjustable auto transformers. The controller is calibrated by magnetic ranging of the ship (Appendix 1). Its output which is proportional to the induced field of the ship, is combined with a bias to compensate the permanent magnetism of the ship, and is used to control the ship's degaussing currents. A detailed description of the system is given in [3]. A separate investigation was carried out on the power amplifier section of the controller to determine its suitability for use in the closed-loop system [4].

CLOSED-LOOP DEGAUSSING SYSTEM

In a closed-loop system the input to the controller is a measure of the error between the actual output and the desired output, the system functioning in such a fashion as to minimize this error. Performance is not critically dependent on system gain as it is in the open-loop system.

An ideal degaussing system of the closed-loop type would provide completely automatic degaussing under all conditions. In such a system the error between the magnetic field of the ship and the field of its degaussing coils must be measured. The method adopted here is shown in Figs. 2(a) and 2(b). Gradiometers were mounted in the "M" and "A" fields above the ship, as shown. It would be preferable to mount the gradiometers below the ship but practical considerations prevent this. Fig. 3 is a block diagram of the "M" component closed-loop system. Details of the closed-loop system are given in Appendix 2.

INSTALLATION OF CLOSED-LOOP SYSTEM

It was planned to install and adjust the closed-loop system during the first two weeks of the trials. The equipment was installed as planned, but the positioning of the gradiometer tubes and the adjustment of the system—which were the major problems of the trials and are described in this section—were carried out over the whole period of the trials concurrently with the range measurements.

The experimental system was arranged as shown in Fig. 4. The ship's "M" and "A" degaussing were modified so that control could be transferred from the installed open-loop system to the experimental closed-loop system by a simple switching operation. Existing three-stage magnetic amplifiers and d-c generators were common to both types of system as the power amplifier stages. These amplifiers were altered slightly to produce higher gain during closed-loop operation.

The gradiometer-type error detectors are described in Appendix 3. These were tested for alignment and drift (Appendix 3) just before installation on the ship. The electronic units (Fig. 5) were mounted in the generator room. The gradiometer tubes were to be mounted above deck, but an extensive investigation was required to find the best position for these.

A position near midship was judged to be the most suitable for the gradiometer tubes for the following reasons:

1) the ship's fields are maximum at this position;
2) the influence of the transverse components of the ship's "L" field on the "M" gradiometer is theoretically minimum, as indicated by the signature shown in Fig. 2(c);
3) a convenient location for the gradiometer exists just forward of the funnel at the level of the forecastle deck. This is near midship.

In order that the closed-loop system produce the same degaussing currents as the open-loop system, the gradients measured by the gradiometer at the position under consideration must be zero with the open-loop system in operation. When this test was applied to the midship position, large gradients were measured. These were attributed to the fields of nearby iron parts. Other positions (Fig. 6) were investigated in the same way, but the only positions free from local gradients, although used during some of the range trials, were considered to be too far aft of midship. The tubes were therefore returned to midship, and an attempt was made to obtain zero gradiometer output by reducing local gradients. Several methods were employed: the steel heating boiler which was directly under the starboard end of the gradiometer tubes, and the 400 cps motor-generator sets on the starboard side of the generator room were degaussed by individual "M" coils; various moveable iron parts, such as the Orapesa sweep, hammer box, and spare gun barrel, were moved out of the area near the gradiometers. An attempt was made to avoid local gradients or balance them out by slight movements of the gradiometer tubes in the transverse direction, but this was unsuccessful.

In spite of the alterations described above, gradients at the detectors remained large. It was concluded that even though the open-loop system produced good degaussing under the ship, degaussing above the ship at the gradiometer positions was poor. The turns distribution between upper and lower "M" coils was readjusted to correct this condition. With the final coiling as shown in Fig. 7, it was possible to obtain zero gradient and good degaussing. These adjustments were made with the ship on a 241° heading. The effect of heading change is discussed later.

In both midship and aft positions of the gradiometers it was possible to switch the control to closed-loop operation and to stabilize both "M" and "A" channels with the "L" channel on the open-loop system while at the same time retaining sufficient gain to null the gradient at the gradiometers. Although some ranging was done using the aft position, the midship position was considered more suitable. The gradiometer tubes were finally mounted rigidly in that position as shown in Fig. 8. Evaluation of the system by ranging in the E-W dock and by sea trials was then carried on.

SYSTEM TRIALS AND RESULTS

Range instrumentation is described in Appendix 4, details of ranging techniques appear in Appendix 5, and the condition of the ship is described in Appendix 6.

a) RCN Dock Trials

The first tests of the closed-loop system were carried out in the RCN dock on a south heading at 15.5 feet depth. Before turning on the closed-loop system, the magnitudes of interfering gradients not due to the ship, were measured. The ship was towed along the center line of the dock while gradients as measured by the gradiometers were being recorded. This test disclosed that gradients due to the dock buildings and fittings were so large that the ship's closed-loop degaussing system could not operate in this area. However, it was possible to make some of the preliminary adjustments of the closed-loop system described in the previous section.

The remaining time in this dock was devoted to measurement and adjustment of coil fit and open-loop degaussing. The local "M" coils described in the previous section and the magnetic clutch degaussing system [5] enabled a much improved coil fit to be obtained.

The degaussing achieved after improved coil fit is shown in Figs. 9 and 10. These profiles were obtained by the towed-ranging technique described in Appendix 5. The effectiveness of the magnetic clutch degaussing system can be judged by noting the reduction in signature on the 8 feet to starboard profile in Fig. 9. Table I contains a summary of the results obtained during these trials and shows comparable results from former tests.

b) DPW Dock Trials

In the DPW dock, interfering gradients due to the dock were found to be small. Extensive ranging of the ship was carried out to compare the performances of closed-loop and open-loop degaussing systems.

Tests on the closed-loop system were begun with the gradiometers in the tentative stern position (Fig. 6) with the ship on the 61° magnetic heading, depth 22 feet. Under static conditions the closed-loop system was adjusted to produce the same degaussing currents as the open-loop system. Static signatures are shown in Figs. 11 and 12.

The ship was then turned into a 241° magnetic heading and neither "A" nor "M" currents, when controlled from the closed-loop system, assumed the same values as when controlled by the open-loop system. The resulting degaussing, as shown in Figs. 13 and 14, was inferior to the open-loop degaussing. The effect of the degaussing of the magnetic clutch is again apparent in Fig. 13.

Ranging was continued on the same heading with the gradiometer tubes in the midship position. The ratio between upper and lower "M" coils was altered to make this position useable, as explained in a previous section.

At this stage of the trials the rolling-towing technique described in Appendix 5 was introduced. Static degaussing and correction for roll can be evaluated simultaneously by this method. Results of these tests on west heading at 22-foot depth are given in Figs. 15 and 16 and at 30-foot depth in Fig. 17. Details of roll correction obtained by using the moored-rolling method are shown in Figs. 18 and 19.

The ship was again reversed in heading (to 61°) but the closed-loop method again failed to give proper degaussing on the new heading. Results of open-loop rolling-towing measurements appear in Figs. 20, 21, 22 for this heading at 22 and 30 foot depths. Further measurements of the behaviour of the closed-loop system with heading changes were made during the sea trials which followed these tests.

c) Sea Trials

The final tests of the trials were carried out on the open sea. Sea trials ensure freedom from external gradients, and give the opportunity of observing degaussing current variations with heading changes, and possibly during natural rolling and pitching of the ship, depending on sea conditions. The instrumentation was arranged so that degaussing currents controlled by the closed-loop system could conveniently be compared with those under open-loop operation, and system performance evaluated in this manner.

The gradiometers were in the final midship position. Variations of degaussing currents with heading changes are shown in Fig. 23. Unfortunately, no similar comparison could be made during rolling and pitching because of the calm sea condition during the sea trials.

To conclude the sea trials, the ship was ranged on the RCN shallow magnetic range (depth 26 ft., approx.). Results are included in Table I and in the graphs of Fig. 24.

DISCUSSION OF RESULTS

A summary of the results of all range measurements is given in Table I. For purposes of comparison, results of previous rangings [2] are included.

It is evident from Table I that the individual degaussing coils installed for these tests have been effective in reducing the ship's field. For instance, during the 1958 tests the sum of maximum static and maximum dynamic degaussed fields at 30 feet was 1.4 milligauss, while in 1959 under the same circumstances (open-loop degaussing) the sum was 0.6 milligauss.

The dynamic fields, Table I, have been extrapolated from test results to maximum roll conditions of ±25°. A recent British report [6] indicates that maximum roll angles for a similar class of ship under severe weather conditions are less than ±10°. The dynamic fields quoted in Table I may, therefore, be unduly pessimistic.

The dynamic field of the ship as obtained by the moored-rolling method was analyzed to obtain the eddy-current components by the method used previously [2]. Eddy-current fields are compared with those measured on the ship's hull in 1957 [7] in Figs. 25 and 26. Those eddy-current fields which are detectable by this measurement (those due to eddy currents in loops which contain longitudinal members) have not changed appreciably since launching.

The closed-loop equipment installed for these trials performed satisfactorily and the system is capable of nulling the field at the detectors. The real problem is to locate the gradiometers at a position above the deck where the field corresponds to the field conditions under the ship. From Table I it is clear that closed-loop degaussing was inferior to open-loop degaussing. The system could be adjusted for good static degaussing on one heading if there were no disturbing external gradients. However, as shown in Fig. 23, where the curves marked "Bogue" represent the correct degaussing currents, the closed-loop system did not have the proper variation with heading. Deviations in the "M" current — which has the larger variations from the required value — appear to be due to the ships "L" field. Possible interaction between "M" and "L" systems is illustrated by Fig. 2. The "M" field detector must be placed at section "MM" (Fig. 2c) in order to be unaffected by the "L" field, a condition which was obviously not met during these trials. Unfortunately the position used was the only possible one near midship.

During closed-loop operation, roll compensation is dependent on both amplitude and phasing of the field to be compensated at the detectors. Roll compensation in these latitudes is almost entirely by the "A" system. The amplitude of the dynamic "A" signal depends directly on the static "M" current, since the "A" system must correct the field due to tilting of the "M" coils. The dynamic field to be corrected by the "A" system is illustrated in Fig. 16, where it is obvious that this field occurs because of static degaussing. In Fig. 16, the poor quality of the dynamic closed-loop degaussing may be due to the low value of "M" current. In Fig. 17 the "M" current has been corrected and dynamic degaussing appears improved.

It was found during the trials that the gradient at the "A" detector had a component due to eddy currents in nearby aluminum structures (funnel and wheelhouse), which could produce an undesirable phase shift in the "A" degaussing current. Careful centering of the "A" tube, by balancing the effect of these symmetrical local eddy-current fields, minimized this phase shift.

CONCLUSIONS

1) It is feasible to design equipment for closed-loop degaussing, and adequate performance in gain and stability can be achieved.

2) Determination of suitable positions for gradient detectors above deck is difficult, since field conditions there must match those under the ship and interactions between systems (such as between "M" and "L") must be avoided. Acceptable positions for the detectors were not found during these trials and therefore degaussing with the closed-loop system was inferior to that with the open-loop system.

3) In this type of ship, efforts are made to keep the undegaussed signature as small as possible. Therefore at any detector position, fields of nearby small iron parts are apt to be as great as the field to be measured. Very extensive experimental work would be required to apply the closed-loop degaussing system successfully to minesweepers.

4) The system could be more suitable for iron ships where it may be possible to locate the detectors in a representative field of the ship.

5) Closed-loop degaussing of the ships "L" field was not investigated during these trials. This system would probably require a gradiometer of long base-length which would be correspondingly more difficult to construct and install.

6) Although the principal objective of the test was to investigate the closed-loop degaussing system, some useful auxiliary results were obtained:-

- a) By addition of local degaussing coils and adjustment of the open-loop system, the ship's total degaussed signature (static and dynamic exclusive of stray fields of electrical equipment) was reduced to 0.6 mg maximum.
- b) The eddy-current signature was found to be unchanged since launching.
- c) An experimental rolling machine was introduced by the RCN and proved to be of great value during the trials. This machine enabled a number of new ranging techniques to be investigated.

APPENDIX 1

ADJUSTMENT OF OPEN-LOOP DEGAUSSING CONTROLLER

The open-loop degaussing system requires correct adjustment of both induced field and permanent field magnitude controls for good degaussing under all conditions.

The AI and AP controls (Fig. 1) are normally set by ranging the ship on east and west headings and adjusting for best "A" degaussing in both cases. On a north or south heading, while the AP control can be set by static ranging, it is impossible to set the AI control. However, rolling tests provide a method of setting the AI control on any heading. As shown in Fig. 27, a rolling ship in the earth's vertical field produces a fundamental-frequency magnetic field which is maximum in the athwartship direction under the keel. This can clearly be seen in Fig. 16. The correct AI setting is the one which reduces this field to a minimum. It was found during these trials that the "A" current could be set satisfactorily in this manner.

Static ranging in a fixed vertical field provides no means of setting the MI and MP controls. However, the towed-rolling method (Appendix 5), or a combination of static ranging and moored-rolling tests, may provide a means of setting both of these controls correctly, although it was not possible to do so during these trials. As shown on Fig. 27 a rolling ship in an athwartship field produces a fundamental-frequency field which is maximum in the vertical direction under the keel. A procedure for setting "M" currents might be as follows, using the towed-rolling method. During several passes over the range, the "M" current for best static degaussing is determined. At the same time the rolling field is observed. A number of additional passes over the range would then be used to set the proportion of MI to MP of the determined static "M" current. The correct setting of MI and MP will give minimum fundamental-frequency vertical field under the keel. This adjustment would require greater amplitudes of roll than those obtained during these trials or greater horizontal ambient field.

The LI and LP controls (Fig. 1) are set by ranging the ship on north and south headings and adjusting for best "L" degaussing in both cases.

APPENDIX 2

DETAILS OF CLOSED-LOOP DEGAUSSING SYSTEM

Fig. 28 is a schematic diagram of the closed-loop degaussing system. The gradiometers, which are the error-detecting components of the closed loop, are described in Appendix 3. As shown in Fig. 4, the degaussing power amplifier [4] is common to the open-loop and closed-loop degaussing systems. A multipole ganged switch, Fig. 29, is connected to enable transfer of control from open loop to closed loop, and to provide increased gain of the amplifier during closed-loop operation. With the switch in the open-loop position, the degaussing current is fed back into the amplifier input winding 21-22, Fig. 29. During closed-loop operation, the switching arrangement eliminates this negative feedback loop, and feedback is provided instead by connecting winding 9-10 in series with a 5.6 megohm resistor across the output of the degaussing generator. This results in much increased amplifier gain while still retaining sufficient negative feedback to stabilize the amplifier.

APPENDIX 3

GRADIOMETERS

Two gradiometers were constructed for the trials, to serve as error detectors in the "M" and "A" closed-loop degaussing systems. Each gradiometer consisted of a detector head and a cabinet containing the associated electronic and metering equipment. A 50-foot multiconductor cable connected head and cabinet.

A diagram of the gradiometer is shown in Fig. 30. The gradiometer head contains three parallel magnetic sensing elements of the second-harmonic flux-gate type. Two of these elements have single-strip Mumetal cores and are connected to detect the difference in magnetic field or gradient between the two elements. The third element is of the double-strip type and detects the ambient field. It provides a signal for automatically balancing out the ambient field at each of the three elements. A further discussion of gradiometers may be found in reference 1.

The gradiometers constructed for the trials employed modified components of the Canadian Applied Research Ltd. type-T613 magnetometer. The double-strip magnetic sensing elements of the gradiometer heads were standard type-T613 magnetometer elements with an added winding for ambient field nulling. The single-strip elements were made by Canadian Applied Research Ltd. for this application and had the same three windings as the double-strip elements. Figs. 31 and 32 show the "M" and "A" gradiometer heads, respectively. The heads had the form of long 8-inch-diameter aluminum tubes reinforced by heavy aluminum rings about every 3 feet along their length. This resulted in an extremely rigid structure. The "M" tube was 15 feet long, with the single-strip elements mounted just inside each end, and the double-strip element mounted near the center of the tube. All three elements were parallel to the longitudinal axis of the tube. The "A" tube was 20 feet long, with the elements mounted in a similar manner but at right angles to the axis of the tube. A mechanism was provided at each gradient detector element to permit changing its physical alignment by a simple screw adjustment. The alignment-change mechanism is visible in Figs. 33 and 34 where the gradiometer elements have been withdrawn from the supporting tubes.

The electronic circuits of the oscillator and frequency doubler, gradient amplifier and ambient field amplifier units of the gradiometers are shown in Figs. 35, 36, and 37. These circuits incorporate the changes necessary to adapt the instrument for use as a gradiometer. Fig. 28 is a schematic diagram of the gradiometers as part of the closed-loop degaussing system. The available output of the instruments for a 1 mg field gradient between the elements was 0.5 volts.

The level of gradients to be measured on the ship by use of these tubes was expected to be in the neighborhood of 5 mg. The maximum allowable error in the gradient measurement due to misalignment of the gradiometer elements was therefore set at ±0.25 mg. As discussed in reference 1, this requires extremely accurate alignment of the gradiometer elements. The alignment procedure used is illustrated in Fig. 38. Misalignment errors were detected by systematic reversals of the gradiometer heads in a uniform field. The alignment was changed to reduce these errors to a minimum.

Drift of the gradiometer output was kept small by the use of high-quality components in all electronic circuits and by line voltage regulation.

It had been found that large gradiometer errors were caused by bending of the tubes when in direct sunlight. In the ship installation the tubes were fitted with white canvas covers to prevent this effect.

The overall maximum error in gradiometer output during the trials was judged to be ±25 gammas.

APPENDIX 4

RANGE INSTRUMENTATION

Magnetic measurements were made with the 30-detector magnetic range described previously [8]. The range patterns used in the RCN and DPW docks are shown in Fig. 39. An instrument truck at the dock side contained the electronic and metering equipment. Three magnetometer electronic units were used, to which the detectors could be connected in groups of three by means of a switching panel. The outputs of the three magnetometers were recorded on Brush oscillographs. This system enabled signals from all detectors to be sampled during a test.

The magnetometer electronic units had been constructed specifically for these trials. The circuit diagram of one magnetometer channel is shown in Fig. 40. The circuit uses a novel phase detector, described in [9], which avoids the usual requirement for a frequency doubler stage. The magnetometers performed well during the trials, requiring less frequent adjustment and exhibiting less drift than those used in previous measurements.

Amplitude and period of the ship's rolling motion were measured by a Muirhead recorder, Fig. 41, and an NRC roll angle recorder, which were installed in the ship's generator room. The roll velocity section of the Muirhead instrument had been fitted with a potentiometer to enable recording of the roll signal on a Brush oscillograph channel in the instrument truck. Common timing pulses could be superimposed on all records for correlation of measurements when required.

Telephones and intercom sets were used for communication between the control truck at the dock side, the ship's generator room, and the rolling device control station (Appendix 5) on the gun platform.

APPENDIX 5

RANGING TECHNIQUES

1) Towing Technique

To determine the static signature, the method of static positioning of the ship over the range [2] was replaced by a towing technique. Because of improved methods used by the dockyard staff, the ship could be towed along the center line of the magnetic field measuring range with only slight lateral deviations. Continuous magnetic field records (Figs. 9 to 14) were made during each pass over the range. Determination of the longitudinal position of the ship was made by visual sighting of objects on the ship's structure with respect to reference marks on the dock side.

In the RCN dock, the ship was towed by truck winches (Fig. 42) and constrained in the lateral direction by men on both sides of the dock who moved along the dockside holding lines fastened to bow and stern. A similar method was used in the DPW dock but the towing was done by power driven capstans.

2) Moored Rolling Technique

A very effective ship-rolling machine was developed by the Commodore Superintendent of the Pacific Coast and his staff. This machine was used in all rolling trials. It consists of two long aluminum cylinders one of which is attached to each side of the ship. The port cylinder is shown in Fig. 43. An open end of the cylinder extends into the water a distance of about five feet. The upper end of the cylinder is closed, except for an opening into a smaller vertical tube which has a constriction in its diameter, as shown in Fig. 43. Two nozzles, which are connected through valves to a supply of compressed air, one above the constriction and the second below it, can direct an air stream downward and upward, respectively, through the constriction. An operator, by means of the solenoid-operated valves, can direct air through each nozzle in turn thereby alternately pressurizing and evacuating the cylinder and thus producing upward and downward forces on the ship's side. This machine rolled the ship to angles of ±6° to ±9°, and could be controlled to produce very constant conditions of amplitude and period during a test.

A large number of measurements, such as those shown in Figs. 18 and 19, were made during the investigations of the two degaussing systems. Similar mooring methods to those described previously [2] were used.

3) Towing Rolling Technique
The new rolling machine and the improved towing technique made it possible to tow the ship across the magnetic range while rolling. This method provided a composite magnetic recording of static and dynamic fields (Figs. 15 to 17). It may be a suitable method for routine ranging of minesweepers since it shows immediately the relative importance of these two types of signature.

For this type of range test, a large compressor (Fig. 44) was mounted on the forecastle deck to supply compressed air to the rolling machine. In this position the compressor was high above the range and in a location under which the ship's signature was small. Its magnetic effect could therefore be accounted for in the measurements.

APPENDIX 6

CONDITION OF SHIP

The principal aluminum and ferromagnetic fittings have been described previously [2]. To determine the number and distribution of smaller ferromagnetic parts, an extensive survey had been carried out on March 10, 1959. This disclosed the presence of more than 300 items such as garbage cans, oil drums, fire extinguishers, spare hammer box diaphragms, etc. A list of such items has been compiled by the dockyard staff.

The rolling machine (Appendix 5) had no ferromagnetic parts. All ammunition was removed from the ship and replaced by 20 iron weights of 100 pounds each in the Bofors Magazine and one 100-pound iron weight in each of the six ready use ammunition lockers. A number of ferromagnetic parts including the Orapesa sweep, hammer box with three spare diaphragms, and two boxes of spares (105 pounds of iron in each) were removed from the ship early in the trials and remained on shore until completion of sea trials. The spare gun barrel was placed on the after-edge of the rolling platform.

Only the stern platform which had been used in the previous trials was fitted. When it was found possible to use the new rolling machine effectively, this platform was used only for holding top weight. Eight tons of lead were placed here and seventeen tons were placed on the forecastle deck. With this top weight in place the rolling period, although it differed slightly in the two docks, was between $10\frac{1}{2}$ and 11 seconds under all circumstances.

The ship's degaussing had been adjusted by ranging over the RCN shallow range by the dockyard staff. No permanent component of "A" field (AP) was discovered during these measurements. Since it was not possible to determine the induced component of "A" field (AI) on the north-south range, the dockyard staff had decided to turn off the "A" system completely. The very elaborate "A" tilt field corrector — which could not have been set properly in any case — had therefore been inoperative.

The hysteresis-type magnetic clutch which had been a source of large stray fields [2] was fitted with a degaussing coil [5], as shown in Fig. 45. This was connected for use only during automatic operation of the clutch as shown in Fig. 46. Two local loops were added to the "M" system, one consisting of 39 turns on the heating boiler and the other of 10 turns around the 400-cycle motor-generator sets on the starboard side of the generator room.

It was reported previously [2] that the degaussing currents were sometimes accidentally reversed while switching from one position on the degaussing controller master switch to the next position. This condition had not been corrected on the "Cowichan" controller.

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6. D.F. Walker. "The Compensation of Eddy Current Fields of Aluminum Framed Minesweepers". Reported by Underwater Weapons Establishment - Portland Eng. at the Conference in Kiel 18th - 23rd June 1959 (NATO, Restricted)

7. R.M. Morris and B.O. Pedersen. "Eddy-Current Magnetic Field Measurements on the Hull of HMCS 'Cowichan' (MCB 162)". NRC Report ERA-314 (Confidential)

8. R.M. Morris and N.L. Kusters. "Eddy-Current Magnetic Field Measurements on Aluminum-Framed Minesweeper HMCS 'Comox' (AMc 146)". NRC Report ERA-300 (Confidential)

9. R.Ia. Berkman. "Phase Detector for Multiple Frequencies". Automation and Remote Control (USSR) 19-4 (April 1958) pp. 355-60

TABLE I

MAGNETIC SIGNATURE OF HMCS "COWICHAN" (MCB 162)

Type of Field	Depth (ft.)	Heading	Field Component	Maximum Field (mg)				
				1958 Trials		1959 Trials		
				D.G. Off	D.G. On	D.G. Off*	D.G. On Open Loop	D.G. On Closed Loop
Static Field	15.5	N	Transv. Hor.	6.8	1.4			
			Vertical	12.4	4.0			
		S	Transv. Hor.			6.0	1.5	
			Vertical			10.8	2.3	
	22	W	Transv. Hor.	4.4	2.0	3.0	0.8	1.6
			Vertical	6.7	3.3	5.7	0.6	1.8
		E	Transv. Hor.			3.2	0.4	0.6
			Vertical			5.4	0.6	0.8
	26†	N	Vertical			3.5	0.55	1.45
		S	Vertical			3.5	0.45	0.65
	30	W	Vertical	3.7	1.0	2.8	0.4	0.65
		E	Vertical			3.2	0.4	

Type of Field	Depth (ft.)	Heading	Field Component	Maximum Field (mg)				
				1958 Trials		1959 Trials		
				D.G. On Hdg. Only	D.G. On Hdg. Pitch and Roll	D.G. On Open Loop Hdg. Only	D.G. On Open Loop Hdg. Pitch and Roll	D.G. On Closed Loop
Dynamic Field (±25° Roll)	22	W	Transv. Hor.	±1.75	±0.75	±1.6	±0.35	±1.0
			Vertical	±1.75	±1.0	±1.4	±0.4	±0.9
		E	Transv. Hor.			±1.2	±0.35	±0.6
			Vertical			±1.4	±0.35	
	30	W	Vertical	±0.85	±0.38	±0.75	±0.2	±0.25
		E	Vertical			±0.9	±0.25	

* Magnetic clutch was degaussed during 1959 trials.

† RCN open range measurements

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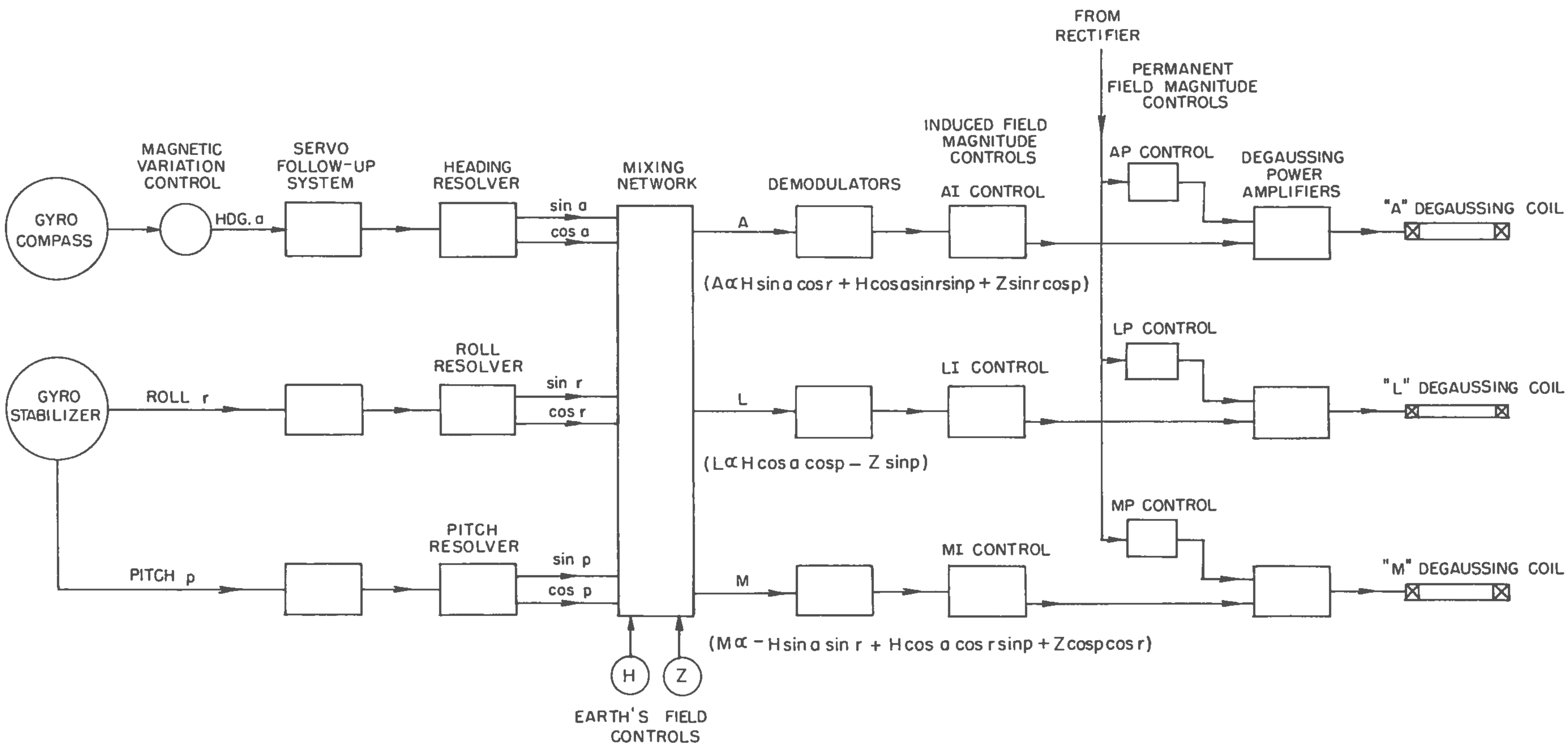
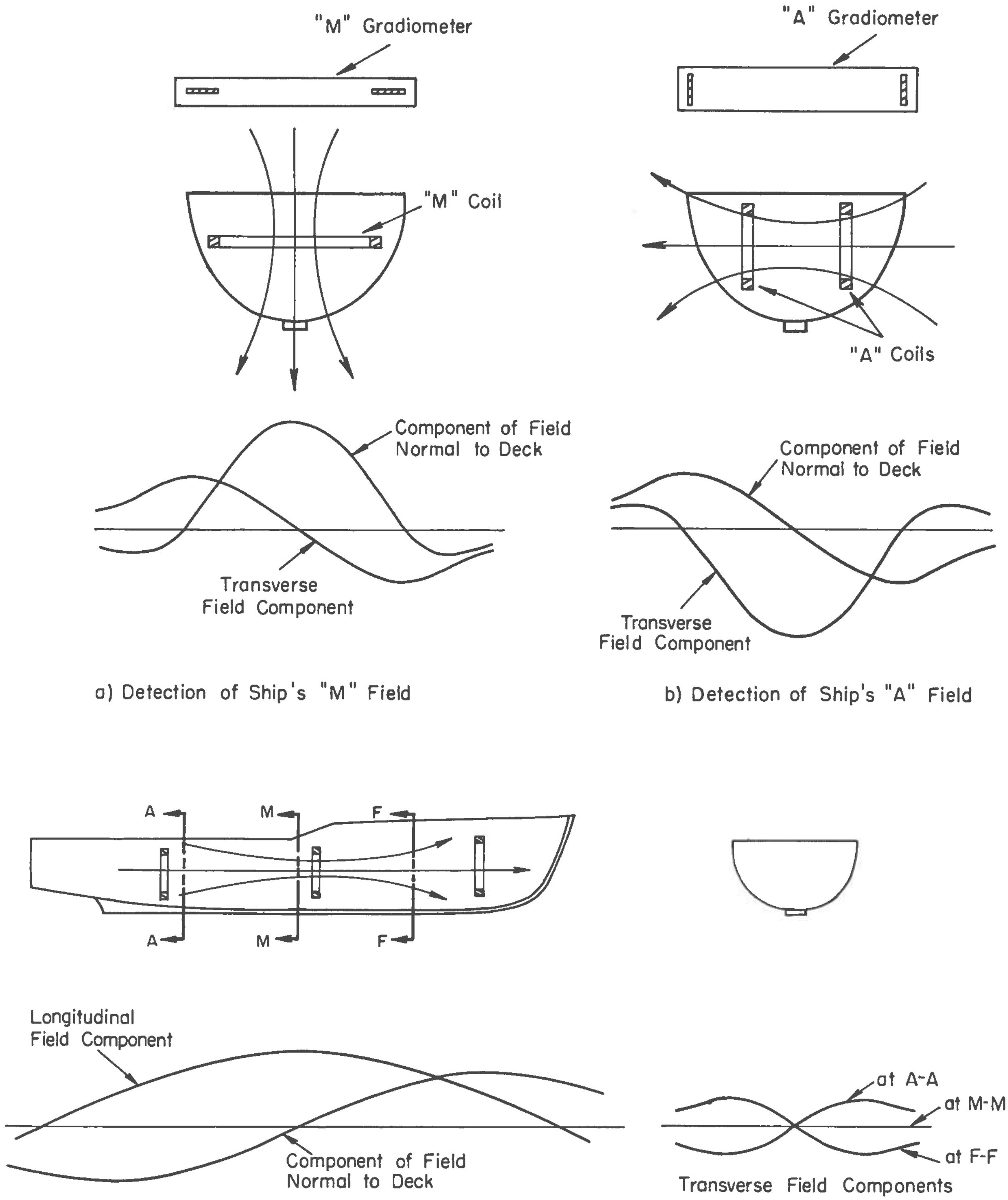


BLOCK DIAGRAM OF OPEN LOOP DEGAUSSING SYSTEM

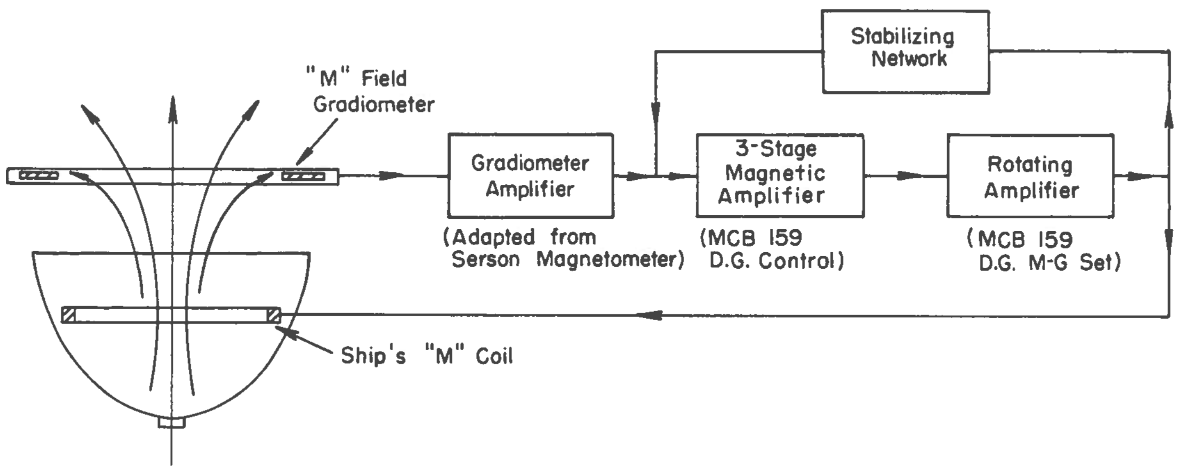
FIG. 1

SECRET

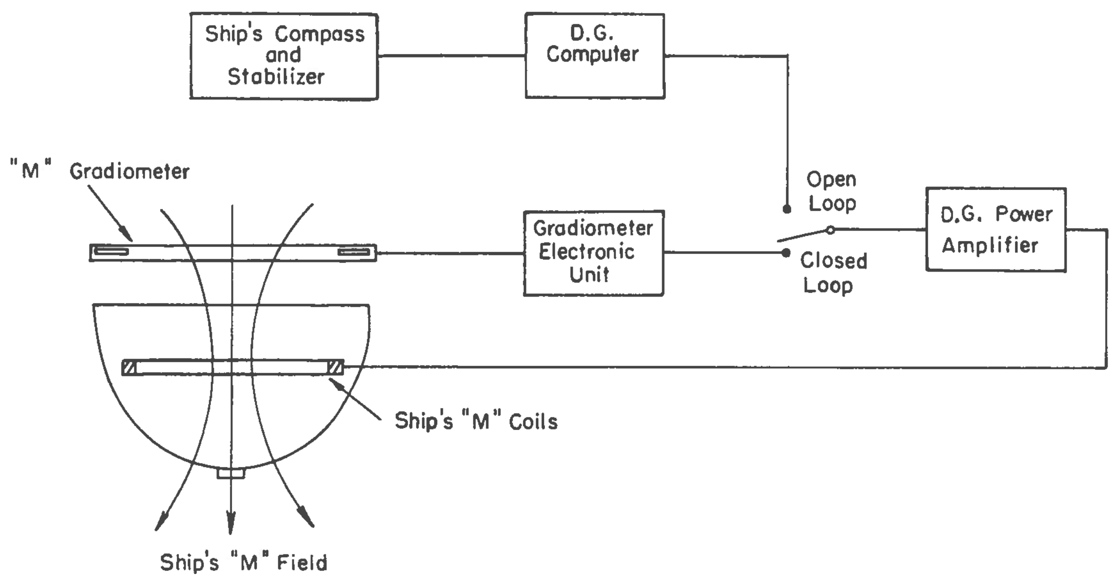


GRADIOMETER METHOD
OF DETECTING SHIP'S FIELD

FIG. 2



BLOCK DIAGRAM OF CLOSED-LOOP D.G. SYSTEM ("M" CHANNEL)
FIG. 3

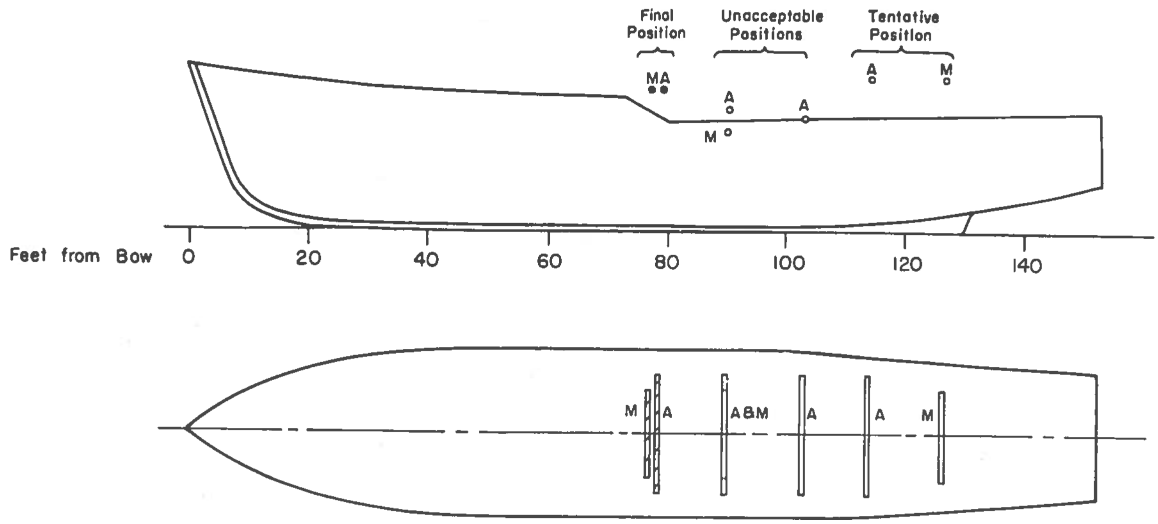


BLOCK DIAGRAM OF
OPEN LOOP TO CLOSED LOOP SWITCHING ("M" CHANNEL)

FIG. 4

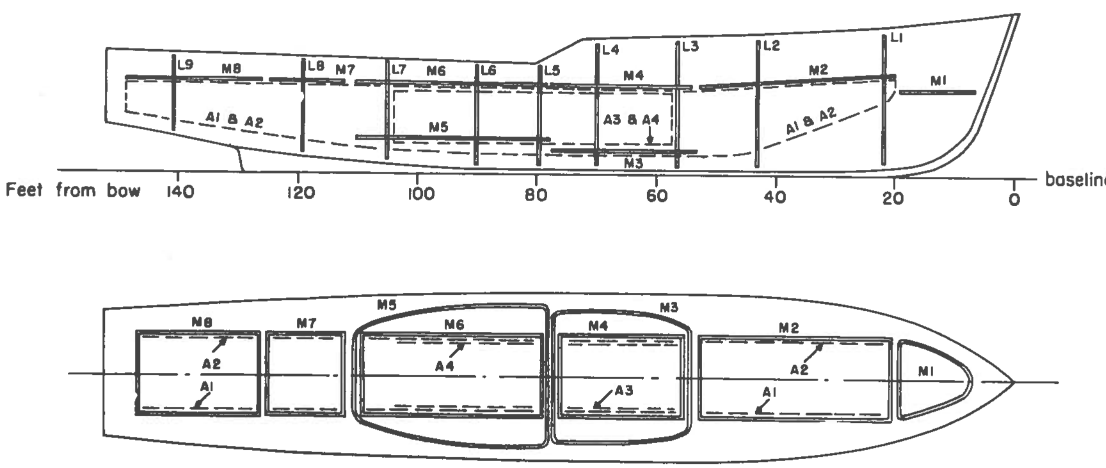
FIG. 5 GRADIOMETER ELECTRONIC EQUIPMENT
RCN Photo

SECRET

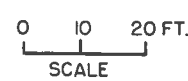


GRADIOMETER POSITIONS

FIG. 6



LOOP	TURNS CONNECTED			
	COILING # 1	COILING #2	COILING #3	COILING #4 (FINAL)
M1 M2 M3 M4 M5 M6 M7 M8 M HEATING BOILER M MG SETS	0 6 4 11 2 12 25 20 30 10	0 6 4 11 2 10 20 16 37 10	0 6 5 3 4 4 20 16 39 10	0 6 5 3 4 4 20 16 39 10
A1, A2 A3, A4	10 19	10 19	10 19	2 4
L1, L2, L3 L4 L5 L6, L7, L8, L9	3 5 (reversed) 3 (reversed) 3	3 5 (reversed) 3 (reversed) 3	3 5 (reversed) 3 (reversed) 3	3 5 (reversed) 3 (reversed) 3

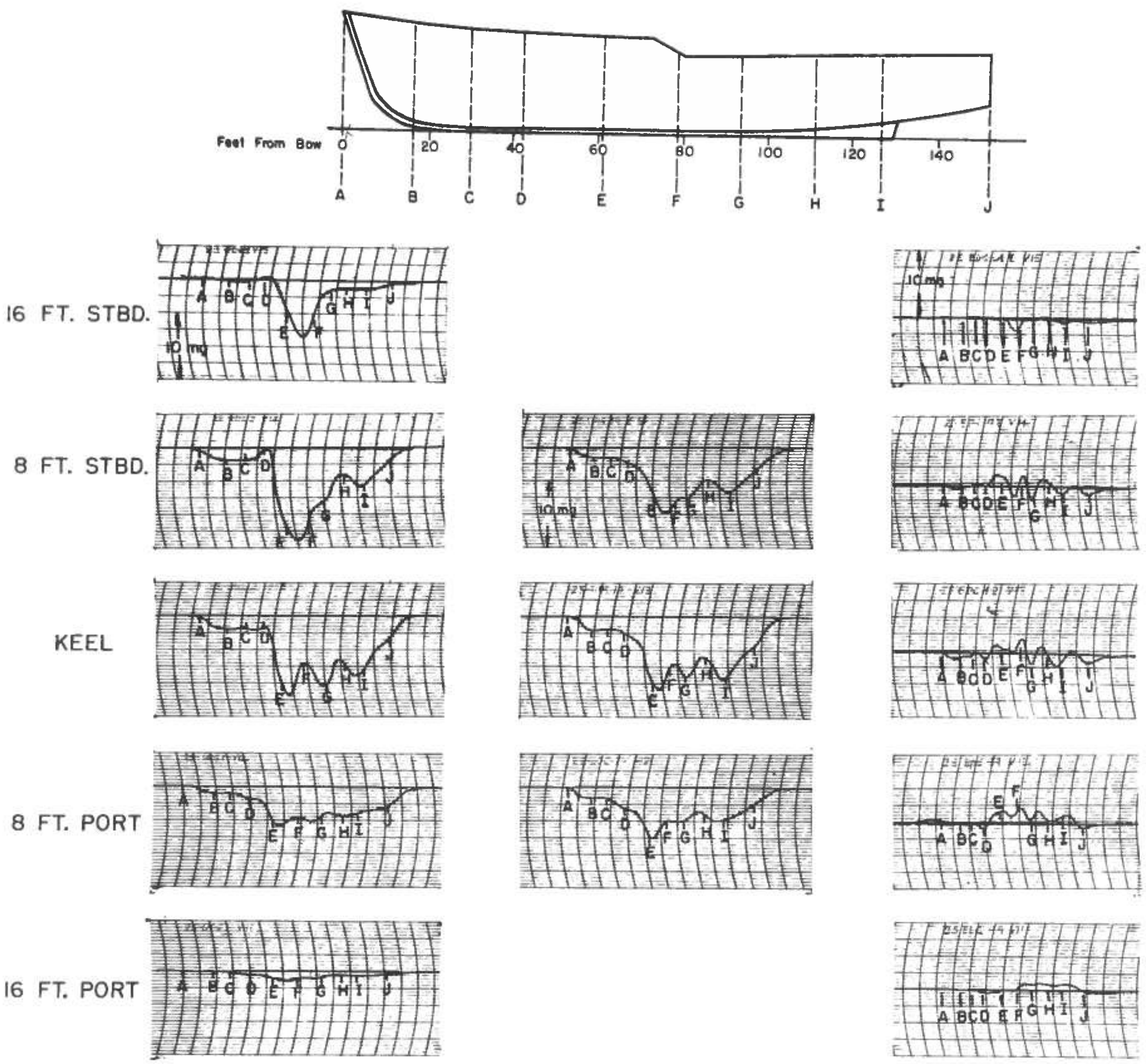


SHIP'S DEGAUSSING COILS

FIG. 7

FIG. 8 GRADIOMETER TUBES MOUNTED ON DECK
RCN Photo

SECRET



DEGAUSSING OFF (TRACED FROM ORIGINAL)

DEGAUSSING OF CLUTCH ONLY ON (TRACED FROM ORIGINAL)

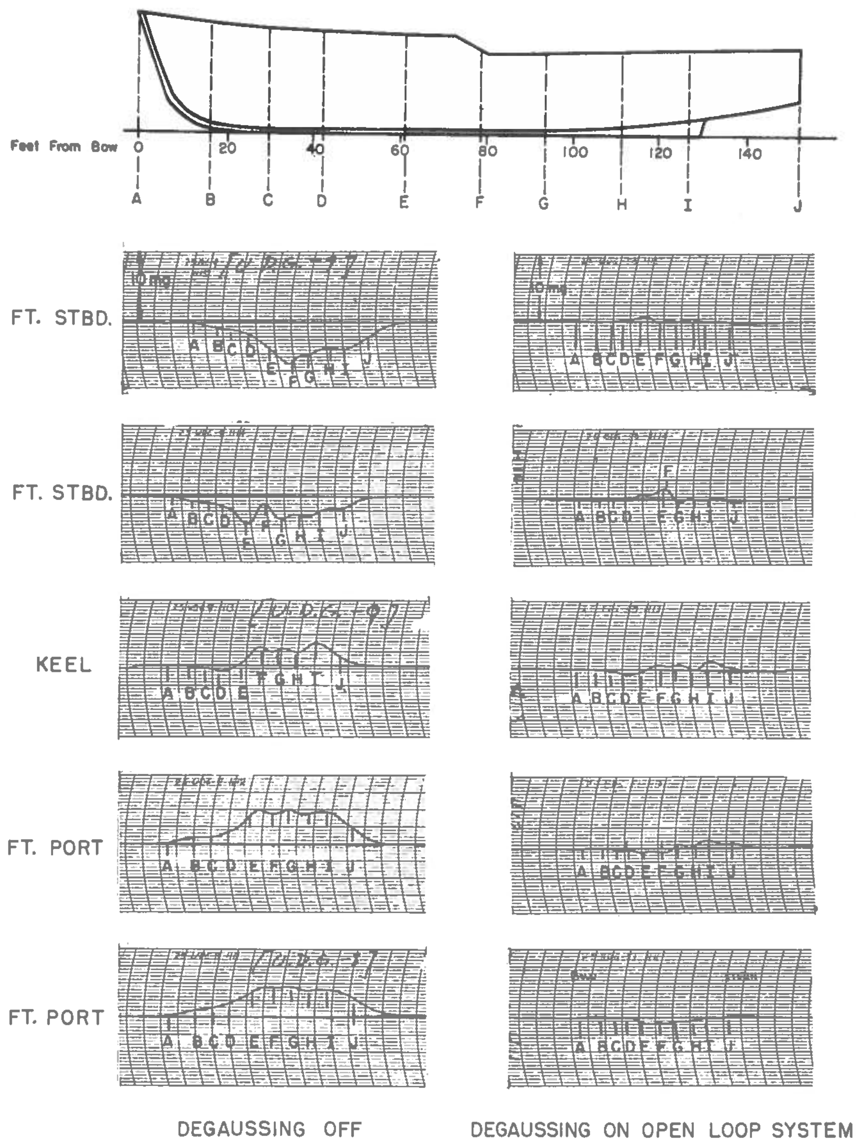
DEGAUSSING ON OPEN LOOP SYSTEM

D.G. CURRENTS: A: −0.2 AMP.
L: +1.5 AMP.
M: +2.1 AMP.

NOTE: UPWARD DEFLECTIONS ARE UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
HEADING: SOUTH DEPTH: 15.5 FT.
(Coiling No. 1, Fig. 7)

FIG. 9

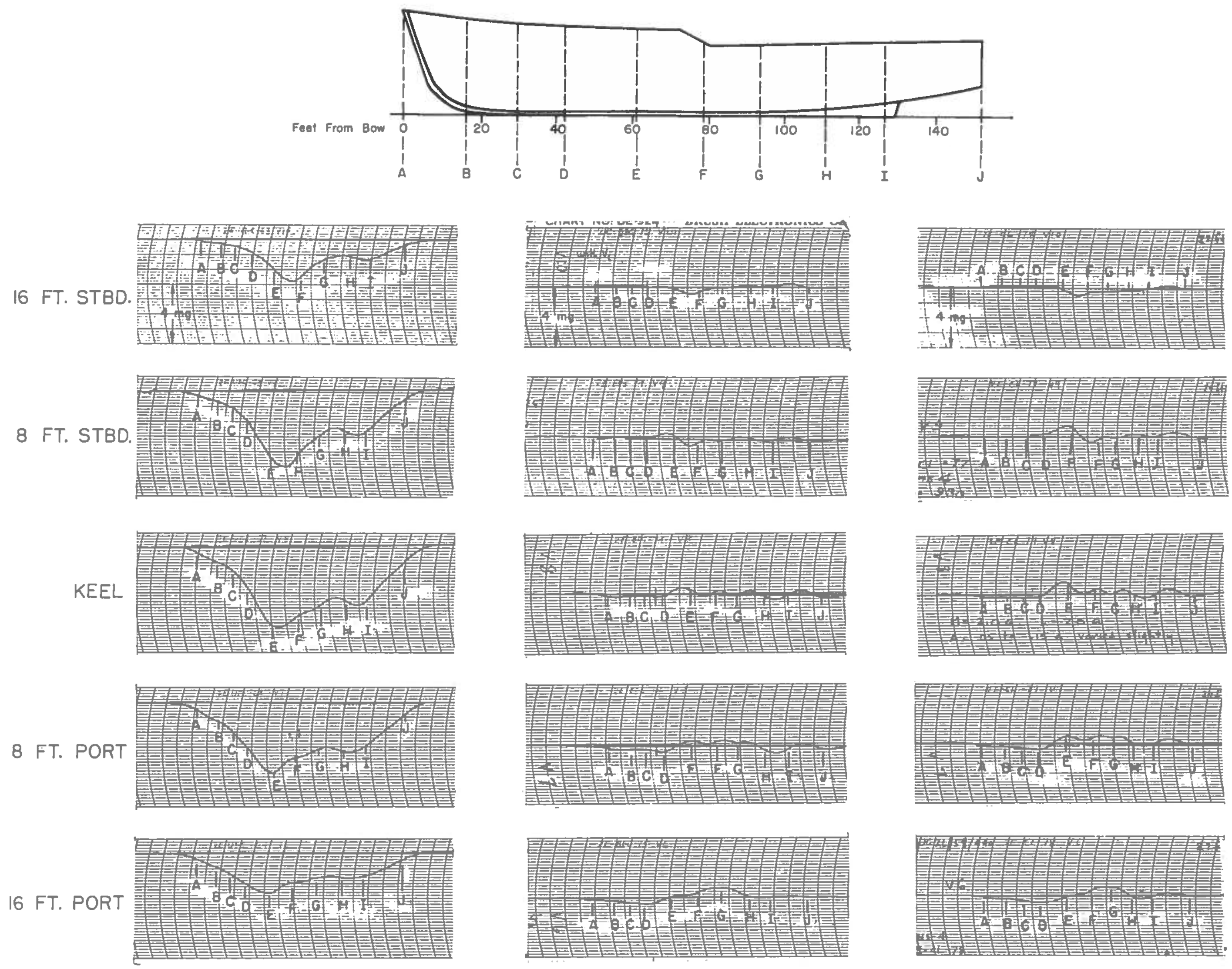


D.G. CURRENTS:
A: − 0.2 AMP.
L: + 1.5 AMP.
M: + 2.1 AMP.

NOTE: UPWARD DEFLECTIONS ARE FIELDS DIRECTED FROM STBD. TO PORT.

LONGITUDINAL PROFILES OF TRANSVERSE HORIZONTAL FIELD
HEADING: SOUTH   DEPTH: 15.5 FT.
(Coiling No. 1, Fig. 7)

FIG. 10



DEGAUSSING OFF

DEGAUSSING ON
OPEN LOOP SYSTEM

D.G. CURRENTS:
A: +0.1 AMP.
L: +2.0 AMP.
M: +2.0 AMP.

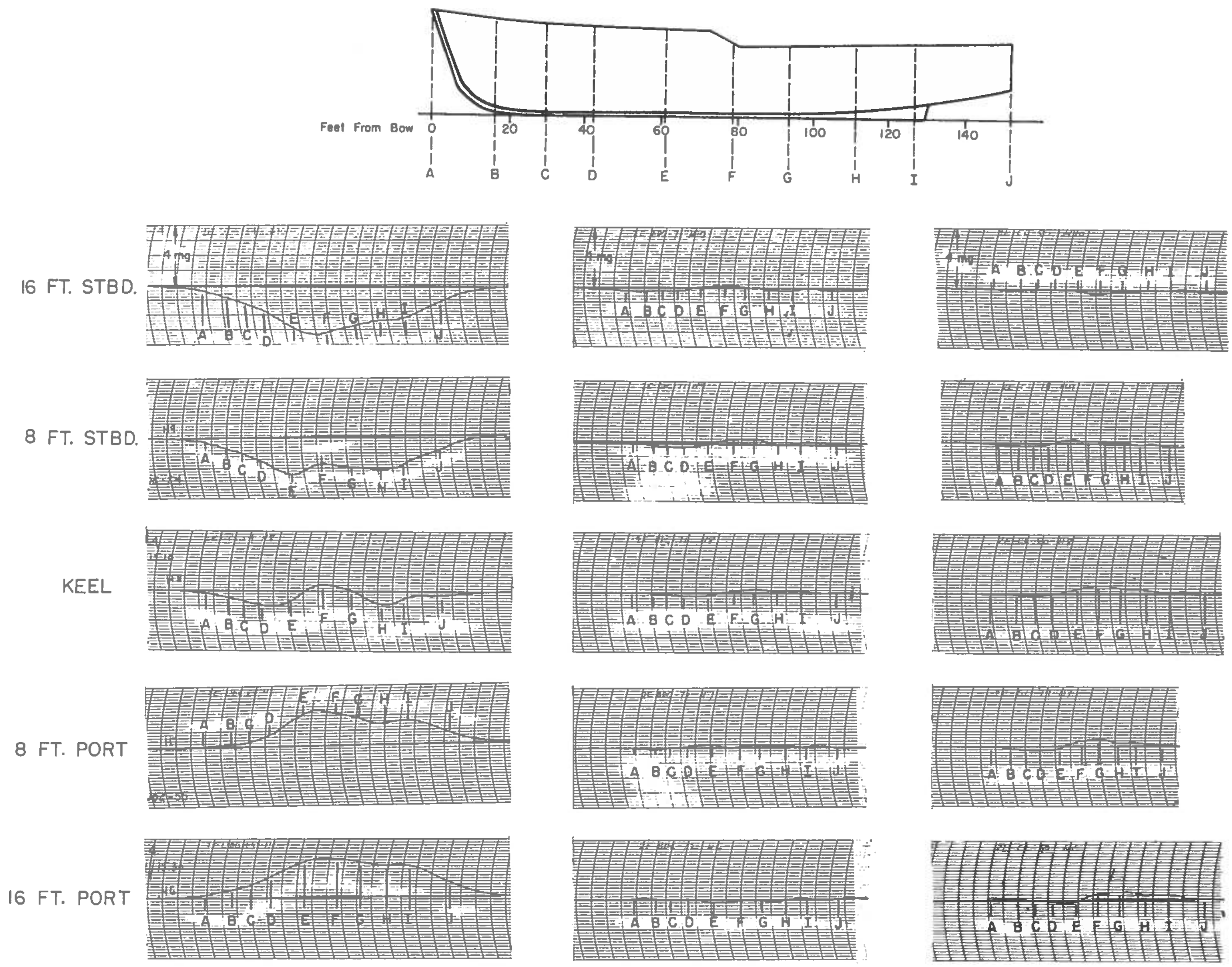
DEGAUSSING ON
CLOSED LOOP SYSTEM

D.G. CURRENTS:
A: +0.1 AMP.
L: +2.0 AMP.
M: +2.0 AMP.

NOTE: UPWARD DEFLECTIONS ARE
UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
HEADING: EAST DEPTH: 22 FT.
(Coiling No. 2, Fig. 7)

FIG. 11



DEGAUSSING OFF

DEGAUSSING ON
OPEN LOOP SYSTEM

D.G. CURRENTS:
A: +0.1 AMP.
L: +2.0 AMP.
M: +2.0 AMP.

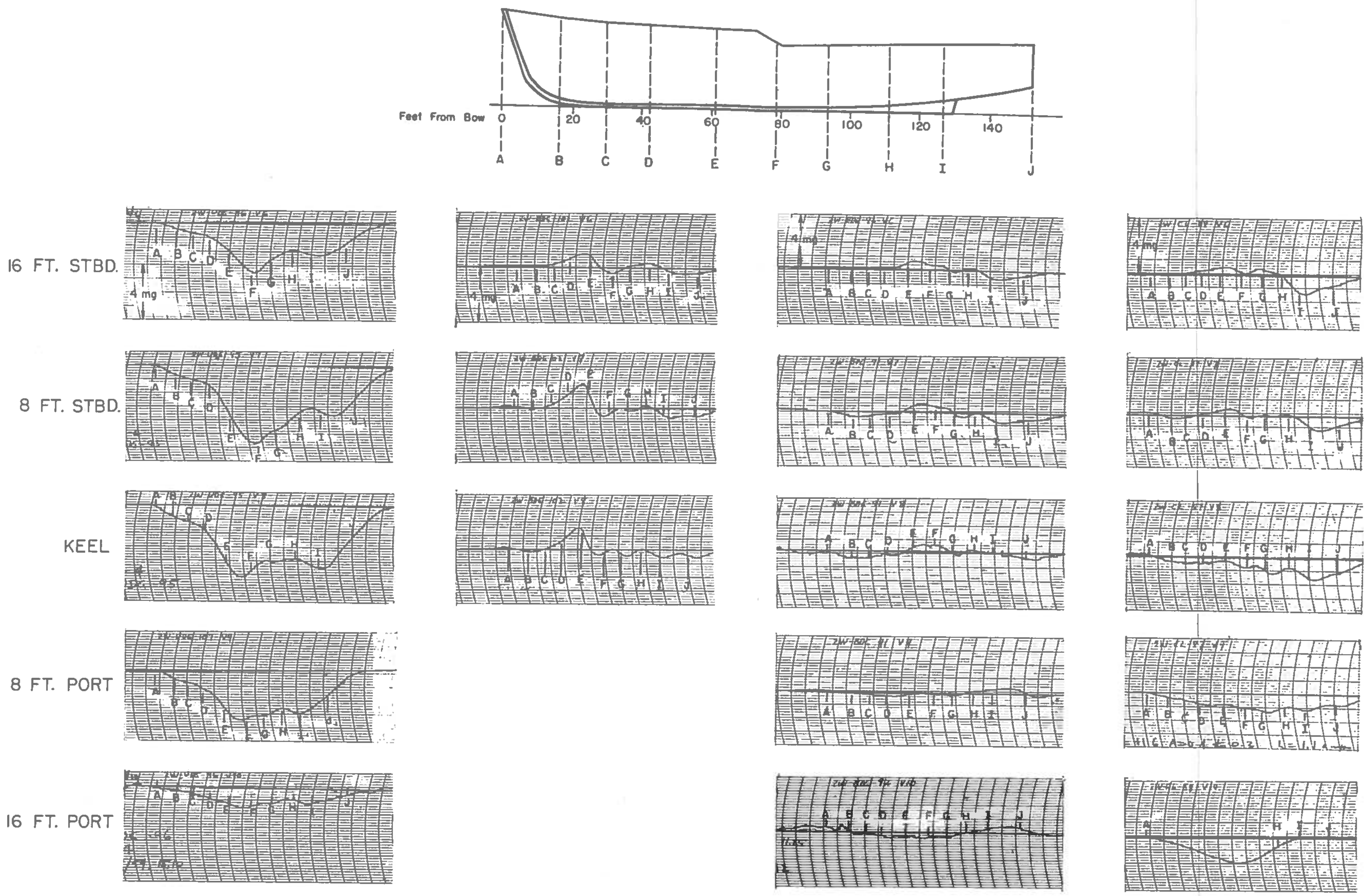
DEGAUSSING ON
CLOSED LOOP SYSTEM

D.G. CURRENTS:
A: +0.1 AMP.
L: +2.0 AMP.
M: +2.0 AMP.

NOTE: UPWARD DEFLECTIONS ARE FIELDS DIRECTED FROM STBD. TO PORT.

LONGITUDINAL PROFILES OF TRANSVERSE HORIZONTAL FIELD
HEADING: EAST DEPTH: 22 FT.
(Coiling No. 2, Fig. 7)

FIG. 12



DEGAUSSING OFF

DEGAUSSING ON
OPEN LOOP SYSTEM
CLUTCH DEGAUSSING OFF
D.G. CURRENTS:
A: −0.2 AMP.
L: +1.1 AMP.
M: +2.0 AMP.

DEGAUSSING ON
OPEN LOOP SYSTEM
CLUTCH DEGAUSSING ON
D.G. CURRENTS:
A: −0.2 AMP.
L: + 1.1 AMP.
M: + 2.0 AMP.

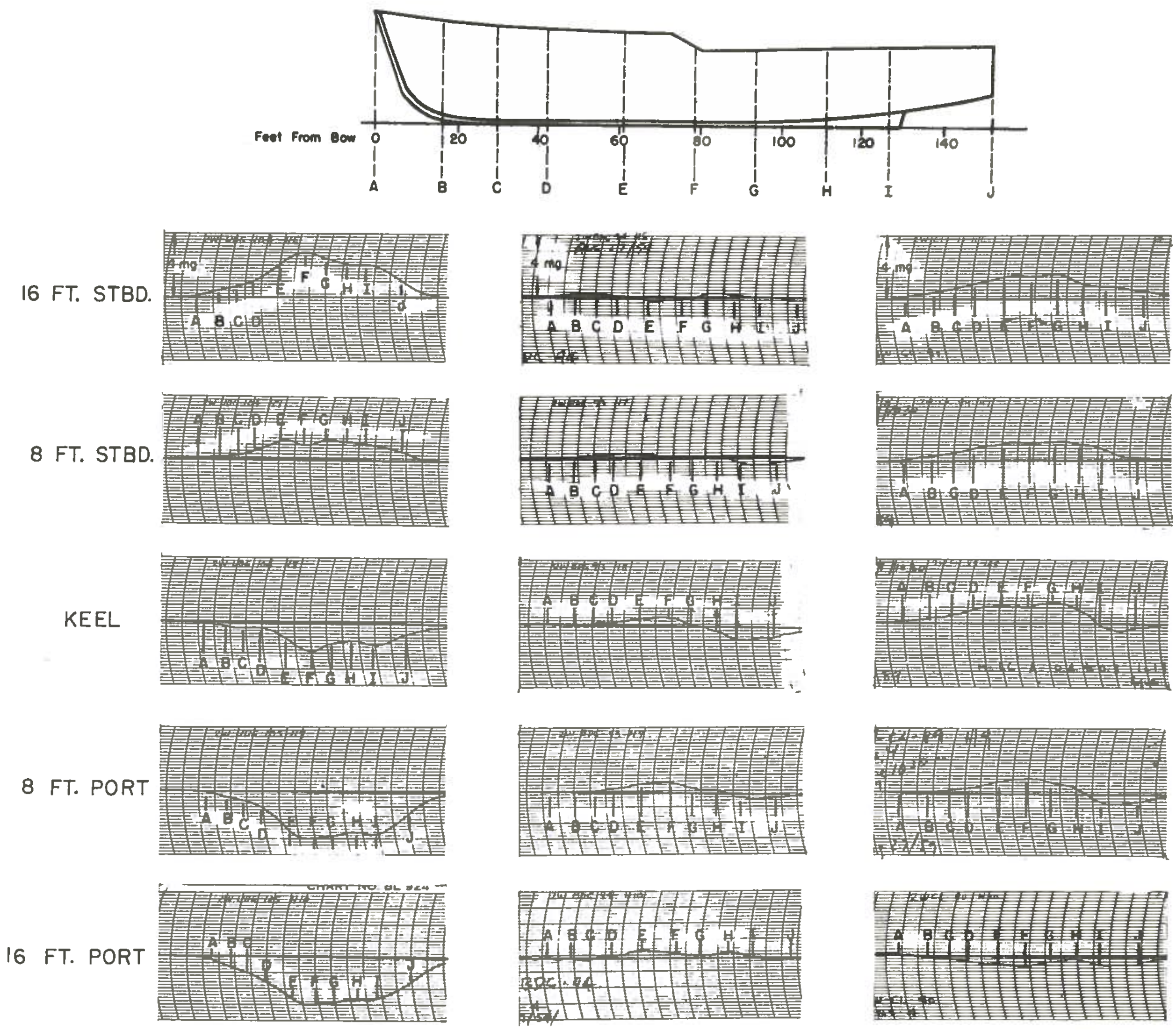
DEGAUSSING ON
CLOSED LOOP SYSTEM
D.G. CURRENTS:
A: −0.4 AMP.
L: + 1.1 AMP.
M: + 1.6 AMP.

NOTE: UPWARD DEFLECTIONS ARE UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
HEADING: WEST DEPTH: 22 FT.

(Coiling No. 2, Fig. 7)

FIG. 13



DEGAUSSING OFF

DEGAUSSING ON
OPEN LOOP SYSTEM

DEGAUSSING ON
CLOSED LOOP SYSTEM

NOTE: UPWARD DEFLECTIONS ARE FIELDS DIRECTED FROM PORT TO STBD.

D.G. CURRENTS (open loop system):
A: −0.2 AMP.
L: +1.1 AMP.
M: +2.0 AMP.

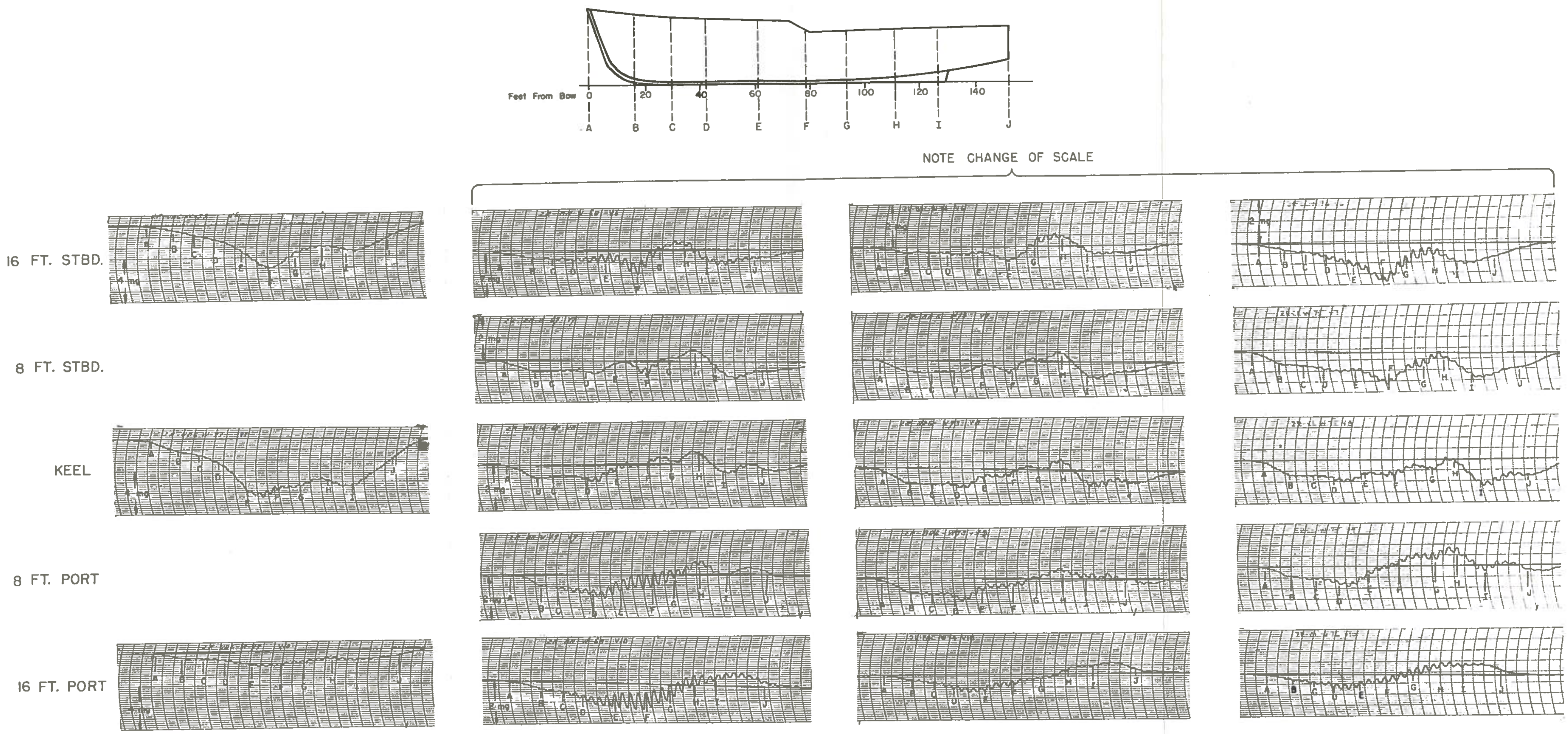
D.G. CURRENTS (closed loop system):
A: −0.4 AMP.
L: +1.1 AMP.
M: +1.6 AMP.

LONGITUDINAL PROFILES OF TRANSVERSE HORIZONTAL FIELD

HEADING: WEST DEPTH: 22 FT.

(Coiling No. 2, Fig. 7)

FIG. 14



DEGAUSSING OFF

DEGAUSSING ON OPEN LOOP SYSTEM (AUTOMATIC: HEADING ONLY)

D.G. CURRENTS: A: −0.2 AMP.
L: +1.1 AMP.
M: +2.1 AMP.

DEGAUSSING ON OPEN LOOP SYSTEM (AUTOMATIC: HEADING, PITCH & ROLL)

D.G. CONTROLLER SETTINGS:
AI: −0.13 AMP. AP: −0.07 AMP.
LI: −0.45 AMP. LP: +1.55 AMP.
MI: +1.6 AMP. MP: +0.5 AMP.

DEGAUSSING ON CLOSED LOOP SYSTEM

D.G. CURRENTS (EVEN KEEL):
A: − 0.06 AMP.
L: + 1.1 AMP.
M: + 1.8 AMP.

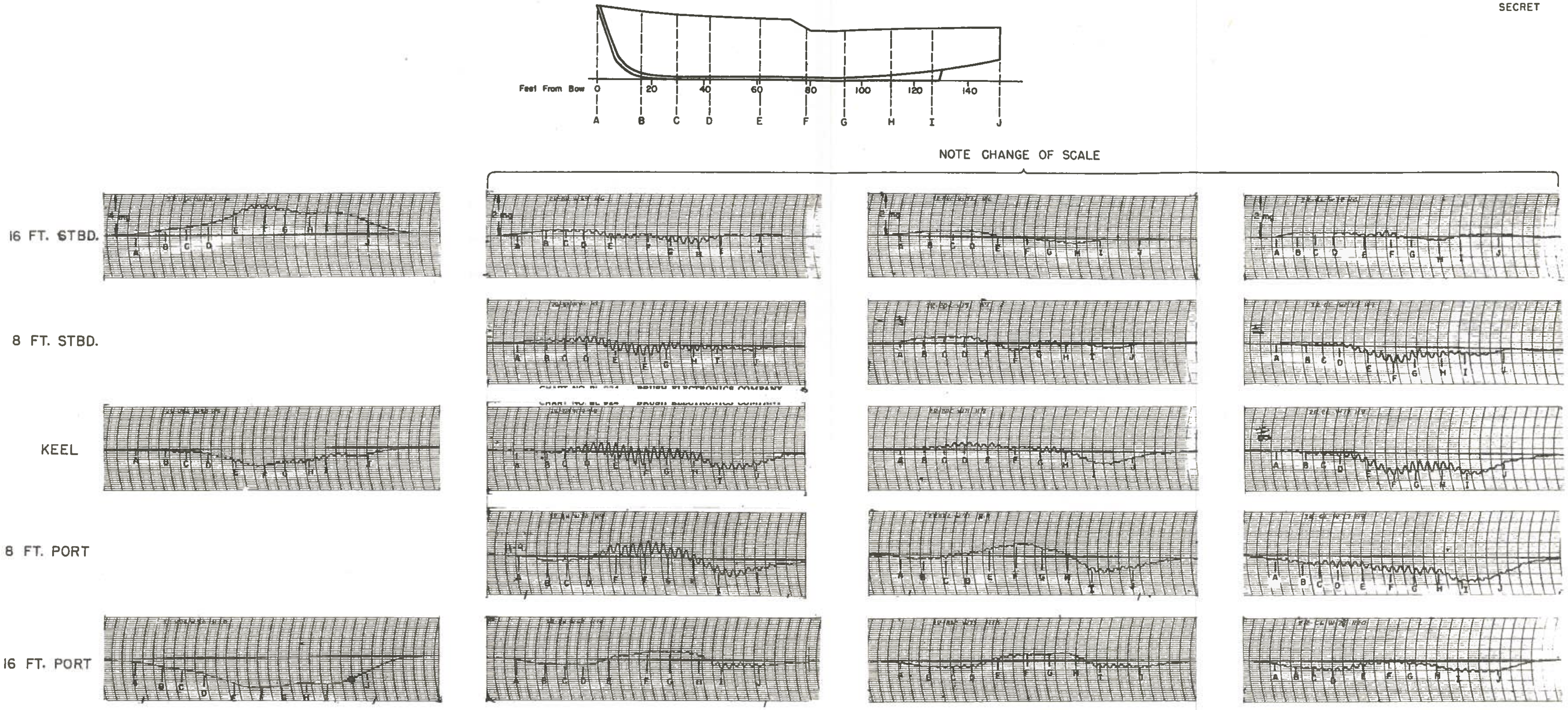
NOTE: UPWARD DEFLECTIONS ARE UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
ROLLING − TOWING TEST

HEADING: WEST DEPTH: 22 FT. ROLL AMPLITUDE: ±6.3°

(Coiling No. 3, Fig. 7)

FIG. 15



DEGAUSSING OFF

DEGAUSSING BY OPEN LOOP SYSTEM (AUTOMATIC: HEADING ONLY)

D.G. CURRENTS: A: −0.2 AMP.
L: +1.1 AMP.
M: +2.1 AMP.

DEGAUSSING BY OPEN LOOP SYSTEM (AUTOMATIC: HEADING, PITCH & ROLL)

D.G. CONTROLLER SETTINGS:
AI: −0.13 AMP. AP: −0.07 AMP.
LI: −0.45 AMP. LP: +1.55 AMP.
MI: +1.6 AMP. MP: +0.5 AMP.

DEGAUSSING BY CLOSED LOOP SYSTEM

D.G. CURRENTS (EVEN KEEL):
A: −0.06 AMP.
L: +1.1 AMP.
M: +1.8 AMP.

NOTE: UPWARD DEFLECTIONS ARE FIELDS DIRECTED FROM PORT TO STBD.

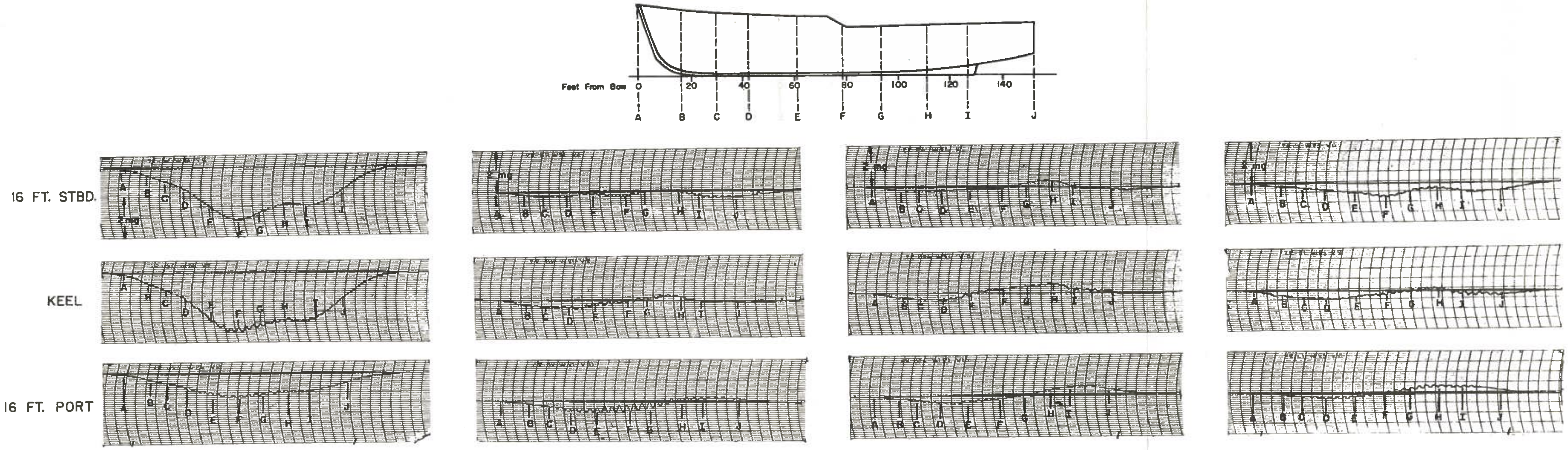
LONGITUDINAL PROFILES OF TRANSVERSE HORIZONTAL FIELD
ROLLING — TOWING TEST

HEADING: WEST DEPTH: 22 FT. ROLL AMPLITUDE: ±6.3°

(Coiling No. 3, Fig. 7)

FIG. 16

SECRET



DEGAUSSING OFF

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING ONLY)

D.G. CURRENTS: A: −0.2 AMP.
L: +1.1 AMP.
M: +2.1 AMP.

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING, PITCH & ROLL)

D.G. CONTROLLER SETTINGS:
AI: −0.13 AMP. AP: −0.07 AMP.
LI: −0.45 AMP. LP: +1.55 AMP.
MI: +1.6 AMP. MP: +0.5 AMP.

DEGAUSSING ON CLOSED LOOP SYSTEM

D.G. CURRENTS (EVEN KEEL): A: 0
L: +1.1 AMP.
M: +2.05 AMP.

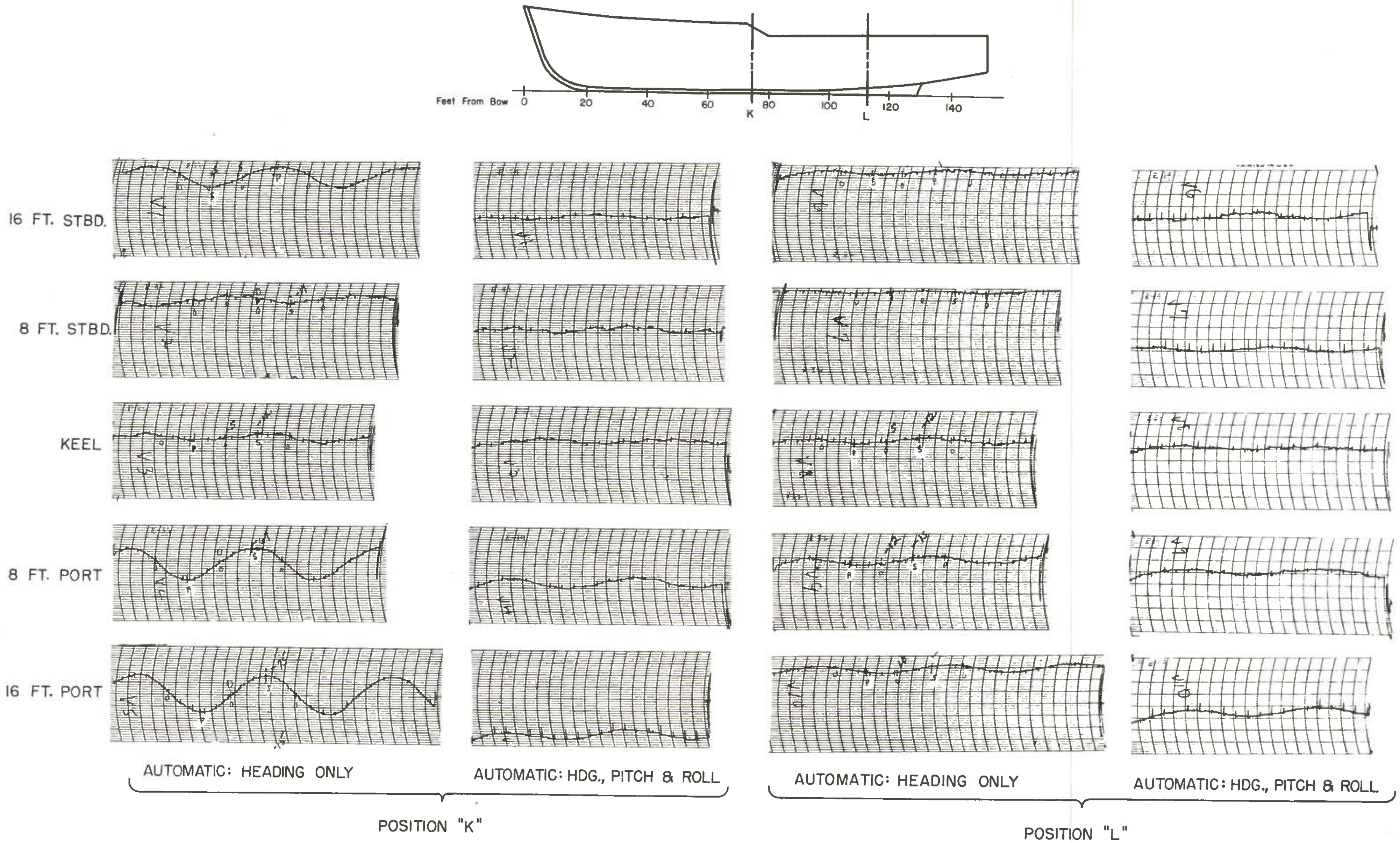
NOTE: UPWARD DEFLECTIONS ARE UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
ROLLING — TOWING TEST

HEADING: WEST DEPTH: 30 FT. ROLL AMPLITUDE: ±6.3°

(Coiling No. 3, Fig. 7)

FIG. 17



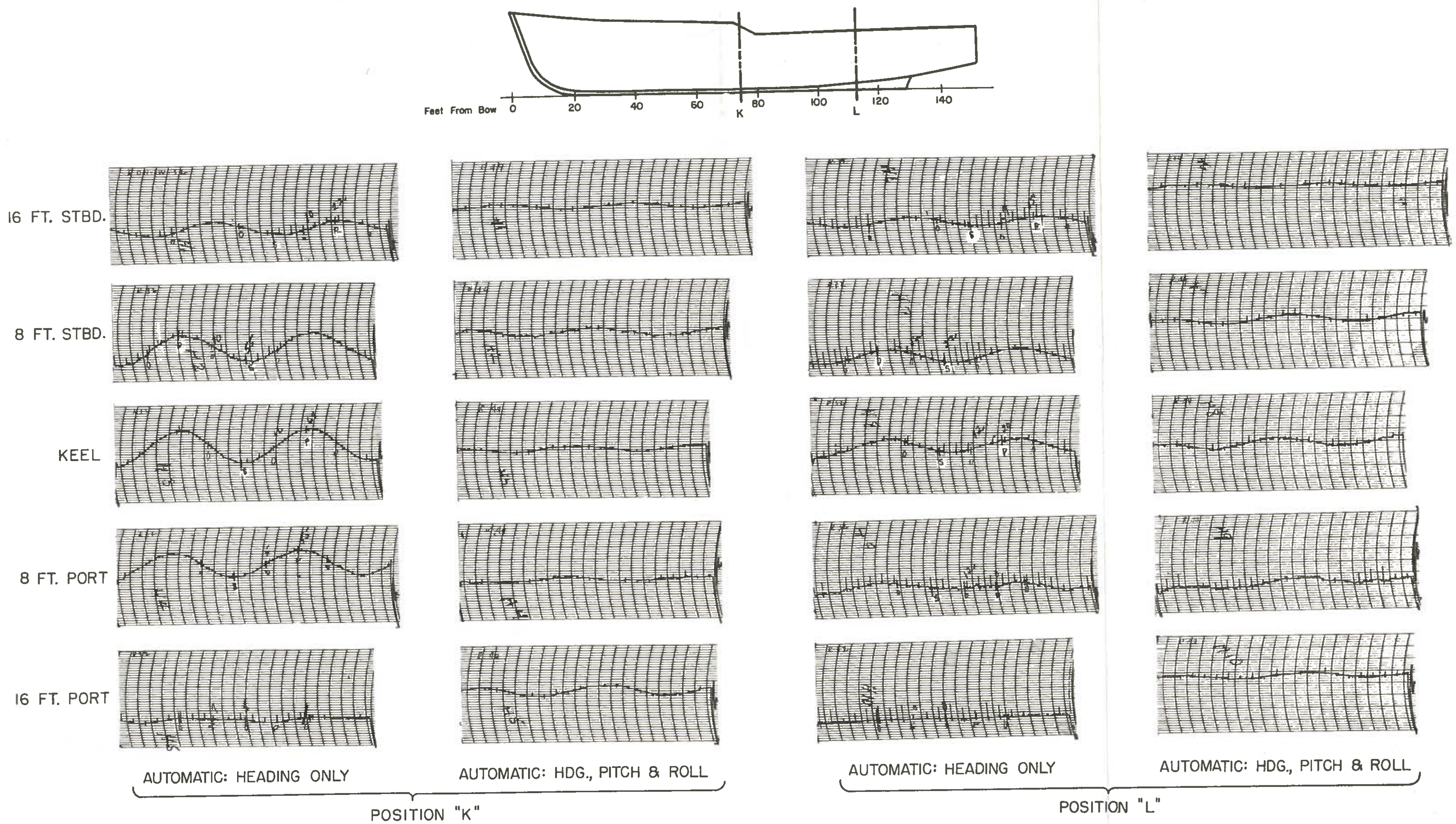
D.G. CONTROLLER SETTINGS:

AI: −0.13 AMP. AP: −0.07 AMP.
LI: −0.45 AMP. LP: +1.55 AMP.
MI: +1.5 AMP. MP: +0.5 AMP.

ROLL FIELD DEGAUSSING BY AUTOMATIC OPEN LOOP SYSTEM
VERTICAL FIELD

HEADING: WEST DEPTH: 22 FT. ROLL AMPLITUDE: ±6.5°
(Coiling No. 3, Fig. 7)

FIG. 18



D.G. CONTROLLER SETTINGS:

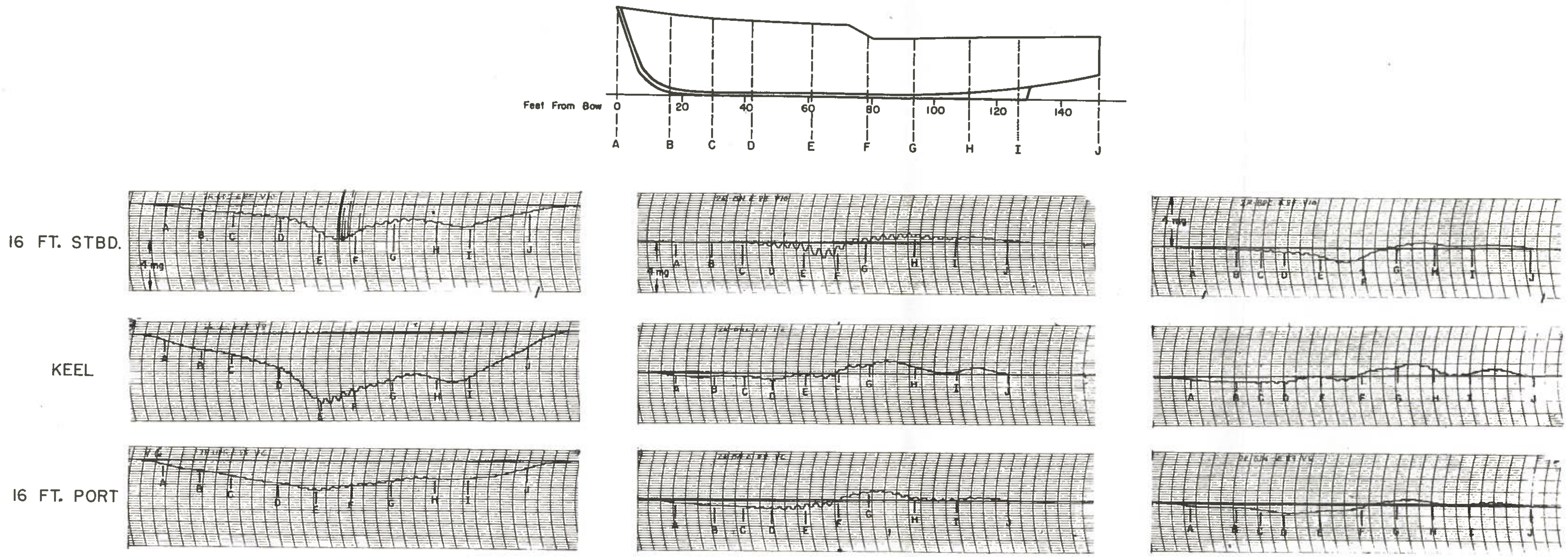
AI: −0.13 AMP.	AP: − 0.07 AMP.
LI: −0.45 AMP.	LP: + 1.55 AMP.
MI: + 1.5 AMP.	MP: + 0.5 AMP.

ROLL FIELD DEGAUSSING BY AUTOMATIC OPEN LOOP SYSTEM
TRANSVERSE HORIZONTAL FIELD

HEADING: WEST **DEPTH: 22 FT.** **ROLL AMPLITUDE: ± 6.5°**
(Coiling No. 3, Fig. 7)

FIG. 19

SECRET



DEGAUSSING OFF

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING ONLY)

D.G. CURRENTS: A: +0.06 AMP.
L: +2.0 AMP.
M: +2.3 AMP.

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING, PITCH & ROLL)

D.G. CONTROLLER SETTINGS:

AI: +0.13 AMP.	AP: −0.07 AMP.
LI: +0.45 AMP.	LP: +1.55 AMP.
MI: +1.7 AMP.	MP: +0.6 AMP.

NOTE: UPWARD DEFLECTIONS ARE UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
ROLLING — TOWING TEST

HEADING: EAST **DEPTH: 22 FT.** **ROLL AMPLITUDE: ±6.3°**

(Coiling No. 3, Fig. 7)

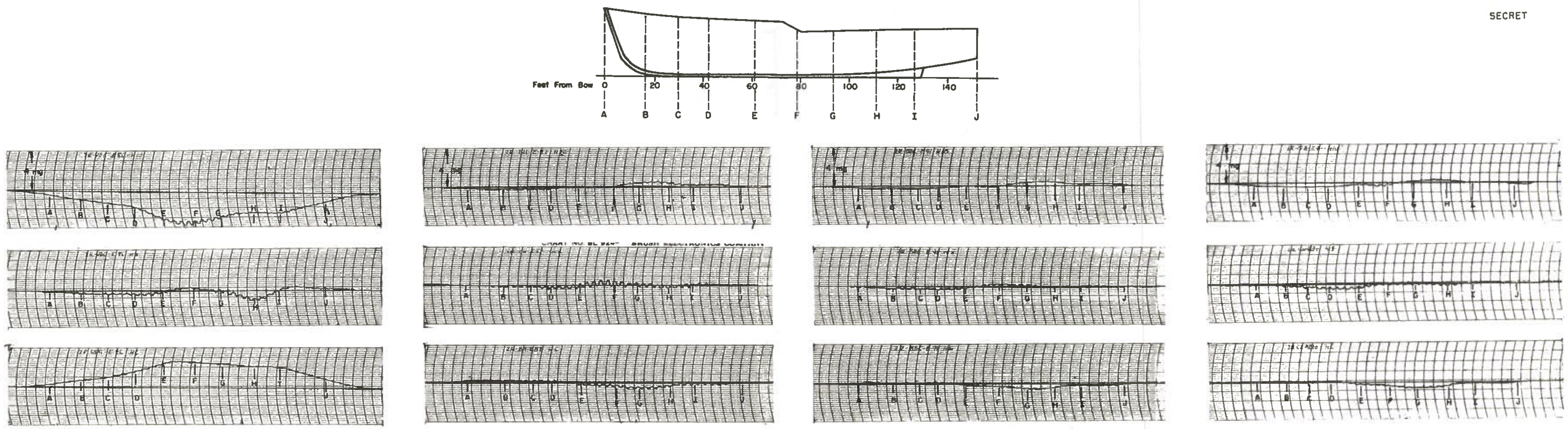
FIG. 20

SECRET

16 FT. STBD.

KEEL

16 FT. PORT



DEGAUSSING OFF

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING ONLY)
D.G. CURRENTS: A: +0.06 AMP.
L: +2.0 AMP.
M: +2.3 AMP.

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING, PITCH & ROLL)
D.G. CONTROLLER SETTINGS:
AI: +0.13 AMP. AP: -0.07 AMP.
LI: +0.45 AMP. LP: +1.55 AMP.
MI: +1.7 AMP. MP: +0.6 AMP.

"A" DEGAUSSING ON CLOSED LOOP SYSTEM
"M" & "L" DEGAUSSING ON OPEN LOOP SYSTEM
D.G. CURRENTS (EVEN KEEL):
A: +0.05 AMP.
L: +2.0 AMP.
M: +2.25 AMP.

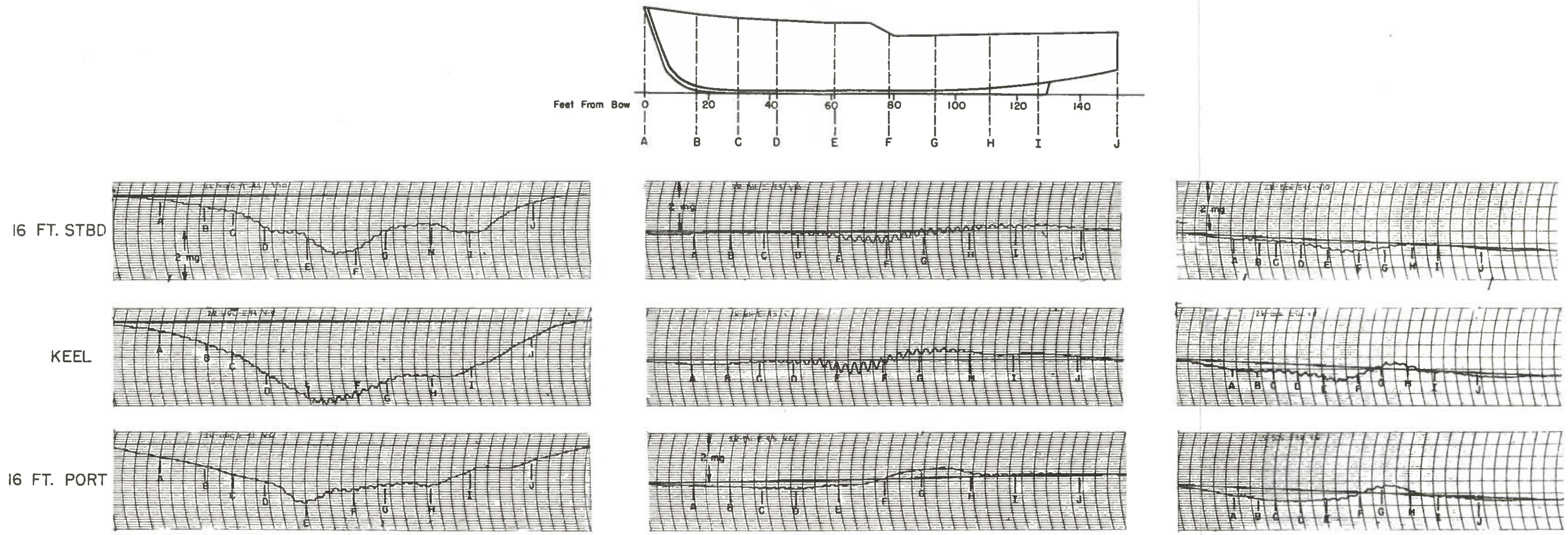
NOTE: UPWARD DEFLECTIONS ARE FIELDS DIRECTED FROM STBD. TO PORT

LONGITUDINAL PROFILES OF TRANSVERSE HORIZONTAL FIELD
ROLLING - TOWING TEST

HEADING: EAST DEPTH: 22 FT. ROLL AMPLITUDE: ±6.3°

(Coiling No. 3, Fig. 7)

FIG. 21



DEGAUSSING OFF

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING ONLY)

D.G. CURRENTS: A: +0.3 AMP.
L: +2.0 AMP.
M: +2.2 AMP.

DEGAUSSING ON OPEN LOOP SYSTEM
(AUTOMATIC: HEADING, PITCH & ROLL)

D.G. CONTROLLER SETTINGS:

AI: +0.65 AMP.	AP: −0.35 AMP.
LI: +0.45 AMP.	LP: +1.55 AMP.
MI: +1.6 AMP.	MP: +0.6 AMP.

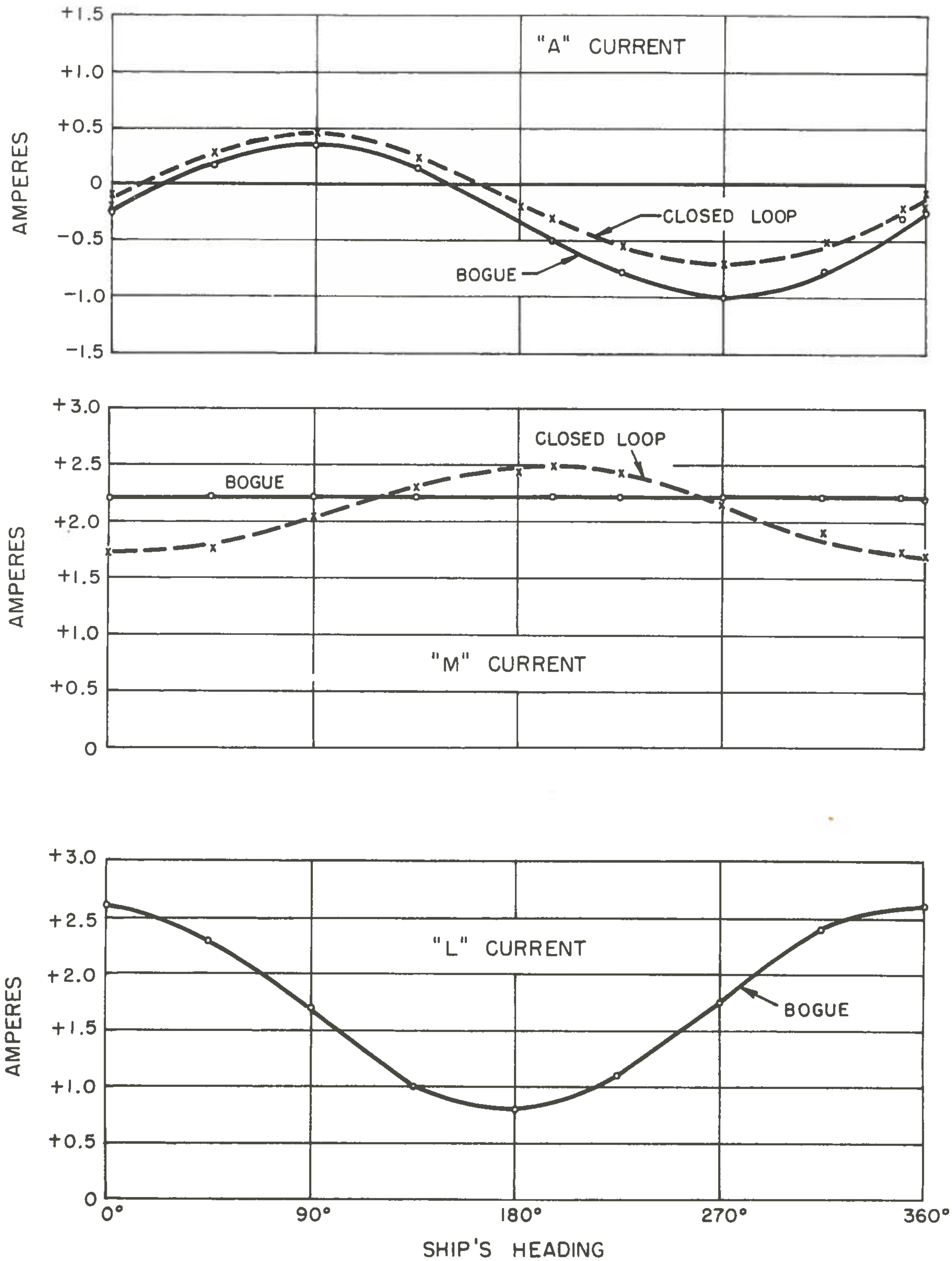
NOTE: UPWARD DEFLECTIONS ARE
UPWARD FIELDS.

LONGITUDINAL PROFILES OF VERTICAL FIELD
ROLLING — TOWING TEST

HEADING: EAST   DEPTH: 30 FT.   ROLL AMPLITUDE: ±6.3°

(Coiling No. 4, Fig. 7)

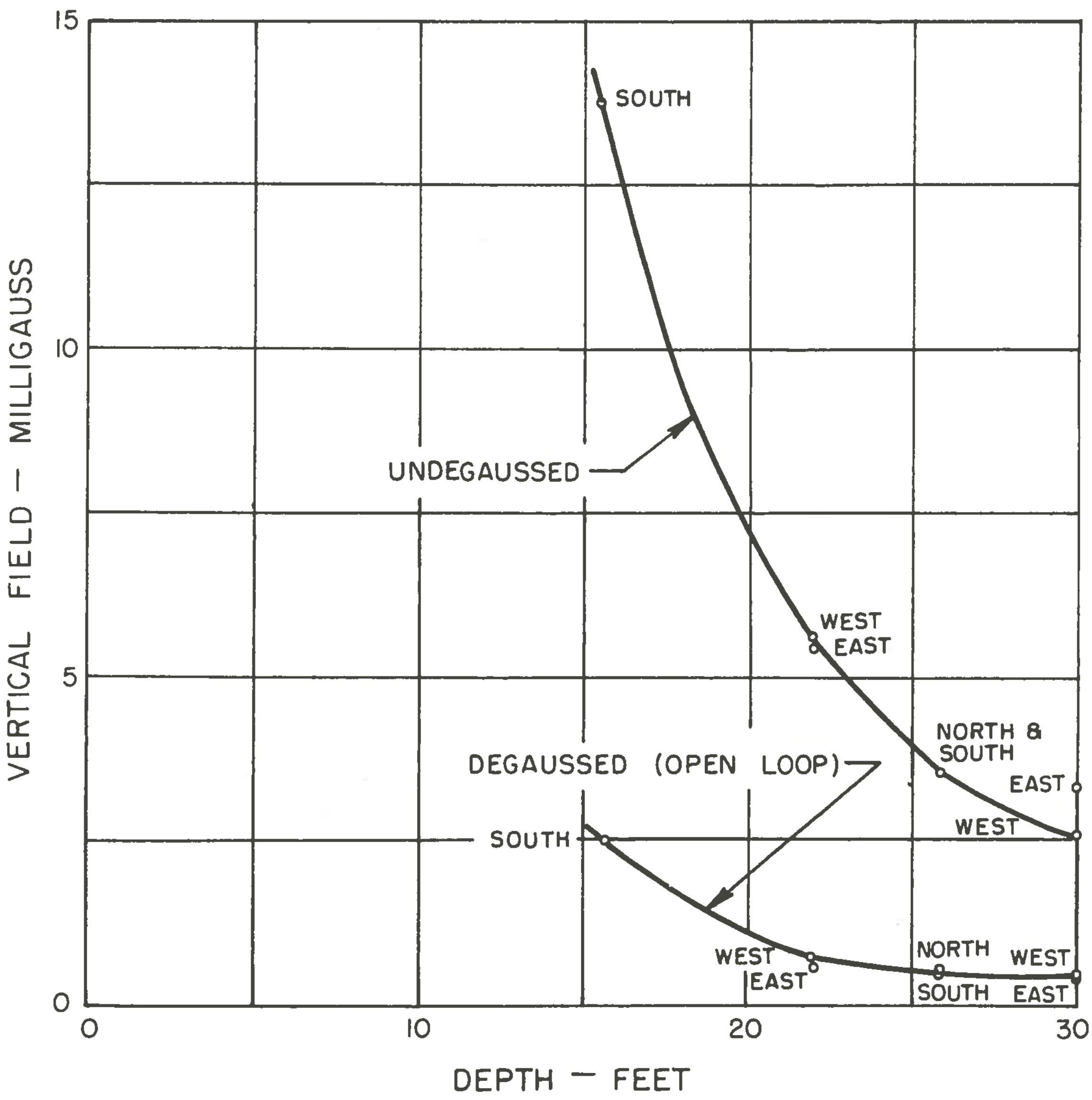
FIG. 22



D.G. CURRENTS vs. HEADING

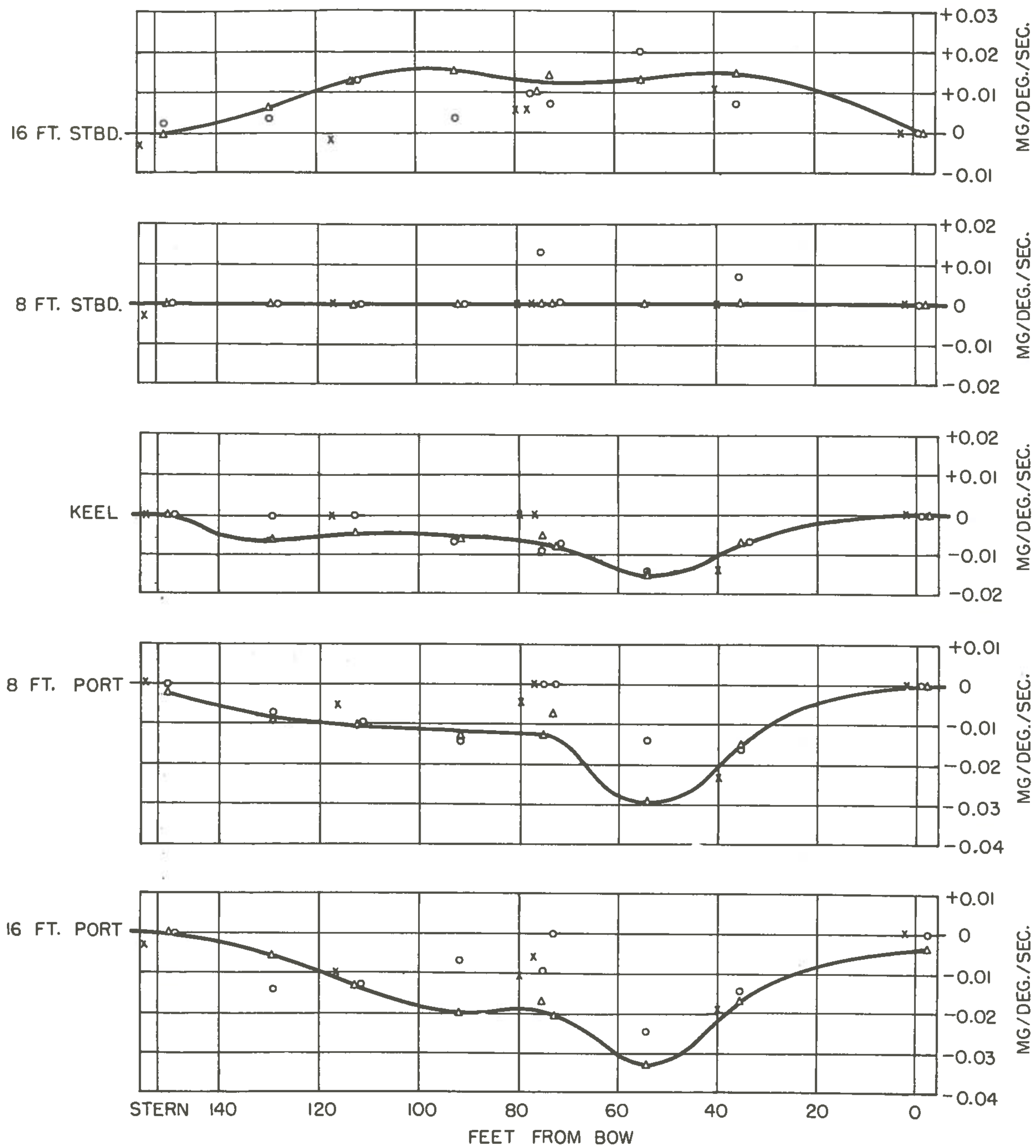
(Coiling No. 4, Fig. 7)

FIG. 23



SHIP'S VERTICAL SIGNATURE VS. DEPTH

FIG. 24

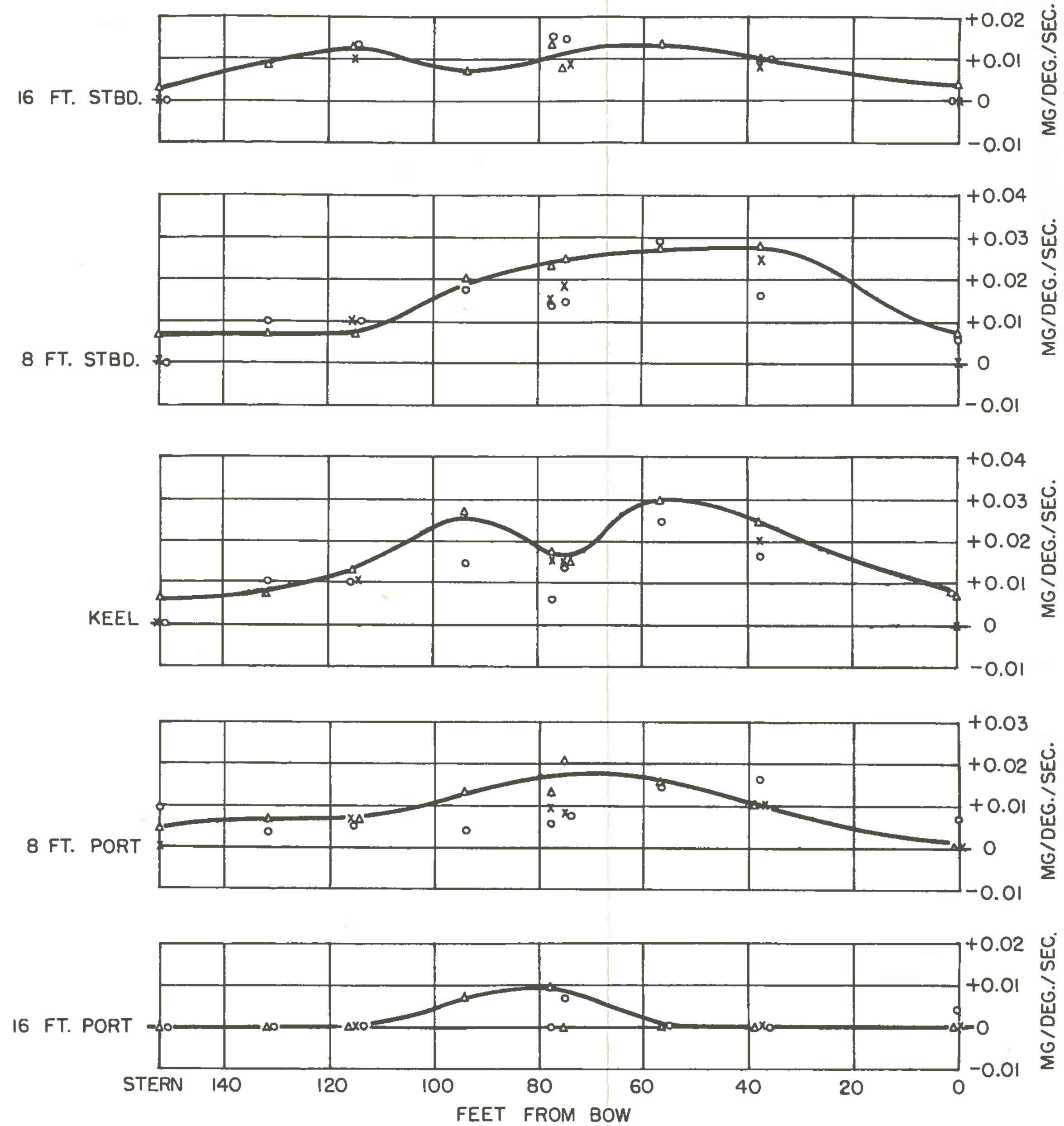


LEGEND: —△— BOGUE D.G. ON (HDG., PITCH & ROLL)
o BOGUE D.G. ON (HDG. ONLY)
x HULL (1957 TRIALS)

NOTE: POSITIVE DIRECTION OF FIELD IS DOWNWARD FOR A ROLL FROM STBD. TO PORT.

LONGITUDINAL PROFILES OF EDDY CURRENT FIELD
VERTICAL COMPONENTS
HEADING: WEST DEPTH: 22 FT.

FIG. 25



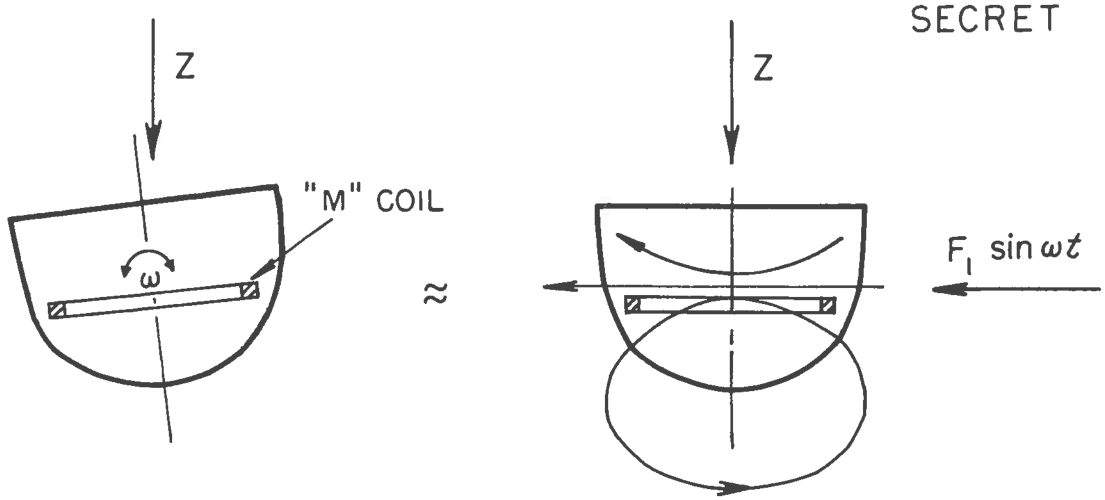
LEGEND: —△— BOGUE D.G. ON (HDG., PITCH & ROLL)
o BOGUE D.G. ON (HDG. ONLY)
x HULL (1957 TRIALS)

NOTE: POSITIVE DIRECTION OF FIELD IS FROM STBD. TO PORT FOR A ROLL FROM STBD. TO PORT.

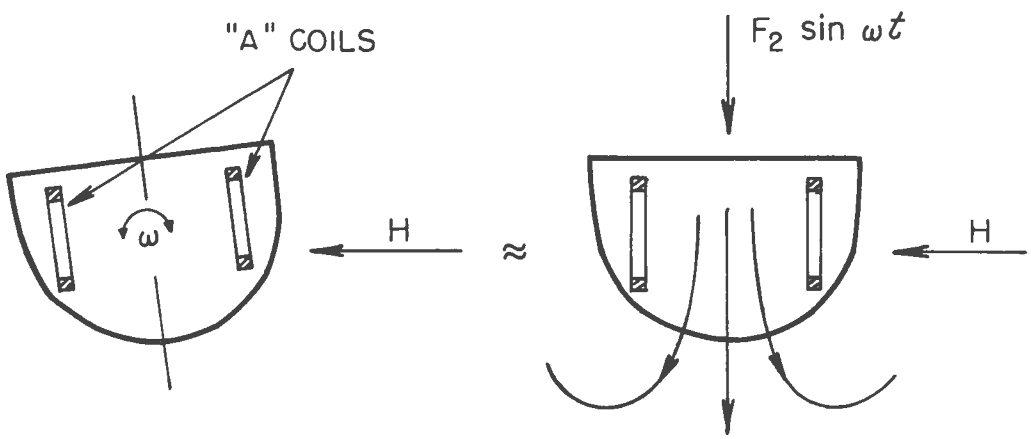
LONGITUDINAL PROFILES OF EDDY CURRENT FIELD
TRANSVERSE HORIZONTAL COMPONENTS
HEADING: WEST DEPTH: 22 FT.

FIG. 26

SECRET



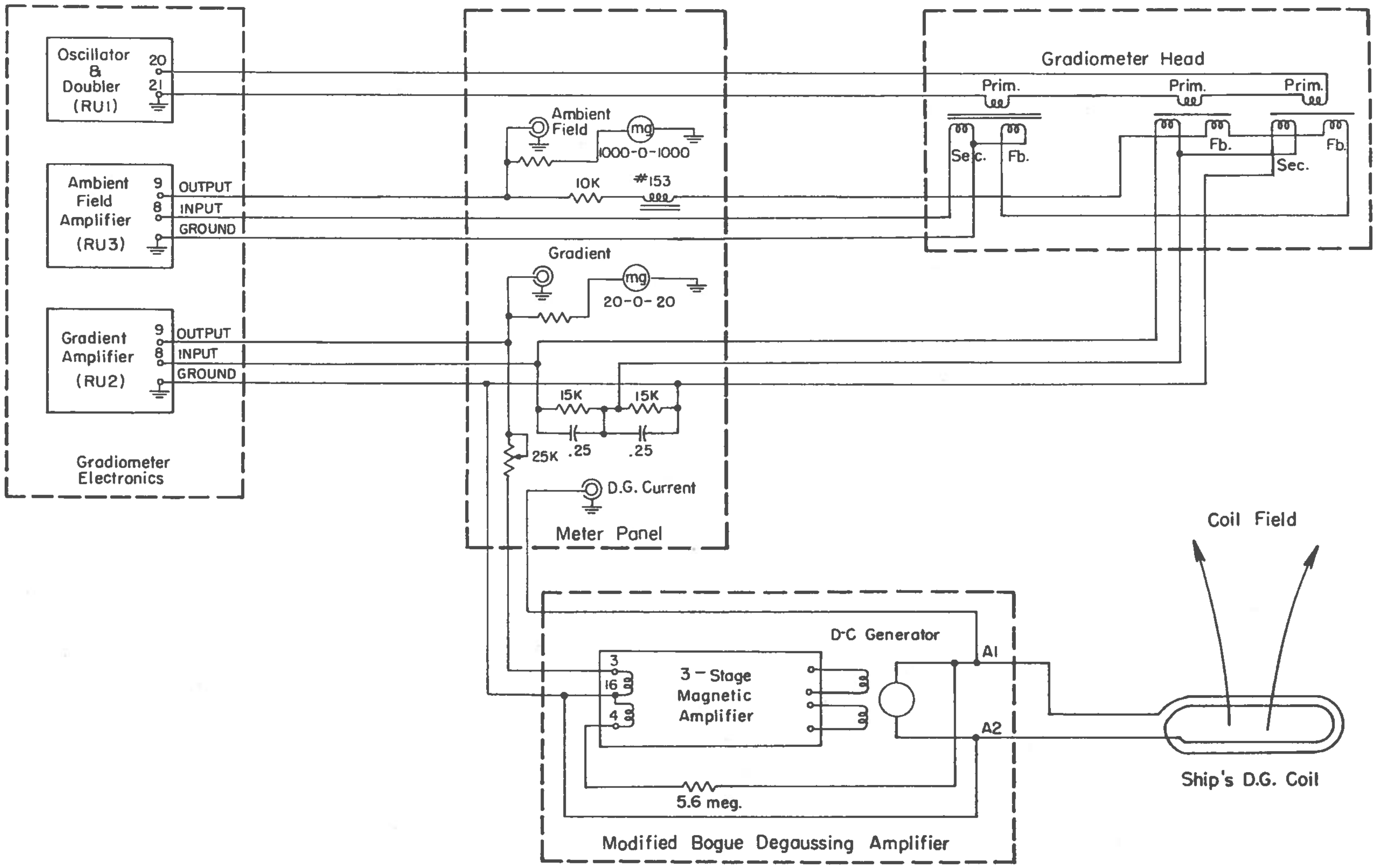
ROLLING SHIP IN A VERTICAL FIELD IS NEARLY EQUIVALENT TO A STATIONARY SHIP IN AN OSCILLATING ATHWARTSHIPS FIELD



ROLLING SHIP IN AN ATHWARTSHIPS FIELD IS NEARLY EQUIVALENT TO A STATIONARY SHIP IN AN OSCILLATING VERTICAL FIELD

FUNDAMENTAL FREQUENCY FIELDS OF ROLLING SHIP

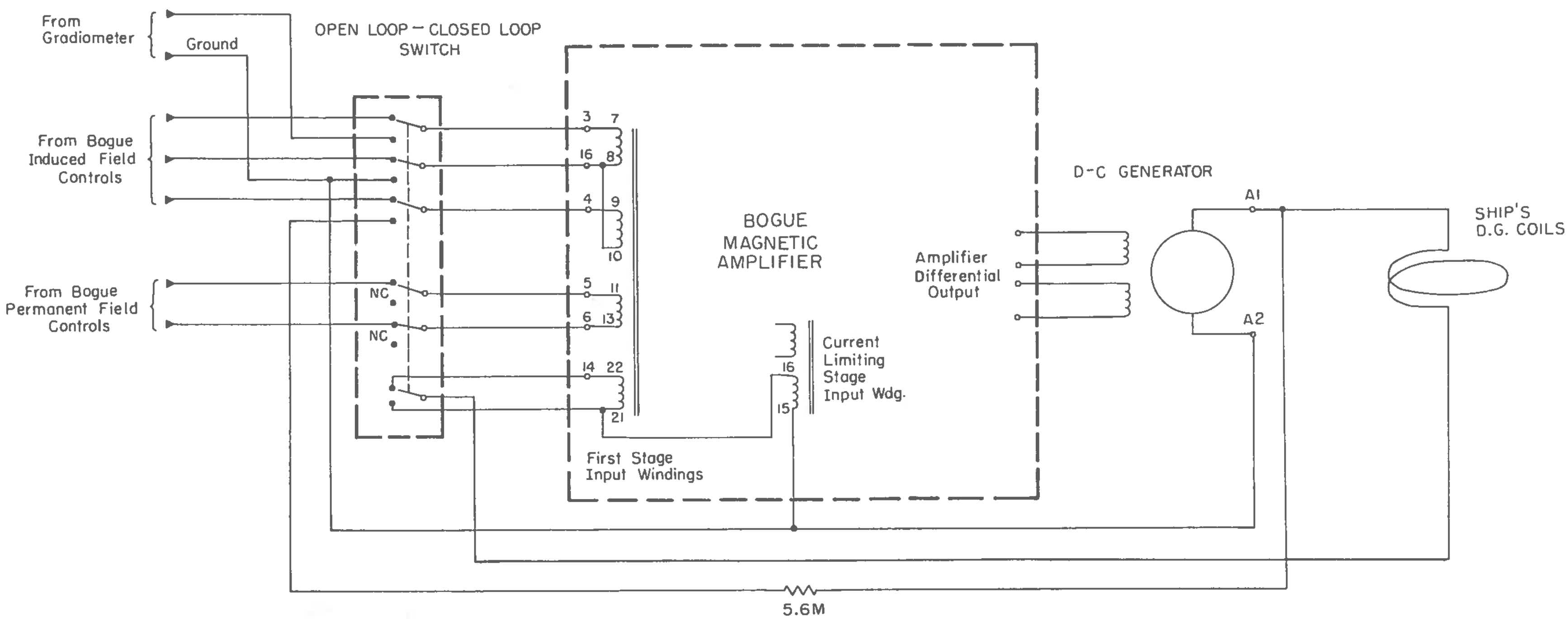
FIG. 27



SCHEMATIC OF CLOSED LOOP DEGAUSSING SYSTEM

FIG. 28

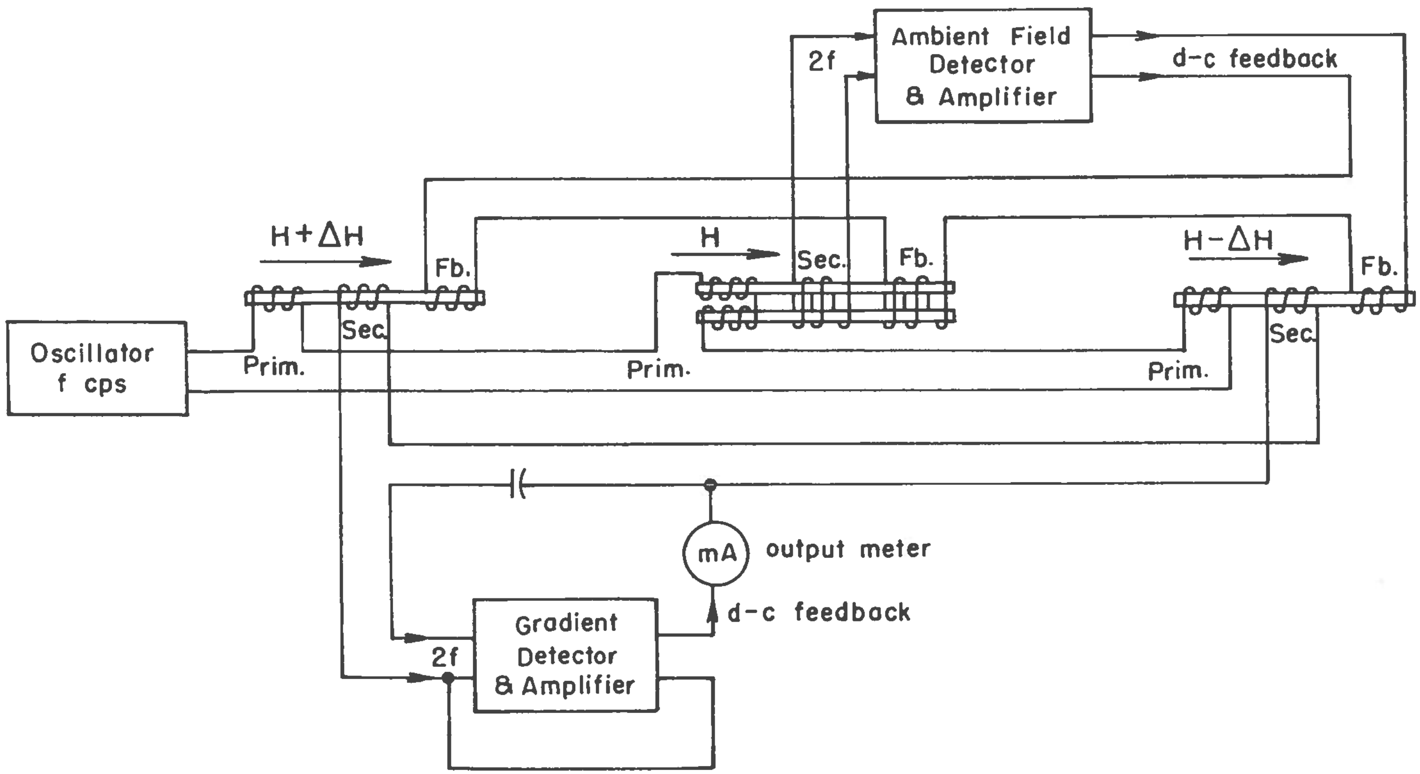
SECRET



METHOD OF SWITCHING BETWEEN
OPEN LOOP AND CLOSED LOOP DEGAUSSING

FIG. 29

SECRET



BLOCK DIAGRAM OF GRADIOMETER

FIG. 30

FIG. 31 "M" CHANNEL GRADIOMETER TUBE
RCN Photo

SECRET

FIG. 32 "A" CHANNEL GRADIOMETER TUBE

SECRET

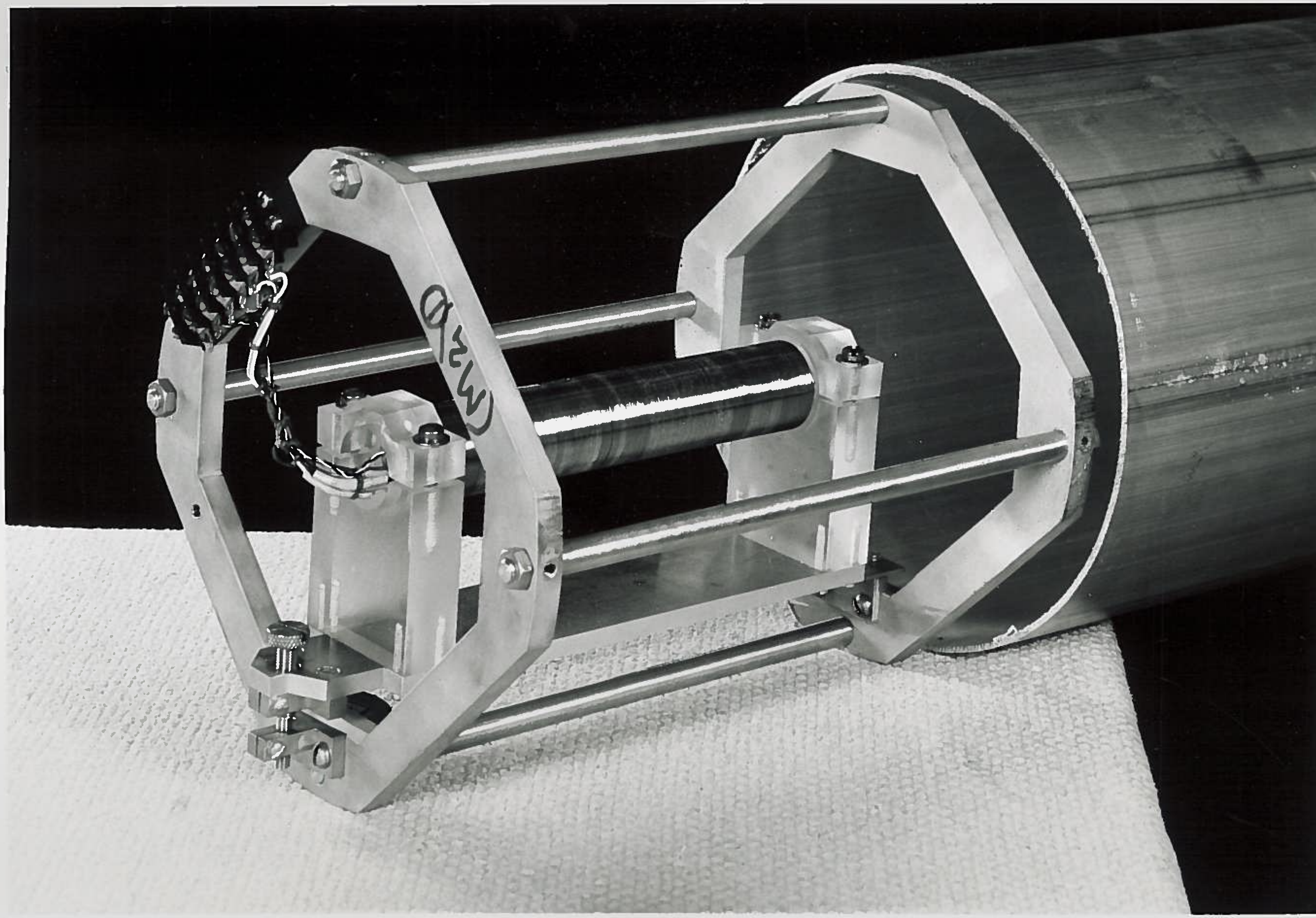


FIG. 33 "M" CHANNEL GRADIENT DETECTOR ELEMENT

SECRET

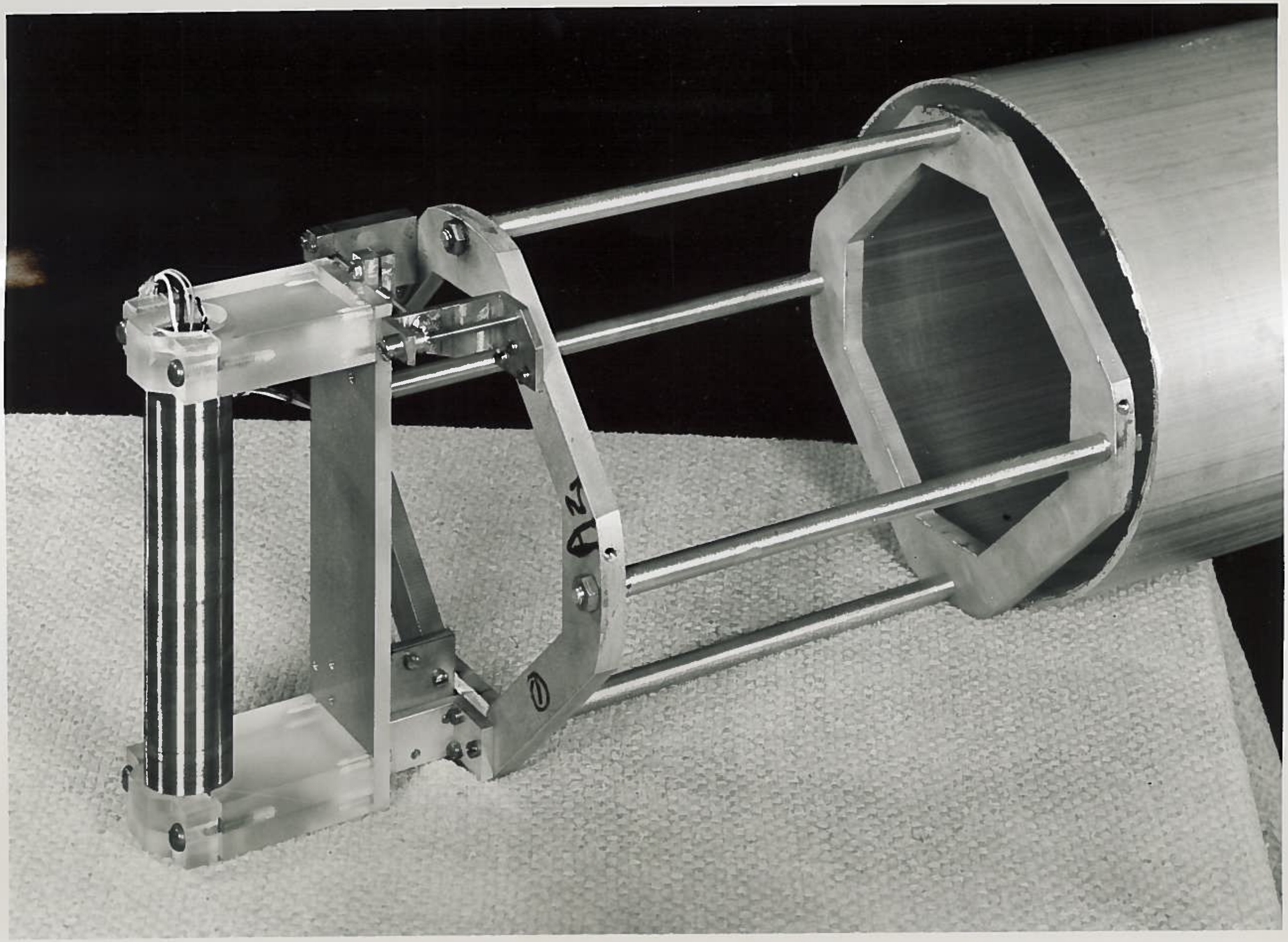
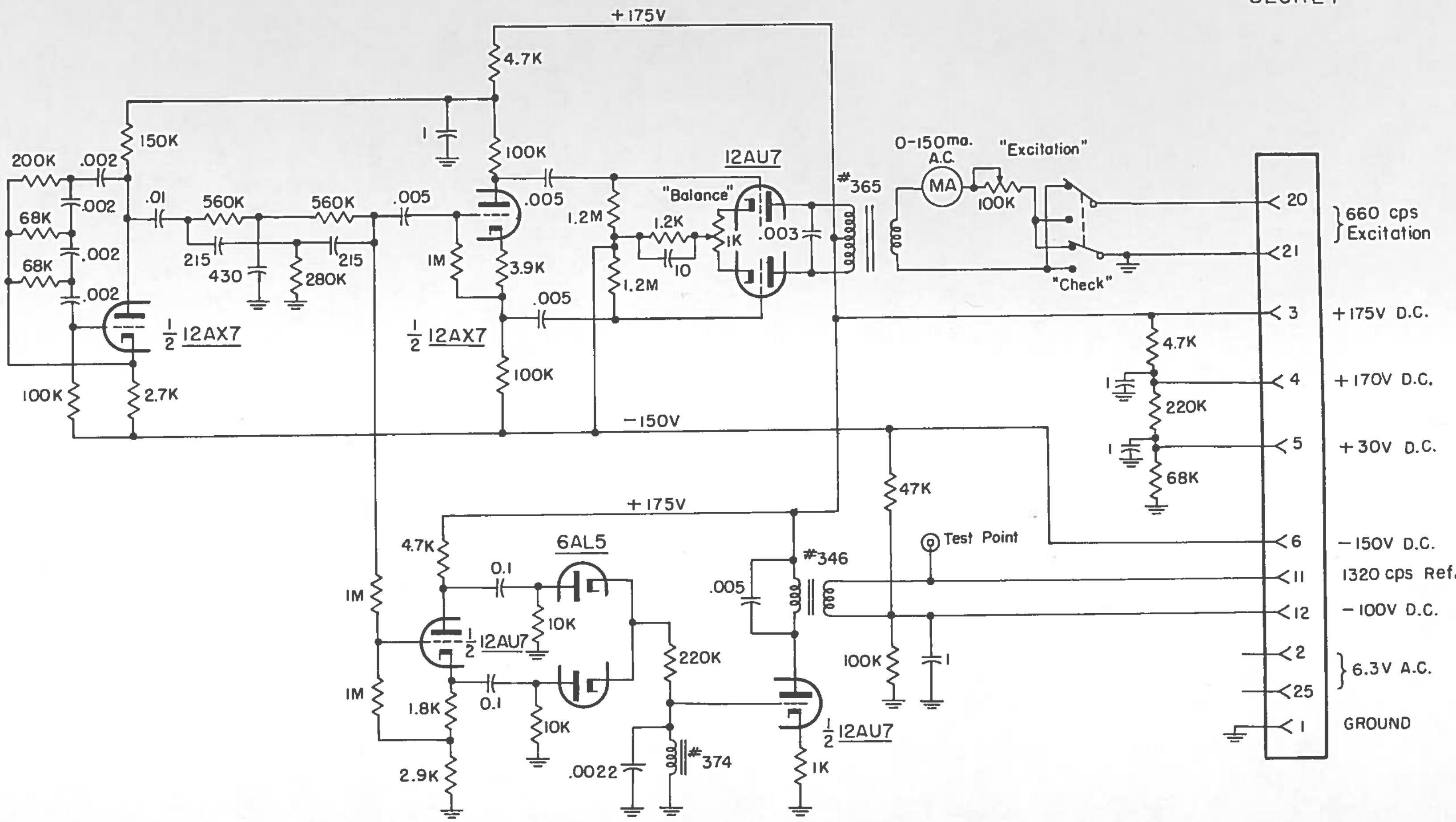


FIG. 34 "A" CHANNEL GRADIENT DETECTOR ELEMENT

SECRET

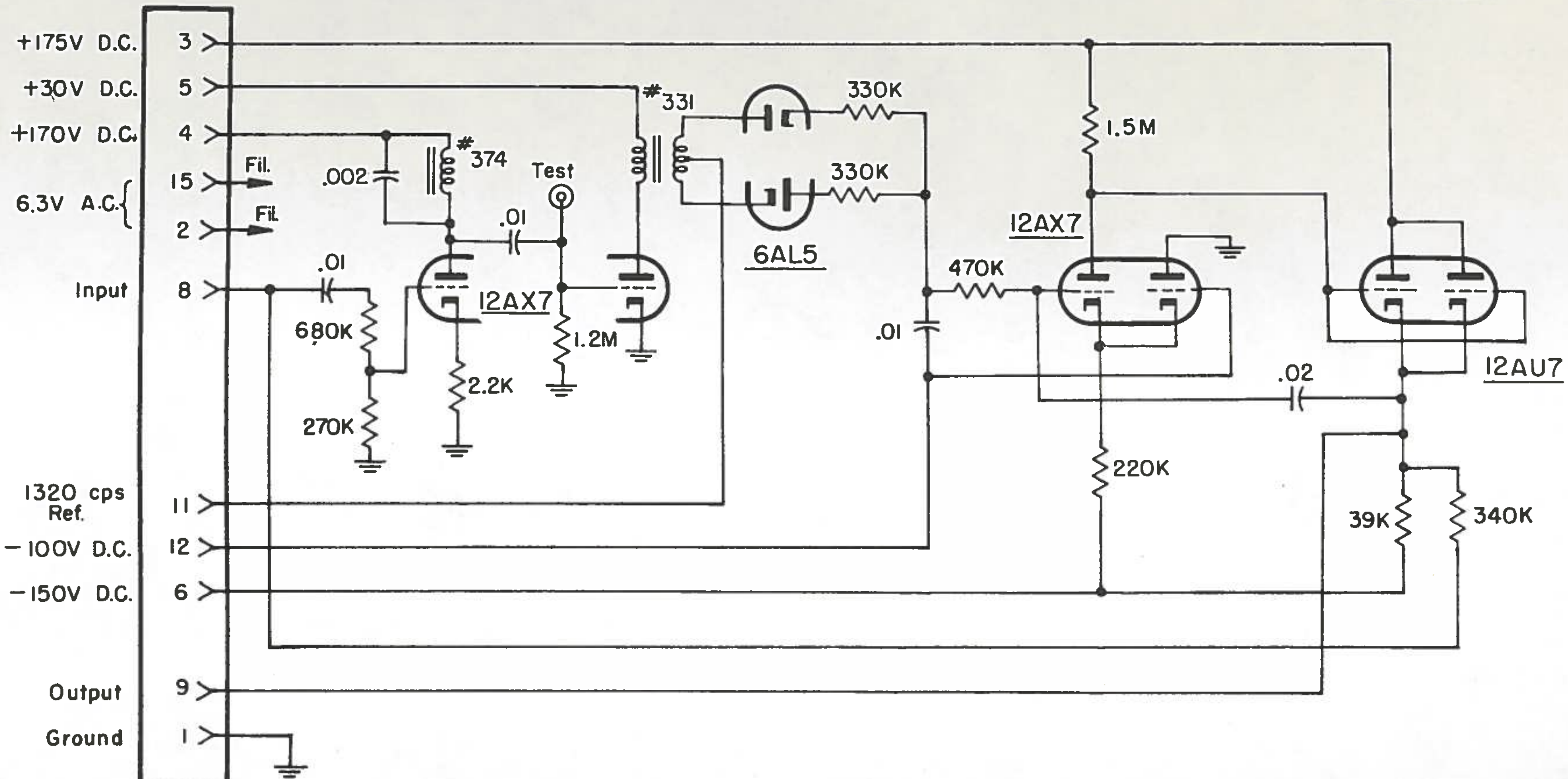


GRADIOMETER ELECTRONIC UNITS
OSCILLATOR AND FREQUENCY – DOUBLER CIRCUIT

(RUI)

FIG. 35

SECRET

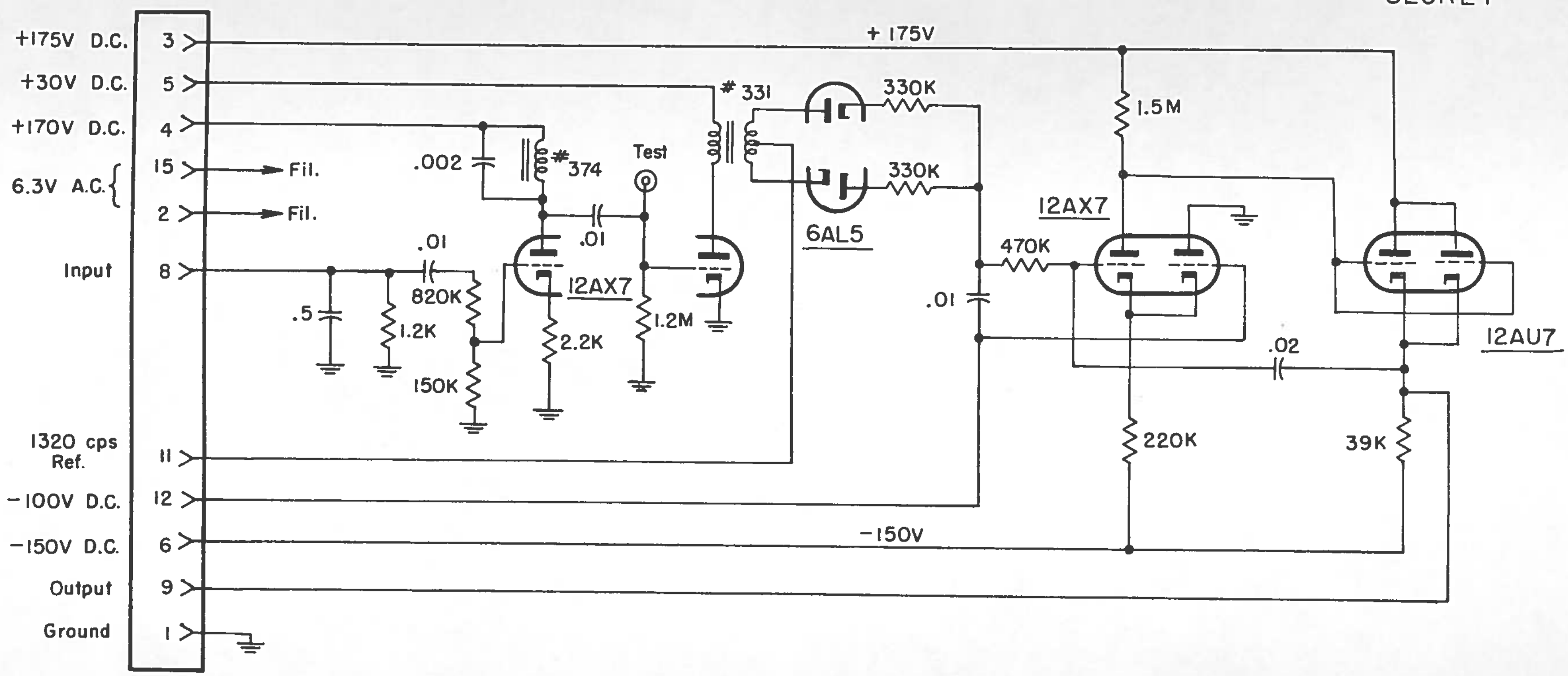


GRADIOMETER ELECTRONIC UNITS
GRADIENT AMPLIFIER CIRCUIT

(RU2)

FIG. 36

SECRET

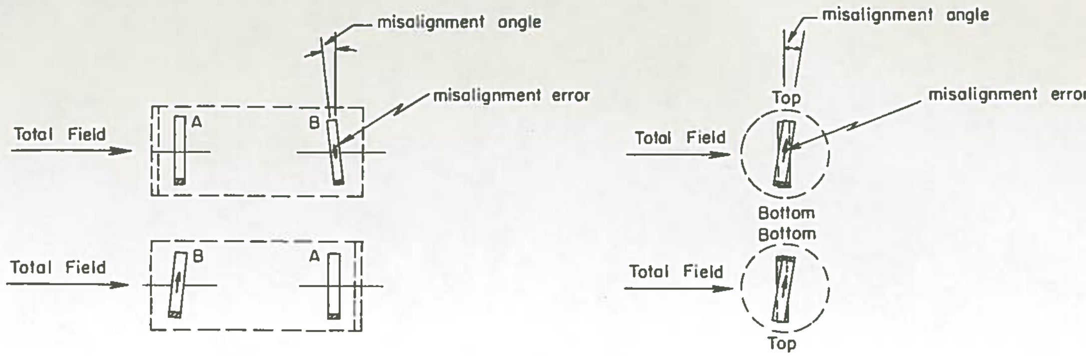


GRADIOMETER ELECTRONIC UNITS
AMBIENT FIELD AMPLIFIER CIRCUIT

(RU3)

FIG. 37

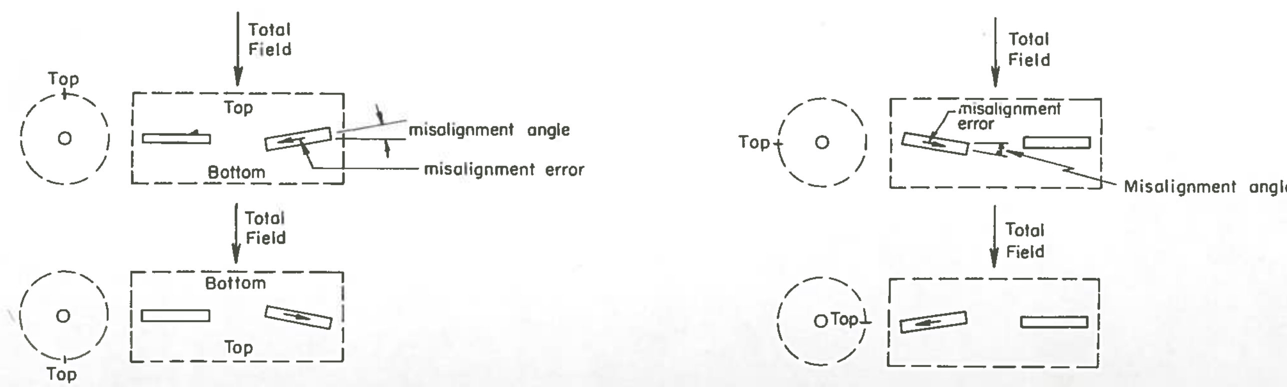
SECRET



DETECTION OF ONE COMPONENT OF MISALIGNMENT BY REVERSING GRADIOMETER END FOR END.

DETECTION OF OTHER COMPONENT OF MISALIGNMENT BY TURNING GRADIOMETER 180° ABOUT LONGITUDINAL AXIS.

"A" GRADIOMETER



DETECTION OF ONE COMPONENT OF MISALIGNMENT BY TURNING GRADIOMETER 180° ABOUT LONGITUDINAL AXIS.

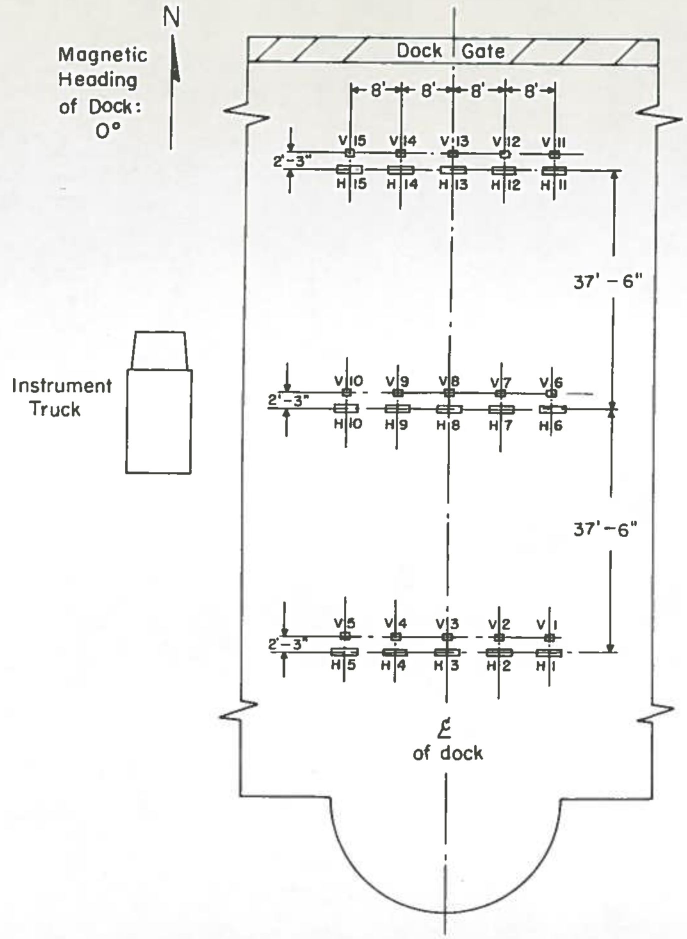
DETECTION OF OTHER COMPONENT OF MISALIGNMENT BY TURNING GRADIOMETER 180° ABOUT LONGITUDINAL AXIS.

"M" GRADIOMETER

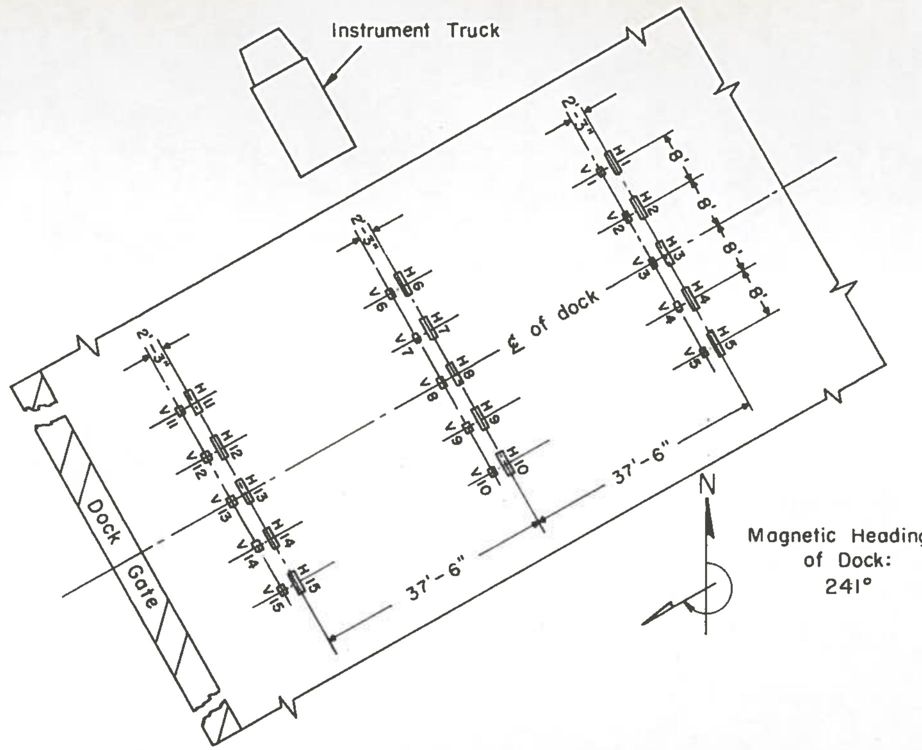
DETECTION OF GRADIOMETER MISALIGNMENT ERRORS

FIG. 38

SECRET



RCN DRY DOCK
ESQUIMALT, B.C.

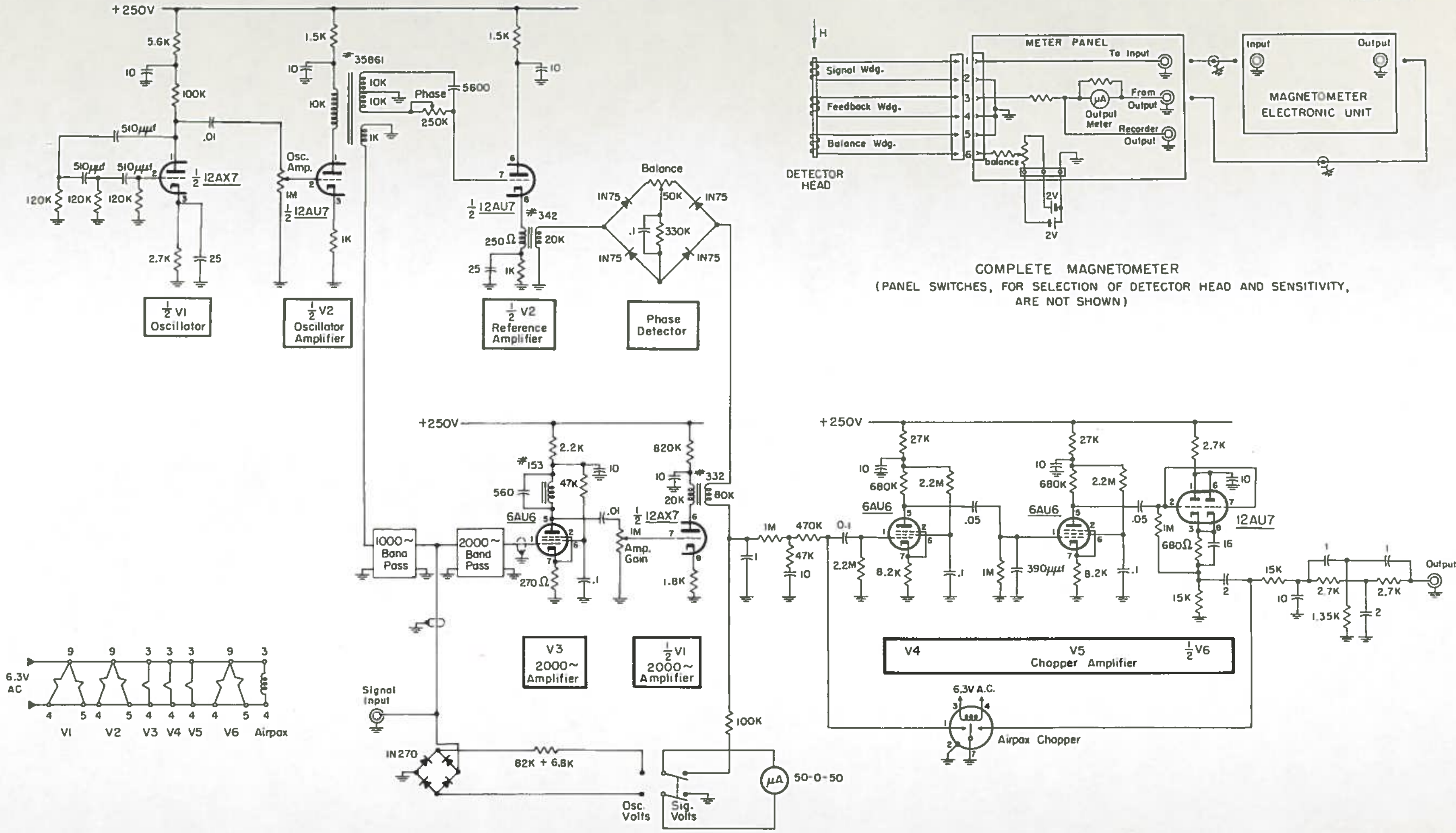


DEPT. OF PUBLIC WORKS DRY DOCK
ESQUIMALT, B.C.

MAGNETIC RANGE PATTERNS

FIG. 39

SECRET



COMPLETE MAGNETOMETER
(PANEL SWITCHES, FOR SELECTION OF DETECTOR HEAD AND SENSITIVITY, ARE NOT SHOWN)

NOTE: All capacitors in mf unless otherwise specified.

MAGNETOMETER CIRCUIT DIAGRAM

FIG. 40

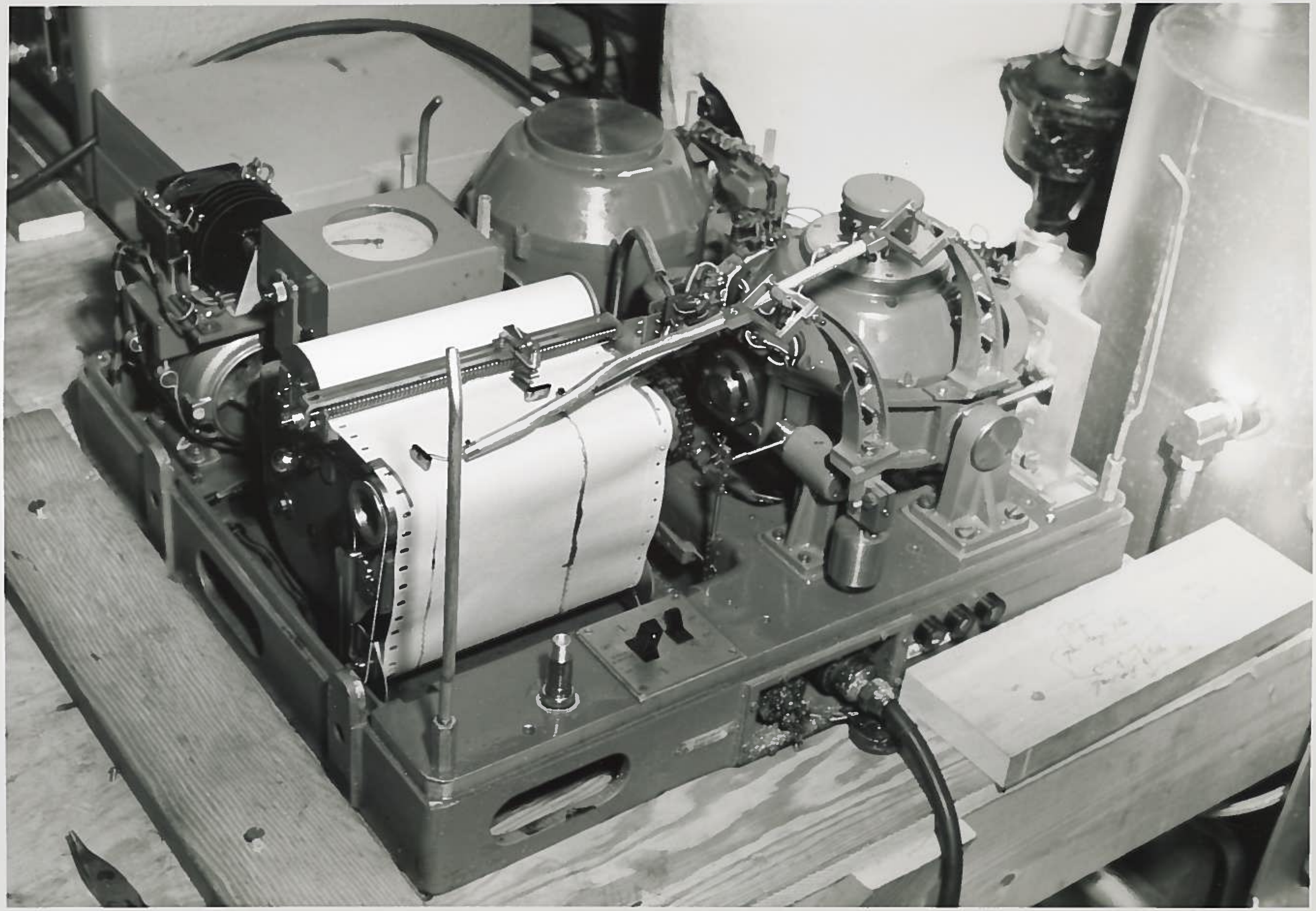
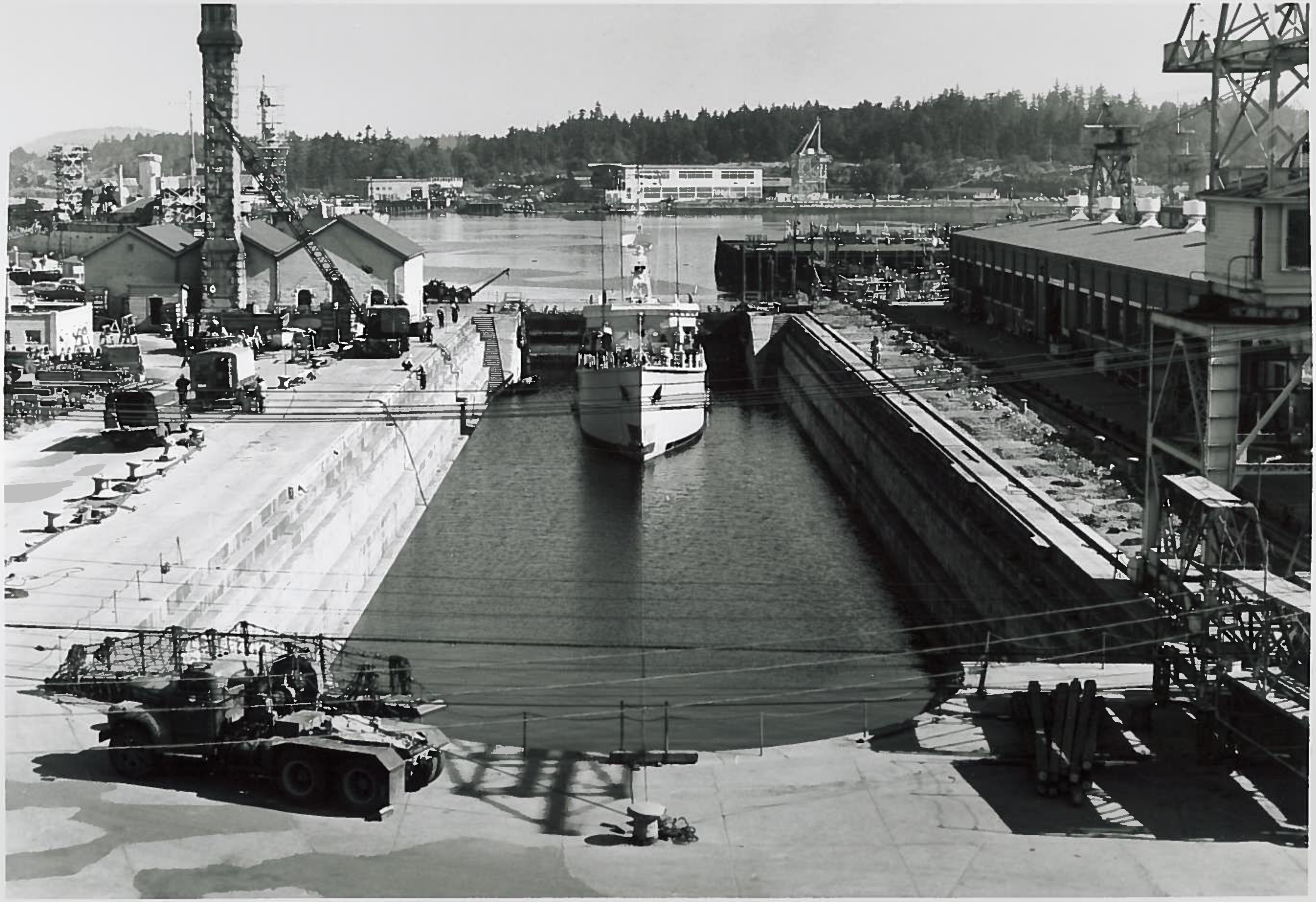


FIG. 41 MUIRHEAD ROLL RECORDER
RCN Photo

SECRET



SECRET

FIG. 42 TOWED RANGING IN RCN DOCK
RCN Photo

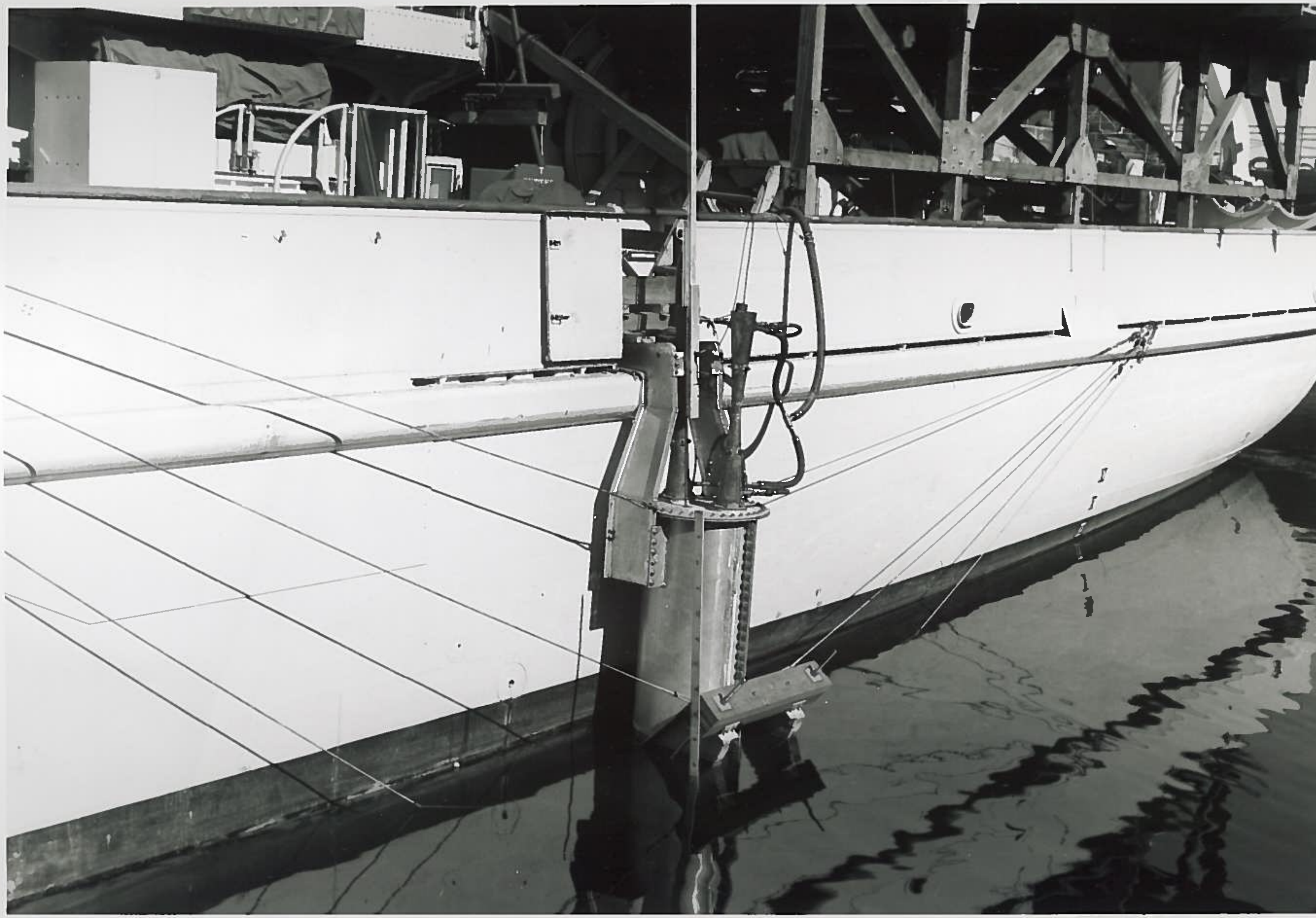


FIG. 43 ROLLING MACHINE, PORT CYLINDER
RCN Photo

SECRET

FIG. 44 AIR COMPRESSOR MOUNTED ON FORECASTLE DECK

SECRET

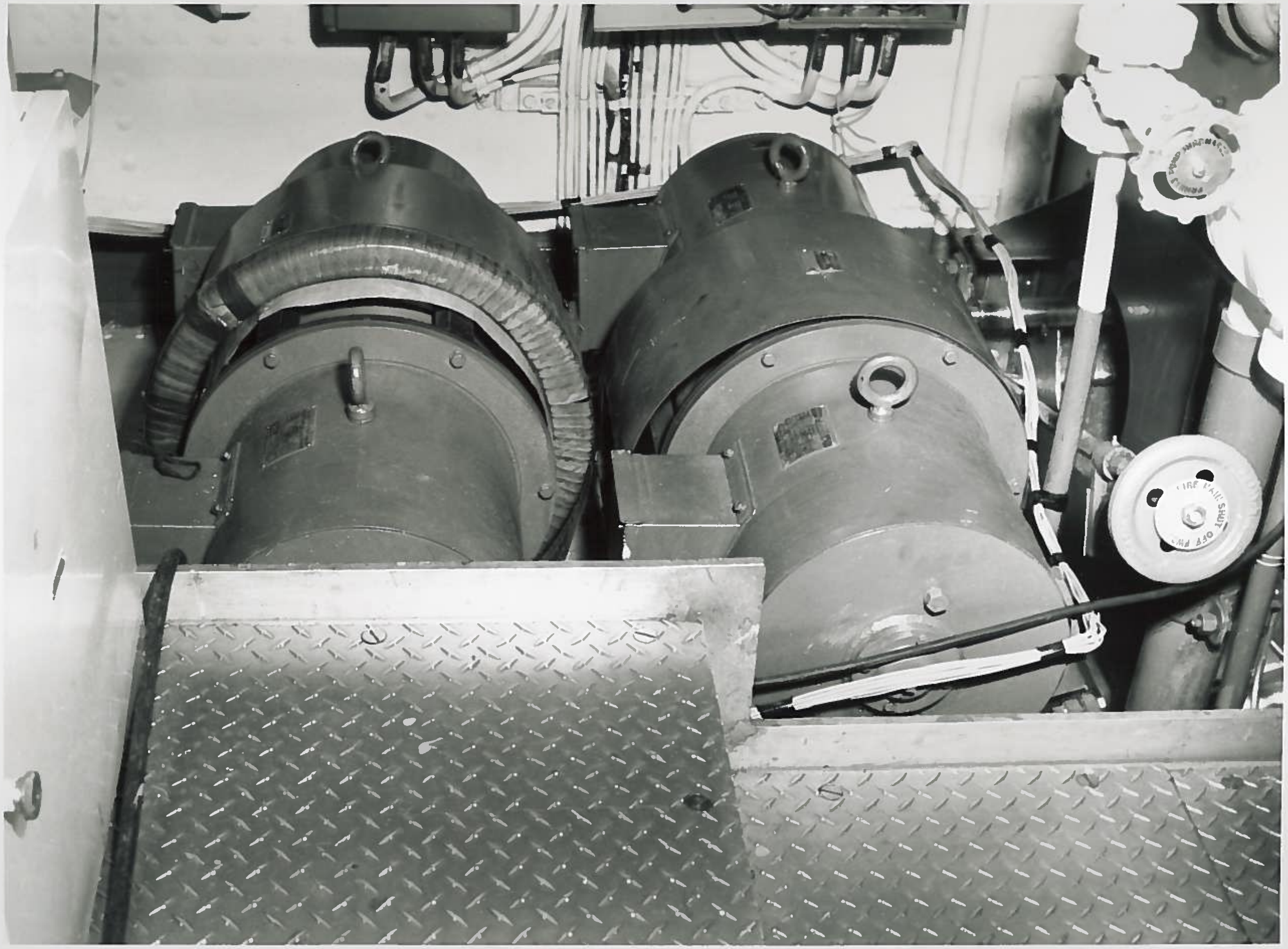


FIG. 45 MAGNETIC CLUTCH DEGAUSSING COIL
RCN Photo

SECRET

SECRET

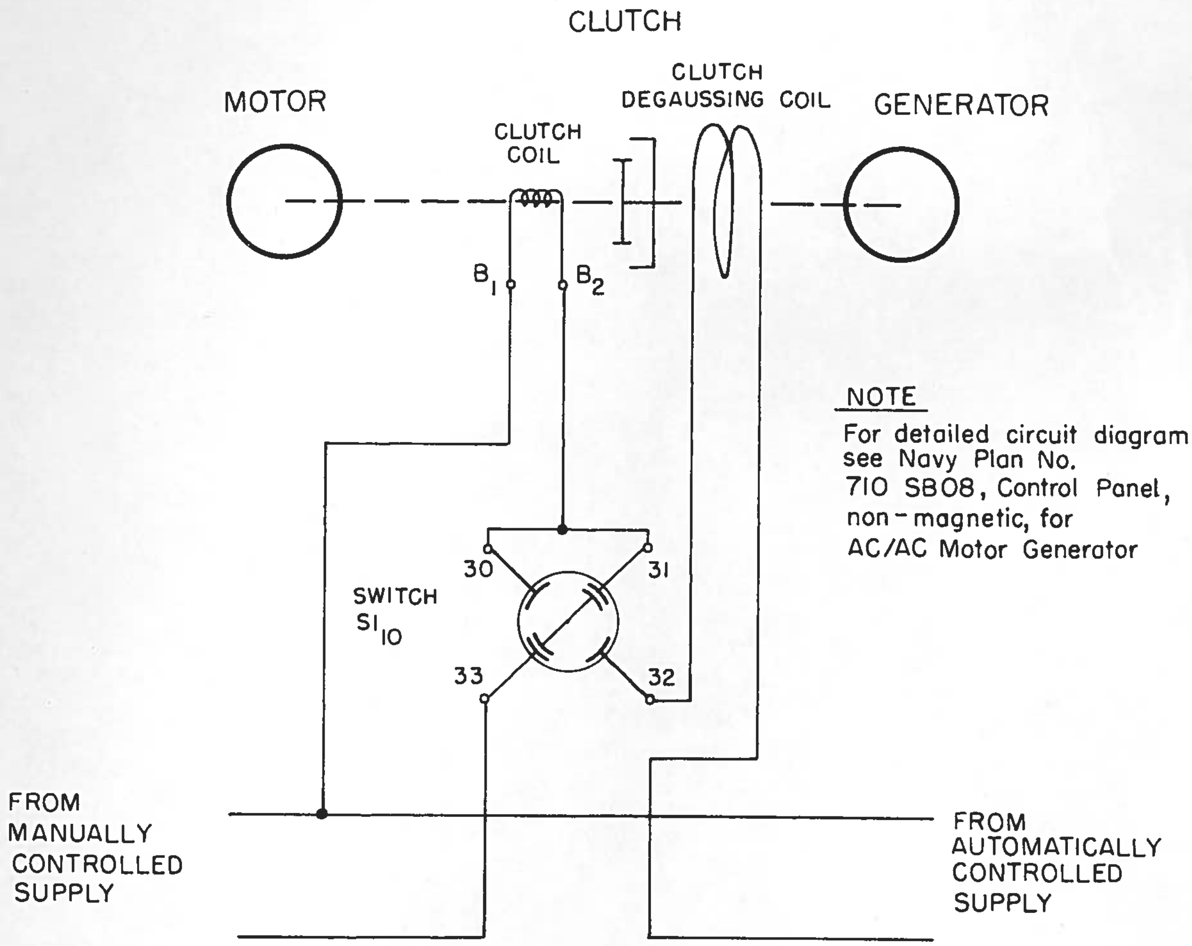


DIAGRAM FOR CONNECTION OF CLUTCH DEGAUSSING COIL

FIG. 46