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EDDY-CURRENT MAGNETIC FIELD DUE TO PITCHING OF MINESWEEPER MCB 159 AND CLASS

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ABSTRACT

A determination of the eddy-current magnetic field produced by the pitching motion of Minesweeper MCB 159 and Class in the earth's magnetic field has been carried out. Several proposed designs of the internal aluminum structure of the minesweeper were submitted by the Royal Canadian Navy for investigation. The maximum eddy currents induced in these structures were obtained by calculation. Magnetic field profiles produced by these currents were obtained by measurement using a reduced-scale model technique. Under normal conditions of pitching ($\rho_o = 4°$, $T = 4.5$ sec, $H_v = 560$ mg) the results show that the maximum eddy-current magnetic field produced under the keel of the ship is less than 0.2 milligauss 30 feet below the waterline, and less than 0.4 milligauss 19 feet below the waterline for all the proposed designs of the internal aluminum structure.

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EDDY-CURRENT MAGNETIC FIELD DUE TO PITCHING OF MINESWEEPER MCB 159 AND CLASS

I. INTRODUCTION

The MCB 159 and Class is a recent design of minesweeper proposed by the Royal Canadian Navy. This ship is largely made of wood, but has an aluminum internal structure. In view of the large eddy-current magnetic fields produced by the rolling of previously designed minesweepers in the earth's magnetic field,[1,2] the aluminum structure has been designed so that it forms no longitudinal conducting loops. This is achieved by constructing hull, decks, girders, and keel of wood. Neglecting any effect due to the aluminum superstructure, such a design of the internal structure will produce no eddy-current signatures due to rolling of the ship in the earth's magnetic field.

In pitching, however, an eddy-current signature is produced. The aluminum internal structure consists of frames and bulkheads. Some of the frames form an array of conducting loops transverse to the longitudinal axis of the ship. The bulkheads are solid sheets of aluminum also transverse to this axis. When the ship pitches in the earth's magnetic field eddy currents are generated in these frames and bulkheads. These currents, induced in a solenoid-like array of conducting loops along the axis of the ship, create an external magnetic field which might fire a magnetic mine.

At the request of the Royal Canadian Navy the National Research Council has determined the magnitude and distribution of the field below the ship for three given designs of its aluminum structure when the ship pitches ±4 degrees with a 4.5-second period at a location where the vertical component of the earth's magnetic field is 560 mg. This report contains the results of the investigation.

II. OUTLINE OF METHOD OF DETERMINING EDDY-CURRENT MAGNETIC FIELD DUE TO PITCHING

The pitching of the minesweeper in the earth's magnetic field induces eddy currents to flow in the array of conducting loops transverse to the longitudinal axis of the ship. The maximum values of these currents were obtained by calculation, assuming a sinusoidal pitching motion and neglecting the inductance of the array. The consequence of neglecting inductance effects, which are described in detail elsewhere[2], is to obtain from the calculation a maximum eddy current, which is slightly too great in magnitude and not exactly in the correct phase with the motion. The calculations with inductance neglected therefore give the upper limits of possible eddy currents. These calculations showed that the eddy currents are maximum when the ship passes through the "deck-horizontal" position. An accurate calculation of the longitudinal magnetic signature produced by these resistance controlled currents flowing in the array would be a difficult and tedious task, since the geometry of the array is far from simple. For this reason a method was devised whereby the signature could be obtained experimentally. A reduced-scale model of the ship was constructed with the conducting loops replaced by insulated wires. Battery currents equal to the maximums of the eddy currents were sent through the insulated wires, and the resulting magnetic field explored in the vicinity of the model by means of a sensitive flux-gate type magnetometer. Surveys were made for several levels below the ship-model which was fixed in the deck-horizontal position. The fields due to the various designs of the aluminum structure of the ship were determined by measuring the fields due to corresponding rearrangements of the structure formed by the insulated wires on the model carrying appropriate battery currents. Conversion of the results to the full-scale ship was accomplished by using a scale factor.

III. INDUCTION OF EDDY CURRENTS BY PITCHING

The following sections contain derivations for the eddy currents induced in the frames and bulkheads of the pitching ship. The method of representing these currents on a model is also given.

(A) EDDY CURRENTS IN FRAMES

A typical frame forming a conducting loop in the minesweeper is shown in Fig. 1A. The loop extends between the forecastle deck and the keel. Fig. 1B shows the frame in position in the ship which is pitching in the earth's vertical and horizontal component magnetic fields, H_v and H_ℓ.

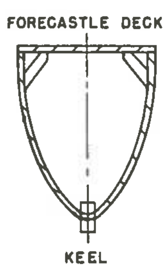

FIG. 1A

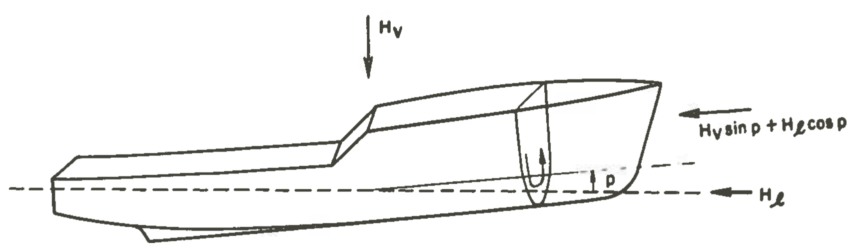

FIG. 1B

The changing flux through the frame induces an electromotive force E, given by

$$E = -\frac{d\phi_T}{dt} \times 10^{-8}* \qquad (1)$$

* The practical system of units is used throughout.

where ϕ_T is the total flux through the frame at time t. This total flux is made up of two separate fluxes, one due to the earth's magnetic field, the other due to the eddy currents set up in the frame itself and in all the other conducting loops in the ship. Neglecting the contribution of this latter flux amounts to ignoring the inductance of the system, and Equation (1) reduces to

$$E = -\frac{d\phi_E}{dt} \times 10^{-8}, \quad (2)$$

where ϕ_E is the earth's flux. If A is the area enclosed by the conducting loop and p is the angle through which the ship has pitched at time t, it follows that

$$E = -\frac{A}{10^8}\frac{d}{dt}\left[H_v \sin p + H_\ell \cos p \right]. \quad (3)$$

For small angles of pitch, $\sin p \simeq p$ and $\cos p \simeq 1$, so this reduces to

$$E = -\frac{A\,H_v}{10^8}\frac{dp}{dt}, \quad (4)$$

and the field H_ℓ does not contribute.

For a sinusoidal pitching motion, the angle of pitch p is given by

$$p = p_o \sin \frac{2\pi}{T} t = p_o \sin \omega t, \quad (5)$$

where p_o is the maximum pitch angle measured from the horizontal, T is the period of pitch, and $\omega = \frac{2\pi}{T}$ is the angular velocity of pitch. Substitution of Equation (5) in Equation (4) yields

$$E = -\frac{A\,H_v\,\omega\,p_o}{10^8} \cos \omega t. \quad (6)$$

Equating this to the resistance drop in the loop gives the eddy current, I, in the loop as

$$I = \frac{A\,H_v\,\omega\,p_o}{10^8 R} \cos \omega t, \quad (7)$$

where R is the resistance of the conducting loop. Since the inductance of the system has been neglected the eddy current in the frame is in phase with the pitching motion. The maximum value of the current occurs when the ship passes through the deck-horizontal position, and from Equation (7) is given by

$$I_{max} = \frac{A\, H_v\, \omega\, p_o}{10^8 R} \, . \tag{8}$$

Formula (8) may be applied to each frame forming a conducting loop to calculate the maximum eddy current induced in each. Apart from a scaling factor, wires carrying these currents on a model preserving the relative positions, sizes, and shapes of the ship-frames should give the magnetic field due to the eddy currents induced in the ship-frames.

(B) EDDY CURRENTS IN BULKHEADS

In the proposed design of the Minesweeper MCB 159 the bulkheads are walls of aluminum of uniform thickness. These walls are subjected to a time-varying flux when the ship pitches in the earth's magnetic field. Fig. 2A shows a typical bulkhead in the ship. It will be assumed that the bulkhead may be considered as being equivalent to a thin circular disc transverse to the longitudinal axis of the ship. As in Section A, the pitching motion of the ship is assumed to be a sinusoidal time function of small angular displacements. These displacements are sufficiently small so that the contribution due to the H_ℓ-component of

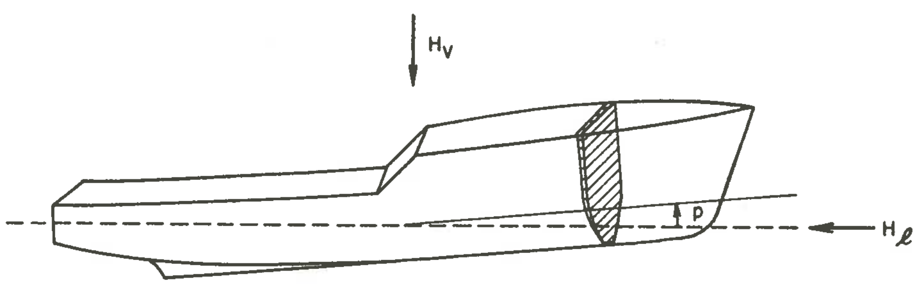

FIG. 2A

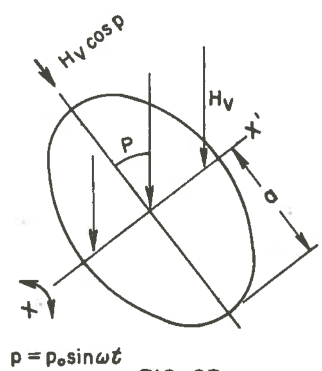

FIG. 2B

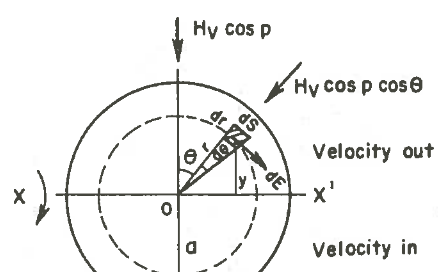

FIG. 2C

the earth's field is again negligible. The motion of the circular disc due to the pitching of the ship may be considered, as far as the induction of eddy currents is concerned, as a composite one; an oscillatory motion about a diameter of the disc and a translation in the direction of the earth's vertical field H_V. This latter motion, since it is parallel to H_V, induces no eddy currents.

Effectively then, eddy currents are induced in the disc due to an oscillating motion about its diameter in the earth's vertical field. In Fig. 2B a disc of radius a oscillates about a diameter X - X' in the uniform magnetic field H_V. At time t the disc is displaced at angle p with the vertical, and the instantaneous velocity of the disc is at right angles to the field $H_V \cos p$. In Fig. 2C a polar co-ordinate system (r, θ) is chosen in the plane of the disc. A small element of arc length ds, distant r from the center O, and at angle θ, is travelling instantaneously at right angles to a field $H_v \cos p \cos \theta$ with a velocity $y \frac{dp}{dt}$, and has an electromotive force induced in it in the tangential direction given by

$$dE = H_v \cos p \cos \theta \, ds \, y\frac{dp}{dt} \times 10^{-8}. \qquad (9)$$

For small pitch angles $\cos p \simeq 1$. From Fig. 2C, $ds = r\,d\theta$ and $y = r \cos \theta$. Using these together with Equation (5), Equation (9) becomes

$$dE = \frac{H_v}{10^8} \cos \theta \, rd\theta \, r \cos \theta \quad \omega p_o \quad \cos \omega t. \qquad (10)$$

The total electromotive force acting about a circle of radius r is

$$E = \frac{H_v \, \omega \, p_o}{10^8} r^2 \cos \omega t \int_{\theta=0}^{2\pi} \cos^2\theta \, d\theta$$

$$= \frac{H_v \, \omega \, p_o}{10^8} \pi r^2 \cos \omega t. \qquad (11)$$

This electromotive force causes current to flow about the circle of radius r. Neglecting inductance effects and letting the current density induced in the disc be j, it follows from Ohm's law that

$$\frac{H_v \, \omega \, p_o}{10^8} \pi r^2 \cos \omega t = (j \, t \, dr) \, \rho \, \frac{2\pi r}{t \, dr}, \qquad (12)$$

where t is the thickness of the disc and ρ is the resistivity of the disc material. Solving for the current density j,

$$j = \frac{\omega \, p_o \, H_v}{2 \times 10^8 \rho} r \cos \omega t, \qquad (13)$$

which is again in phase with the pitching motion of the ship, and has a maximum value occurring when the ship passes through the deck-horizontal position given by

$$j_{max} = \frac{\omega\, p_o\, H_v}{2 \times 10^8 \rho}\, r. \tag{14}$$

Thus the current density distribution is a linear function of the radial distance from the center.

The magnetic effect of these eddy currents in the disc will now be found. The magnetic field produced along the axis of a circular loop of wire carrying a current I, as shown in Fig. 3A, is given by

$$H_z = 0.2\,\pi\, I \frac{r^2}{(r^2 + z^2)^{\frac{3}{2}}}. \tag{15}$$

At large distances, $z \gg r$, Equation (15) becomes

$$H_z = \frac{0.2\,\pi}{z^3}\, I\, r^2. \tag{16}$$

FIG. 3A

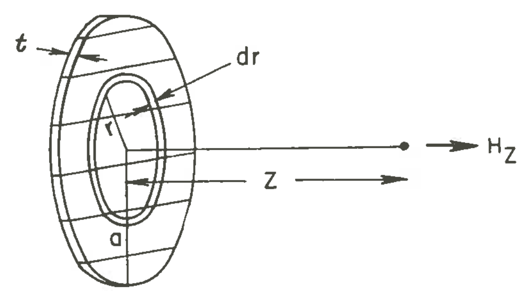

FIG. 3B

In Fig. 3B the magnetic field at large distances along the axis of the disc due to a thin ring of radius r and width dr, is

$$dH_z = \frac{0.2\,\pi}{z^3}\, j_{max}\, t\, dr\;\; r^2. \tag{17}$$

The field due to the whole disc will be, using Equation (14),

$$H_z = \frac{0.2\,\pi}{z^3} \int_{r=0}^{a} \frac{\omega\, p_o H_v}{2 \times 10^8 \rho}\, r\, t r^2\, dr,$$

which, upon performing the indicated integration, becomes

$$H_z = \frac{0.2\,\pi}{z^3}\left[\frac{1}{4}\,\frac{\omega p_o H_v}{2 \times 10^8 \rho}\; t\; a^2\right] a^2. \tag{18}$$

Comparing Equation (18) with Equation (16), it is seen that a turn of wire carrying a current I_b around the periphery of the circular disc produces the same field at large distances as the eddy currents induced in the disc. The current I_b is given by

$$I_b = \frac{1}{4}\,\frac{\omega\, p_o H_v}{2 \times 10^8 \rho}\; t\; a^2. \tag{19}$$

Using the result given by Equation (19), each bulkhead on the ship may be represented on a ship model. The effective circular radius a of the bulkhead may be found by equating the area of the bulkhead to that of a circular disc. Using this value of a, and knowing the thickness and resistivity of the bulkhead material together with the conditions under which the ship is pitching, the current I_b may be calculated using Equation (19). Apart from a scaling factor, a wire carrying a current around the periphery of the bulkhead on a model should produce approximately the same magnetic field as the eddy currents in the bulkheads.

IV. EDDY-CURRENT CALCULATIONS FOR MINESWEEPER MCB 159

Three proposed designs of the aluminum structure of the ship were submitted by the Royal Canadian Navy for investigation. These designs differ from each other in that the number and sizes of the transverse conducting loops formed by the frames are reduced from one design to the next. This reduction is achieved by electrically open-circuiting or removing certain of the aluminum frames. The aluminum bulkheads of the ship are the same for all the designs. The first design of the aluminum structure (Design I) has the greatest number of conducting loops; the third design (Design III) has the least number.

Design I of the structure is shown in Fig. 4A. This photograph shows the ship-model which was constructed for the purpose of magnetic field measurement (described in Section V). Those frames on the ship forming conducting loops are represented by the insulated wires seen on the model. The representation of the bulkheads may also be seen. In the bow region, the frames are electrically connected at the keel and form conducting loops which extend from forecastle deck to keel. Conducting loops are formed from forecastle deck to lower deck in the quarter-fore region and from forecastle deck to upper deck aft of the quarter-fore region. No loops due to frames are present in the midship region, but a group of them extend from upper and lower decks in the quarter-aft region.

Design II of the structure is shown in Fig. 4B. Frames extending to the lower deck no longer form conducting loops and so are not represented on the ship-model; otherwise, the structure is the same as in Design I.

Design III of the structure appears in Fig. 4C. Conducting loops extending to the keel in the bow-region have been eliminated; otherwise, the structure is the same as in Design II.

(A) EDDY CURRENTS IN FRAMES OF MINESWEEPER

Eddy current calculations were necessary for each of the three given designs of the aluminum framework of the ship in order that separate investigations of the magnetic field due to each design be possible. In performing these calculations the formula given by Equation (8) was applied to those frames forming conducting loops. The given conditions of pitch were $p_o = 4° = 0.07$ radians, $T = 4.5$ sec, and $H_v = 560$ mg. The area, A, enclosed by a conducting loop was obtained by measurement from scale plans of the ship. The lengths and cross-sectional areas of the members making up a loop were also obtained from the ship's plans, and using a value for the resistivity of aluminum of $\rho = 4 \times 10^{-6}$ ohm-cm, the resistance, R, of the loop was calculated. Substitution of these values into Equation (8) enabled the maximum eddy current produced in a given frame, I_{max}, to be calculated. For a series of frames not differing greatly in their dimensions, the number of calculations required were reduced by calculating the currents in several of the frames of the series and then obtaining an average current for the series. Currents in conducting loops made up of two loops were calculated by considering only the outer loop. For example, referring to Design I (Fig. 4A), the loops in the quarter-fore region are each made up of two loops, one extending from forecastle deck to upper deck, and the other from upper deck to lower deck. Only the outer loop extending from forecastle deck to lower deck was considered in the current calculation. The approximation introduced is not serious.

The calculations for the maximum eddy currents in the frames for all three designs were carried out by the Royal Canadian Navy. The results of these calculations are given in the first four columns of Table I.

TABLE I

CALCULATIONS FOR EDDY CURRENTS IN FRAMES

Frame* No.	Current per frame I_{max} (ma)			No. of turns per frame		
	Design I	Design II	Design III	Design I	Design II	Design III
-2	55	55	↑	1	1	---
-1	89	89		1	1	↑
0	126	126		2	2	
1	162	162	Average	2	2	Average
2	196	196	= 168	2	2	= 2
3	228	228		3	3	
4	254	254		3	3	
5	266	266	↓	3	3	↓
7-10	364	364	202	4	4	3
12-27	364	217	217	4	3	3
29-44	225	225	225	3	3	3
69-90	228	---	---	3	-	-

* Numbering of frames is from bow to stern

(B) EDDY CURRENTS IN BULKHEADS OF MINESWEEPER

The bulkheads in the minesweeper are twelve in number and are not altered from one design to the next. Their positions, relative sizes, and shapes may be best seen by their representation on the ship-model in Fig. 4C.

The formula given by Equation (19) determines the current which, when sent around the periphery of the bulkhead, will produce approximately the same magnetic field as the eddy currents in the bulkhead. Substitution of the pitching conditions, $p_O = 4^\circ = 0.07$ radians, T = 4.5 sec, and H_V = 560 mg, the resistivity of aluminum $\rho = 4 \times 10^{-6}$ ohm-cm, and the thickness of the bulkheads t = 3/16 in. = 0.476 cm, reduces the formula given by Equation (19) to

$$I_b = 0.00815a^2, \qquad (20)$$

where a is the equivalent circular radius of the bulkhead. In determining the radius, a, the areas of the bulkheads were measured from scale plans of the ship by means of a polar planimeter. These areas were equated to that of a circular disc, πa^2, and the value of the radius, a, was then determined for each bulkhead. Substitution of these values into Equation (20) determined the currents, I_b. A summary of the calculations appears in the first four columns of Table II.

TABLE II

CALCULATION OF EQUIVALENT CURRENTS FOR BULKHEADS

Bulkhead at Frame No.	Measured Cross-Section of Bulkhead (cm^2)	$a^2 (cm^2)$	I_b (ma)	No. of Turns
6	195,400	62,300	508	6
11	312,000	99,500	810	10
15	121,400	38,600	314	4
22	106,000	34,000	276	3
28	502,000	160,000	1300	16
35	502,000	160,000	1300	16
51	370,000	118,000	960	11
68	191,800	61,000	497	6
72	191,800	61,000	497	6
74	96,000	30,600	249	3
82	234,000	74,500	607	7
90	163,000	52,000	423	5

V. EXPERIMENTAL TECHNIQUE FOR DETERMINING EDDY CURRENT MAGNETIC FIELDS

(A) MODEL DESIGN

A reduced-scale model of the minesweeper was built to enable the magnetic field produced by its current-carrying loops to be measured in the laboratory. The model was built of plywood to a scale factor of 1/24. The construction of the model was not complicated, since it was required to reproduce to scale only the outer shape of the minesweeper. Figs. 4A, 4B, and 4C show photographs of the model corresponding to the three designs of the ship construction.

The current-carrying frames and bulkheads of the ship were reproduced to scale in shape, size, and relative position by a structure of insulated wires on the model. In order that the model produce the same field at scale distance as the full-scale ship, the currents to be sent through the insulated wires are those given in Tables I and II reduced by the scale factor 24. This follows from consideration of the fact that the magnetic field produced by an array of current-carrying loops is proportional to the current and inversely proportional to the linear dimension of the system.

The individual current-carrying loops were all connected in series. The relative numbers of turns per frame and per bulkhead were governed by the relative currents in Tables I and II. This eliminated the use of many battery circuits to produce the individual currents listed in the tables and enabled a single battery current to be sent through the loops. Exact reproduction of the currents in the tables is not achieved by this method, but the representation is of the same order of accuracy as the method used in calculating the current. Precautions were taken in the wiring of the model to prevent the production of stray magnetic fields by wires interconnecting the various loops. All loops were wound in the same sense.

In Table I the last three columns list the numbers of turns of insulated wire wound on the model for the frames for each of the three designs of framework construction. The last column of Table II lists the number of turns wound for the individual bulkheads. This series current which must be sent through this array of loops in order to produce the same magnetic field at scale distance as the ship is $\frac{84}{24}$ ma.

A board made of plywood (see photographs) was constructed to enable a magnetometer to be positioned at various levels beneath the keel of the ship-model. Two horizontal rows of holes were drilled in the board at levels corresponding to 19 feet and 30 feet below the waterline. The waterline of the minesweeper was taken as being 7 feet above the keel at the midship position. The holes along both horizontal levels were spaced 8 ship-frames apart. In the photographs the first pair of holes, beneath the bow, is in line with Frame 0; the last pair, beneath the stern, is in line with Frame 96.

The model was placed on a stand 6 feet high, and away from the walls of the laboratory. This precaution was taken to guard against field distortion by ferromagnetic material.

(B) APPARATUS

The series current through the coils was supplied by means of 6-volt storage batteries in series with a rheostat and ammeter. Care was taken to twist the leads together from the current source to the model in order not to introduce stray magnetic fields.

The magnetometer used in making measurements was a slightly modified version of the flux-gate type magnetometer designed by Rose and Bloom.[3] The detecting head of the magnetometer is shown fastened to the measuring board in the photographs. The sensitive element of the detecting head is a strip of mu-metal $1\frac{1}{2}$" long, 1/8" wide, and 0.022" thick. Three windings surround this strip, an exciting coil, an earth-balancing coil, and a feedback coil, all housed inside the Lucite block shown in the photographs. The exciting coil supplies an alternating signal of constant frequency (first harmonic) to the mu-metal strip; the earth-balancing coil bucks out the earth's magnetic field; and the feedback coil is used to null out the magnetic field under measurement. This condition of null is achieved by varying a battery current through the feedback coil until the amplitude of the second harmonic signal appearing on an oscilloscope across the filtered output of the exciting coil is a minimum. The current through the feedback coil multiplied by the feedback coil constant gives the magnetic field being measured.

(C) EXPERIMENTAL PROCEDURE

The ship-model was set up as shown in Fig. 4A, which corresponds to Design I of the ship's construction. The magnetometer was bolted to the measuring board in one of the holes and aligned in either a horizontal or vertical direction with the aid of an attached protractor.

With no current through the array of insulated wires on the model, the component of the earth's magnetic field along the axis of the detector was cancelled out by means of a current through the earth-balancing coil. A known current was then sent through the array of insulated wires. Since the magnetic field produced is directly proportional to this series current sent through the coils, a conveniently large value of this current was used. The resulting large magnetic signal could be accurately measured. The current sent through the array was one ampere, and was kept constant by adjustment of a series rheostat. The current required through the feedback coil of the magnetometer to null out the magnetic signal due to the one ampere flowing in the array of wires on the model was measured on a milliammeter.

The above procedure was repeated for horizontal and vertical positions of the magnetometer in all the holes shown in the measuring board. Another complete set of measurements was made to serve as a check. Multiplication of the feedback coil current readings by the appropriate factor yielded the longitudinal eddy-current magnetic field profiles of the minesweeper for 19 feet and 30 feet below the waterline.

The method was repeated with the model wired in accordance with Design II and Design III of the aluminum structure of the ship.

VI. RESULTS

The feedback coil current readings could be converted directly to give the eddy current magnetic field profiles due to the full-scale ship. The feedback coil had a coil constant of 77 mg/ma. Using a current of 1 ampere (= 1000 ma) through the array of coils on the ship-model, the relation used to give the magnetic field due to the full-scale ship at a given point was

$$H_s = \frac{77}{24 \times \frac{1000}{84}} I_f,$$

$$= 0.27\, I_f, \qquad (21)$$

where H_s is the field in milligauss of the ship and I_f is the nulling current in milliamperes in the feedback coil of the magnetometer.

The horizontal and vertical eddy current magnetic field profiles for Minesweeper MCB 159 are given for positions 30 feet and 19 feet below the waterline, and for Designs I, II, and III of the minesweeper construction in Figs. 5A, 5B, 5C, and in Figs. 6A, 6B, and 6C. The magnetic fields are plotted in milligauss-versus-distance along a horizontal line. This line is marked off in frame-number positions in accordance with the previously described measuring board shown in Fig. 4. The experimental points on the curves are the readings obtained with the magnetometer placed in the holes of the board. An arbitrary but consistent sign convention has been used in obtaining the profiles.

Figs. 5A, 5B, and 5C are the profiles obtained for the level 30 feet below the waterline. The profiles are complex in nature since the geometry of the array of current-carrying loops is not simple. Fig. 5A is the profile obtained for Design I. Maximum field occurs in the vertical direction beneath the bow and has a value of 0.19 mg. The profile for Design II, given in Fig. 5B, shows a general reduction of the field due to the absence of frames forming conducting loops about lower decks. The field is now maximum in the horizontal direction at the Frame-32 position, having a value of 0.14 mg. The profile for Design III, given in Fig. 5C, shows that frame removal in the bow has little effect in reducing the profile. A maximum field of 0.14 mg still occurs at the Frame-32 position.

Figs. 6A, 6B, and 6C are the profiles obtained for 19 feet below the waterline. The profiles are much larger and their complex shape more pronounced than for the 30-foot level. Fig. 6A is the profile obtained for Design I. Maximum field again occurs in the vertical direction beneath the bow and has a value of 0.36 mg. The profile for Design II, given in Fig. 6B, again shows a general reduction of the field. The field is again maximum in the horizontal direction at the Frame-32 position, having a value of 0.30 mg. The profile for Design III, shown in Fig. 6C, shows that the field has been altered somewhat in the bow region, but still has a maximum of 0.30 mg. in the Frame-32 position.

VII. CONCLUSIONS

The eddy-current magnetic field due to pitching of Minesweeper MCB 159 and Class in the earth's magnetic field has been determined for various proposed designs of the ship's aluminum framework construction. The results show that the maximum eddy-current magnetic field produced 30 feet below the waterline directly under the keel of the ship is less than 0.2 milligauss for all proposed designs. The maximum field 19 feet below the waterline is less than 0.4 milligauss for all proposed designs. The results also show that the maximum field due to Design II of the proposed construction is about 20 per cent less than the maximum field due to Design I, while Design III offers no improvement over Design II.

ACKNOWLEDGMENT

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(3) "A Saturated Core Recording Magnetometer", D.C. Rose and J.N. Bloom, Canadian Journal of Research, A-28, pp.153-156.

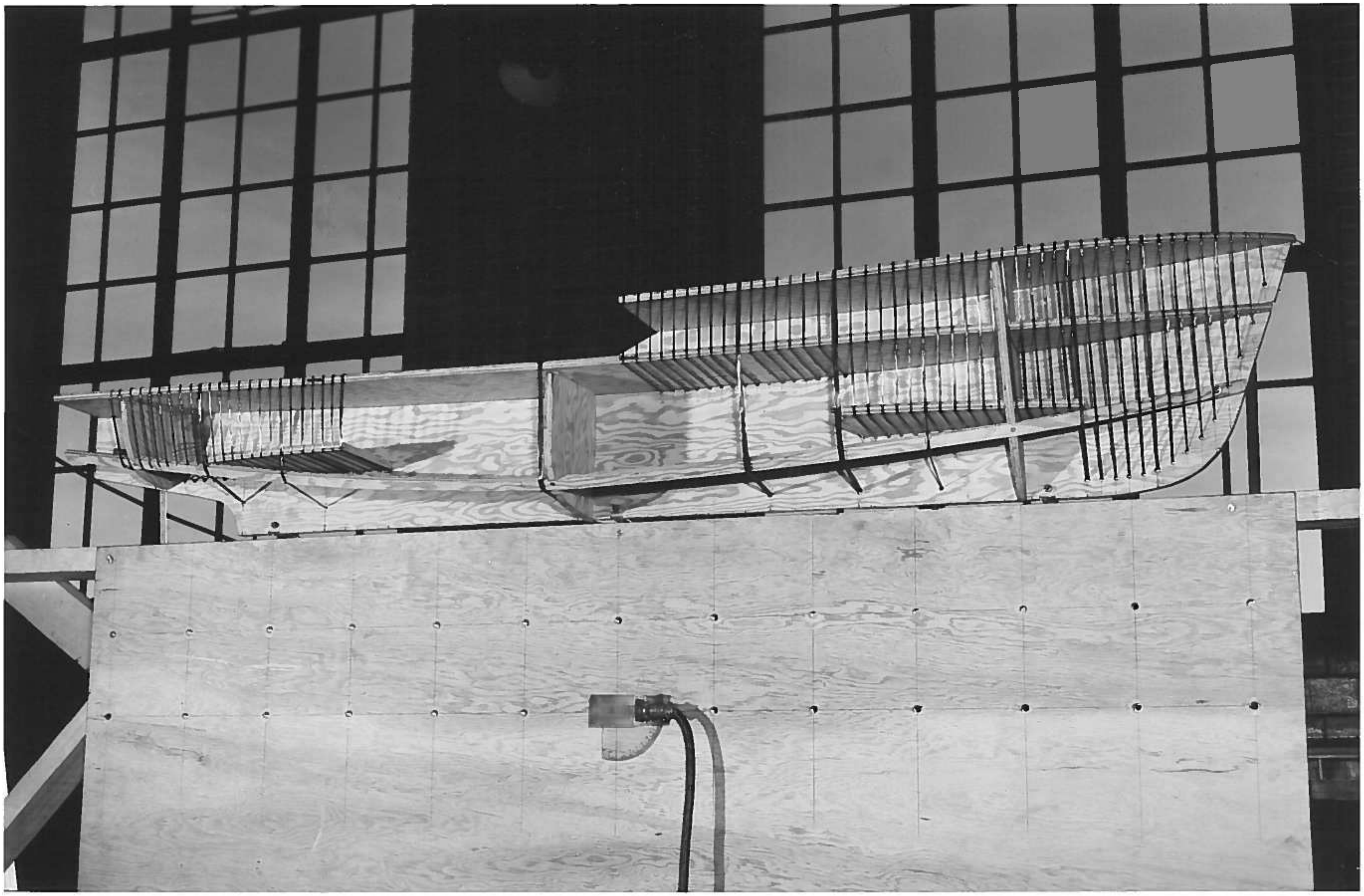

FIG. 4A
SHIP-MODEL CORRESPONDING TO DESIGN I OF CONSTRUCTION

SECRET

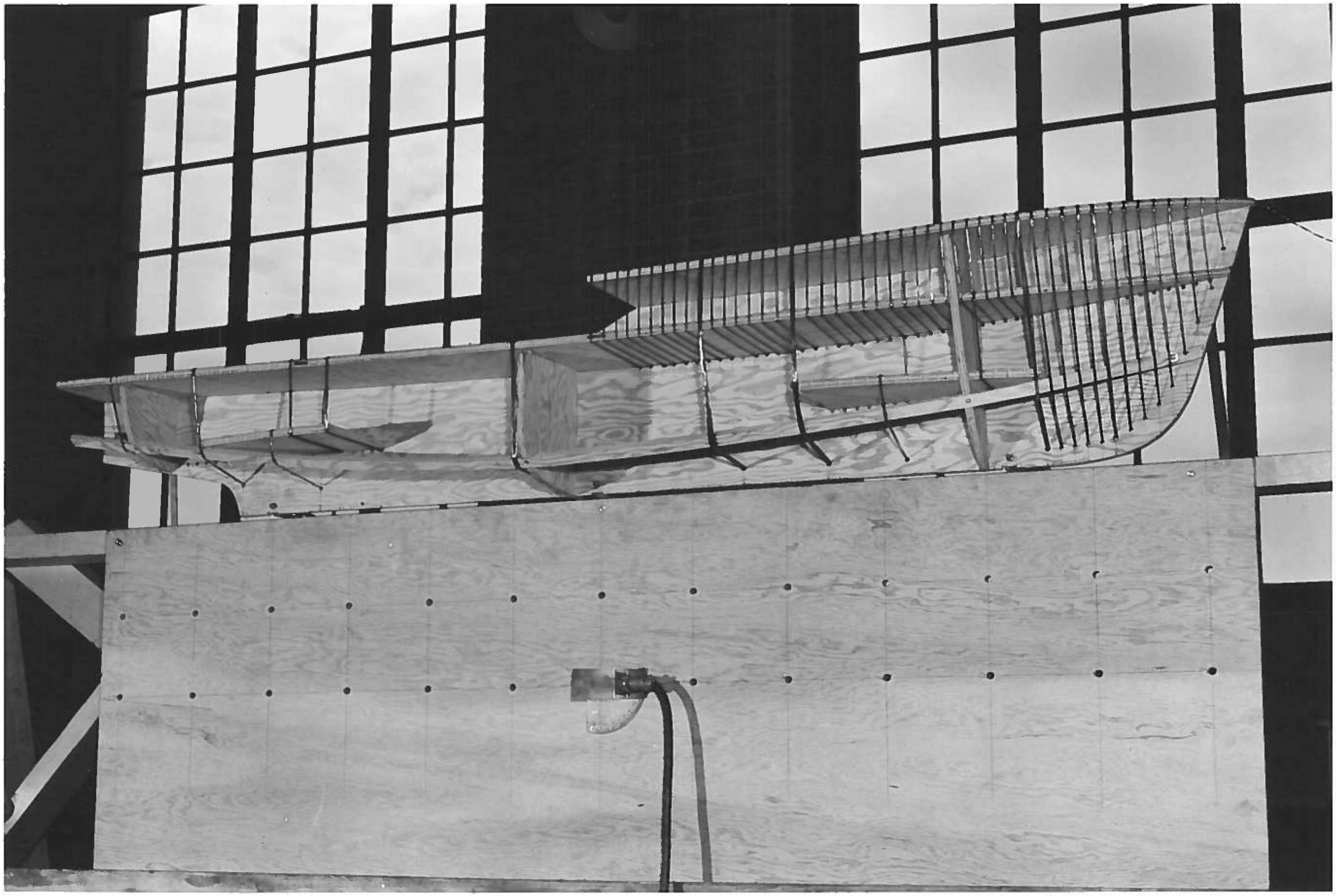

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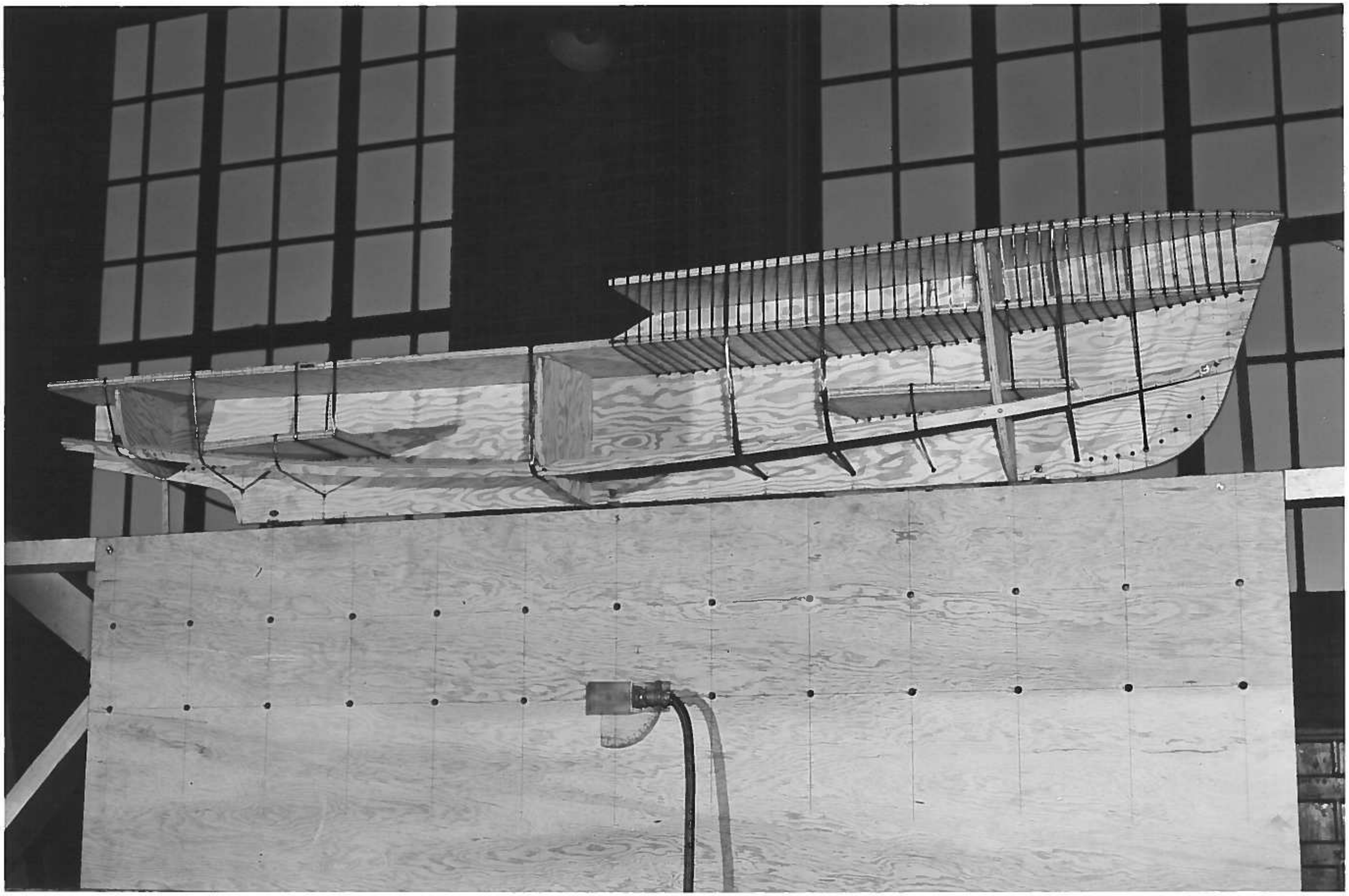
FIG. 4B
SHIP-MODEL CORRESPONDING TO DESIGN II OF CONSTRUCTION



SECRET

FIG. 4C
SHIP-MODEL CORRESPONDING TO DESIGN III OF CONSTRUCTION

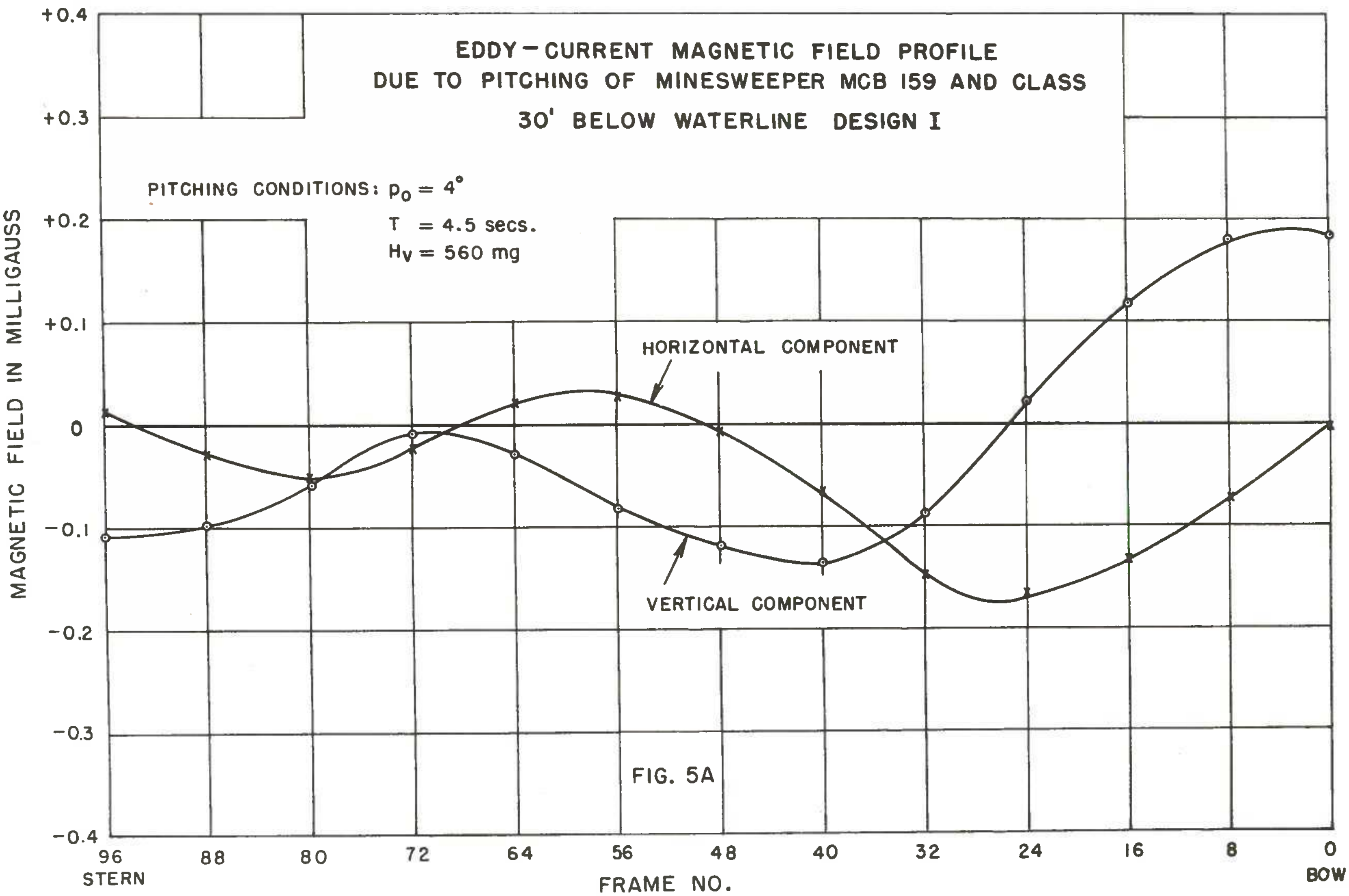
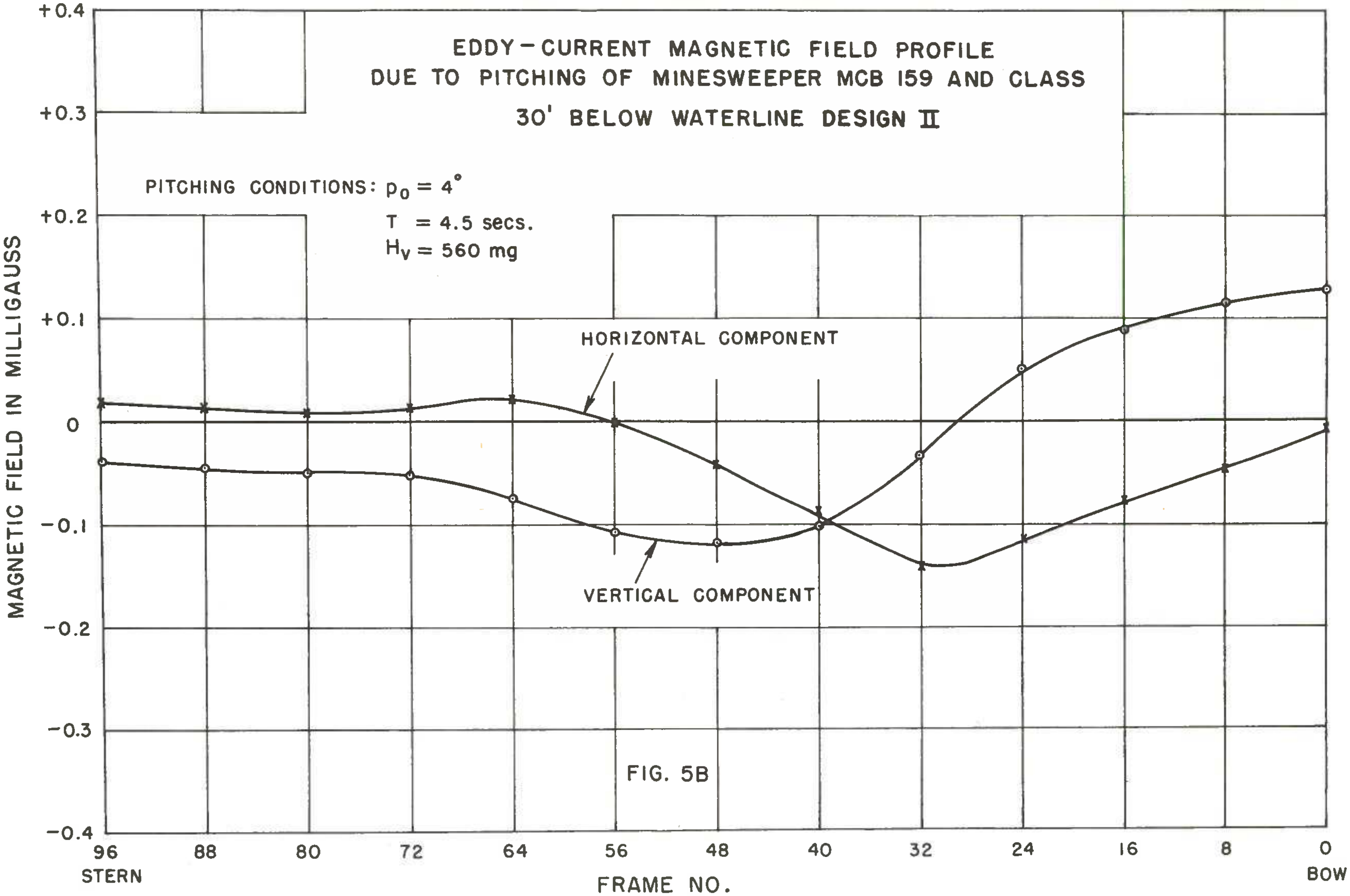


FIG. 5A

SECRET



EDDY-CURRENT MAGNETIC FIELD PROFILE
DUE TO PITCHING OF MINESWEEPER MCB 159 AND CLASS
30' BELOW WATERLINE DESIGN II
PITCHING CONDITIONS: $p_0 = 4°$
$T = 4.5$ secs.
$H_V = 560$ mg
HORIZONTAL COMPONENT
VERTICAL COMPONENT
FIG. 5B
MAGNETIC FIELD IN MILLIGAUSS
+0.4
+0.3
+0.2
+0.1
0
−0.1
−0.2
−0.3
−0.4
96 STERN
88
80
72
64
56
48
40
32
24
16
8
0 BOW
FRAME NO.

SECRET

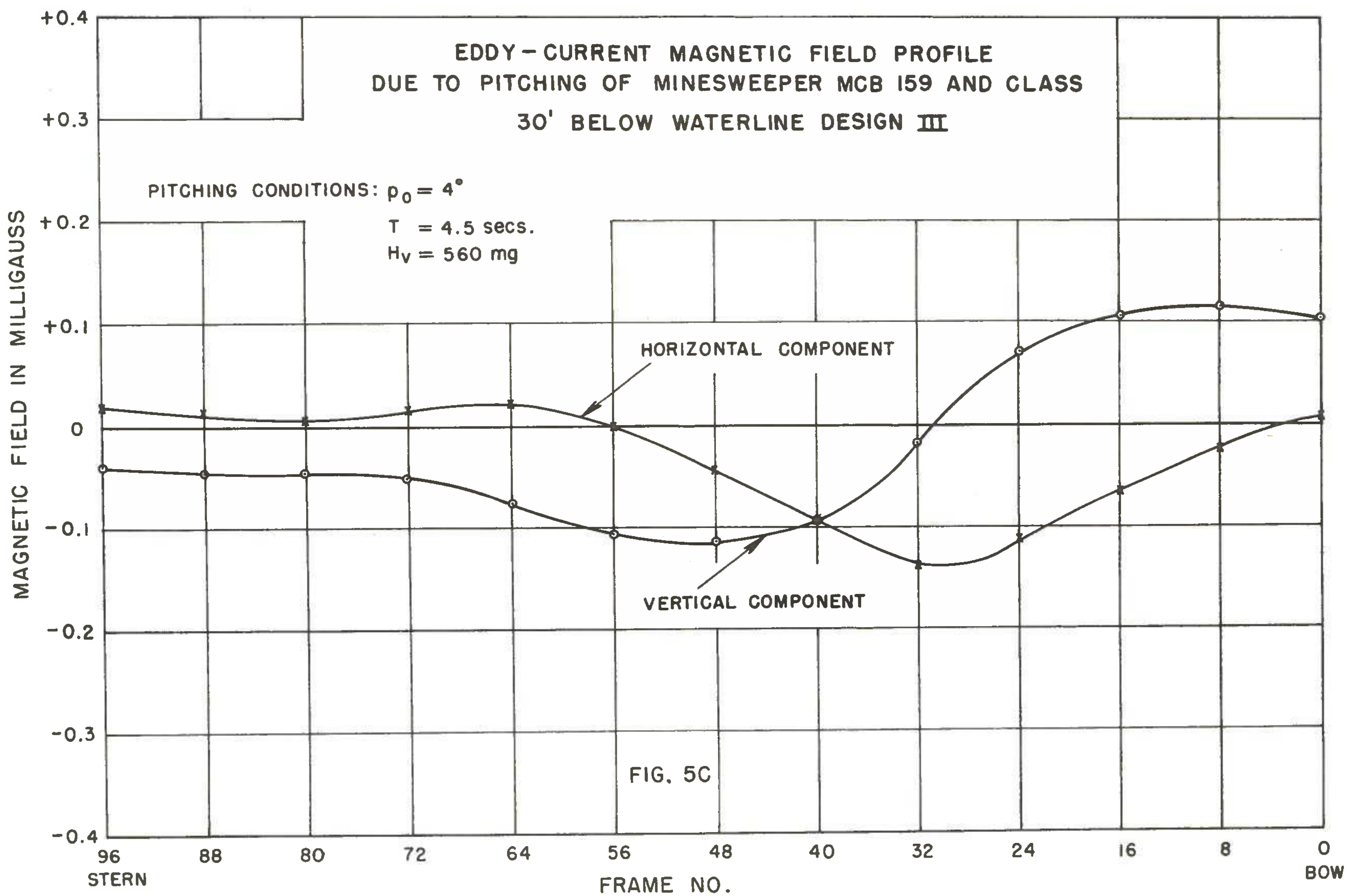


FIG. 5C

SECRET

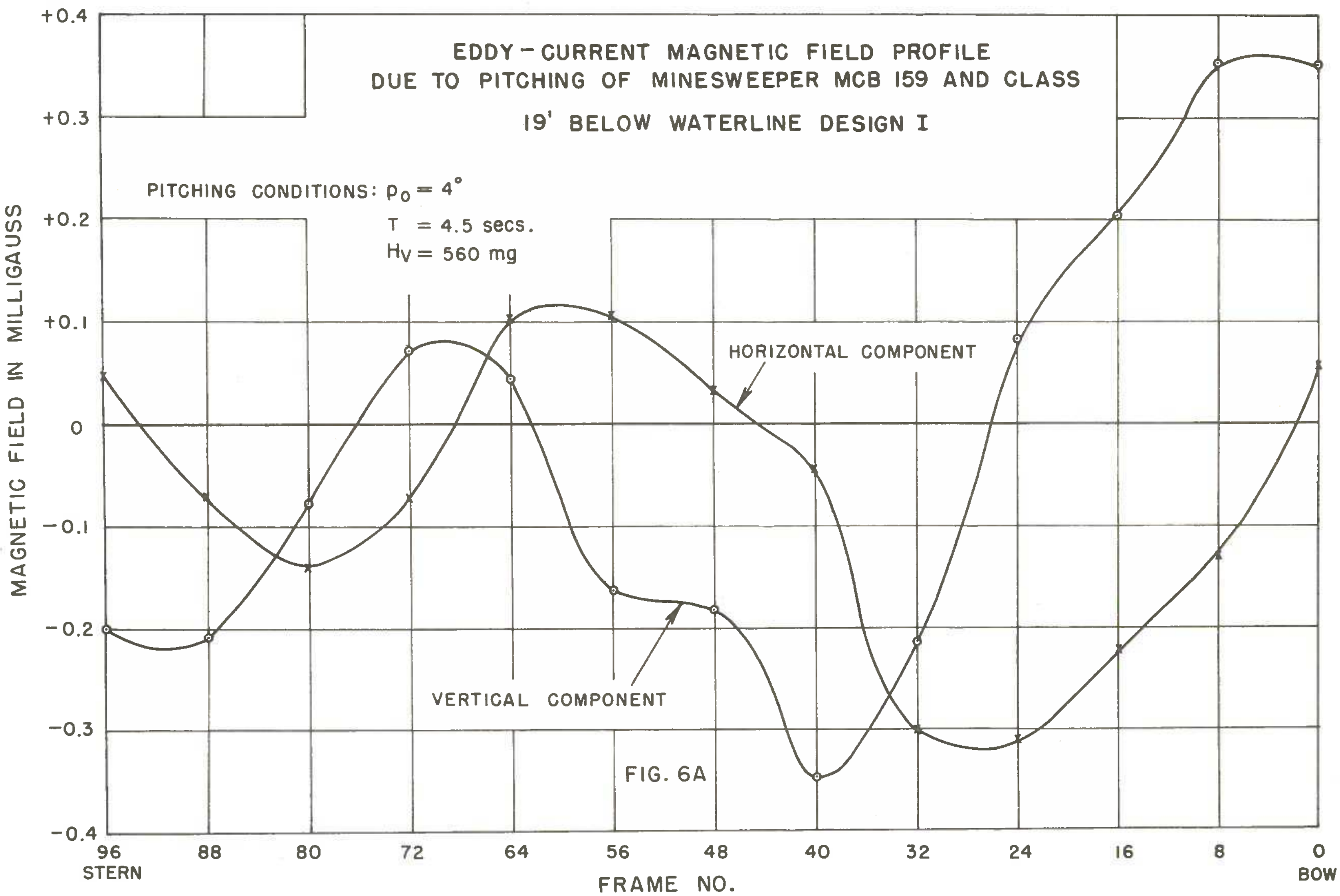


FIG. 6A

SECRET

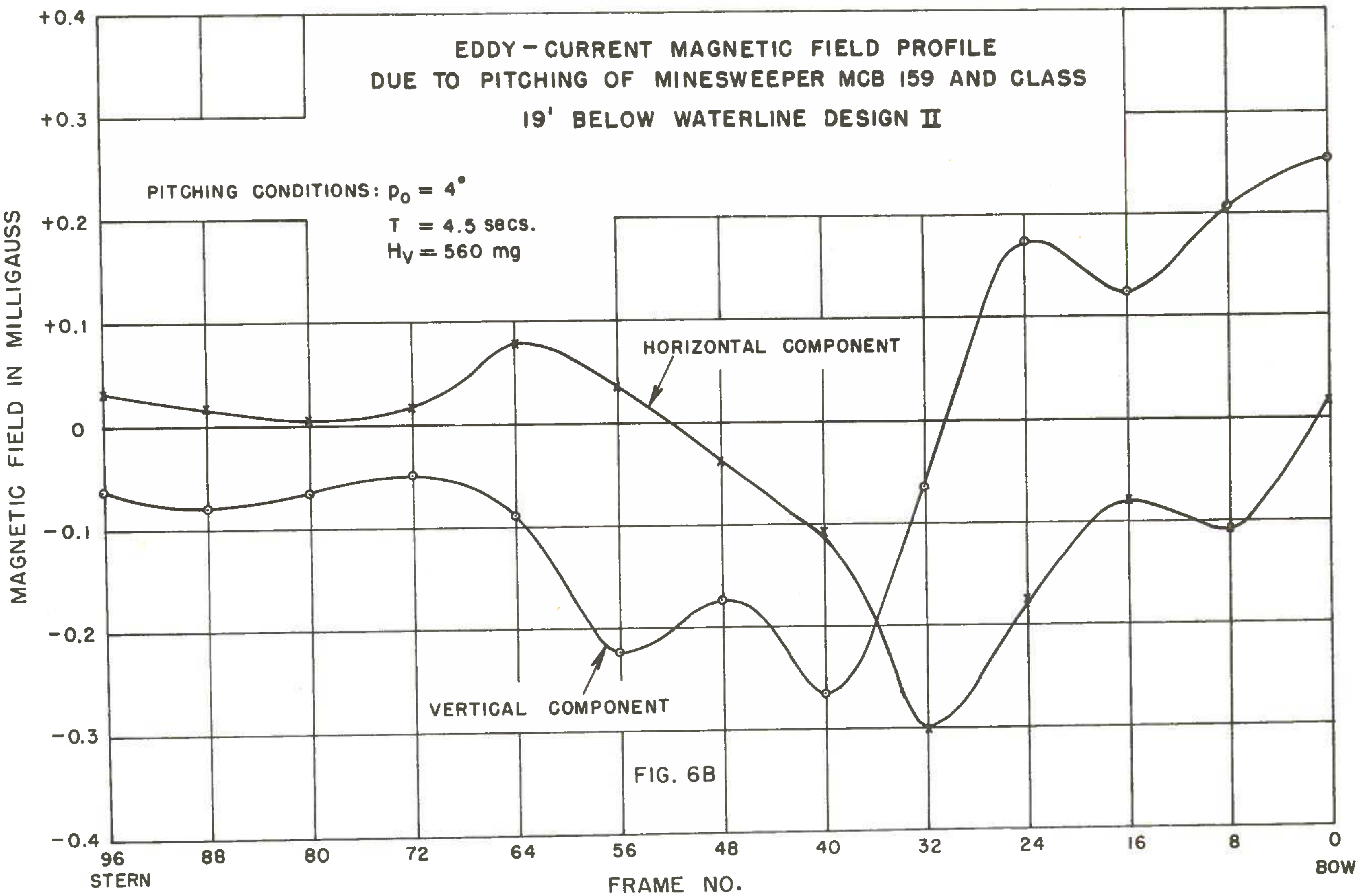


FIG. 6B

SECRET

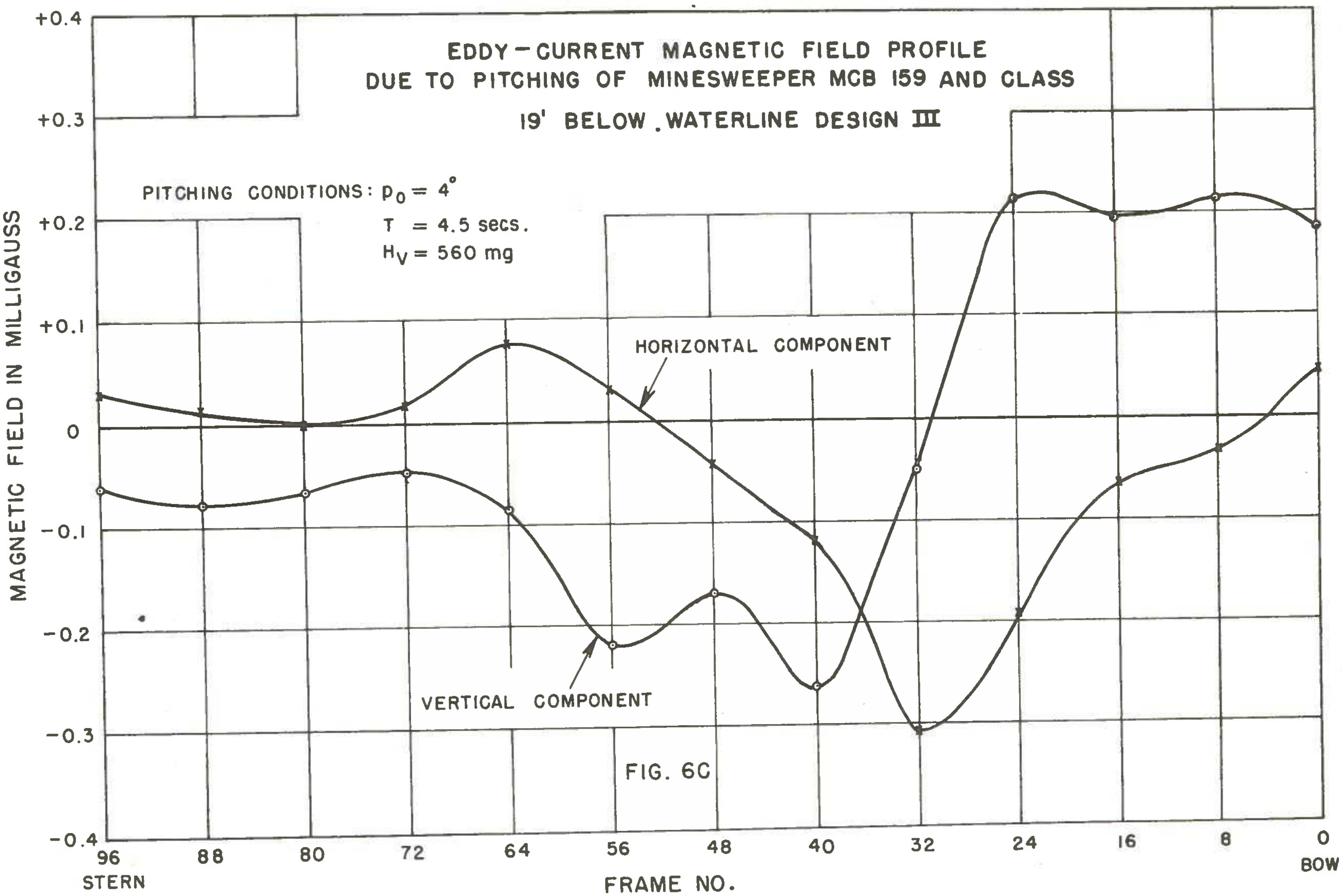


FIG. 6C

SECRET