Investigation of the stray field of a minesweeping impulse generator

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INVESTIGATION OF THE STRAY FIELD OF A MINESWEEPING IMPULSE GENERATOR

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ABSTRACT

The stray fields of two impulse generators of the same design with impulse ratings of 540 kilowatts, 3000 amperes were measured. First tests showed that the magnitude of the stray field increased more than linearly with impulse current. More extensive measurements were then performed which disclosed two main sources of stray field: leakage flux from the yoke and flux produced by current loops in the machine. The yoke leakage effect is non-linear and is predominant at high impulse currents.

Possible methods of reducing the stray fields are discussed.

SUMMARY

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In the summer and autumn of 1956 the National Research Council and the Royal Canadian Navy made measurements of the stray magnetic field of a type of minesweeping impulse generator used by the RCN. Two machines with impulse ratings of 540 kilowatts, 3000 amperes were tested.

First tests showed that the magnitude of the stray field increased more than linearly with pulsing current. The discovery of this effect led to an extensive investigation of stray fields. The following is a summary of test results:

1) Relationship Between Magnitude of Stray Field and Pulsing Current, when Pulsing into the Normal 0.061 Ohm Load.

Pulsing Current (Amp.)	Maximum Vertical Stray Field (Mg)		
	Generator No. 1		Generator No. 2
	10 ft. above shaft	30 ft. above shaft	10 ft. above shaft
1200	1.4	—	2.6
2000	3.5	0.05	5.2
2600	6.4	0.15	8.3
3000	16.0	0.45	14.2
3200	24.0	—	—

2) Form of the Stray Field.

At high output currents the field resembles that of a nearly vertical dipole. The polarity of the dipole in generator No. 2 is opposite to that in generator No. 1.

3) Relationship Between Magnitude of Stray Field and Depth.

The stray field was found to vary as the inverse 3.4 power of depth.

4) Stray Field of the Generator without Exciters.

No change was observed when the exciters, which are normally mounted on top of the generator, were removed.

5) Sources of Stray Field.

Short-circuit tests showed an axial dipole field which was linear with armature current. This field was attributed to current loops formed by the main current buses within the machine.

Open-circuit tests showed a radial dipole field. The axis of this dipole appeared to rotate from a horizontal to a nearly vertical position as the excitation was increased. The direction of rotation was opposite for the two machines, so that vertical dipoles of opposite polarity were obtained at high excitation. The strength of the dipole is approximately linear with excitation. This field was attributed to yoke leakage flux.

Normal load tests showed a field which at low currents was similar in appearance to the short-circuit field, and at high currents was similar to the open-circuit field at high excitation. At rated pulse output the magnitude of the field was much greater than the separate effects of armature current and excitation would indicate. The table below illustrates this characteristic for generator No. 2.

Pulse Current (Amp.)	Maximum Vertical Stray Field at 10 ft. above Generator Shaft (Milligauss)		
	Normal Load (.061 ohms)	Short Circuit (.023 ohms)	Open Circuit (same excitation as at normal load)
1200	2.6	1.8	0.6
2000	5.2	3.2	1.3
2600	8.3	4.6	2.0
3000	14.2	5.2	2.8

The yokes of both machines are of non-uniform thickness. The thickest sections are at top and bottom. The welds occur at the thin sections at the sides.

This yoke shape may be one of the causes of high stray fields.

6) Degaussing of Stray Field.

Because of the nonlinear nature and varying shape of the stray field with current, a simple degaussing system is not possible. However, for any one output current it is possible to reduce the stray field by connecting a suitable compensating coil across the generator terminals. A test was conducted, for example, at rated pulse output (3000 amperes). The maximum vertical field at 10 feet could be reduced from 12 milli-gauss to 3.5 milligauss in this case.

7) Reducing the Stray Field

In future designs of machines of this type (without compensating windings etc.), the following modifications are suggested:

a) Cross section of yoke to be 25% larger

b) Cross section of yoke to be more uniform

c) Improved magnetic balance of the main current-carrying buses between brush gear and output terminals.

8) Field of the Iron of the Unexcited Generator.

When measured in an ambient vertical field of 490 milligauss, the maximum vertical component of field at the 10-foot level was 7.1 milligauss. The field resembled a vertical dipole field.

9) Bias Effect Due to the Earth's Field.

A difference between the magnitudes of vertical stray fields as measured for forward and reverse current pulses appeared consistently, upward field pulses being always larger than downward field pulses. This bias effect was found to be due to coupling with the earth's magnetic field. At rated pulse output (3000 amperes) the upward bias field was about 15 percent of the field of the iron of the unexcited generator.

10) Auxiliary Equipment.

Stray fields of the special service controller, the auxiliary controller, the towing connection box, and a loop of quadded cable were measured. See Appendix A for results.

CONTENTS

	Page
PURPOSE OF TESTS	1
DESCRIPTION OF MACHINES	1
INSTRUMENTATION	1
TESTS AND RESULTS	2
1) Stray Field Measurements in Horizontal Planes Above the Machines	2
2) Axial Stray Field Measurements in a Vertical Plane 8' - 10" from the Yoke	3
3) Radial Stray Field Measurements in the Center Plane of the Yoke at 10 ft. Radius	3
4) Flux Measurements Close to the Yoke	3
5) Internal Flux Measurements in the Yoke and Poles	3
6) Characteristics of the Machines	4
7) The Field of the Iron of the Unexcited Generator	4
8) Bias Effect Due to the Earth's Field	4
9) Degaussing of Generator Pulse Field	5
DISCUSSION OF RESULTS	5
CONCLUSIONS	7
APPENDIX A	
Stray Fields of Impulse Generator Auxiliary Equipment	8
APPENDIX B	
Nameplate Data	10

FIGURES

SECRET

1. View of Generator and Exciters
2. View of Diesel-Generator Set
3. General View of Testing Arrangement
4. View of Control Equipment
5. View of Load Resistor
6. Waveforms of Pulsing Current and Stray Field
7. Diagram of Horizontal Magnetic Range
8. View of Magnetic Range Installed at 30 ft. Level
9. View of Magnetometer Switching Panel and Recorders in Instrument Hut
10. GENERATOR NO. 1, Contours of Vertical Stray Field (Mg), Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms) — 10 ft. level, 1200 amp.
11. " — 10 ft. level, 2000 amp.
12. " — 10 ft. level, 2600 amp.
13. " — 10 ft. level, 3000 amp.
14. " — 10 ft. level, 3200 amp.
15. " — 15 ft. level, 2000 amp.
16. " — 15 ft. level, 2600 amp.
17. " — 20 ft. level, 2600 amp.
18. GENERATOR NO. 1, Contours of Vertical Stray Field (Mg), Forward Pulses, Short Circuit Operation (Load Resistance = 0.023 ohms) — 10 ft. level, 1200 amp.
19. " — 10 ft. level, 2000 amp.
20. " — 10 ft. level, 2600 amp.

21.	GENERATOR NO. 1, Contours of Vertical Stray Field (Mg), Forward Pulses, Open Circuit Operation	10 ft. level, 100 volts
22.	"	10 ft. level, 150 volts
23.	"	10 ft. level, 200 volts
24.	"	10 ft. level, 250 volts
25.	"	10 ft. level, 260 volts
26.	GENERATOR NO. 1, Contours of Axial Stray Field (Mg), Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)	10 ft. level, 1200 amp.
27.	"	10 ft. level, 2000 amp.
28.	"	10 ft. level, 3000 amp.
29.	GENERATOR NO. 1, Contours of Transverse Stray Field (Mg), Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)	10 ft. level, 1200 amp.
30.	"	10 ft. level, 2000 amp.
31.	"	10 ft. level, 3000 amp.
32.	GENERATOR NO. 2, EXCITERS REMOVED, Contours of Vertical Stray Field (Mg), Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)	10 ft. level, 1200 amp.
33.	"	10 ft. level, 2050 amp.
34.	"	10 ft. level, 2600 amp.
35.	"	10 ft. level, 3050 amp.
36.	GENERATOR NO. 2, Contours of Vertical Stray Field (Mg), Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)	20 ft. level, 3000 amp.
37.	GENERATOR NO. 2, EXCITERS REMOVED, Contours of Vertical Stray Field (Mg), Forward Pulses, Short Circuit Operation (Load Resistance = 0.023 ohms)	10 ft. level, 1100 amp.

38.	(see 37)	10 ft. level, 1900 amp.
39.	"	10 ft. level, 3000 amp.
40.	GENERATOR NO. 2, EXCITERS REMOVED, Contours of Vertical Stray Field (Mg), Forward Pulses, Open Circuit Operation	10 ft. level, 83 volts
41.	"	10 ft. level, 163 volts
42.	"	10 ft. level, 228 volts
43.	"	10 ft. level, 270 volts
44.	"	10 ft. level, 299 volts
45.	GENERATOR NO. 2, EXCITERS REMOVED, Contours of Vertical Stray Field (Mg), Forward Pulses Load Resistance = 0.036 ohms	10 ft. level, 3000 amp
46.	GENERATOR NO. 2, EXCITERS REMOVED, Contours of Vertical Stray Field (Mg), Forward Pulses Load Resistance = 0.050 ohms	10 ft. level, 3000 amp
47.	GENERATORS 1 and 2, Maximum Vertical Stray Field at 10, 15, 20 and 30 ft. vs. Output Current, Forward Pulses, Normal Operation, (Load Resistance = 0.061 ohms)	
48.	GENERATORS 1 and 2, Maximum Vertical Stray Field at 10 ft. vs. Terminal Voltage, Forward Pulses, Open Circuit Operation	
49.	GENERATORS 1 and 2, Maximum Vertical Stray Field at 10 ft. and 20 ft. vs. Output Current, Short Circuit Operation, (Load Resistance = 0.023 ohms)	
50.	GENERATORS 1 and 2, Maximum Vertical Stray Field vs. Depth, 2000 and 2600 amp. Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)	
51.	GENERATOR NO. 1, Law of Variation of Stray Field with Depth, 2000 and 2600 amp. Forward Pulses, Normal Operation, Vertical Component	
52.	GENERATOR NO. 2, Effect of Disconnecting and Removing Exciters, Maximum Vertical Stray Field vs. Output Current at 10 ft., Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)	

53. GENERATOR NO. 2, Maximum Vertical Stray Field vs. Load Amperes for Various Loads, at 10 ft., Forward Pulses.

54. GENERATOR NO. 2, Maximum Vertical Stray Field vs. Load Resistance, at 10 ft. Forward Pulses

55. GENERATOR NO. 1, Axial Stray Field, Commutator End 8' - 10" from Yoke, Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms) 1200 amp.

56. " 2600 amp.

57. GENERATOR NO. 2, Axial Stray Field, Commutator End 8' - 10" from Yoke, Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms) 1200 amp.

58. " 2600 amp.

59. GENERATOR NO. 2, Polar Plot of Radial Stray Field 10 ft. from Generator Shaft 2600 amp. Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)

60. GENERATOR NO. 2, Radial Stray Field 3/4 in. from Yoke vs. Load Amperes, Normal Operation, (Load Resistance = 0.061 ohms)

61. GENERATOR NO. 2, Survey of Radial Stray Field at Yoke Surface, 3000 amp. Forward Pulses, Normal Operation (Load Resistance = 0.061 ohms)

62. GENERATOR NO . 2, Internal Flux in Yoke and Poles vs. Excitation.

63. GENERATOR NO. 2, Characteristic Curves

64. GENERATORS 1 and 2, Survey of Thickness of yokes.

65. GENERATOR NO. 2, EXCITERS REMOVED, Contours of Vertical Pulse Field Due to Earth's Field Effect at 10 ft. level, 299 volt Forward and Reverse Pulses, Open Circuit Operation, Z = 535 mg.

66. GENERATOR NO. 1, EXCITERS REMOVED, Contours of Vertical Static Field at 10 ft., Z = 490 mg.

67.	GENERATOR NO. 2, Vertical Stray Field with Degaussing On and Off at 10 ft., Forward Pulses	2000 amp.
68.	"	2600 amp.
69.	"	3000 amp.

INVESTIGATION OF THE STRAY FIELD OF A MINESWEEPING IMPULSE GENERATOR

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PURPOSE

The National Research Council was asked originally to provide suitable instrumentation and to conduct measurements of stray magnetic field on one type of impulse generator used on minesweepers of the Royal Canadian Navy. After first tests the scope of the project was enlarged to include a more extensive investigation of stray fields and their causes.

DESCRIPTION OF MACHINES

Two identical Westinghouse d-c generators, referred to here as generators 1 and 2, were tested. The continuous rating of the machines is 290 kw, 1200 amperes, and the impulse rating is 540 kw, 3000 amperes. They are eight-pole 1200-rpm machines, with interpoles, but are not equipped with compensating windings. The yoke has a nominal cross section 12" × 2" and is fabricated from two half-rings with faces welded together in the horizontal plane. Two exciters are mounted on top of the generator and are driven from it by belts. The same exciters were used for both machines. All materials except those in the magnetic circuits of the machines are non-magnetic. The internal current paths were designed to eliminate current loops around the generator shaft. A generator and its exciters are shown in Fig. 1.

The two generators were driven in turn by a General Motors Corp. 420-hp diesel engine. All parts of the diesel engine were non-magnetic, except the crank shaft. The diesel-generator set is shown in Fig. 2.

For complete nameplate data on the machines see Appendix B.

INSTRUMENTATION

The diesel-generator set and the magnetic range were set up at the Naval Engineering Test Establishment in Ville La Salle, Quebec, as shown in Fig.3. The machines were located in the plywood shed. The generator was operated from two control cabinets, Fig. 4, located inside the test plant 300 feet from the generator. The generator was connected, by a quadded cable, to a load resistor, Fig. 5, located near the controllers.

Square waves of current (Fig. 6) were used throughout the tests. Pulse lengths and intervals were adjustable. Both unidirectional and alternate forward and reverse pulses were used. During automatic pulsing the main field of the generator was pulsed by the exciter and auxiliary controller system. During manual pulsing, with the exciters removed, the main field was supplied from storage batteries and pulsed by a manually operated switch. The output current of the generator was measured on the special service controller panel meter (the large cabinet in Fig. 4).

The magnetometer range consisted of 30 second-harmonic fluxgate detectors located on the grid shown in Fig. 7. The range could be placed at levels 10, 15, 20 or 30 feet above the center of the generator. Fig. 8 shows the range at the 30-foot level. Three fluxgate magnetometers, with recording channels, were used. A switching system enabled the operator to sample the outputs of three detectors simultaneously on the three recording channels. The switching panel, magnetometers, and recorders which were located in a hut 100 feet from the impulse generator, are shown in Fig. 9.

Stray field measurements at points not on the horizontal range were made with a single detector unit (see Figs. 55 to 59).

In measurements of the larger fluxes in or near the yoke and poles of the machine, a search coil and fluxmeter method was used (see Figs. 60, 61, 62).

TESTS AND RESULTS

1) Stray Field Measurements in Horizontal Planes Above the Machines.

A large number of tests were conducted by using the range shown in Fig. 7. These tests were made under various conditions of loading and also under open-circuit conditions. From the measurements the contours given in Figs. 10 to 46, inclusive, were constructed.

The code number given on the lower right hand corner of each contour sheet indicates:-

Generator Number	Depth (ft.)	Pulses	Load	Field Component	Load Current or Terminal Voltage (amps or volts)
		F - Forward	FL - .061 ohms	V - Vertical	
		R - Reverse	$\frac{2}{3}$L - .050 ohms	A - Axial	
			$\frac{1}{3}$L - .036 ohms	T - Transverse	
			SC - .023 ohms		
			OC - Open Cct.		

Only the contours obtained by forward pulsing are presented. The stray field during reverse pulses differed slightly in magnitude. The cause of this difference is discussed in section 8 below.

Various characteristics of the stray field, as determined by the above tests, are given in Figs. 47 to 54. These include the magnitude of stray field as a function of load current, excitation, depth, and load resistance. These magnitudes are the maximum fields measured anywhere at the given level above the machine. They were determined from the contour plots in most cases. In the case of generator no. 2, the effect of the exciters on the stray field was investigated by making measurements with the exciters in place and operating, with the exciters disconnected electrically, and with the exciters removed from the generator. The results of these tests are shown in Fig. 52.

2) Axial Stray Field Measurements in a Vertical Plane 8' - 10" from the Yoke

A range pattern was laid out on the end wall of the building nearest the commutator end of the machine, and measurements of axial field components were made at each point with a single magnetometer detector. The range pattern and the measured fields are shown in Figs. 55 to 58.

3) Radial Stray Field Measurements in the Center Plane of the Yoke at 10 ft. Radius

Magnetometer supports were set up on a radial pattern with the center at the shaft. A single detector unit was used to measure the radial field component at points on a 10-foot circle about the shaft. A polar plot of the stray field is given in Fig. 59.

4) Flux Measurements Close to the Yoke

Two forms of radial field tests were made near the yoke. The first of these, Fig. 60, was carried out to determine whether the nonlinear field vs. current effect could be detected at the yoke. The second test was made to determine the distribution of the flux emanating from the yoke. Results are shown in Fig. 61.

These measurements were made with a search coil connected to a fluxmeter. This combination was calibrated in preparation for these tests by use of a Helmholtz coil.

5) Internal Flux Measurements in the Yoke and Poles

In order to investigate the degree of saturation in the yoke and poles, internal fluxes were measured over a range of excitations. The results are shown in Fig. 62. The measurements were made by means of single turn search coils wound around the yoke and poles as indicated in Fig. 62.

6) Characteristics of Machine

The characteristic curves of generator No. 2 are given in Fig. 63. These show the relationship between open-circuit, voltage, load current, and excitation.

Measurements were made of the thickness of the yoke at various points around the periphery. These measurements are given in Fig. 64.

7) Field of the Iron of the Unexcited Generator

The vertical component of the static field of generator No. 1 (without exciters) induced by the earth's field, was measured. Contours of the field at 10 feet are given in Fig. 66.

To make these measurements, three magnetometer detectors were mounted inside the test plant at the 10-foot level, 3 feet apart. Wooden guides were placed on the floor under the magnetometers. The generator was moved continuously along the guides, starting from a remote position. Field profiles were automatically taken by three recording magnetometers connected to the detectors. These profiles were used to construct the contour plot.

8) Bias Effect Due to the Earth's Field

Contours of the bias field (described in Summary, sect.9) are shown in Fig. 65 for 299-volt open-circuit pulsing. The magnitude at each point is determined as one-half of the sum of forward and reverse stray fields, considering upward fields negative and downward fields positive.

This bias effect was investigated further by changing the ambient field at the generator by means of a large Helmholtz coil supplied by storage batteries. The vertical component of the ambient field could be reduced to zero or doubled by this coil. For 3000-ampere normal load pulsing, the results of the test are given in the following table.

GENERATOR NO. 2, 3000 AMPERES, NORMAL LOAD, AT 10 FEET

Ambient Field "Z" (milligauss)	Milligauss at 3-3 (see Fig.7)			Milligauss at 4-2 (see Fig.7)		
	Forward	Reverse	Bias	Forward	Reverse	Bias
0	- 9.2	+9.6	+0.2	-11.2	+11.0	-0.1
535	-10.0	+7.6	-1.2	-12.0	+10.0	-1.0
1070	-11.2	+6.0	-2.6	-13.0	+ 8.8	-2.1

The bias effect appears to be proportional to the ambient field. It is thought to be due to a decrease in permeability of the iron, as seen by the earth's magnetic field, when the generator is excited. This reduces the static field of the iron induced by the ambient field. The effect is to produce an upward pulse of stray field for either forward or reverse current pulses.

9) Degaussing of Generator Pulse Field

The magnetic range (Fig.7) was used in an investigation of the effectiveness of a degaussing system as applied to generator No. 2. A 72-turn 25-inch-diameter coil in series with a rheostat was connected across the generator terminals. The coil was placed in a horizontal position close to the generator and directly below the position where the maximum vertical stray field was measured at the 10-foot level at rated pulse output (3000 amperes). With the machine pulsing at a desired load current, the degaussing coil current was adjusted to give zero vertical field at the former maximum position. Figs. 67, 68 and 69 give the results of this test for 2000, 2600 and 3000 amperes, respectively.

DISCUSSION OF RESULTS

Examination of Fig. 47 will show that although the variation of magnitude of stray field with pulsing current is slightly different for the two generators, the stray fields are equal in magnitude at full output. However, the contours, Figs. 10 to 46, show that there is considerable difference between the shapes of the fields.

A study of the contours enables us to give an approximate picture of the stray field characteristics on the basis of imaginary dipoles within the machine. At low currents and normal load each machine has a stray field like that of a horizontal dipole with axis skewed relative to the generator shaft, Figs. 10 and 32. However, as the output current is increased towards 3000 amperes the fields of the two machines begin to differ in appearance. At the maximum output of 3000 amperes, both machines have stray fields similar to the fields of nearly vertical dipoles; but these dipoles are of opposite polarity, Figs.13 and 35.

The contours of the short-circuit and open-circuit tests show the separate effects of armature current and excitation, respectively.

The stray field under short-circuit operation is similar in appearance for the two machines, Figs. 18, 19 and 20, and Figs. 37, 38 and 39. The shape of the field resembles that of the normally loaded machine operating at low currents, i.e., it is like that of a skewed horizontal dipole, and does not alter with output current. The strength of this dipole is nearly linear with output current, Fig. 49. This nearly axial dipole is thought to be due to current loops in the main current bus structure in the machine.

On open circuit, with low excitation, the stray fields of the two machines are again very similar, Figs. 21 and 40. They appear to be produced by a horizontal radial dipole. As the excitation is increased, rotation of the dipole about the generator shaft seems to occur until a nearly vertical dipole is obtained at high excitation , Figs. 25 and 43. However, this rotation is in opposite directions for the two generators. The nearly vertical dipoles at high excitation are therefore of opposite polarity. It will also be noticed that at high excitation the open-circuit field is very similar in appearance to the field of the normally loaded machine operating at high currents, Figs. 25,13 and Figs. 43,35. The radial dipole effect is considered to be due to leakage flux from the yoke of the machine.

It might be expected that under normal loading, when both armature current and excitation are present, both these dipole effects would occur. This seems to be the case, but the radial dipole appears amplified at high currents. This amplification may be explained as follows.

The curves of flux density in the yoke versus field current on open circuit, Fig. 62, show a decrease in slope beginning at about 9 kilogauss (for generator No. 2). The excitation at this point is 17.5 amperes and the terminal voltage is 270 volts(from Fig. 63), where, as shown in Fig. 48, there is also a sudden increase in the stray field of generator No. 2. This seems to indicate that at flux densities in the yoke exceeding 9 kilogauss the permeability of the steel decreases, causing a sharp increase in leakage flux, with a corresponding increase in stray field.

At the excitation producing the rated output of 3000 amperes on load (17.5 amperes, Fig. 63), the maximum flux density in the yoke is 12 kilogauss (Fig. 62), whereas on open circuit at the same excitation the flux density in the yoke is only 9 kilogauss(Fig. 62). The additional flux is, of course, provided by the interpoles, and adds to the main pole flux in some parts of the yoke and subtracts from it in others. This flux density under load, since it exceeds the critical value of 9 kilogauss, would be expected to produce a large stray field.

The horizontal position of the radial dipole at low excitation is unexplained. The rotation of this dipole to a nearly vertical position as the excitation is increased is possibly because the yokes are thicker near top and bottom than at the sides (Fig.64). Flux will tend to leave the yoke nearest the thinnest sections, so that the axes of the dipoles will tend to follow the axes of maximum thickness, which are indicated by the dashed lines in Fig. 64. Looking at the 3000-ampere normal-load contours,(Figs 13 and 35), the radial dipole actually seems to have swung around to this position. The presence of the radial dipole is also indicated in Fig. 59. The fact that leakage of flux is greatest near the thinnest parts of the yoke is confirmed in the plot of radial flux (Fig. 61).

CONCLUSIONS

At rated pulse output the stray field of the type of impulse generator tested appears to be due principally to the approach of saturation in the yoke. The results of these tests indicate that a 25 percent increase in the cross section of the yoke may eliminate this saturation effect and thereby reduce the stray field.

The shape of the field at rated output is that of a nearly vertical dipole and is thought to be due to the non-symmetrical shape of the yoke. It appears likely that the stray field of the generator may be reduced by making the yoke of more uniform thickness, since this would prevent leakage of flux in any specific direction.

On open circuit with low excitation, the stray field of the generator resembles the field of a horizontal radial dipole. The reason for this could not be traced to any structural characteristic of the machine. In future tests it is suggested that the effect of the earth's field be determined by altering the position of the generator with respect to the horizontal component of the earth's field. The effect of the yoke welds should be investigated. If the welds are found to cause appreciable leakage flux, their effect could probably be decreased by positioning the welds under main poles rather than under interpoles where they are located in these machines. If the effect of the welds is large, adoption of a laminated yoke construction may be advisable. It might also be interesting to measure the stray field of the generator with the main field excited, but with the machine at rest, and to compare this with the results of the open-circuit tests.

The field associated with the main current buses in the machine also contributes to the stray field of the generator. This effect is comparatively small at present, but if the above changes in the yoke of the machine are adopted, its relative magnitude might become appreciable. In that case a better magnetic balance of the internal bus structure should be considered.

* * * *

APPENDIX A

STRAY FIELDS OF IMPULSE GENERATOR AUXILIARY EQUIPMENT

a) Special Service Controller

d Height Above Cabinet (ft.)	Pulsing Current (amp.)	B Stray Field (mg)		
		Vertical	Transverse	Longitudinal
6	0	1.9	0	3.8
	1200	1.0	2.8	12.0
	2000	2.8	5.3	20.8
	3000	7.2	9.4	
8	1200	1.5		
	2000	3.0	1.8	7.6
	3000	5.7	3.6	12.2
10	1200			
	2000		1.0	3.9
	3000		2.0	5.9
12	1200	0.55		
	2000	1.0		
	3000	1.9		
15	1200	0.3		
	2000	0.5		
	3000	0.9		

Depth Law is $B \approx kd^{-3.1}$ (see note on following page)

NOTE: All readings taken vertically above the center of the cabinet. Longitudinal direction is perpendicular to the front of the cabinet. Transverse direction is parallel with front of cabinet.

b) Auxiliary Controller Mark VI

d Height Above Cabinet (ft.)	Pulsing Current (amp.)	B Stray Field (mg) Vertical Component
4	0 2000	0.5 0.3
8	0 2000	0.1 0.2
12	0 2000	0.05 0.2

NOTE: All readings taken vertically above the center of the cabinet.

c) Towing Connection Box

d Height Above Center of Cabinet (ft.)	Pulsing Current (amp.)	B Stray Field (mg) Vertical Component
5	1300	22.4
6	1300	11.2
7	1300	6.8
8	1300	4.4
10	1300	1.9
12	1300	0.6

NOTE: Height d measured from center of box, 8 in. below top.

Depth Law is $B \approx kd^{-3.6}$

d) Quadded Cable

The stray field of a horizontal coil of 5 turns of quadded cable was measured. The coil was elliptical in shape, the major and minor axes being 5 $\frac{1}{2}$ feet and 4 feet, respectively.

Pulsing Current (amp.)	Vertical Stray Field 10.5" above coil 15 ft. from side of coil (mg)	Radial Horizontal Stray Field 7.5 ft. above coil 15 ft. from side of coil (mg)
2000	0.9	—
3000	1.3	0.5

* * * *

APPENDIX B

NAMEPLATE DATA

Impulse Generators

Westinghouse D-C Generator
Shunt Wound, Type QH
Frame DB 810-6
kW 290, Amps 1200
Volts Full Load 240, RPM 1200

For Impulse Application:

kW 540, Amps 3000
Volts Full Load 180, RPM 1300-1000

Generator No.1, Serial No. 1-10E-0062
Generator No.2, Serial No. 6-10E-0062

Constant Potential Exciter

Mfr. Westinghouse
Shunt Wound, Type SK, Frame 284

kW 5, Amps 20, Volts Full Load 250
RPM 2400/1800
No. 2-10 E-0068

Rototrol Exciter

Mfr. Westinghouse
Type SK, Frame 43E
kW 3/4, Amps 15, Volts Full Load 50
RPM 2400/1850
No. 1-10E-0065

Diesel Engine

General Motors Corp. — Cleveland Diesel Engine Division
Model 8-268A, No. 31199
Hp. 420 (Max.), RPM 1200

Special Service Controller (Large Cabinet)

Mfr. Canadian Westinghouse Co.
Stype S.O. 1-Y-288, Volts 250 DC
Amps (Max.) 4000, Serial No.4
Assembly Plan 65-NJ-11
Wiring Plan 65-NJ-49

Auxiliary Controller Mark VI (Small Cabinet)

Made for U.S. Navy Bureau of Ships by General Electric Co.
Cat. 8014421 G24, No. 1259274
Contract NOB_S-410, Input Volts 250 DC

Towing Connection Box

Camber and Nicholson Ltd.

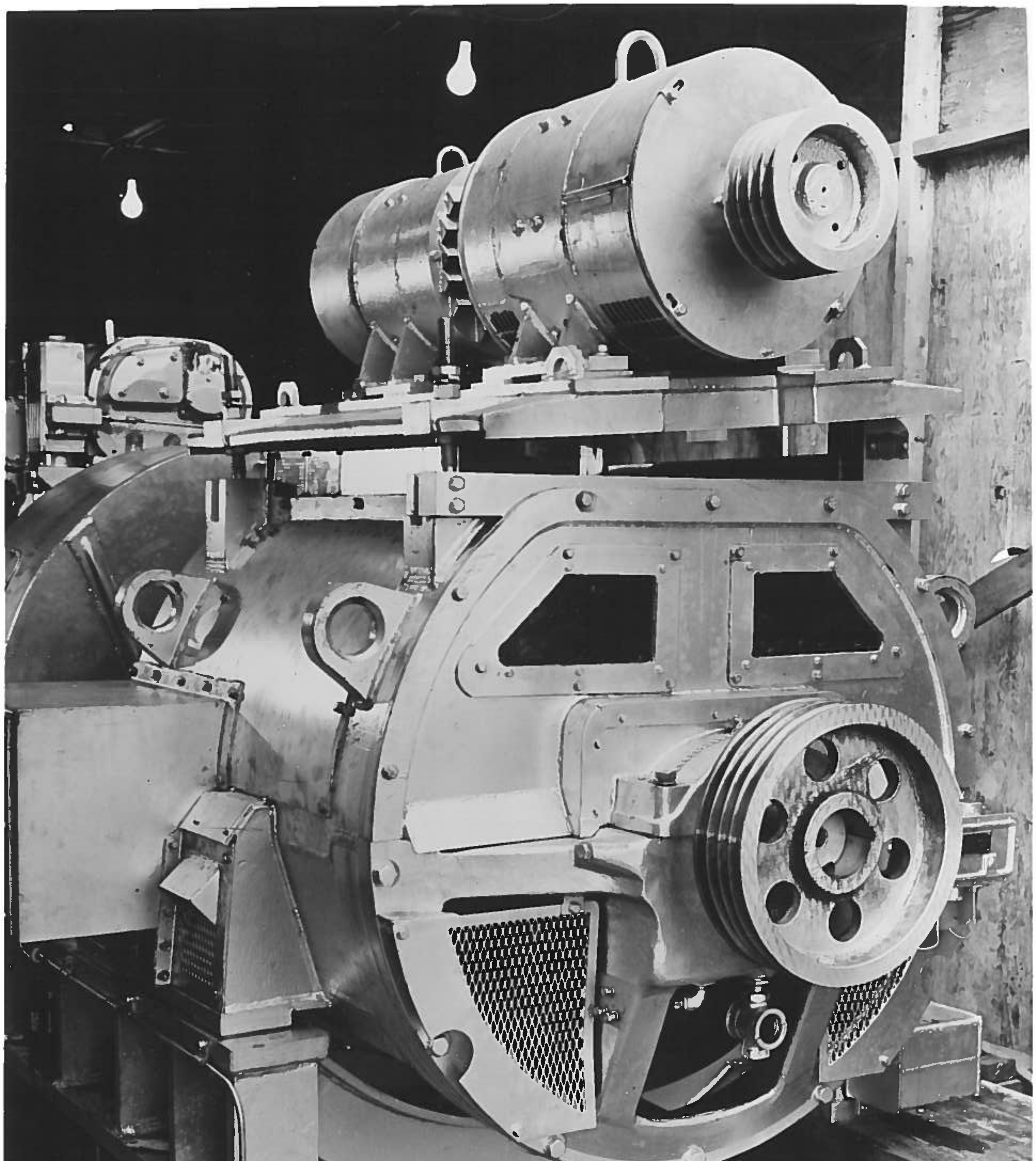


FIG. 1 GENERATORS AND EXCITERS
NETE Photo

SECRET

FIG. 2 DIESEL-GENERATOR SET
NETE Photo

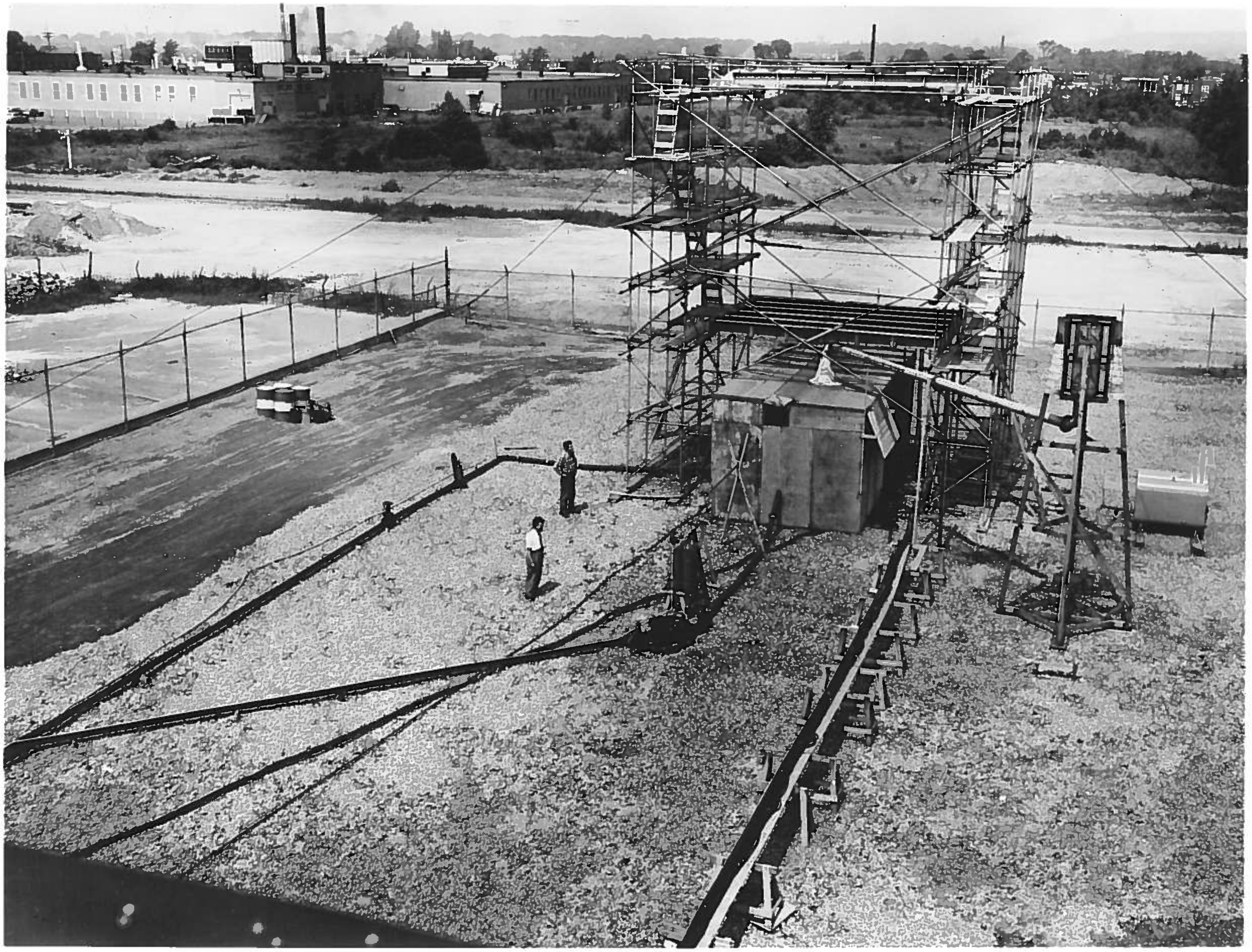
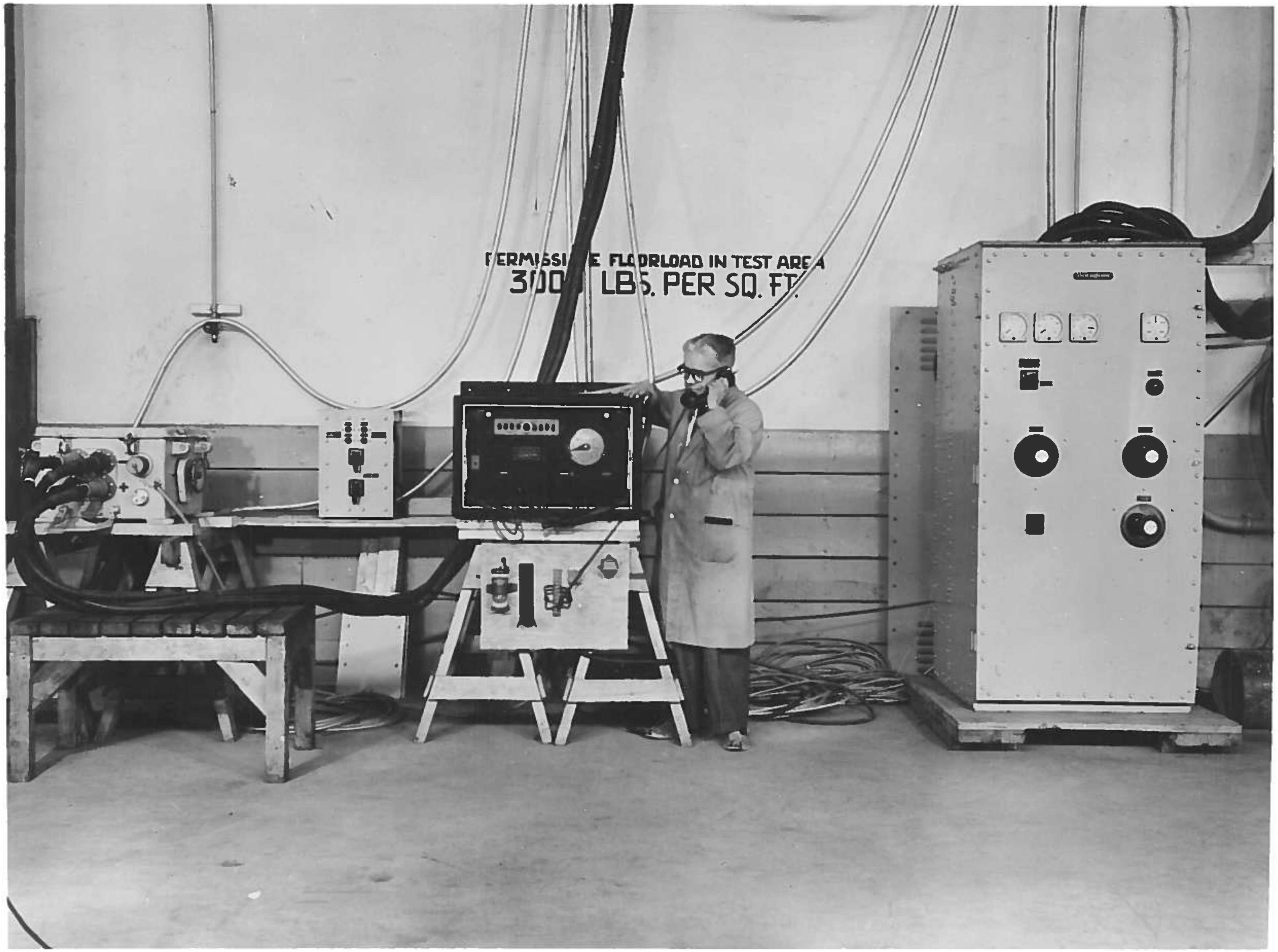


FIG. 3 GENERAL VIEW OF TESTING ARRANGEMENT
NETE Photo

SECRET



SECRET

FIG. 4 CONTROL EQUIPMENT
NETE Photo

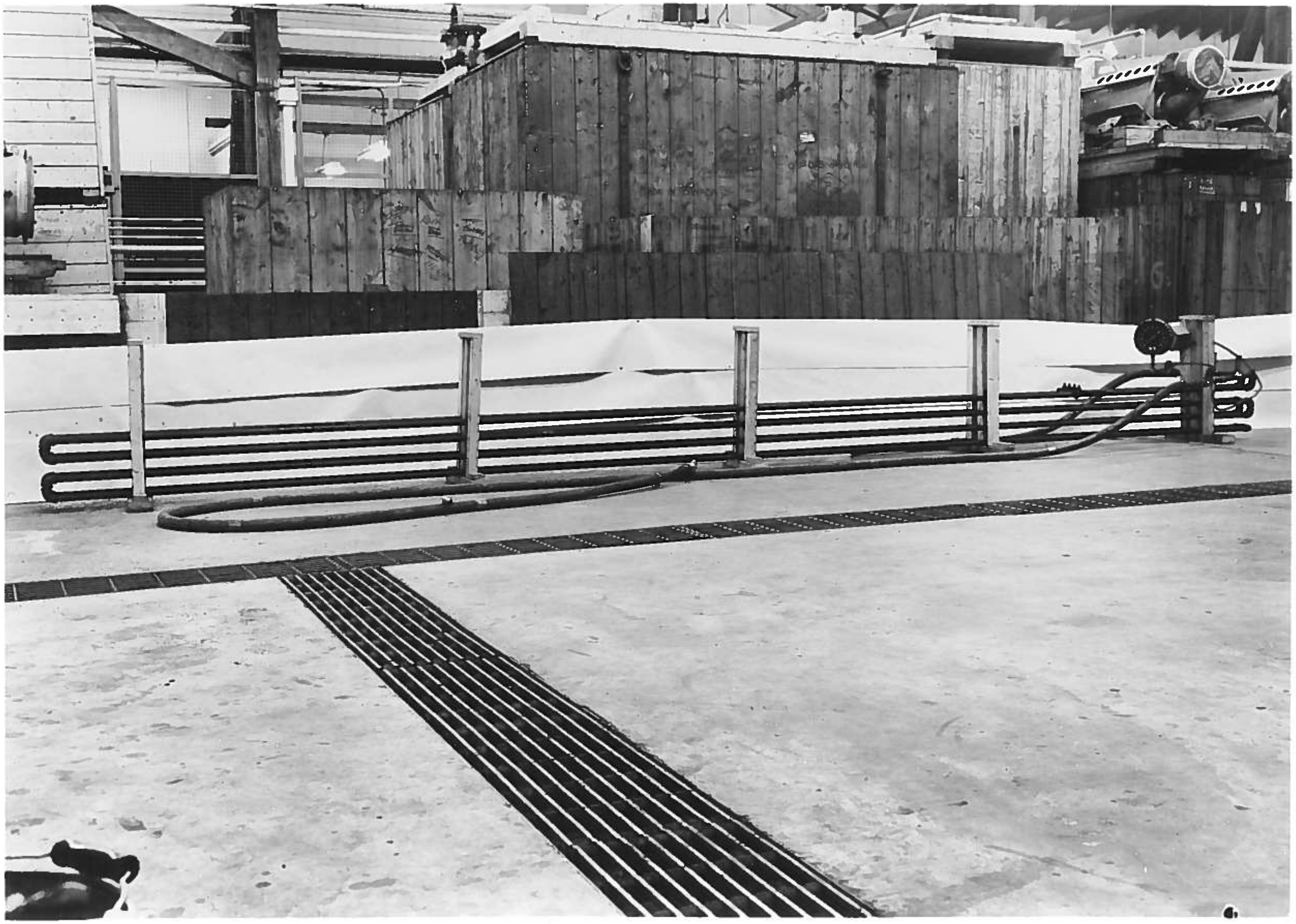
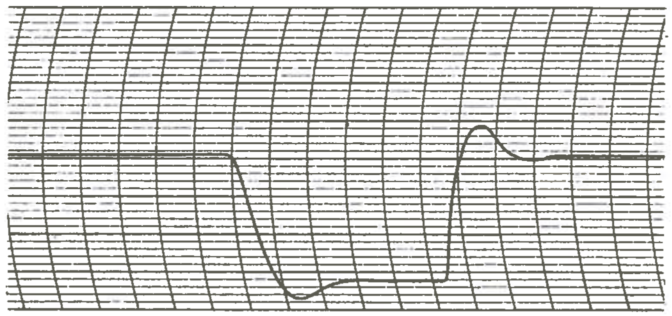


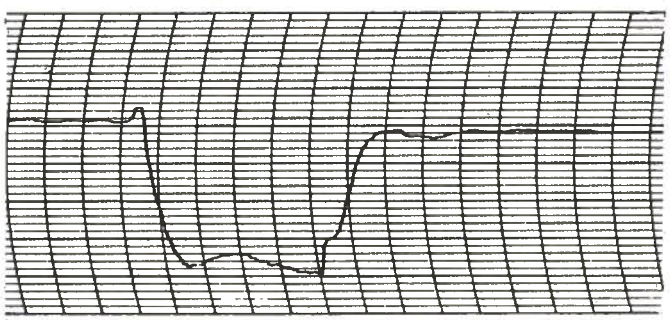
FIG. 5 LOAD RESISTOR
NETE Photo

SECRET

WAVEFORMS OF PULSING CURRENT AND STRAY FIELD



Typical Current Pulse
(2000 Amperes)



Typical Stray Field Pulse

(Position 2-4, 10 ft. level,
2000 amp., normal operation)

FIG. 6

DIAGRAM OF HORIZONTAL MAGNETIC RANGE

NOTE: Thirty magnetic detectors were available, so that only thirty of the positions shown below were used in any one test.

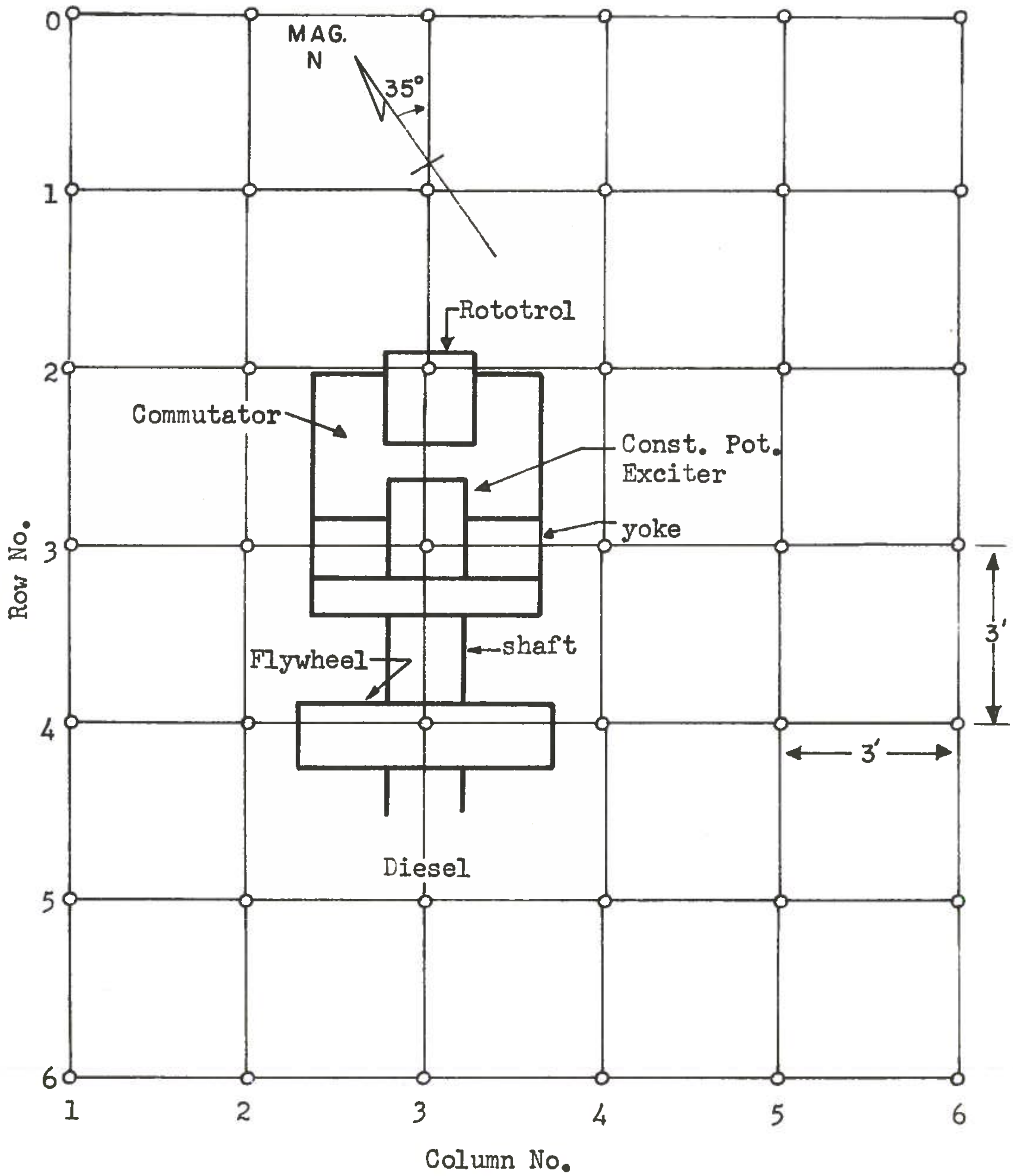


FIG. 7

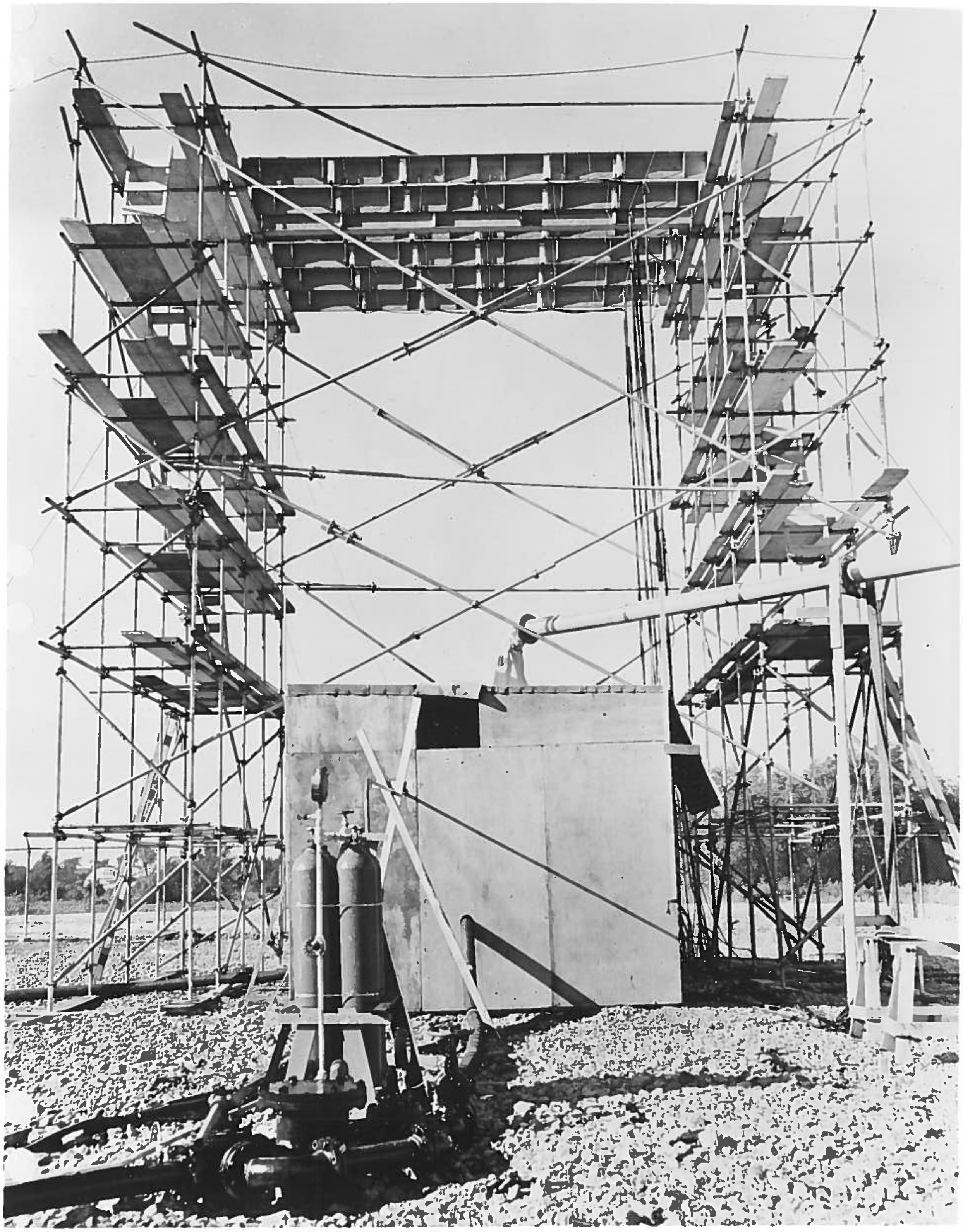
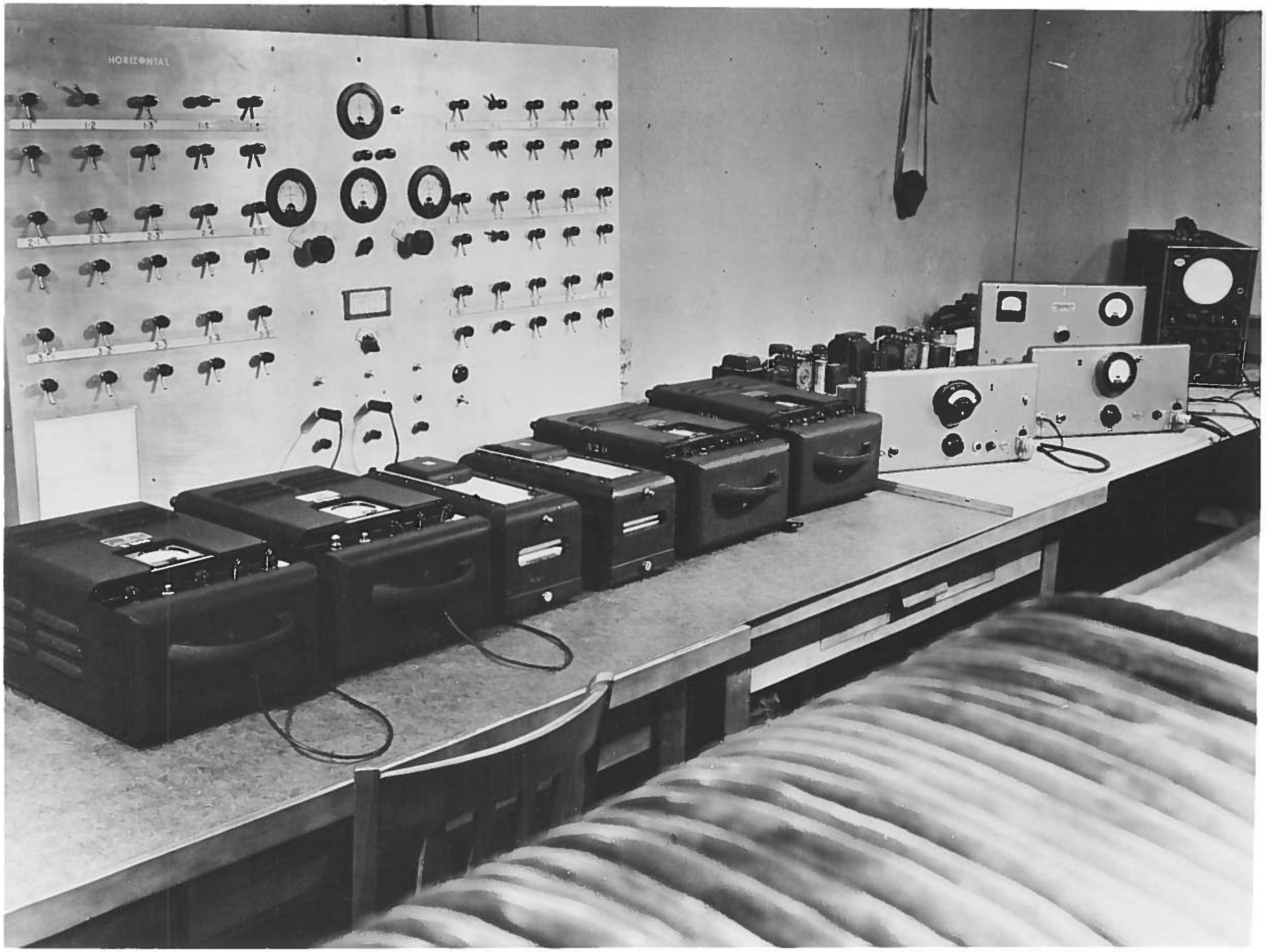


FIG. 8 MAGNETIC RANGE INSTALLED AT 30-FOOT LEVEL
NETE Photo

SECRET



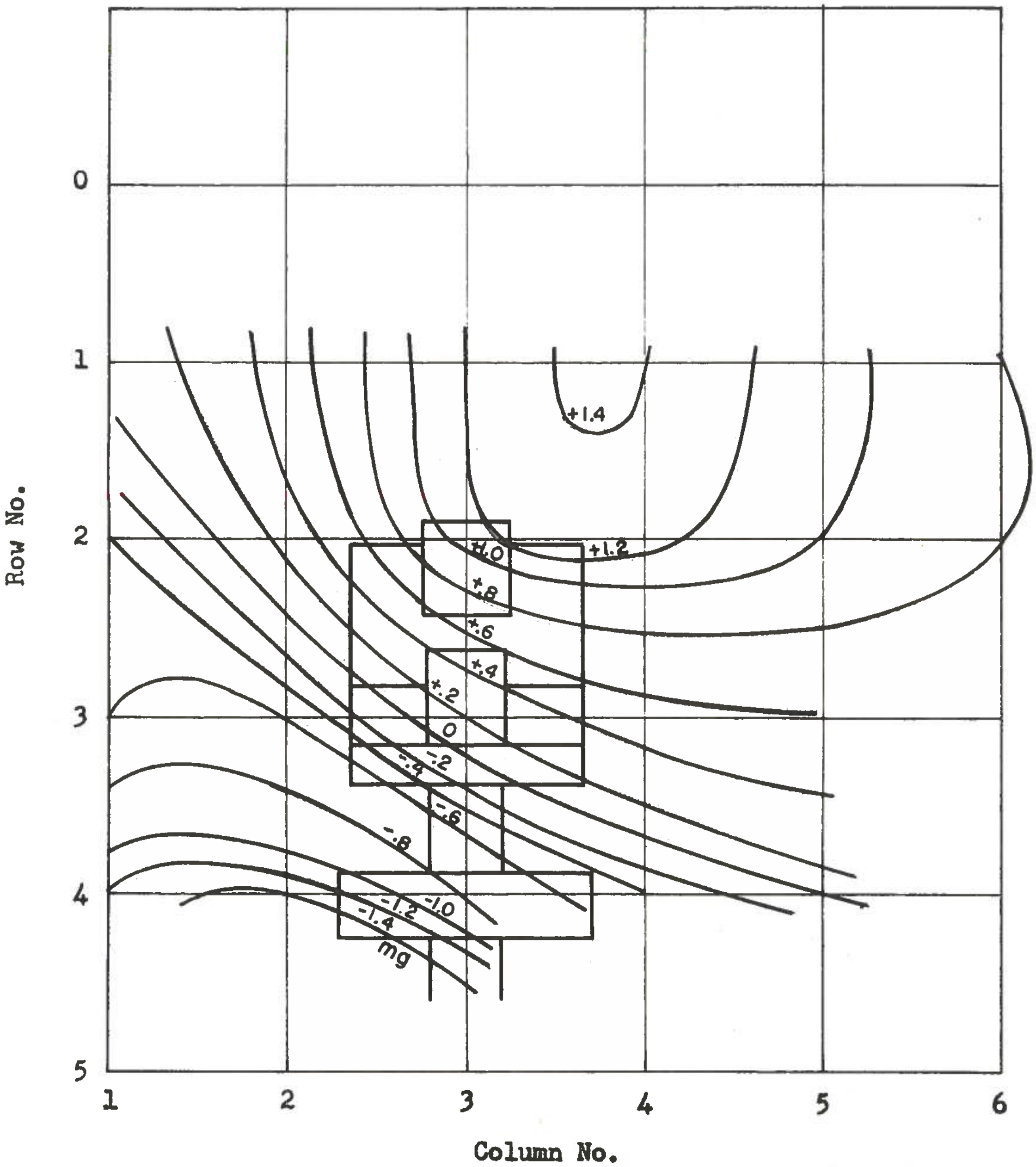
SECRET

FIG. 9 MAGNETOMETER SWITCHING PANEL AND RECORDERS IN INSTRUMENT HUT
NETE Photo

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

1200 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

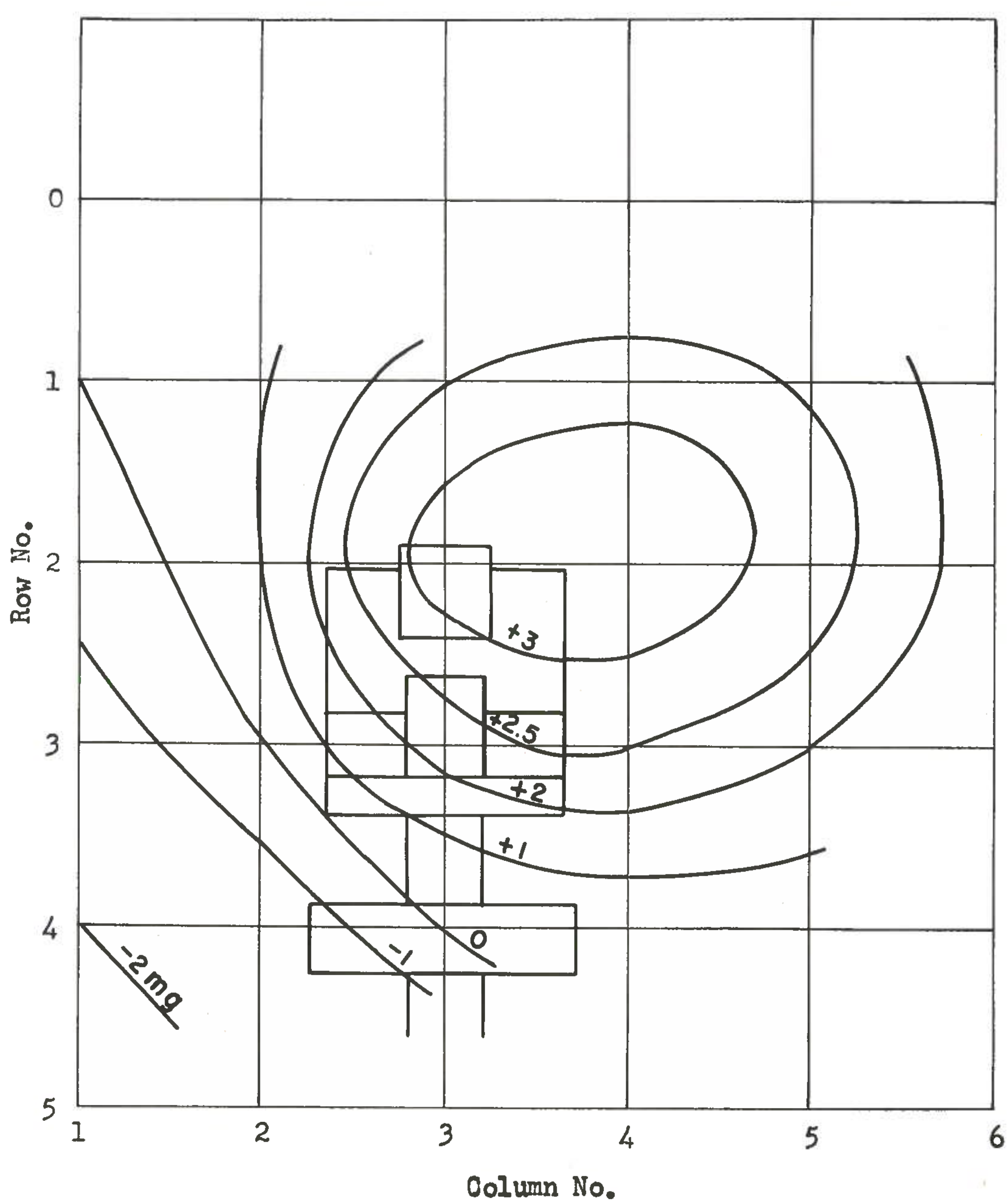
FIG. 10

1-10-F-FL-V-1200

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

2000 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

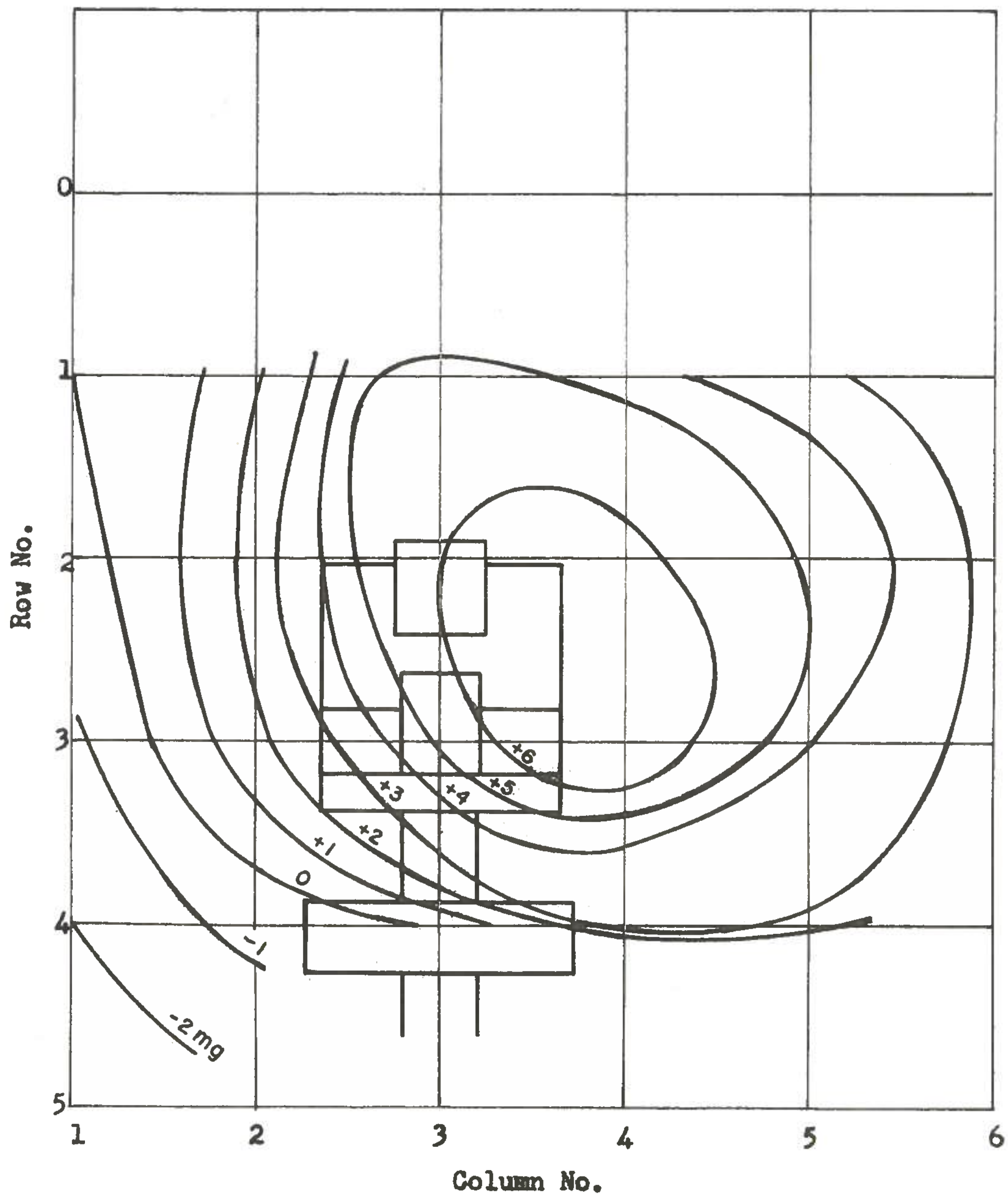
FIG. 11

1-10-F-FL-V-2000

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

2600 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

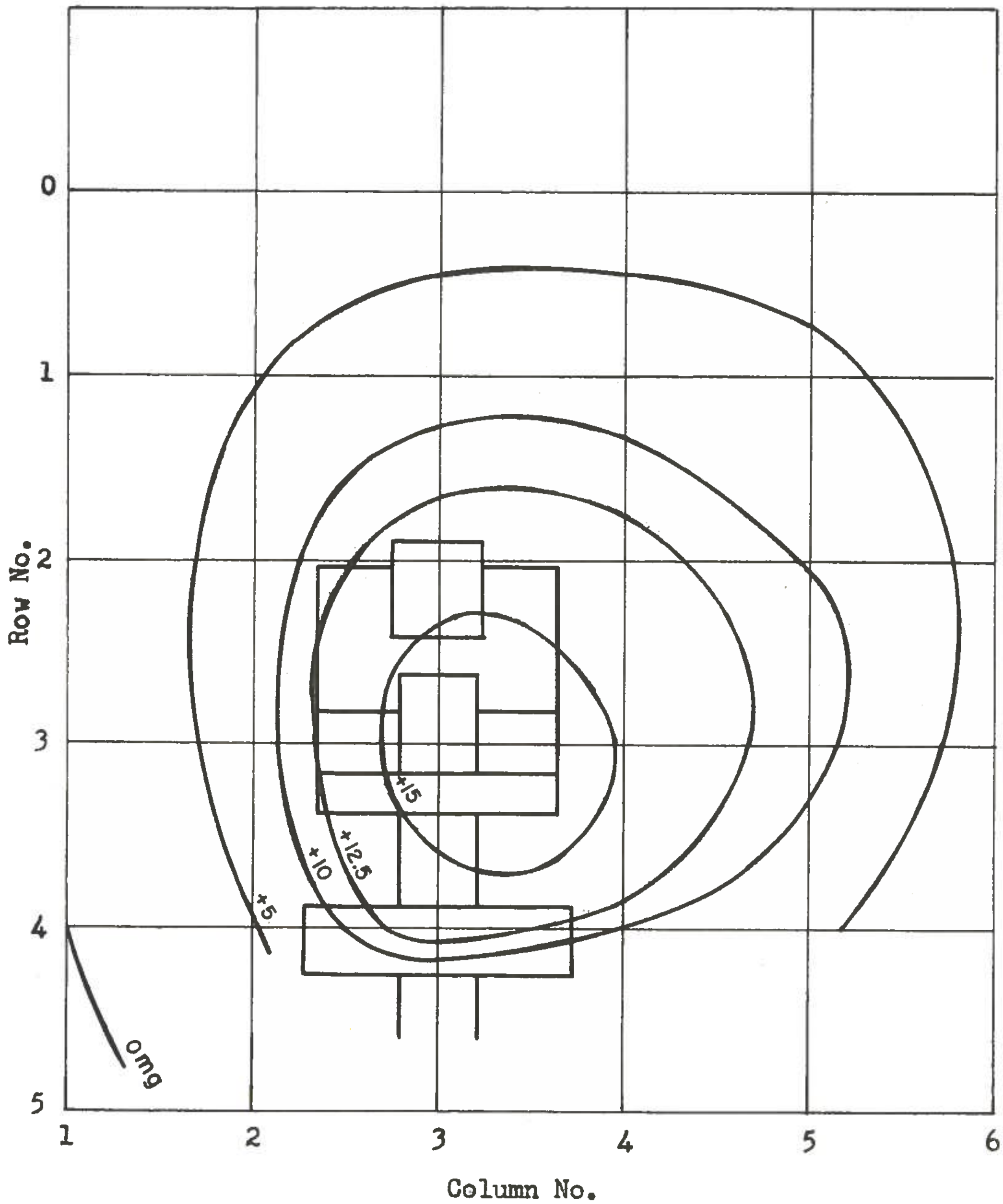
FIG. 12

1-10-F-FL-V-2600

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

3000 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

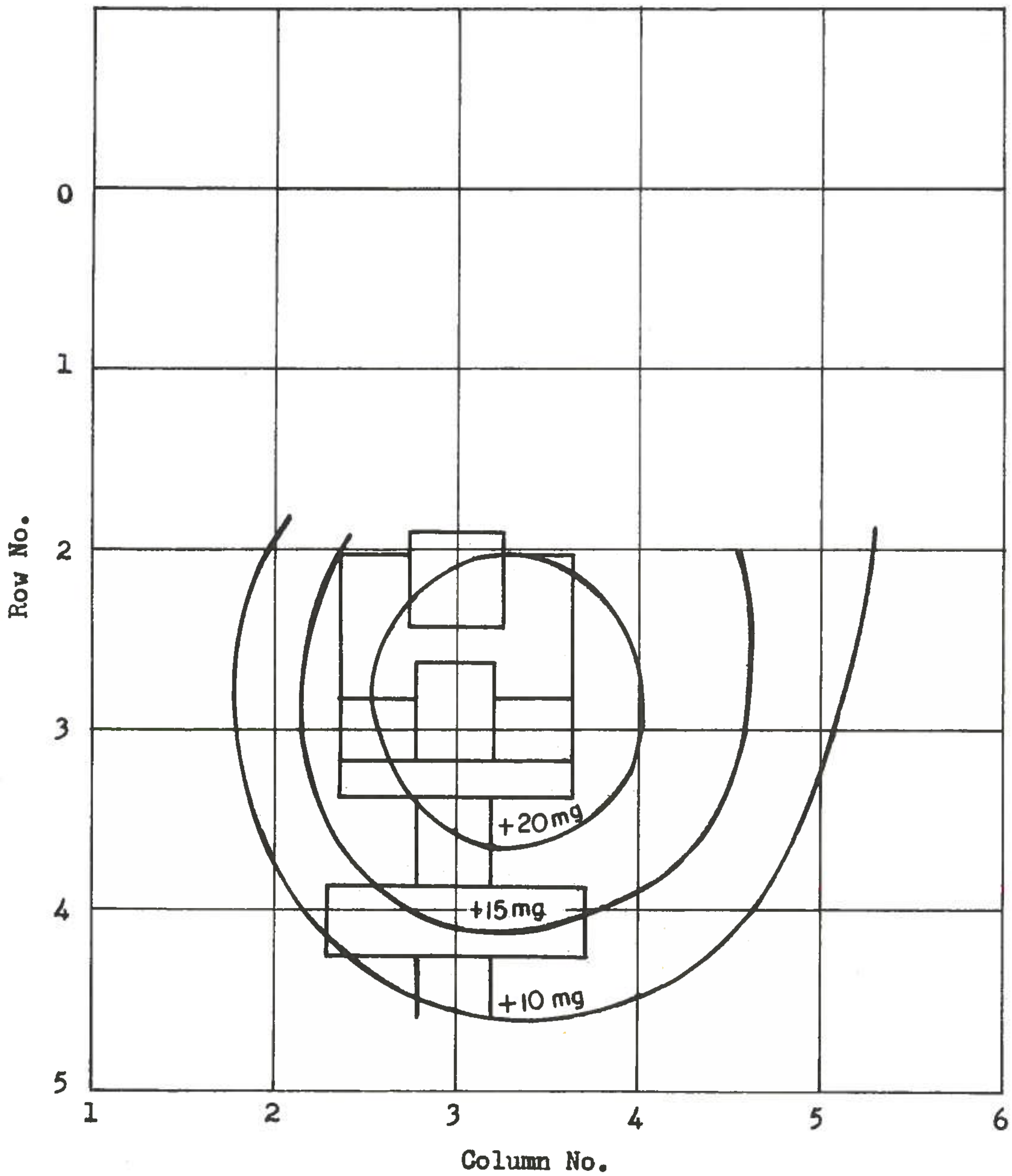
FIG. 13

1-10-F-FL-V-3000

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

3200 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

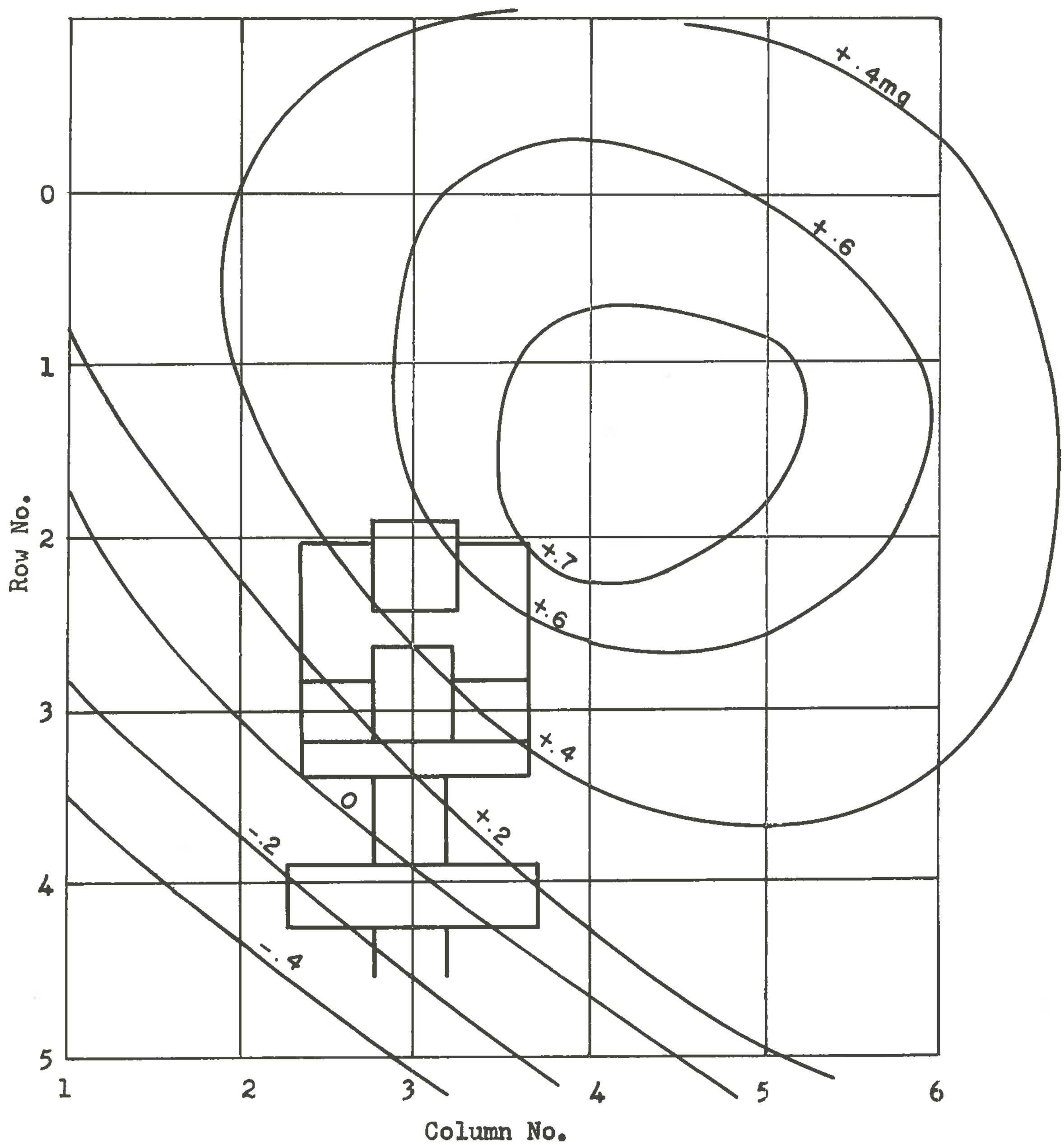
FIG. 14

1-10-F-FL-V-3200

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 15 ft.

2000 amp forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

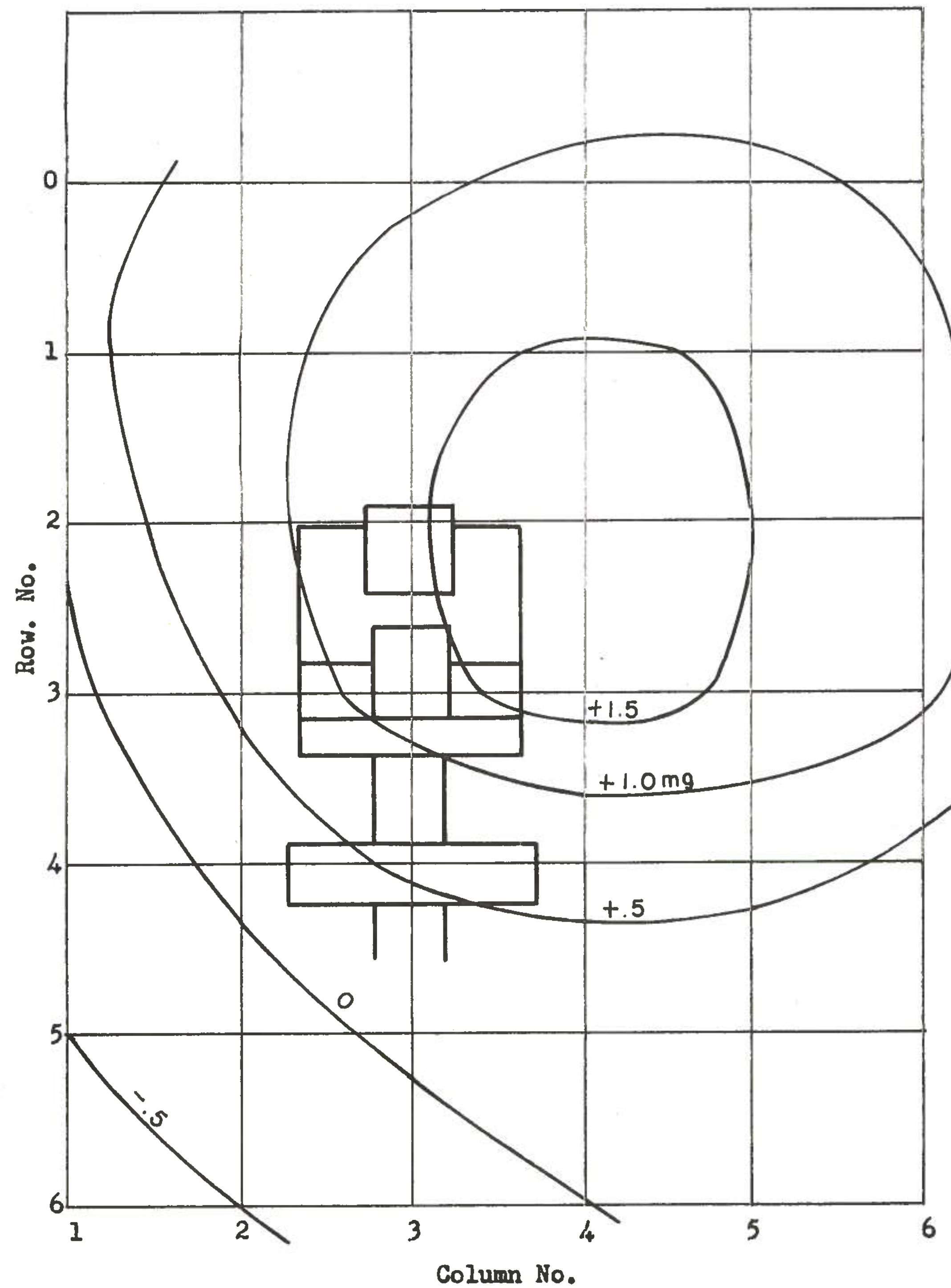
FIG. 15

1-15-F-FL-V-2000

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 15 ft.

2600 amp forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

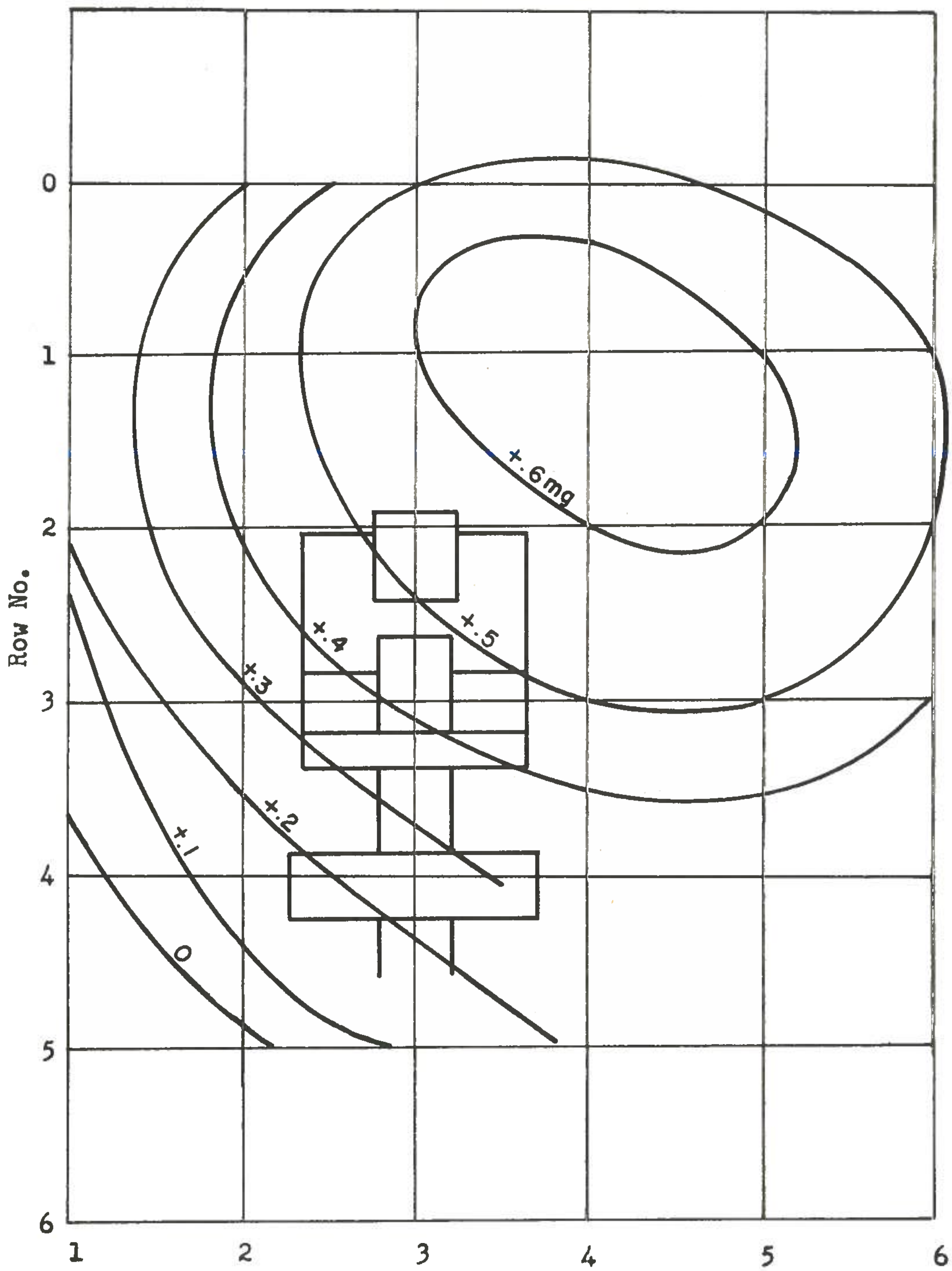
FIG. 16

1-15-F-FL-V-2600

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 20 ft.

2600 amp forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

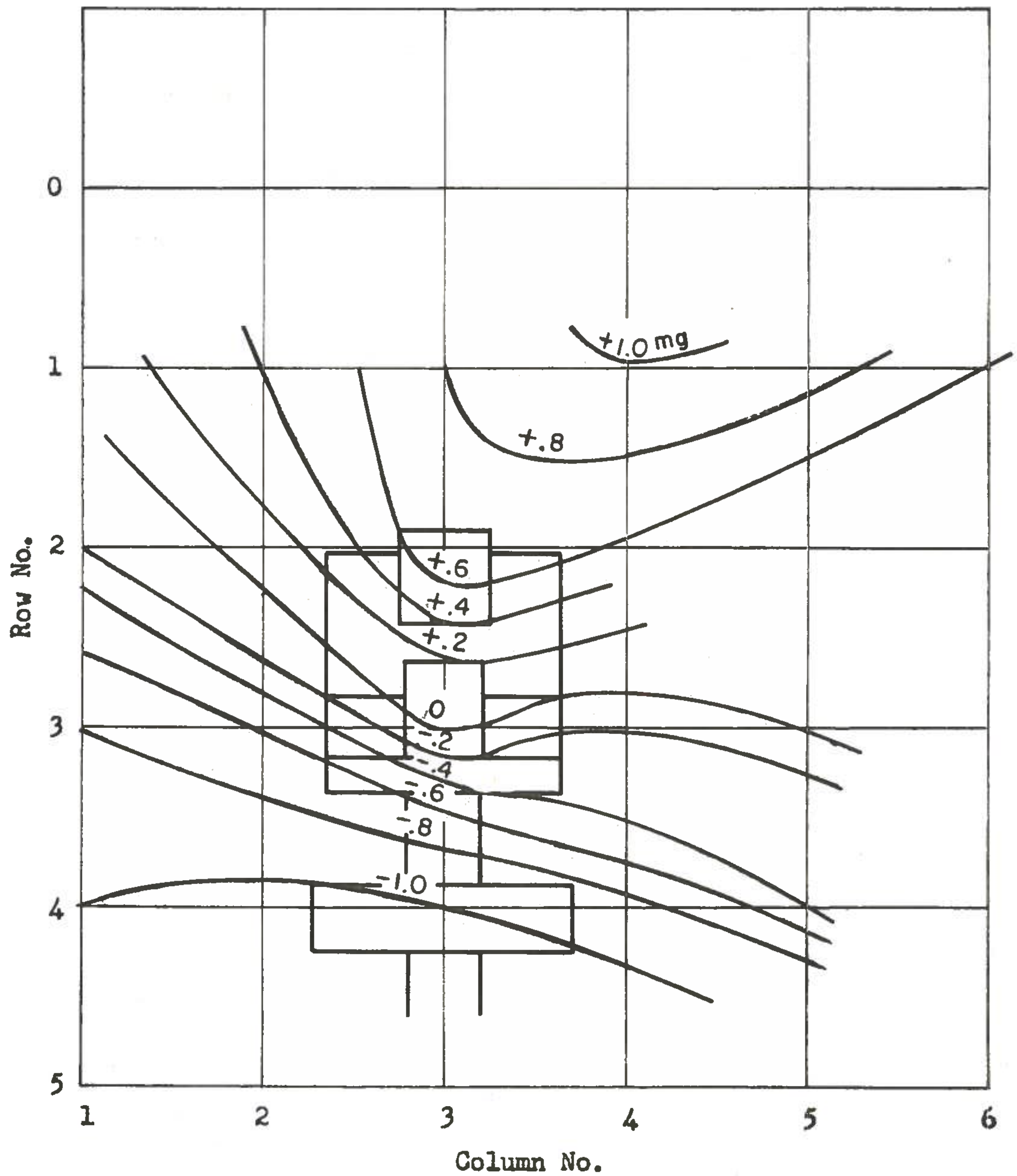
FIG. 17

1-20-F-FL-V-2600

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

1200 amp. forward pulses
short circuit operation
(load resistance = .023 ohms)



Downward Field - Positive
Upward Field - Negative

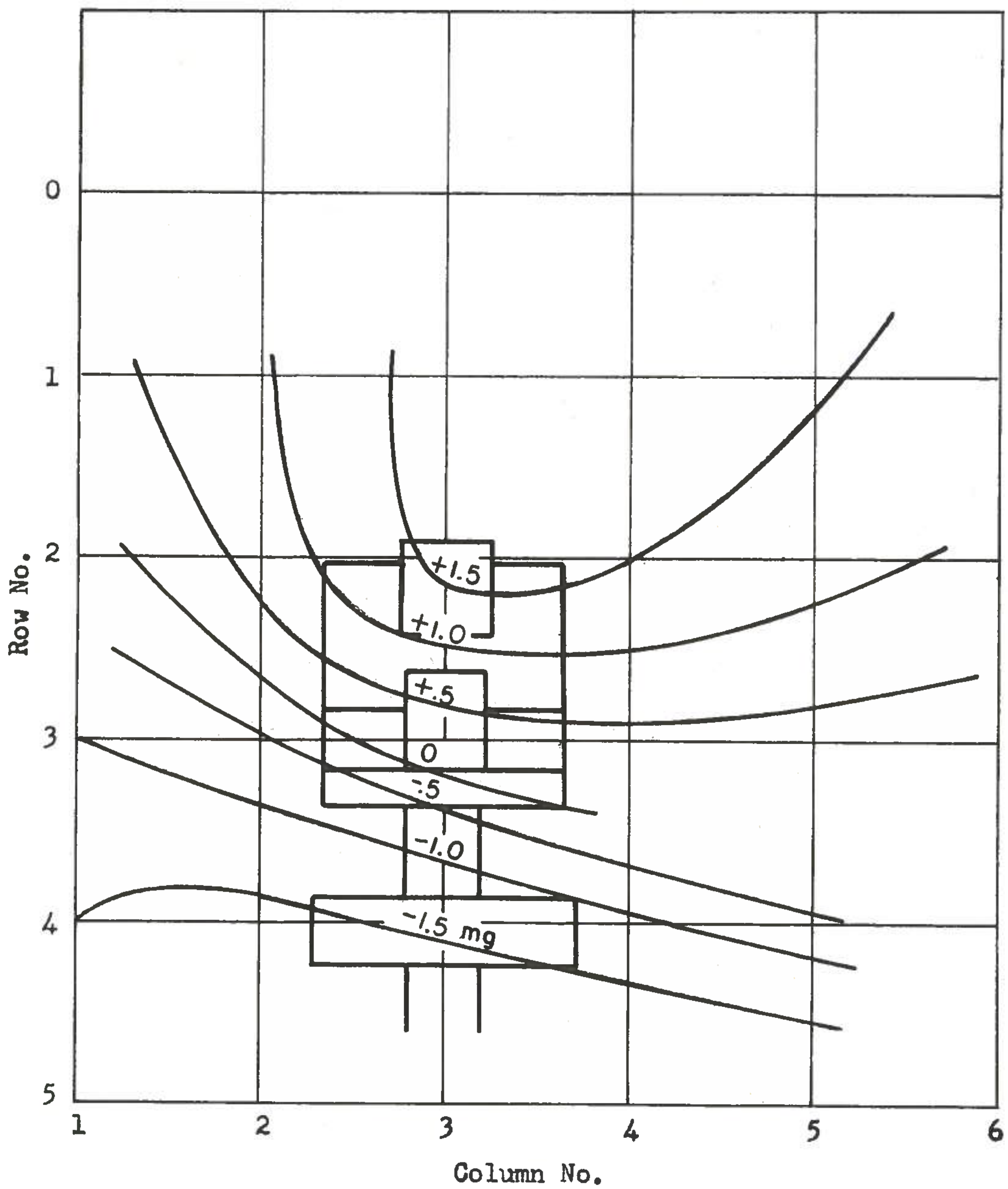
FIG. 18

1-10-F-SC-V-1200

GENERATOR NO. 1

Contours of Vertical Stray Field (mg) at 10 ft.

2000 amp. forward pulses
short circuit operation
(load resistance = .023 ohms)



Downward Field - Positive
Upward Field - Negative

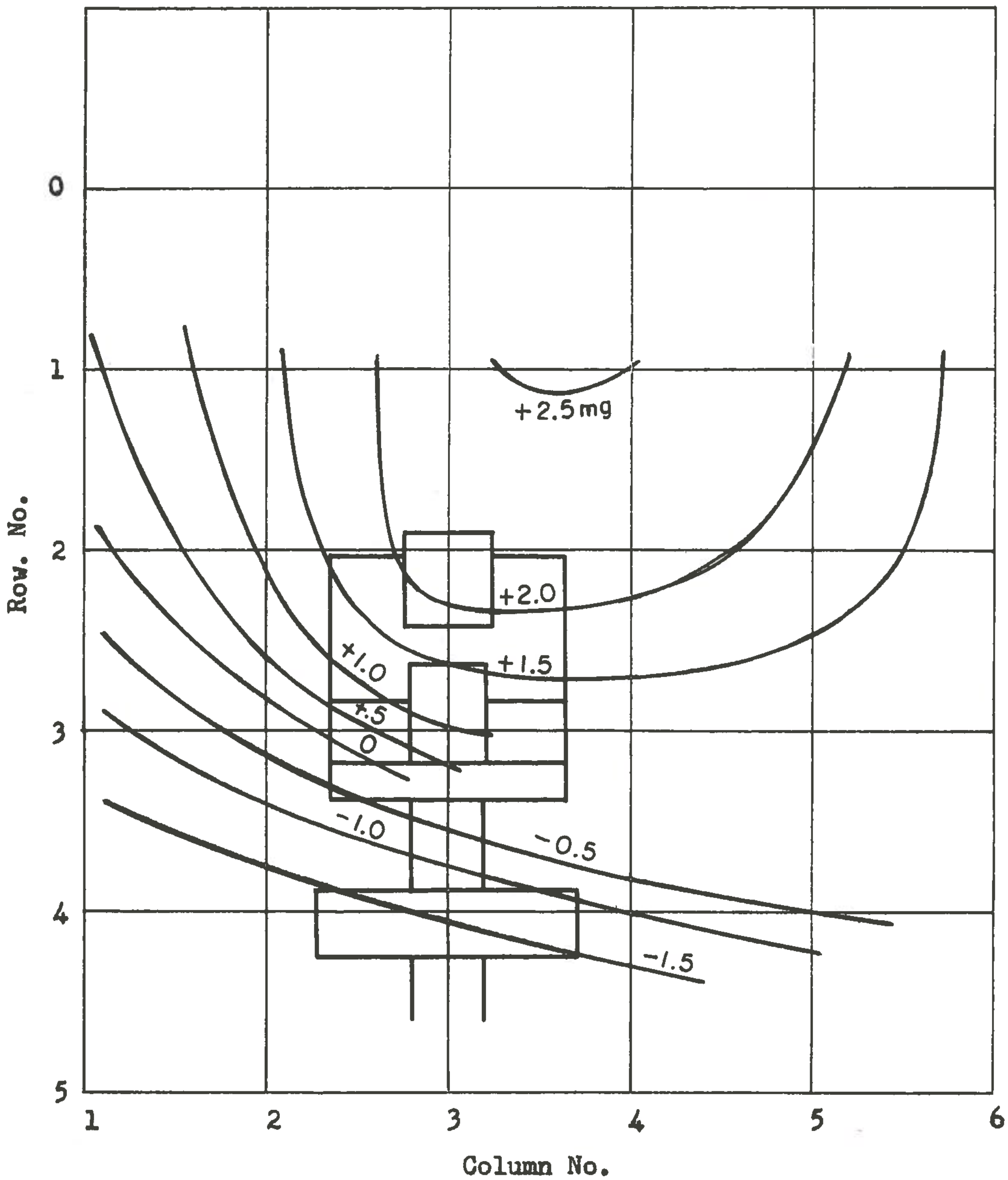
FIG. 19

1-10-F-SC-V-2000

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

2600 amp. forward pulses
short circuit operation
(load resistance = .023 ohms)



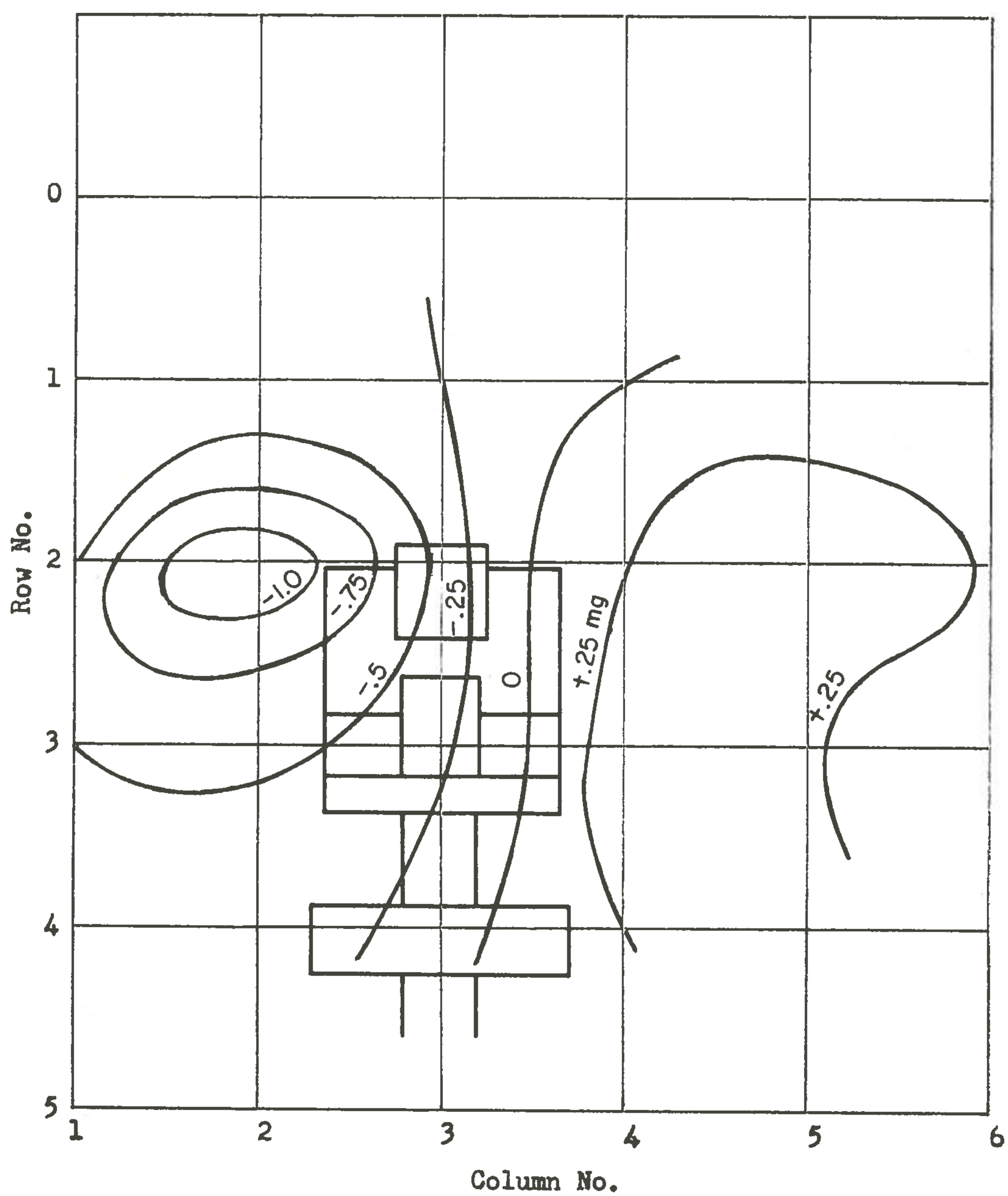
Downward Field - Positive
Upward Field - Negative

FIG. 20
1-10-F-SC-V-2600

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

100 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

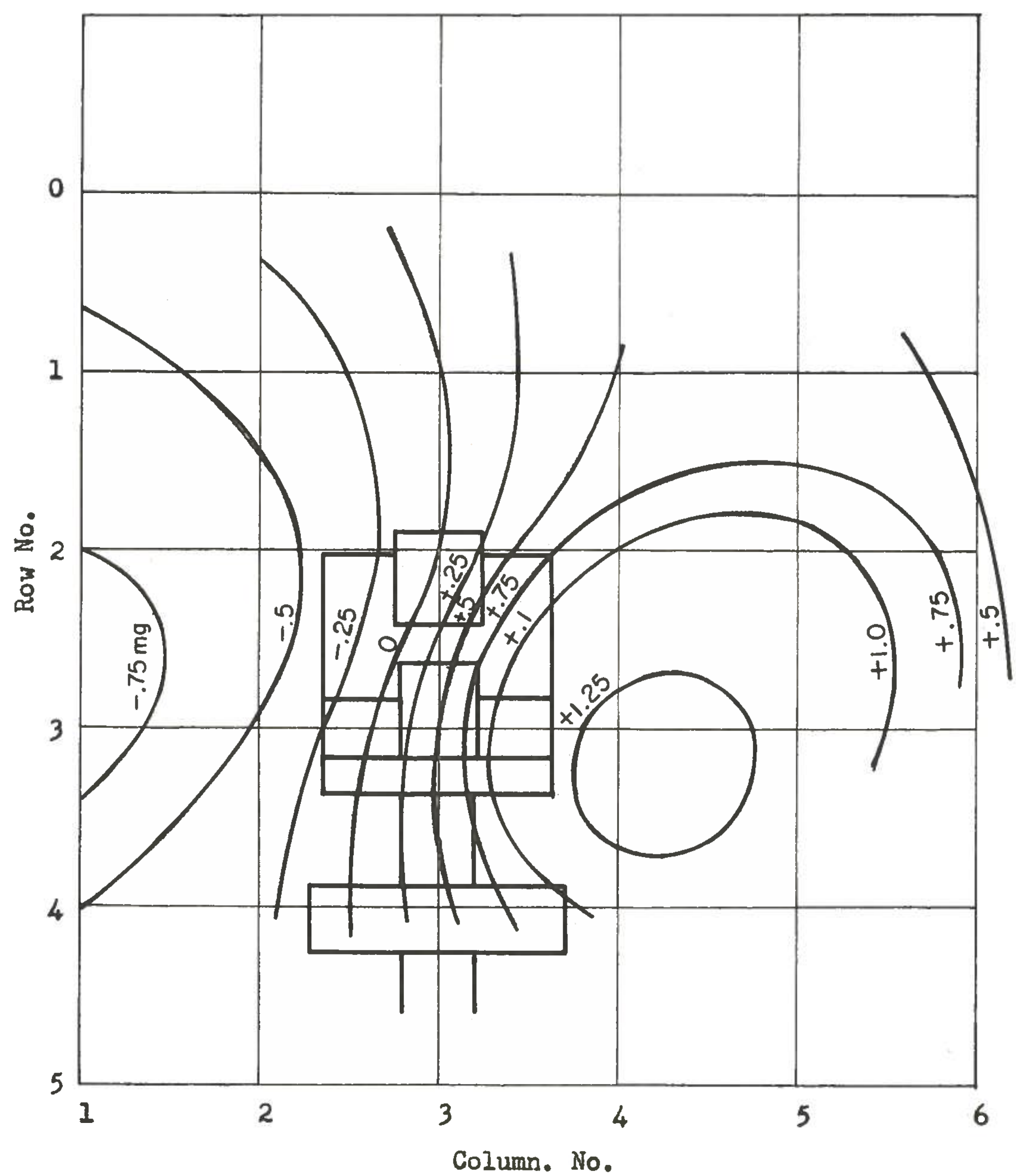
FIG. 21

1-10-F-OC-V-100

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

150 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

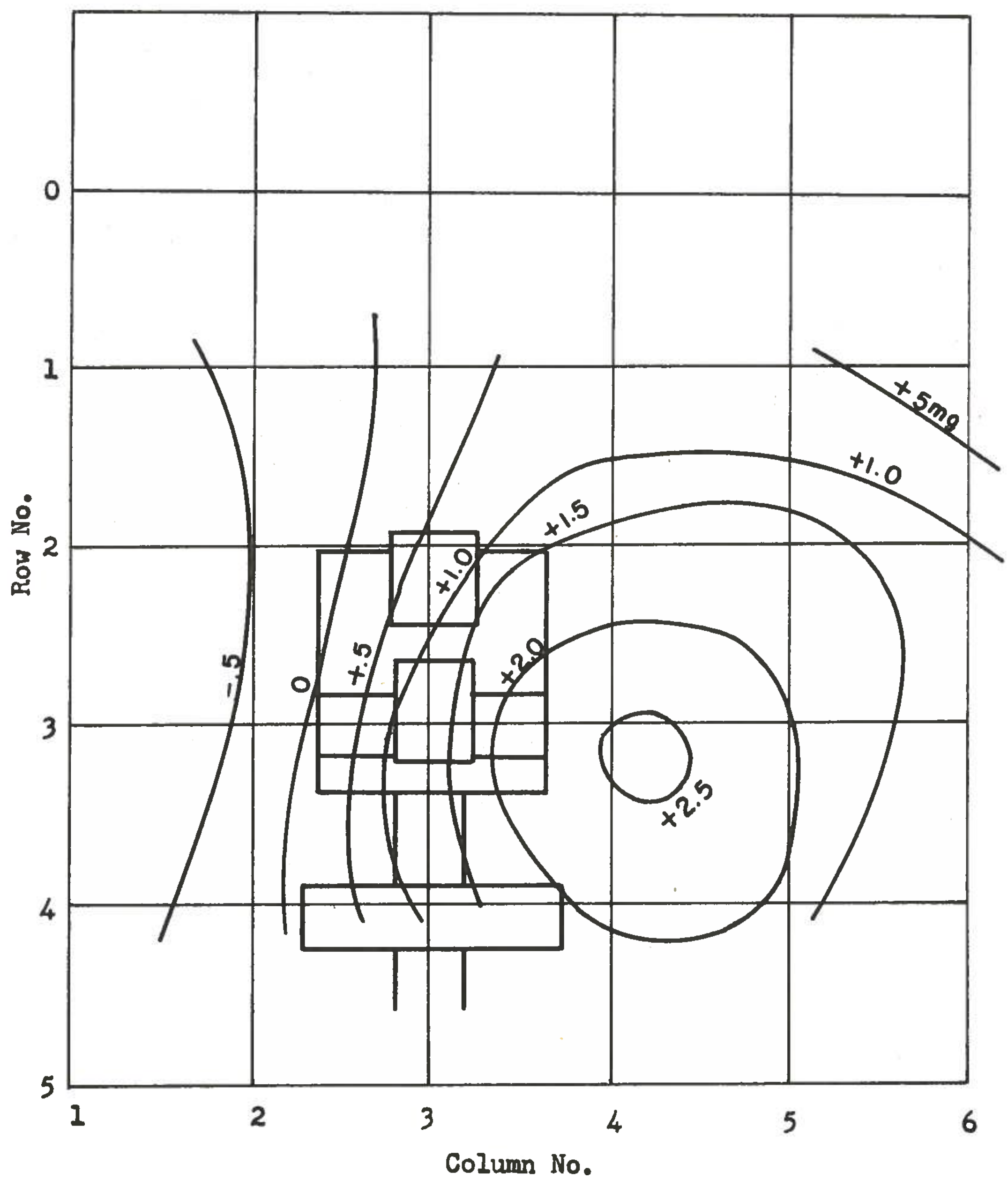
FIG. 22

1-10-F-OC-V-150

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

200 volt forward pulses
open circuit operation



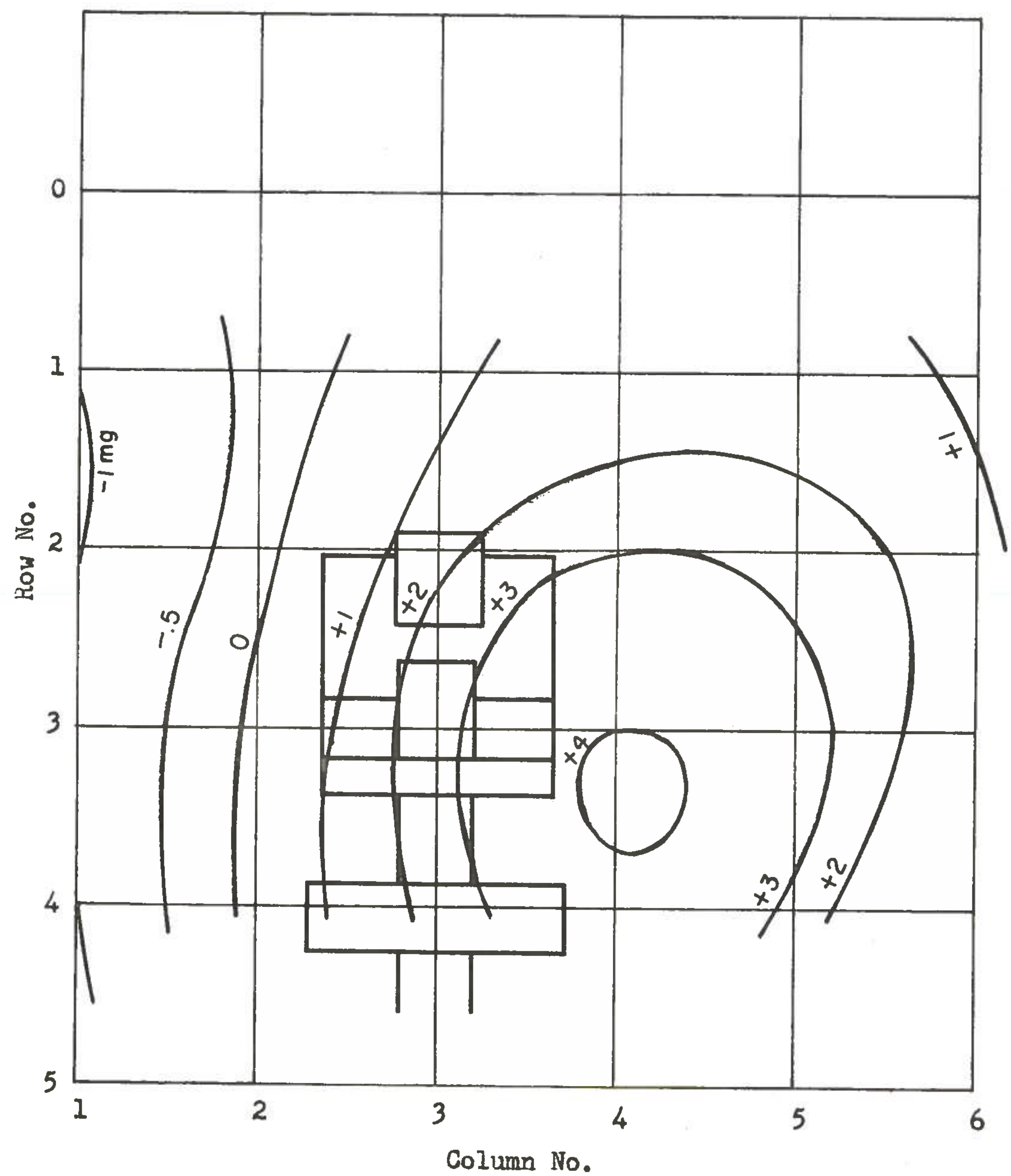
Downward Field - Positive
Upward Field - Negative

FIG. 23
1-10-F-OC-V-200

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

250 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

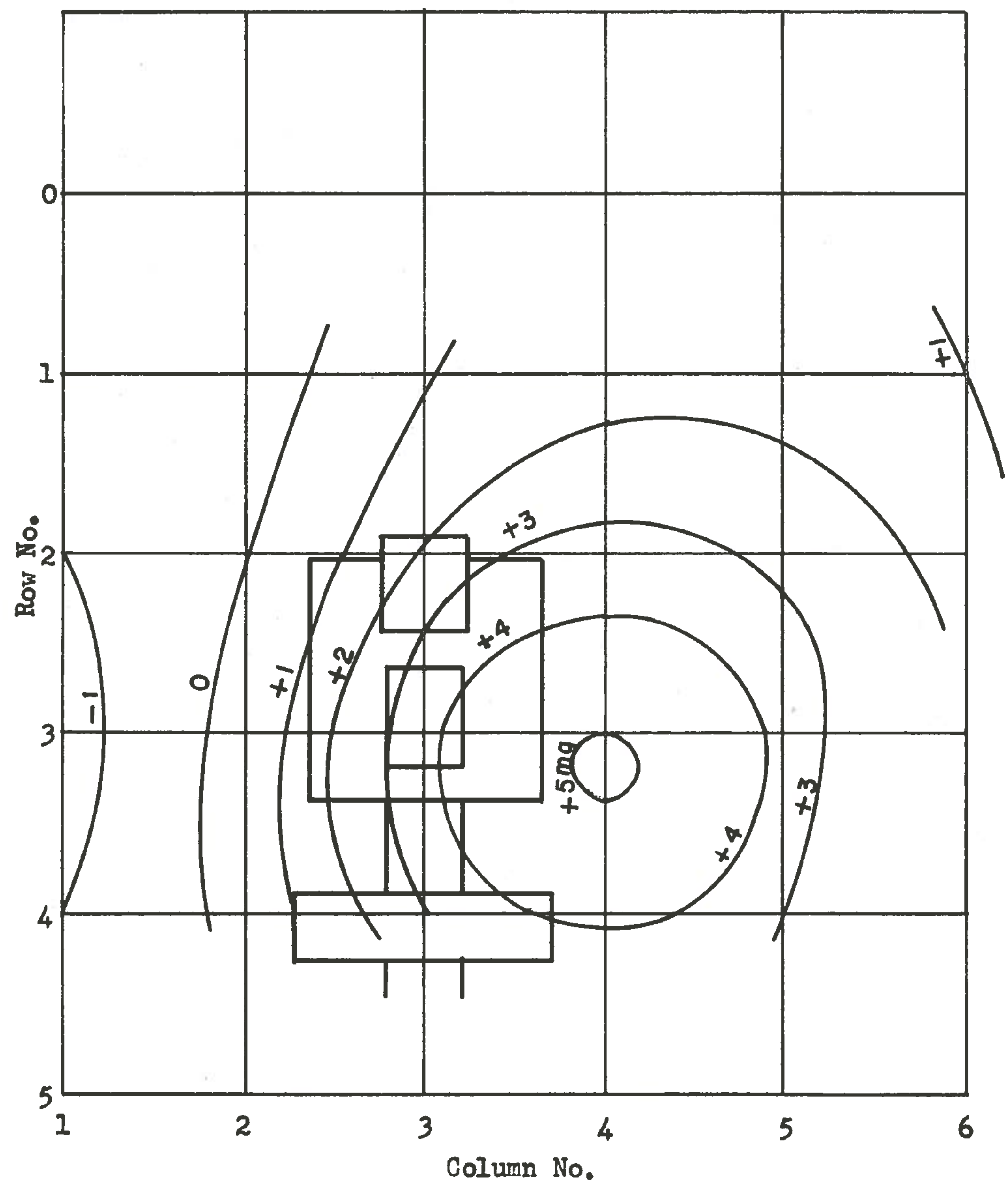
FIG. 24

1-10-F-OC-V-250

GENERATOR NO. 1

Contours of Vertical Stray Field (mg)
at 10 ft.

260 Volt Forward Pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

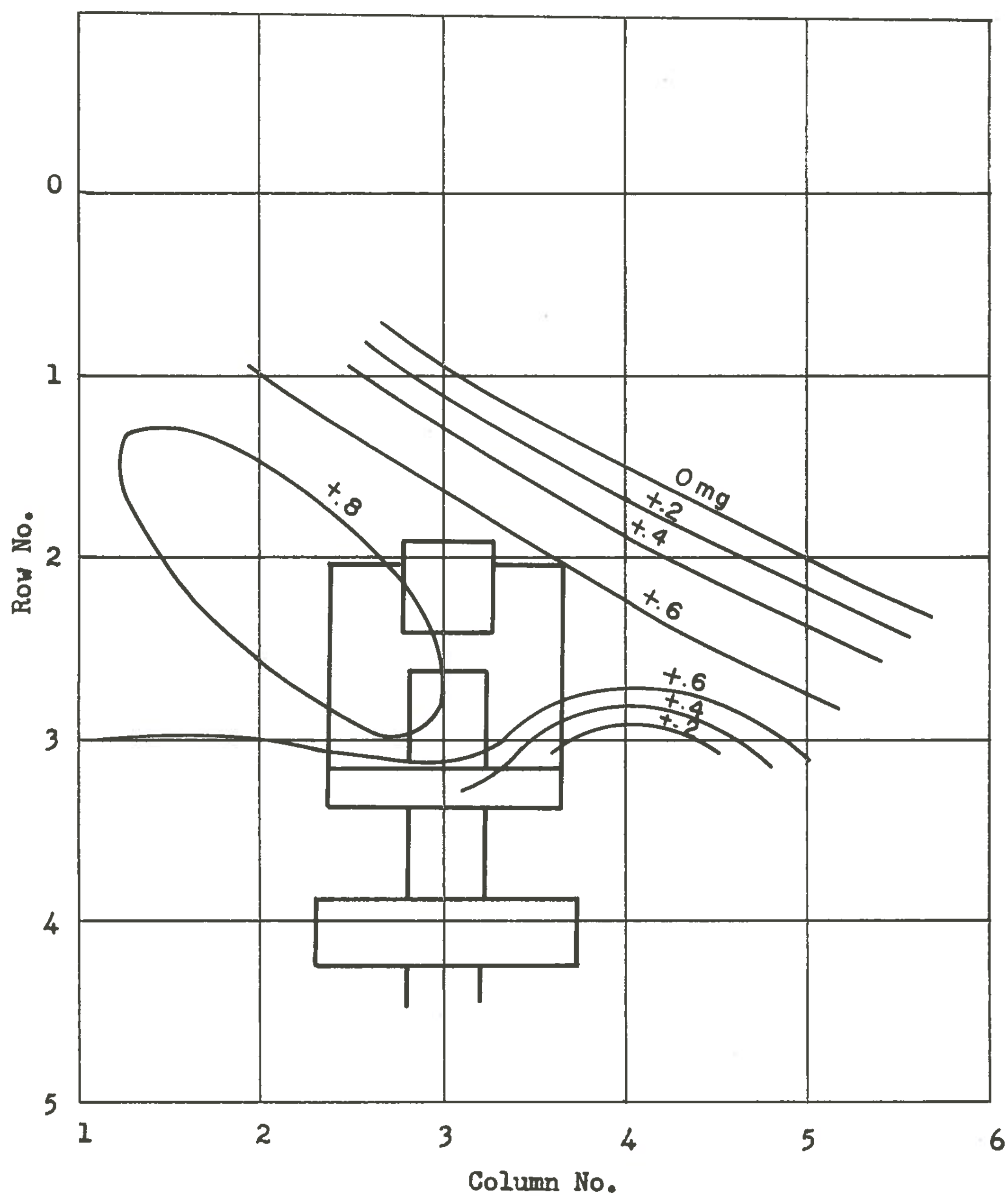
FIG. 25

1-10-F-OC-V-260

GENERATOR NO. 1

Contours of Axial Stray Field (mg)
at 10 ft.

1200 amp forward pulses
normal operation
(load resistance = .061 ohms)



Positive
Direction
of
Field

FIG. 26

1-10-F-FL-A-1200

GENERATOR NO. 1

Contours of Axial Stray Field (mg)
at 10 ft.

2000 amp forward pulses
normal operation
(load resistance = .061 ohms)

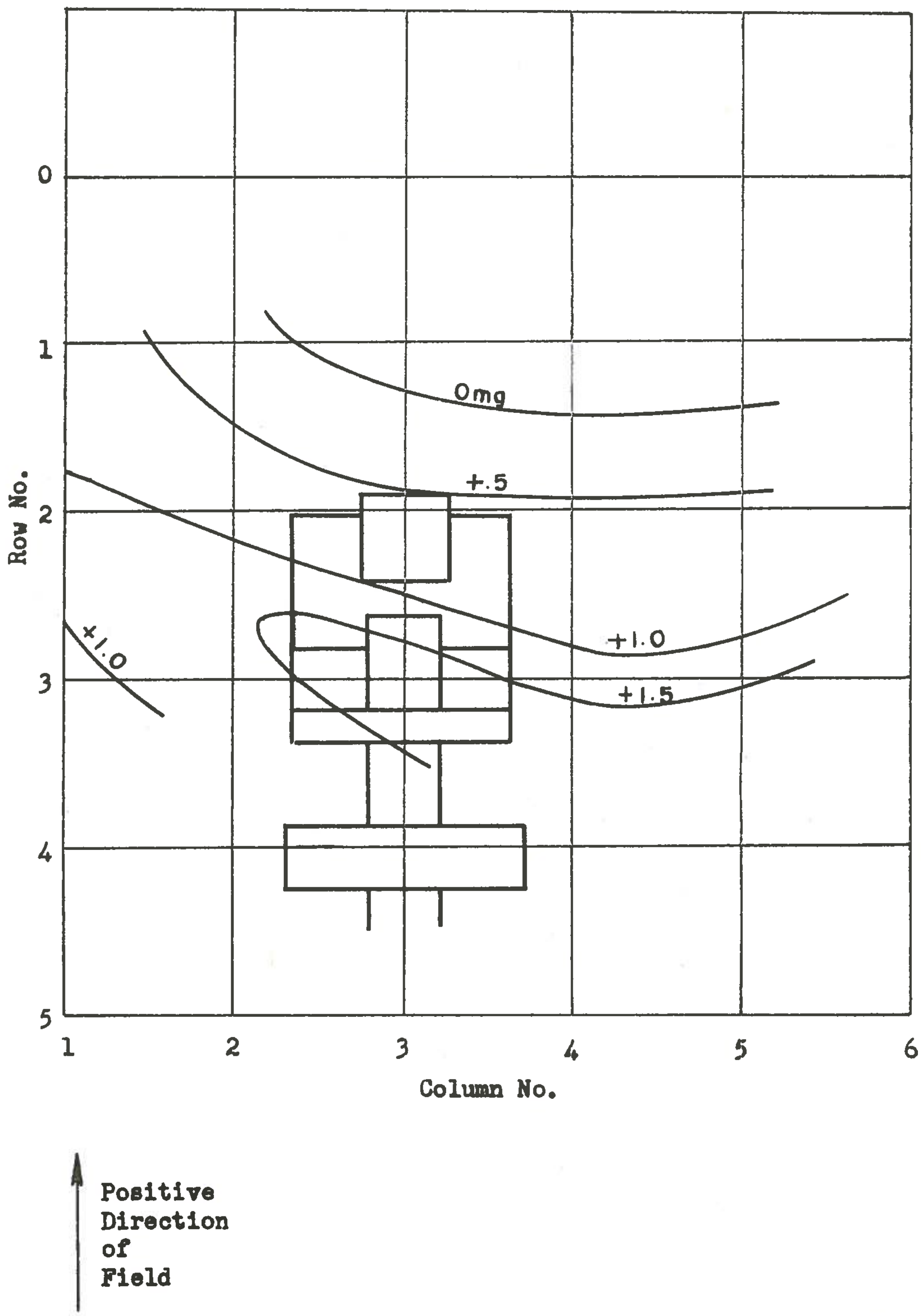


FIG. 27

1-10-F-FL-A-2000

GENERATOR NO. 1

Contours of Axial Stray Field (mg)
at 10 ft.

3000 amp forward pulses
normal operation
(load resistance = .061 ohms)

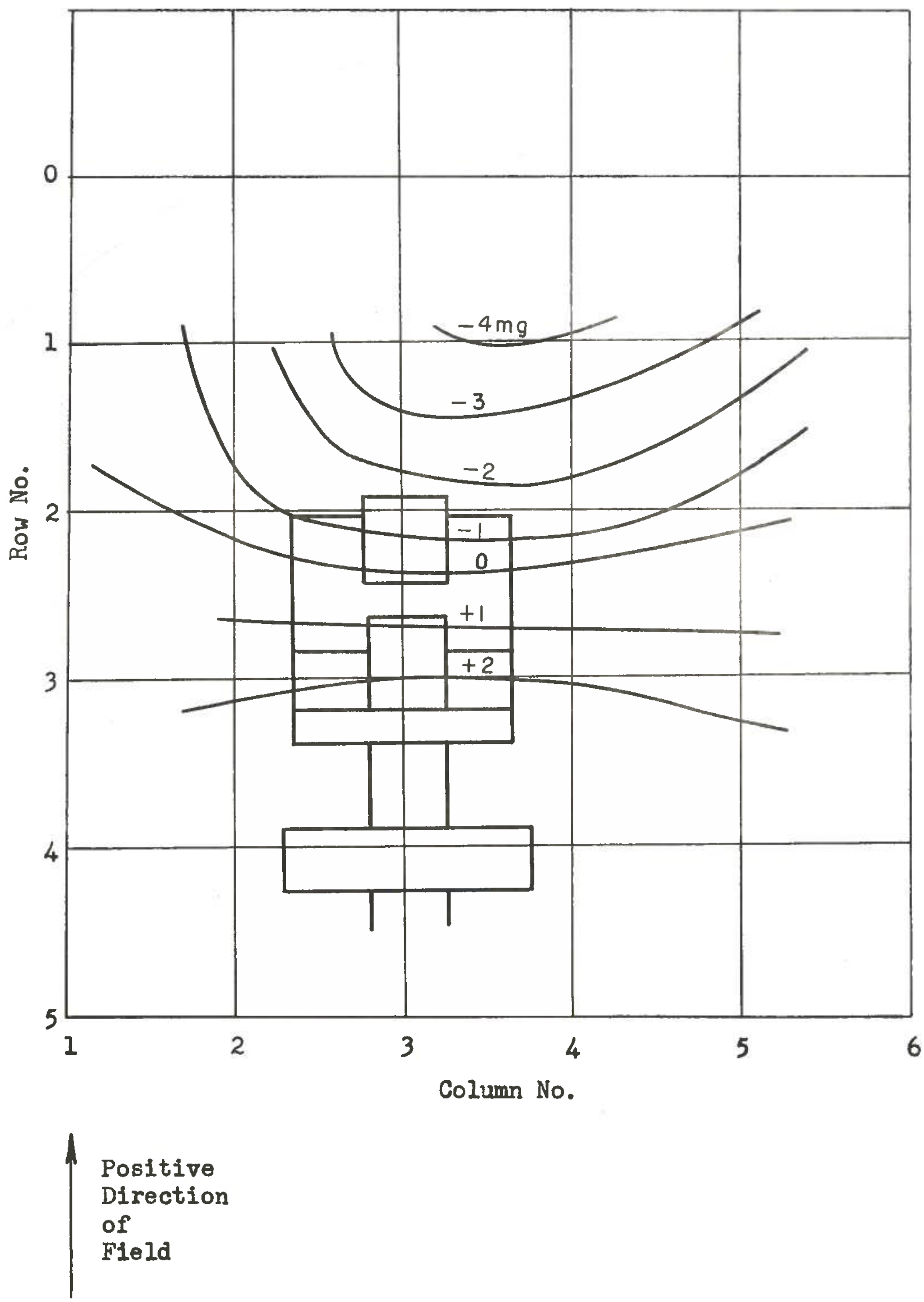
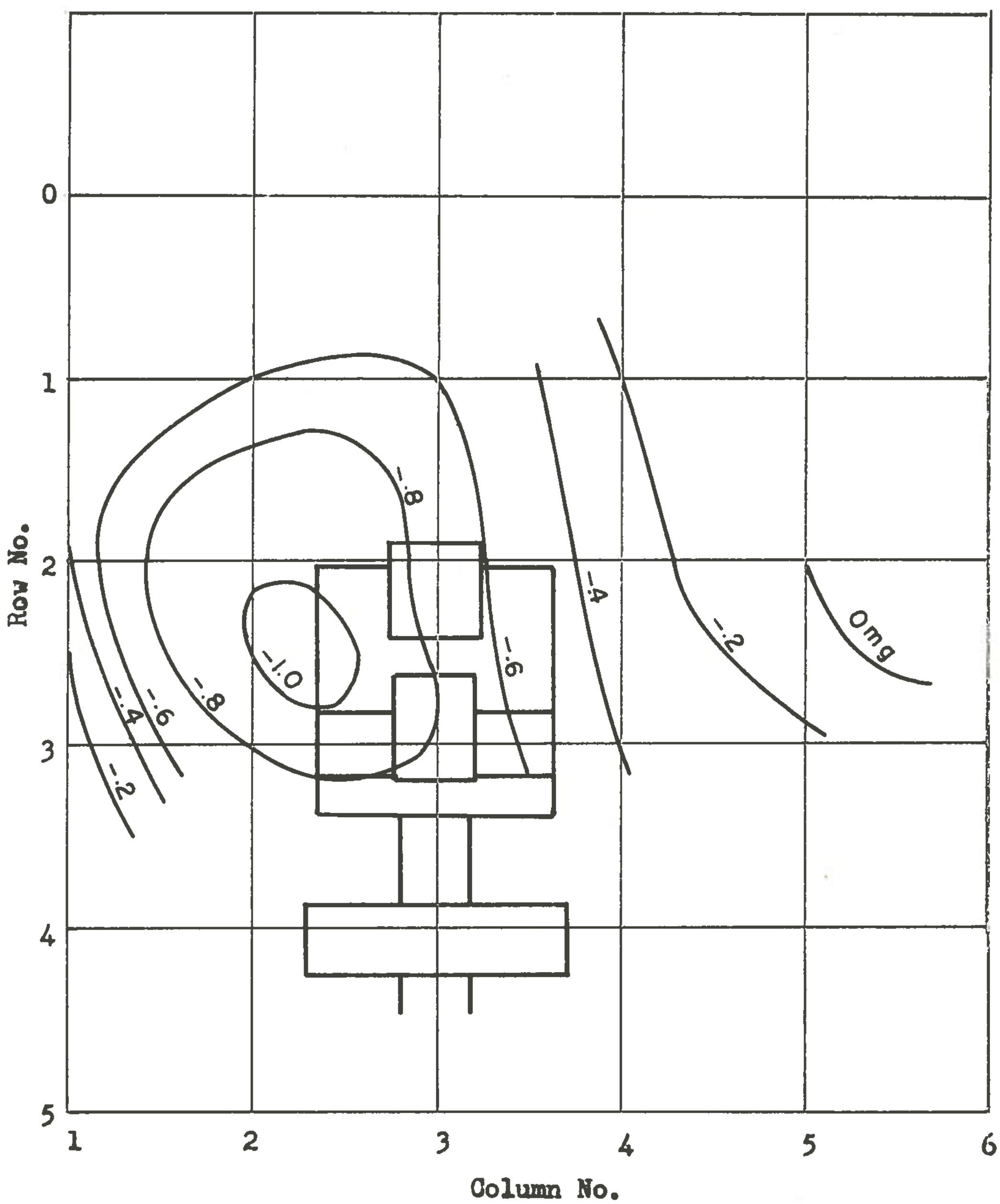


FIG. 28
1-10-F-FL-A-3000

GENERATOR NO. 1

Contours of Transverse Stray Field (mg)
at 10 ft.

1200 amp forward pulses
normal operation
(load resistance = .061 ohms)



Positive Direction
of Field

FIG. 29

1-10-F-FL-T-1200

GENERATOR NO. 1

Contours of Transverse Stray Field (mg)
at 10 ft.

2000 amp forward pulses
normal operation
(load resistance = .061 ohms)

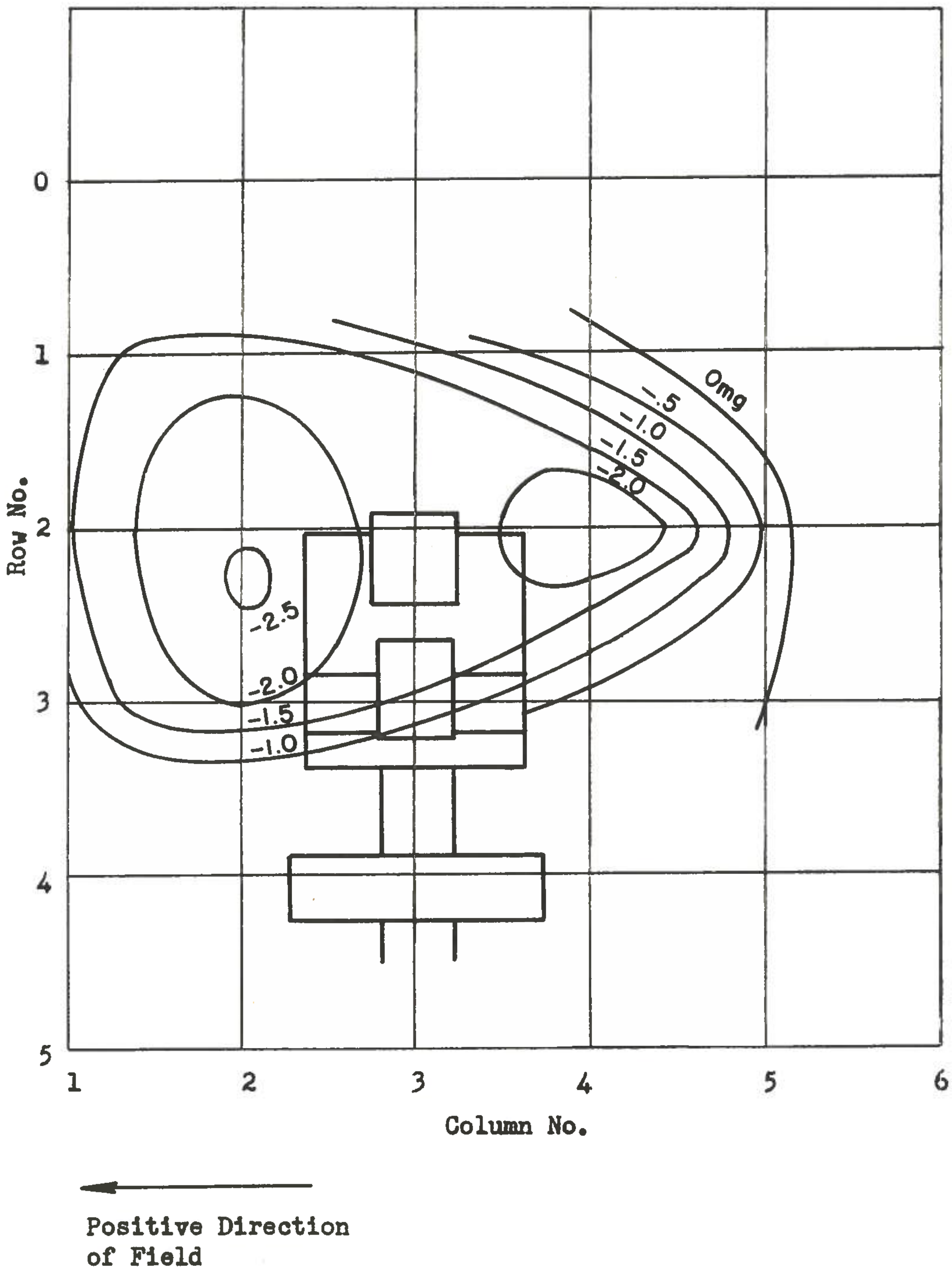


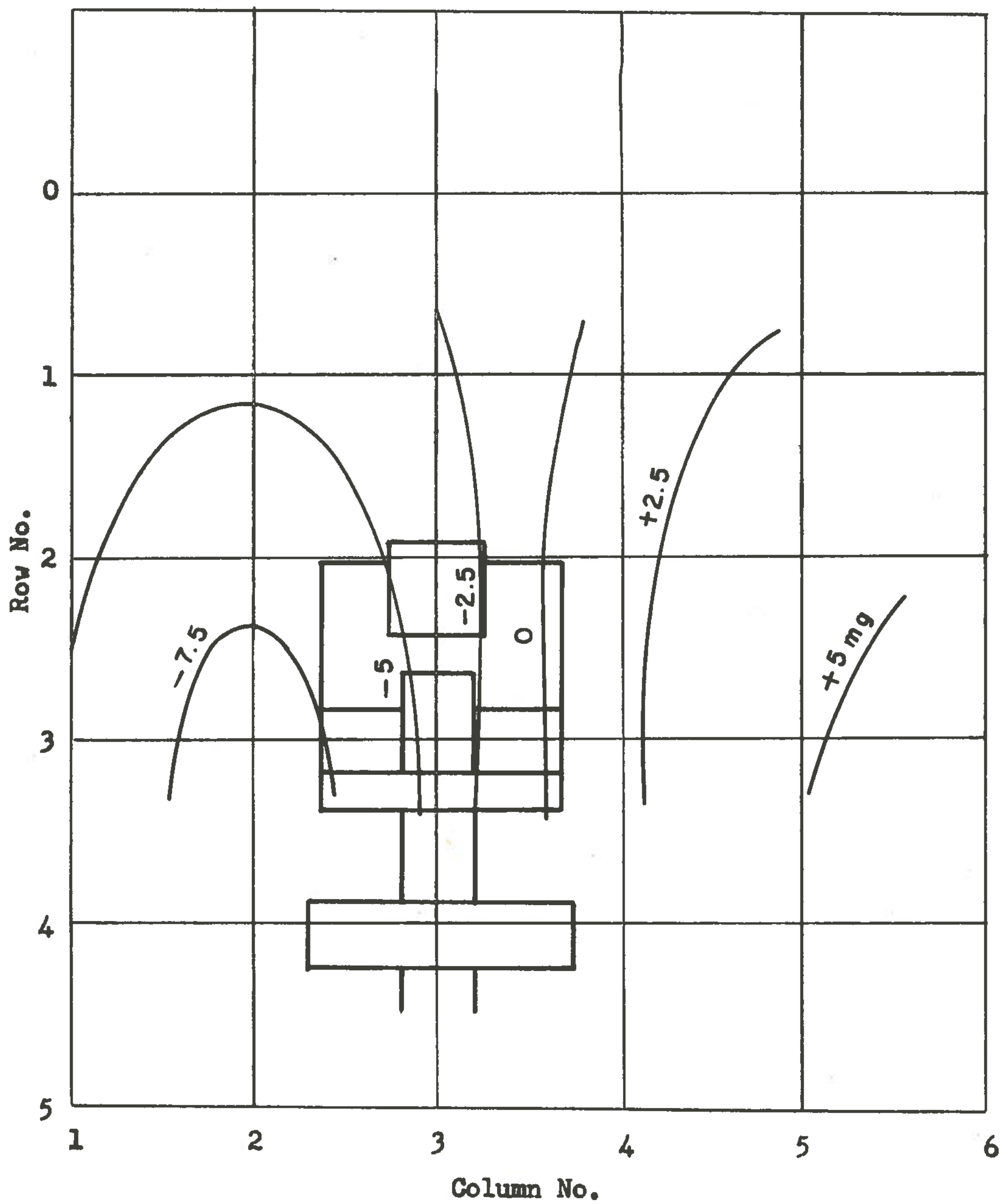
FIG. 30

1-10-F-FL-T-2000

GENERATOR NO. 1

Contours of Transverse Stray Field (mg)
at 10 ft.

3000 amp forward pulses
normal operation
(load resistance = .061 ohms)



Positive Direction
of Field

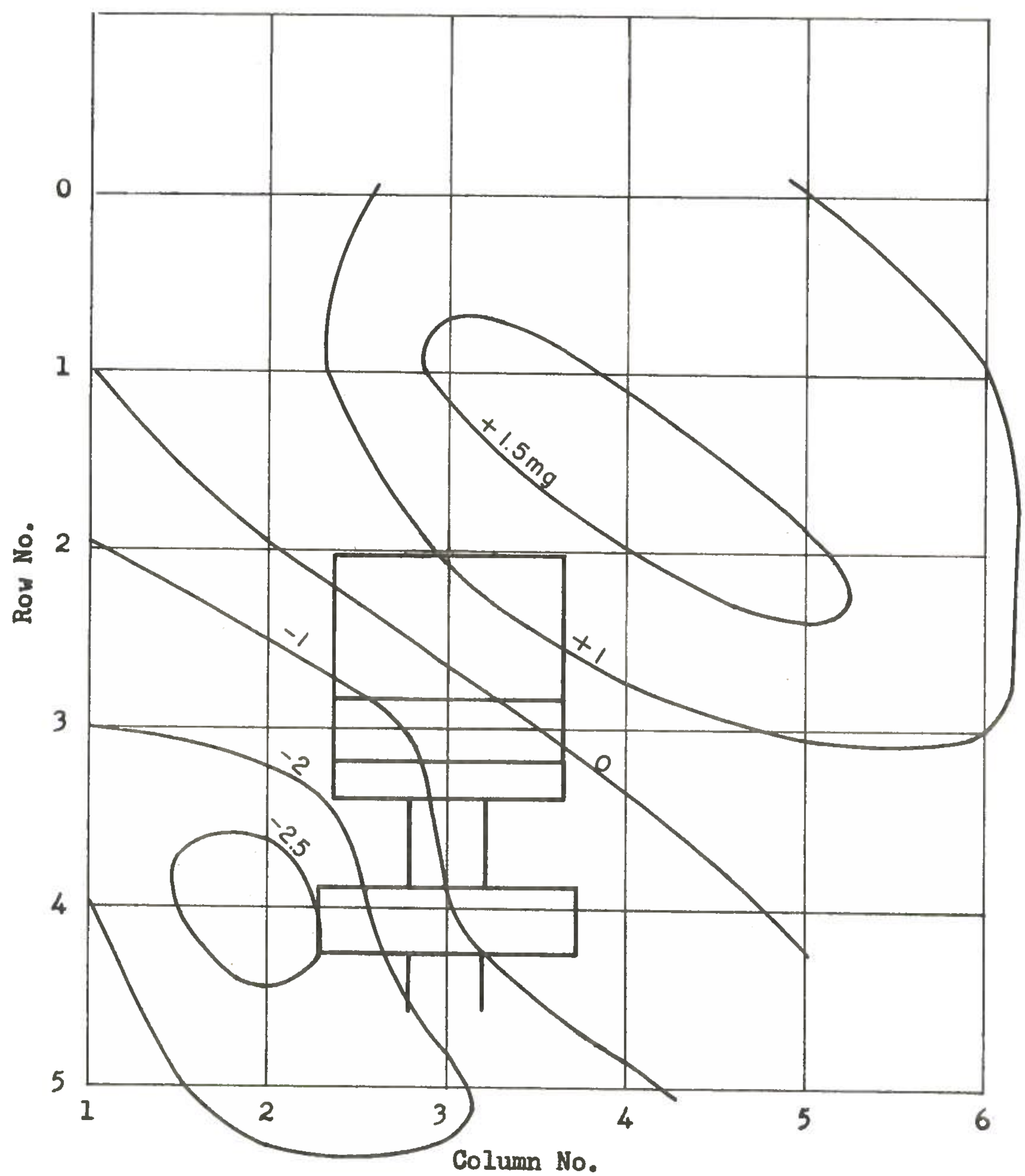
FIG. 31

1-10-F-FL-T-3000

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

1200 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

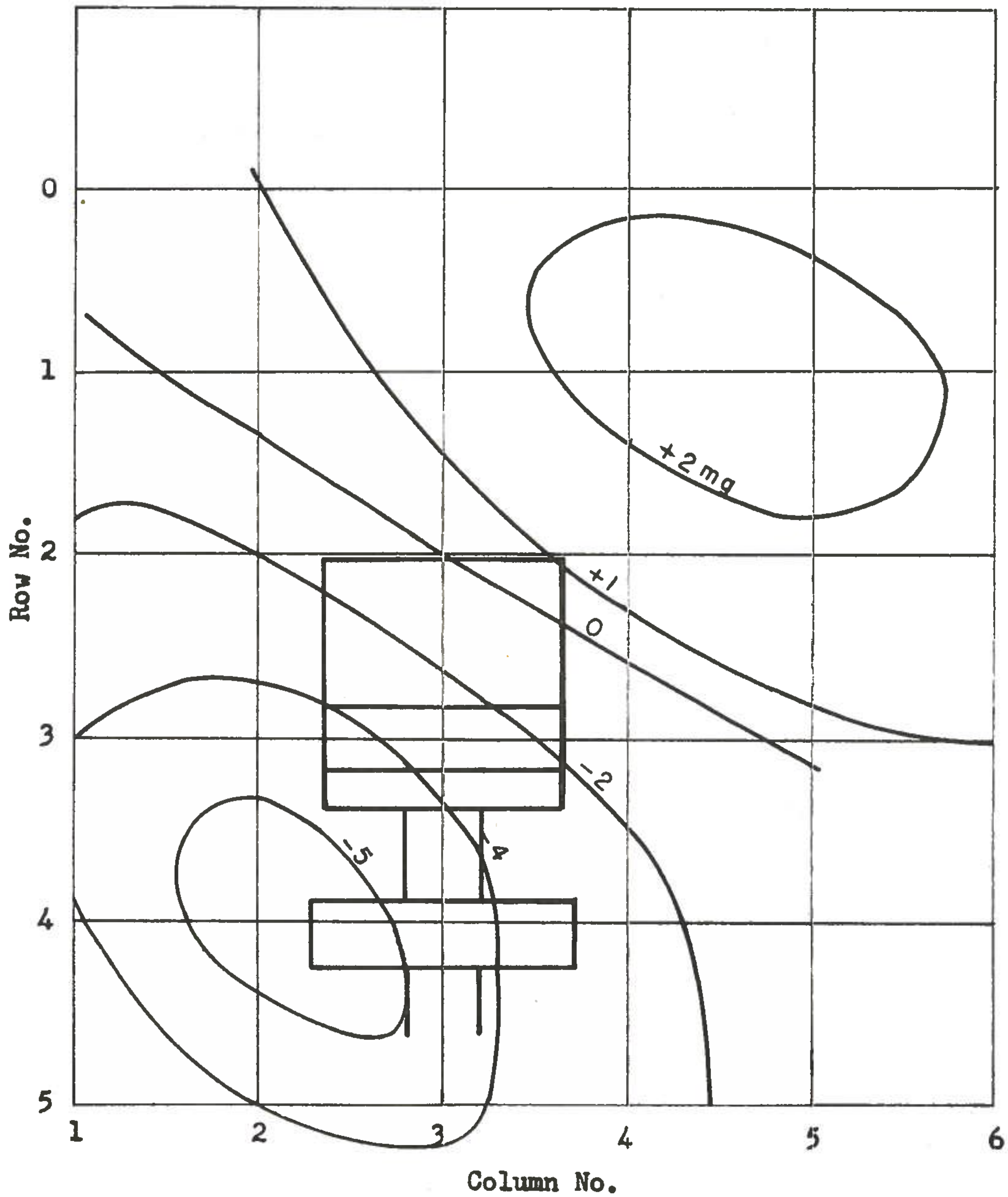
FIG. 32

2-10-F-FL-V-1200

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

2050 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

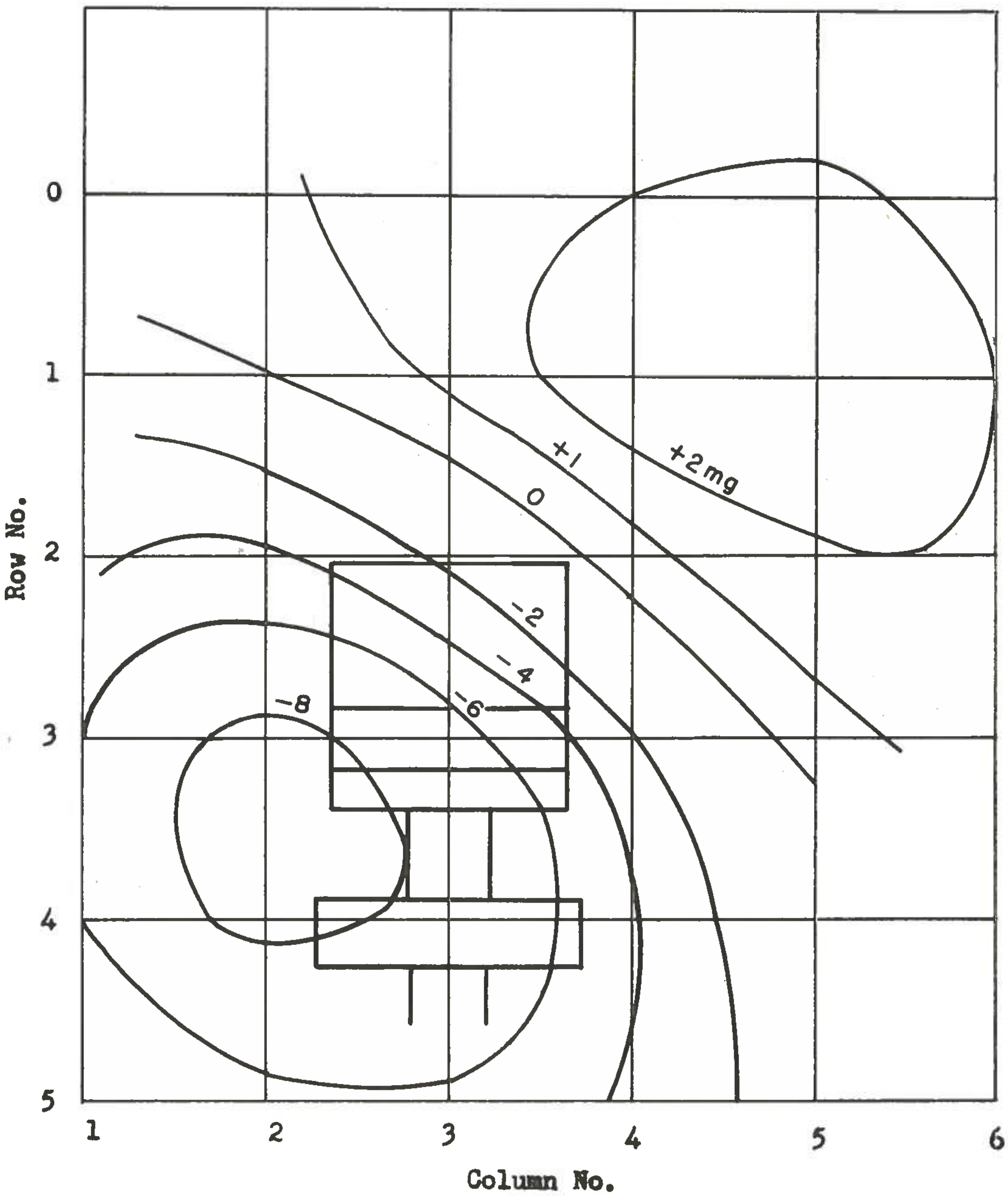
FIG. 33

2-10-F-FL-V-2050

GENERATOR NO. 2
EXCITER REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

2600 amp. forward pulses
Normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

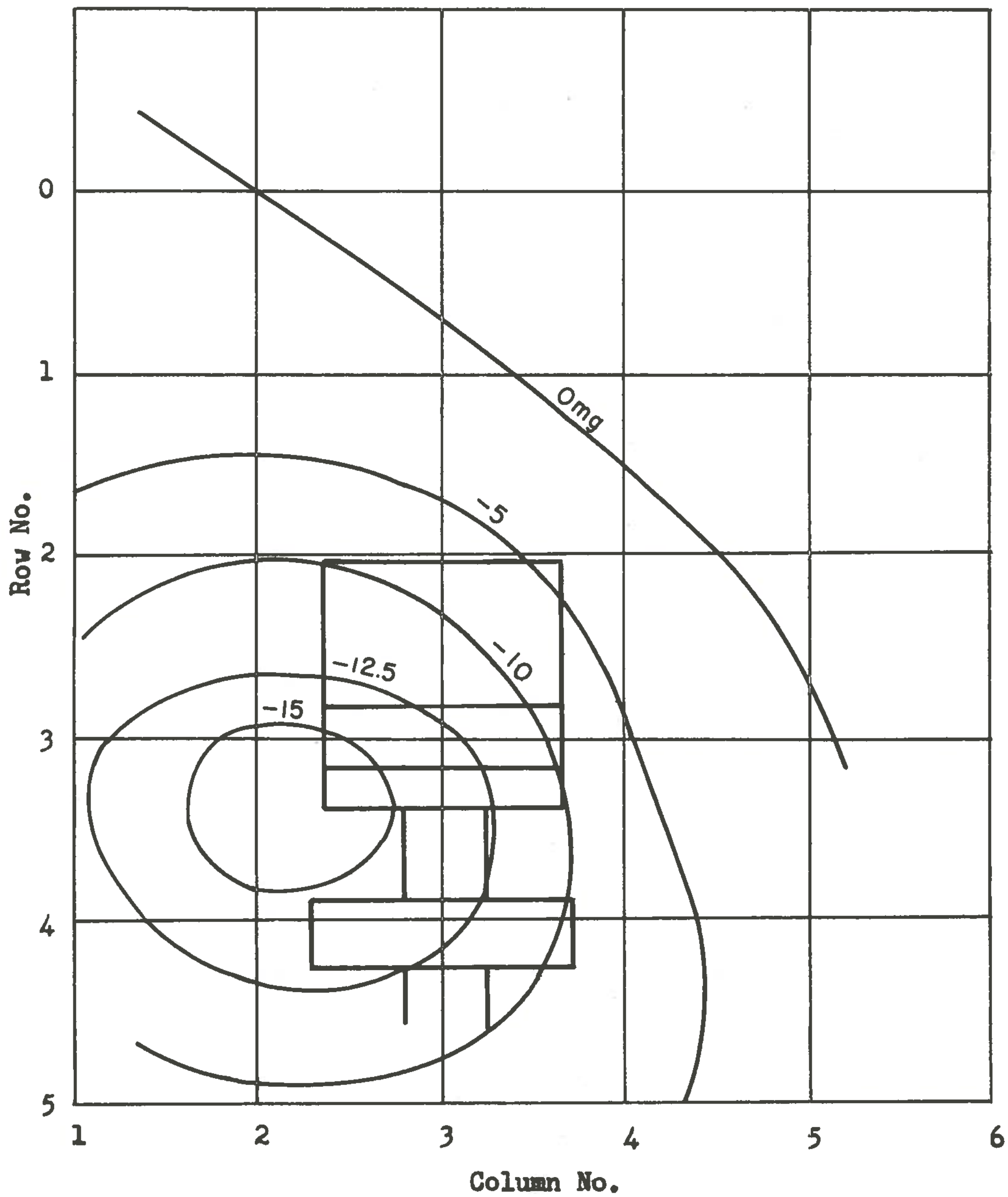
FIG. 34

2-10-F-FL-V-2600

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

3050 amp. forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

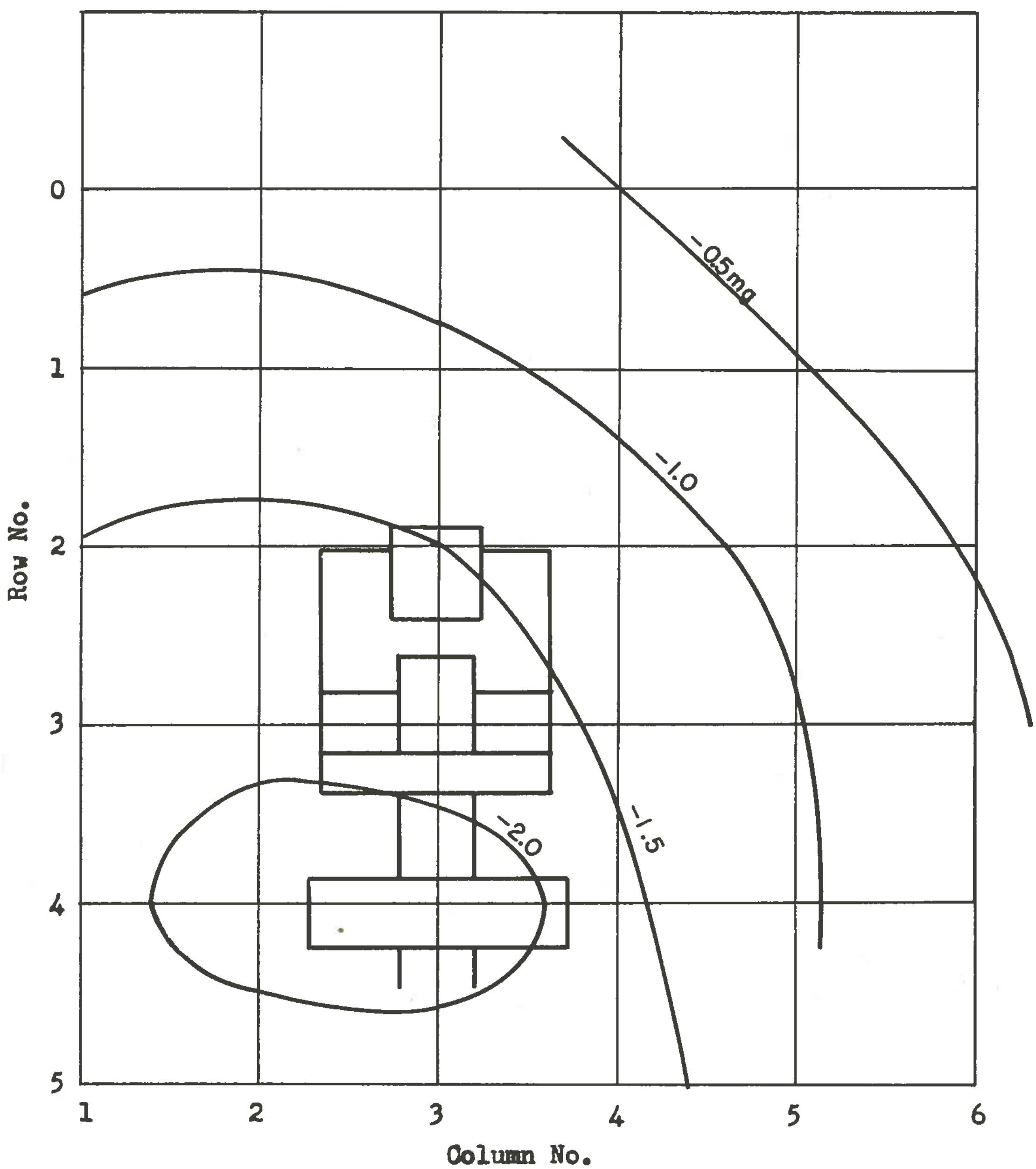
FIG. 35

2-10-F-FL-V-3050

GENERATOR NO. 2

Contours of Vertical Stray Field (mg)
at 20 ft.

3000 amp forward pulses
normal operation
(load resistance = .061 ohms)



Downward Field - Positive
Upward Field - Negative

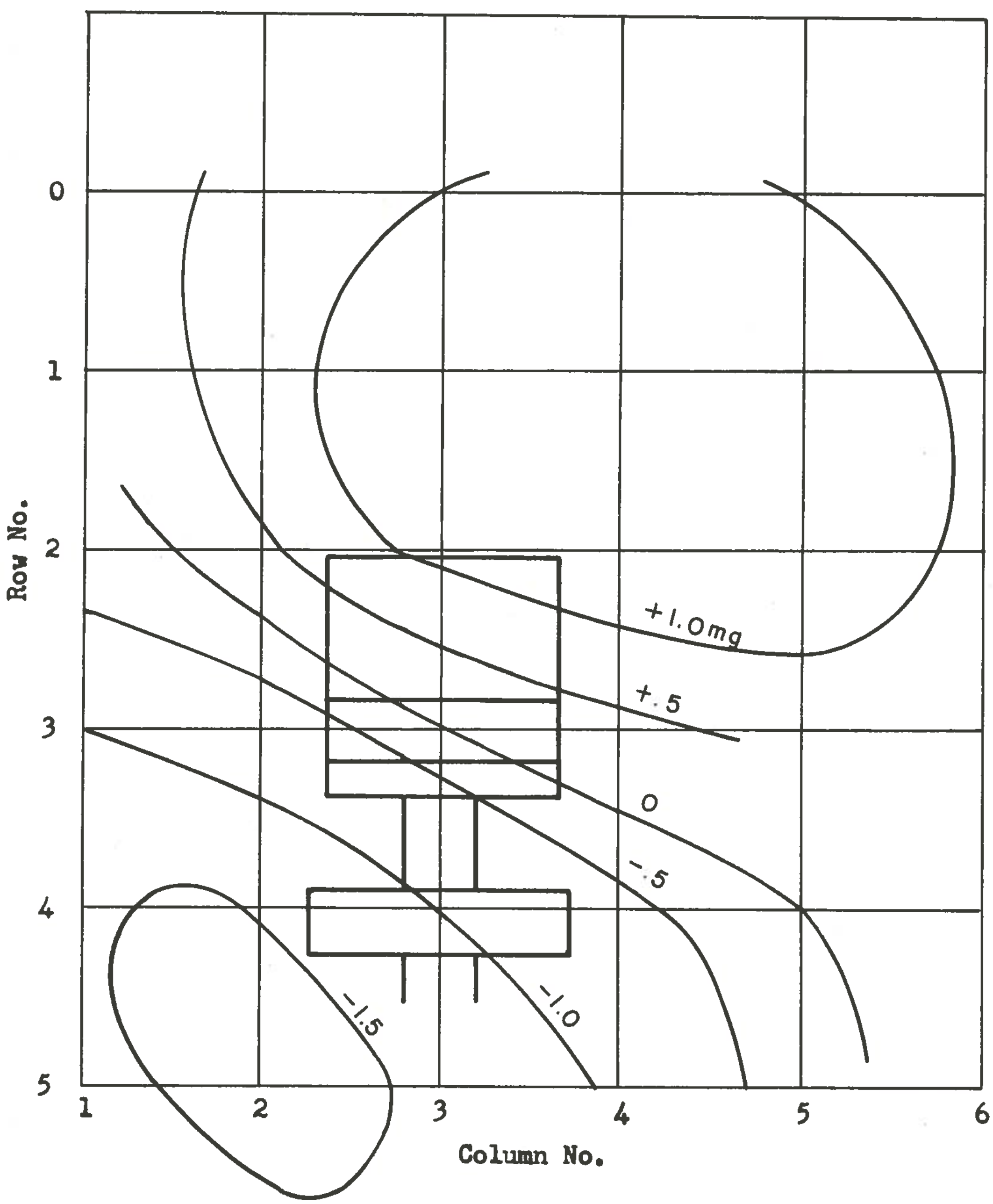
FIG. 36

2-20-F-FL-V-3000

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

1100 amp. forward pulses
short circuit operation
(load resistance = .023 ohms)



Downward Field - Positive
Upward Field - Negative

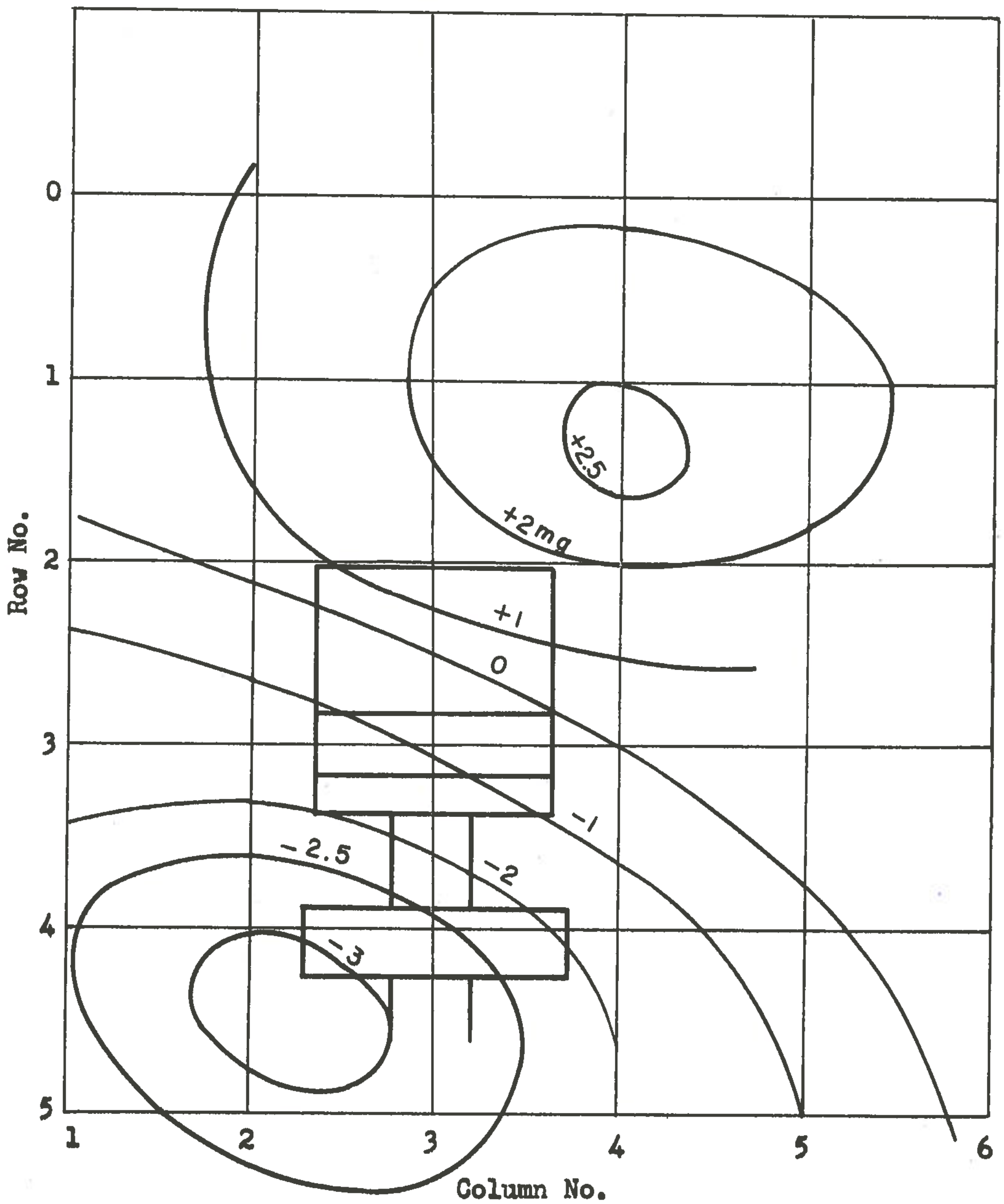
FIG. 37

2-10-F-SC-V-1100

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

1900 amp. forward pulses
short circuit operation
(load resistance = .023 ohms)



Downward Field - Positive
Upward Field - Negative

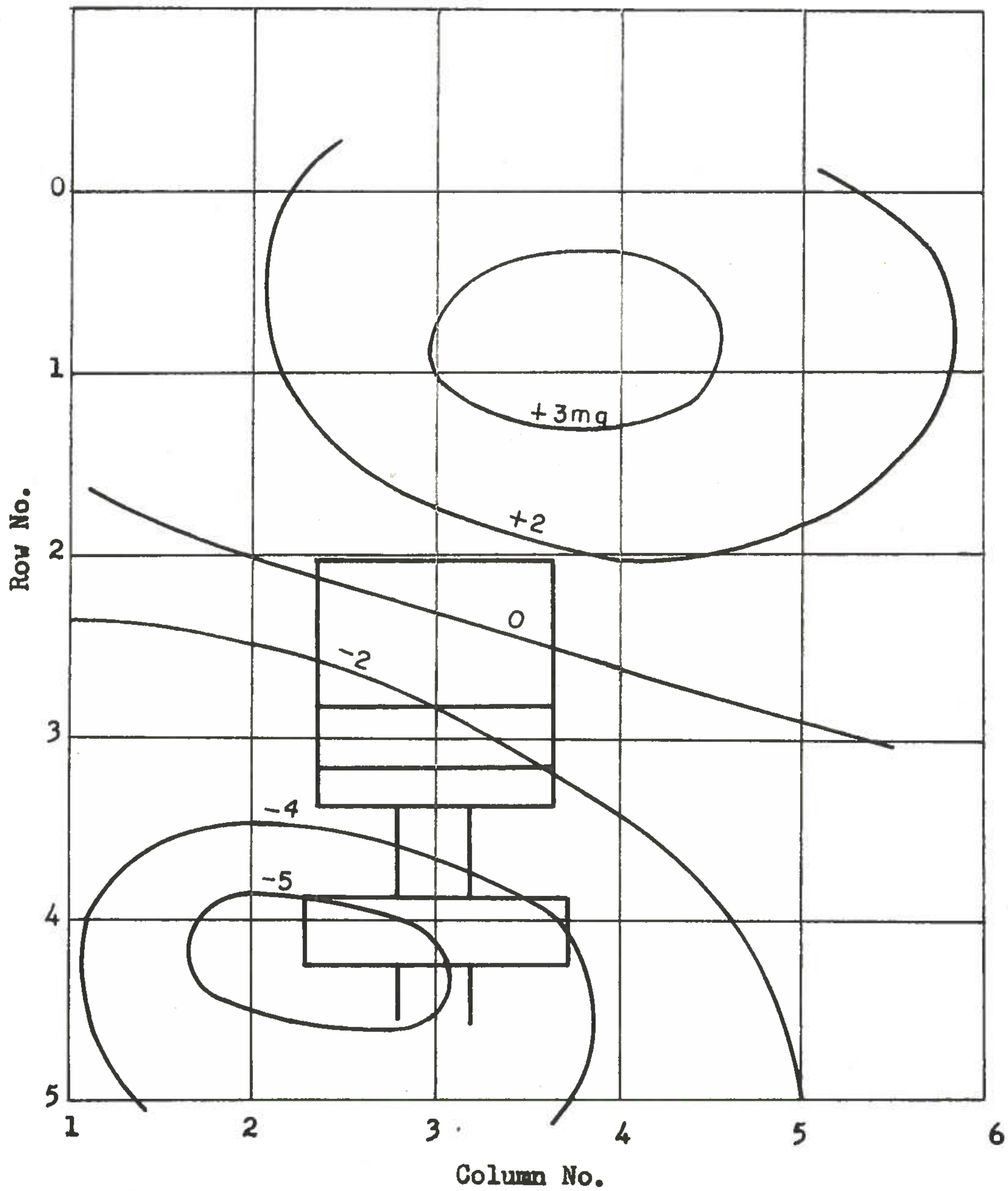
FIG. 38

2-10-F-SC-V-1900

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

3000 amp forward pulses
short circuit operation
(load resistance = .023 ohms)



Downward Field - Positive
Upward Field - Negative

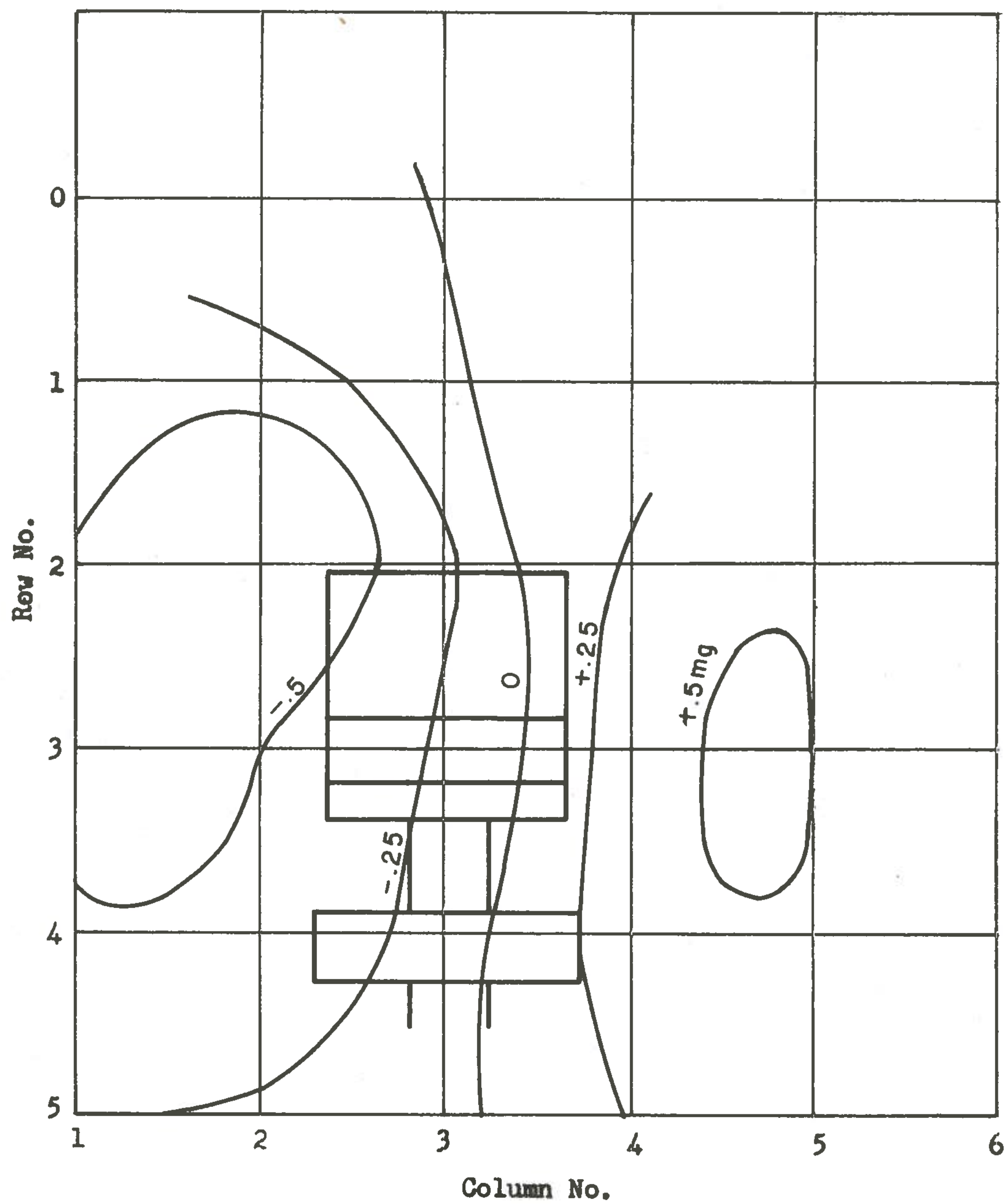
FIG. 39

2-10-F-SC-V-3000

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

83 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

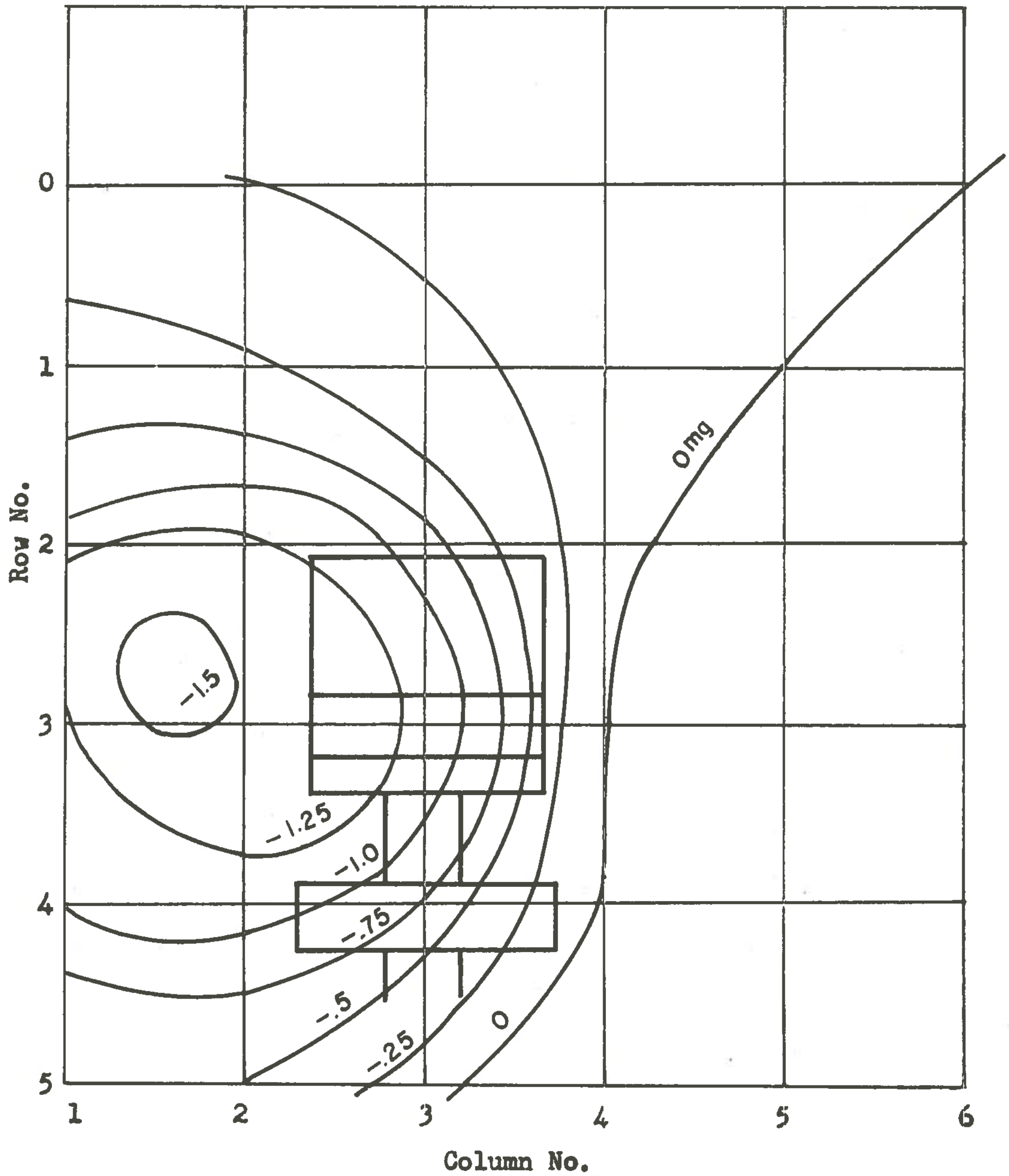
FIG. 40

2-10-F-OC-V-83

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

163 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

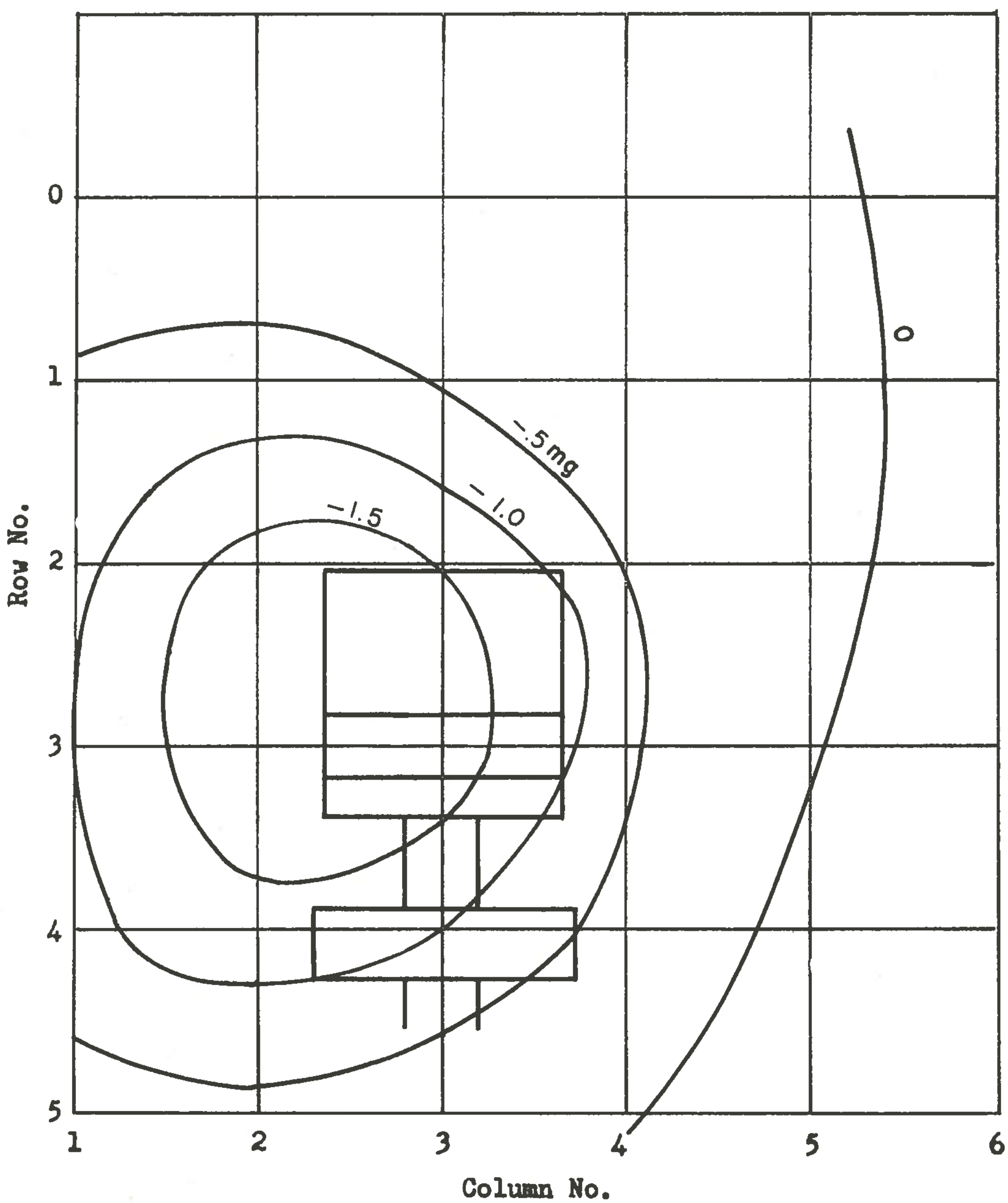
FIG. 41

2-10-F-OC-V-163

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

228 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

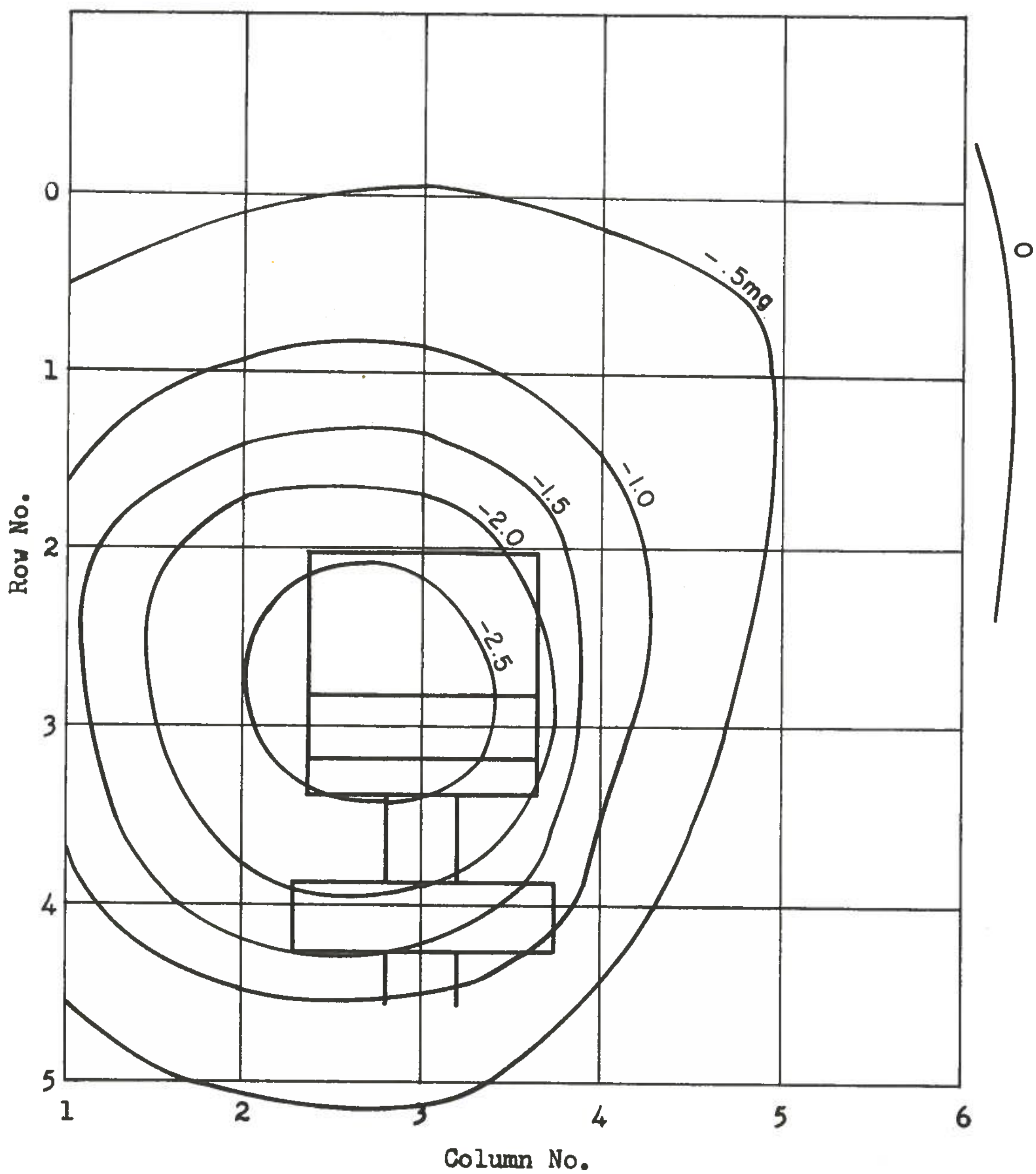
FIG. 42

2-10-F-OC-V-228

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

270 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

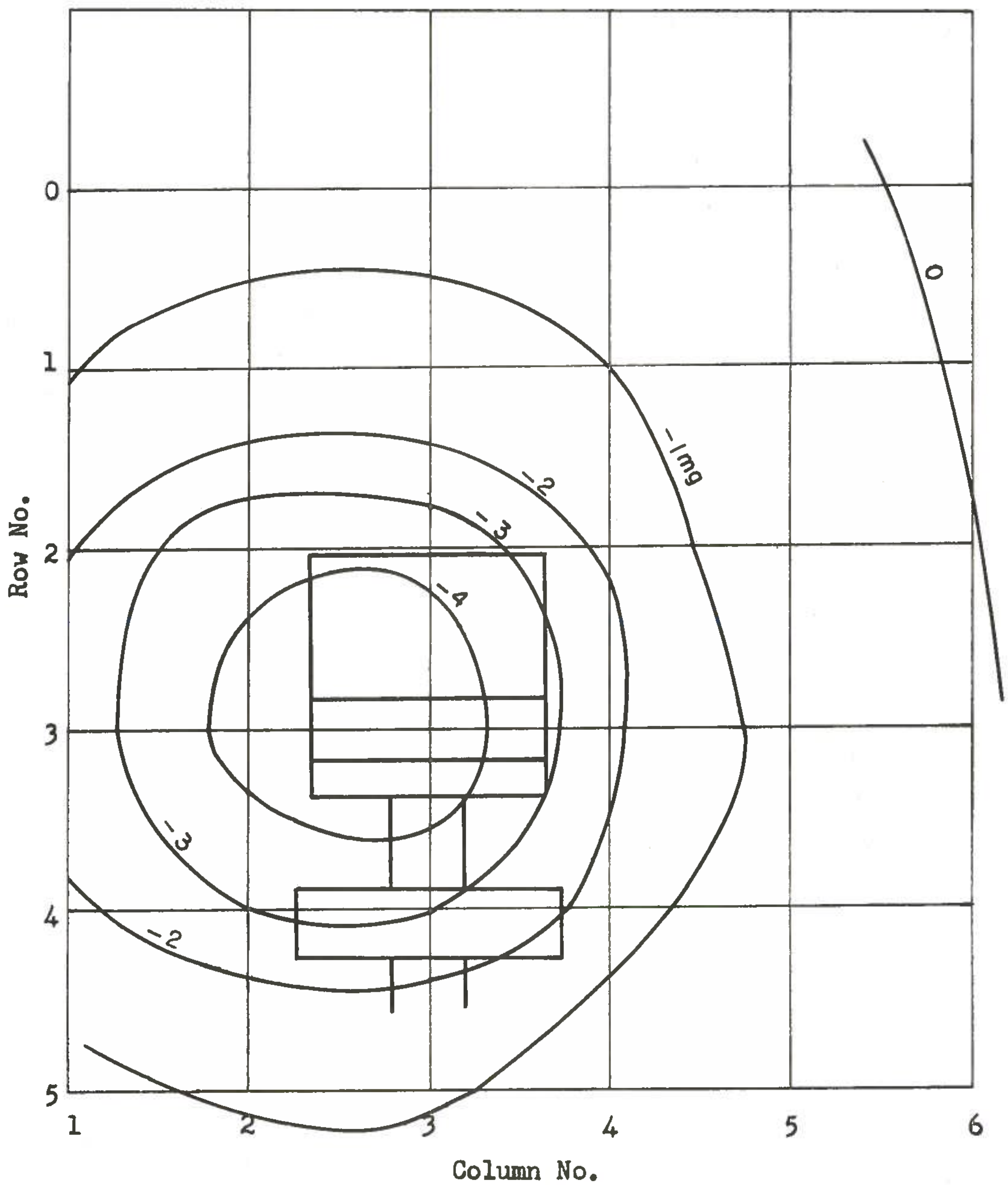
FIG. 43

2-10-F-OC-V-270

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

299 volt forward pulses
open circuit operation



Downward Field - Positive
Upward Field - Negative

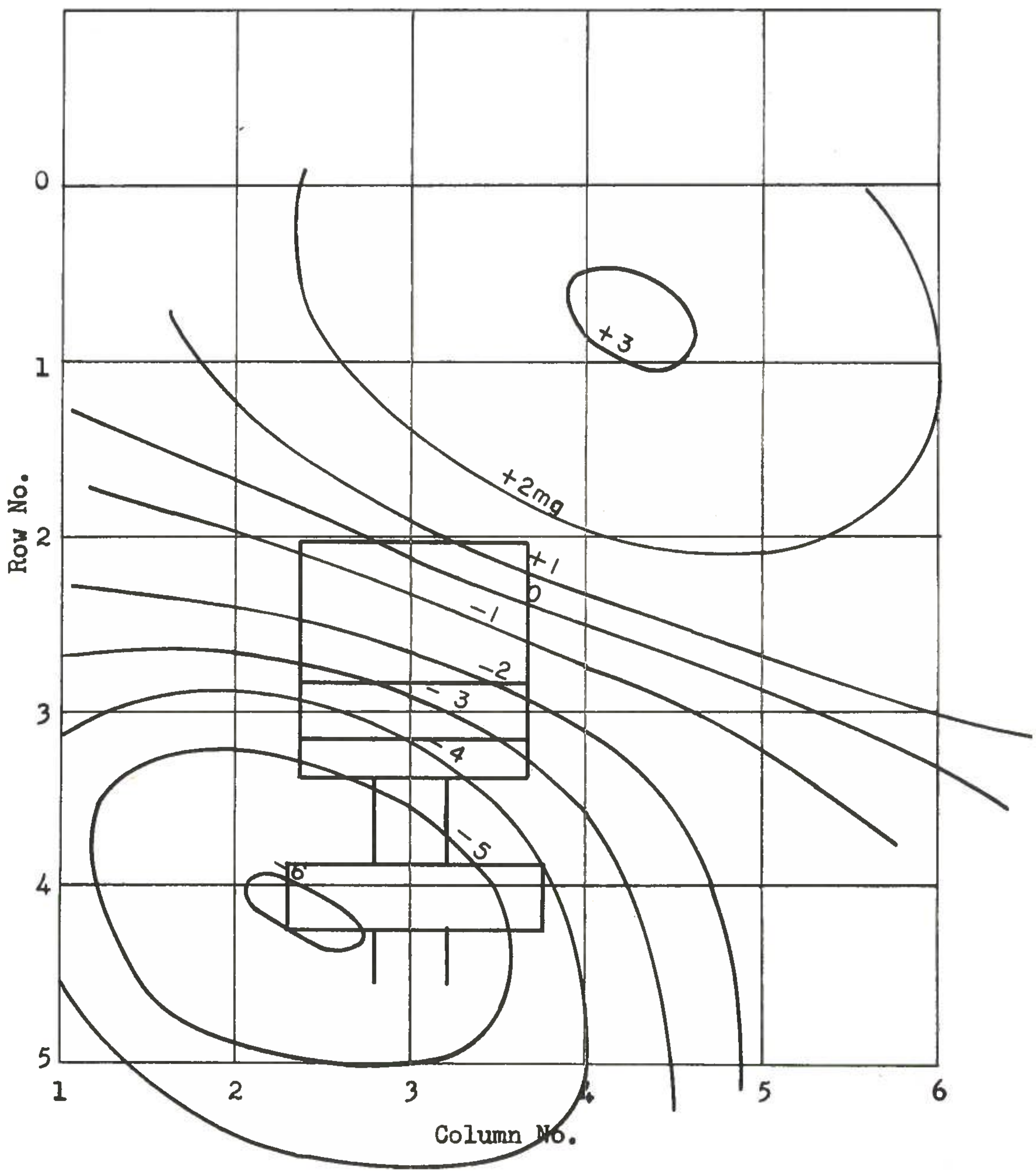
FIG. 44

2-10-F-OC-V-299

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

3000 amp forward pulses
Load Resistance = 0.036 ohms



Downward Field - Positive
Upward Field - Negative

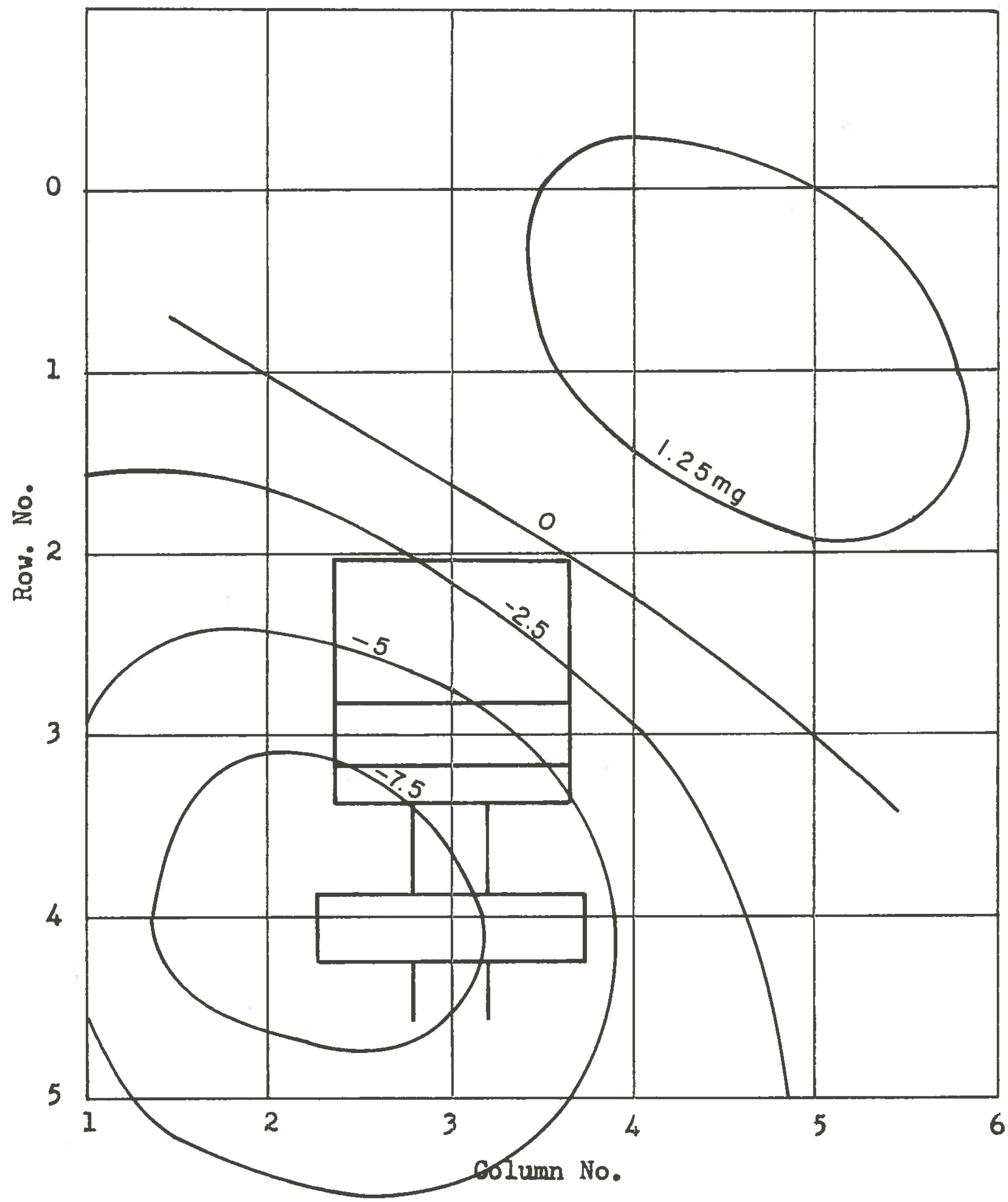
FIG. 45

2-10-F-1/3L-V-3000

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Stray Field (mg)
at 10 ft.

3000 amp forward pulses
Load Resistance = 0.050 ohms



Downward Field - Positive
Upward Field - Negative

FIG. 46

2-10-F-2/3L-V-3000

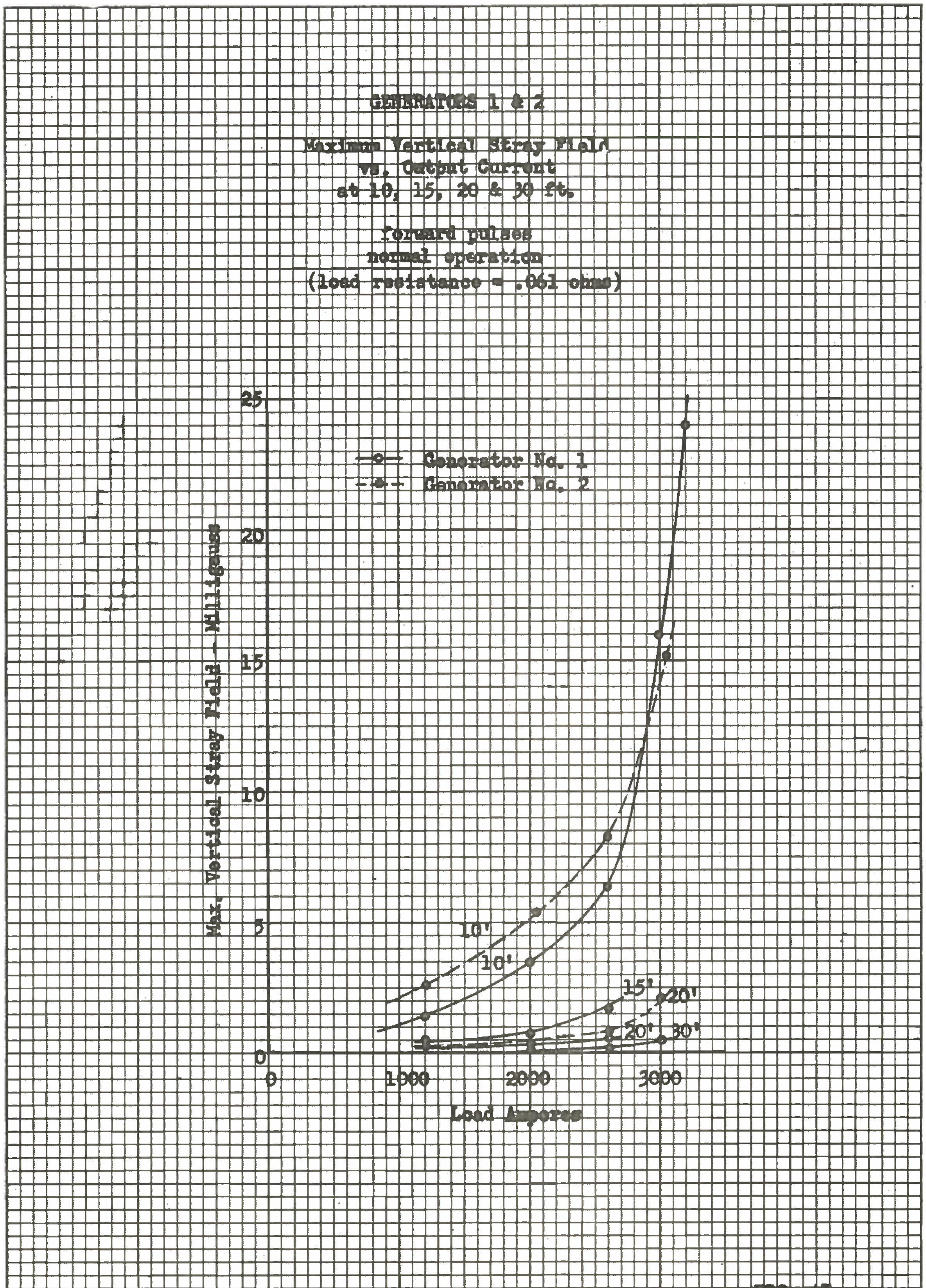

GENERATORS 1 & 2
Maximum Vertical Stray Field
vs. Output Current
at 10, 15, 20 & 30 ft.
forward pulses
normal operation
(load resistance = .061 ohms)
Generator No. 1
Generator No. 2
Max. Vertical Stray Field - Milligauss
25
20
15
10
5
0
10'
10'
15'
20'
20'
30'
0
1000
2000
3000
Load Amperes

FIG. 47

GENERATORS 1 & 2

Maximum Vertical Stray Field
vs. Terminal Voltage
at 10 ft.
Forward Pulses
open circuit operation

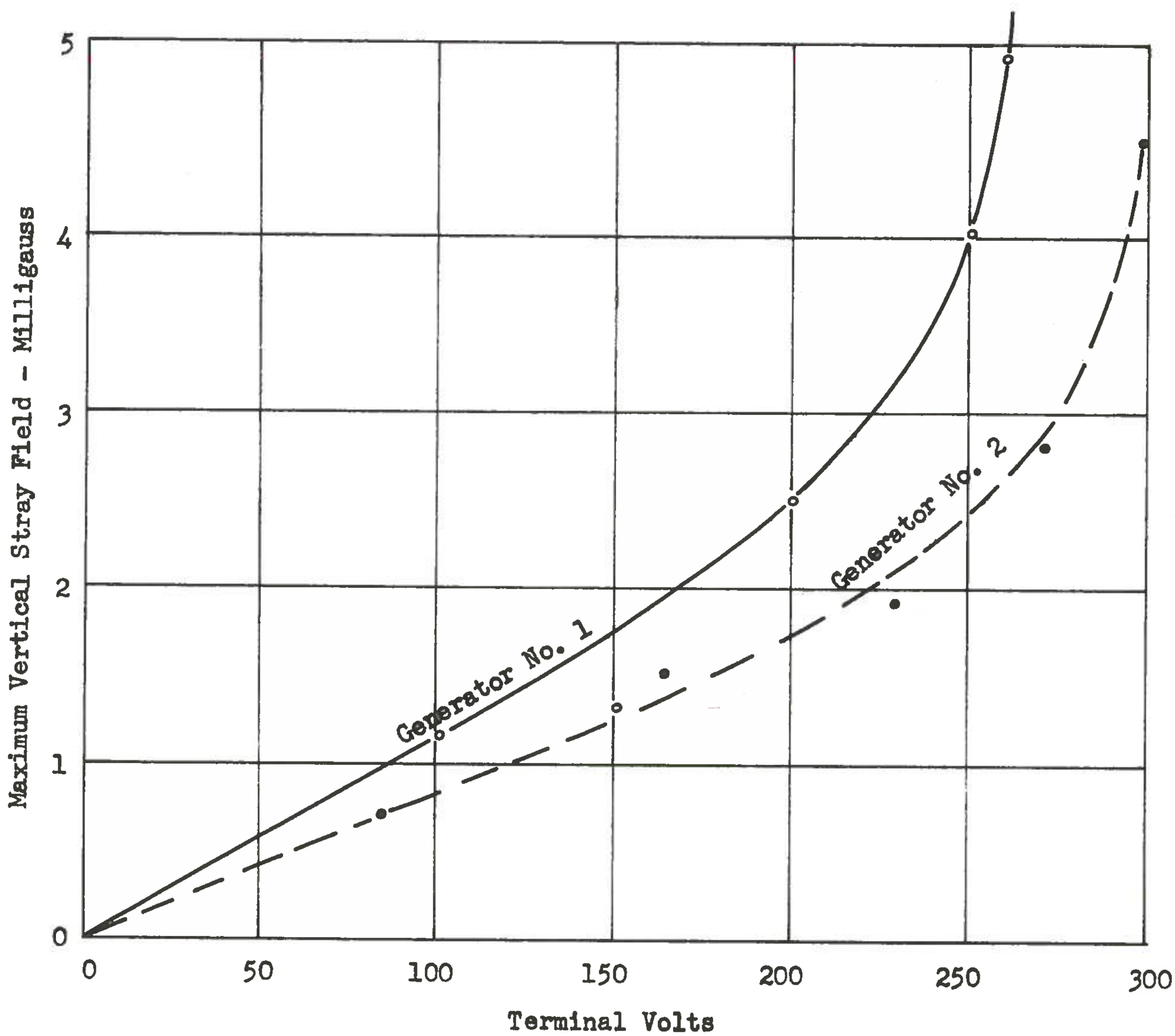
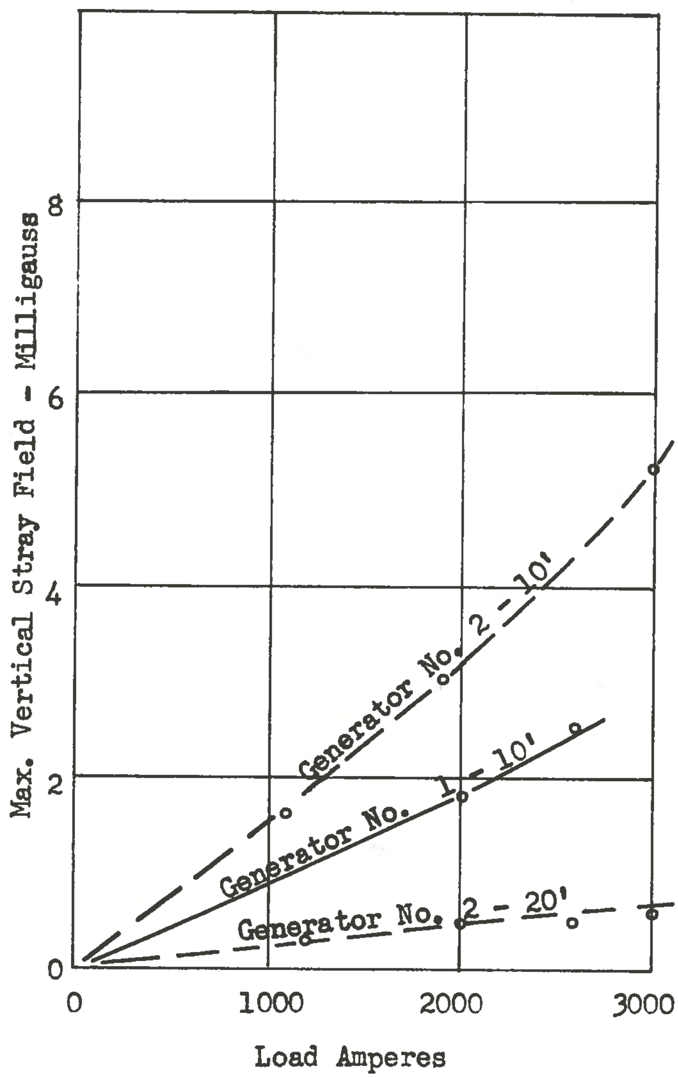


FIG. 48

GENERATORS 1 & 2

Maximum Vertical Stray Field
vs. Output Current
at 10 & 20 ft.

short circuit operation



NOTE: Generator load resistance = 0.023 ohms

FIG. 49

GENERATORS 1 & 2

Maximum Vertical Stray Field
vs. Depth

2000 & 2600 amp forward pulses
normal operation
(load resistance = .061 ohms)

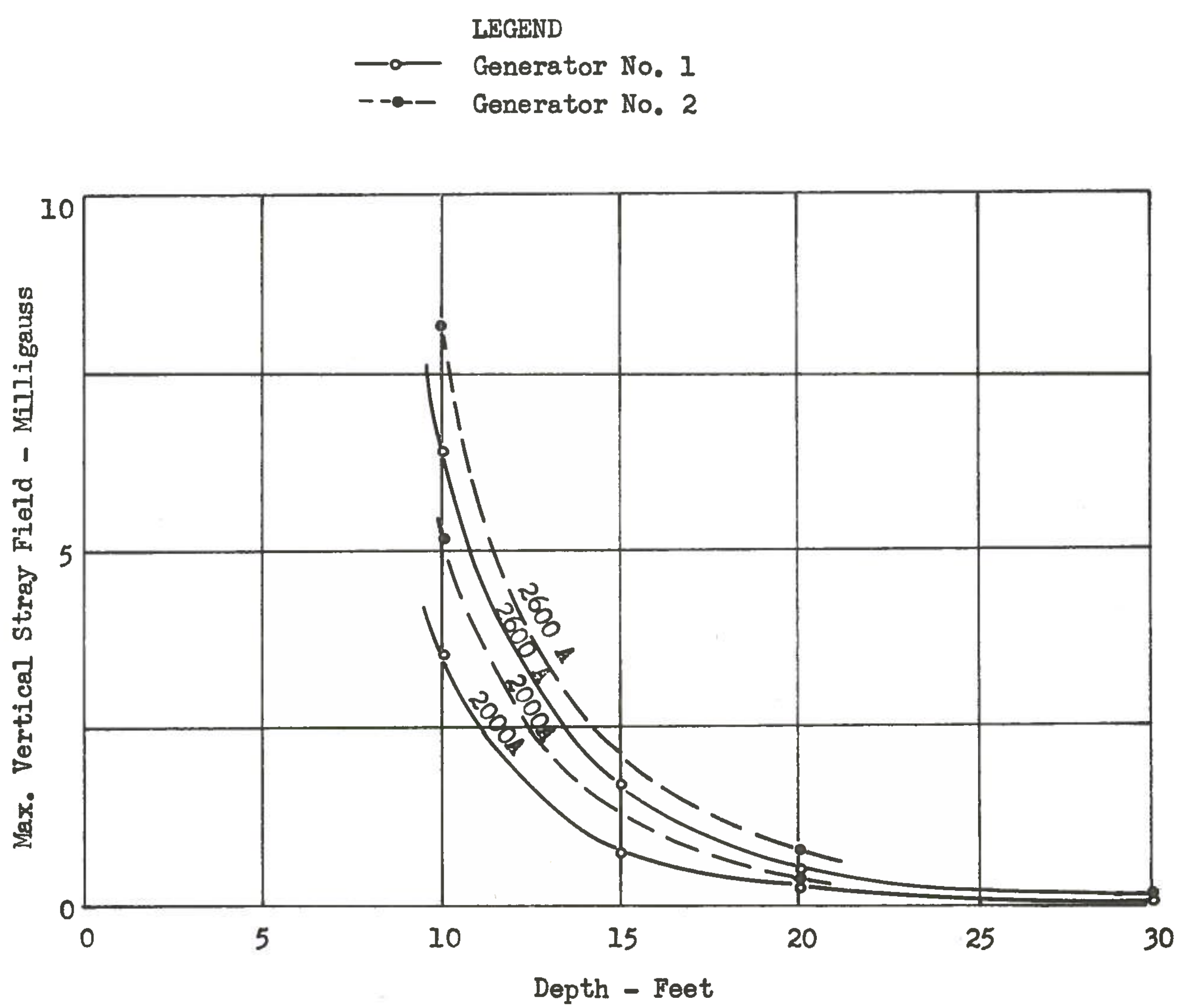


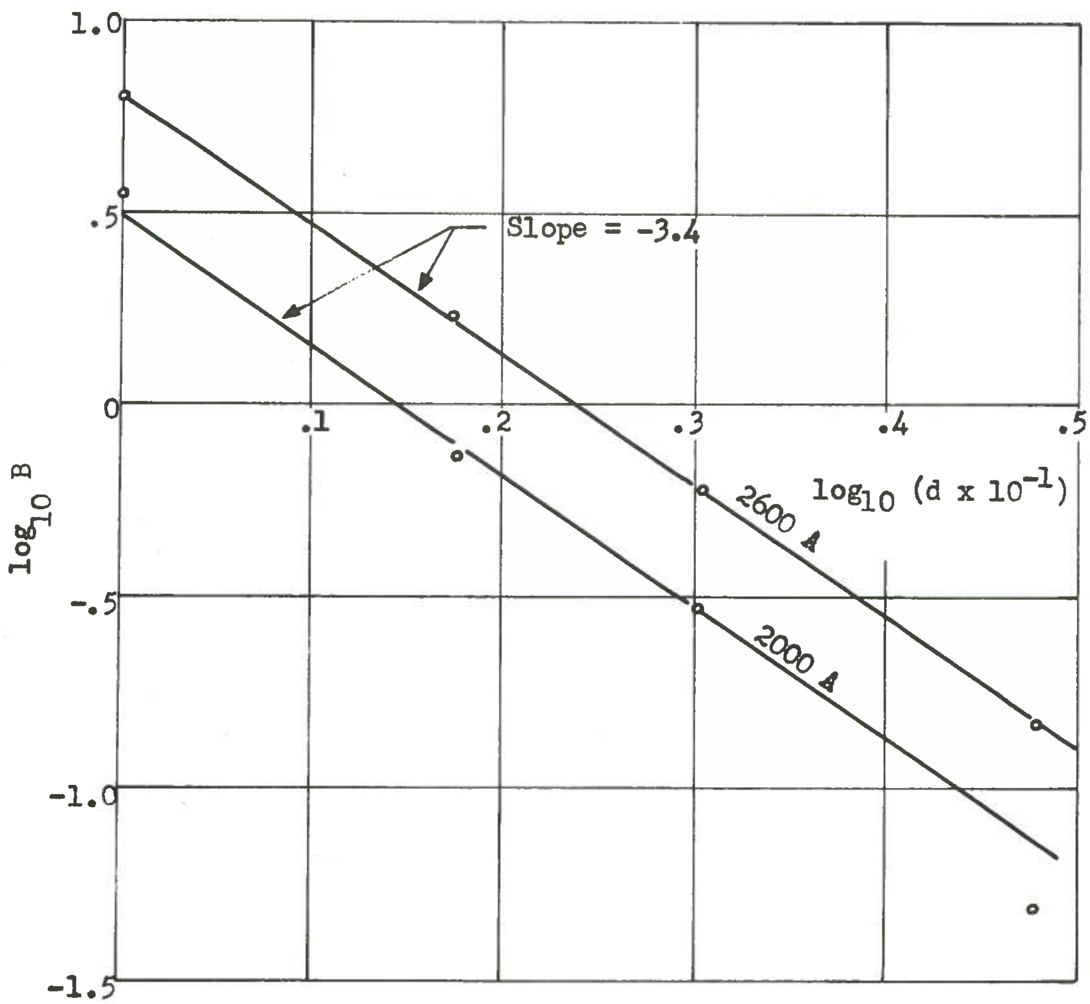
FIG. 50

GENERATOR NO. 1

Law of Variation of Stray Field With Depth

2000 and 2600 amp. forward pulses
normal operation
(vertical component)

SYMBOLS
B = Flux Density in Milligauss
d = Depth in Feet



from Graph:

$B = K\ d^{-3.4}$

FIG. 51

GENERATOR NO. 2

Effect of Disconnecting & Removing Exciters
Maximum Vertical Stray Field
vs. Output Current
at 10 ft.

forward pulses
normal operation
(load resistance = .061 ohms)

LEGEND
o - Exciters in Place & Connected
△ - Const. Potential Exciter Disconnected
□ - C.P. Exciter & Rototrol Disconnected
• - C.P. Exciter & Rototrol Removed

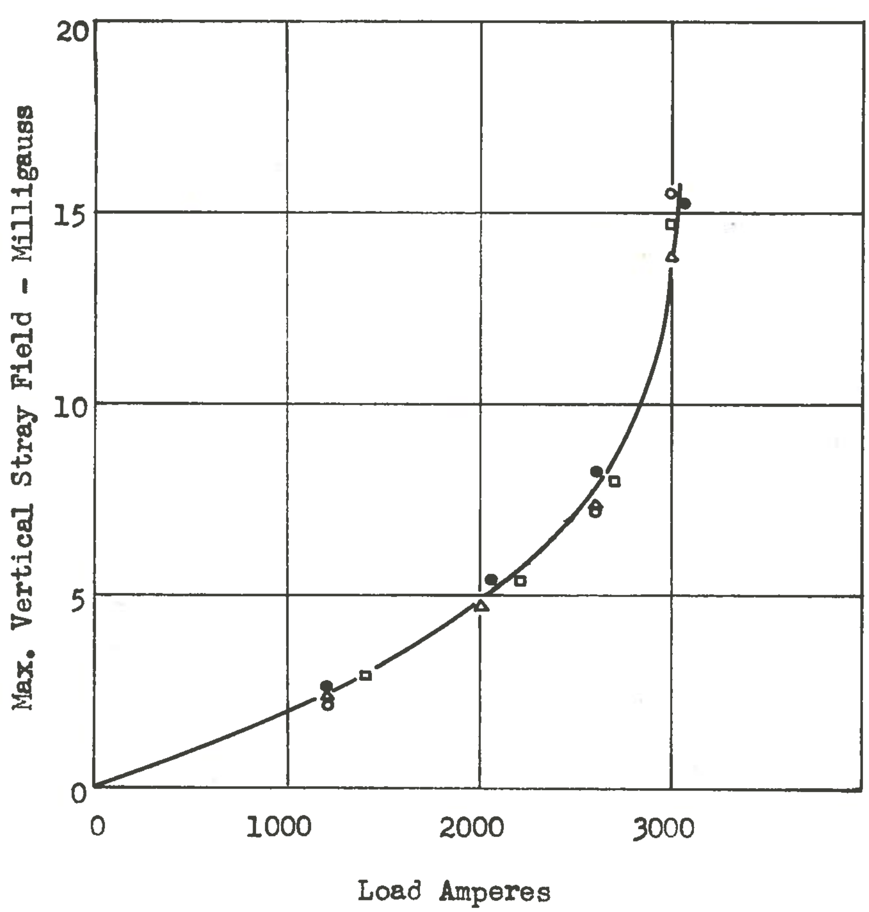


FIG. 52

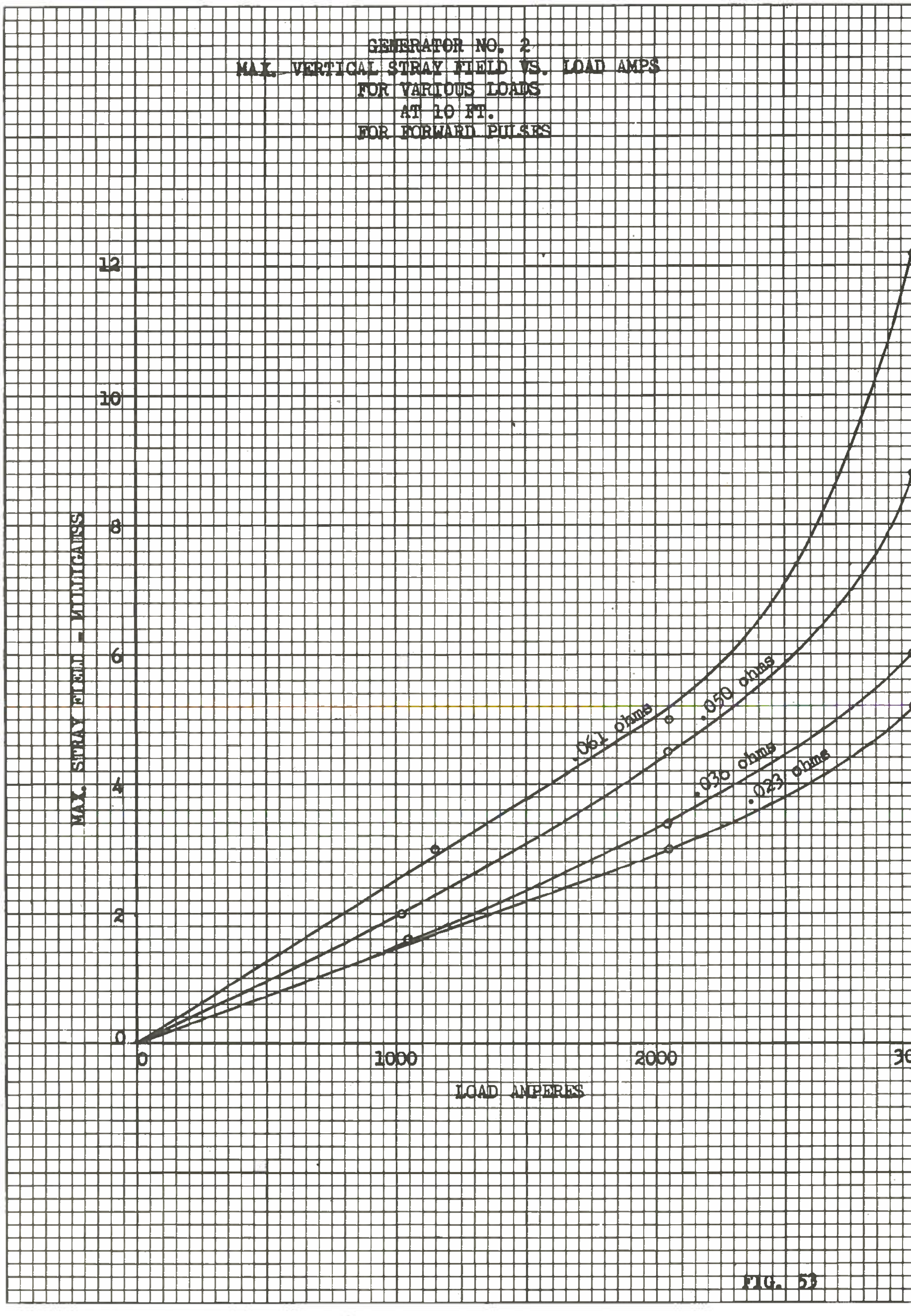

GENERATOR NO. 2
MAX. VERTICAL STRAY FIELD VS. LOAD AMPS
FOR VARIOUS LOADS
AT 10 FT.
FOR FORWARD PULSES
MAX. STRAY FIELD - MILLIGAUSS
0
2
4
6
8
10
12
LOAD AMPERES
0
1000
2000
3000
.061 ohms
.050 ohms
.036 ohms
.023 ohms

FIG. 53

SECRET

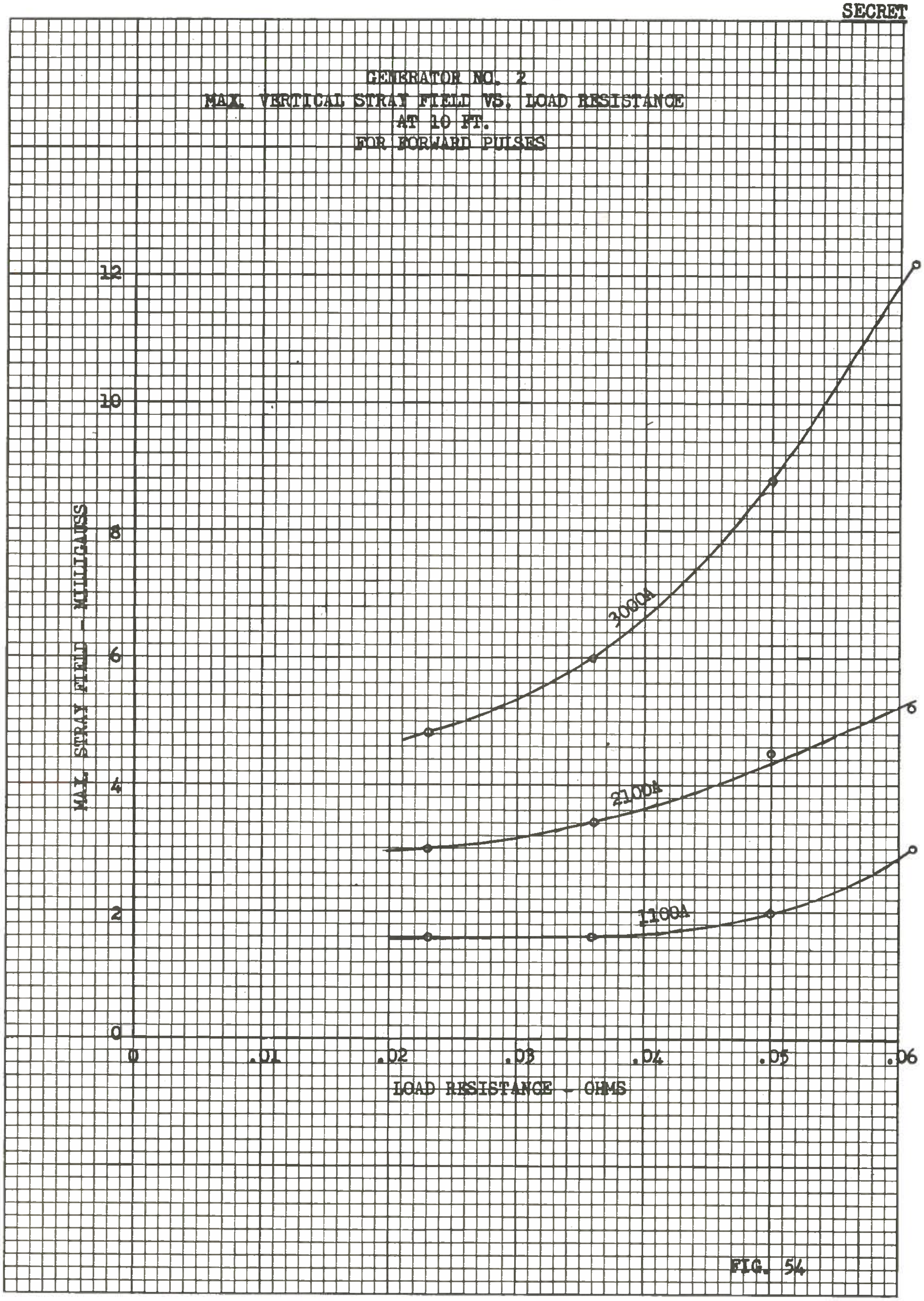


FIG. 54

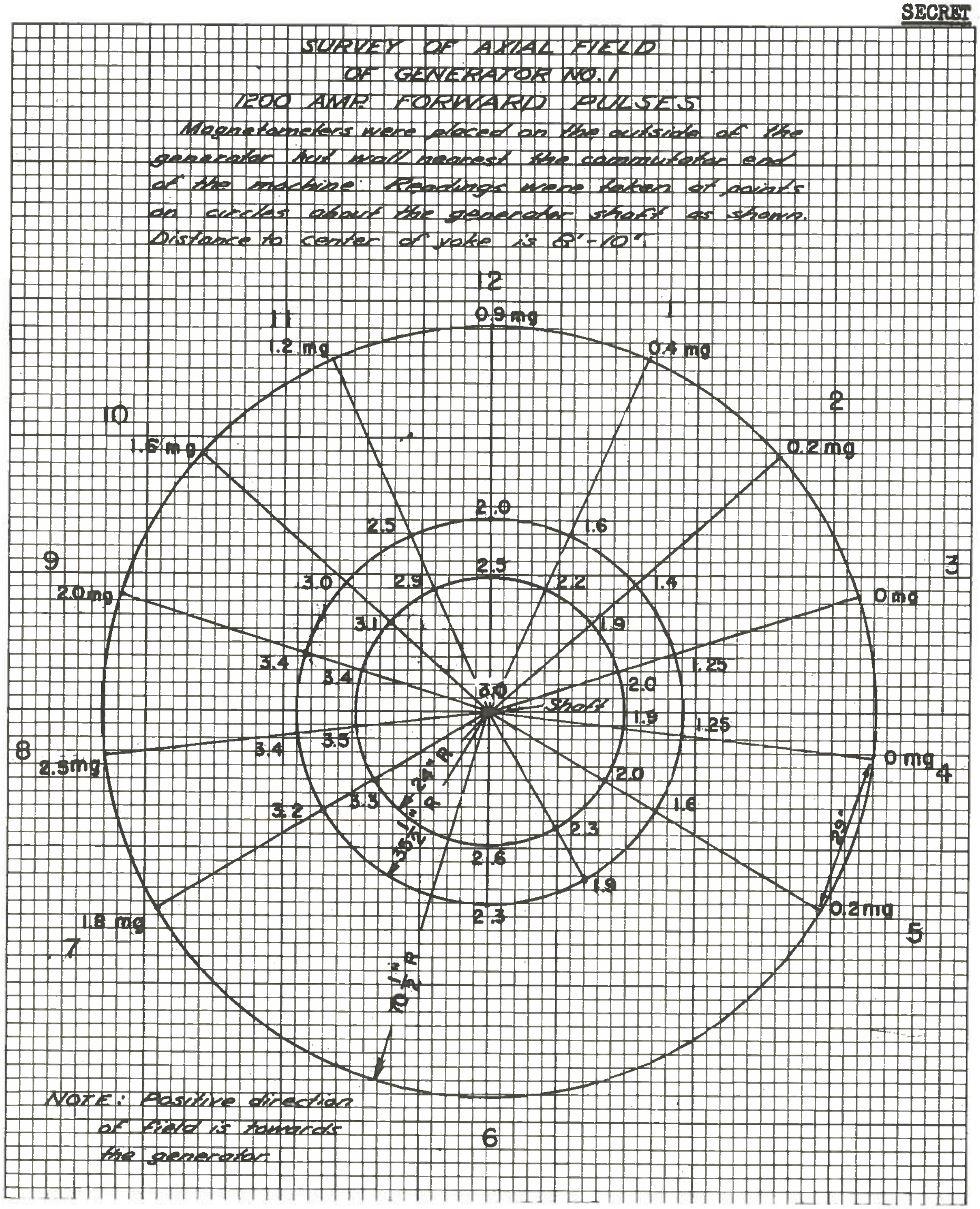

SURVEY OF AXIAL FIELD
OF GENERATOR NO. 1
1200 AMP. FORWARD PULSES
Magnetometers were placed on the outside of the generator pit wall nearest the commutator end of the machine. Readings were taken at points on circles about the generator shaft as shown. Distance to center of yoke is 8'-10".
12
0.9 mg
1
0.4 mg
2
0.2 mg
3
0 mg
4
0 mg
5
0.2 mg
6
7
1.8 mg
8
2.5 mg
9
2.0 mg
10
1.5 mg
11
1.2 mg
2.0
2.5
1.6
2.2
1.4
1.9
1.25
2.0
1.9
1.25
2.0
1.6
2.3
1.9
2.6
2.3
3.3
3.2
3.5
3.4
3.4
3.4
3.1
3.0
2.9
2.5
3.0
Shaft
24" R
35 1/2" R
70 1/2" R
29"
NOTE: Positive direction of field is towards the generator.

FIG. 55

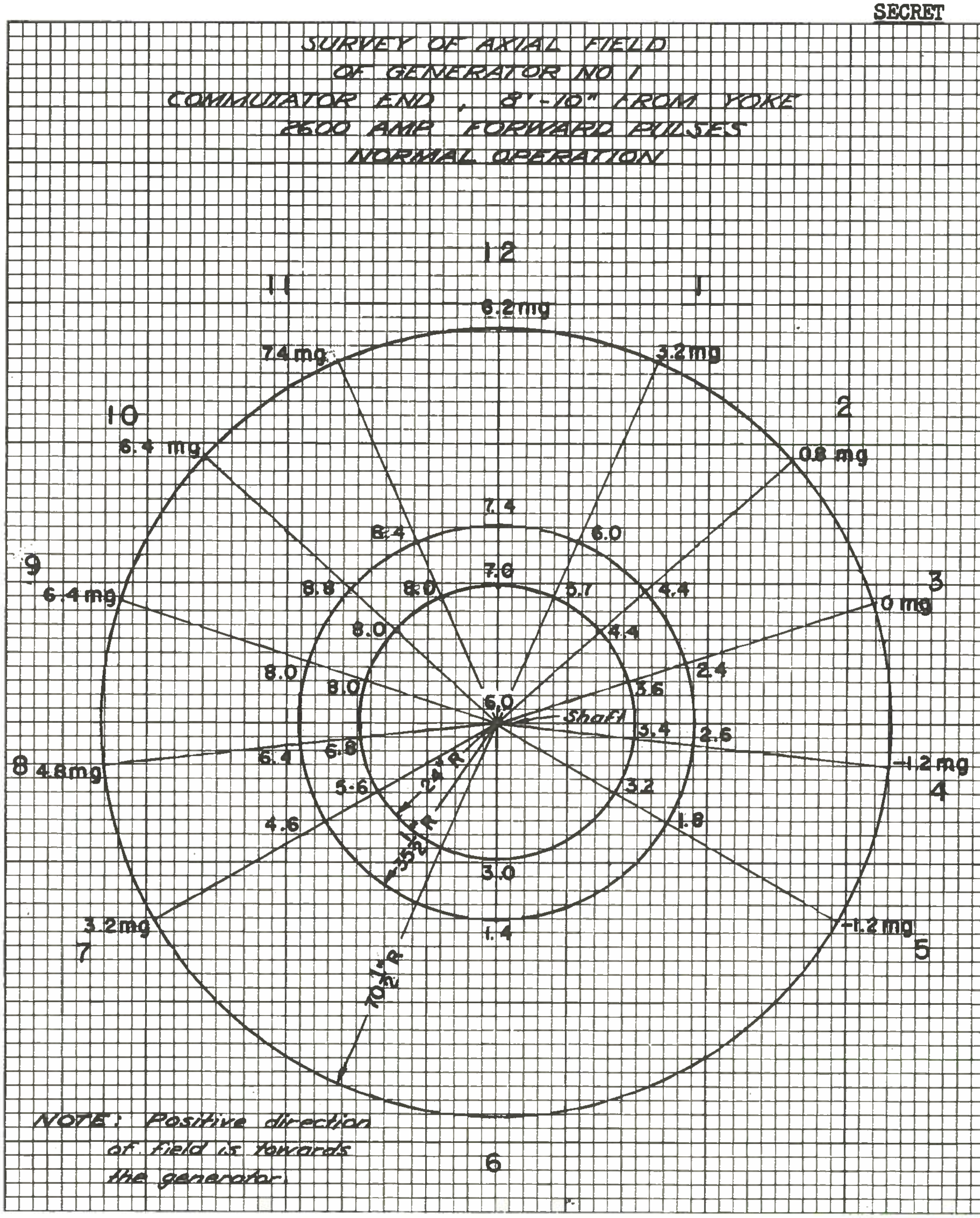
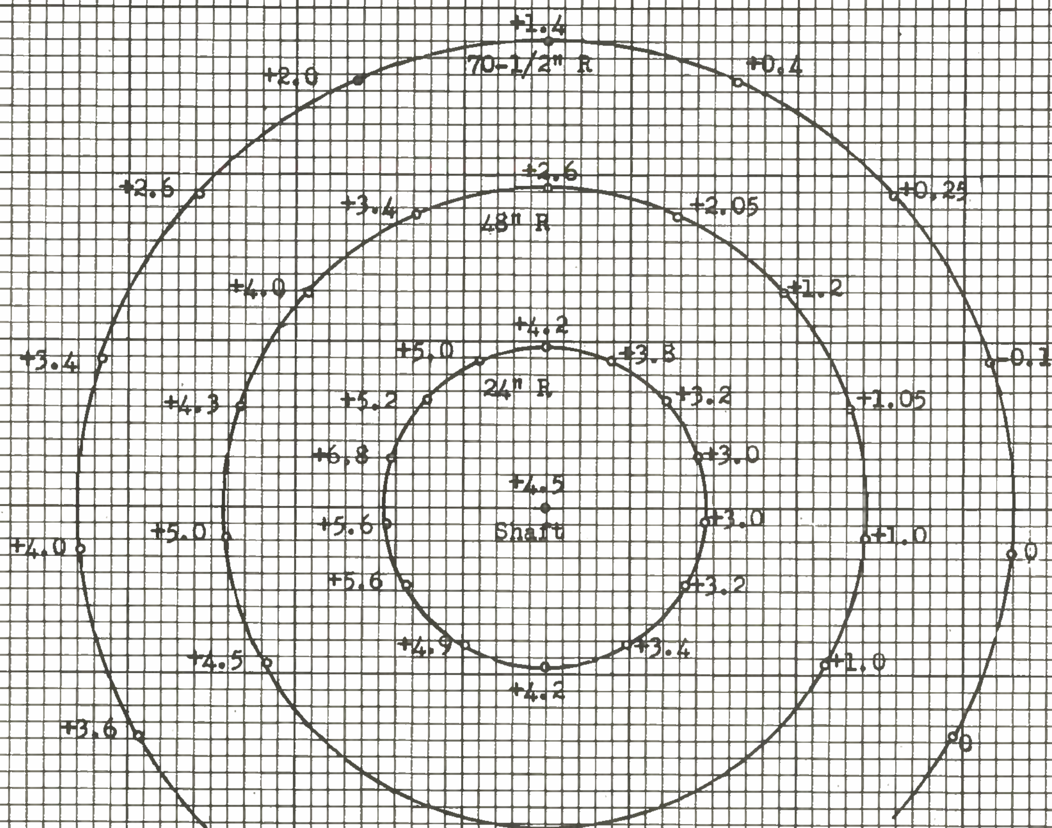

SURVEY OF AXIAL FIELD
OF GENERATOR NO 1
COMMUTATOR END , 8'-10" FROM YOKE
2600 AMP FORWARD PULSES
NORMAL OPERATION
12
11
1
2
10
9
3
8
4
7
5
6
6.2 mg
7.4 mg
3.2 mg
6.4 mg
0.8 mg
6.4 mg
0 mg
4.8 mg
-1.2 mg
3.2 mg
-1.2 mg
7.4
8.4
6.0
8.8
4.4
8.0
2.4
6.4
2.6
4.6
1.8
1.4
7.6
8.0
5.7
8.0
4.4
8.0
3.6
6.8
3.4
5.6
3.2
3.0
6.0
Shaft
24" R
35 1/2" R
70 1/2" R
NOTE: Positive direction of field is towards the generator.

FIG. 56

GENERATOR NO. 2
AXIAL STRAY FIELD
COMMUTATOR END, 8'10" FROM YOKE
1200 AMP FORWARD PULSES

NORMAL OPERATION
(Load resistance = .061 ohms)



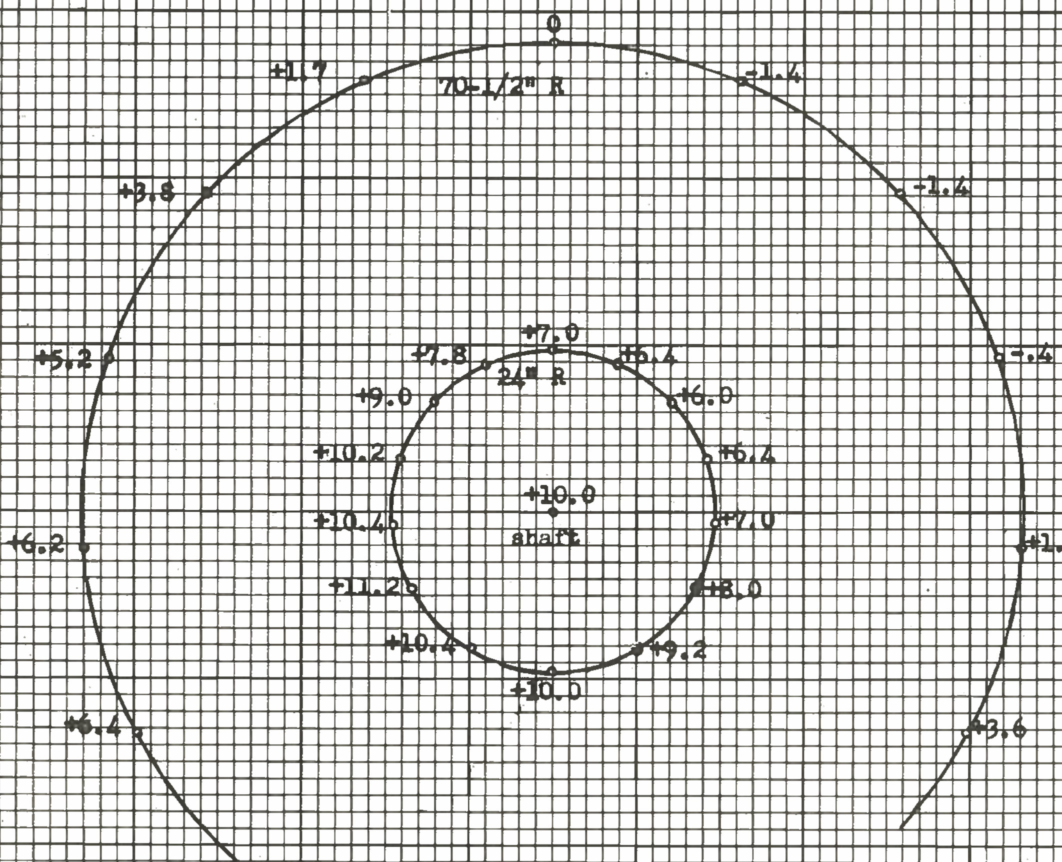
NOTE: Figures indicate field strength in milligauss. Positive direction towards generator.

FIG. 57

SECRET

GENERATOR NO. 2
AXIAL STRAY FIELD
COMMUTATOR END, 8'10" FROM YOKE
2600 AMP FORWARD PULSES

NORMAL OPERATION
(load resistance = .061 ohms)



NOTE: Figures indicate field strength in milligauss. Positive direction towards generator.

FIG. 58

SECRET

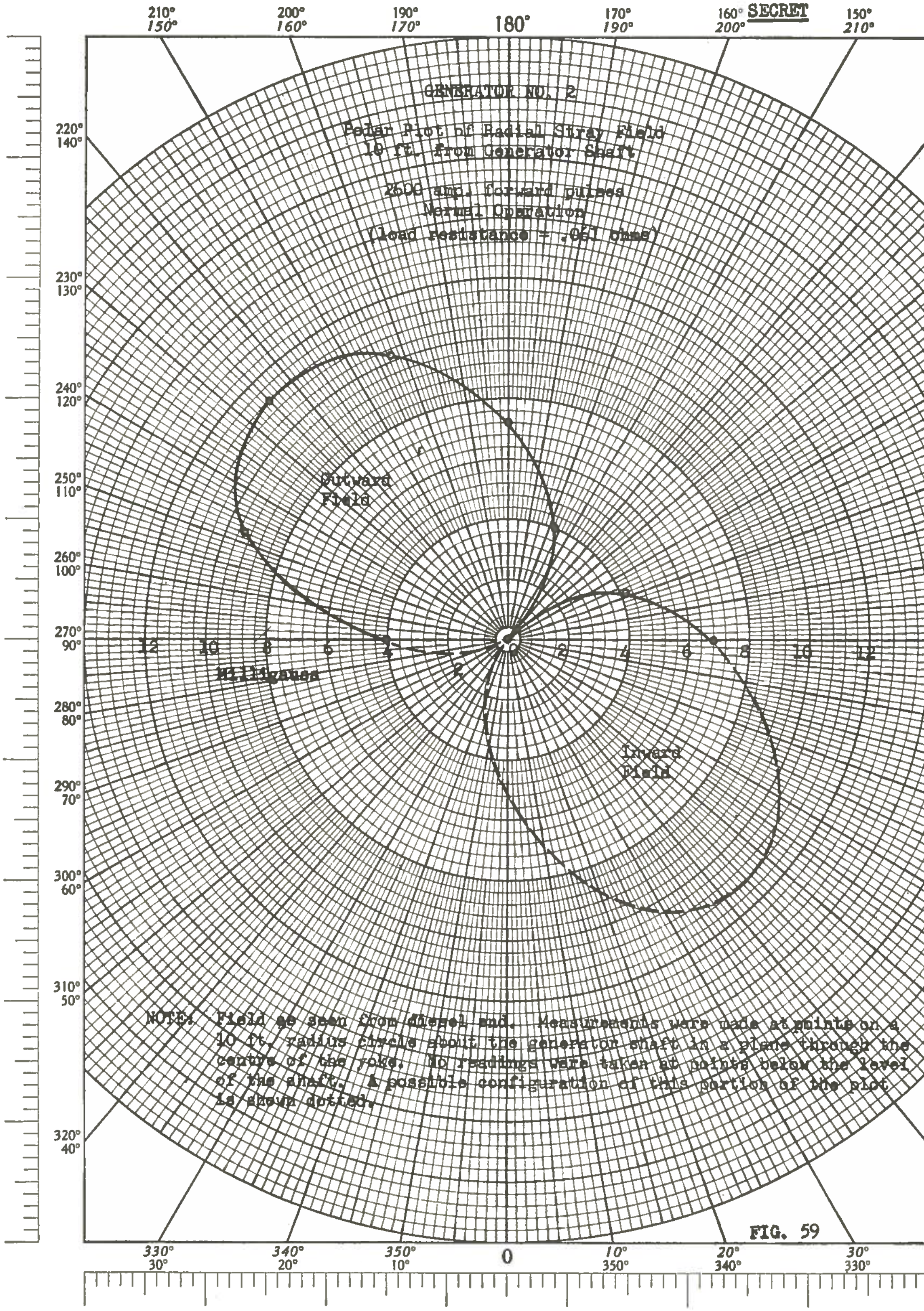


FIG. 59

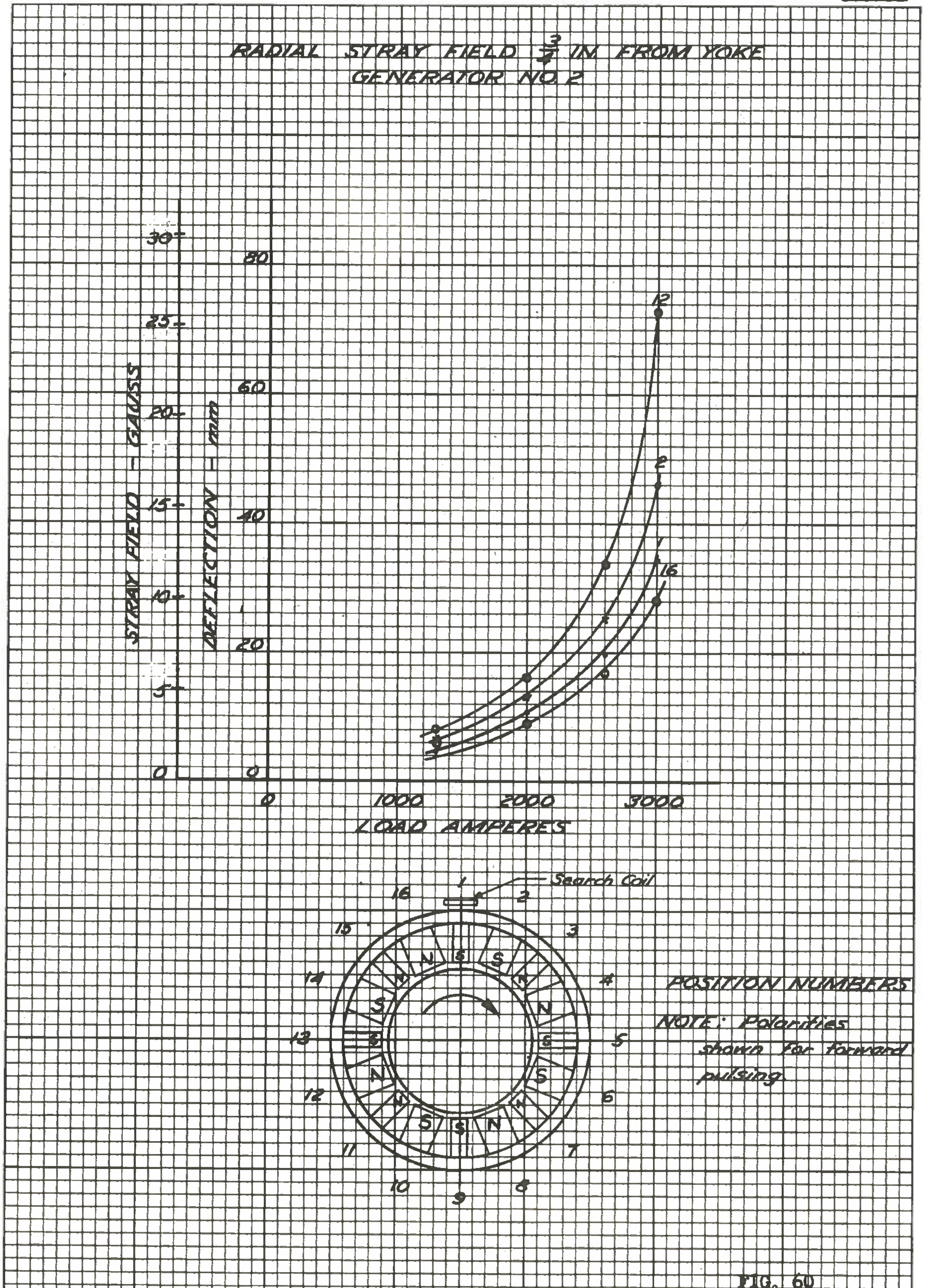

RADIAL STRAY FIELD 3/4 IN FROM YOKE
GENERATOR NO. 2
STRAY FIELD - GAUSS
DEFLECTION - mm
0
5
10
15
20
25
30
0
20
40
60
80
0
1000
2000
3000
LOAD AMPERES
12
2
1
16
Search Coil
POSITION NUMBERS
NOTE: Polarities shown for forward pulsing.

FIG. 60

SECRET

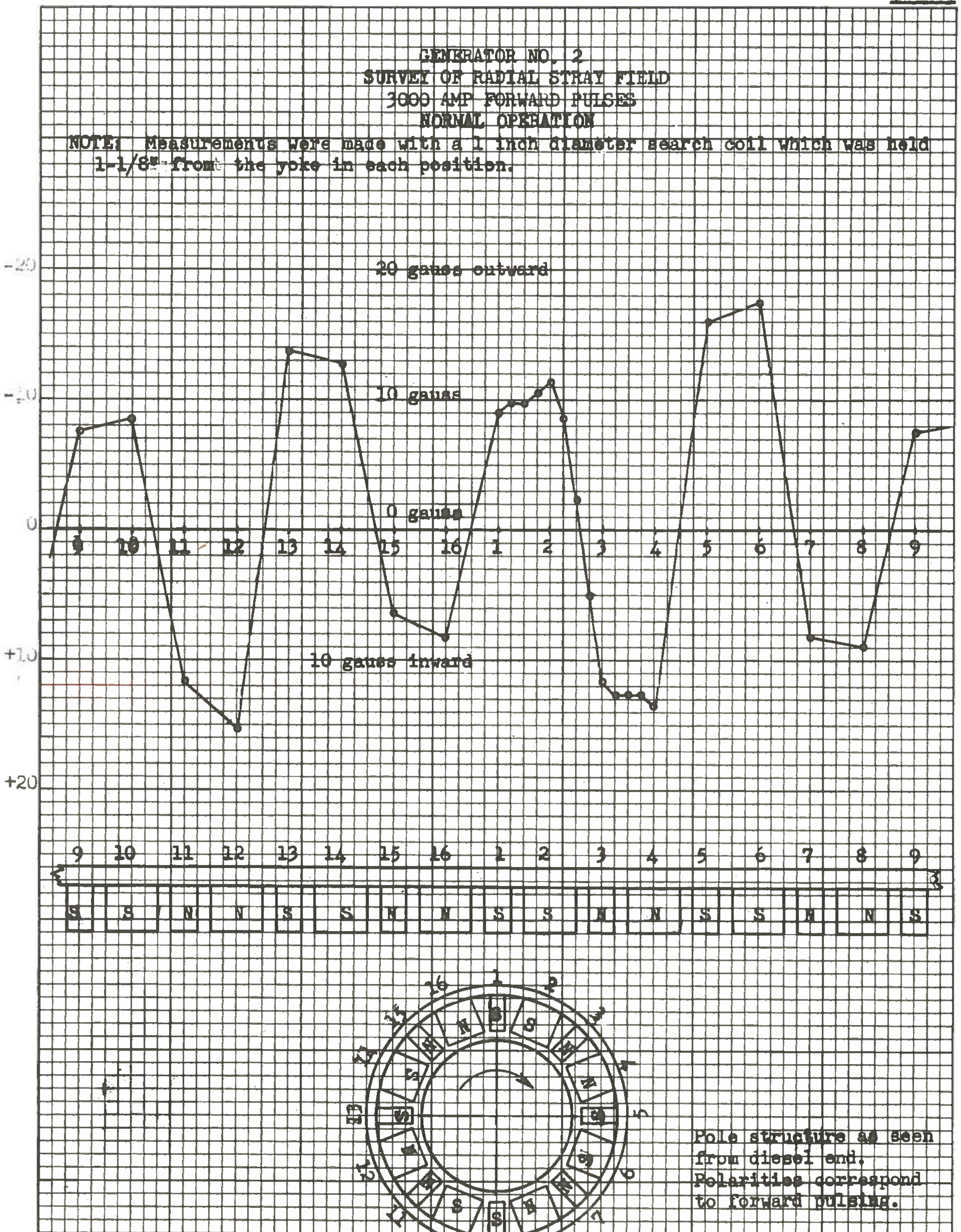


FIG. 61

SECRET

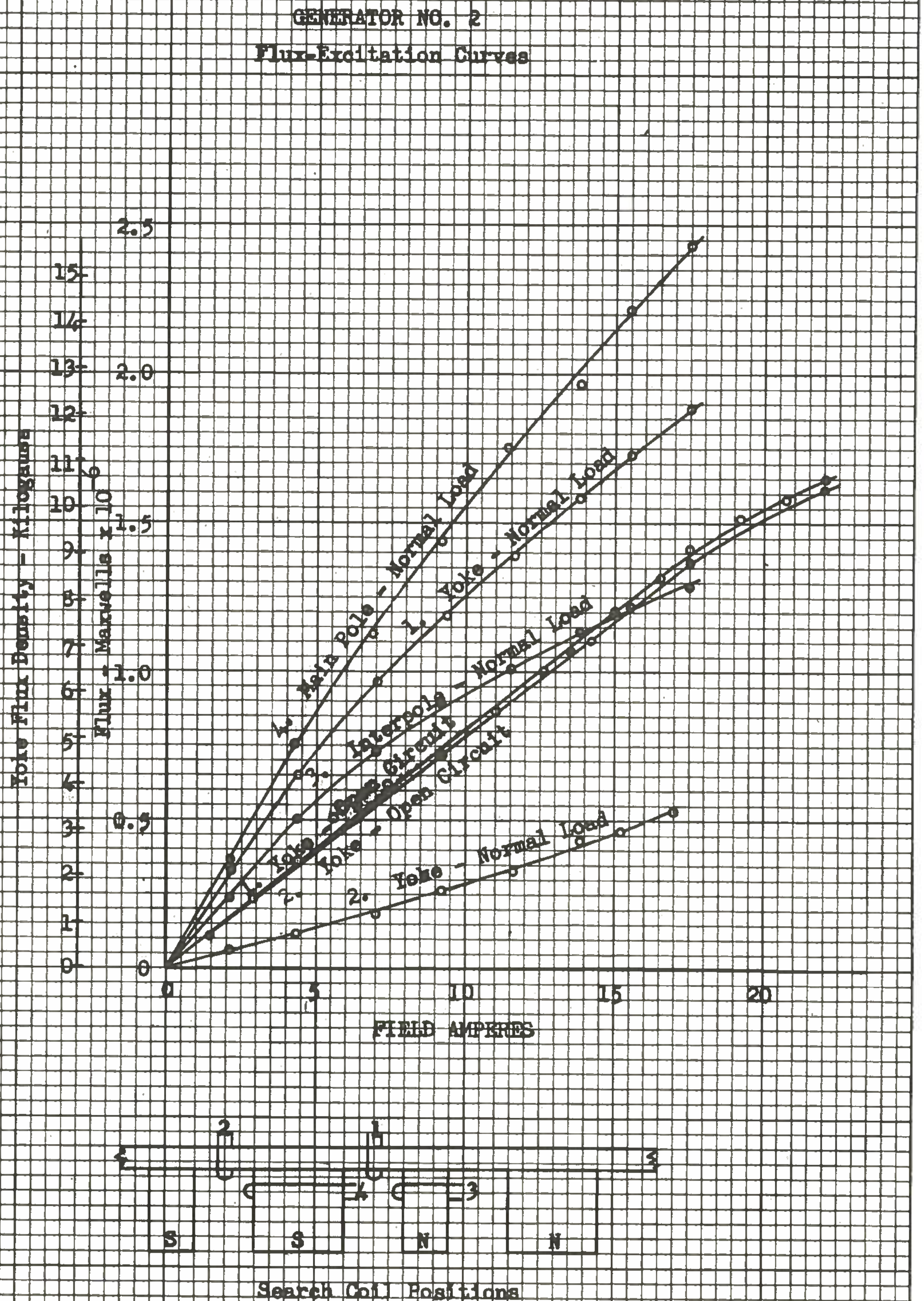


FIG. 62

SECRET

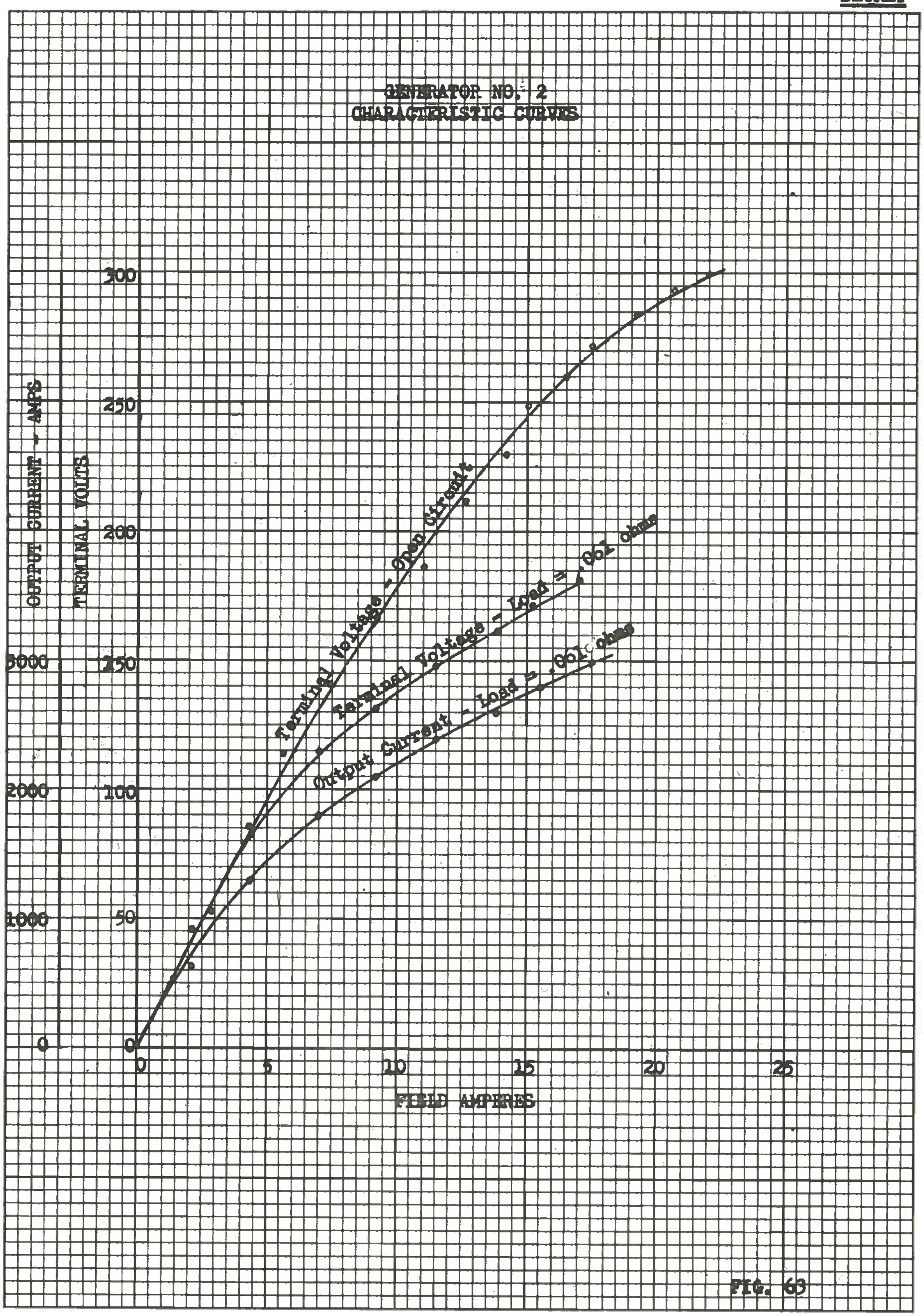
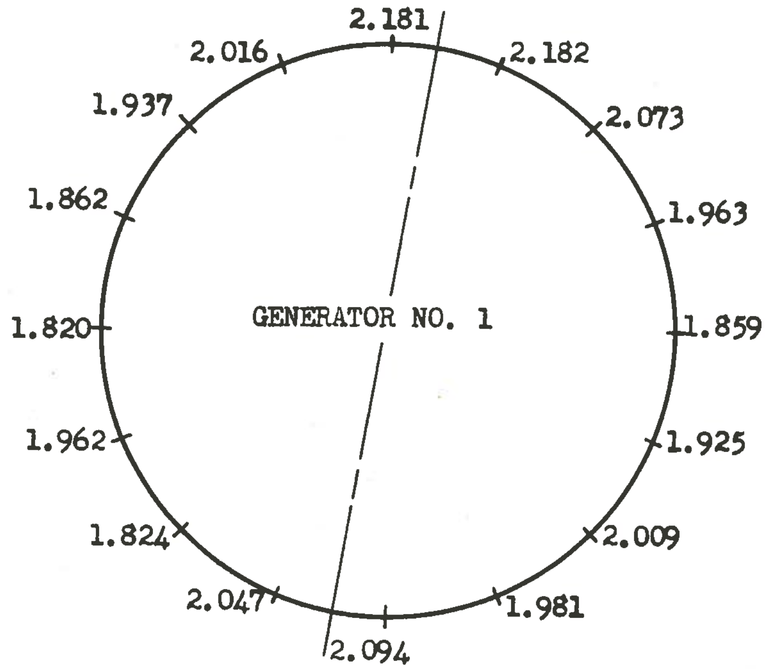
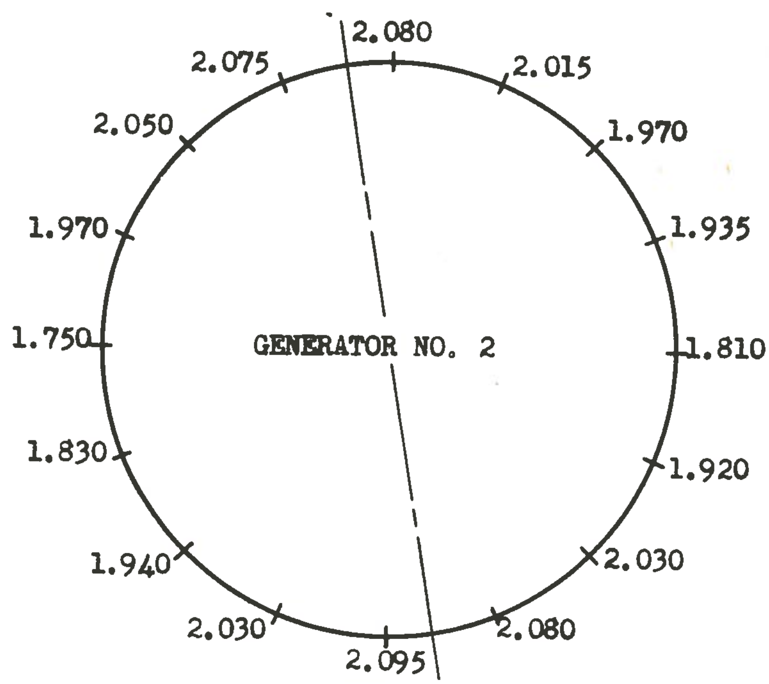


FIG. 63

GENERATORS 1 and 2

Survey of Thickness of Yoke





NOTE: Yoke seen from diesel end.
Dimensions given in inches.

FIG. 64

GENERATOR NO. 2
EXCITERS REMOVED

Contours of Vertical Field
Due to Earth's Field Effect
at 10 ft.

299 volt forward and reverse pulses
open circuit operation
(Z = 535 mg.)

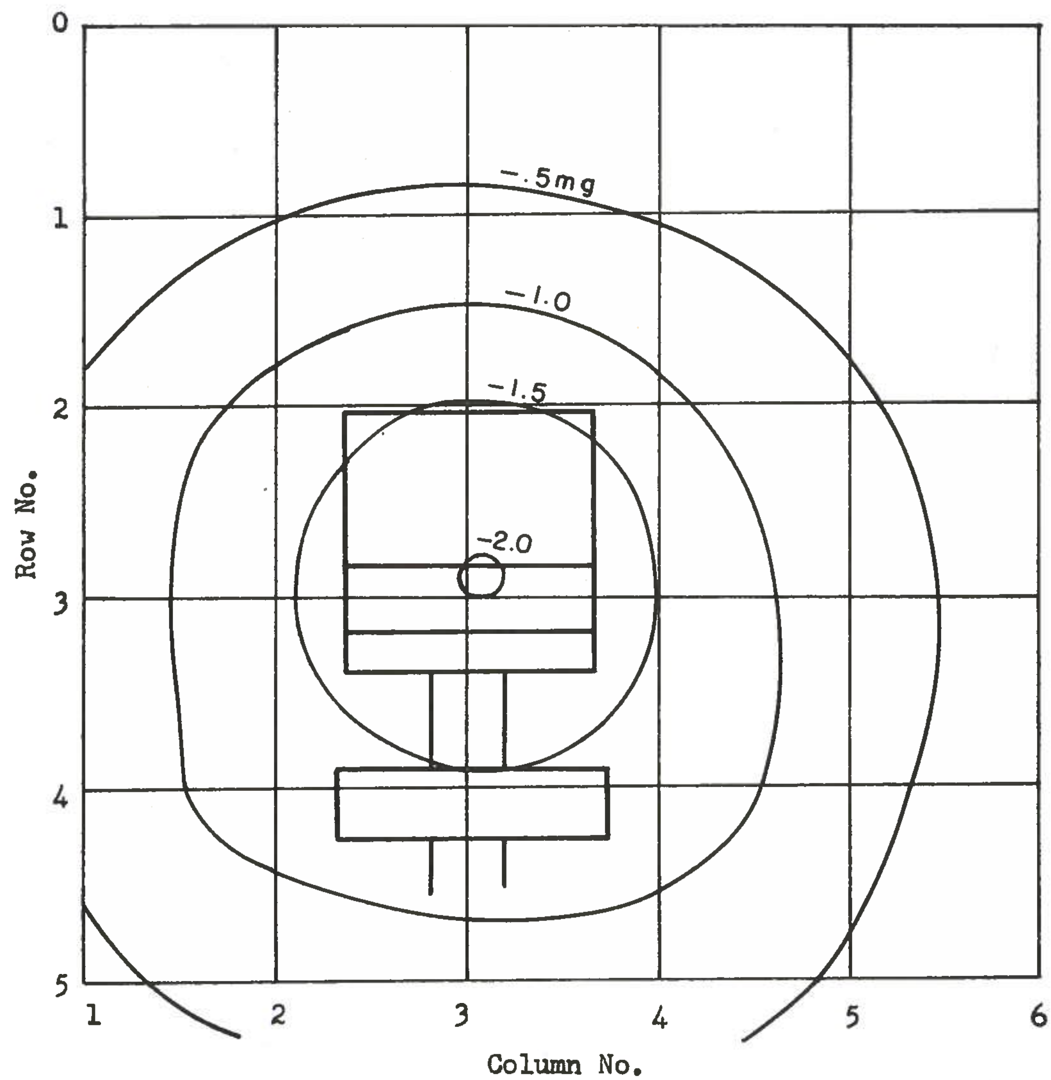


FIG. 65

GENERATOR NO. 1
EXCITERS REMOVED

Contours of Vertical Static Field
at 10 ft.

(Z = 490 mg.)

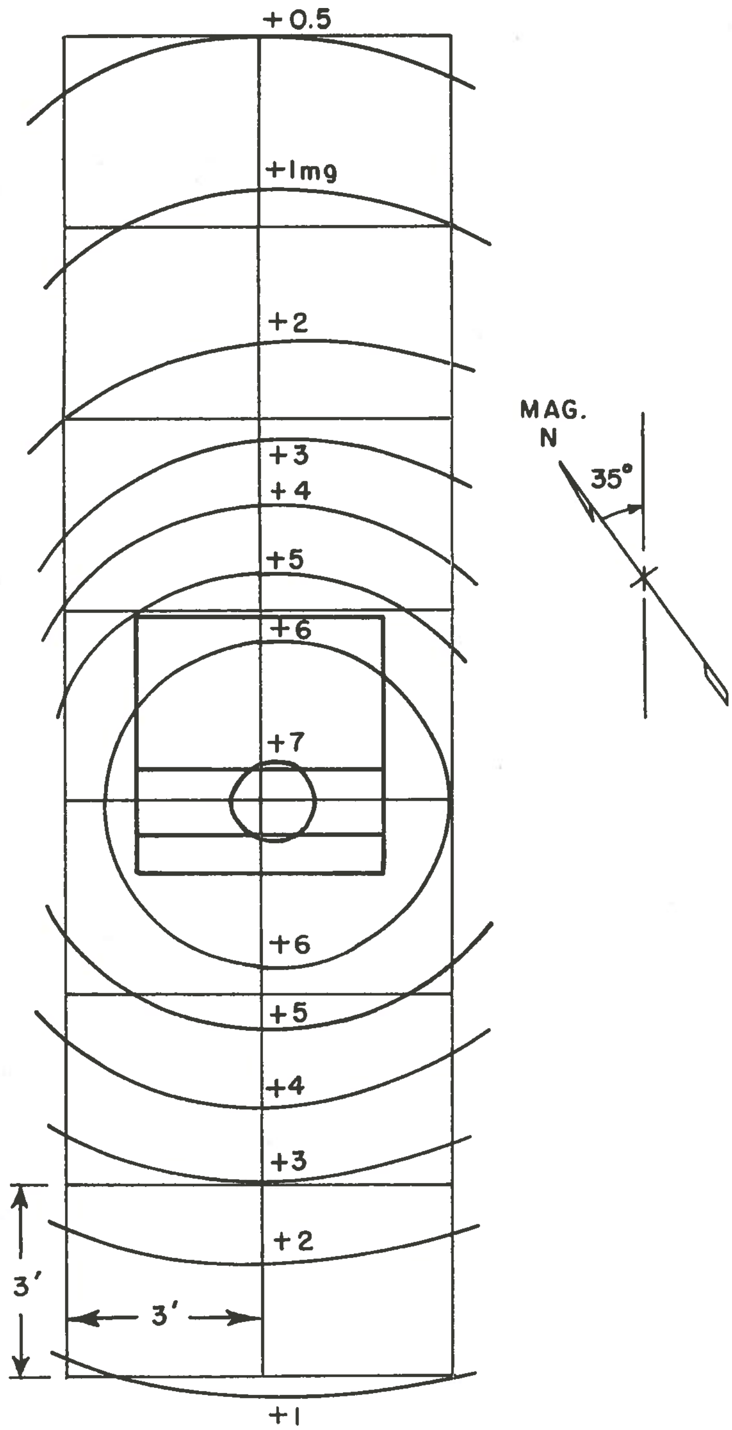


FIG. 66

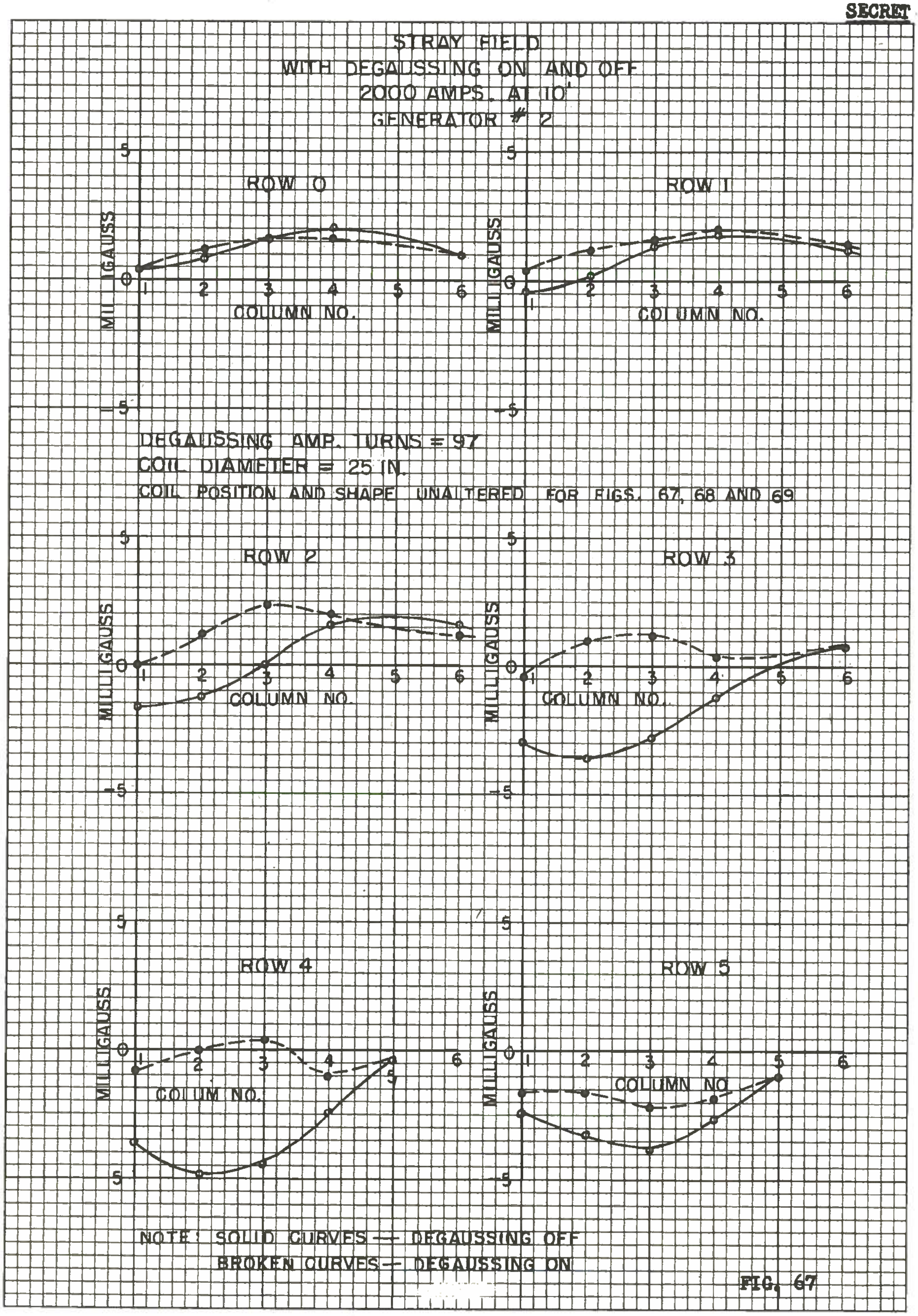

STRAY FIELD
WITH DEGAUSSING ON AND OFF
2000 AMPS. AT 10'
GENERATOR # 2
ROW 0
ROW 1
ROW 2
ROW 3
ROW 4
ROW 5
MILLIGAUSS
COLUMN NO.
DEGAUSSING AMP. TURNS = 97
COIL DIAMETER = 25 IN.
COIL POSITION AND SHAPE UNALTERED FOR FIGS. 67, 68 AND 69
NOTE: SOLID CURVES — DEGAUSSING OFF
BROKEN CURVES — DEGAUSSING ON

FIG. 67

SECRET

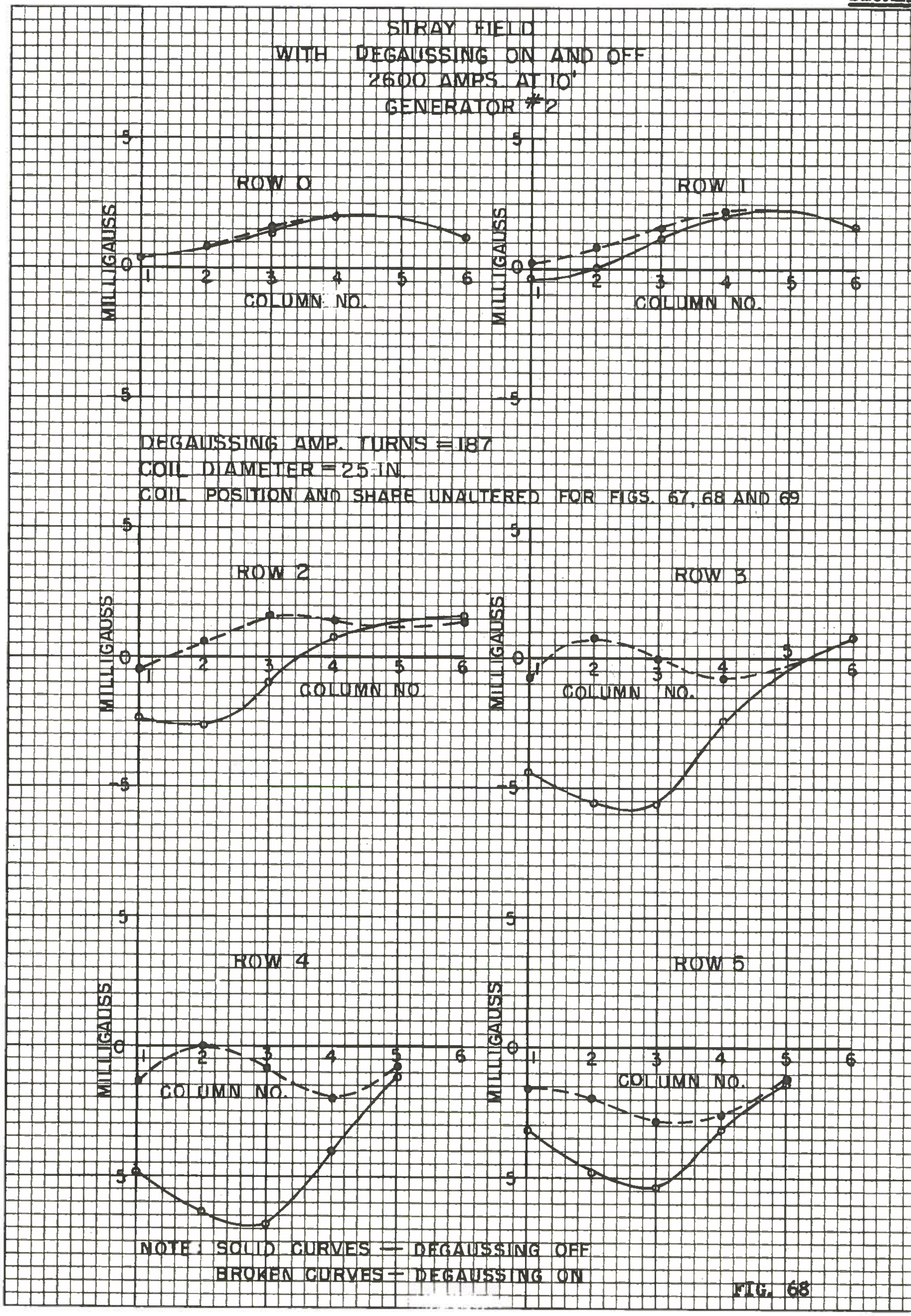


FIG. 68

SECRET

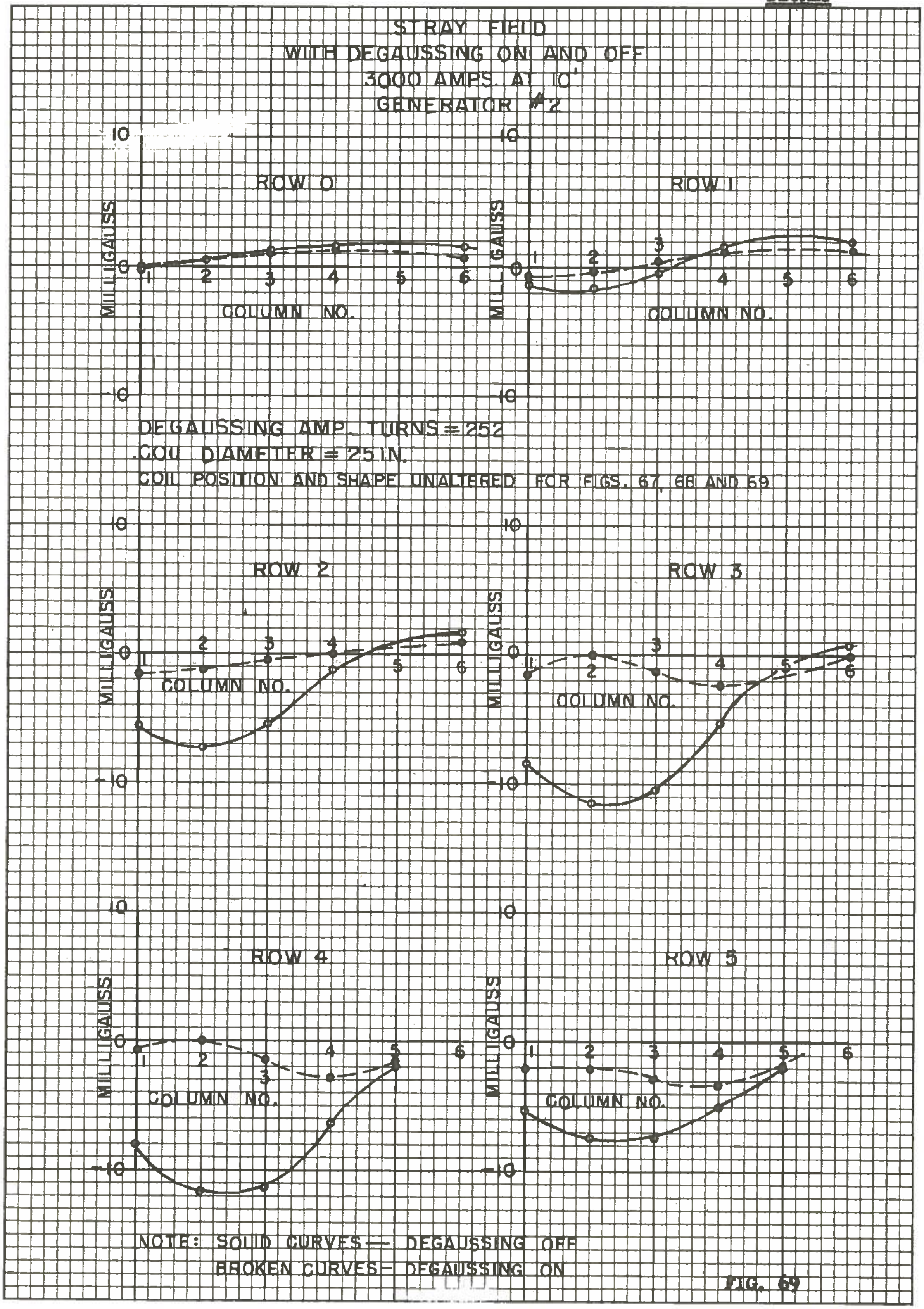


FIG. 69