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N° A F 61(052) - 410

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Final report

July 1961.

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ONE WAIT "O" TYPE CATHOTRON

FOR OPERATION AT 150 KMc/s

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INFORMATION

ONE WATT "O" TYPE CARCINOTRON
FOR OPERATION AT 150 kMc/s

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INTRODUCTION

1. This report is a summary of the studies which have been made to build on "O" Carcinotron delivering an average output power of one watt at the wave length of two millimeter with a bandwidth of 5 to 10 %.

The contract specified that the tube might be pulsed to obtain this result. In this case, the peak output power must be not exceed 50 watts.

2. In the first part of this report, the main features of the design of a tube for the watt level will be examined.

In the second and third parts the results of the study of the main components of the tube : The gun and the slow wave structure will be reported.

....

DETAILED REPORT

The technology will be described in the fourth part.

In the fifth part, the equipment for wavelength measurements, power measurements will be reported.

In the sixth part, the operating characteristics of different experimental and final tubes will be reported and the results will be discussed.

3. A comparative study with the 4 mm Carcinotron will be made during the course of the report. Concerning a theoretical survey and bibliography [1-2] reference is to be made to the report (W.R.411 - 95029) on design and development of 4 millimeter prototype Carcinotron tubes, made under contract A.F.61(514)-919

DETAILED REPORT

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I. DESIGN OF THE TUBEI.1. DESIGN CONSIDERATION.

The studies which have been made at 70 or 75 kMc/s have lead to the construction of tubes CO.40 which have delivered up to four watts in C.W. operation. Characteristics are shown in figures 1 and 2. Indeed these figures have not been obtained with all tubes but with the best ones. But it was felt that such a result was not at all a limit at 4 mm, because their main features having not been yet perfectly realized. This empharized the feasibility of an one watt C.W. tube at 2 mm, and this objective has been fixed for the first design of the 2 mm Carcinotron. If this turned out to be difficult to achieve, the design would be modified towards a pulsed operation with a duty cycle as high as possible.

During the course of this work, an attempt has been made on a 4 mm Carcinotron and 6 watts C.W. power has been obtained (fig.3). This reinforced the C.W. operating design consideration of an one watt tube at 2 mm.

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1.2. THE MAIN FEATURES OF THE DESIGN.

1.2.1. Basic solutions.

Three basic solutions have been contemplated, depending on the beam to be used :

- a) Cylindrical solid beam (used in a design similar to the CO.40). A current density of the order of 200 A/cm^2 is necessary. This means a current of the order of 50 mA through a hole 0,15-0,20 mm in diameter.

A vane type structure could be used, the dimensions of which should be approximately :

- hole diameter	0,15 - 0,2 mm
- finger width	0,35 - 0,4 mm
- pitch	0,2 - 0,3 mm

The tube construction should be quite similar to the 4 mm Carcinotron. The final result of this work has confirmed the success of a design of this type which will be named type "A" tube in the text.

- b) Flat beam. In this case the total current should be approximately the same but the density could be somewhat smaller because a wider line may be used. With such a beam two types of structure have been used. The type "B" using a slotted vane line having a width nearly a wavelength large without nodding problem, and the type "C" tube, using a double vane line structure.

Some tubes of these two types have been constructed and tested. Some results have been obtained, but many construction difficulties have been encountered and some of them have not been solved.

....

I.2.2. Basic problems.

Whatever the solutions, the same basic problems must be faced :

A. Accuracy.

An accuracy of the order of one micron must be achieved. A new milling machine has been ordered to meet this requirement.

B. Heat dissipation.

The dissipation of a vane line should be good enough due to the small height (less than half a millimeter) of the fingers to be used. As experienced in the study of the CO.40 attention must be paid to the collector. A beam power density up to 1 MW/cm^2 must be used. Such a power density would lead to local evaporation of the collector if not carefully designed.

C. Gun design.

An high convergence must be used to minimize the cathode current density. A careful insulation must be achieved to prevent high voltage arcing.

D. R.F. measurements.

Equipment and sources must be designed mainly to measure the line losses and the reflexions and losses of the output windows of the tube; which cannot be deduced from large scale model measurements.

Most of these problems have been solved. Their good solutions have contributed to the final success of the tube.

II. ELECTRON GUNS.

II.1. CYLINDRICAL GUN.

The structure of the gun used on type "A" tube is similar to gun structure of 4 mm Carcinotron. It is Müller-Pierce type.

The gun performance shall have a current density of 200 to 300 A/cm² in the beam which diameter will be below 0,2 mm and going down to 0,10 mm if possible.

Two types have been designed and tested :

	Cathode diameter	Curvature radius	Cathode current density	beam current
Type I	1,8 mm	2,22 mm	$\approx 4 \text{ A/cm}^2$	100 mA
Type II	1,4 mm	1,58 mm	$\approx 4 \text{ A/cm}^2$	65 mA

These guns have a convergence around 100 and a perveance $\approx 1.10^{-6} \text{ A/V}^{3/2}$.

An impregnated cathode is used instead of the C.S.F. 103 cathode used ⁱⁿ the CO.40 because it has a higher current density charge. It will be described later.

....

In order to make the beam transmission not sensitive to the line voltage variations during the operation of the tube. The gun has been designed so as to obtain a large magnetic flux through the cathode approximately 80 % of the flux through the beam. These mode of operation requires a total magnetic field significantly larger than the minimum theoretical one. This latter is given by figure 4 for the design values

$$\frac{R_k}{R_c} = 9 \quad I_o = 100 \text{ mA}$$

Due the high convergence ratio of the gun the cathode region must be heavily shielded. The magnetic shield has been designed mainly by cut and try methods. The saturation of the magnetic material making a theoretical calculation not accurate enough.

At set of the gun construction basic data are given in figures 5 to 11, where the symbols have the following meaning. [3]

δ	cathode current density.
I_o	beam current.
r_a	anode aperture radius.
r_k	cathode curvature radius.
θ	cathode aperture angle
$D_o = 2R_o$	beam diameter.
$D_K = 2R_K$	cathode diameter.
α	wehnelt aperture angle.
h	cathode-wehnelt space.
$D_w = D_k + 2d = D_k + 2h \text{ tgo}$	wehnelt aperture diameter.
L	cathode-anode space.

....

The gun test mounting is shown with his constituting parts in Fig.12 and with the pumping system in Fig.13.

The beam diameter have been tested by using a cylindrical tunnel, 1 mm in diameter and 20 mm in length, which was screened with a concentrical small aperture of the same diameter at each end. An accuracy better than 1/100mm has been achieved. The collector is designed for high power density dissipation. It is a copper piece with a very sharp conical hole carefully polished in beam impact region and with a water cooling system closely placed behind it.

Results.

- The type I gun, designed from the optical diagram of figure 14 has been given a beam transmission nearly 100 % through a hole of 0,25 mm in diameter (test CO.C.20.II.8. Fig.15,16,17) and an optimum transmission about 80 % has been obtained through a hole 0,18 mm in diameter (test CO.C.20.II.7.Fig.18).

In this latter case the cathode current can be 70 mA, the beam current density of order of 200 A/cm^2 and the beam power density $1,0 - 1,5 \text{ MW/cm}^2$

This gun is used presently in the type "A" tubes in construction. Satisfactory results have been obtained.

- The type II gun, designed from the optical diagram of figure 19 has given a beam transmission nearly 90-100 % through a hole of 0,20 mm for a beam of 70 mA (Fig.20,21,22) and a transmission about 50 % in a hole 12/100 mm in diameter.

....

This gun has been mounted in two experimental type "A" tubes. It was seen that improved results of the tube should be possible with such a design, but the gun operation turned out to be very critical.

These two types of gun have tested in a depressed collector operation. Such an operation is interesting because it could simplify the heat dissipation problem in the collector and would allow an increase of the overall efficiency of the tube. The curves figure 23 and figure 24 show that, without H.F. operation, the collector voltage can be decreased down to only 10 % of the line voltage while having a beam transmission of 85 % or more. R.F. measurements would be indeed necessary, but because coupling coefficient is low and the space charge effects are not important, there is a good possibility that a depressed collector operation would increased very significantly the overall efficiency of the tube.

II.2. RECTANGULAR GUN.

1. The beam to be used in the B and C design is a rectangular one. The dimensions of the gun which have been tested varied widely due to the possibility of using slow wave structure of very different width.

A first converging gun was designed having the following characteristics :

beam dimensions	0,4 x 0,8 cm
convergence	20 .
perveance	$1 \cdot 10^{-6} \text{ A.V}^{-3/2}$
beam density	up to 25 A/cm ² .

The photographs 25 and 26 show the components of this gun, and figure 27 shows the first results.

....

The testing mount is similar to the mount for cylindrical one except indeed for the shape of the tunnel and screens.

This gun has been used in the first tube up to the serial number n^o48 (see below).

2. An other design was studied with the following characteristics :

beam dimensions	0,25 x 1,5 mm
perveance	$2 \cdot 10^{-6}$
beam density	50-100 A/cm ² .

The tests showed a beam transmission of 40 % only. This bad operation can be explained by centering inaccuracies, and to good a shielding of the gun region which lead to a rotation of the beam.

Nevertheless two tubes (n^o49 - n^o51) have been mounted with this gun. The results have been disappointing. Due to the success of the A design, the work with rectangular guns have been stopped.

III. CIRCUITS AND COLD TESTS

III.1. MAIN FEATURES OF THE CIRCUITS.

The main requirements which must be met by a circuit for one watt two millimeters tube are the following :

- high thermal dissipation,
- good coupling impedance,
- low losses,
- good accuracy.

Though its coupling impedance is rather low, the vane type structure appeared as the best compromise concerning the above requirements.

Because the power requirements are fairly high thinking of the wavelength it has been necessary to choose a relatively high maximum voltage.

III.2. VANE TYPE STRUCTURE WITH A HOLE.

These lines are used in the type A design. They are machined in a block of copper with a cylindrical hole, made according to processes indicated below.

The following dimensions gave satisfactory results.

....

pitch 0,23 mm
 height 0,42
 width 0,3
 hole diameter 0,18
 finger width : half the pitch
 number of vane 85.

The photography 28 shows the line. The photo n^o29 makes a comparison with a 4 mm line machined more than one year ago.

- The hole diameter is a compromise between beam-line coupling, and beam transmission. With a voltage 6 kV, the beam radius measured in transit angle is.

$$\gamma_a = 1,8$$

- With such a design at a beam density of 200 A/cm² it is easily seen that beam bunches are made of a fairly large number of electrons ($> 10^6$) showing no limitations due to the granular structure of the current.

- Losses of the vane type structure have been measured to be less than 12 dB at the center frequency.

III.3. SLOTTED SIMPLE LINE.

These lines are used in the type B tube.

Two models have been made, three slots or six slots, used in the first two millimeter models.

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The figure 30 shows such a structure.

To evaluate the influence of the width of a vane type line on its dispersion curve, two series of such lines scaled up by a factor of 25 have been made. The pitches of these scaled up lines are 6,25 mm and 5 mm corresponding respectively to 0,25 mm and 0,20 mm for the 2 mm wavelength lines. The width to height ratios are : 0,5 - 1 - 2 and 4. The dispersion curves which have been measured are given on figures 31 and 32.

On the lines with a width 4 times the height, it has been verified that the slow waves are still propagating on the symmetric mode.

The use of such a line which is approximately a wavelength wide sets up two new fundamental problems.

- 1^a The problem of the junction to the output waveguide.
- 2^a The problem of designed an r.f trap to prevent power radiation through the beam hole.

Solutions have been found for these two problems, but because of the bad operation of the whole design it has not been though necessary to study them in a more profound a way.

III.4. SLOTTED DOUBLE LINES.

These structures are used in the type C tubes. This design is a way to obtain a large number of elementary lines in parallel.

....

But the construction of the structure is much more intricate than a single line. The relative position of the two parts must be fairly accurate.

Two different relative positions have been tested :

- 1st Component lines placed symmetrically.
- 2nd Component lines shifted by half the pitch.

The dispersion curves measured in these two cases, on large scale models (X 25) are shown in the figures 33 and 34.

Three lines of the symmetrical type have been machined. The photographs 35, 36, 37 show different aspects of the mount.

A tube have been mounted with such a structure which gave no results.

-:-:-

IV. OVERALL TECHNOLOGY OF THE TUBE

IV.1. GENERAL SURVEY.

The overall technological design of the tube is quite similar to the 4 mm 0 Carcinotron. The objectives of the design are :

- 1° A simple mounting : making the tests easier, and allowing changes of internal parts.
- 2° High heat dissipation. The tube must dissipate a power of the order of 500 watts.
- 3° A good mechanical strength.
- 4° A good accuracy.

The figure 38 shows the structure of the type A tube. The figure 39 shows its envelope and its components. The components of the B tube can be seen on the photography n° 40.

IV.2. OUTPUT WINDOWS.

The machining of the waveguides through the kovar collector are made by a sparking machine. The accuracy is approximately 0,01 mm which is good enough for a two millimeter wave guide.

....

The glass thickness is $2/100$ to $3/100$ mm.

The losses through the glass window are estimated to be a few tenths of a dB. The voltage standing wave ratio due to reflection on the window is less than 1.4 in the required bandwidth.

IV.3. SLOW WAVE STRUCTURES.

IV.3.1. Milling.

For most of the dimensions, the accuracy of the machined of the line as compared to what has been made at 4 mm have been increased by more than a ratio of two; mainly due to the use of a new milling machine.

The pitch can be machined with an accuracy of 1μ . The width is not so accurately machined due to a milling tool problem.

Slots down to 0.03 mm can now be machined using very thin tools of a small diameter. A particular attention must be paid to the straightness of the cutting part of the tool. By a careful selection of milling tools, an accuracy of $\pm 2,5 \mu$ can be achieved on the width of the line. The height can now be machined with $\pm 5 \mu$ accuracy.

The progresses made in machining are well shown in the photography 29 which makes a comparison of an old 4 mm line with a new two millimeter structure.

- Bending of the tools are prevented by making them with a small diameter and maintaining them between two steel cylindrical blocks; the diameter of which is nearly the same as the diameter of the tool.

....

- A very significant improvement in the results have been obtained by using a tool with only one tooth. The photographs 41 and 42 show such good results. The linear magnification in the photo 41 is 4/1 and is 35/1 in the photo 42.

In such an operation the speed of the tool must be increased. The rotation speed is 2000 turns per minute, machining the line at only 8 mm per minute.

- The slow wave structure is a part of a larger block of copper to achieve a good heat dissipation. Longitudinal slots have been managed along the block of copper, so as to make possible its brazing to the outer envelope.

The collector is made of a piece of tungsten having the shape of an anticathode.

- The figure 43 shows a comparison of a 2 mm line assembly with a 4 mm line.

The figure 44 shows a line assembly for a type B tube.

IV.4. TUBE ENVELOPE.

- The tube envelope is made of a copper part and a kovar base, and a kovar"collector"part. They are brazed together in hydrogen by r.f heating in one operation.

....

IV.5. ATTENUATION.

The collector end of the line must be loaded by a lossy section. This attenuation is placed outside of the tube, in order to prevent the increase of the line itself.

The lossy material which is used is Eccosab MF-116.

IV.6. GUN.

All part of the gun are fitted inside of a magnetic shield of the gun which is screwed inside of the envelope so as to insure a good mechanical strength.

Good electrical insulation must be achieved due to the use of relatively large voltages.

Metal parts are electrolytically polished so as to eliminate arcing.

Some field emission has been observed from a ~~gun~~ ^{gun} which was formerly made of titanium. This material has been then replaced ^{by} molybdenum.

IV.7. CATHODE.

Two types of cathode have used : the 103 cathode and the impregnated type. This last one is now preferred, because it can deliver a somewhat a higher current density at the same temperature [4]. Diode tests have shown a current density up to 15 A/cm². With a 10 A/cm² load at 1200°C, the life in diode tests, is larger than 1000 hrs. In the two mm tube, these cathodes are used in much more conservative conditions : less than 4 A/cm² at a temperature of 1050°C. The heater power is 11^w,5 at 6,5 volts. The cathode is activated at 1200°C.

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IV.8. THERMAL DISSIPATION - COOLING SYSTEM.

The power to be applied to the tube is a few hundred watts. The cooling is achieved through the use of a water flow around the envelope and in a cooling system which is in a tight contact with the collector.

This last cooling system is fitted there for safety it could be suppressed; only the cooling of the envelope is strictly necessary.

IV.9. CAPILLARY.

A lot of work has been made to make the copper block with the capillary hole in which the line is machined.

The different methods which have been tried are classified in the following list :

- A₁ Electro forming.
- A₂ Fusion.
- A₃ Drawing.
- A₄ Extension.
- A₅ Pressing.
- A₆ Drilling
- A₇ Electro erosion.
- A₈ Milling.

....

A₁ Electro forming.

The photograph 45 shows the experimental assembly. Copper is obtained from a conventional cyanide bath. Three weeks are necessary to obtain a block of 16 mm in diameter. The coating is made of molybdenum the behaviour of which is quite satisfactory in the thermal processes and the machining of the block of copper. Furthermore, it can be dissolved easily.

A₂ Zone fusion.

The process and results are shown in Fig.46 and 47.

A wire is stretched by a spring along a slot made inside of a block of copper, which is placed inside a graphite crucible.

The fusion is made in argon starting with the bottom end of the copper.

A₃ Drawing.

Satisfying results are obtained only by drawing relatively thin tubes. The piece is then brazed on a larger block as shown in Fig.48.

A₄ Extension.

Fig.49 shows the matrix and the tools used in this process. It does not work satisfactorily.

A₅ Pressing.

This process is the widely used at this time.

The photograph 50 shows a matrix.

....

The assembling of two part are made through diffusion at 9000C in a mount shown in fig.51. The slots in each component are made by the following process : A small slot is machined on a piece of copper which has been pre-viously baked at 6500C for a few hours. A tungsten wire maintained by the matrix is pressed in the slot with an hydraulic press.

A₆ Mechanical drilling.

Small diameter holes can only be drilled on very small length. It is possible nevertheless to use this process in making the capillary. Thin pieces can be drilled and then assembled ^{by} diffusion. The photographies 52 and 53 show the process and the results.

A₇ Electro erosion.

This process makes possible the drilling of the hole after the line has been machined. But satisfactory results could be obtained by guiding the tungsten wire which is used as an electrode. This problem is not yet solved.

A₈ Milling of slots.

This can be used in connexion with the A₅ process.

IV.i0. PUMPING PROCESS.

Improvements in the pumping process have been a fundamental condition of the success of the two millimeter tube.

The technics which have been developped consist in the use of a titanium getter together with a miniature Bayard.Alpert gauge. The process has made the object of a paper presented at "Journées du Vide".Paris [5].

....

The photography 54 shows a pumping assembly with two getters (one for safety) and a gauge. Fig. 55 shows the tube operated in an electric magnet.

The main interests of the pumping process are the following :

- Final pressure less than 10^{-8} Torr. "Clean" vacuum.
- Constant control of the pressure evolution during the processing of the tube.
- Fitting of the tube in its magnet simplified in the "hardening of the tube".
- Sharp decrease of the duration of the whole tube processing.

The whole processing cycle is described below :

- The tube and its pump is evacuated quickly on a diffusion pump. A rough outgassing of the heater of the tube and of the getters is made.
- The assembly is soldered. The tube is then baked in a hydrogen-nitrogen flow, to prevent oxidisation. During the baking the heater is operated to one third of its nominal power.

At 480°C , the cathode is heated at 16 watts during 15 minutes. At this temperature a pressure of 10^{-6} Torr. is generally achieved within 3 hours.

- After the baking the tube is operated at its full power in an electromagnet, before the getter and the gauge are removed.

-:-:-

V. EQUIPMENT

During the course of this research, it was found necessary to complete and create new measuring equipment. The measuring technic has also been improved.

We shall briefly describe the following items :

Detector.

We possess adjustable detectors (Fig.56).

The adjusting mechanism is such that longitudinal movement and rotation of the crystal is possible independently of each other. This is very convenient as the point of contact can be changed without destroying the tip.

Wavemeter.

A 2 mm wavemeter operating on the TE 01 mode (cylindrical cavity $\phi = 3,71^{mm}$) has been made (photo 57). The absolute reading accuracy is of $\pm 1\mu$ over the whole range of displacement of the piston which is of the order of 10 mm. The cavity diameter is known with a precision of 2 microns so that the relative precision on the measurement of the wavelength is about $\pm 1.10^{-3}$.

....

This wavemeter has been compared with that of F.X.R. and shows good agreement.

Slotted line.

We make use of equipment supplied by F.X.R. Their detector however is unsatisfactory.

Interferometer.

In order to calibrate the wavemeters and to measure the dielectric constants of materials we have constructed a Boltzman type interferometer. Fig. 58 shows the working principle and Fig. 59 the system with two mirrors.

Two interferometers have been built, one working in the 4 mm range (Fig.60) and the other in the 2 mm wave band (Fig.61).

Measurements carried out with these devices proved entirely satisfactory. Further details on this work will be published later.

Wattmeter.

This is the same as the one used at 4 mm, but a matching section has been added in the input.

The wattmeter assembly has been improved (Fig.62). The entire system is now bridge-mounted. (thermal conductivity, water flow, heater, thermistors etc ...). Thermal drift can be reduced to a few tens of microwatts. The time-constant with large flow is of the order of 2 seconds, thus making possible the continuous recording of the power output of the tube.

....

Further details have been given in the following reports :
Measurement of H.F. power by means of a water wattmeter [6]. Assembly of the elements of a wattmeter [7].

Photos 63 and 64 show the general lay-out of this equipment associated with a recorder.

Fig.65 shows an example of a recording taken during the ageing of a tube. It shows how a tube behaves through out each cycle of voltage-sweep. (Time cycle 20 minutes). The curves with compressed scale correspond to a slower paper speed.

The continuously-variable high tension was obtained by a rotating potentiometer which applied a varying voltage to the grid of a power triode, with the stabilised high tension connected in series with the carcinotron to the plate and cathode of the triode [8].

-:-:-

VI. TESTING OF THE TUBES AND RESULTS OBTAINED

The required measurements and main characteristics of these lines are tested in the following table :

Tube N°	Pitch	Number active vanes	Height	Width	Transversal slots	Type	line sole distance	Gun		Focussing arrangement
								beam	named	
1-2-3	0,2	99	0,46	0,78	0,10	3 slots	0,09	R	CO.R.20.I	Electromagnet and permanent mag.
7-8-9	0,26	75	0,41	0,82	0,13	3 "	0,13	R	CO.R.20.I	Electromagnet
10-11-12	0,2	85	0,44	0,76	0,10	3 "	0,10	R	CO.R.20.I	"
16- 17-18	0,26	70	0,41	0,82	0,13	3 "	0,13 to axe	R	CO.R.20.II	"
28-29-30	0,2	85	0,44	0,76	0,10	3 "	0,10	R	CO.R.20.I	Permanent mag.
34-35-36	0,24	73	0,41	0,82	0,12	3 "	0,13	R	CO.R.20.I	Electromagnet
46-47-48	0,24	114	0,41	0,82	0,12	3 "	0,13	R	CO.R.20.I	"
49-(50)	0,24	114	0,41	1,56	0,12	6 "	0,33	R	CO.R.20.II	"
51	0,24	114	0,45	1,56	0,12	6 "	0,49	R	CO.R.20.II	"
52-53-54	0,25	114	0,47	0,4	0,12	capillar 0,18	0,50	C	CO.C.20.II	"
80-81-82	0,23	85	0,42	0,3	0,11	capillar 0,18	0,47	C	CO.C.20.II	"
82bis	0,23	71	0,42	0,3	0,11	capillar 0,18	0,47	C	CO.C.10.I	"

....

Tube No	Max. power mW	Bandwidth	Remarks
1	78	2,37 to 2,058mm (2800v) to (4500v)	
2	23	2,6 to 1,95 (2190v) to (5700v)	
3	300	2,12 to 1,98 3000v to 6000v	
7	300	2,77 - 2,25 3250v - 6000v	High starting current unstable
9		2,26 - 2,045 5200v - 7100v	High starting current (80 mA) Discontinuous
10		2,49 - 1,79 2600v - 5100v	Modification of characteristics Fall in power; line molten on gun side
16			Not operated
28		2,45 - 1,96 2500v - 5200v	Low-power. Mismatched
29		2,43 - 1,95 2560v - 5270v	} Gun fixing deficient }
46		2,78 - 2,055 2640 - 6000v	Discontinuous Mismatched
34 B	800	2,48 - 2,03 3600v - 6500v	} Line current 120 mA }
47	200	2,70 - 2,05 2900v - 6000v	} Adjustment critical }
36	400	2,27 - 1,91 4100v - 7000v	Discontinuous

....

Tube №	Max.power mW	Bandwidth	Remarks
48		2,11 - 1,855 5000v - 7500v	Unstable
49		1,975-1,86 6350v - 8100v) Discontinuous Tungstenmolten
53	530	2,475 - 2,145 3860v - 7500v) Poor insulation
54	1100	2,60 - 2,2 3400v - 6600v) Short circuit cathode-wehnelt
51			Oscillated at 7100v (80 nA) unable to adjust.
81	2100	2,26 - 1,96 3900v - 7200v) 1 watt through bandwidth of 7 %
80 A	3000	2,245 - 1,96 4040v - 7400v) 1 watt through bandwidth of 4 %
80 B	2500	similar to 80A	1 watt through bandwidth of 5 %
82 C	1600	2,25 - 1,96 4200v - 7600v	1 watt through bandwidth of 6 % Arcing-line molten in middle part
82bis	600 (before and after brazing)	2,15 - 1,95 4500v - 7500v) Unstable after brazing of the line Poor insulation

....

The following information results from the above :

1. In the series of type A tubes, after trying out two tubes (53-54) in the experimental series, the second series of tubes gave the required performance straight away. The four tubes gave approximately the same results. Except that gun structure CO.C.10.I seems to be less satisfaction than ^{the} gun CO.C.20.II.

In spite of the instability noticeable after brazing of the line of tube 82 bis, we can consider this process as satisfactory.

2. In the series of type B low power tubes, satisfactory results were obtained in permanent magnets but their reproductibility is not good.

3. The B series did not give interesting results. As this has been said before this must be related to the difficulties in adjusting the slow wave structure, which is a very difficult problem, and in a bad design of the rectangular gun.

4. For similar reasons the C tubes did not operate.

Characteristics of some tubes.

Results concerning some tubes are listed below.

....

Tube N^o1 : mounted in the first three months. It delivered 10 mW through a 14 % tuning range between 127-146 GHz with a maximum power of 80 mW at 140 GHz. (Fig.66and67). Focussing field 4000 oersteds.

Tube N^o3 : 100 mW through a 13,5 % tuning range (131-150 GHz) max.300 mW at 141 GHz (Fig.68). Magnetic field 4000 oersteds.

Tube N^o80 : It has been pumped three time due to cathode defects. (A.B.C.).

80 A and 80 B have similar starting current (Fig.69).

80 A gave 1 watt from 147,5 to 153,5 GHz (4 %), and two watts through 3 % centered at 150 GHz, with a maximum 3 watts at 152 GHz.

80 B delivered one watt from 144 to 152,5 GHz (5 %) (see fig.70) and 1,5 watt in a 3,5% tuning range centered at 148,5 GHz.

80 C delivers more than 1 watt through the required range but with a somewhat less sharp maximum power. The tube is shown in its electromagnet in figure 71.

Tube N^o81 : See Fig. 72 and 73.

The output power is larger than 0,5 watt through a 9 % tuning range, and larger than 1 watt through a 7 % range centered at 147 GHz.

The output power is larger than 1,5 watt through 3 % centered at 150,5 GHz.

- The maximum power is 2,1 watts at 152 GHz.
- The magnetic field is 5400 Gaussses.
- The current density in the beam larger than 200 A/cm².
- The power density in the beam larger than 1,5 MW/cm².

....

Tube N982.C : See figure 74.

The tube has been destroyed. It gave :

0,5 watt	tuning range 9 %	139 to 152,3 GHz
1 watt	tuning range 6 %	142,5 to 152,3 GHz

The maximum power was 1,6 watt at 148 GHz.

-:-:-

VII. CONCLUSIONS

1°) At the end of this contract we can conclude that the assigned objectives have been fully attained :

tubes have been designed which deliver an output power larger than one watt, in cw operation at a wavelength of two millimeter with a tuning range larger than 5% (7500 Mc/λ).

- the tubes are operated in electromagnets, but the design of permanent magnets to focuses them should not be too difficult.

and under the tubes work in such conditions that a good life should be expected.

- their efficiency, while low, is comparable to the efficiency achieved in the first 4 mm tubes designed two years ago. It is felt that this efficiency could be increased significantly (as happened with the 4 mm tube) in the production of a few tens of such 2 mm tubes.

2°) Conclusions of a broader nature can also be drawn. To meet the goal significant progress was made in machining accuracy, in vacuum processing and general technology. Important progress has been made in gun designs for very high current density and in large power density handling problems. Taking account of these, the design of a 10 watts tube at 4 mm for instance should be quite straight forward.

....

- No true limitations appear yet to be attained. New progresses can be made, which, for instance, could be marked by a further step : the design and construction of a one watt c.w. tube at 1 mm.

---oOo---

B I B L I O G R A P H Y

- 1) G. Convert, T. Yeou and B. Pasty, "Millimeter Wave O-Carcinotron". Symposium Proceedings, 1959.
- 2) T. Yeou, "Carcinotron O sur une longueur d'onde de 2 mm". L'Onde Electrique p. 789-794.
- 3) S. Rocherolles, "Canon pour un carcinotron millimétrique . CO E 20 (150 GHz) will be published.
- 4) J.P. Freytag and J. Lehman, " Etude de cathodes pour carcinotrons M. DTW. 3186.JPF/RB.
- 5) M. Warnecke et P.C. Moutou, "Sur une pompe miniature à titane". Le Vide. N° 85, P. 50. (1960).
- 6) T. Yeou, A. Billès et A. Guillemin, "Etude d'un wattmètre pour la bande $\lambda = 4$ mm. W.R. 575.
- 7) T. Yeou et A. Guillemin, "Mise en place des éléments du wattmètre 4 mm. W.R. 599.
- 8) A. Billès, "Dispositif d'enregistrement des caractéristiques puissance-tension des carcinotrons O millimétriques. W.R. 630.

FIGURES

Fig.

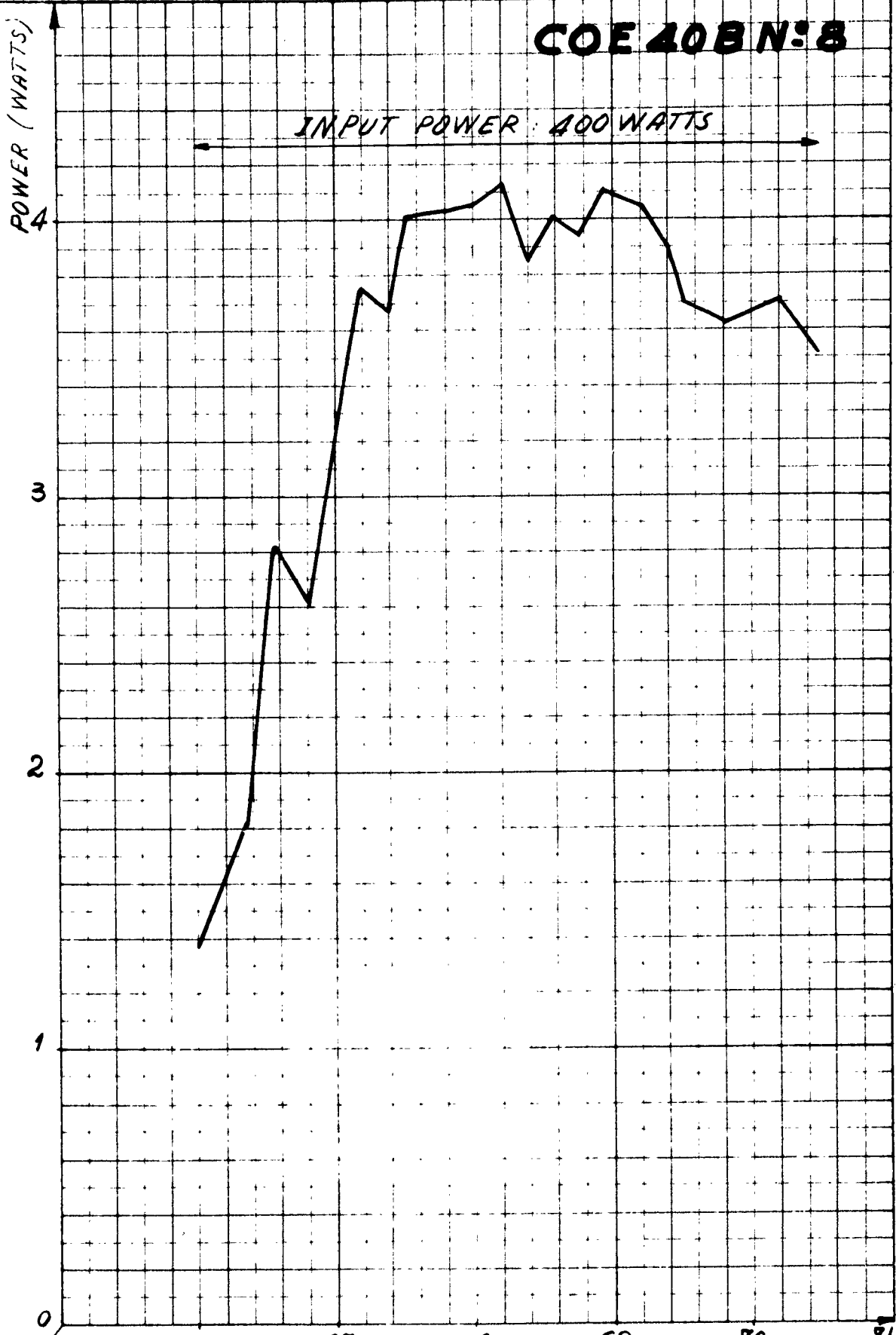
1. Characteristics COE 40 B N° 8 (d.c. applied power
2. (pulsed operation
3. Power/line current characteristic of COE 40 B N° 34.
4. Gun magnetic field $R_K/R_O = 9$ and $I_O = 100$ mA.
5. Cathode current density for different cathode diameters.
6. R_A/R_K and θ° versus D_O/D_K . R_A = anode radius; R_K = cathode curvature radius;
 θ° = cathode aperture angle; D_O = beam diameter;
 D_K = cathode diameter.
7. Wehnelt aperture angle versus cathode aperture angle.
8. Wehnelt aperture diameter calculation;
9. Rk/Dk and ra/Dk versus Dc/Dk .
10. L/Dk and D_A/D_K versus Dc/Dk (L = cathode anode space).
11. Current density for different beam diameters.
12. Constituting parts of the cylindrical gun mount.
13. Pumping system for gun tests.
14. Optical diagram of the gun CO C 20 II.
- 15, 16 and 17. Transmission characteristics of the gun CO C 20 II 8.
18. Optimum transmission of the gun CO C 20 II 7.
19. Optical diagram of the gun CO C 10 I.
- 20, 21 and 22. Transmission characteristics of the gun CO C 10 I.
23. Efficiency of the gun CO C 20 II 8 versus V_C/V_L .
 $(V_C$: collector voltage)
 $(V_L$: line voltage)
24. Efficiency of the gun CO C 10 I versus V_C/V_L .
- 25, 26. Rectangular beam gun. Components and assembled gun.
27. Beam transmission of the rectangular beam.

....

63. Wattmeter assembly.
64. Wattmeter and recorder.
65. Tube forming recording curves.
66. Starting current of the tube N° 1.
67. Power of the tube N° 1.
68. Power of the tube N° 3.
69. Starting current of the tube N° 80 A.
70. Power of the tube N°80 B.
71. The tube in electromagnet.
72. Starting current of the tube N° 81.
73. Power of the tube N° 81.
74. Power of the tube N° 82 C.

---o0o---

COE 40BN:8



65 66 67 68 69 70 71
FREQUENCY (GHz)
(3600 Volts ← → 6000 Volts)

Fig: 1

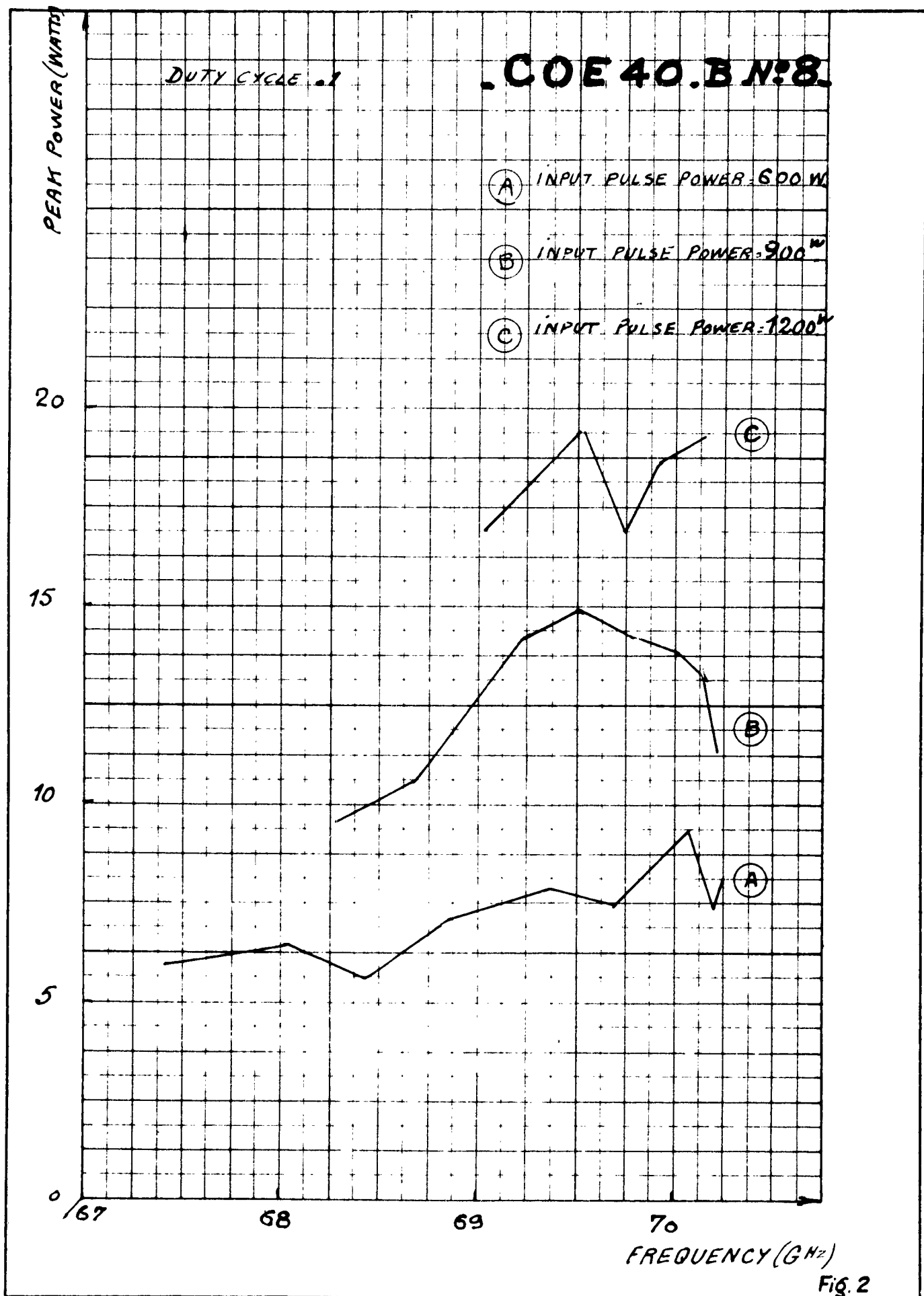


Fig. 2

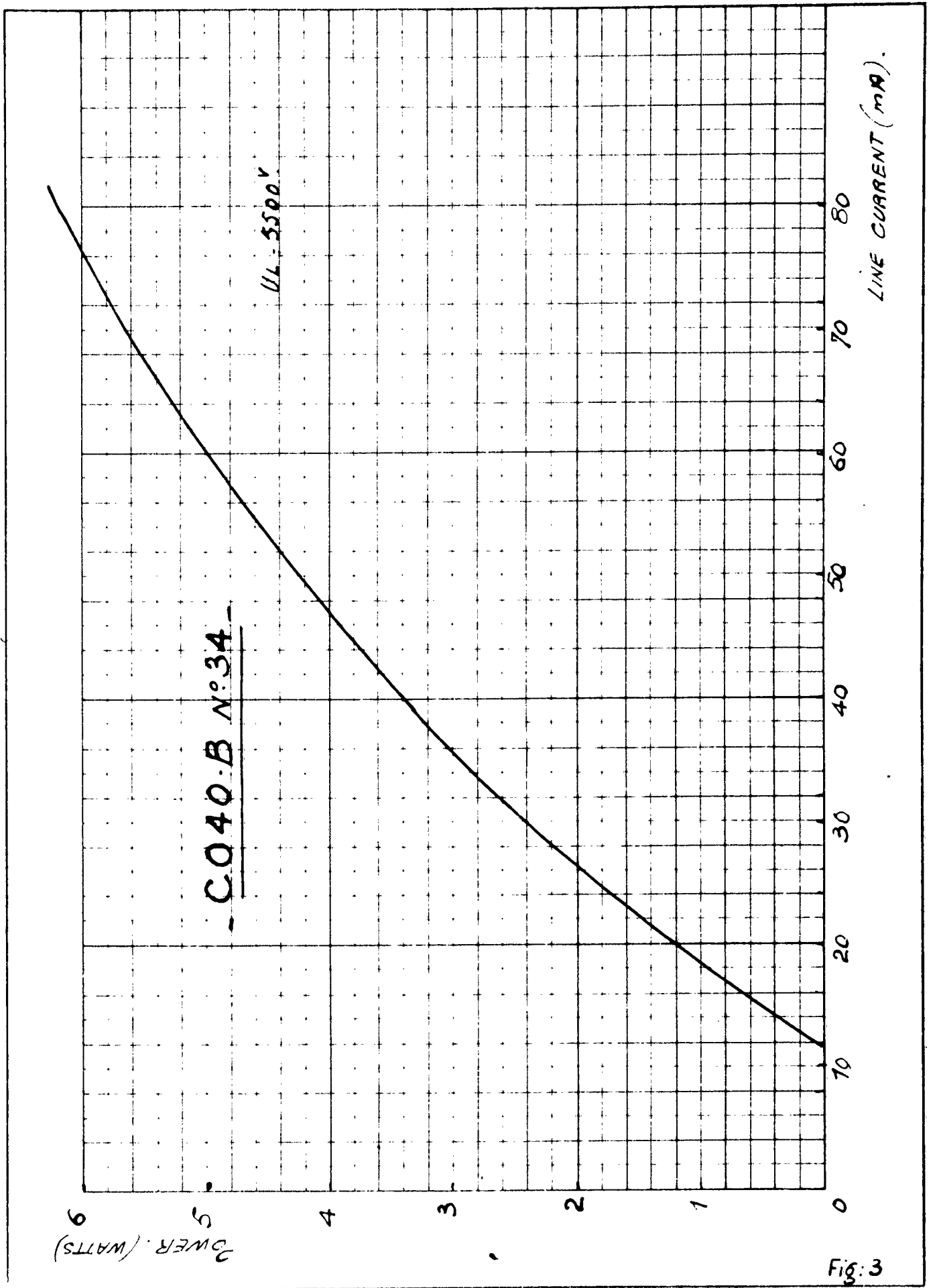


Fig: 3

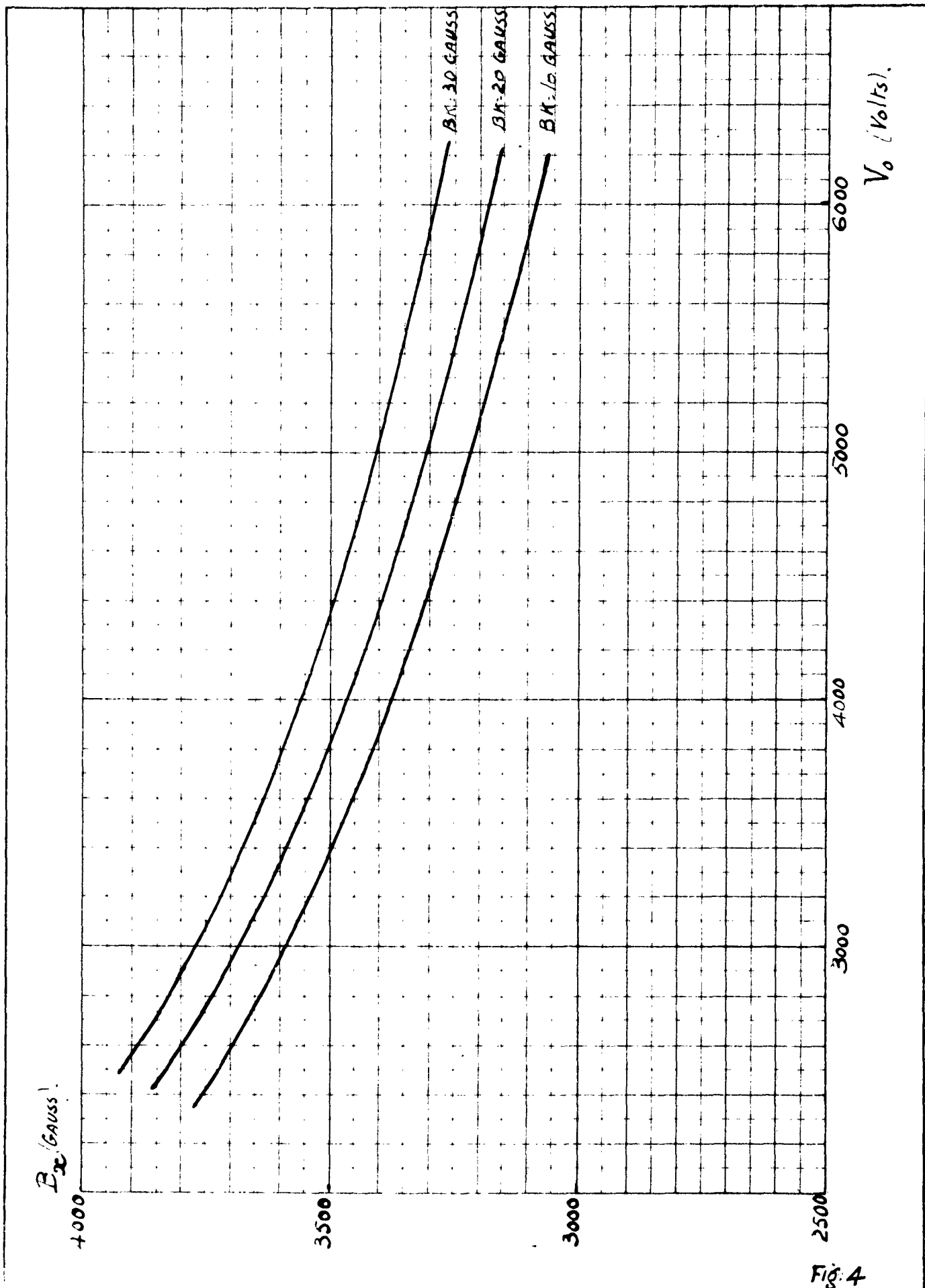


FIG. 4

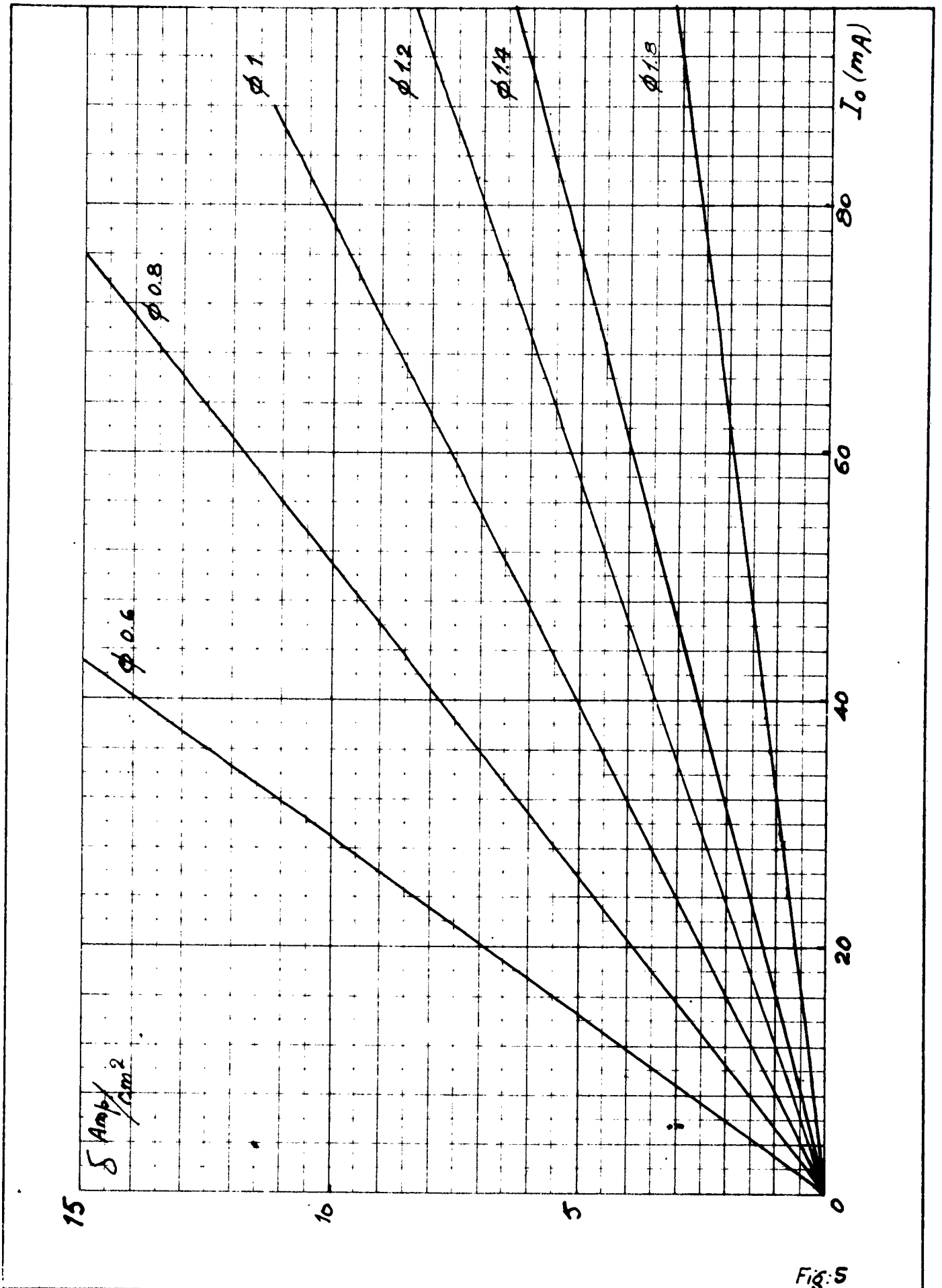
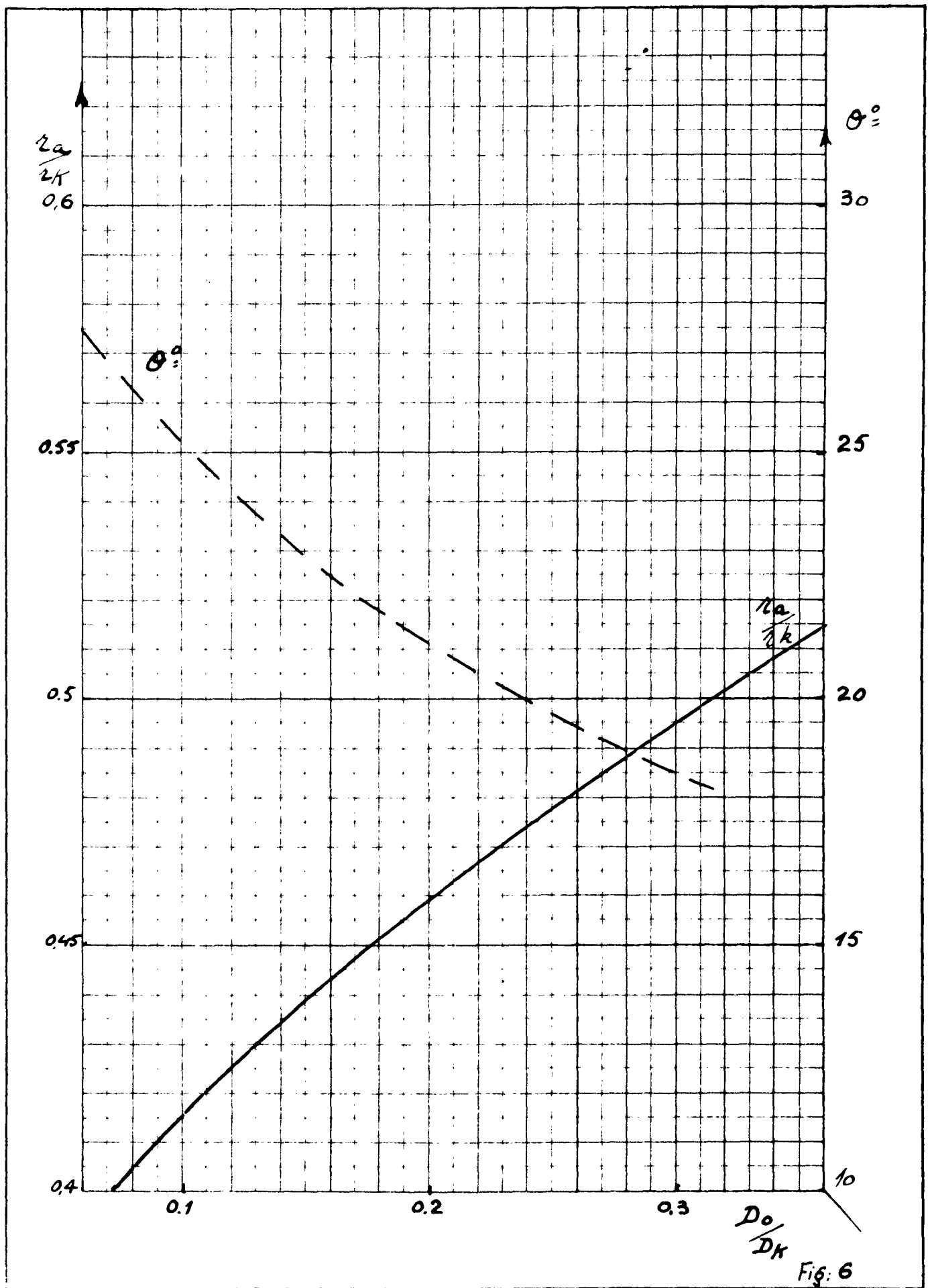


Fig:5



D_o/D_k
Fig: 6

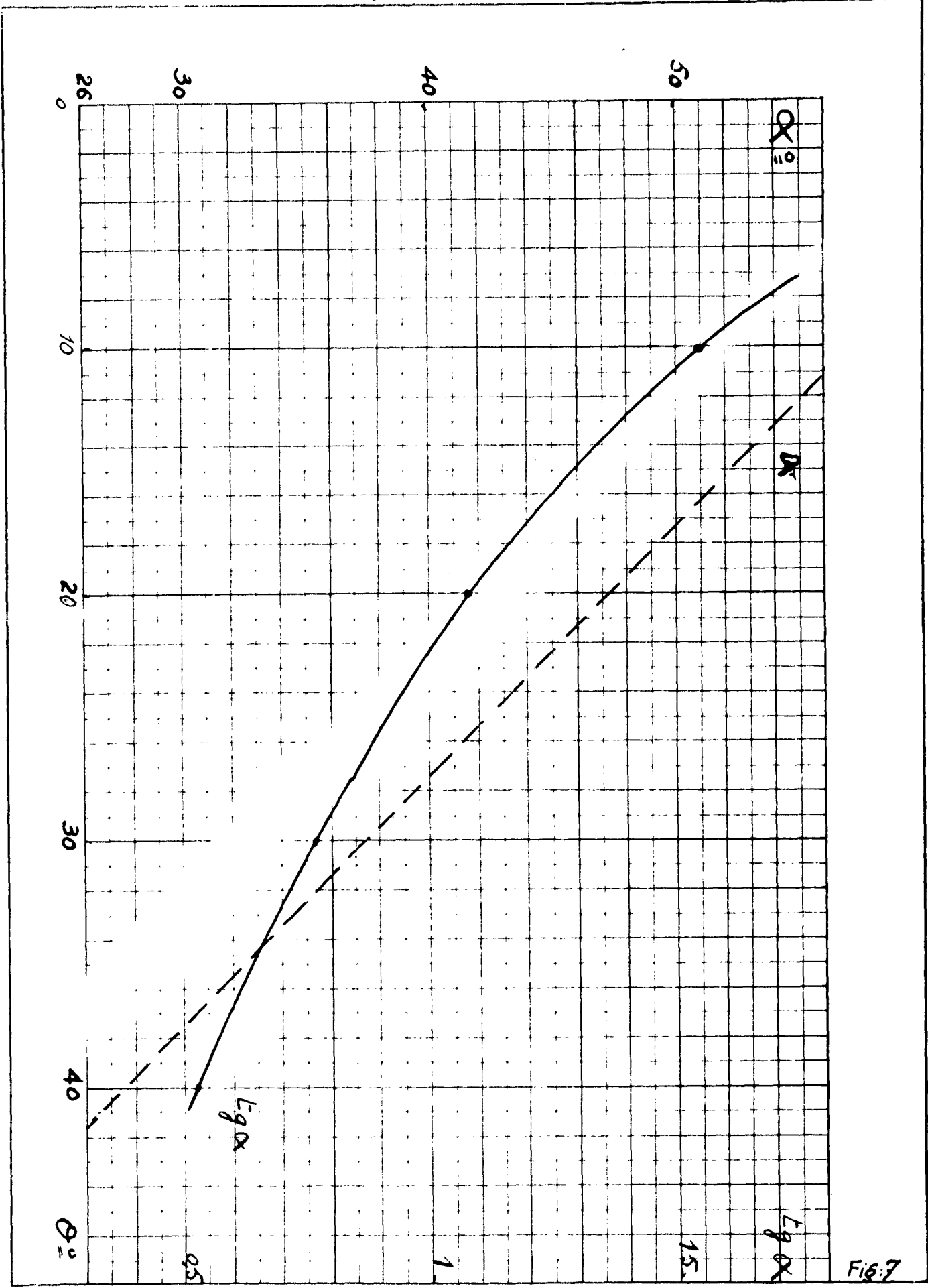


Fig:7

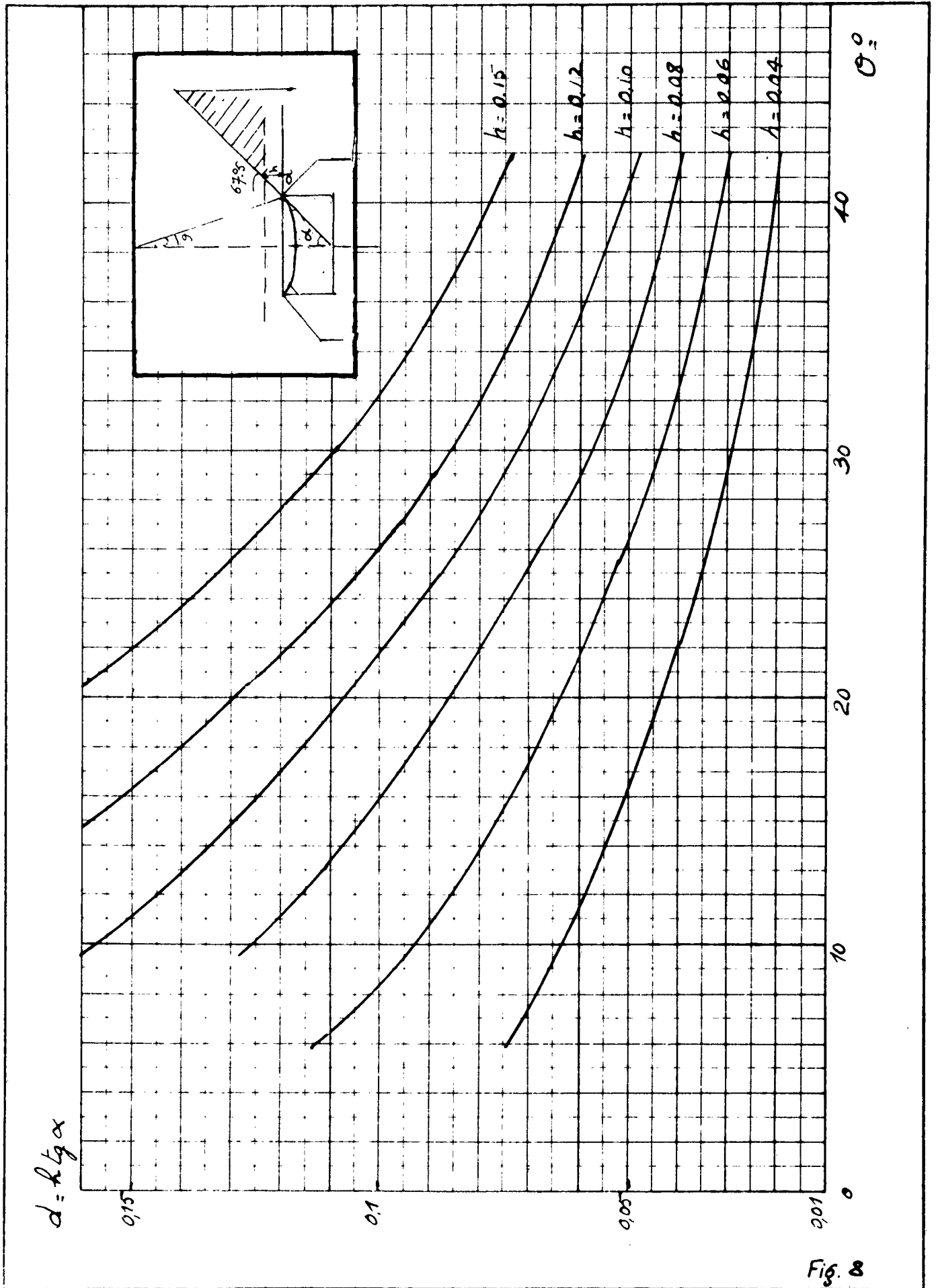


Fig. 8

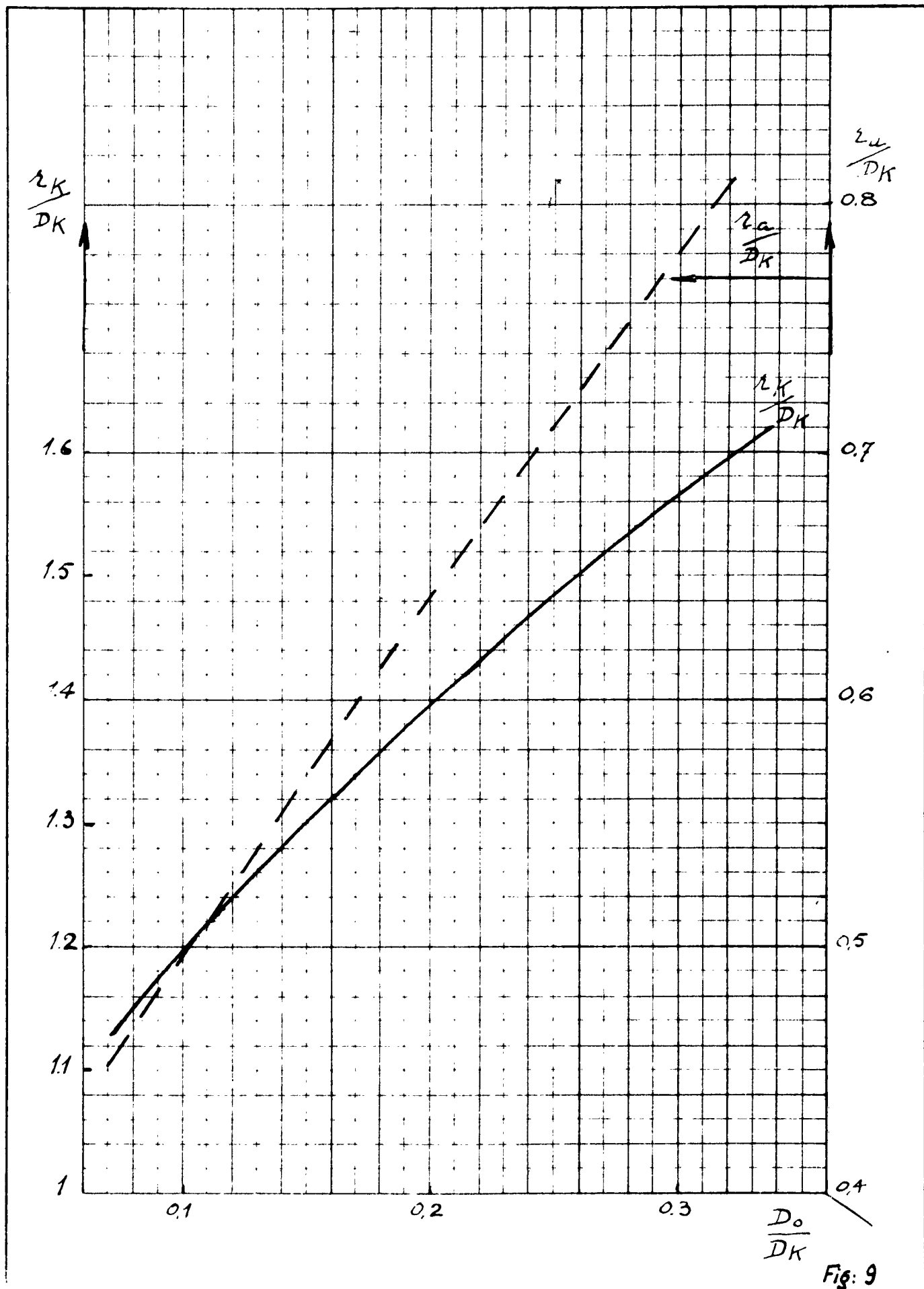
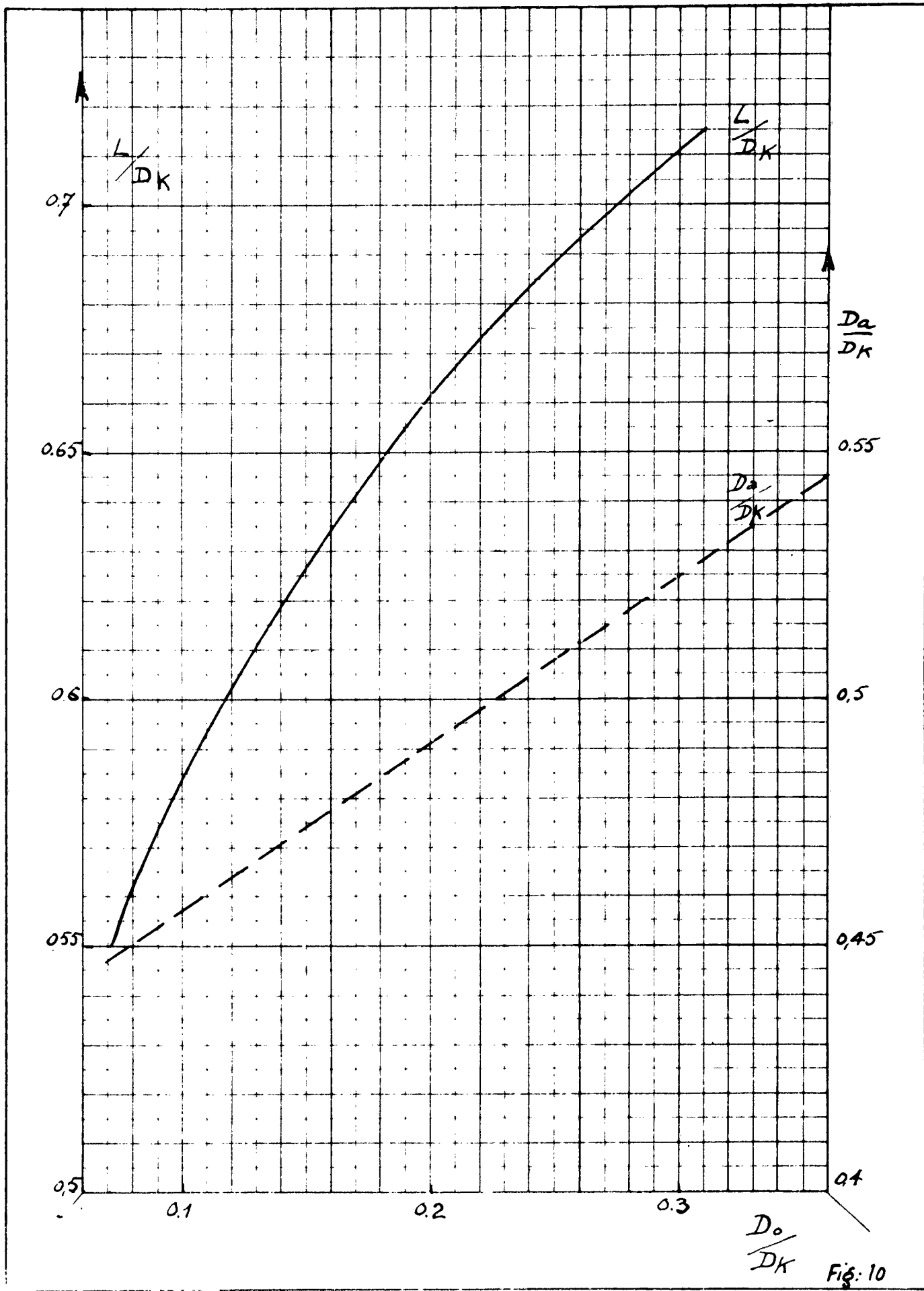


Fig: 9



D_0/D_K

Fig: 10

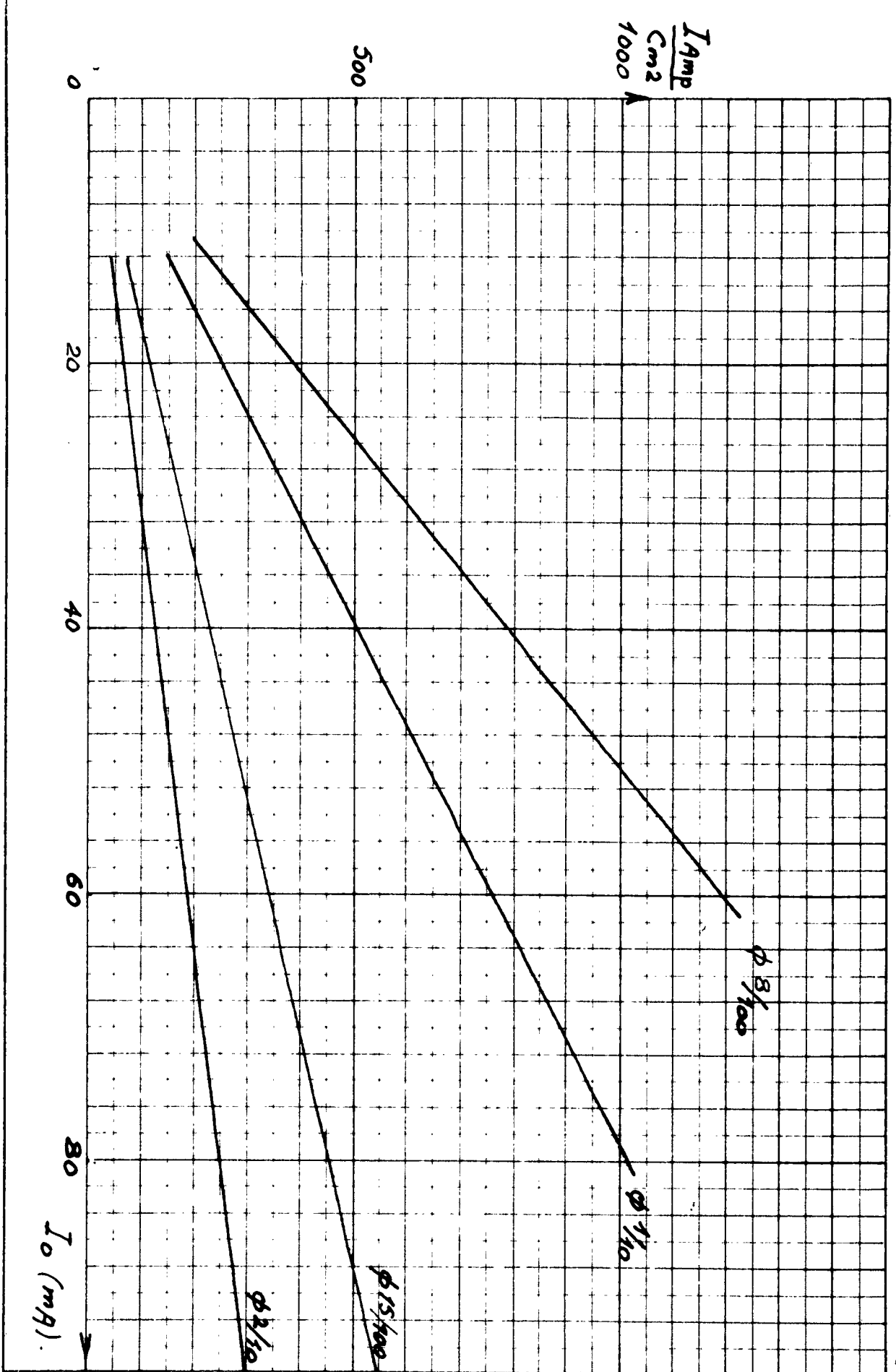


Fig: 11

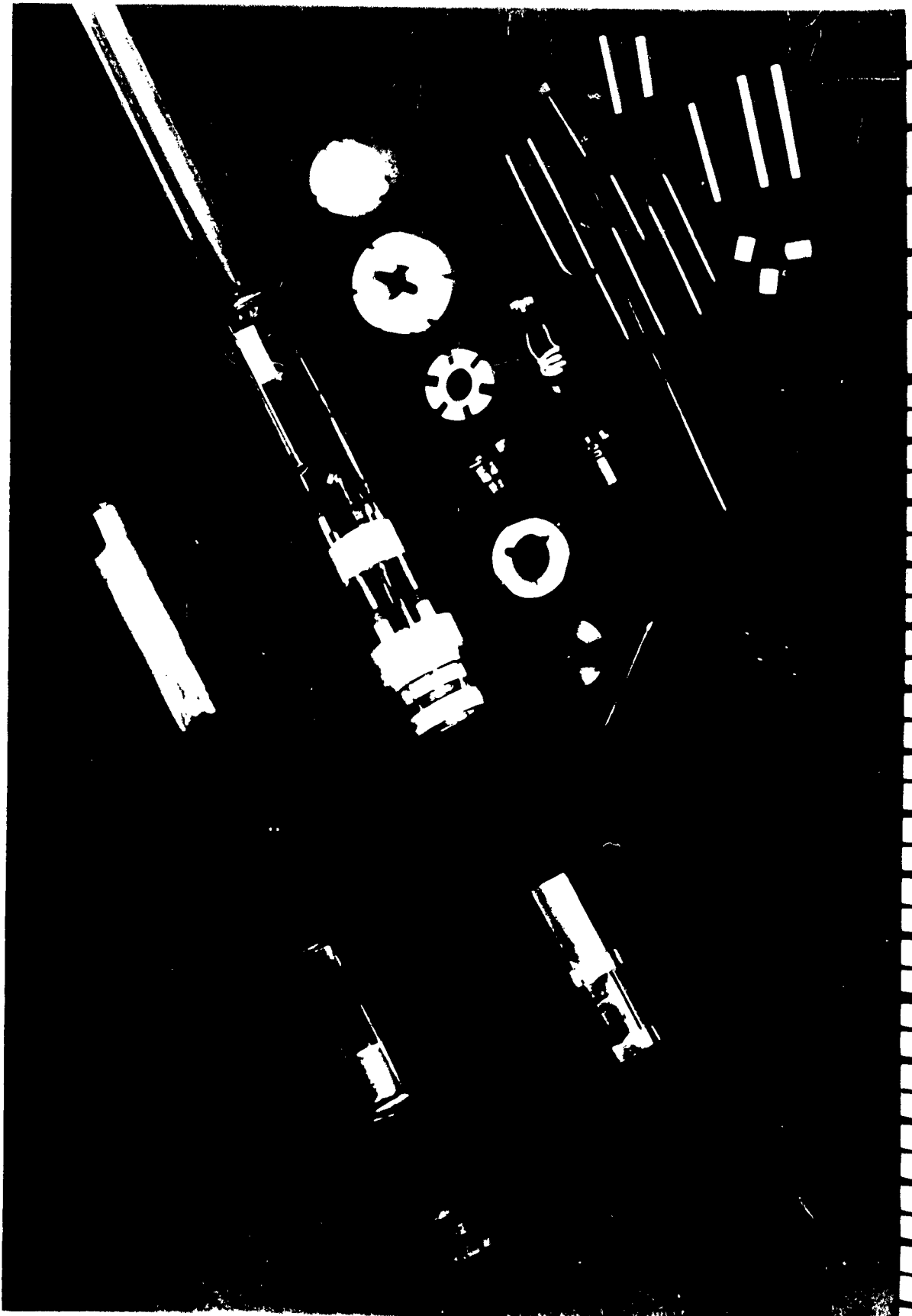


FIG. 12

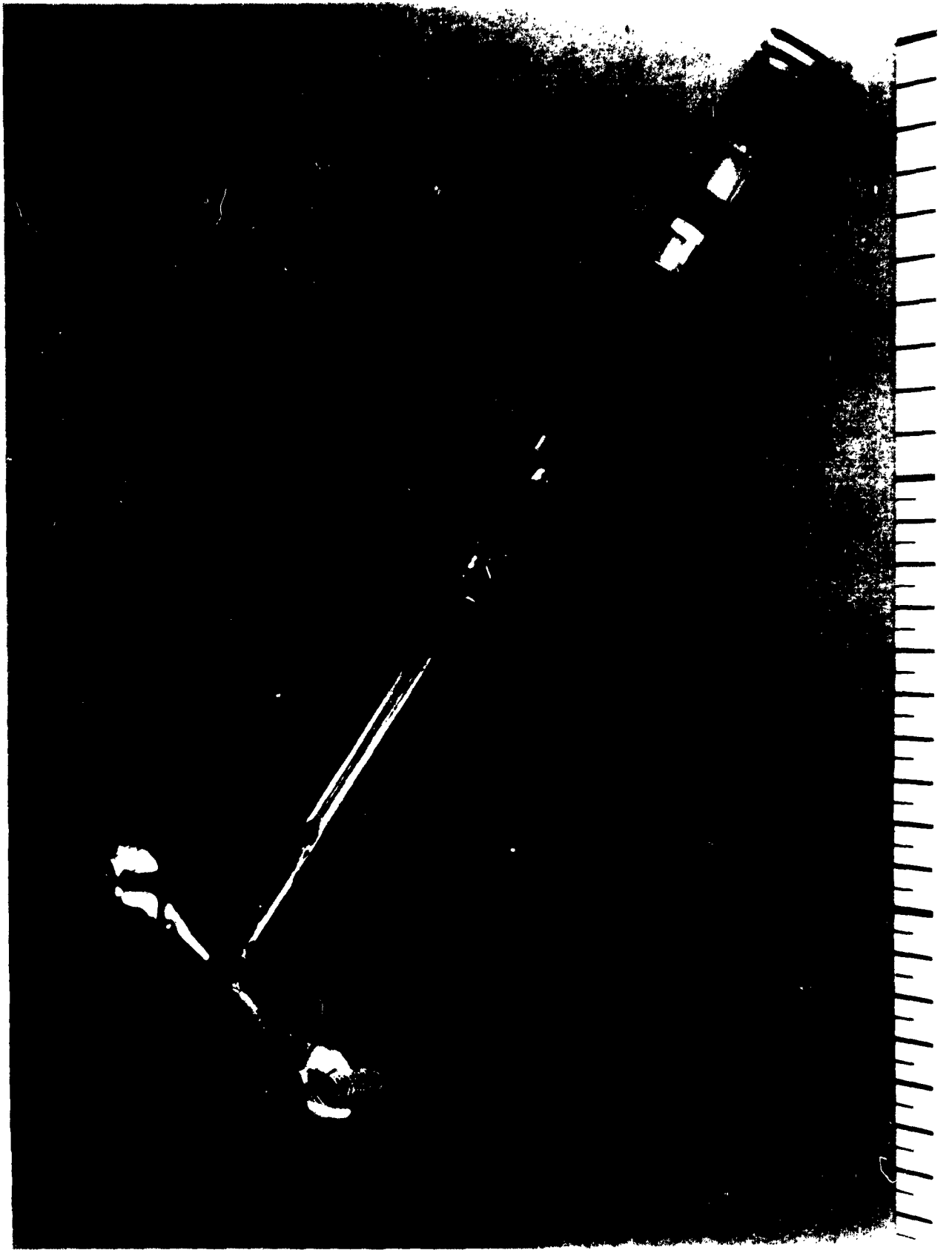
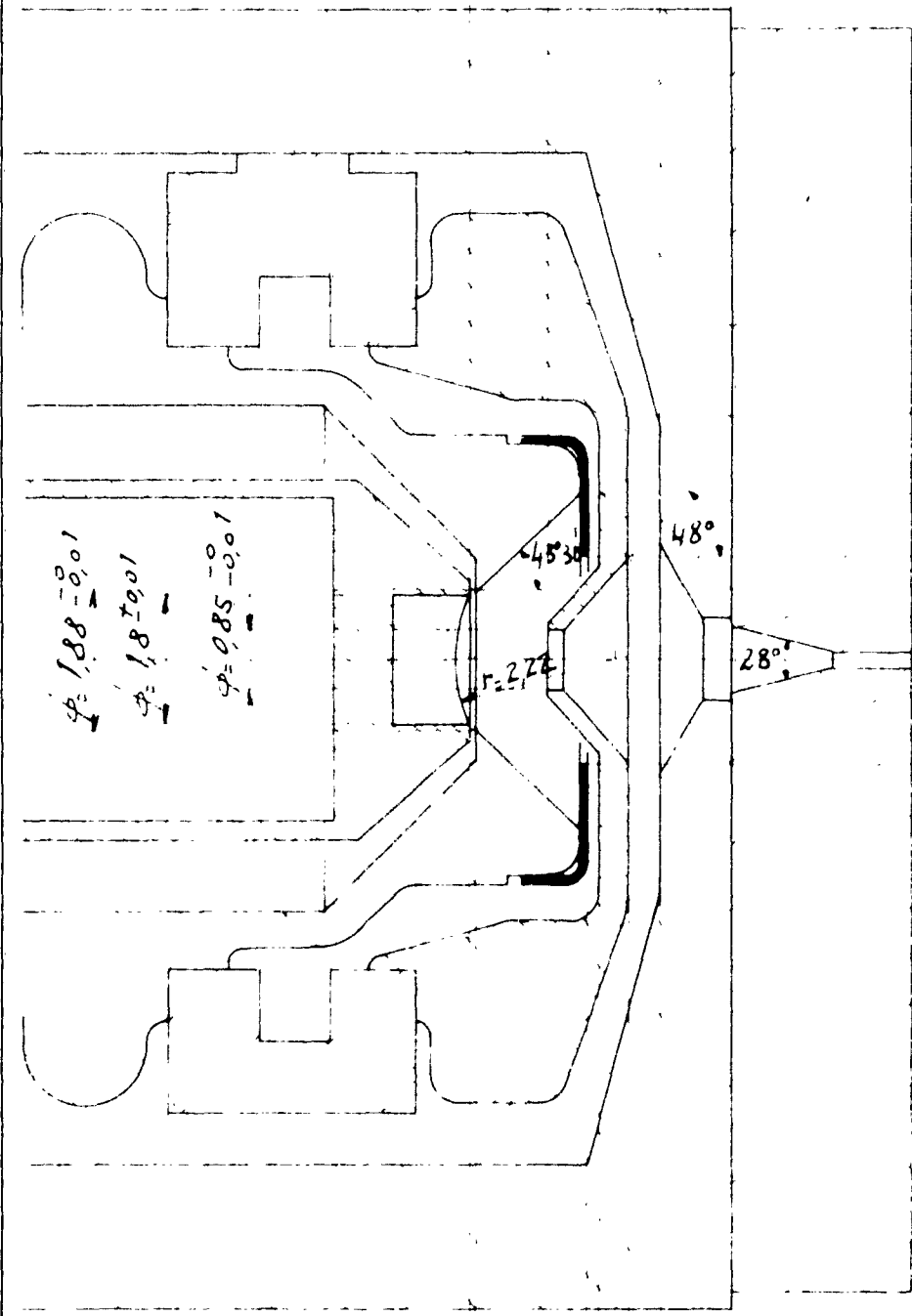


FIG.13

2,58 $\pm 0,02$
1,1 $\pm 0,02$



$\phi = 0,2 \pm 0,01$
 $\phi = 0,9$
 $\phi = 1,2 \pm 0,02$
 $\phi = 2,9 \pm 0,01$

$0,04 \pm 0,01$
 $0,2 \pm 0,02$
 $0,4 \pm 0,02$

Fig: 14

"GUN" COC-20-II.8

HOLE DIAMETER: 25100 mm

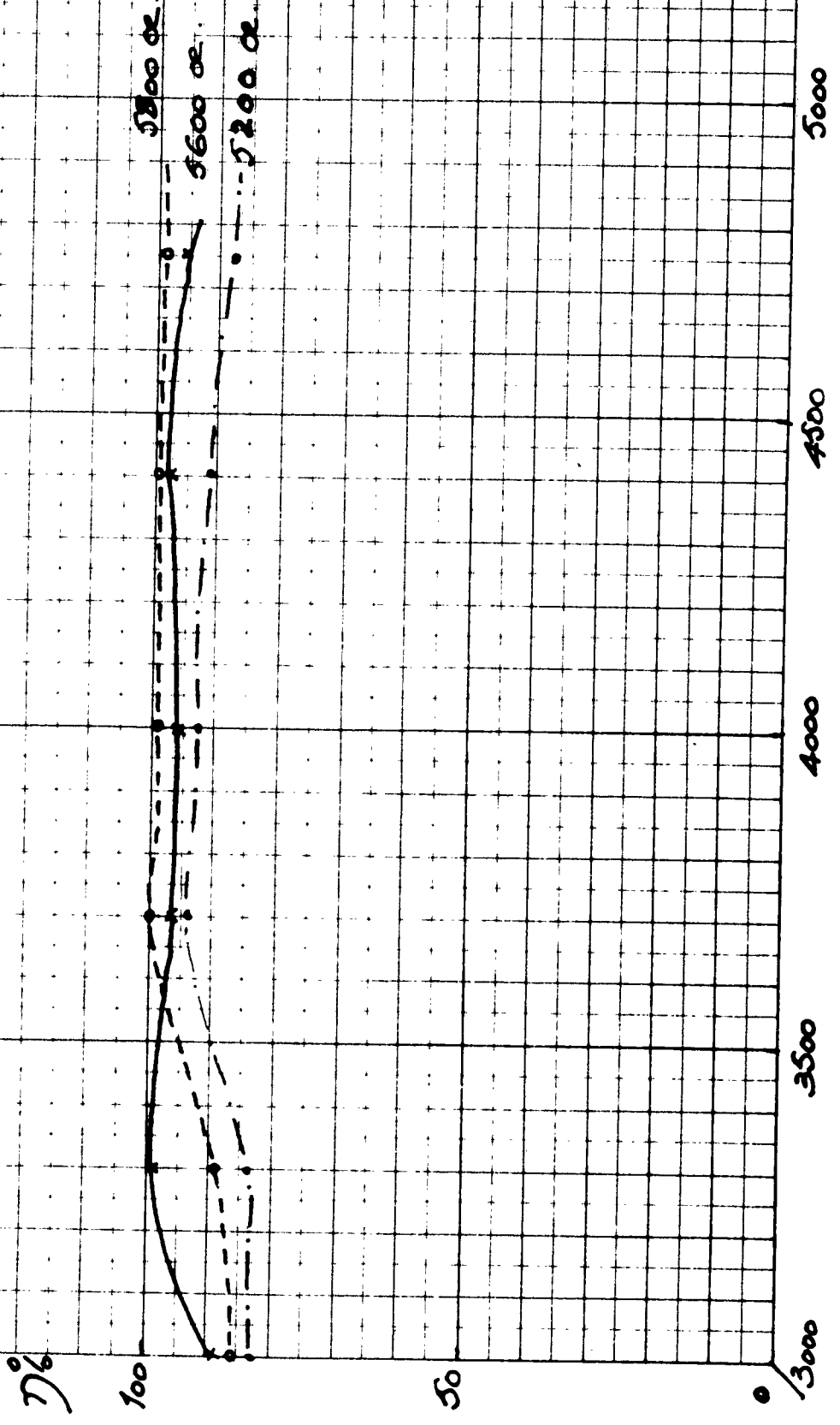


Fig: 16

"GUN" COC-20-II-B

$V_A = 1170 \text{ V}$

$I_0 = 45 \text{ mA}$

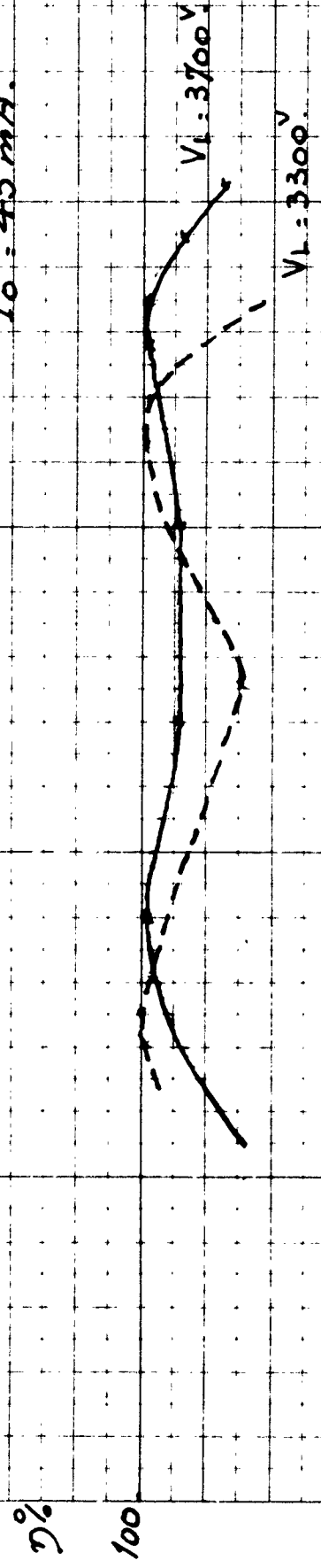


Fig: 17

ELECTRONIC GUN CO.C20.II.7

OPTIMUM EFFICIENCY

100
50
0/10

Magnetic field

Line Voltage

5750 oe 3250 V

5750 oe 3500

5900 oe 3600

5800 oe 3400

5850 oe 3400

5750 oe 3200

5600 oe 3000

5500 oe 3100

5200 oe 2800

5300 oe 2800

CATHODE CURRENT
(mA)

100
90
80
70
60
50
40
30
20
0/10

Fig: 18

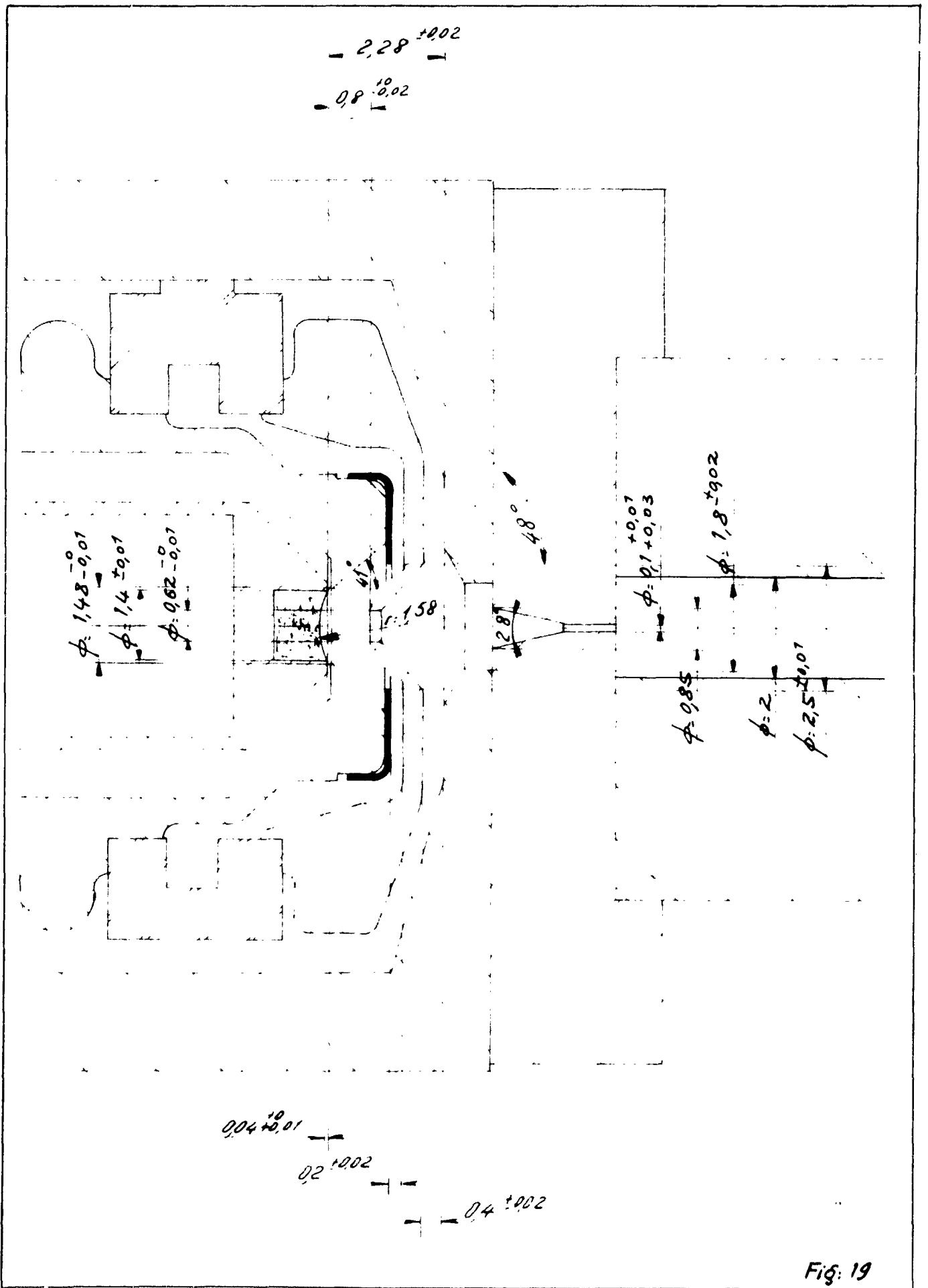


Fig: 19

"GUN" COC. 10. I.

HOLE DIAMETER: $2/10$ mm

$N = 5500$ carstecks

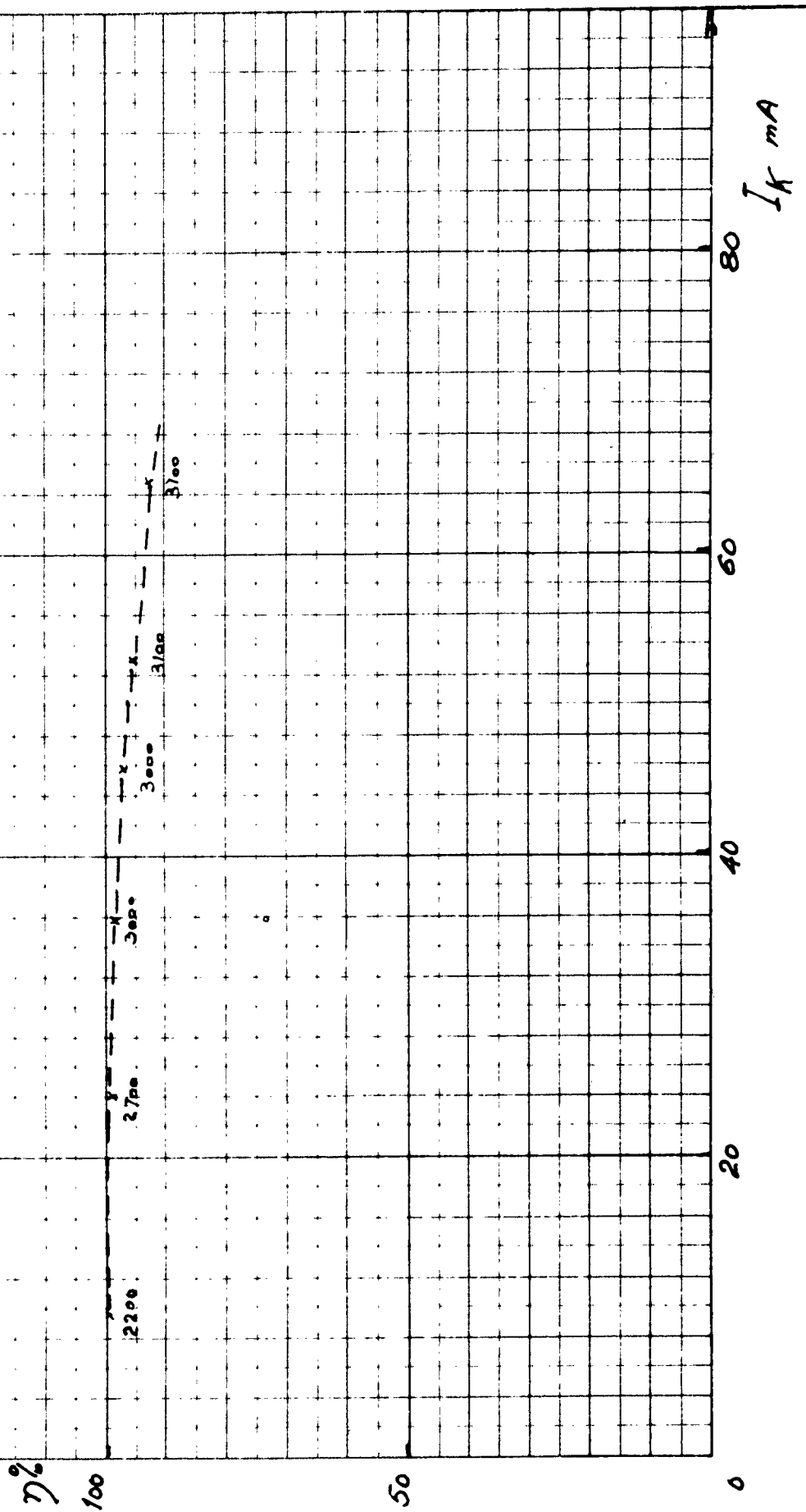


Fig: 20

1" GUN' COC-10-I

$H = 5600$ volts

$I_k = 32$ mA

SOLE DIAMETER: $2/10$ mm

$\eta\%$

100

50

0

2000

2500

3000

3500

4000

LINE VOLTAGE (VOLTS)

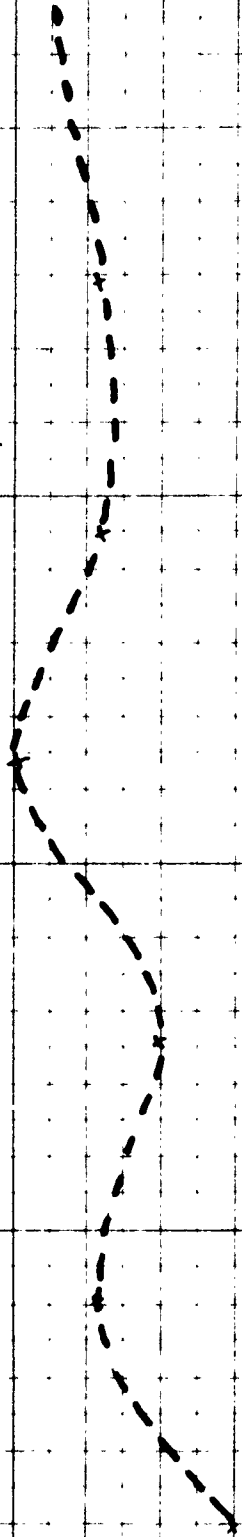


Fig: 21

"GUN" C.O.C. 10. I -

SOLE DIAMETER: $2/10$ mm

$V_L = 3150$ VOLTS.

$I_A = 32$ mA.

%

100

50

0

0/1000

5000

6000

Hørstedts.

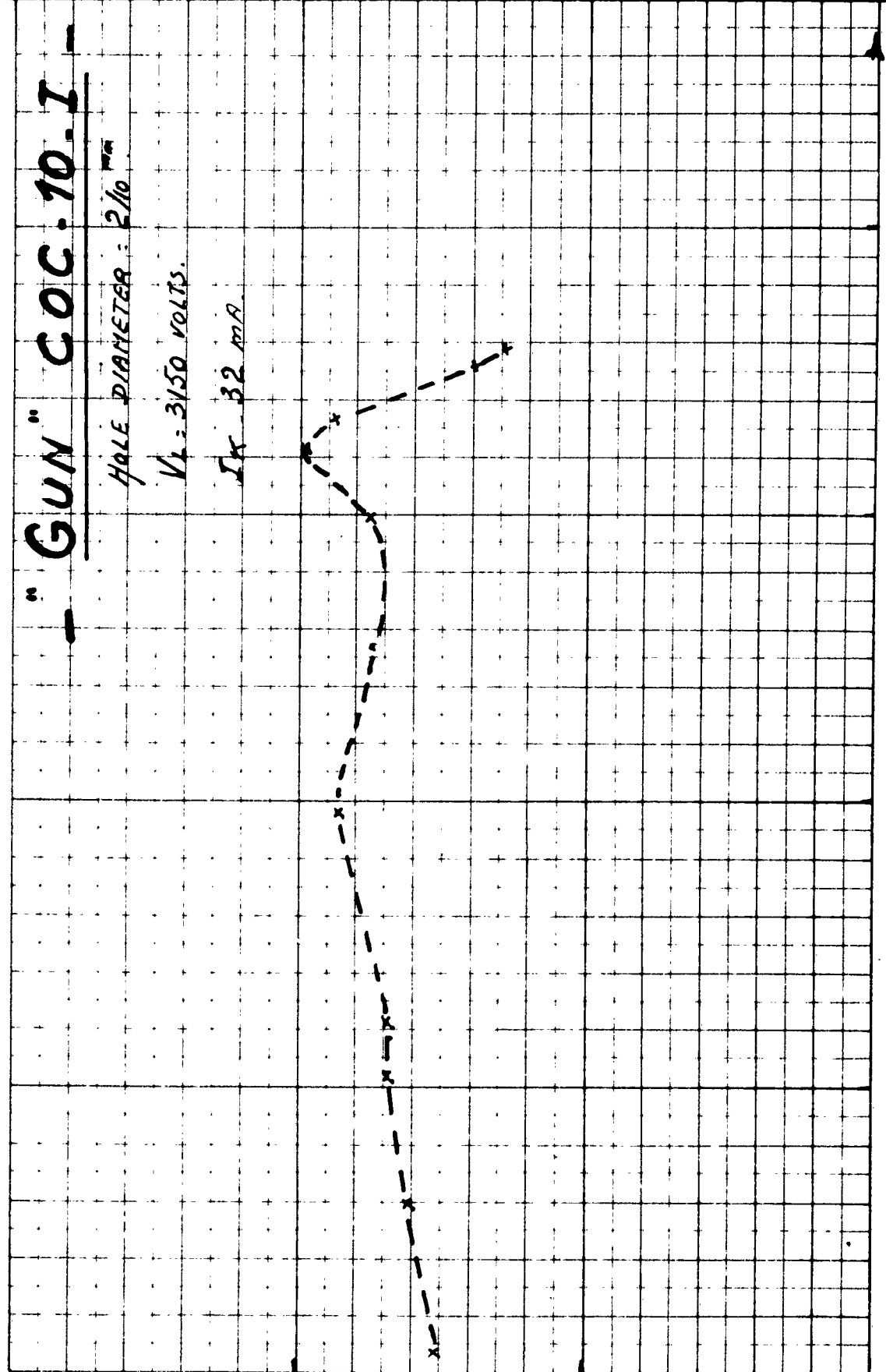


Fig:22

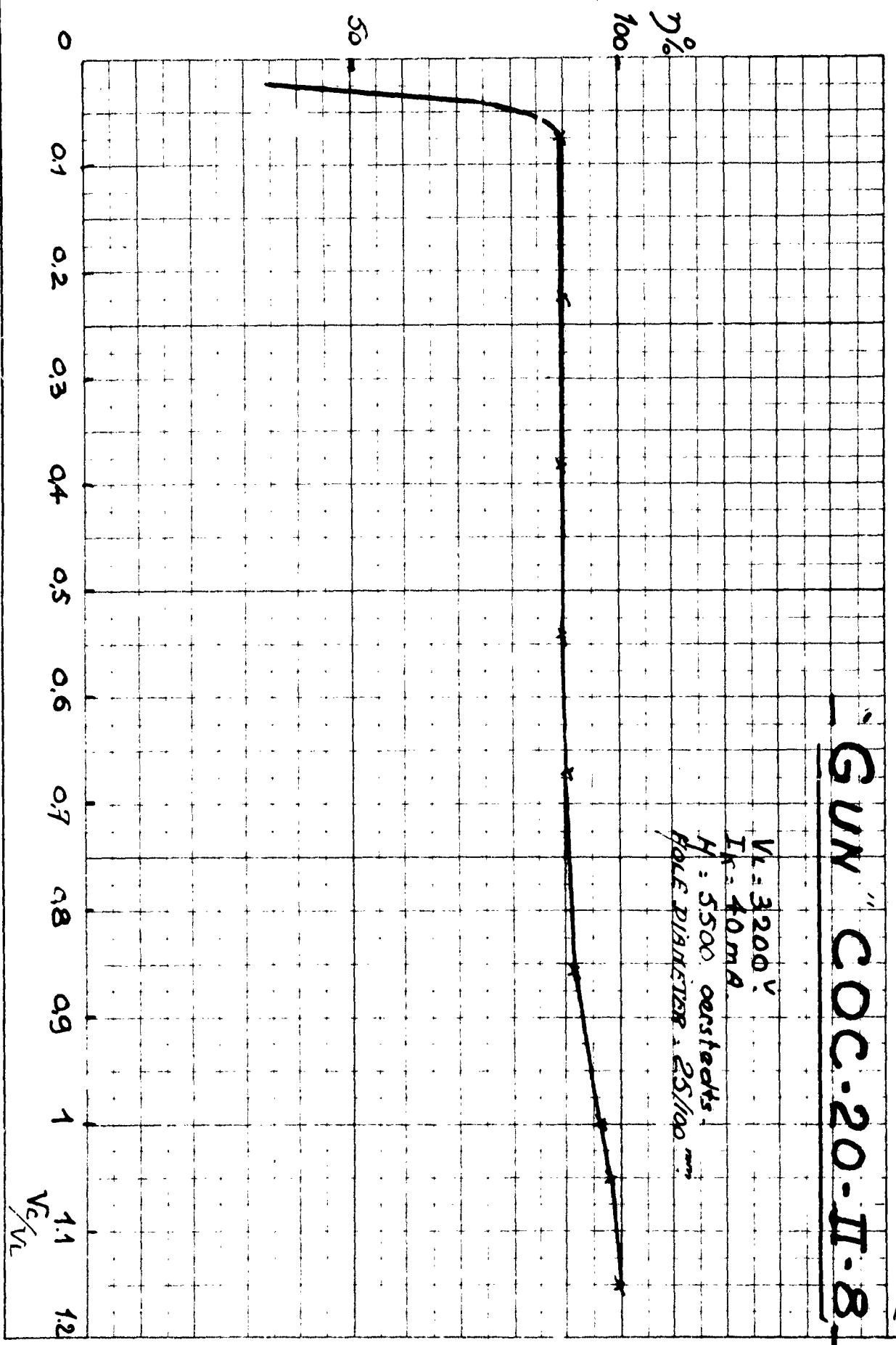


Fig: 23

"GUN" COC-10-I

HOLE DIAMETER : 2/10 mm

$I_f = 30 \text{ mA}$
 $V_f = 3000 \text{ Volts}$
 $H = 5600 \text{ PERCENTS}$

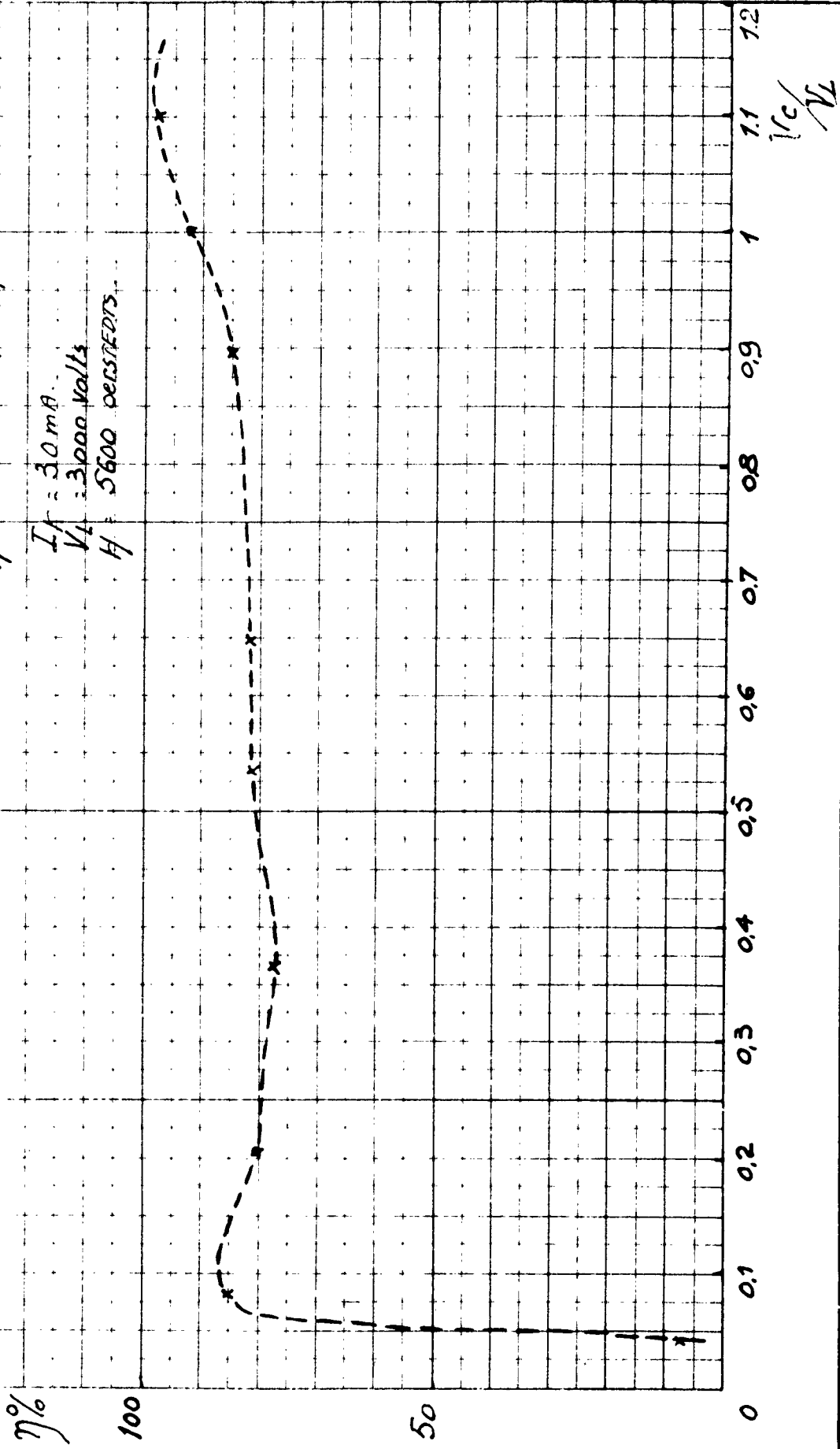


Fig: 24

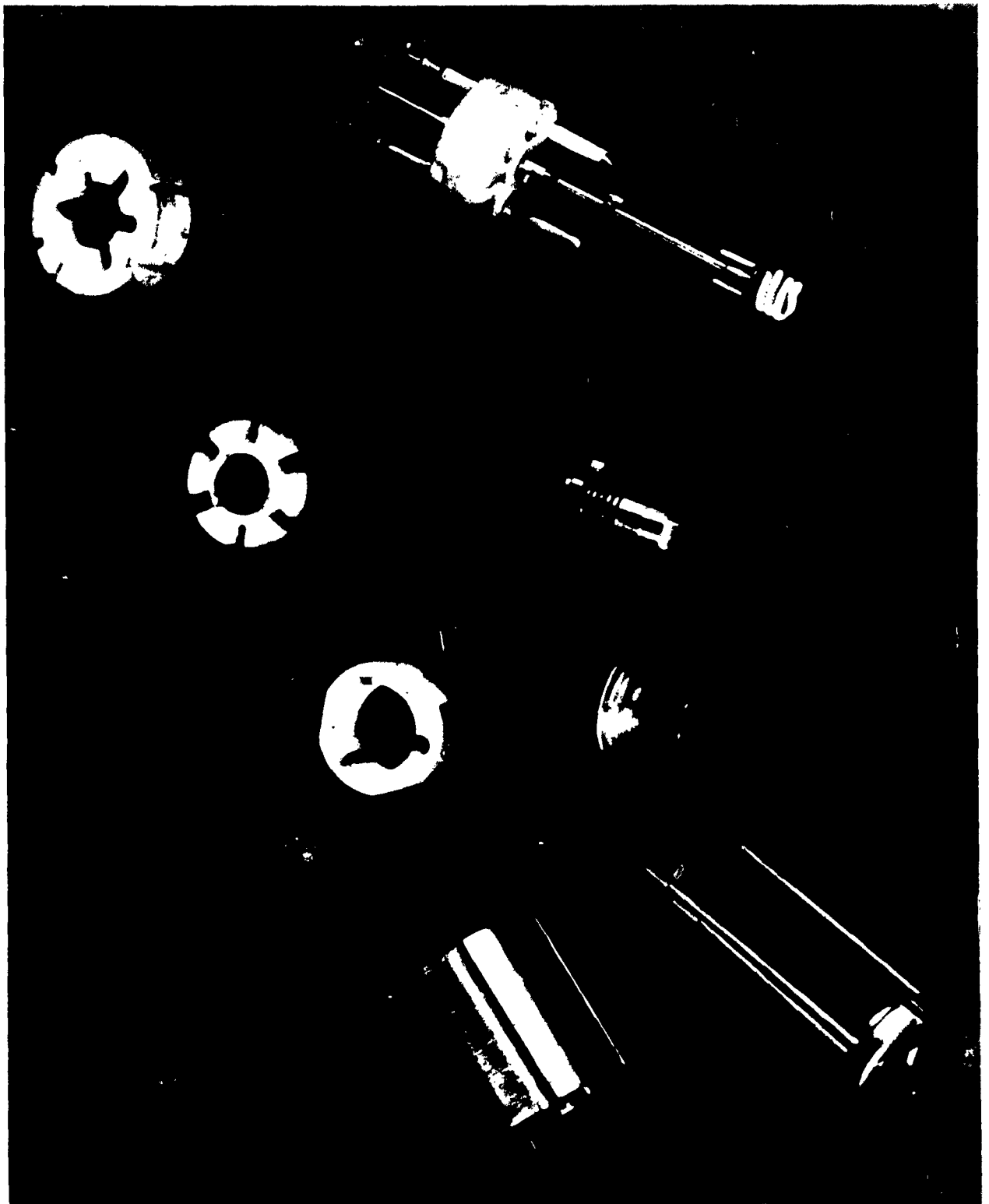


FIG. 25



FIG.26

RECTANGULAR BEAM GUN (section: 0.8 x 0.4 mm)

- Magnetic Field: 4000 Oe -

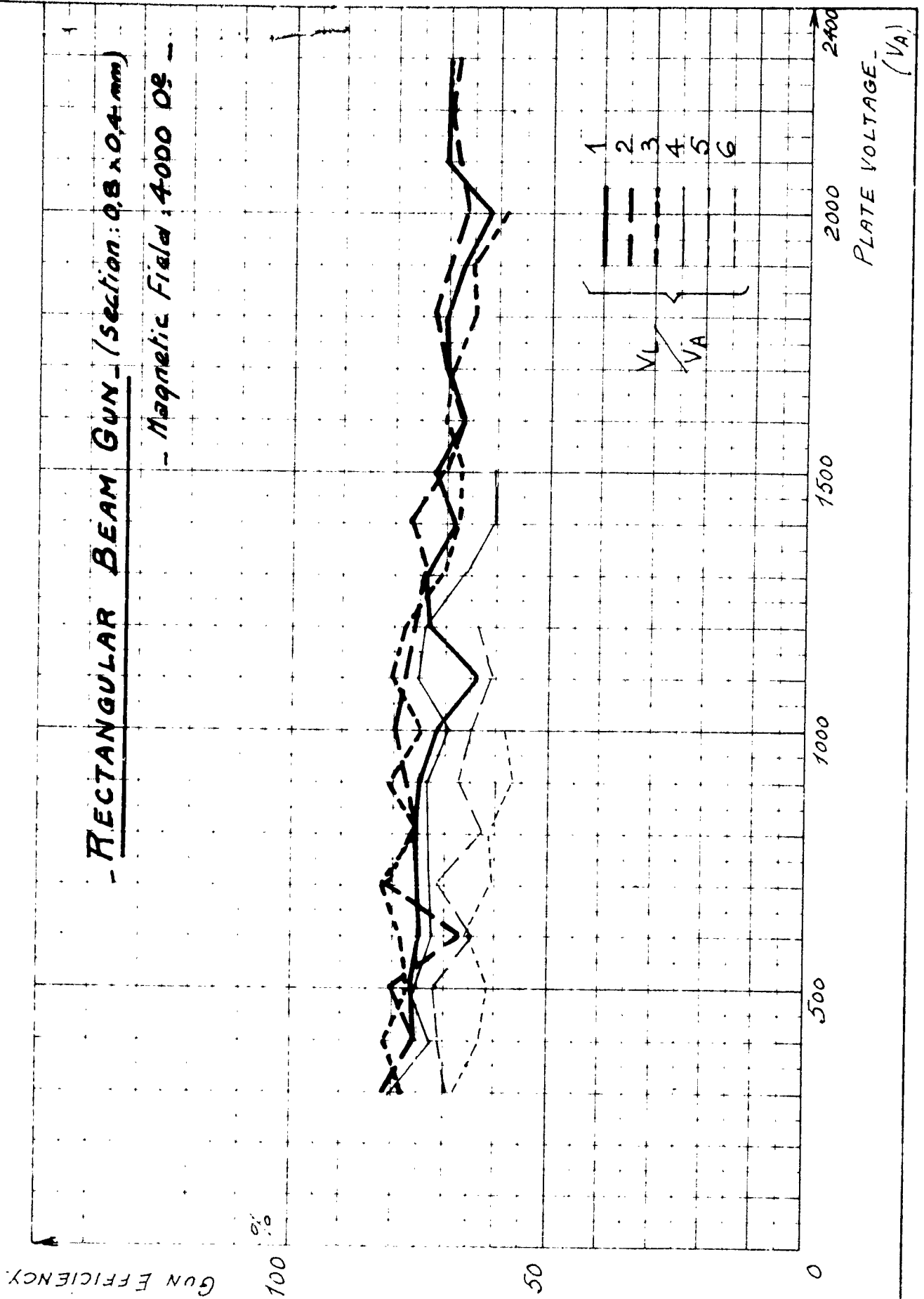


Fig: 27

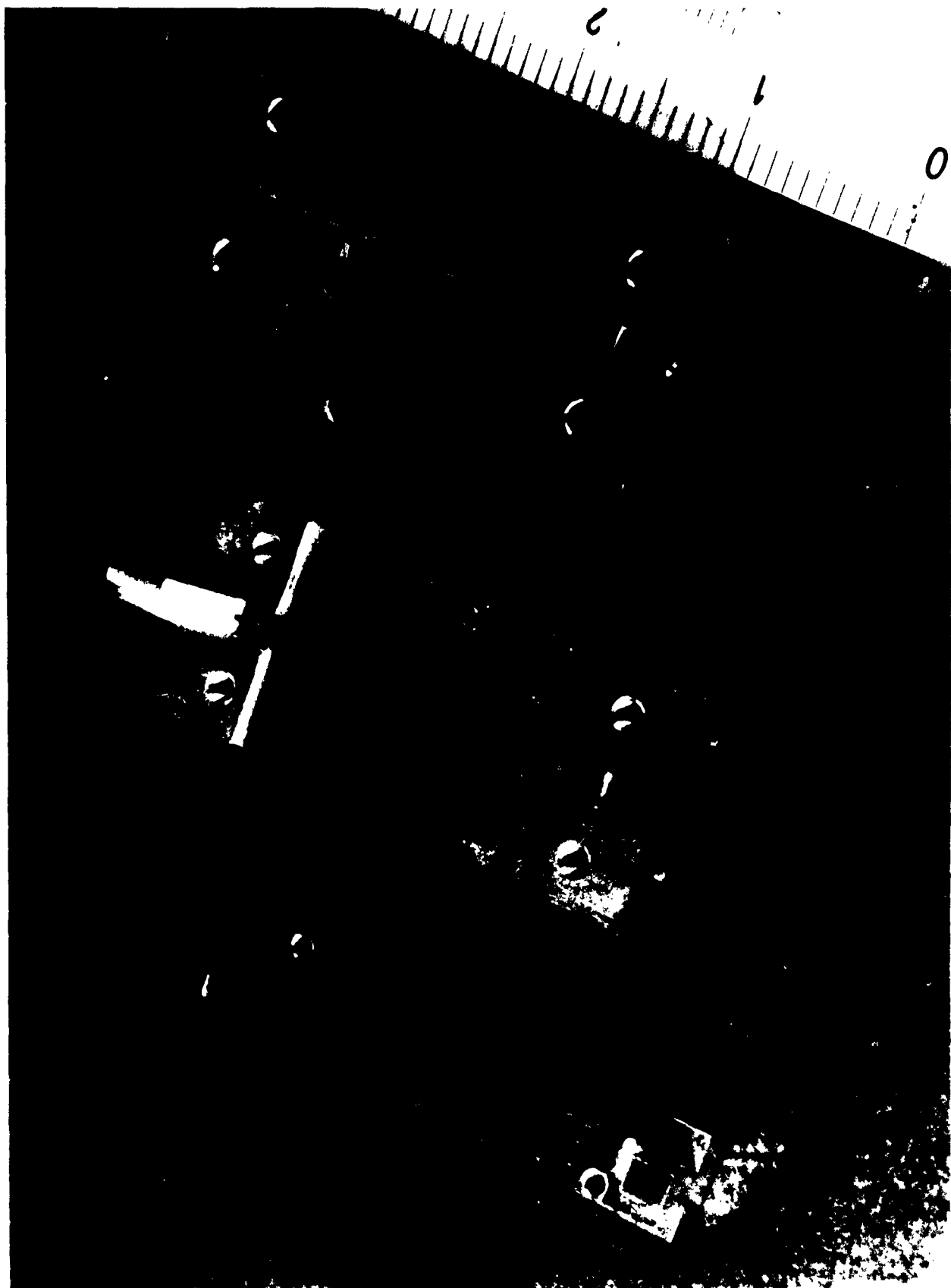
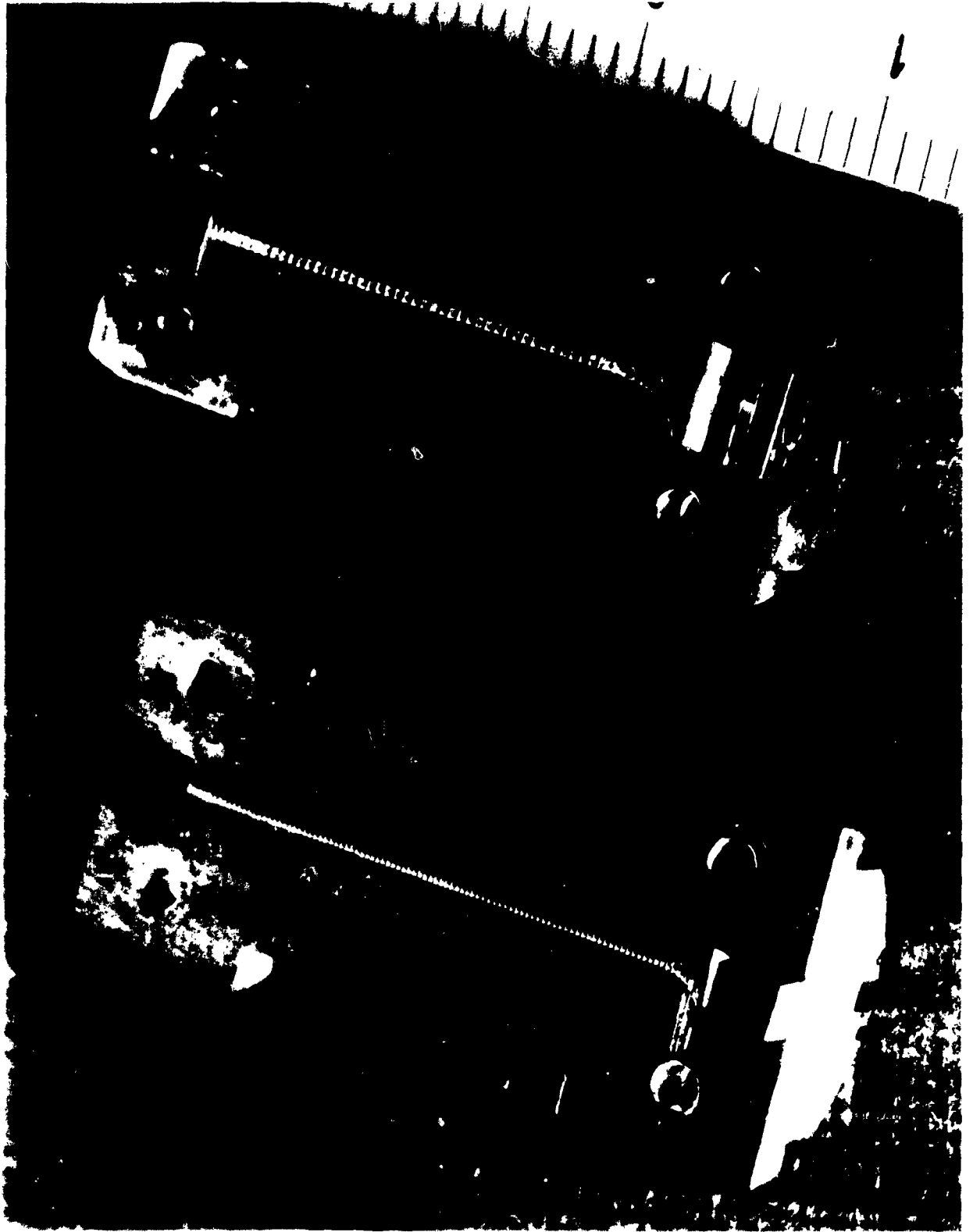


FIG. 28



PT. 100



FIG. 30

VANE LINE

PITCH: 6.25 mm

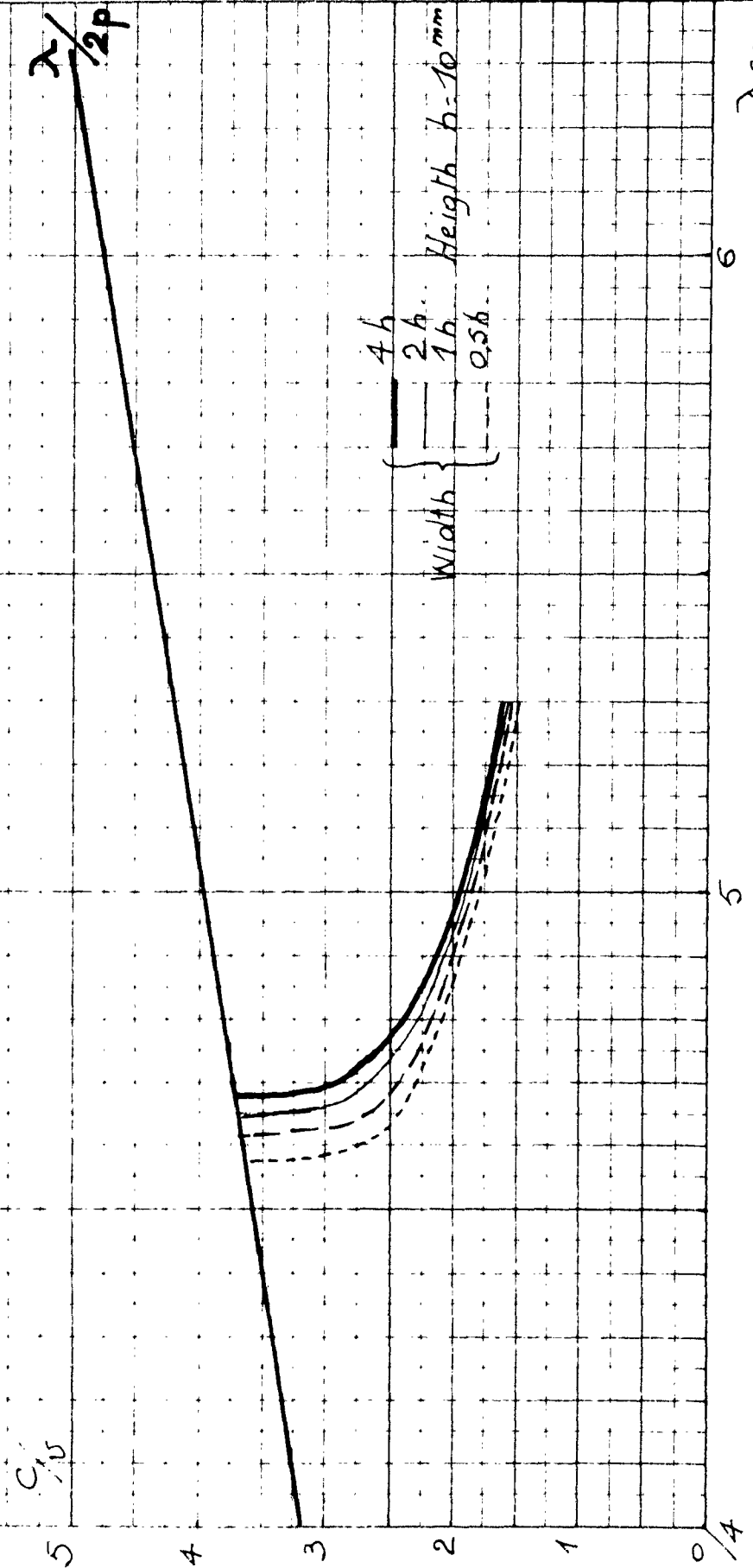


Fig: 31

- VANE LINE -

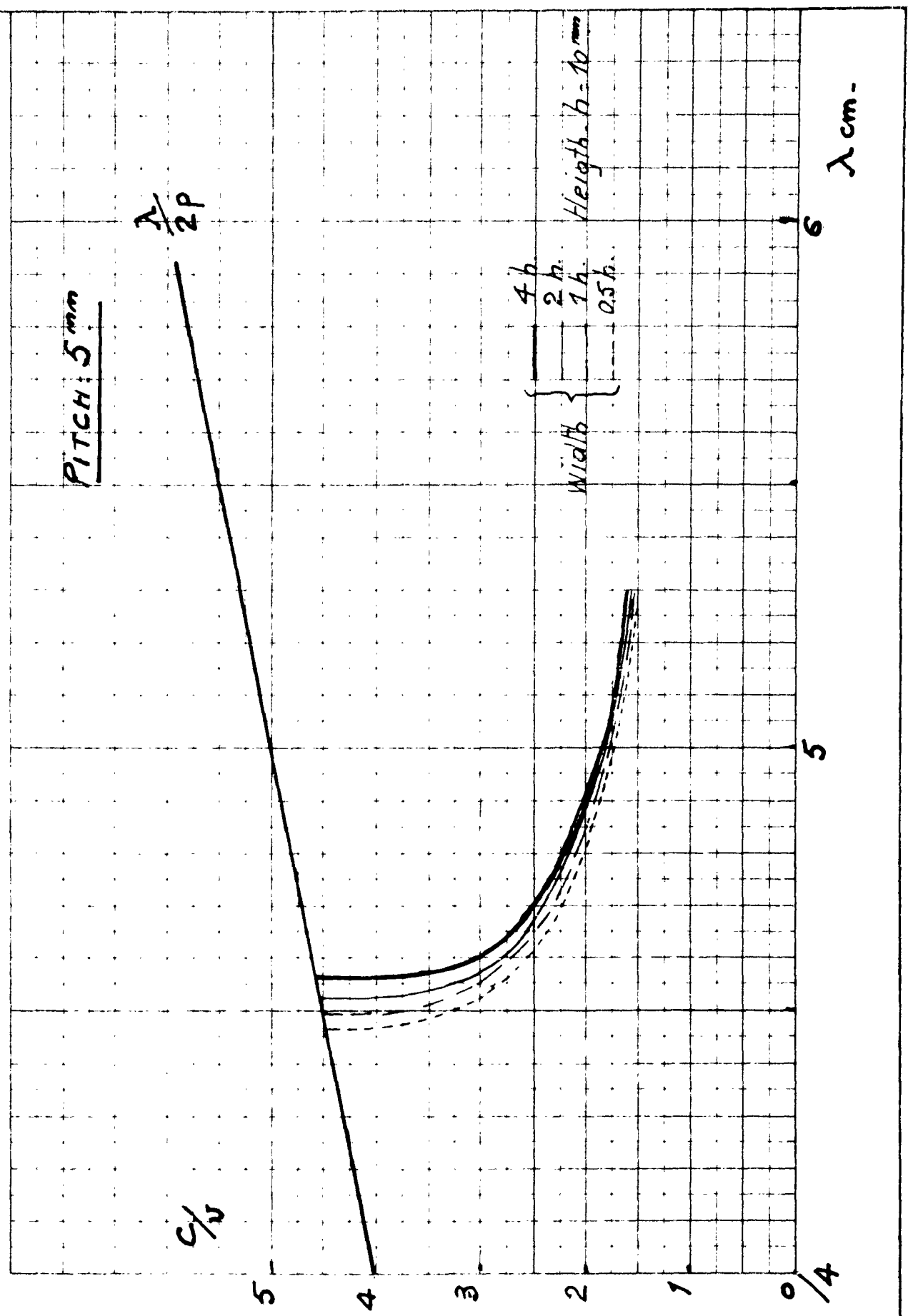
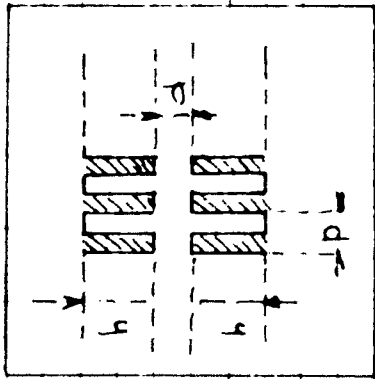


Fig: 32

DISPERSION CURVES OF SYMMETRIC DOUBLE VANES LINES -



$p = 6.35 \text{ mm} \quad h = 16.25$

Ⓐ $d = p$

Ⓑ $d = 2p$

$\frac{c}{\nu}$

$\lambda \text{ cm.}$

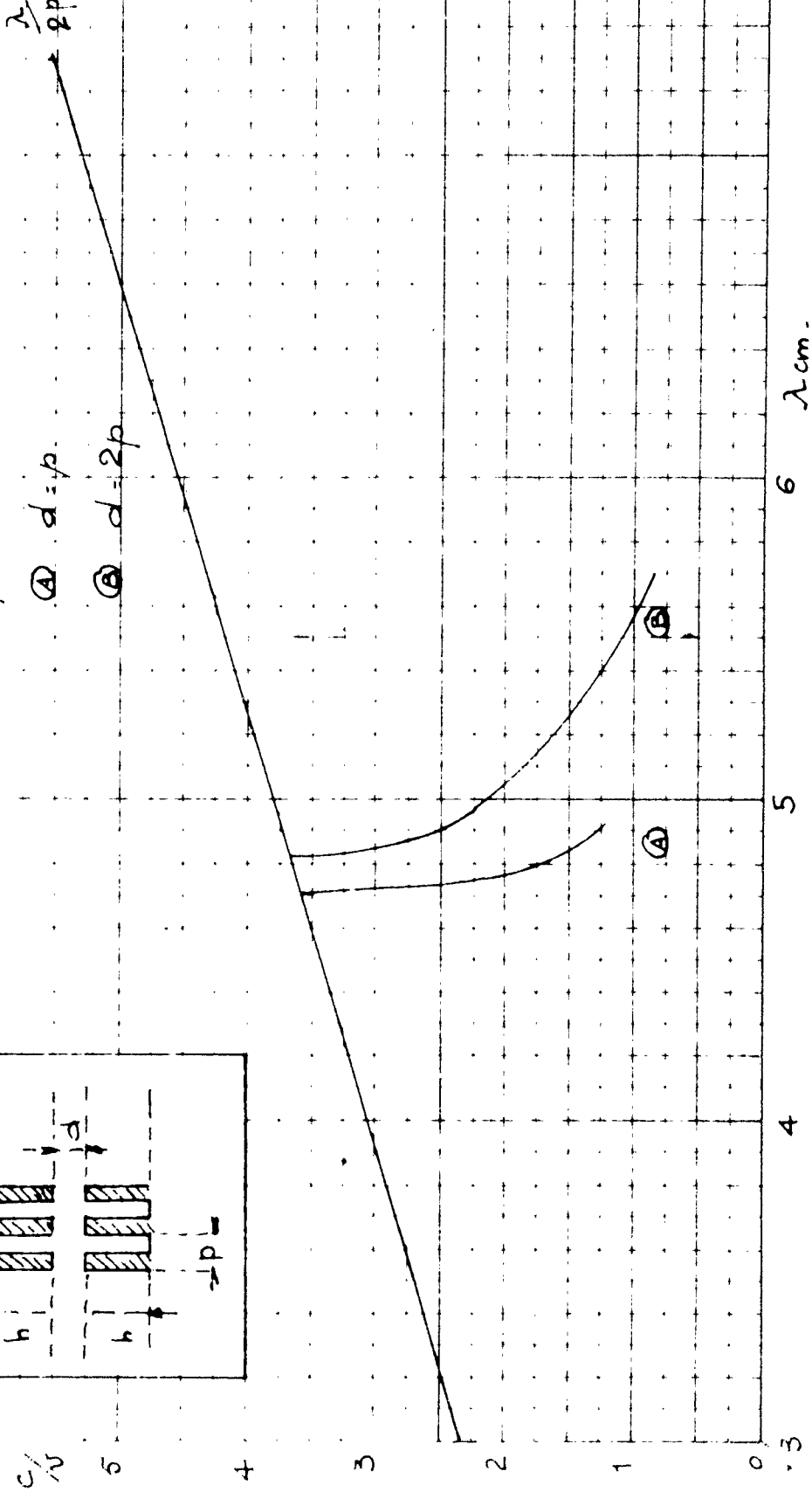


Fig: 33

DISPERSION CURVES OF DOUBLE VANES DECALED OF $\frac{1}{2}$ PITCH

$(P = P/2)$

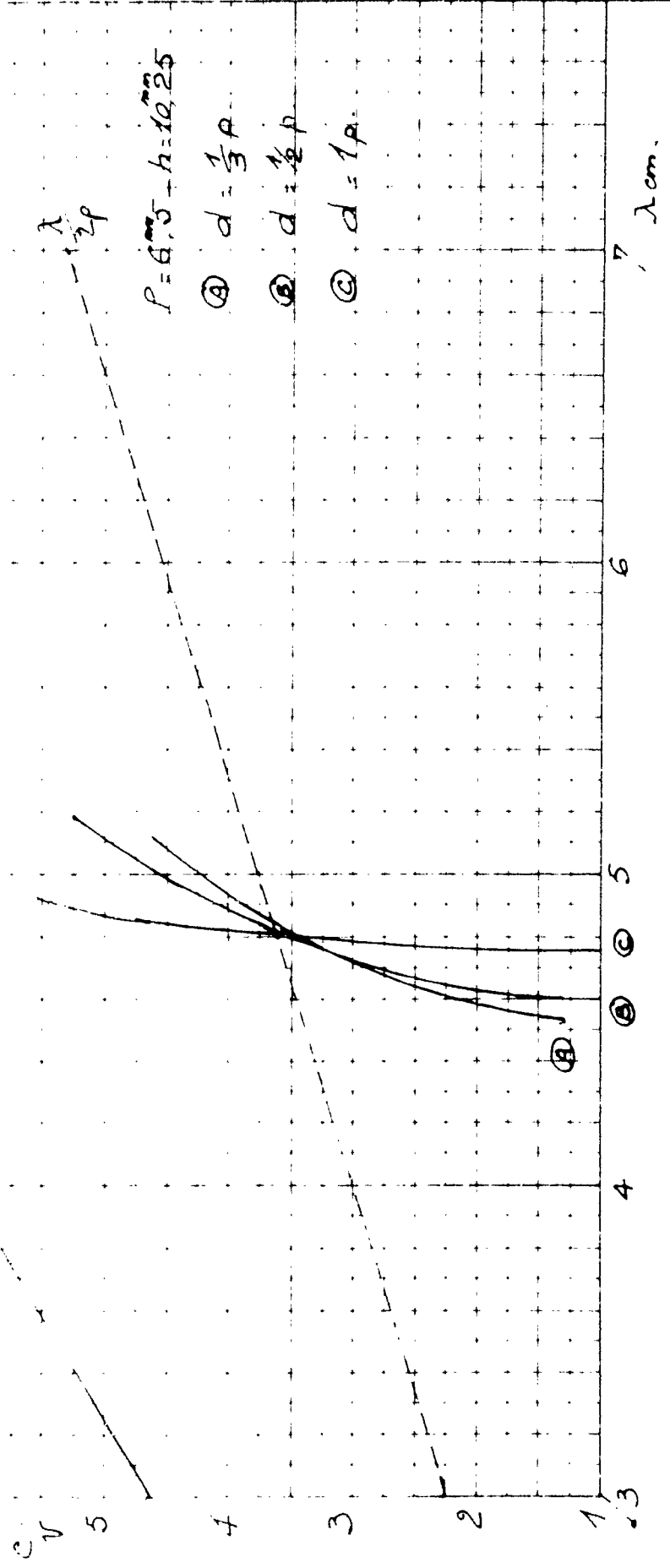
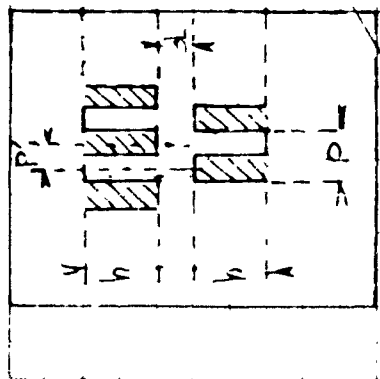


Fig: 34

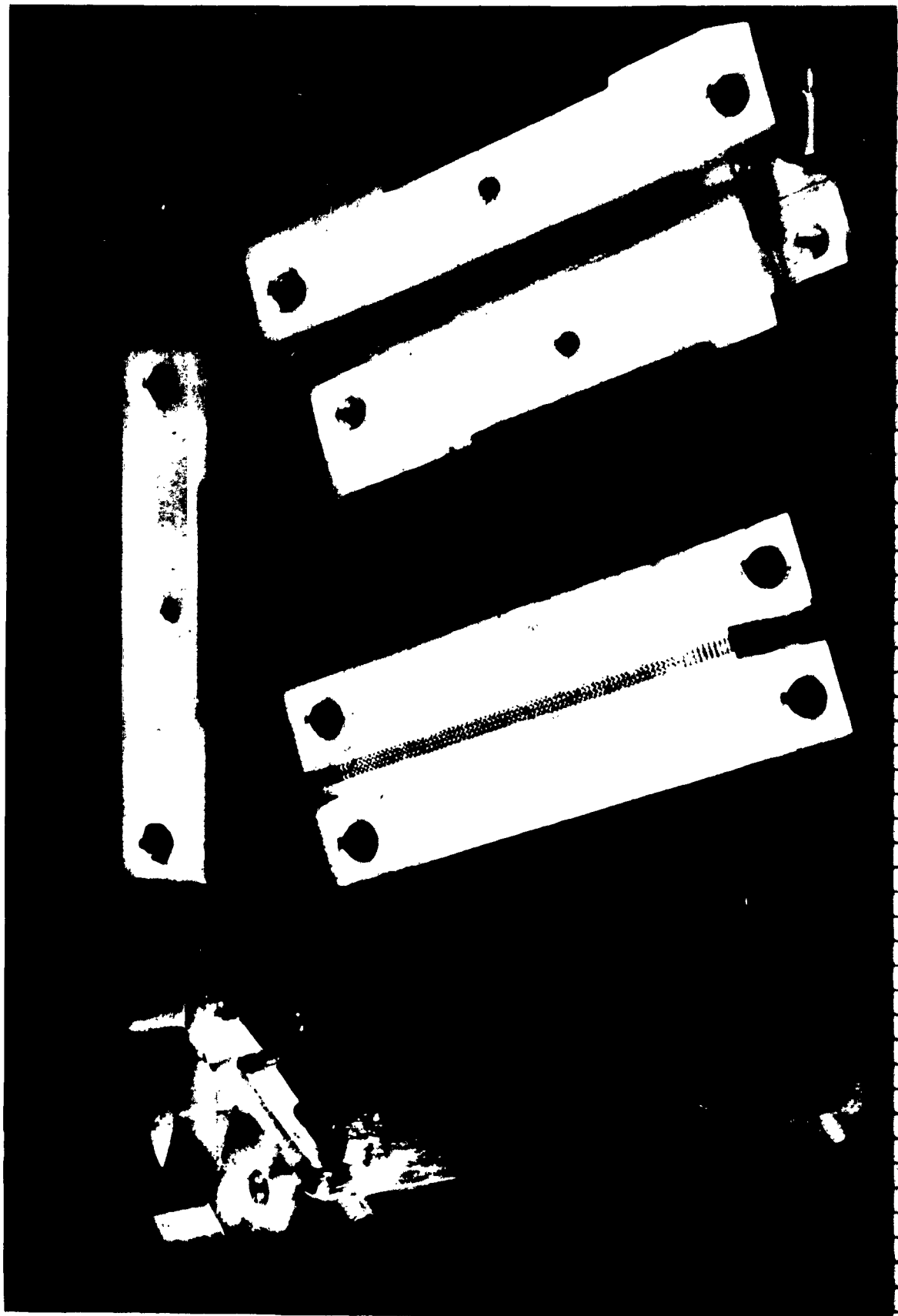


FIG. 35

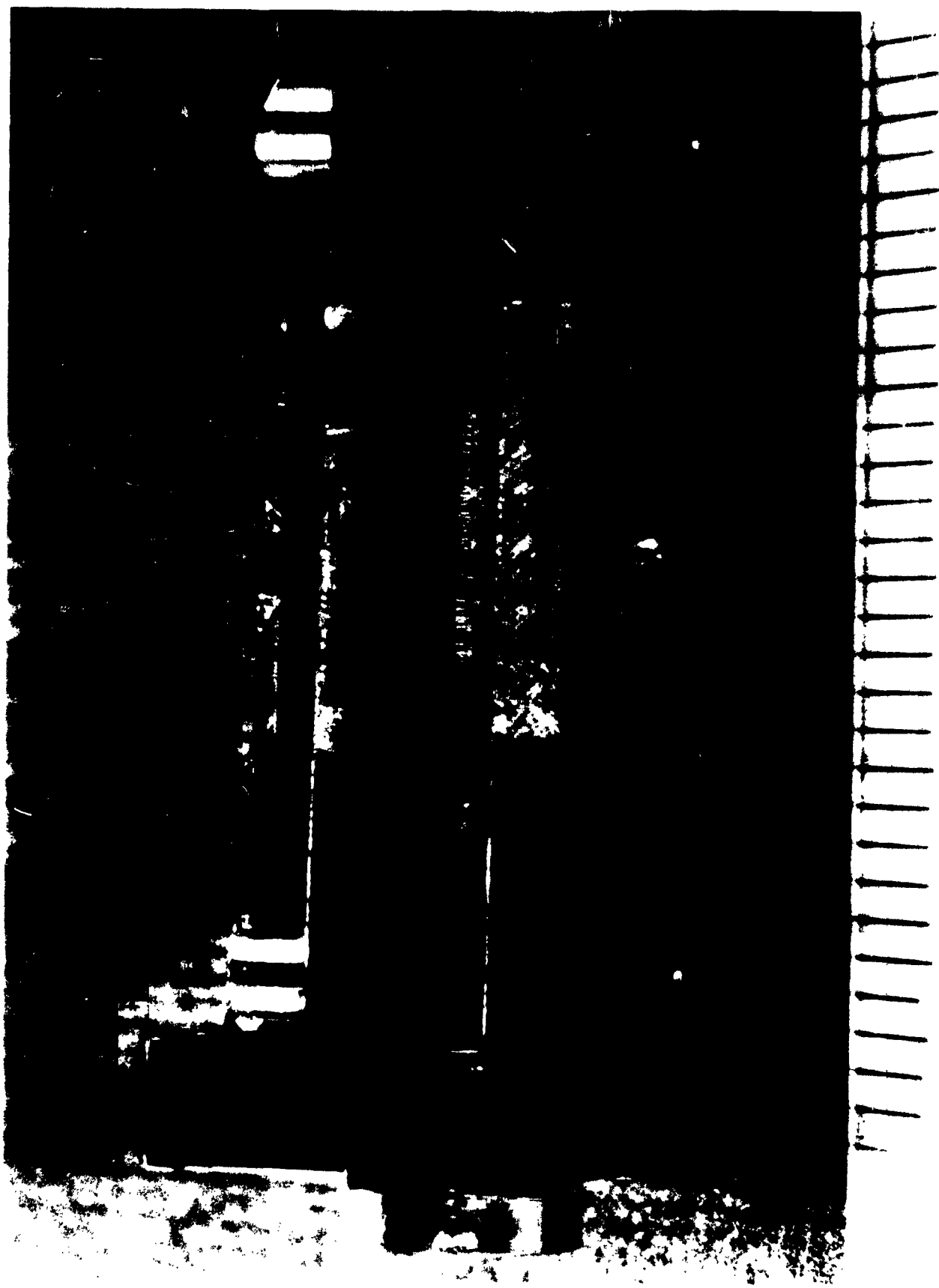


FIG. 36

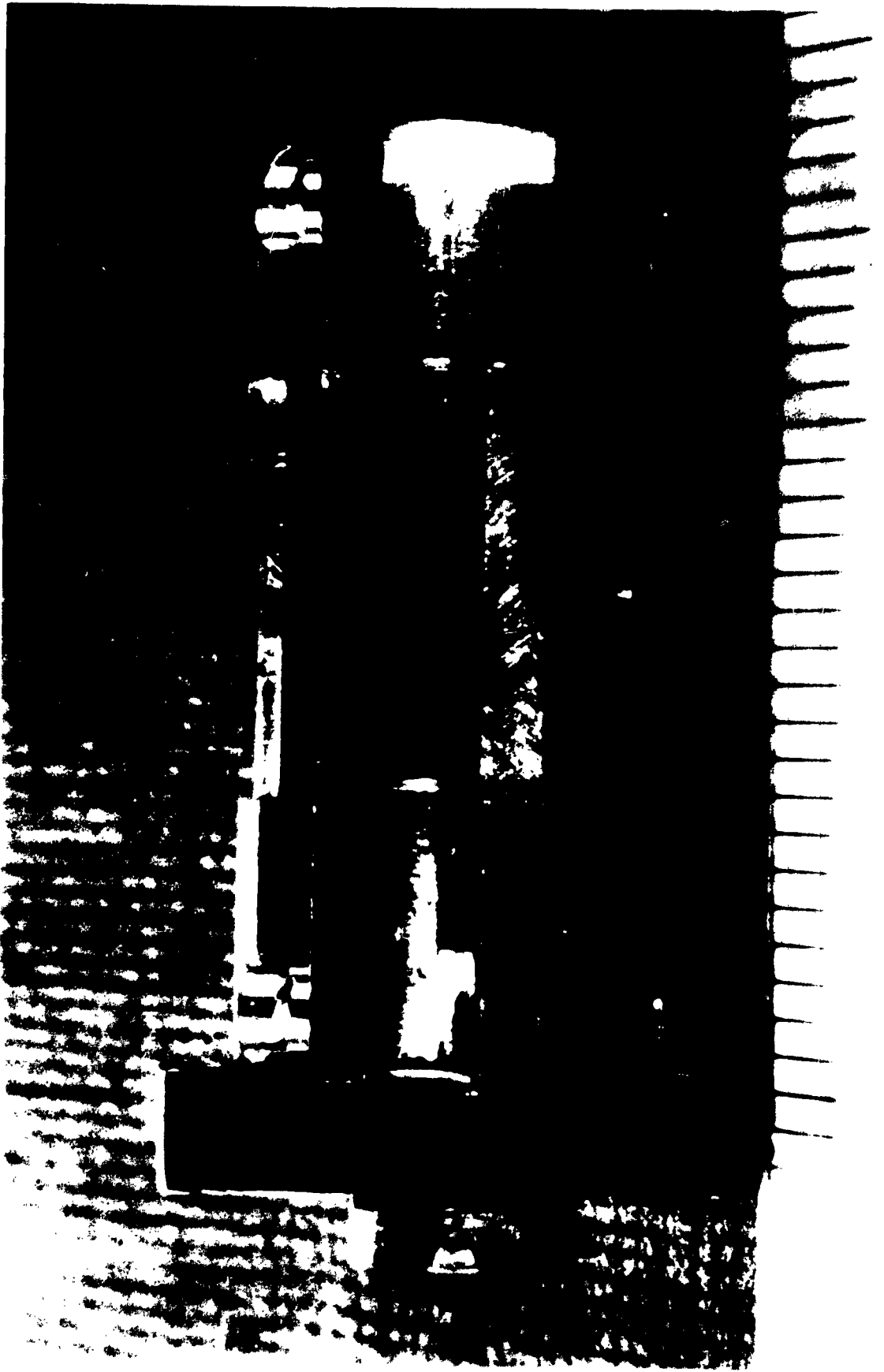
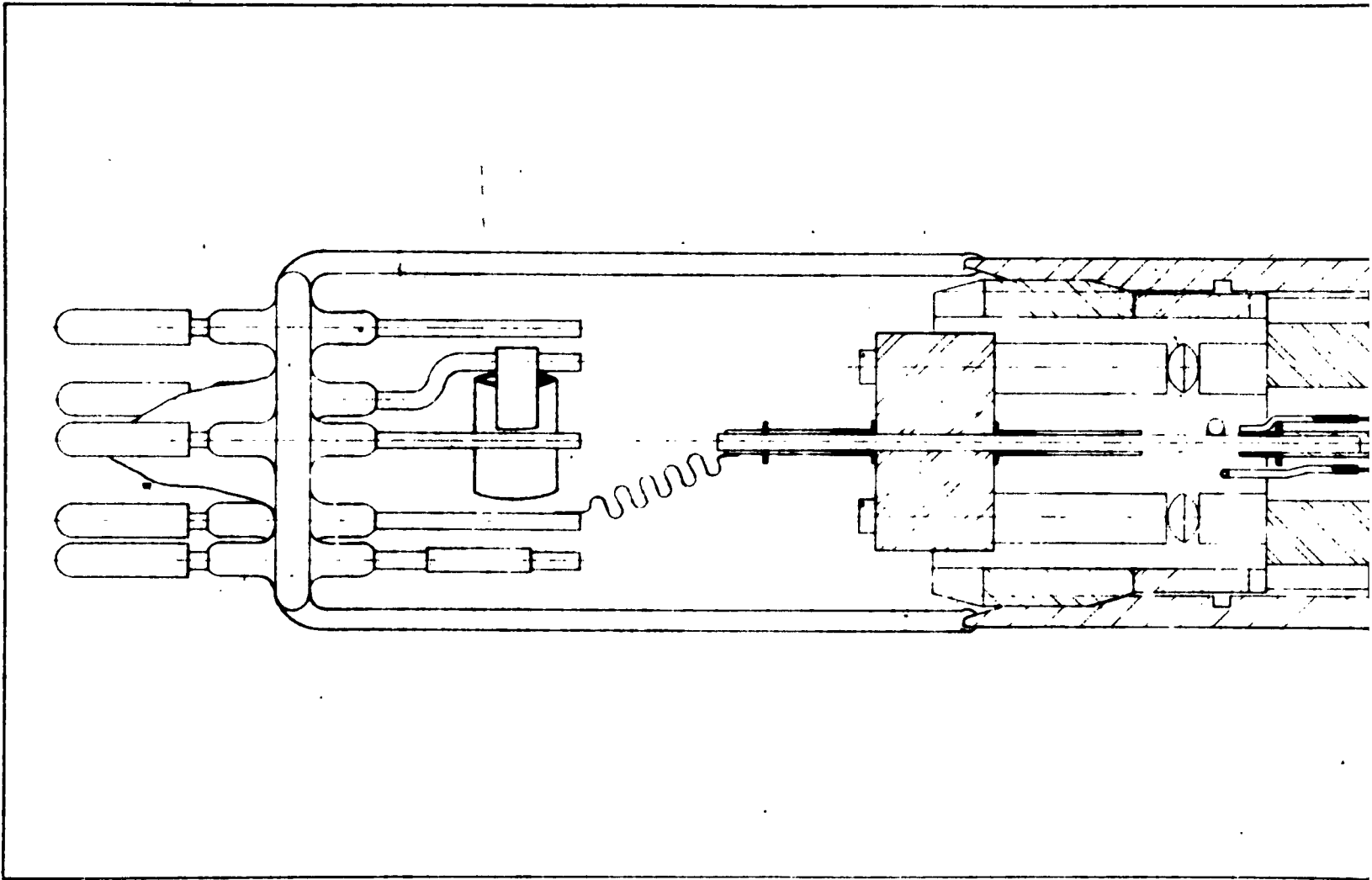


FIG. 37



1

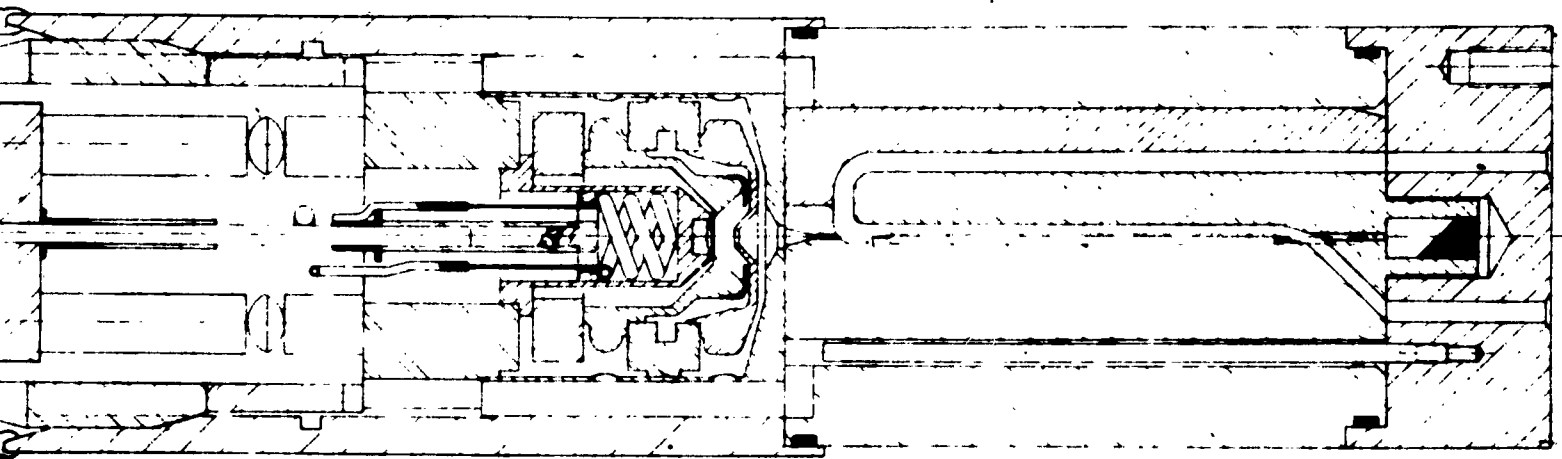


Fig 32

2

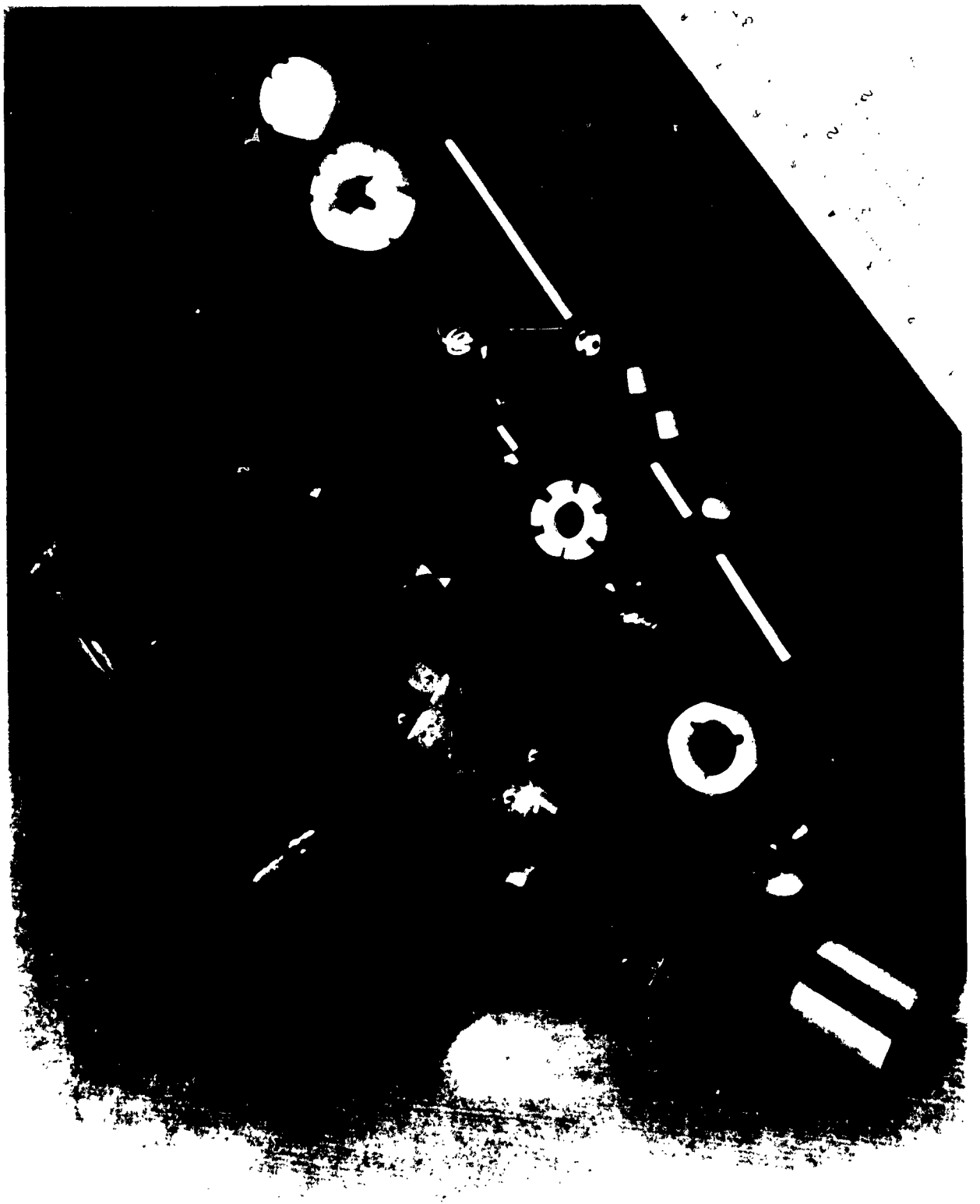


FIG. 39

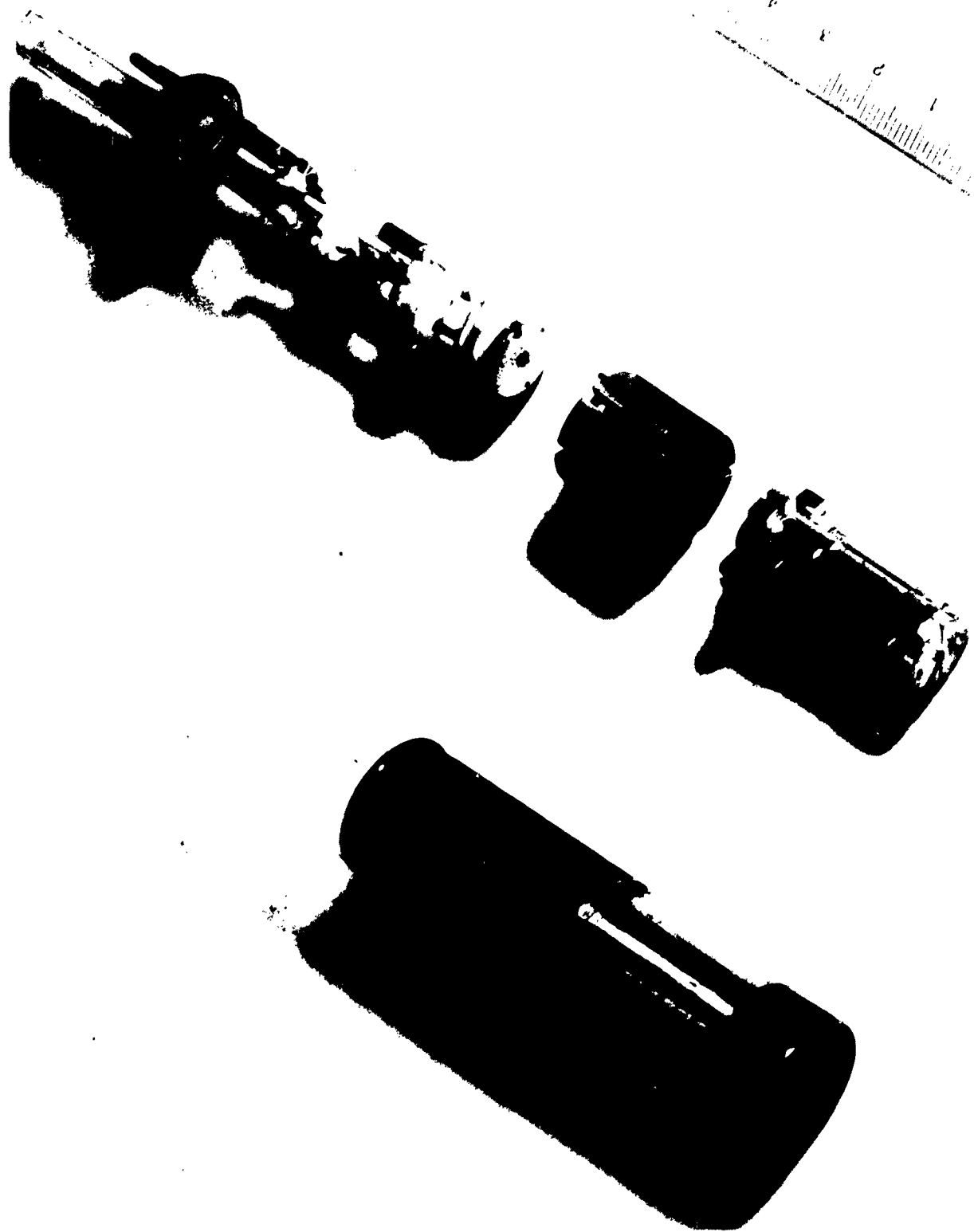


FIG. 40

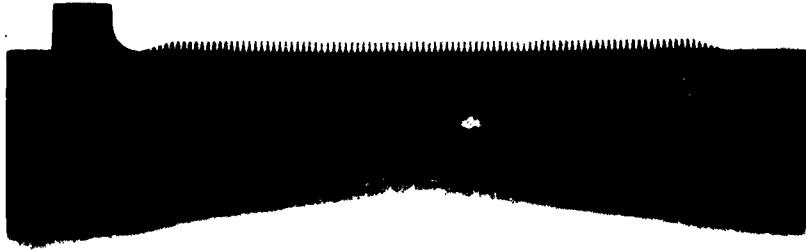


Fig. 41



FIG. 42

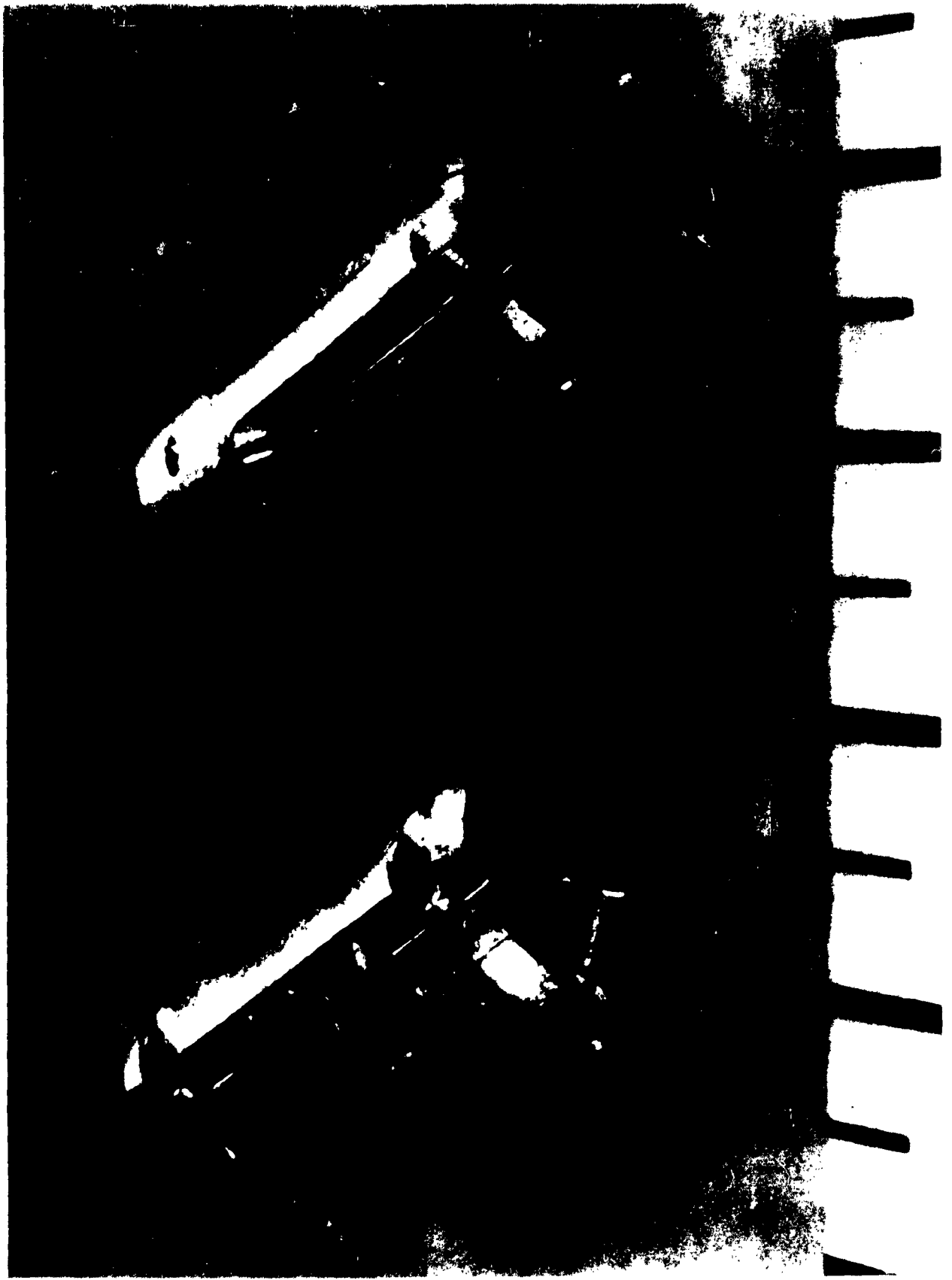


FIG. 43

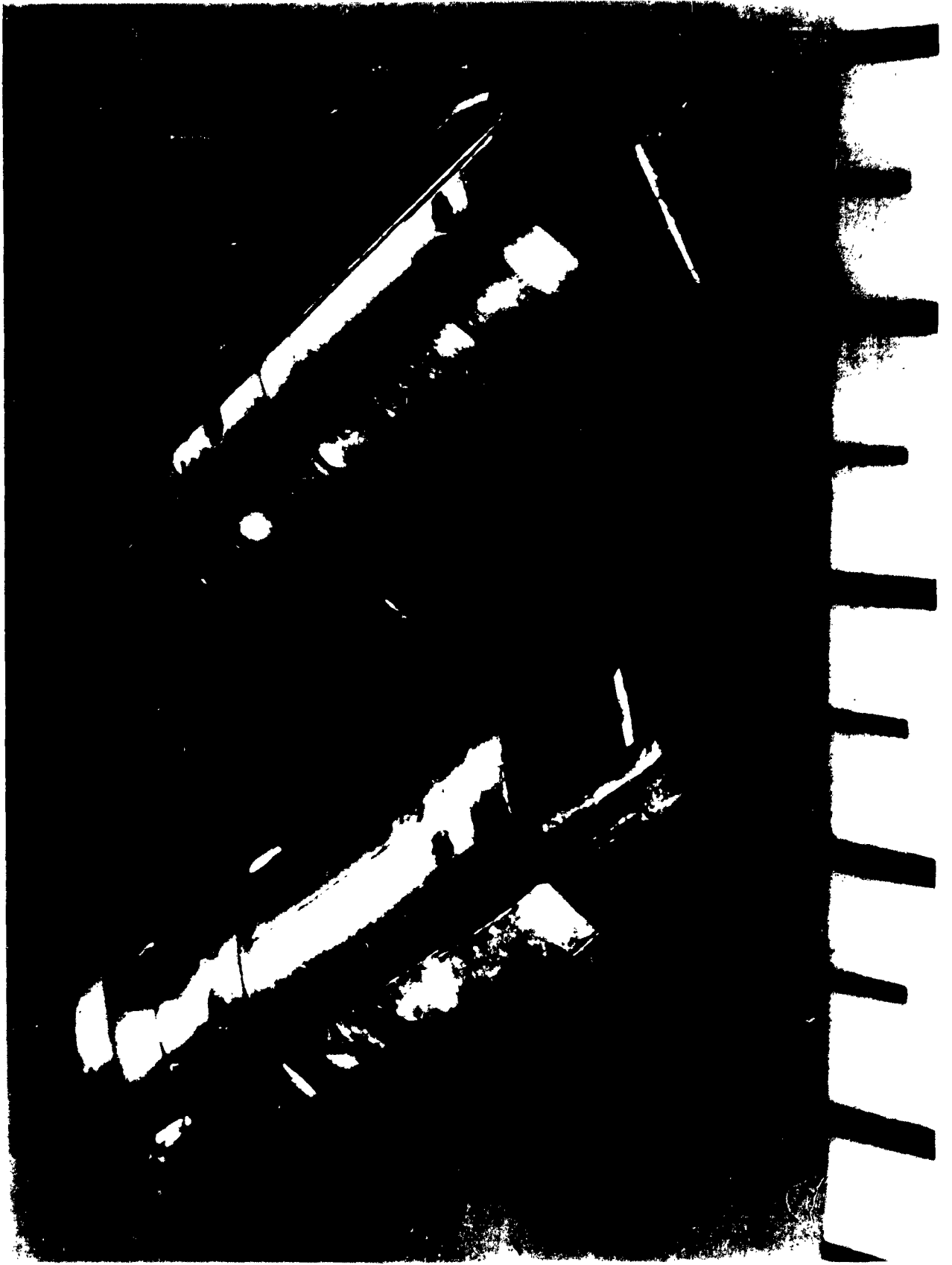


FIG. 44

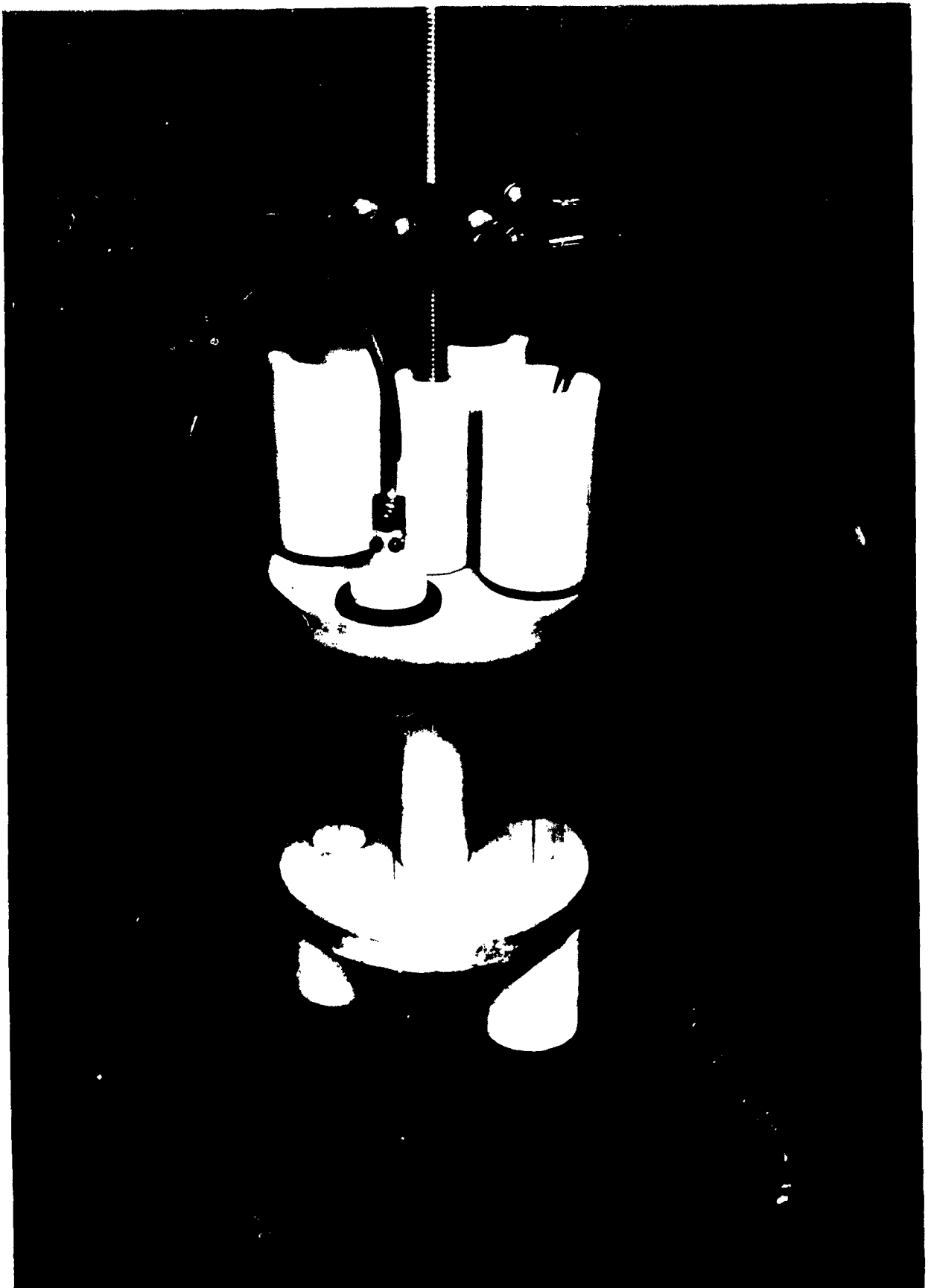
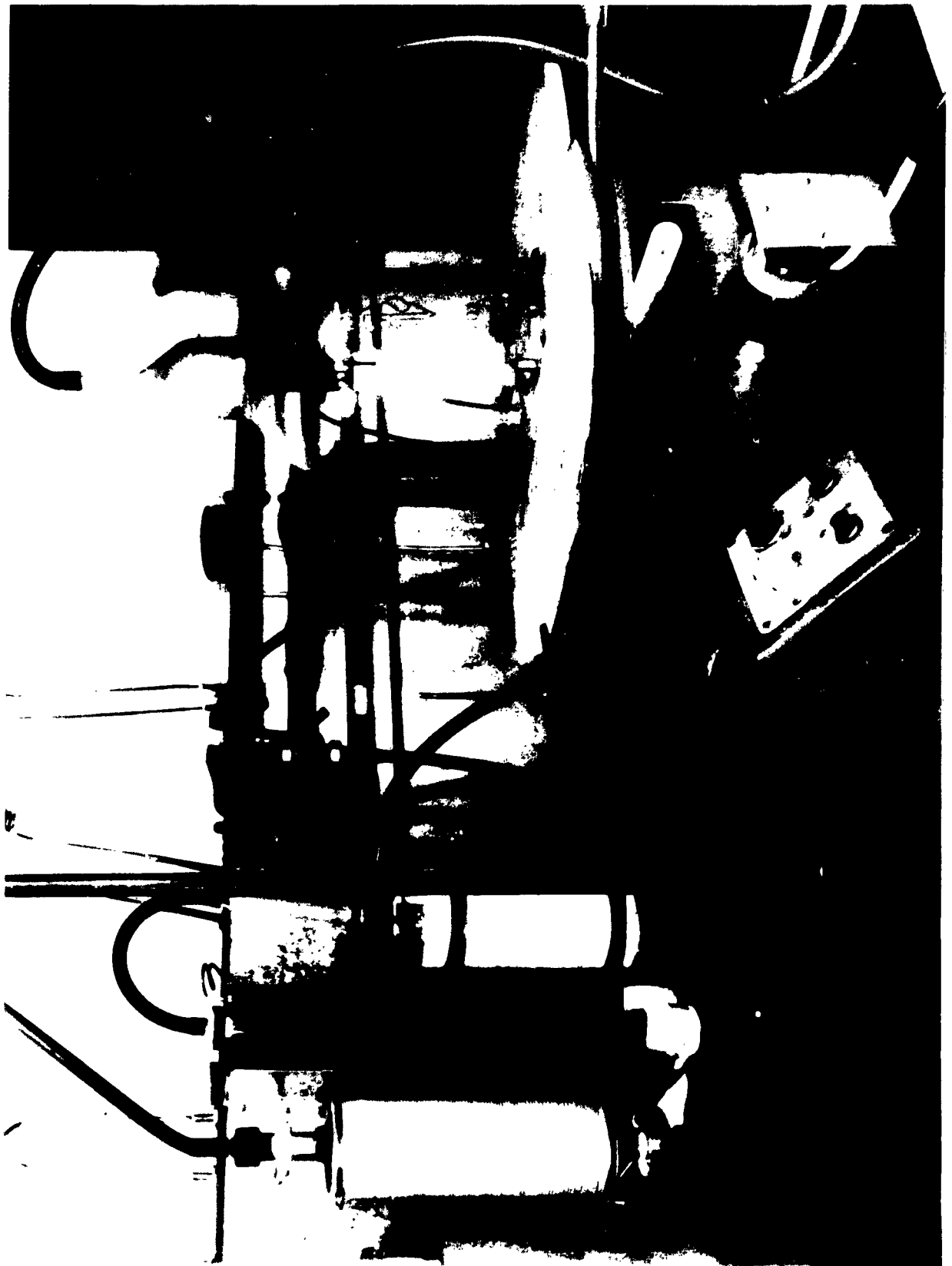


FIG. 45



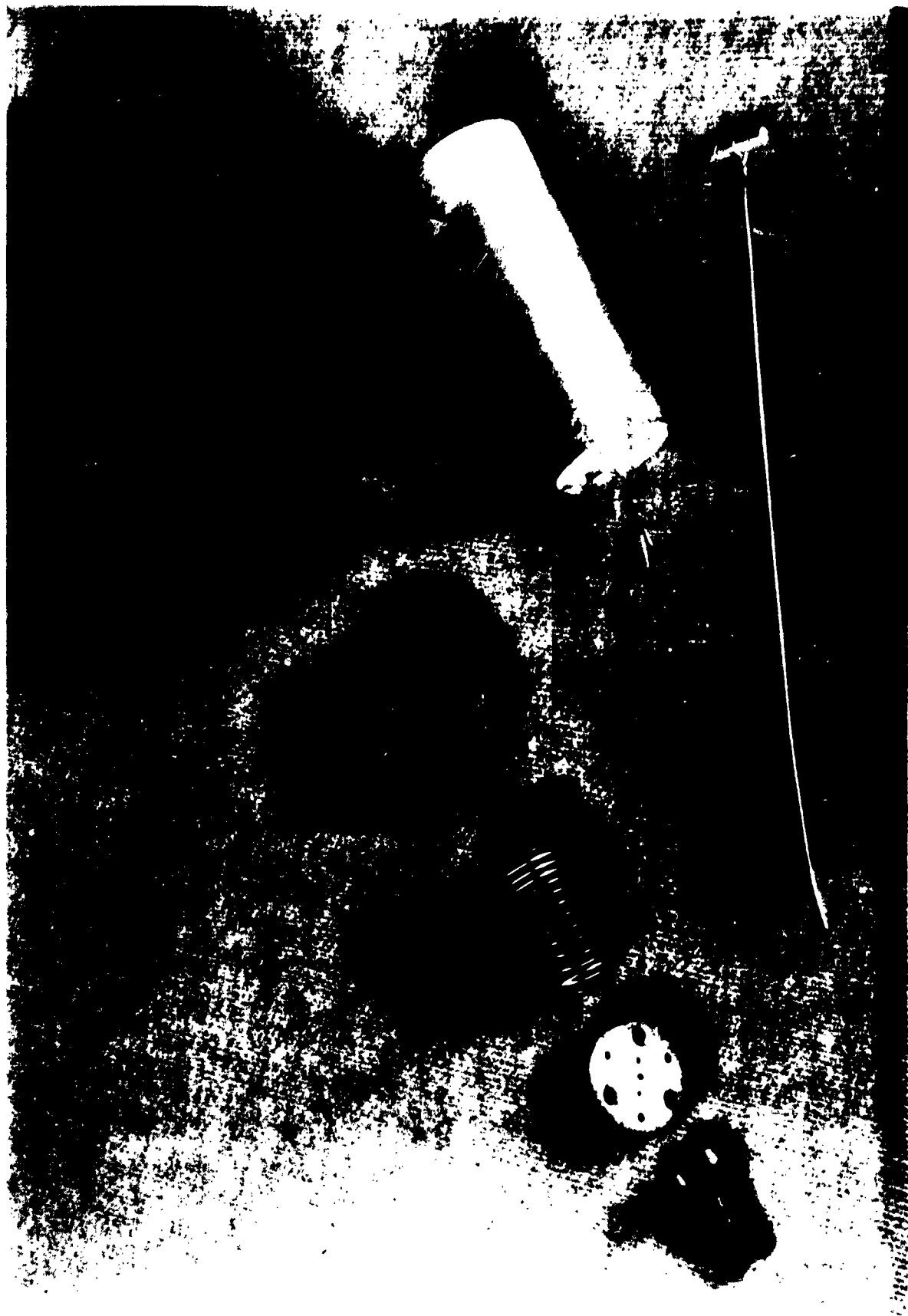


FIG.47



FIG. 48

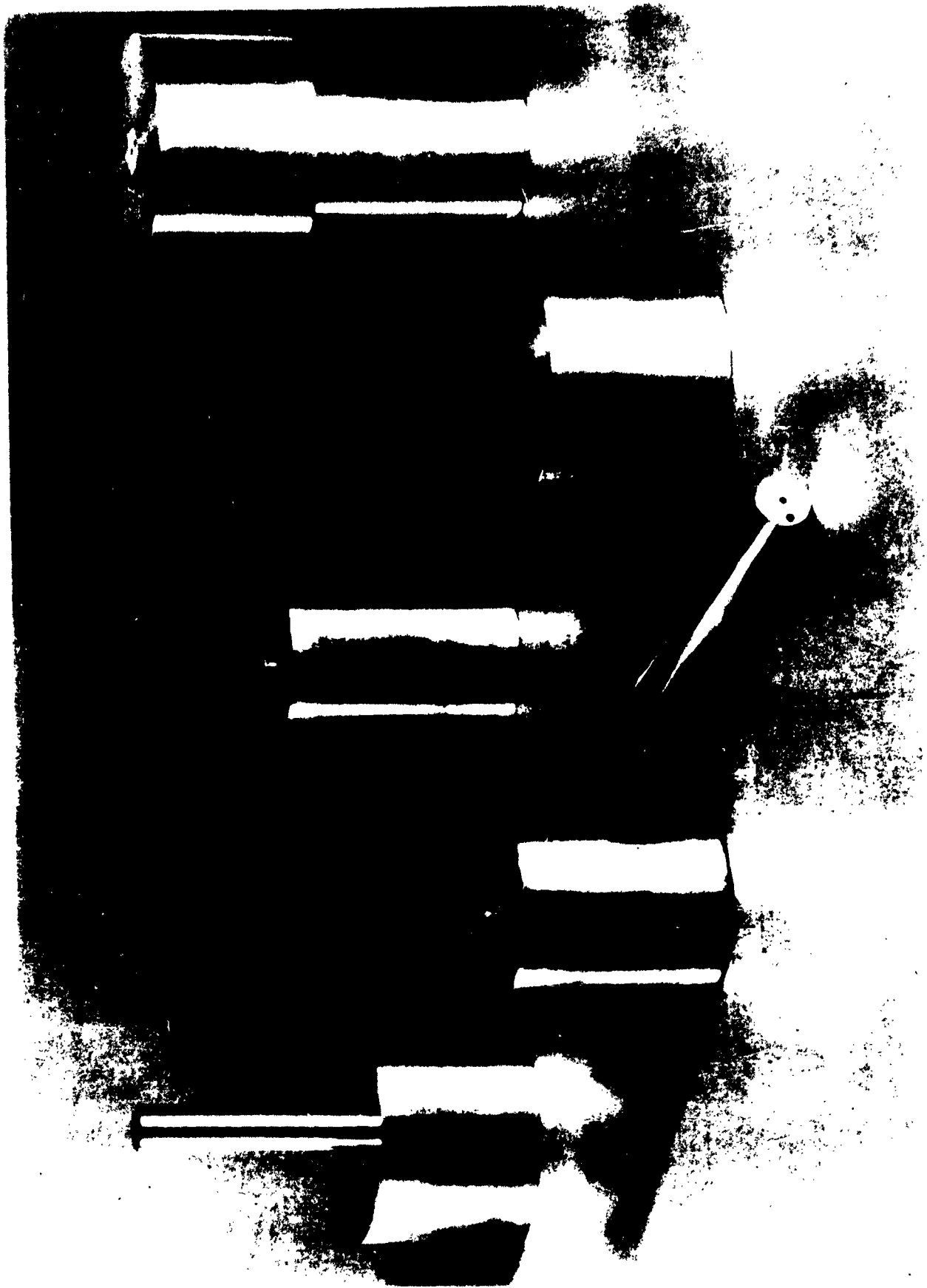


FIG. 49

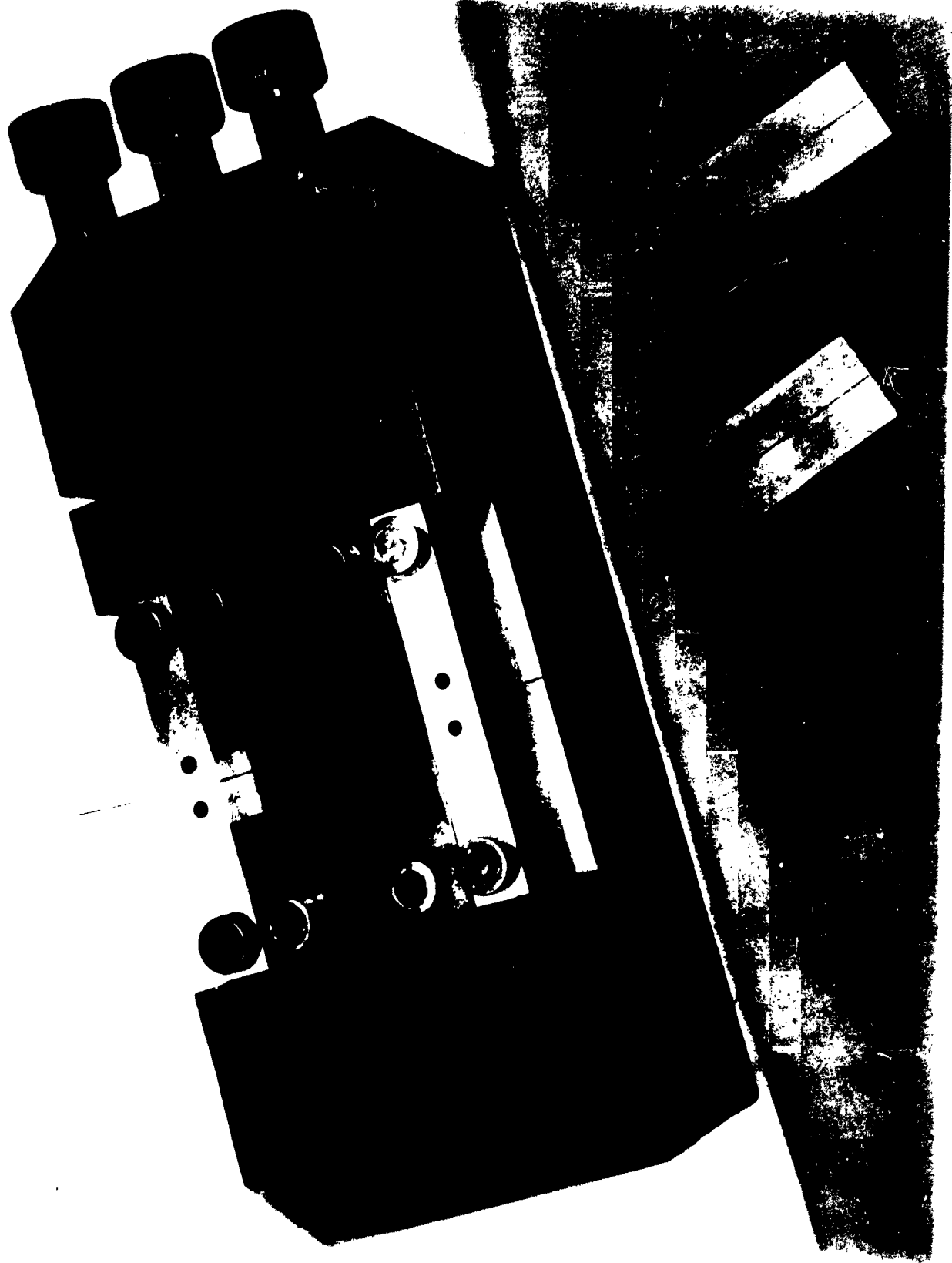


FIG. 50

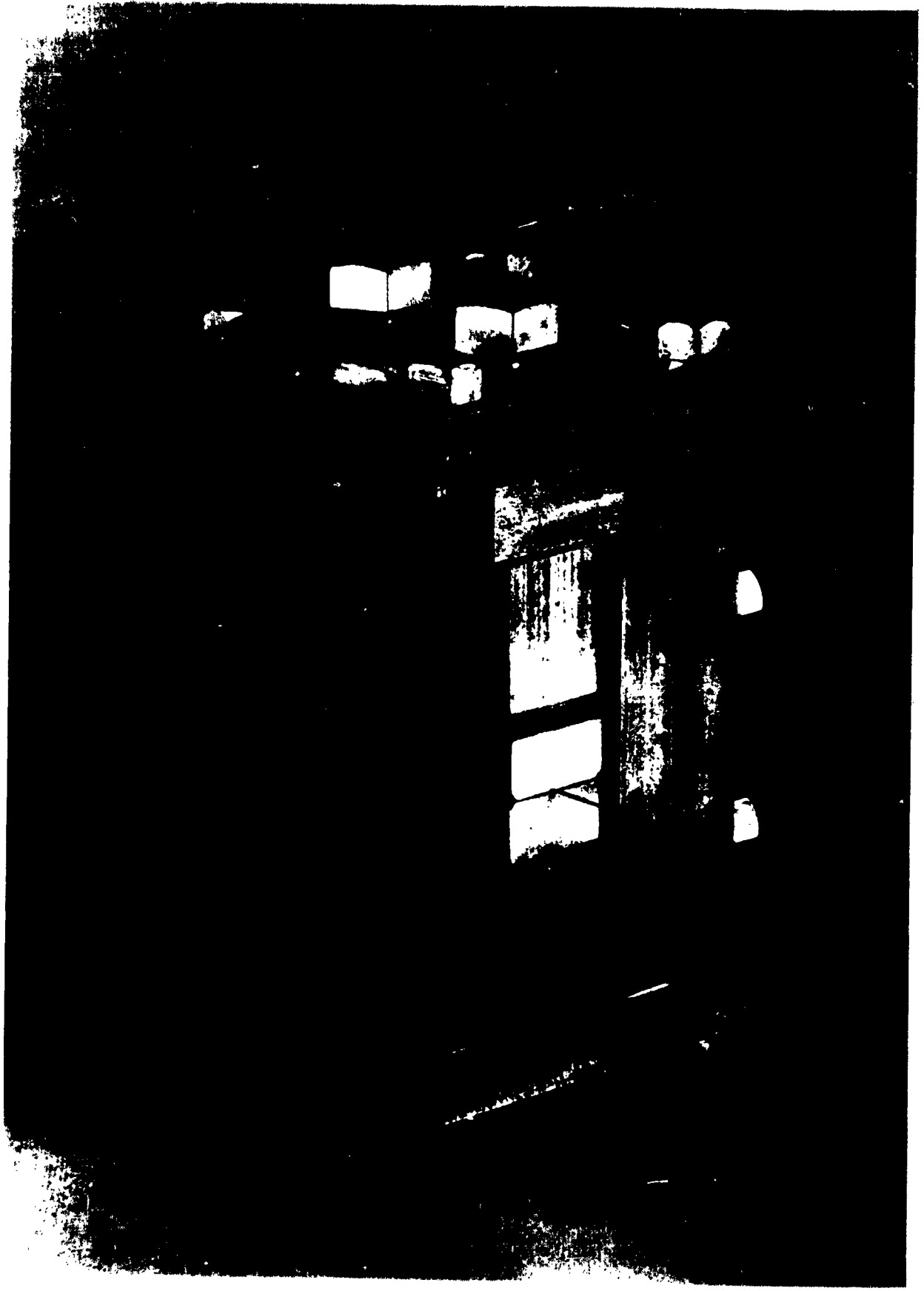




FIG. 52

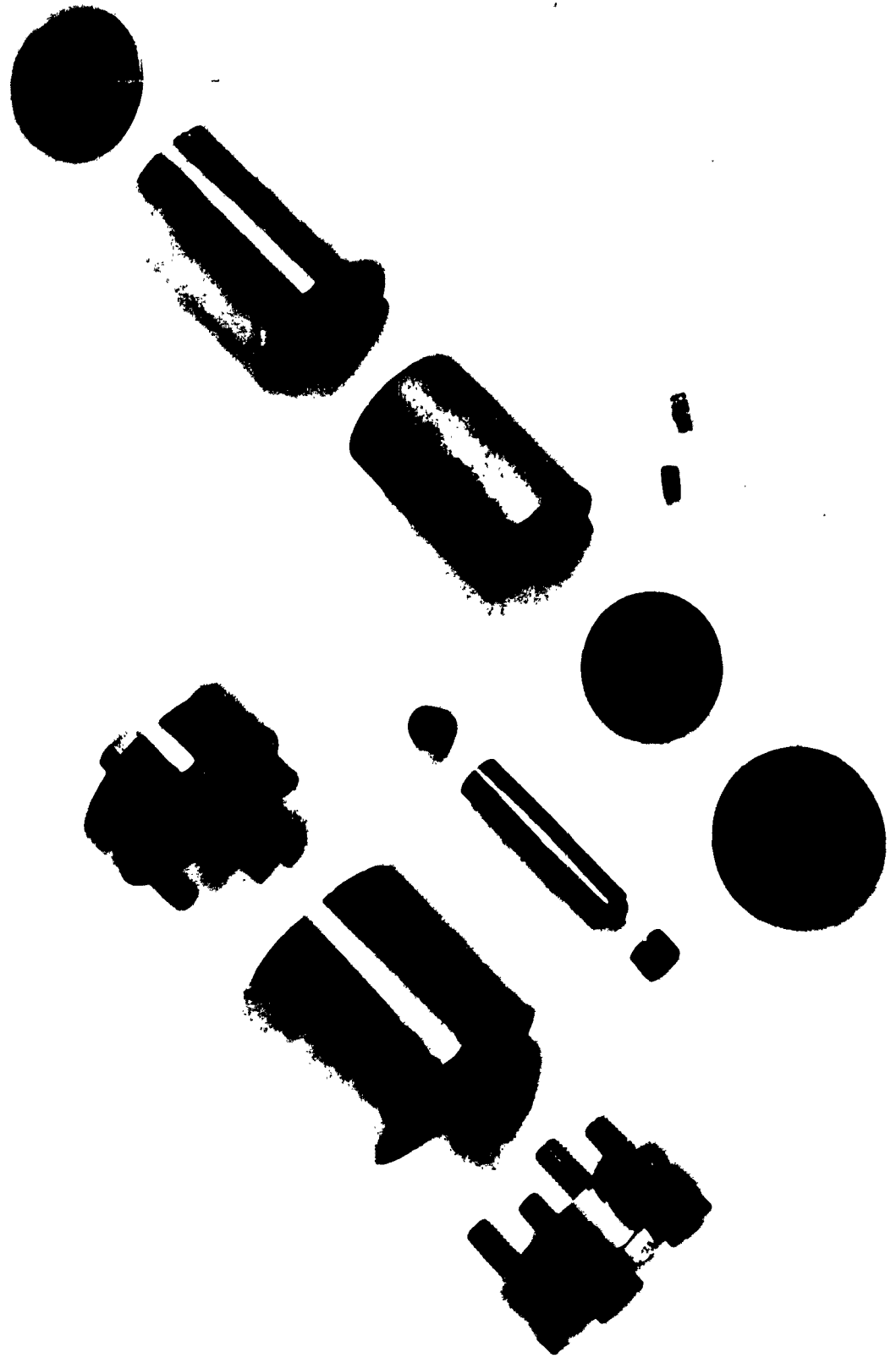


FIG. 53

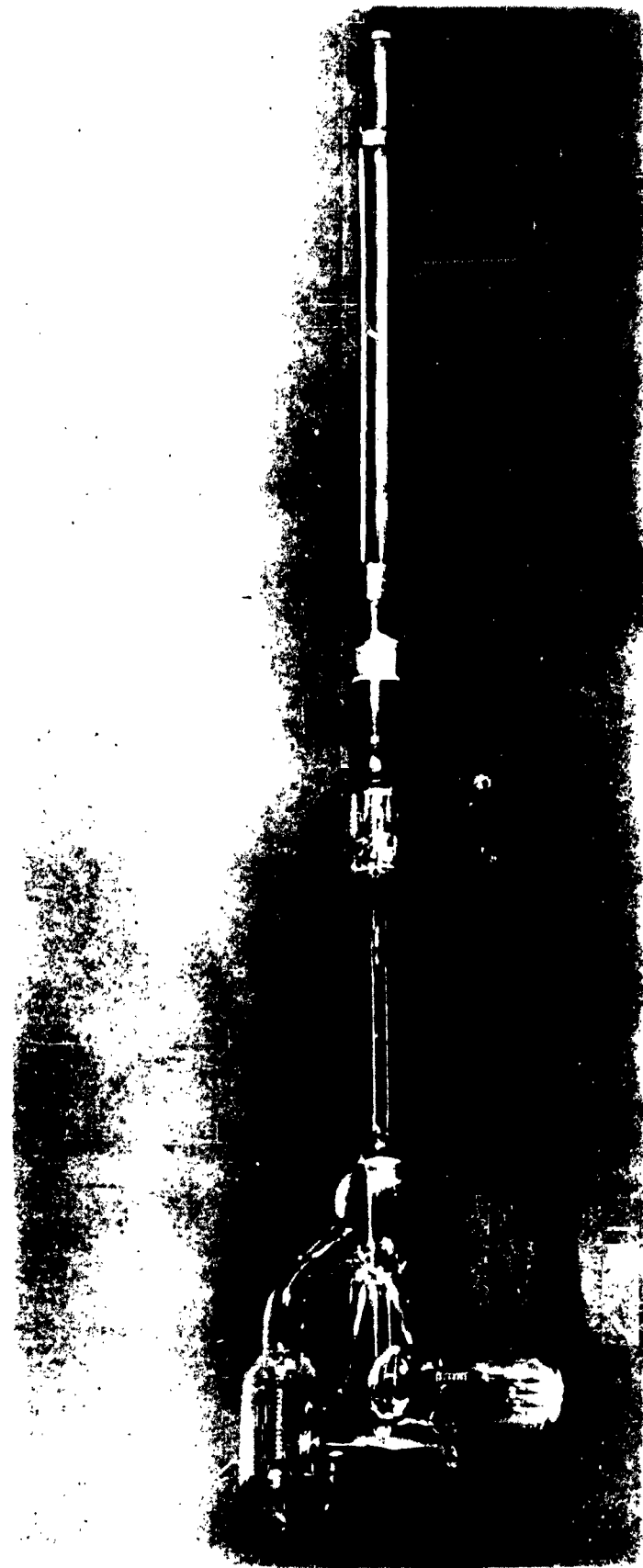


FIG. 50



FIG. 55

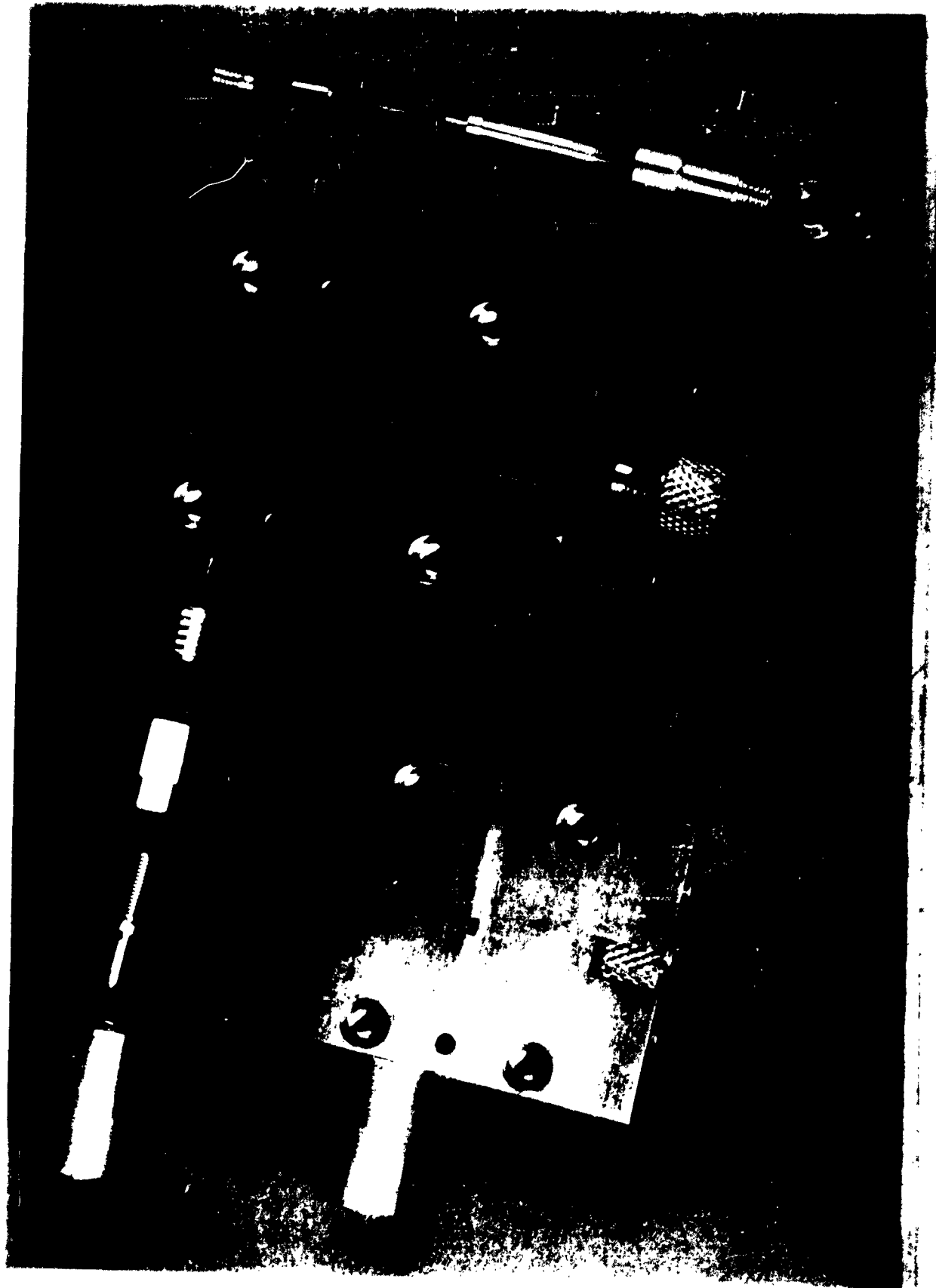


FIG. 56

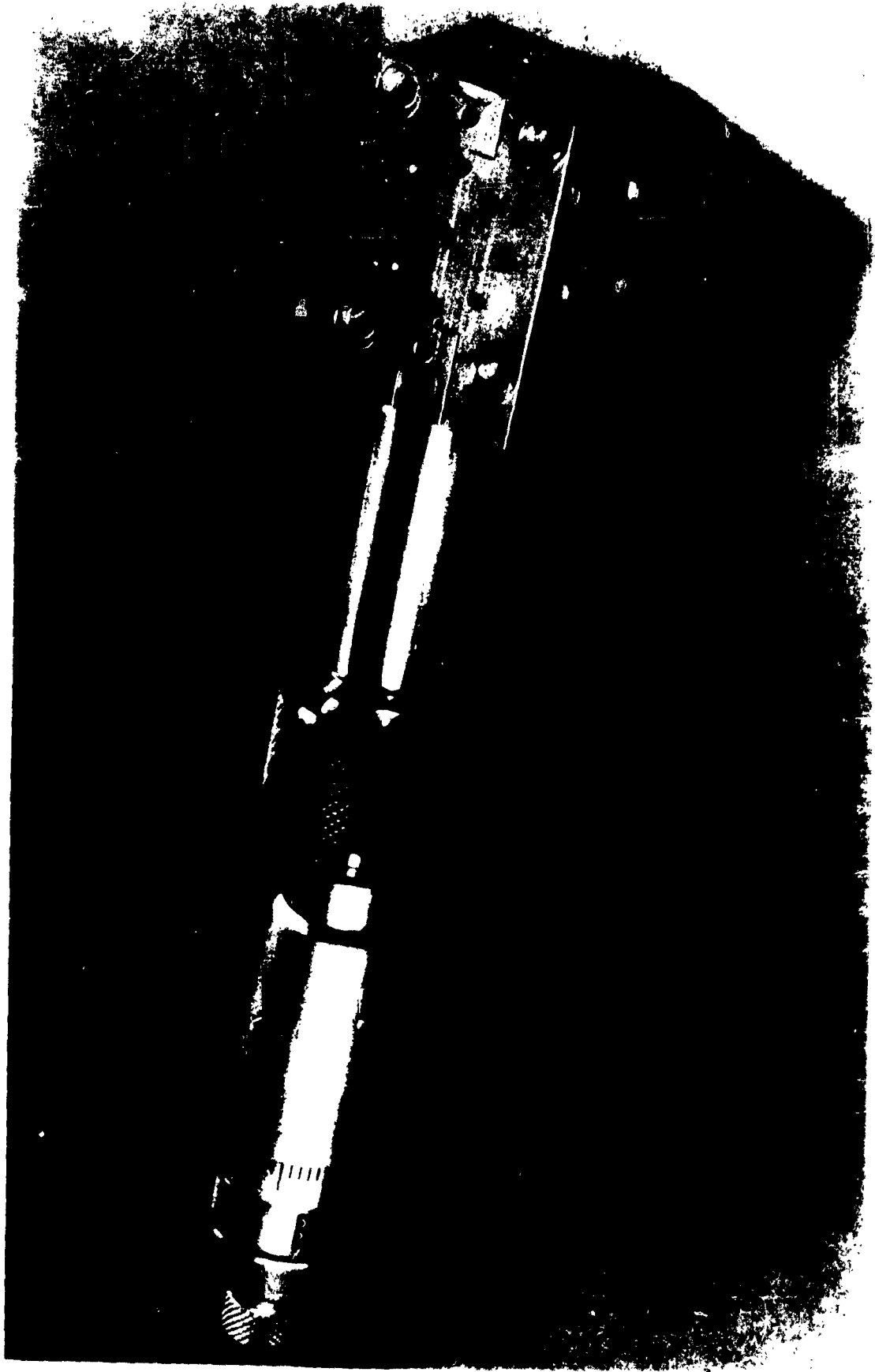


FIG. 57

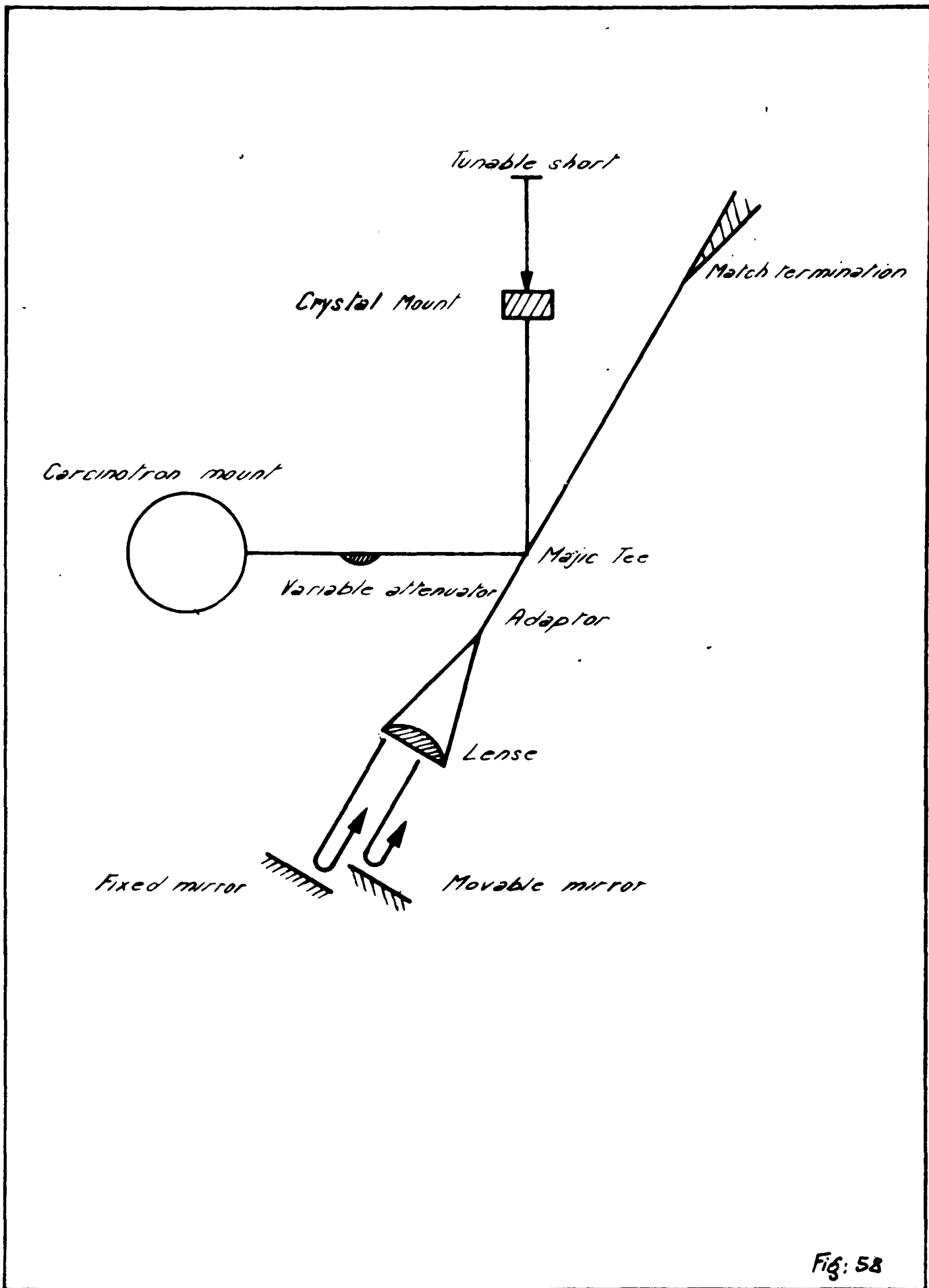


Fig: 58







FIG. 61

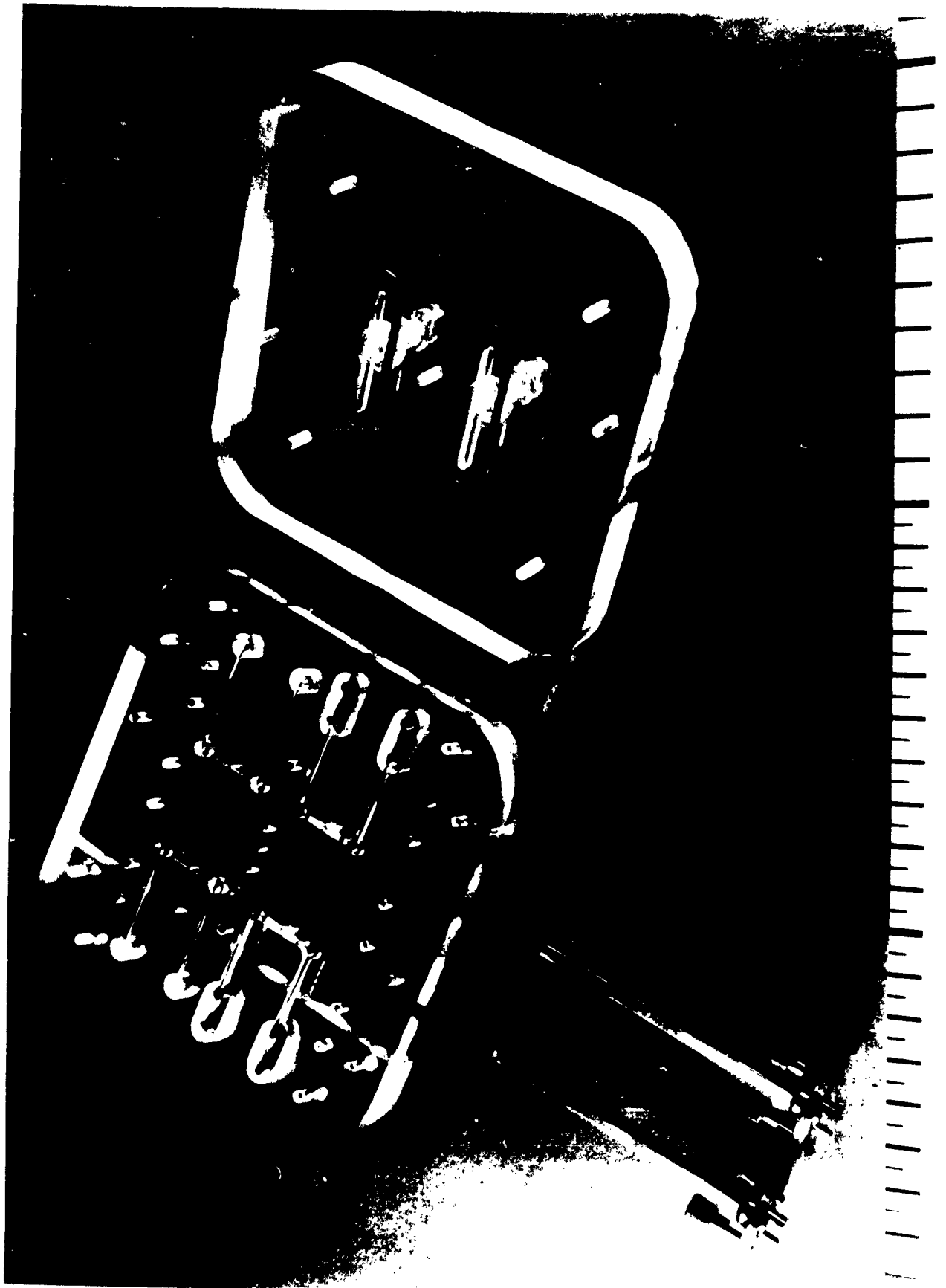
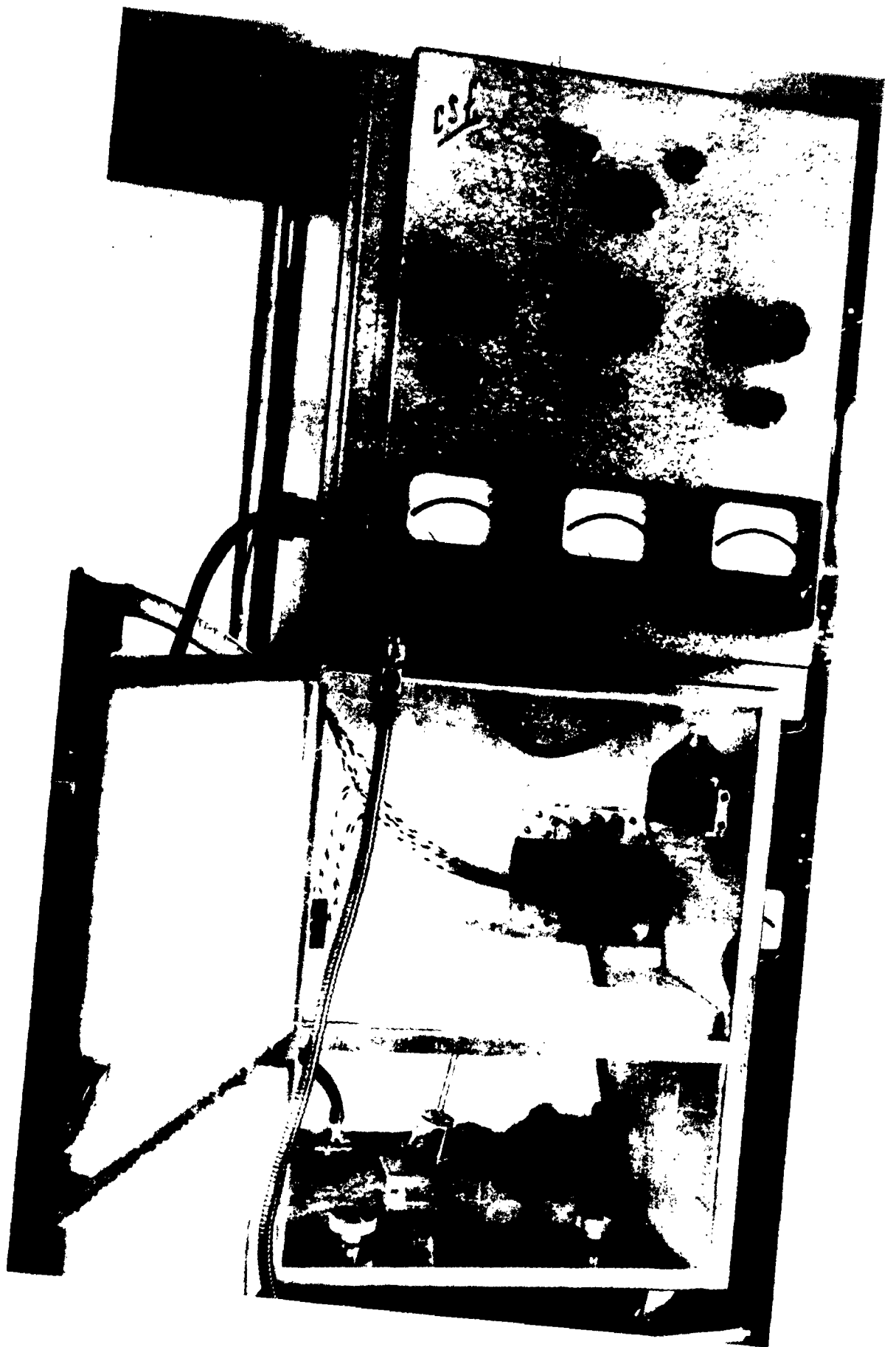


FIG. 52



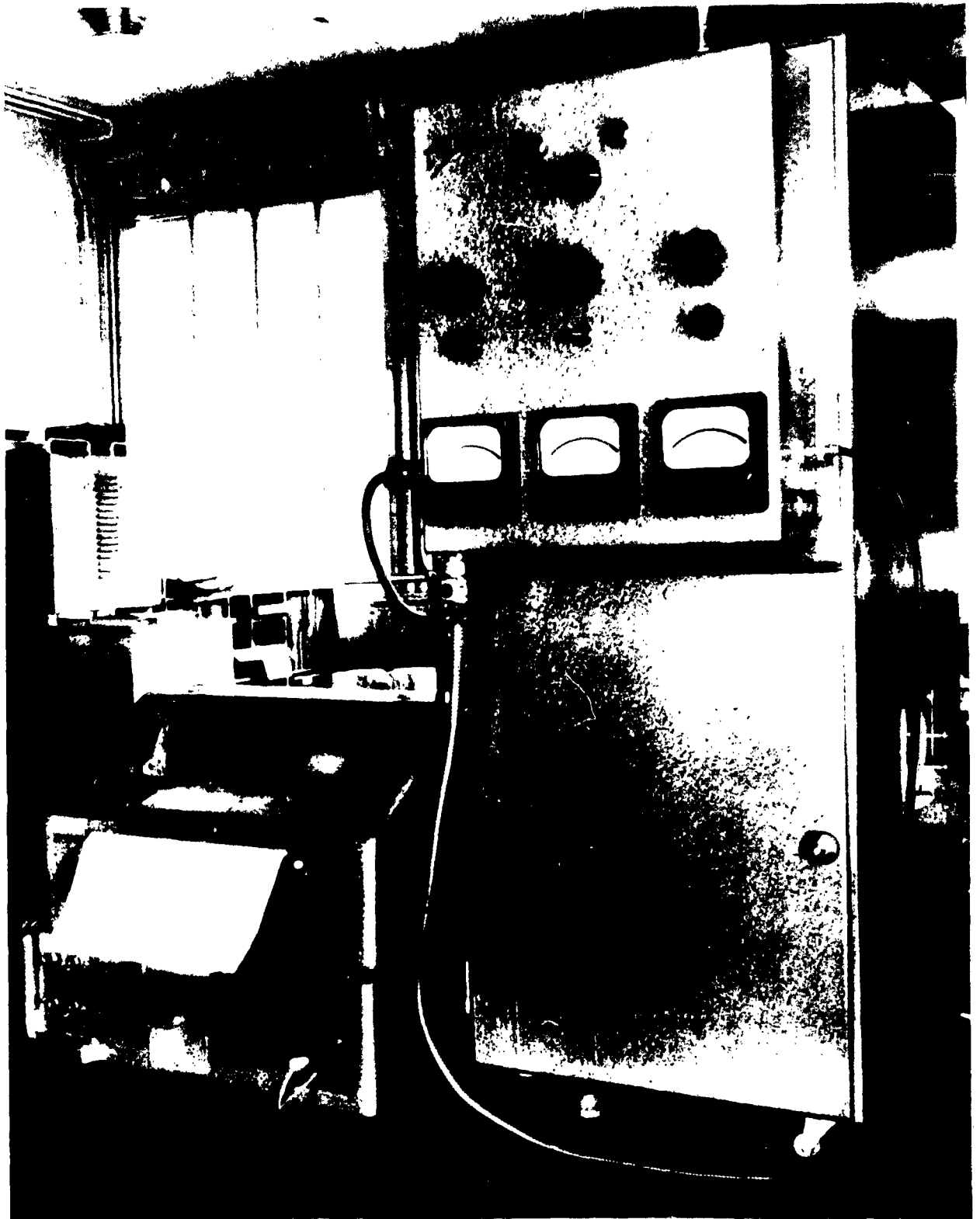
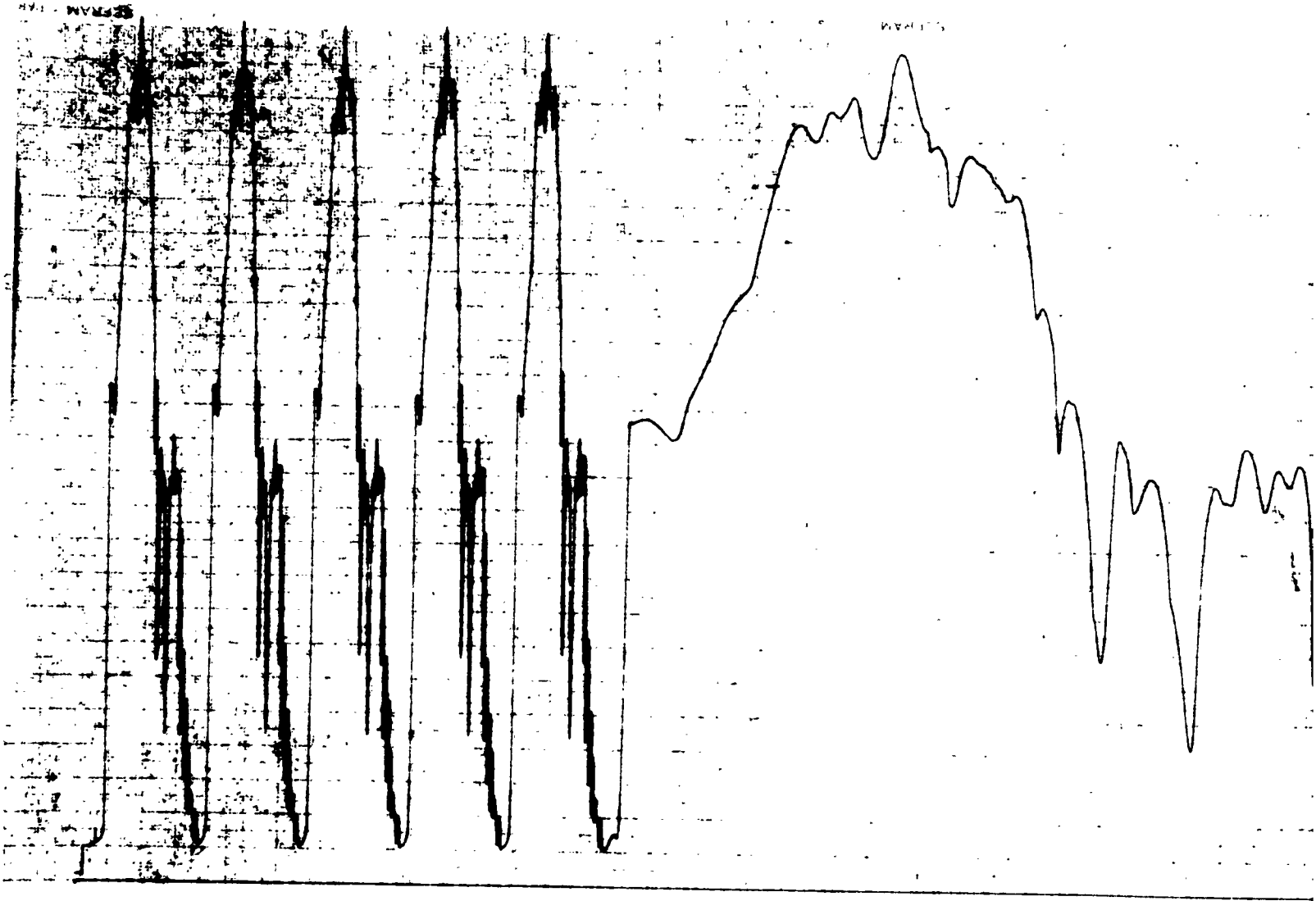


FIG. 64



1

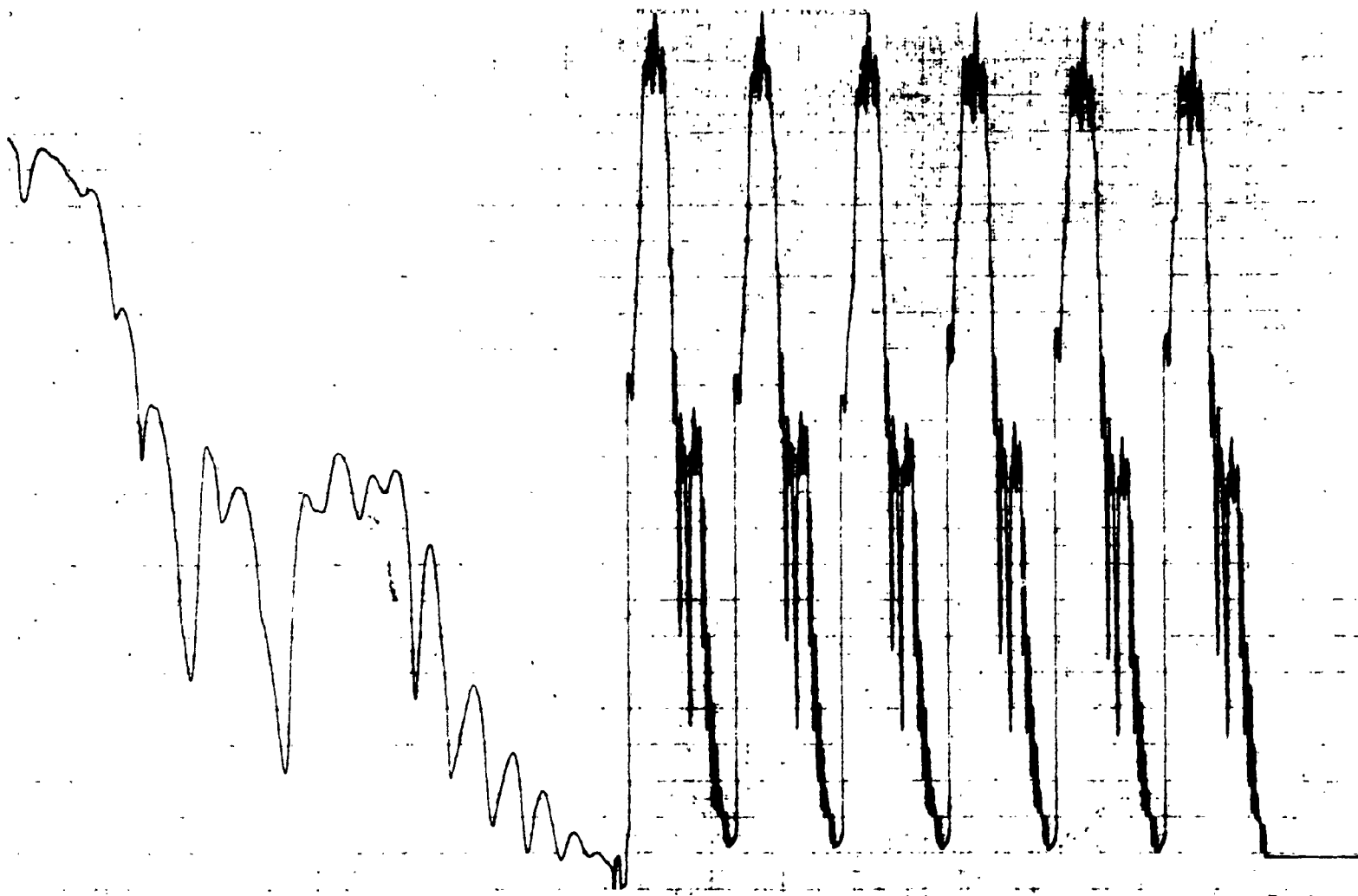


Fig. 65

2

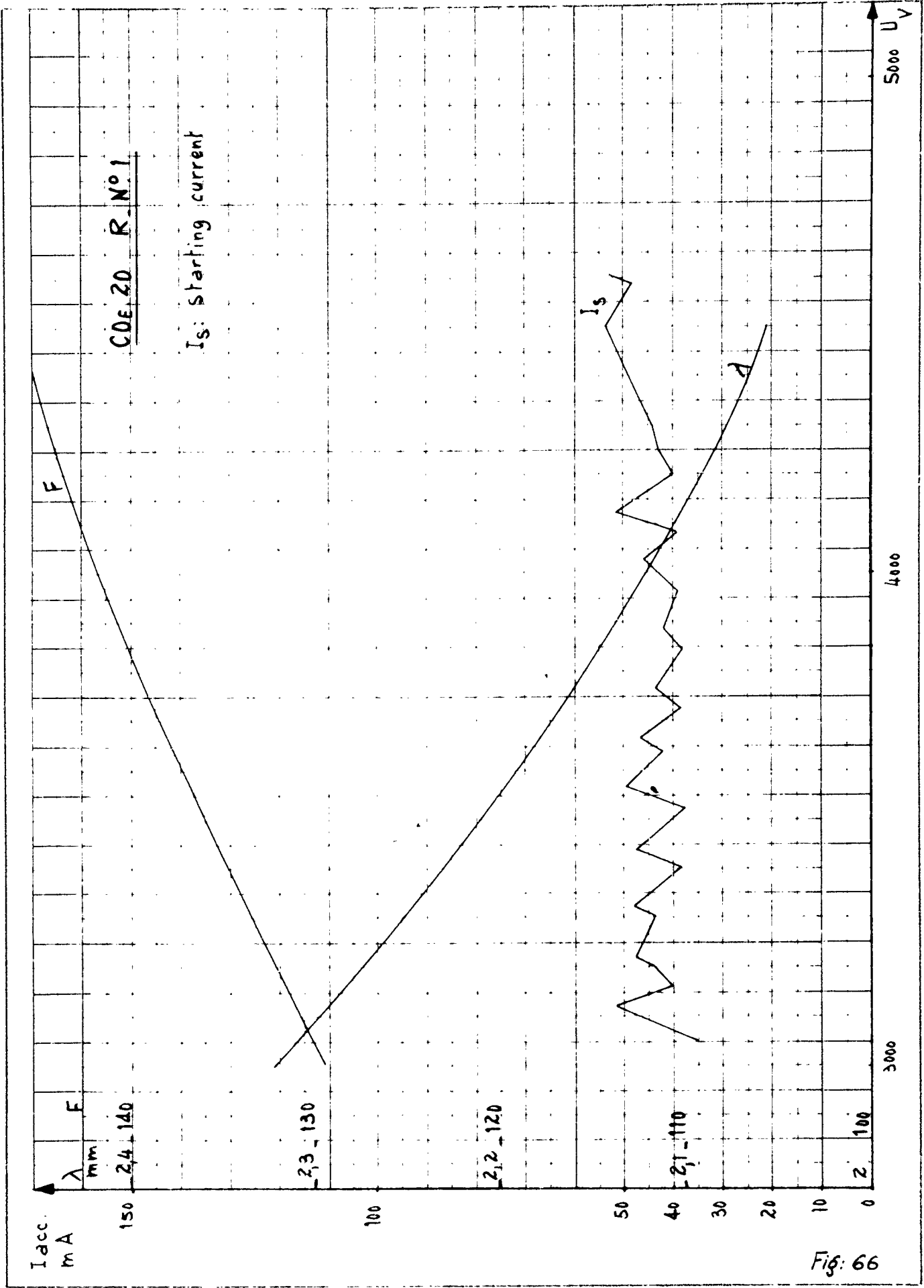


Fig: 66

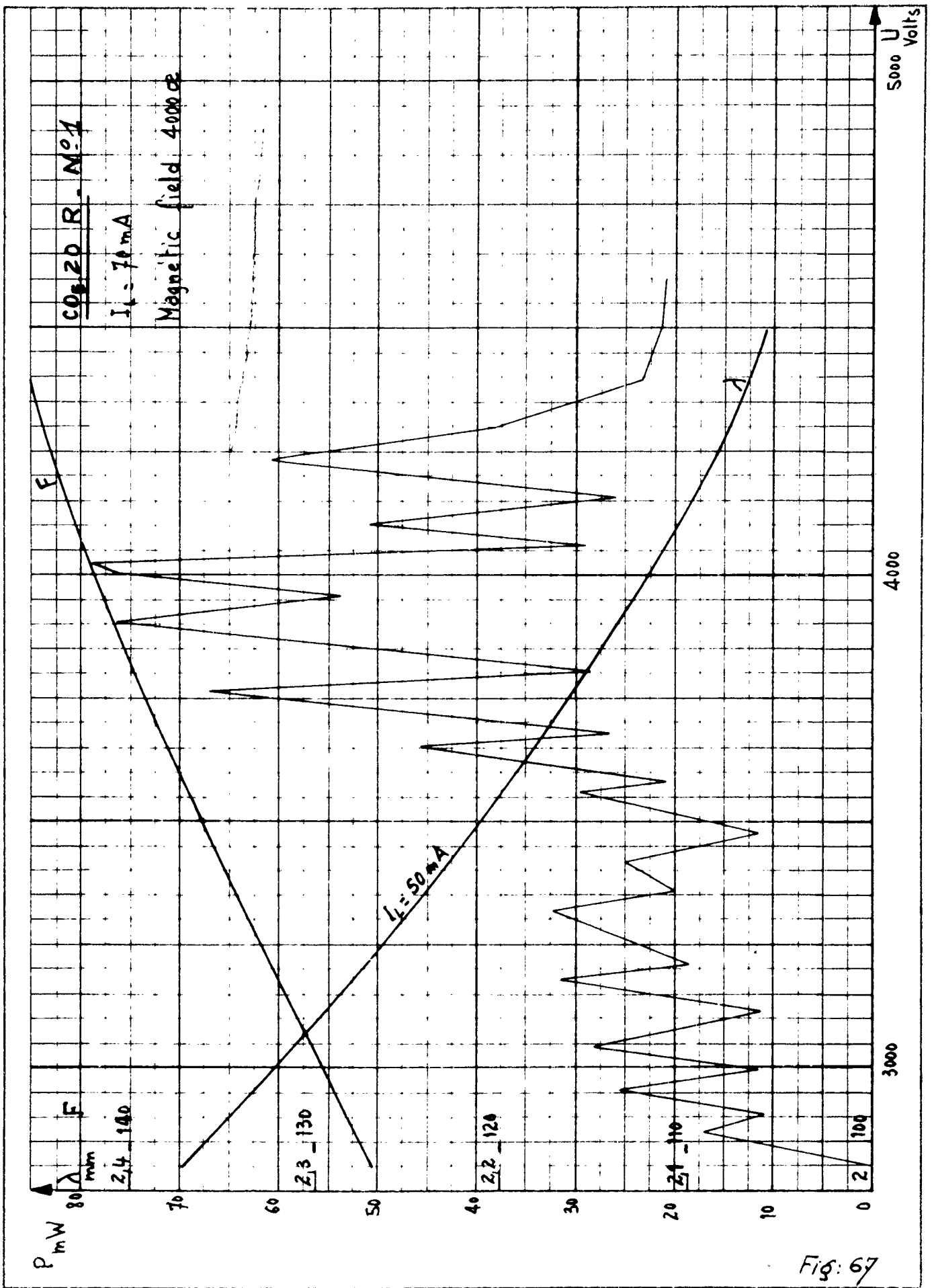


Fig: 67

COE 20
(R03)

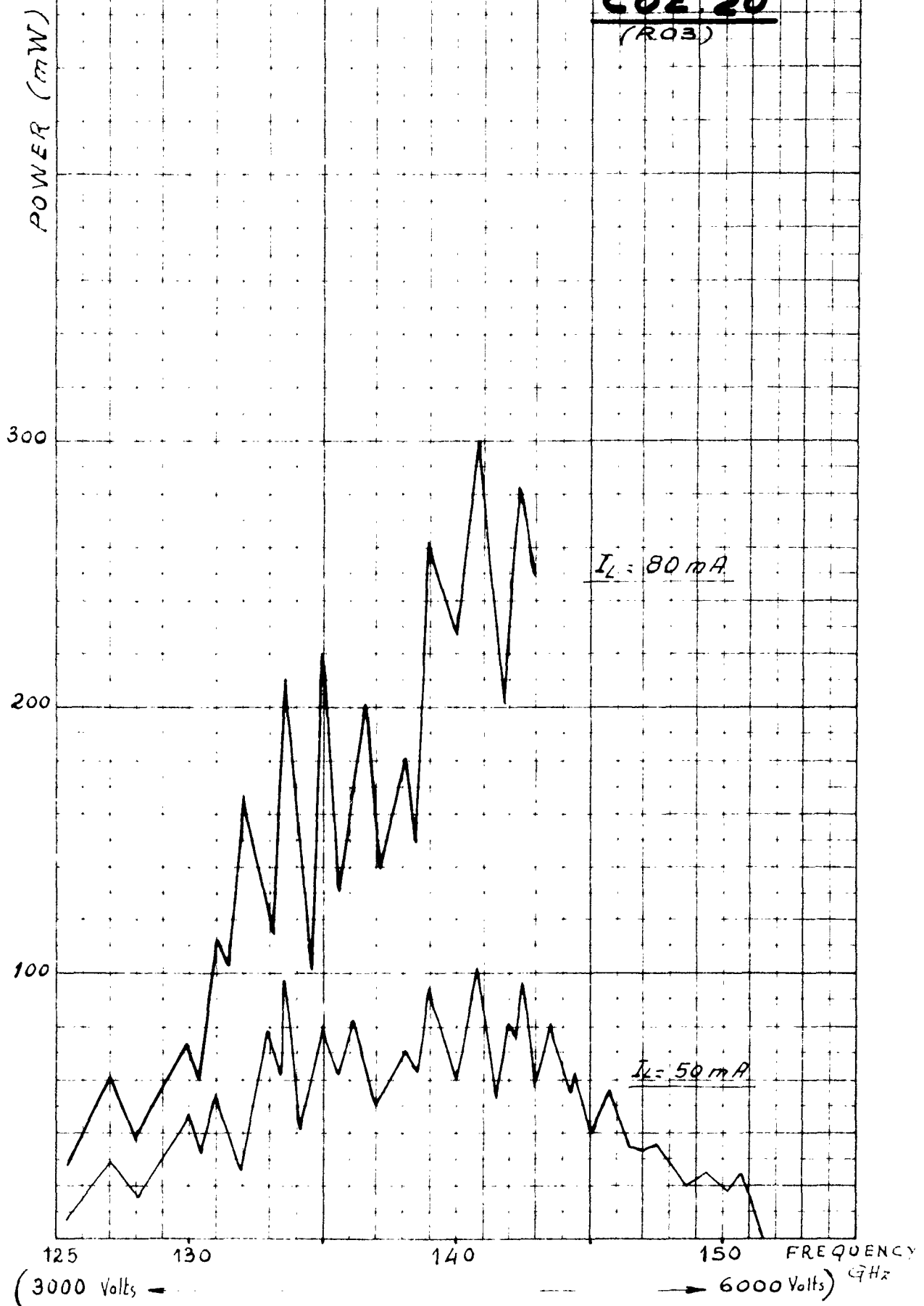


Fig: 68

COE. 20 N:80A

Magnetic Field: 6300 oer

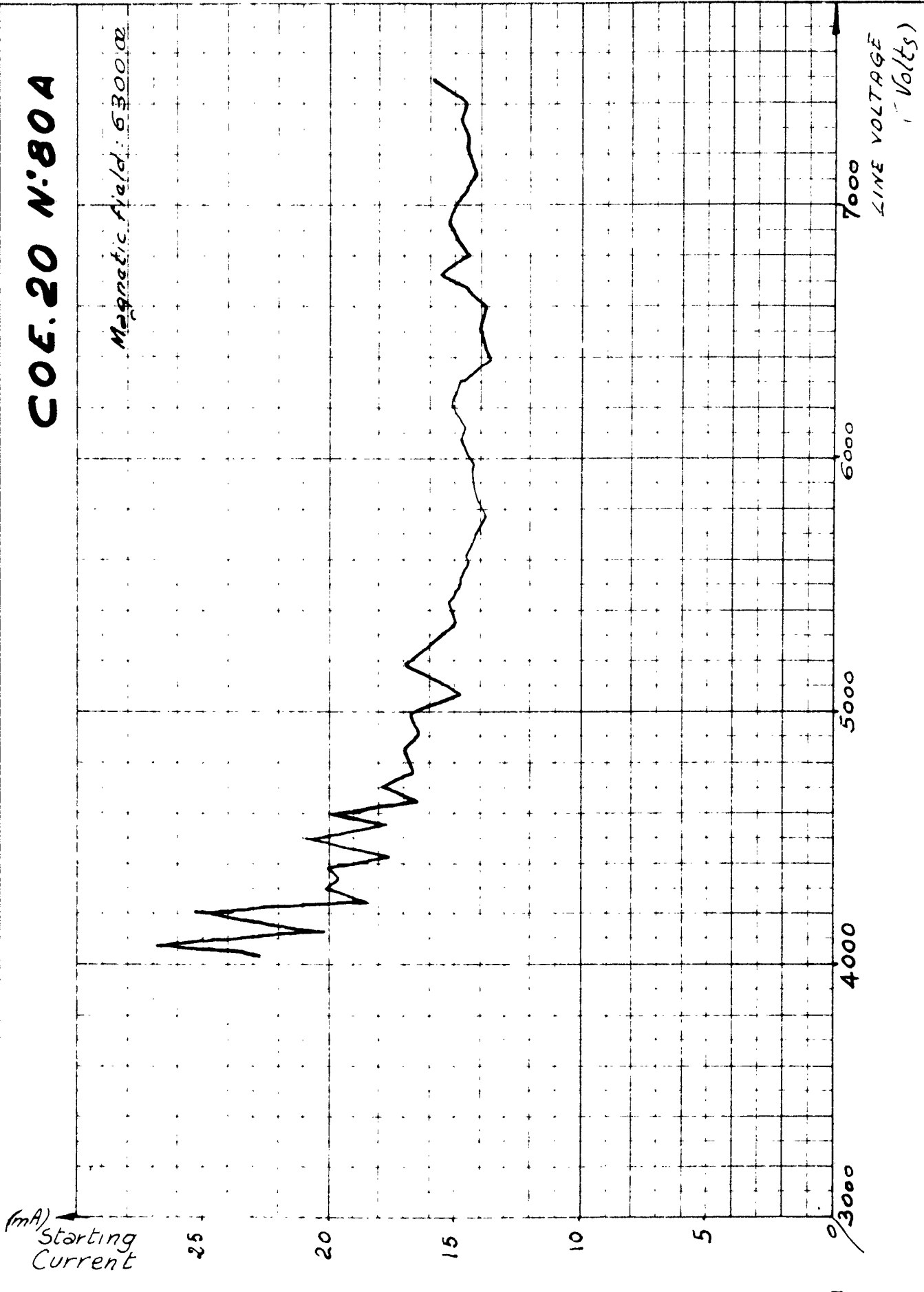
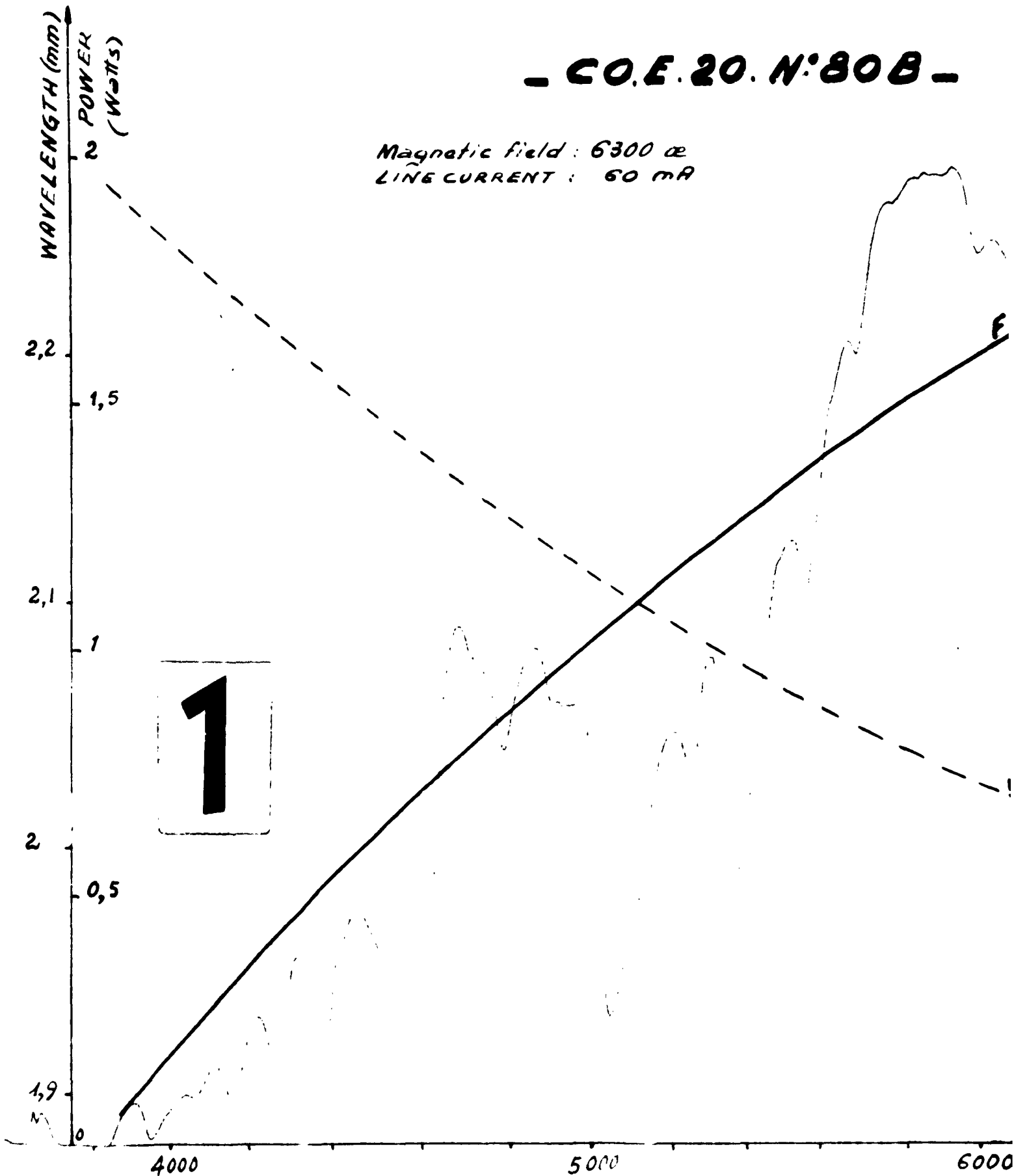


Fig: 69

- CO.E. 20. N° 80 B -

Magnetic field : 6300 œ
LINE CURRENT : 60 mA



20. N° 80 B -

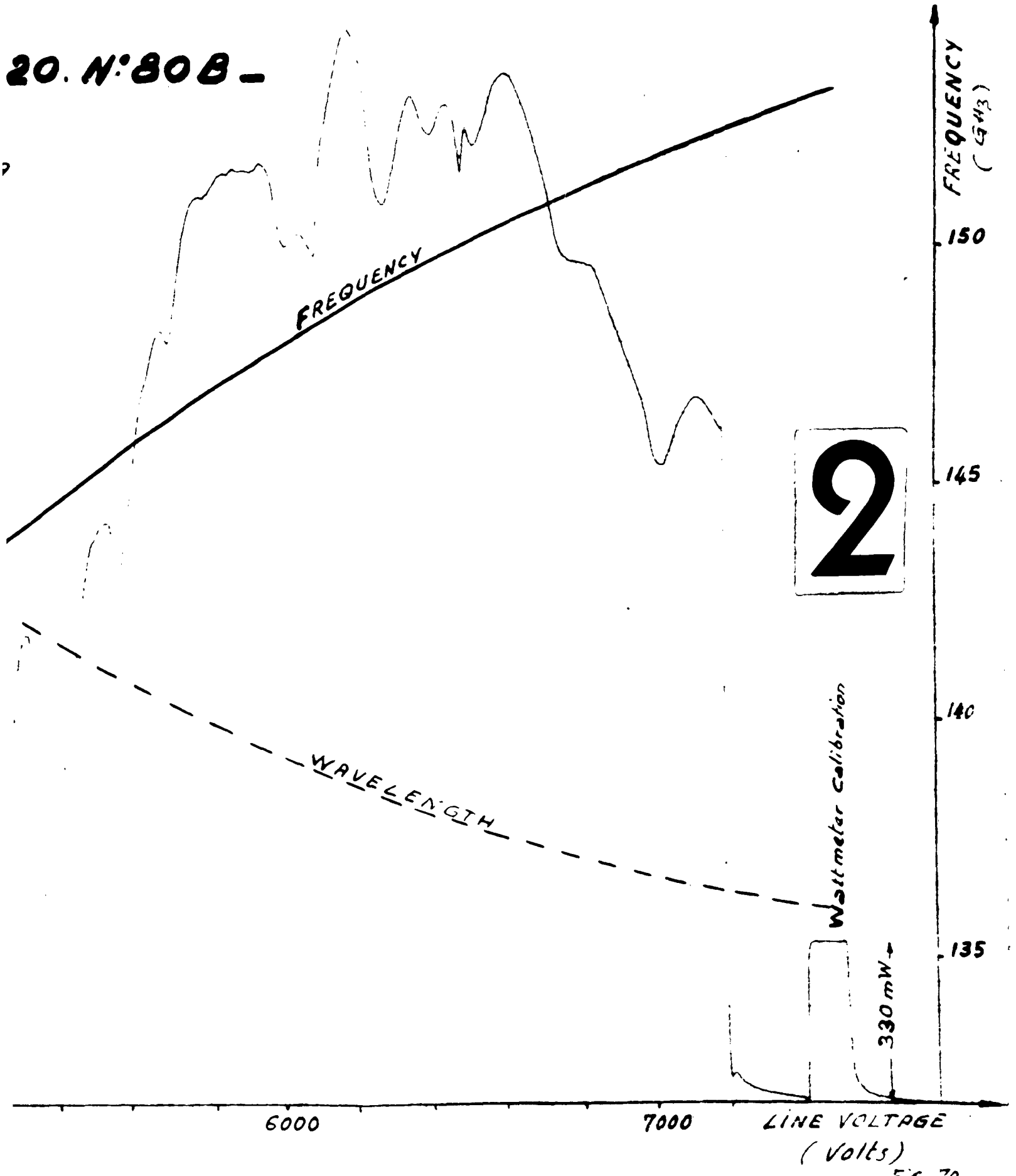


Fig. 70



370.07

COE. 20 N: 81

Magnetic field 5400 Oe

(mA) Starting Current

25

20

15

10

5

0

3000

4000

5000

6000

7000

LINE Voltage (Volts)

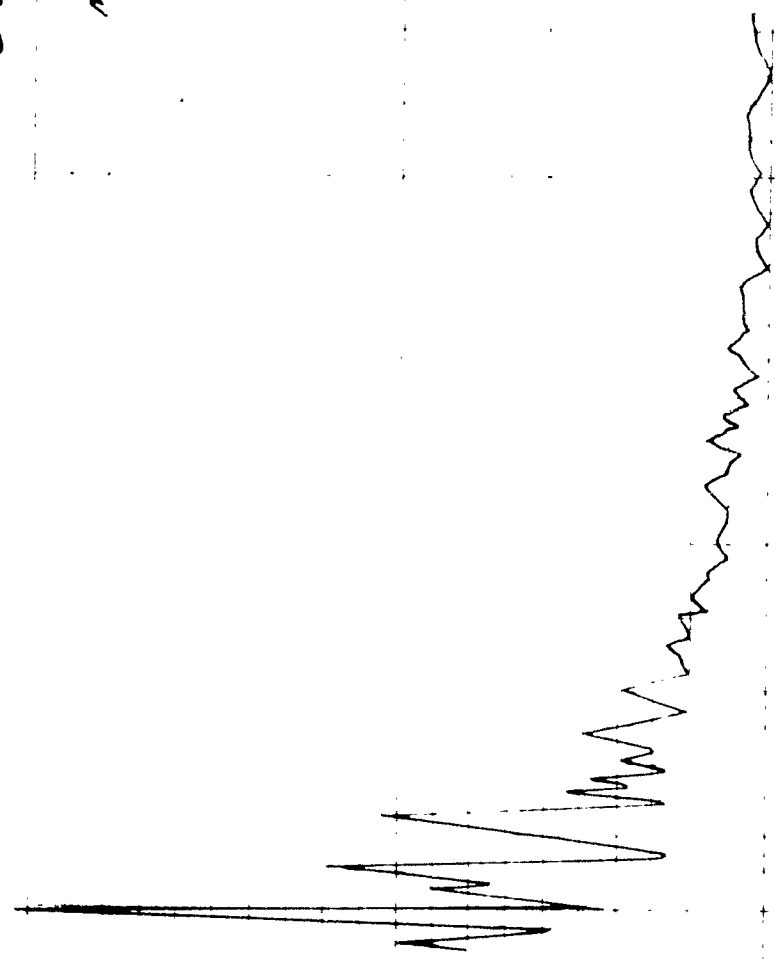
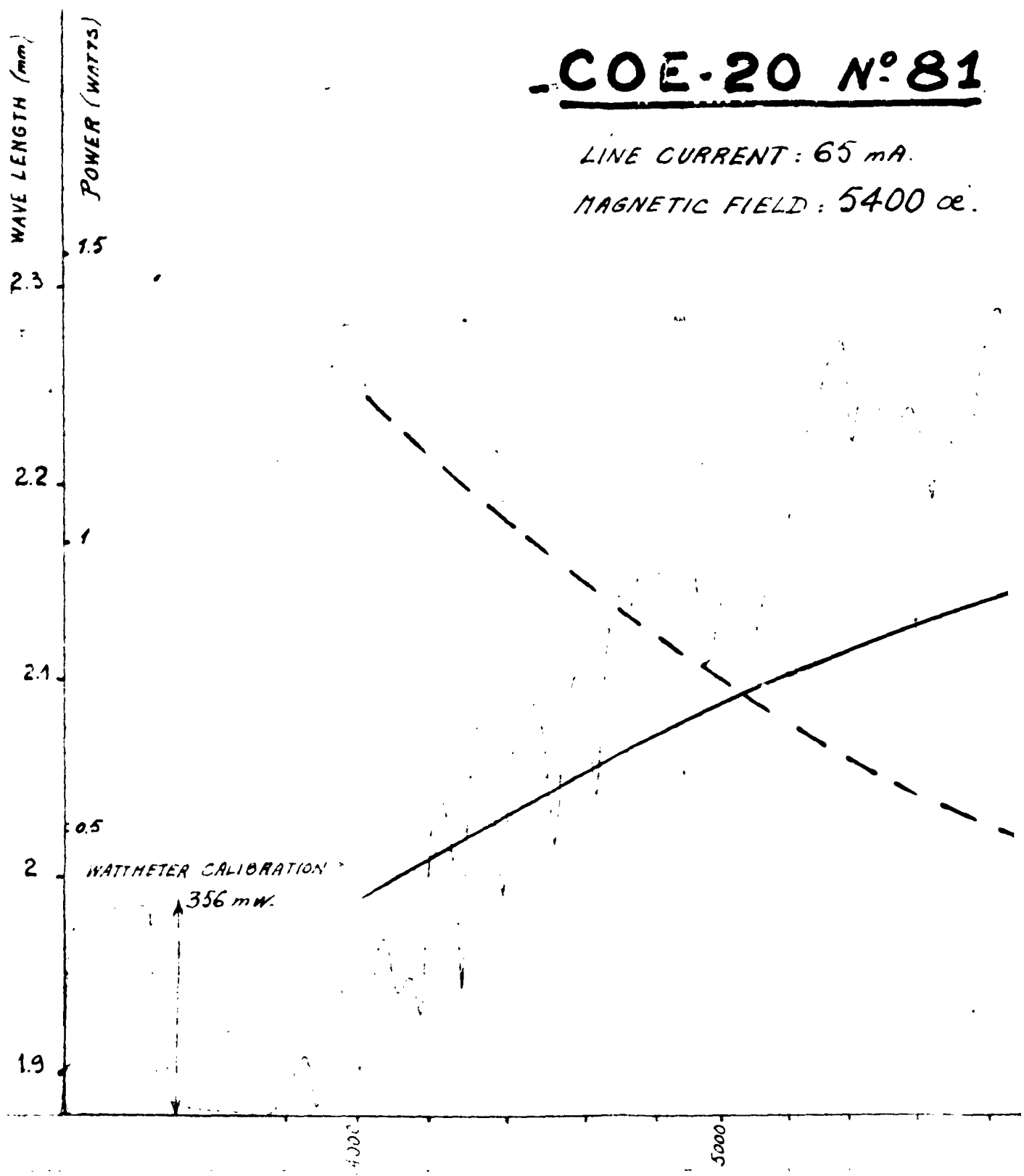


Fig: 72

COE-20 N°81

LINE CURRENT: 65 mA.

MAGNETIC FIELD: 5400 oe.

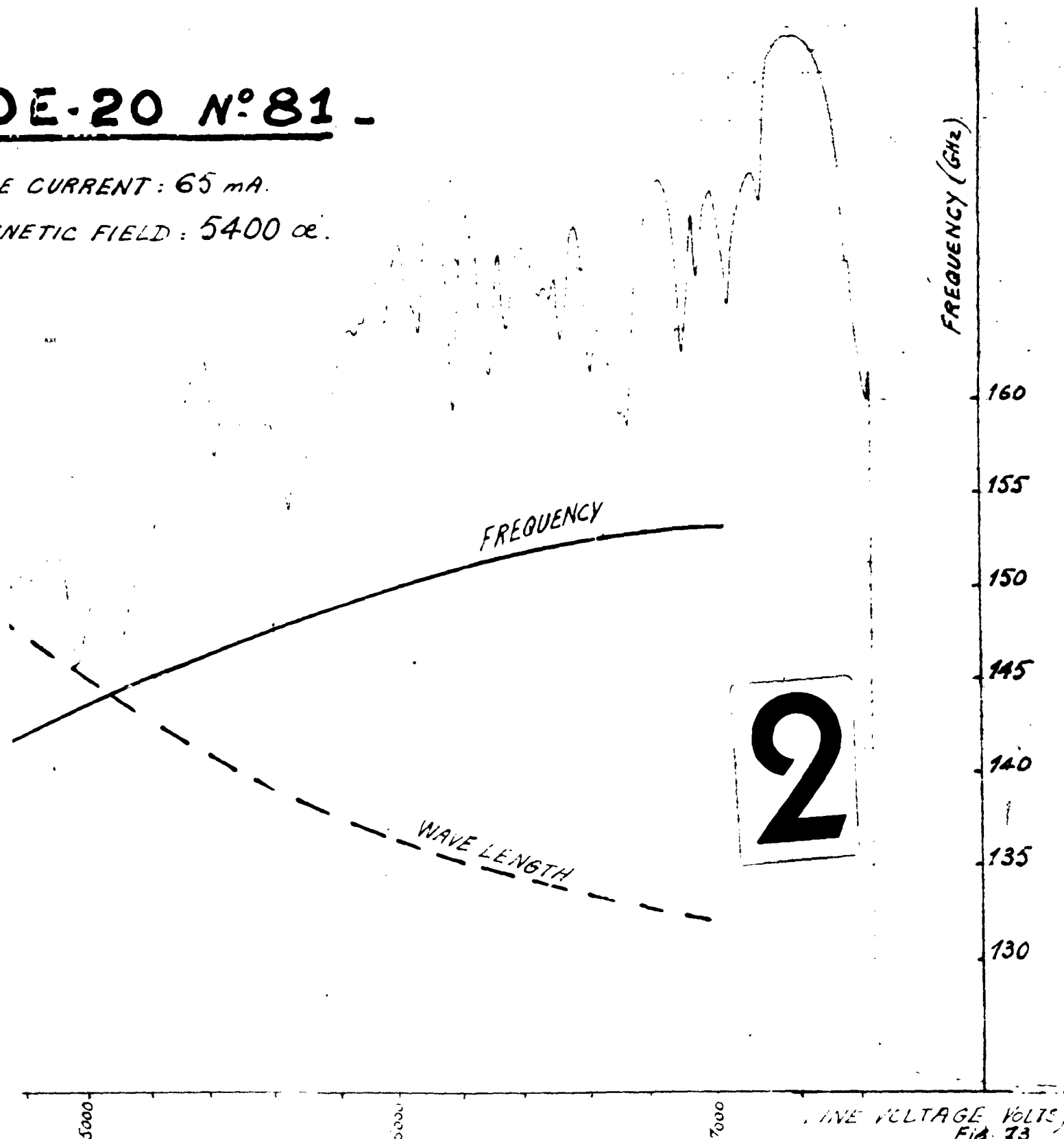


1

DE-20 N°81 -

CURRENT: 65 mA.

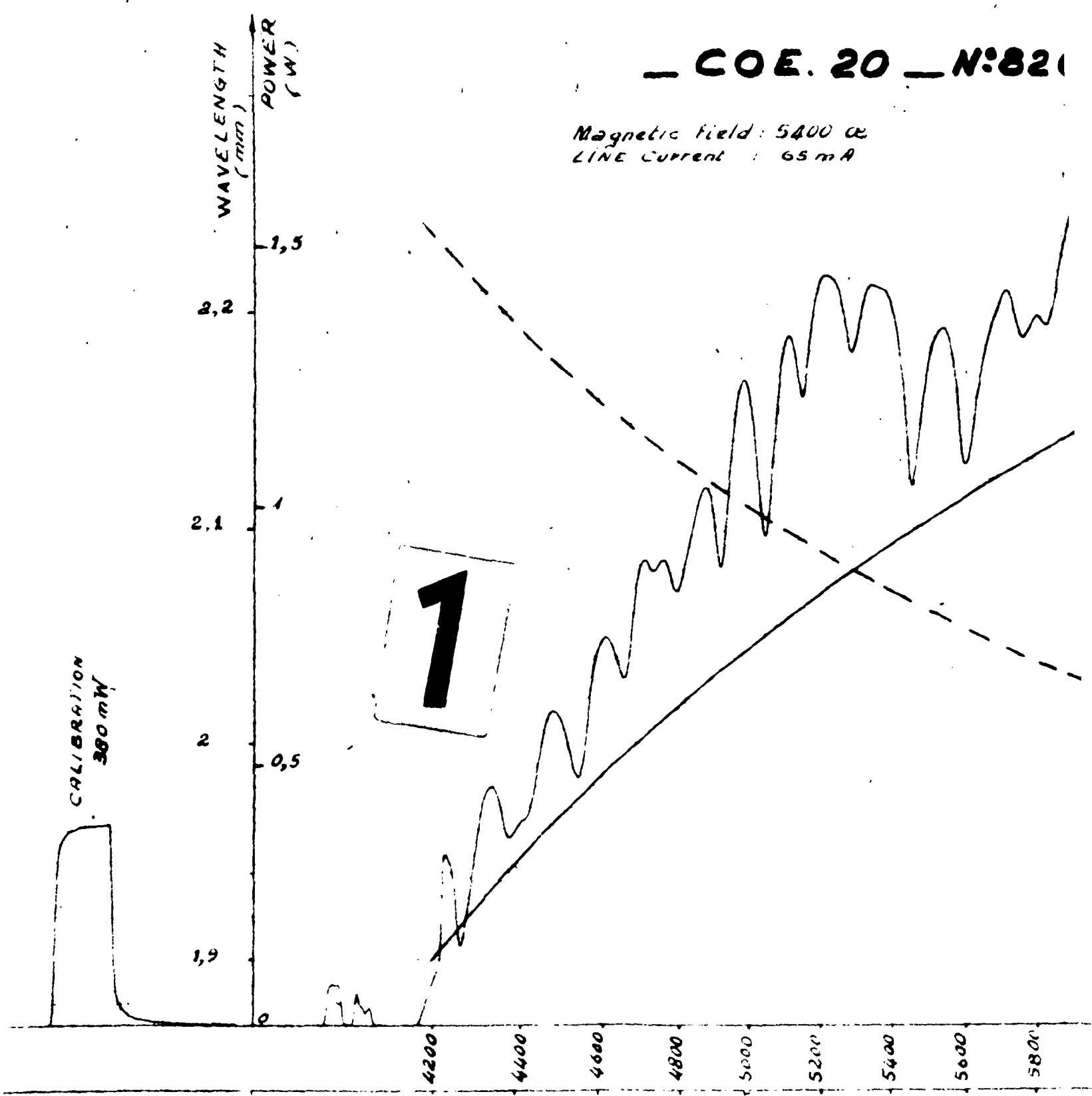
MAGNETIC FIELD: 5400 oe.



LINE VOLTAGE VOLTS
FIG. 73

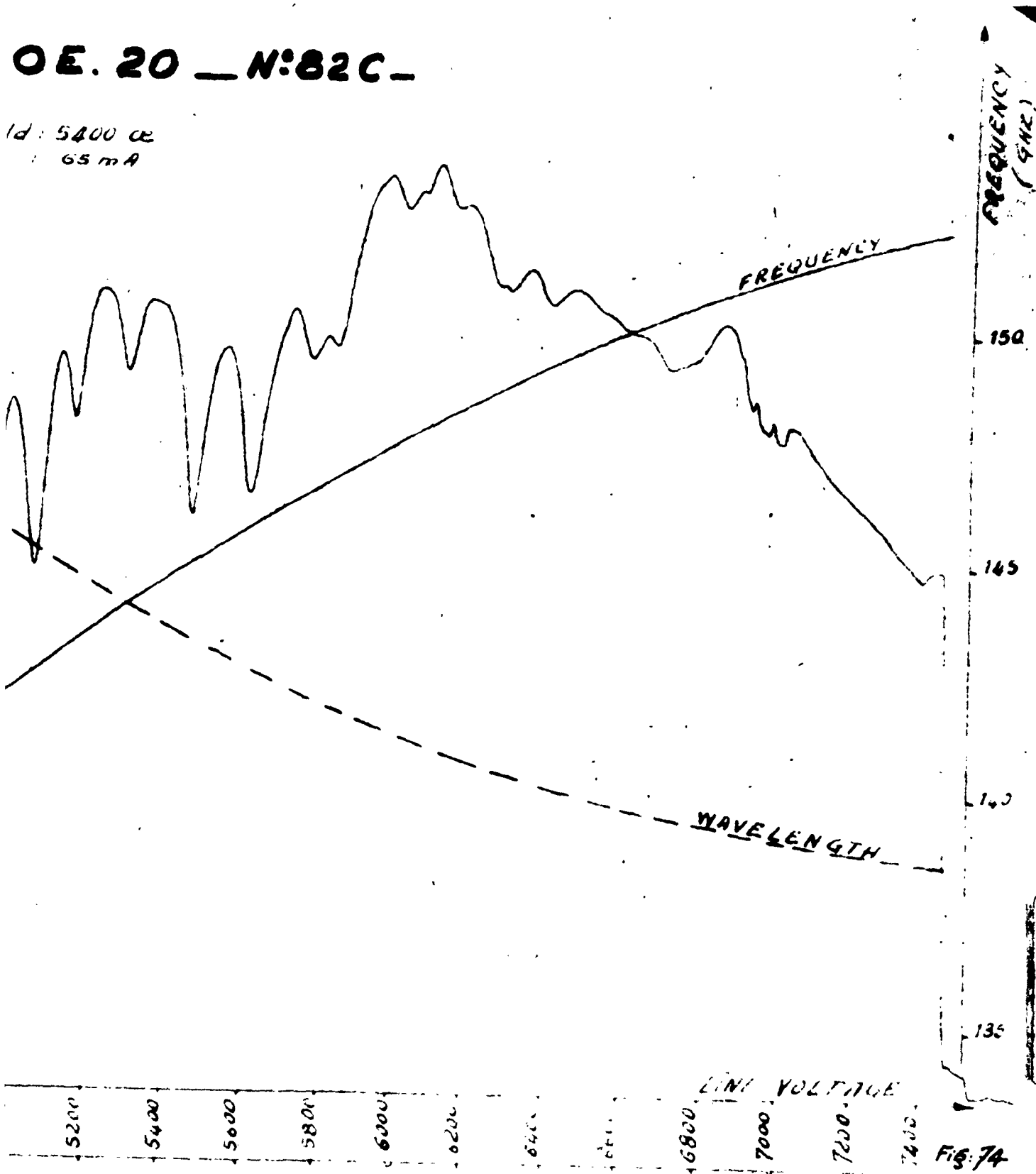
COE. 20 - N:820

Magnetic field: 5400 G
LINE current: 65 mA



OE. 20 - N:82C -

Id: 5400 μ e
65 mA



2

FIG. 74