W. Abruel

ELECTRONICS LABORATORY

POST-ACCELERATION COLOR TUBE

VOLUME I

GENERAL ELECTRIC

CLASS 4

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ELECTRONICS LABORATORY POST-ACCELERATION COLOR TUBE

VOLUME I

Chapters I to III Inclusive

VOLUME II

Chapters IV to XVIII Inclusive

ELECTRONICS LABORATORY POST-ACCELERATION COLOR TUBE MANUAL

By

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of the
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December 1954

PREFACE

This report covers the practical and theoretical considerations necessary to construct and operate the Post-Acceleration Color Tube. Its purpose is to give a working knowledge to those concerned with the development, manufacture, and application of this type tube.

The report has been organized to meet these objectives as lucidly as possible. Each chapter is self-contained and may be read separately without constant reference to other sections. The chapters contain a "flow chart" where necessary, description of the operations performed, and the design considerations, which were necessary to change an idea into an operable and demonstrable device.

Although the "flow chart" deals with the latest model developed, discussion has not been limited to the successful tube, but also includes results of unsuccessful experiments in an attempt to preclude a repetition of our mistakes by others.

The report represents the combined effort of the entire Tube Unit and, hence, covers many man-hours of work. Because the work covered is so extensive, complete detail may be lacking along certain lines. With the report, therefore, is an invitation for detailed discussions with members of our unit.

The various sections of the report were written by the members of our unit most intimately concerned with the particular phase discussed.

This has been a major development and represents the combined efforts of many people from within the Electronics Laboratory, from other departments such as Tube and RTV, and from the Knolls Research Laboratory. The advice and encouragement given to this program by L. T. DeVore, J. P. Jordan, and I. J. Kaar has been of inestimable value and in no small way has contributed to the success of this program.

C. G. Lob

12/10/54

TUBE NOMENCLATURE

1.	Name:	Electronics Laboratory Post-Acceleration Tube
2.	Screen:	Area on which phosphor is printed and the picture displayed.
3.	Grille:	An array of parallel wires placed between the screen and the gun which serve to mask or focus the electron beams into the proper direction for color selection.
4.	Plane of Deflection:	A plane passing through the yoke parallel to the grille and located along the tube axis by the point formed by the intersection of the straight electron paths before and after deflection by the yoke field.
5.	Plane of Static Convergence:	A plane passing through the static convergence elements parallel to the grille and located along the tube axis by the point formed by the intersection of the straight electron paths before and after deflection by the static convergence field.
6.	Plane of Dynamic Convergence:	A plane passing through the dynamic convergence elements parallel to the grille and located along the tube axis by the point formed by the intersection of the straight electron paths before and after deflection by the dynamic convergence field.
7.	Static Convergence Coils:	Coils positioned between the end of the gun and the plane of deflection providing a magnetic field which corrects static convergence of the three beams.
8.	C.P. Screws:	Four screws which form the contact points between the lava spacers and the phosphor plate. When adjusted, they determine the grille-phosphor plate distance.
9.	Bird:	A cross containing four pads in a plane, which contact the four C.P. screws, and four posts of definite length which contact the grille adjacent to the posts thus allowing the C.P.'s to be set in a plane at a predetermined distance from the grille.
10.	Color Center:	A point lying in the plane of deflection determined by the intersection of the undeflected electron beam with the plane of deflection. There are three such points, one for each beam.
11.	Color Base:	The distance between two adjacent color centers.

Potentials

12. Vs — Screen potential measured with respect to the cathode

13. Vm — Grille " " " " " " "

14. Vc — Cone " " " " " " "

15. ΔV — Suppressor voltage equals cone potential minus grille potential

16. ψ — Post-acceleration voltage ratio $= \frac{Vs}{Vc}$
This differs by about 2% from $\frac{Vs}{Vm}$

Distances

17. d — The distance between the grille and screen

18. D — " " " " " " plane of deflection

19. C1 — The distance between the plane of deflection and the plane of convergence

20. C2 — The distance between the plane of deflection and the plane of dynamic convergence

21. Dc — The distance between the grille and the light source in the lighthouse

$$\frac{Dc}{D} = \frac{\psi - 1}{2(\sqrt{\psi} - 1)}$$

22. S — The color base

23. δ — The distance between two adjacent electron beams in the plane of dynamic convergence

24. So — The distance between two adjacent gun axes in the plane of convergence

25. p — The grille pitch or the distance between adjacent wire centers

26. s — The distance between the centers of adjacent color stripes in the center of the screen

27. (1 + K) — The factor of enlargement from grille to screen where

$$K = \frac{d}{D} = \frac{s}{S}$$

28. M The color shift at the center of the screen, measured in units of color stripes, which a vertical magnetic field of .6 gauss produces on a 6.5 kilovolt electron beam. This is not the distance the magnetic field deflects the electron beam

CONTENTS

CHAPTER I BULB PREPARATION

SECTION I TECHNICAL DISCUSSION

The first important construction step in preparing the bulb consists in drilling and tapping the funnel flange pads (3) which receive the dowels for location of the frame. The pads are not accurately flat nor are they in one plane. In addition, even if the above defects were not present, the correct plane of reference still has to be located with respect to the mid-line of the neck and this line is not necessarily perpendicular to the flange pad plane.

The mid-line of the neck is determined by insertion of a Textolite cylinder having a 3/4" concentric hole. The drilling mandrel is an aluminum plate with hardened steel bushings in the appropriate places. The center point of the mandrel has a perpendicular 3/4" rod which slides inside the Textolite cylinder. Insertion of the mandrel in the cylinder plus appropriate shimming and clamping then determines a rigid reference plane for proper drilling of the necessary holes. The stainless steel pads are very tough so that only a high quality tap should be used in threading the holes.

Along with the dowel pin holes the hole for the high voltage flange feed-through insulator and the holes for mounting the high voltage button shield are drilled. These need not be particularly accurate.

The remainder of the bulb preparation steps needs no particular comment. A possible exception is concerned with the hydrofluoric acid treatment of the funnels. Although this undoubtedly does a good job of cleaning, it invariably causes the flange to rust thus making a wire wheel cleaning a further necessary step. A less drastic method of cleaning might be acceptable and do away with the rusting situation.

SECTION II FLOW CHART

1 - Funnel as shipped from manufacturer inspected for obvious defects (e.g. crooked neck, glass cracks, etc.). Funnel and cap numbered on flange to correspond (all funnels do not fit well all caps). Funnel flange is drilled and tapped as needed.

2 - Funnel washed in HF solution, aquadaged, and baked. Chromic oxide painted on clear section around high-voltage button.

3 - Funnel flange wire brushed to remove rust deposit. Flange cleaned with lintless tissue and methyl alcohol. Aquadaged brushed or rubbed down to remove flakes.

4 - Tinnerman clip (K69982-16A42) and wire lead added to high voltage button.

5 - Gun mandrel inserted, shimmed up, and gun sealed. Tissue closure placed in neck to keep out dirt (see gun sealing).

6 - Mounting shims (from 5) and dowels degreased and installed (K69982-16A62, 16A63).

7 - High-voltage shield (K6998-16A41) mounted over high-voltage button.

8 - Corrugated aluminum gasket placed on funnel flange.

9 - Electron shield added.

10 - Funnel covered to keep out dirt.

11 - Cap cleaned with lintless tissue and methyl alcohol.

12 - Fit of funnel and cap checked. Gaps corrected by local bending as needed. Overlap corrected by trimming (see welding).

CHAPTER II GUNS FOR THE POST-ACCELERATION COLOR TUBE

SECTION I ASSEMBLY OF TRI-COLOR POST ACCELERATION GUN

In this part of the report, the assembly of the presently used tri-color gun is described. In Section II of this report, other and the latest designs are shown. The tri-color gun consists of three identical electrostatic focus guns assembled together into one unit. The individual gun is shown in Fig. II-1. A sketch of this color gun assembly is shown in Fig. II-2, and a photographic picture of it is shown in Fig. II-3. Tentative operating data for the tube with this gun are given in Table I.

Parts for the single gun are shown in Figures II-4 to II-14. All parts are of Type 305 stainless steel.

Control grid G_1	Fig. II-4
First anode G_2	" II-5
First focusing electrode G_3 }	" II-6
Second anode G_4 }	
Second focusing electrode G_5 }	
Third anode	" II-7
Limiting aperture cup	" II-8

Two methods of cathode assembly in control grid G_1 were used. The first assembly is shown in Figures II-9 to II-11; the second assembly in Figures II-12 to II-14.

First cathode assembly method:

Cathode with ceramic disk	Fig. II-9
Cathode spacer ring	" II-10
Cathode retainer ring	" II-11

Second cathode assembly method:

Cathode with ceramic disk	Fig. II-12
Cathode retainer cup	" II-13
Cathode retainer ring	" II-14
End plate for tri-color gun	" II-15
Collar for welding of center gun to end plate	" II-16
Collar for welding of side guns to end plate	" II-17
Metal strips for welding of guns together	" II-18 (a) & (b)
Metal strip for stemming of gun	" II-18 (c)
Getter with support	" II-18 (d)
Double spring for mounting of gun in tube neck	" II-18 (e)
Kovar bridge for heater support	" II-19 (a)
Heater nickel tab	" II-19 (b)
Quartz sleeve for cathode tabs	" II-19 (c)
Mu-metal shield	" II-20

Tools: Beading tools are shown in Figures II-21 to II-30. Pin alignment is used.

Shell of beading fixture	Fig. II-21
End pieces of beading fixture	" II-22 - II-25
Pin alignment strip and spring	" II-26
Beading mandrel (male) with ring	" II-27 (a) & (b)
Beading mandrel (female)	" II-28
G_1-G_2 spacer	" II-29
High-voltage electrode spacers	" II-30

Tools for inserting of cathodes:

Tool for inserting of spacer ring, cathode and cathode retainer ring (first assembly method)	Fig. II-31 (a)
As above for second assembly method	" II-31 (b)
Holder for cathode retainer cup	" II-32

Micrometer for shaping of cathodes:

Pressure clamp	Fig. II-33
Indicating thimble	" II-34
Pressure screw	" II-35
Mount extension	" II-36
Anvil base	" II-37
Anvil	" II-38
Spring	" II-39
End pieces	" II-40

Fixture for inserting of cathodes by the second method:

Photograph of fixture with gun	Fig. II-41
Frame of fixture	" II-42
Parts for fixture	" II-43 - II-45

Welding tools:

Limiting aperture cup welding mandrel & spacer sleeve	Fig. II-46
Cathode retainer ring welding mandrel for first method	" II-47 (a)
As above, for second method	" II-47 (b)
Welding jig for tri-color gun assembly	" II-48
Mandrels for welding jig of Fig. II-48	" II-49
Stand for welding jig	" II-50

Microscope adapter:

For checking of alignment of G_1 with rest of gun — Fig. II-51
For checking of alignment of G_1 and limiting aperture — " II-52

Stemming and basing diagrams — Fig. II-53 (a) & (b)

Preparation and Inspection of Parts:

Control Grid G_1 (Fig. II-4): Check hole for burrs. Spot check size of hole (.0205"). Spot check on optical comparator concentricity of hole which should be within .0015" from axis of the part measured from the outside diameter. Spot check concentricity of coined part and flatness of upper surface of grid.

The first anode G_2 (Fig. II-5) has to be checked for perpendicularity of shaped end with axis of part. If not within .001" full indicator reading, this end has to be faced off. Here and elsewhere do not use sulfur-based oil when machining. The edges on the open end have to be rounded, with a full radius and high polish. Requirement of perpendicularity of open end as above.

Second and third anodes, G_4 amd G_6 respectively (Fig. II-6), and first and second focusing electrodes, G_3 (Fig. II-6) and G_5 (Fig. II-7) respectively: Ends to be perpendicular with axis within .001" full indicator reading, edges to have full radius with high polish.

Limiting aperture cups (Fig. II-8): To be spot checked for concentricity of the whole with outside diameter. The limiting apertures should have a close sliding fit in the first anode G_2. Edge on open end with full radius and high polish. No burrs around hole.

Cathodes: The cathodes shown in Figures II-9 and II-12 have to be formed using tools shown in Figures II-33 to II-40, so as to obtain an indentation .002" deep in the central part of the cathode cap.

Flatness of rim of cathode caps to be checked on optical comparator after spraying and removal of coating from cathode cup rim.

Until ceramics the proper size for cathodes are available, the ceramic disks have to be ground to proper size (Fig. II-9 and Fig. II-12). Do not use sulfur-based compounds.

Cathodes to be washed, oxidized, hydrogen fired and sprayed. The thickness of the coating should be .0023 to .0025".

Cathode spacers (Fig. II-10 are to be matched with individual cathodes. The length of the (sprayed) cathodes is measured on an optical comparator. All parts coming in contact with the cathode should be degreased. The cathode spacers are lapped down so as to be .0055" longer than the cathodes.

TABLE II - I

MAXIMUM OPERATING VALUES
(Tentative)
FOR POST ACCELERATION COLOR TUBE

V_{screen}	27KV
V_{cone}	7.1KV
V_{mask}	$= V_{cone} - 150$ V
V_{focus}	approx. 3.1KV
Heaters	6.3V, approx. 1.8 amp.

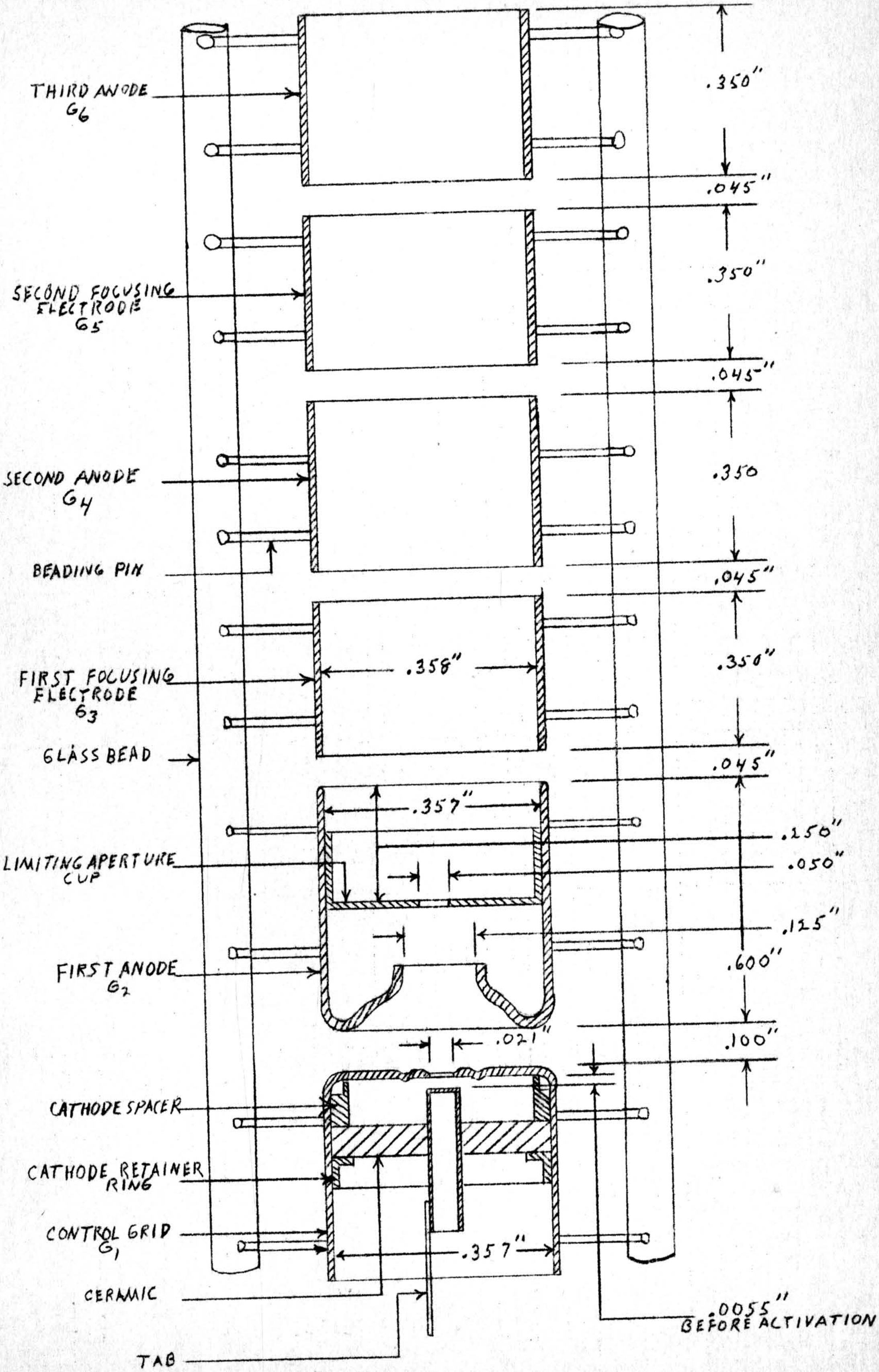


FIG. II - 1

INDIVIDUAL GUN OF POST ACCELERATION TRI-COLOR GUN

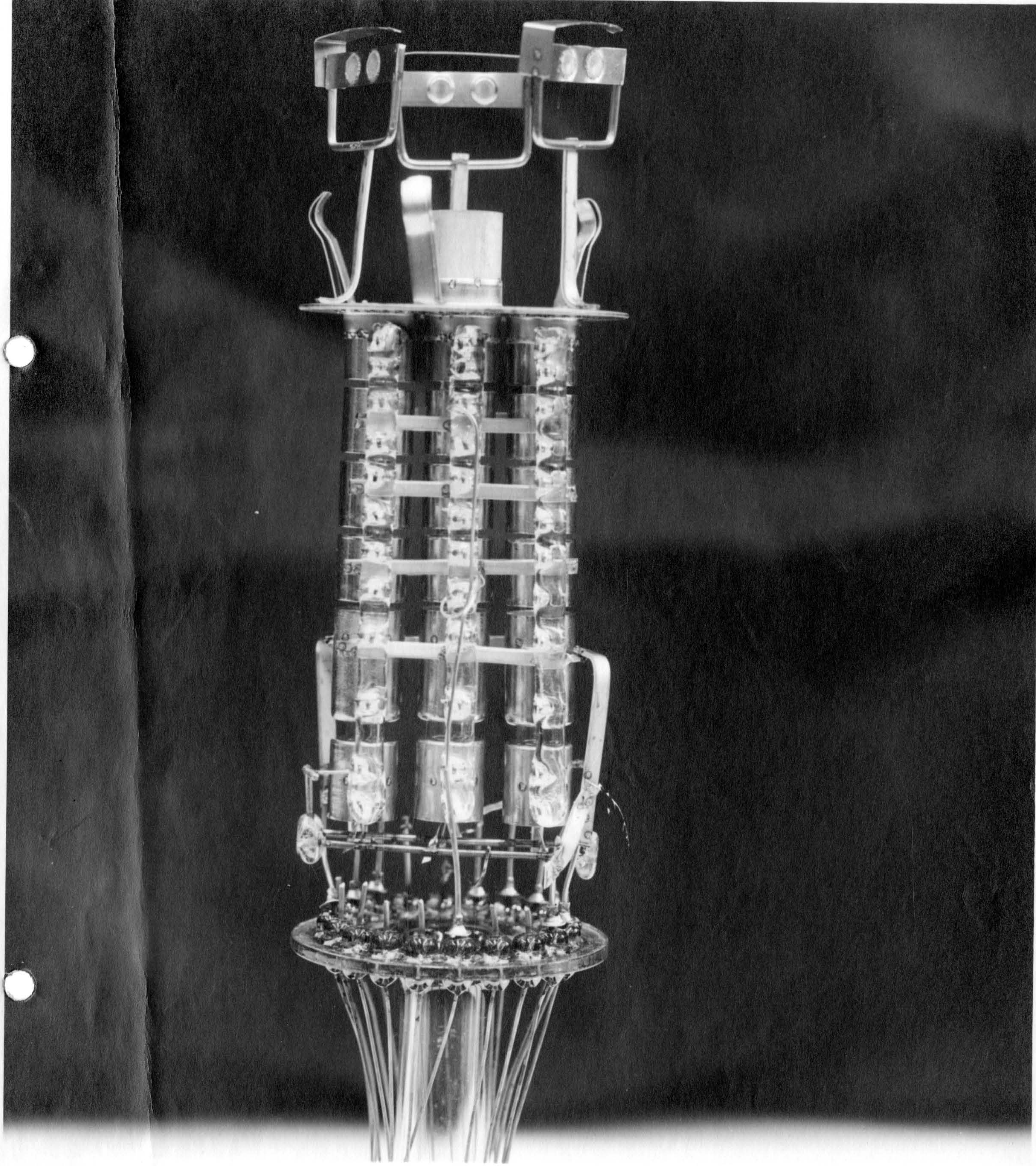


FIG. II-3
POST ACCELERATION TRI-COLOR GUN

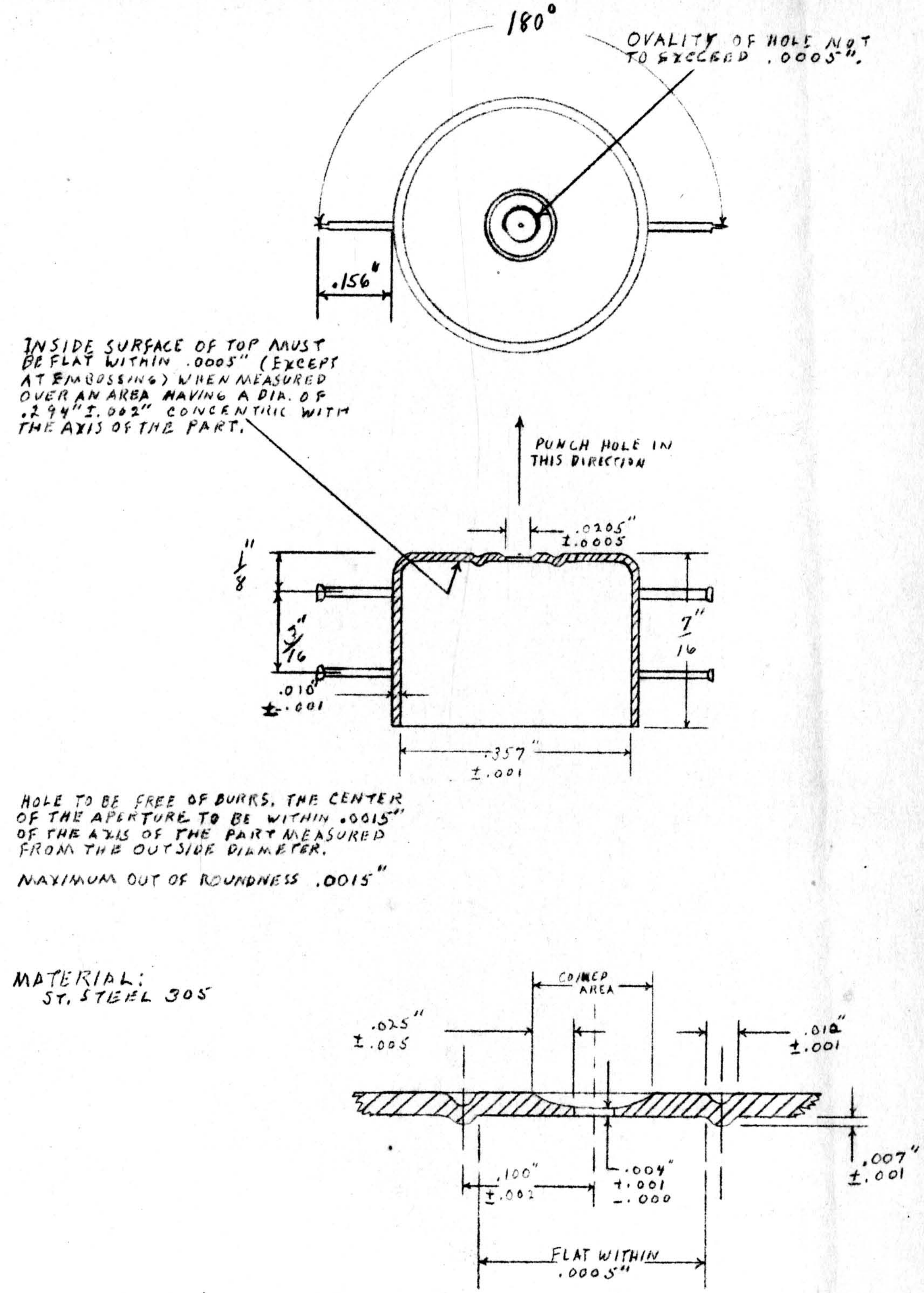
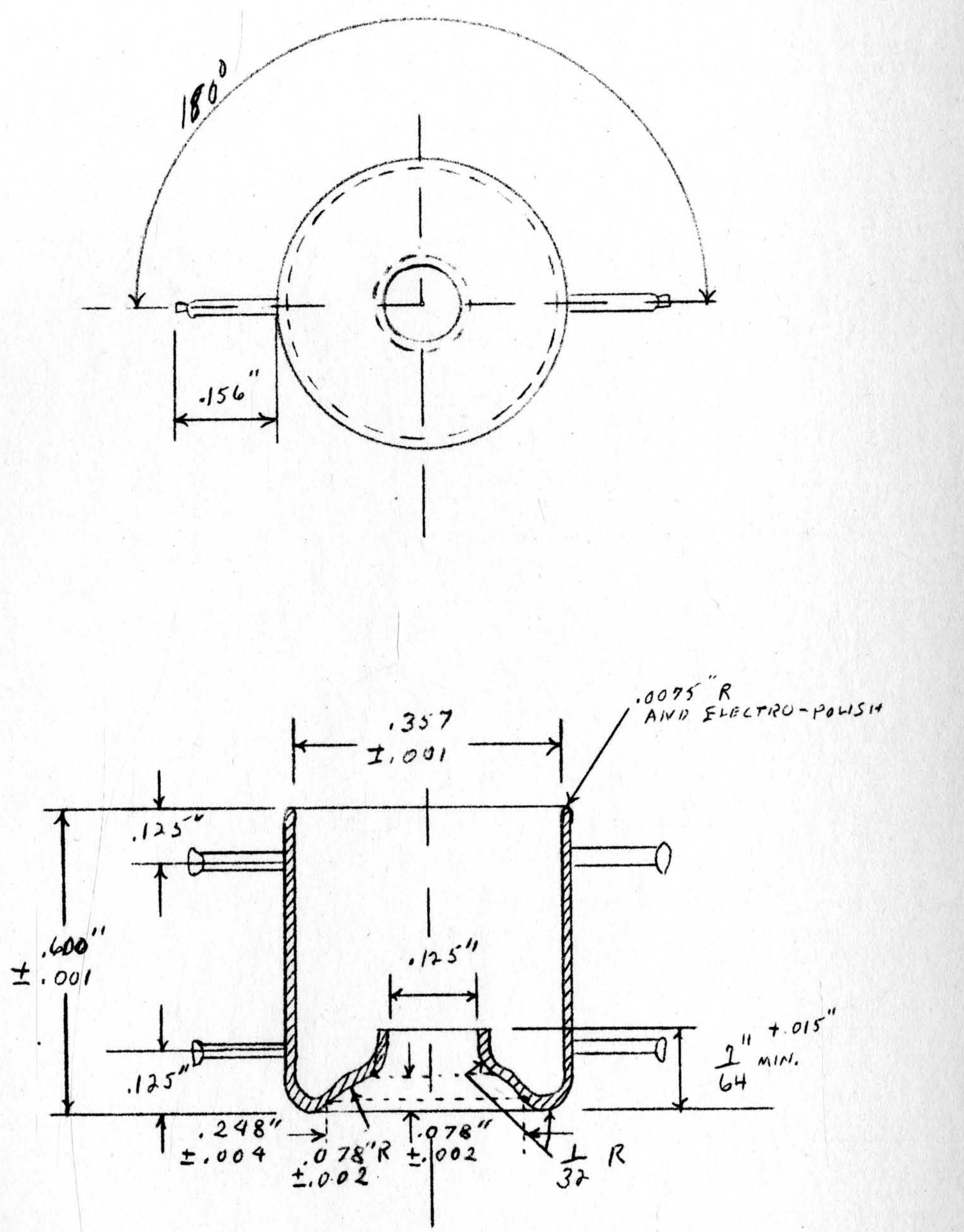


FIG. II - 4

CONTROL GRID G_1



MATERIAL:
ST. STEEL 305
.015"

PLANES OF ENDS TO BE PARALLEL AND PERPENDICULAR TO AXIS WITHIN .001" FULL INDICATOR READING.

FIG. II - 5

FIRST ANODE G_2

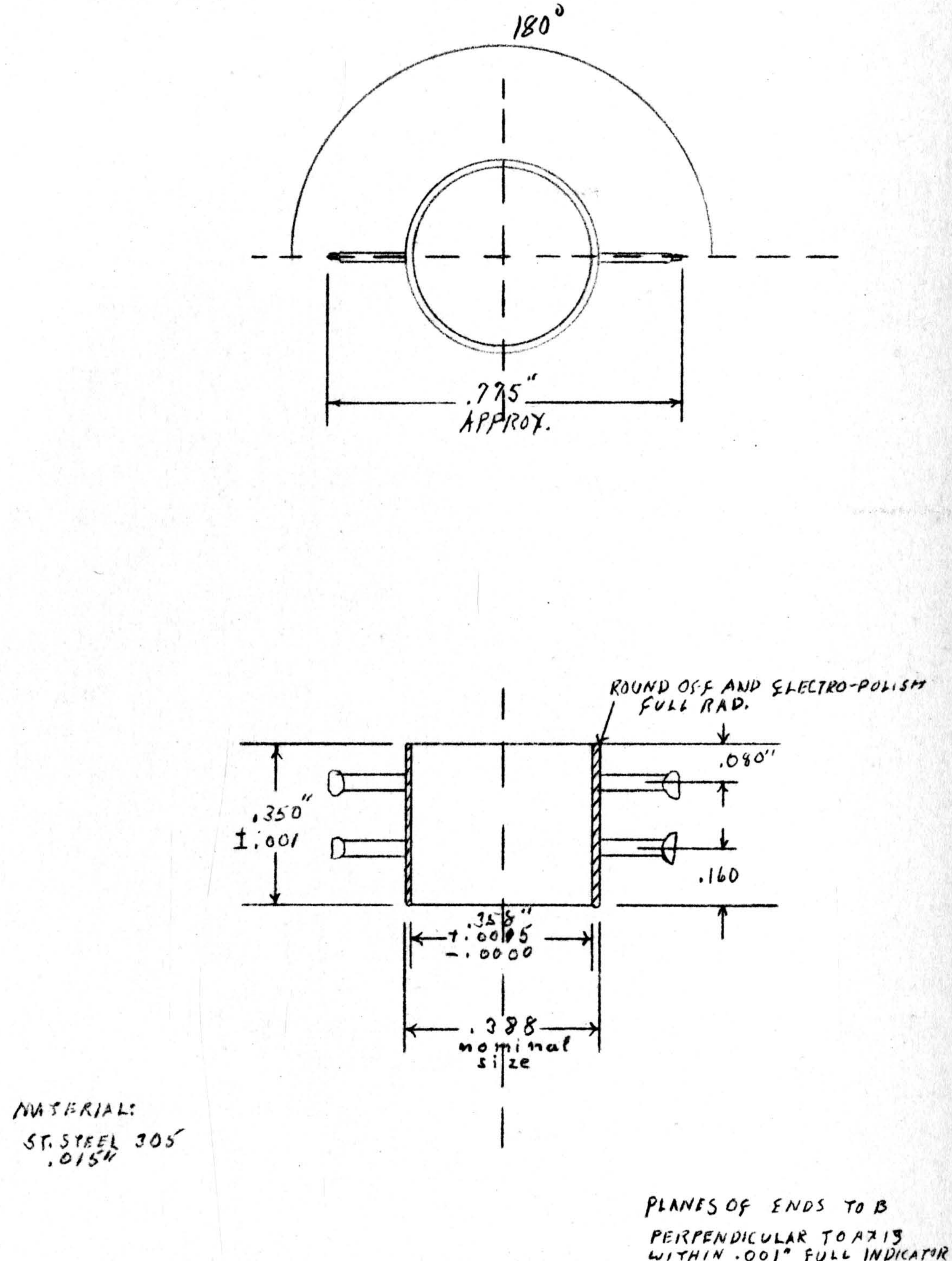


FIG. II - 6

SECOND ANODE, FIRST AND SECOND FOCUSING ELECTRODE

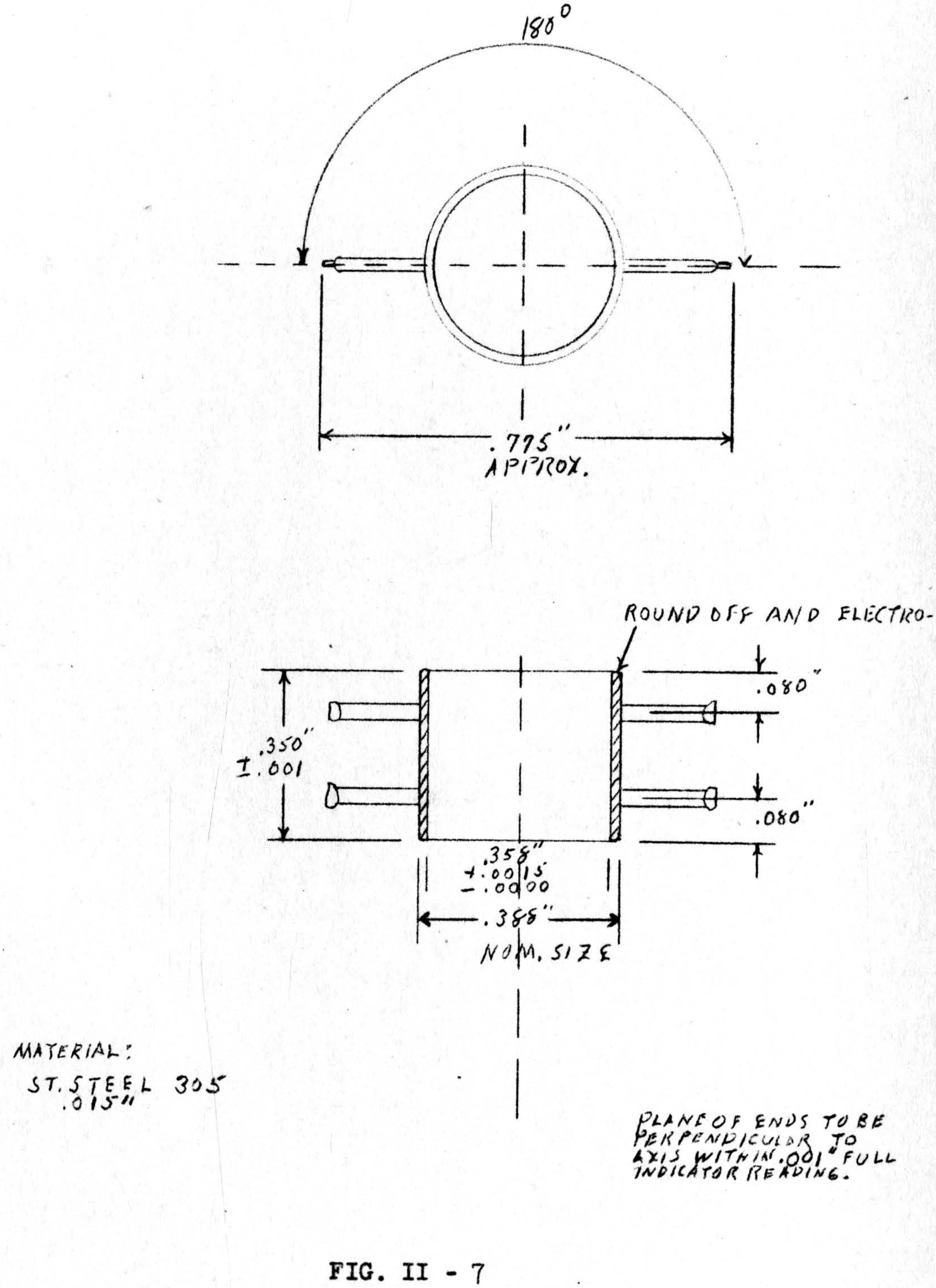
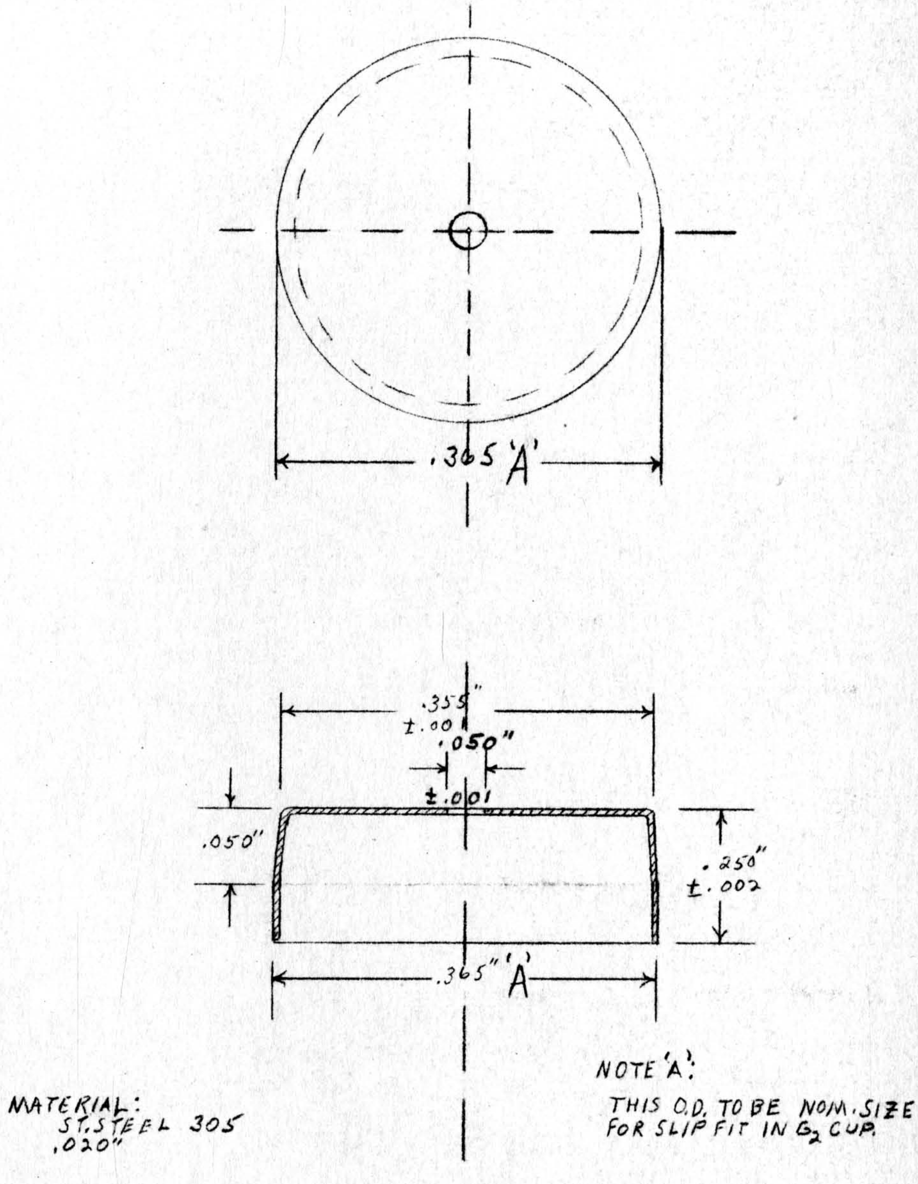


FIG. II - 7

THIRD ANODE



LIMITING APERTURE CUP

FIG. II - 8

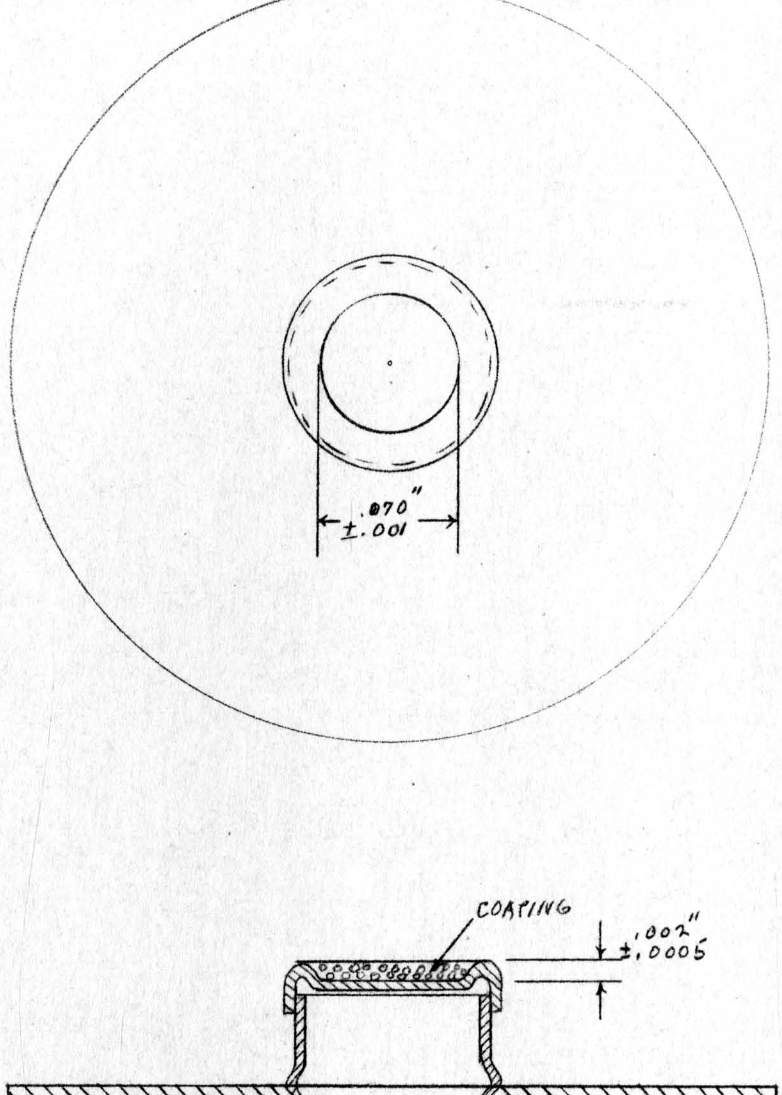


FIG. II - 9

CATHODE WITH CERAMIC DISK
FOR FIRST ASSEMBLY METHOD

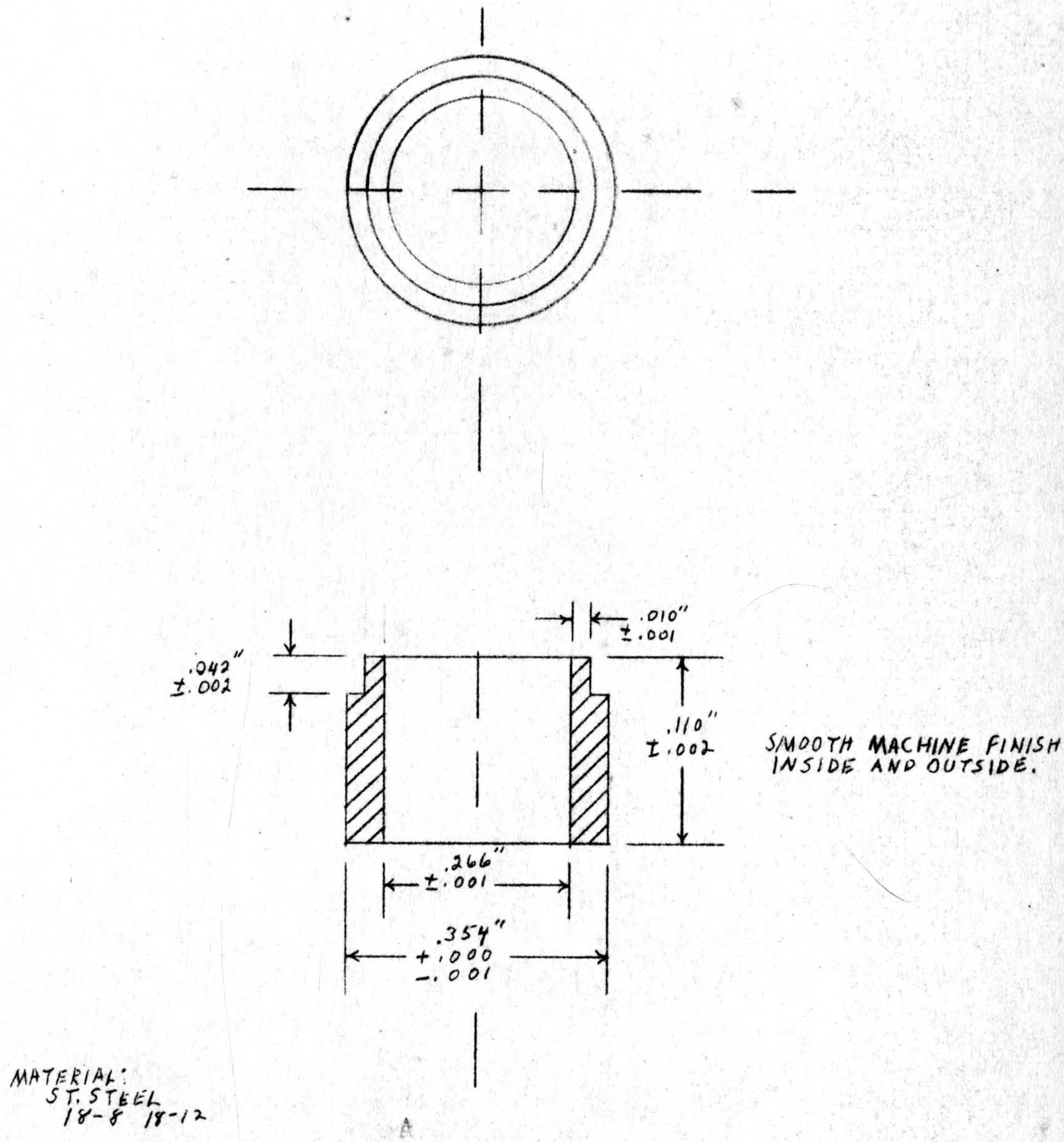
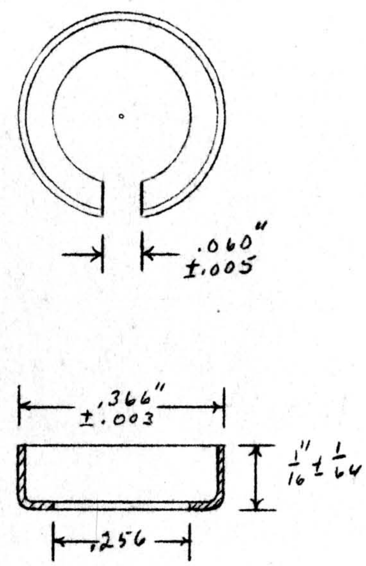


FIG. II - 10

CATHODE SPACER RING
FOR FIRST ASSEMBLY METHOD



MATERIAL:
.008" ±.0015" ST. STEEL 305

FIG. II - 11

CATHODE RETAINER RING

FOR FIRST ASSEMBLY METHOD

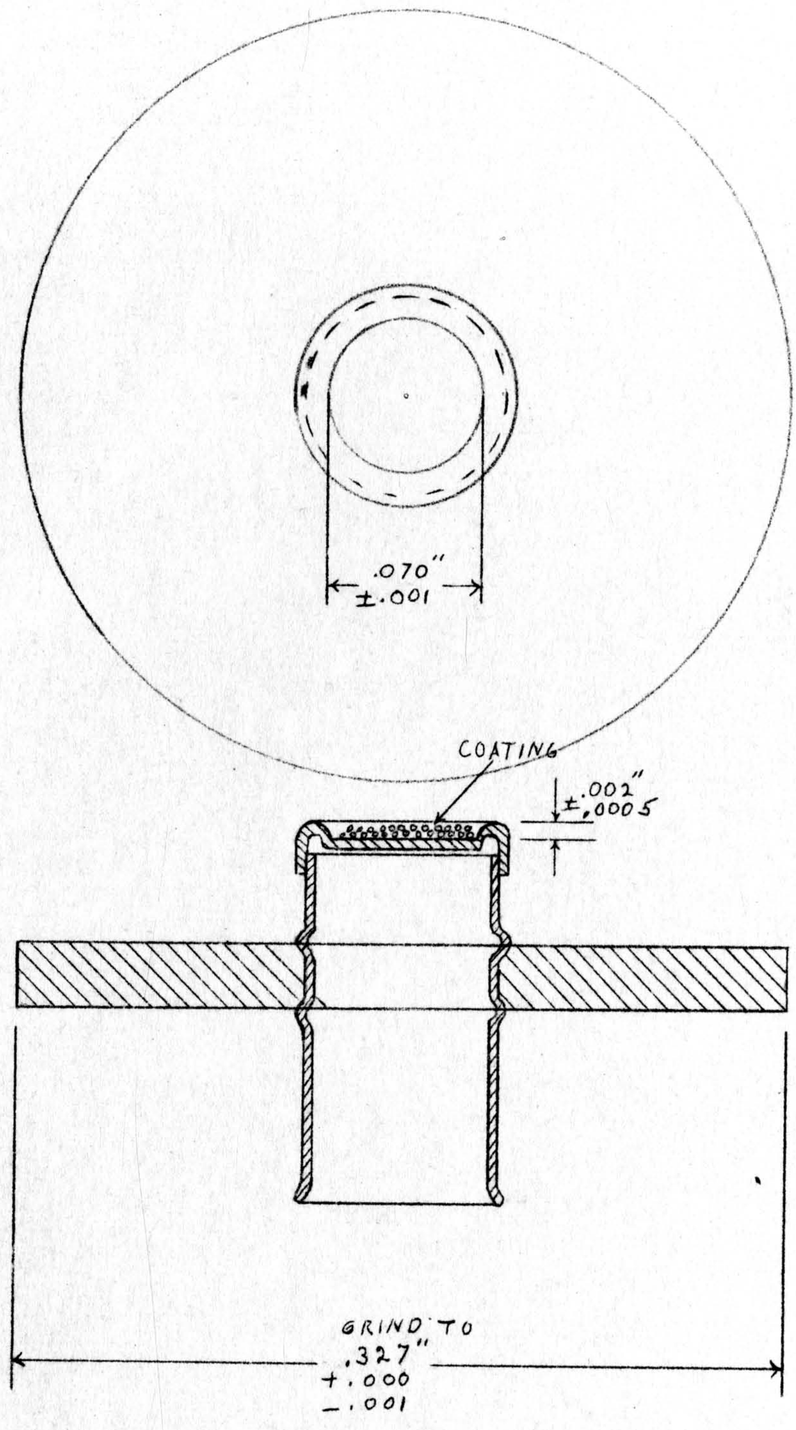
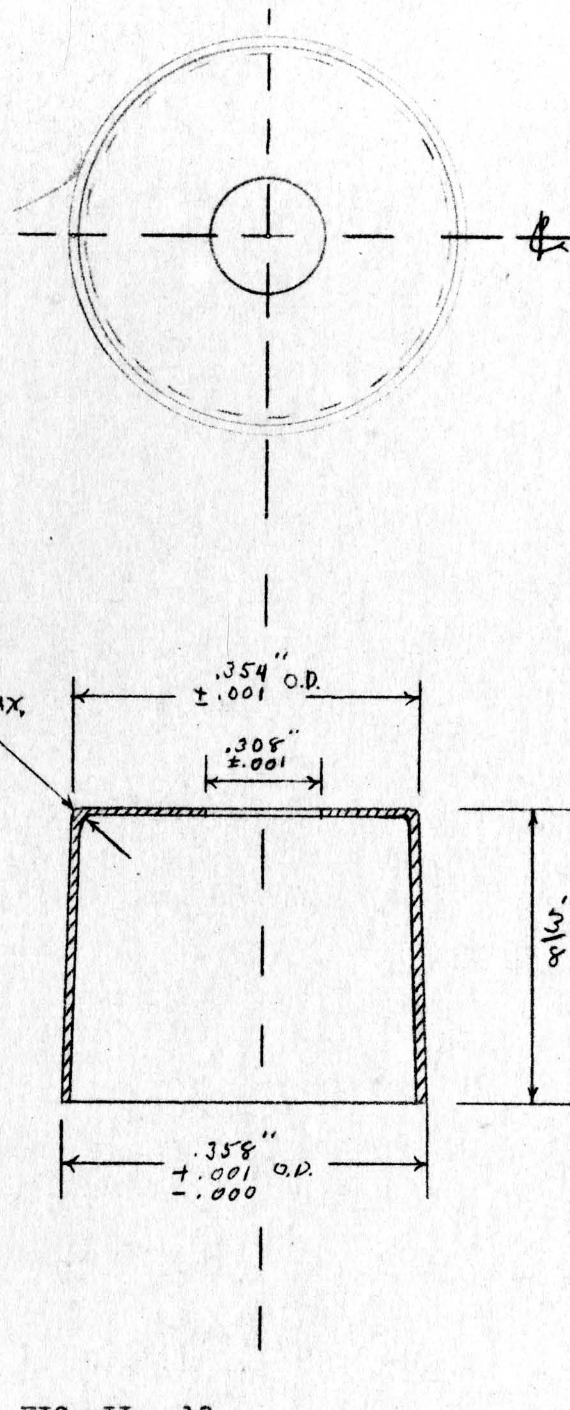


FIG. II - 12

CATHODE WITH CERAMIC DISK
FOR SECOND ASSEMBLY METHOD



MATERIAL:
0.007" ST. STEEL
(NON-MAG)

FIG. II - 13

CATHODE RETAINER CUP FOR
SECOND ASSEMBLY METHOD

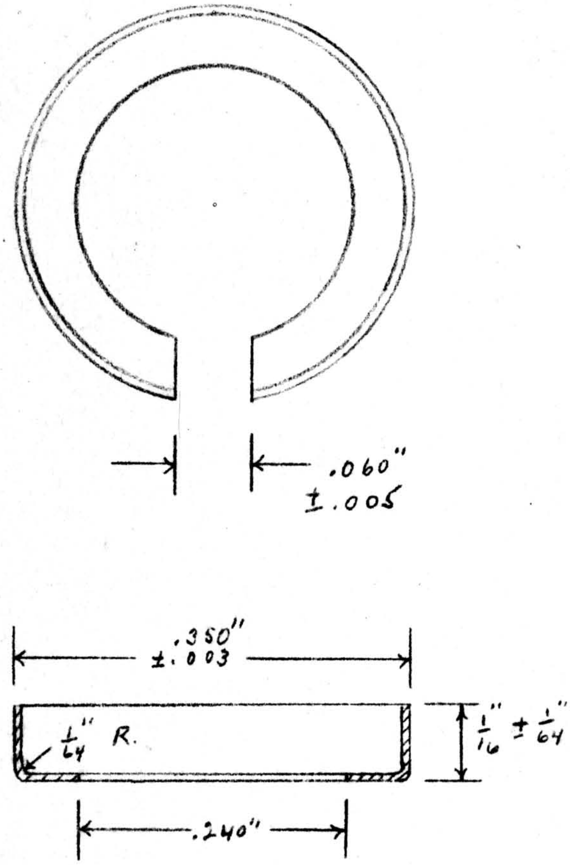
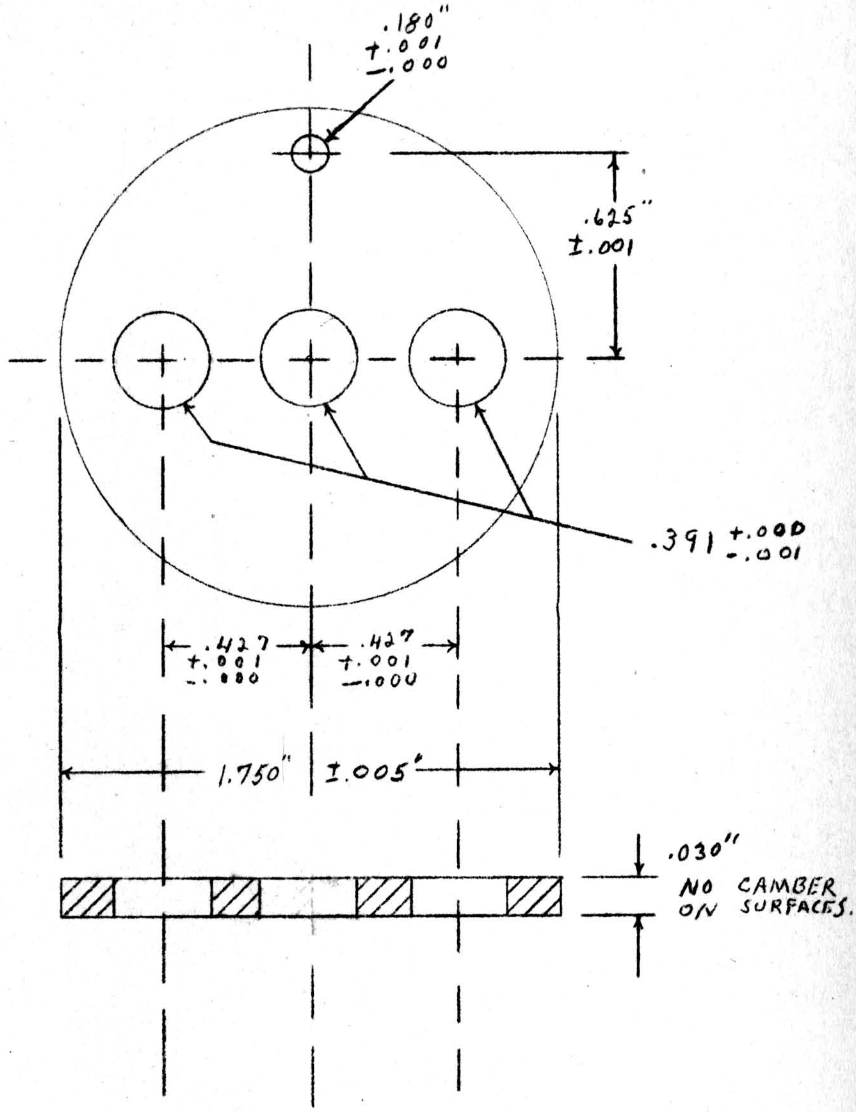


FIG. II - 14

CATHODE RETAINER RING
FOR SECOND ASSEMBLY METHOD

MATERIAL:
0.008" ±.0015" ST. STEEL 305



MATERIAL:
ST. STEEL
18-12

FIG. II - 15

END PLATE FOR TRI-COLOR GUN

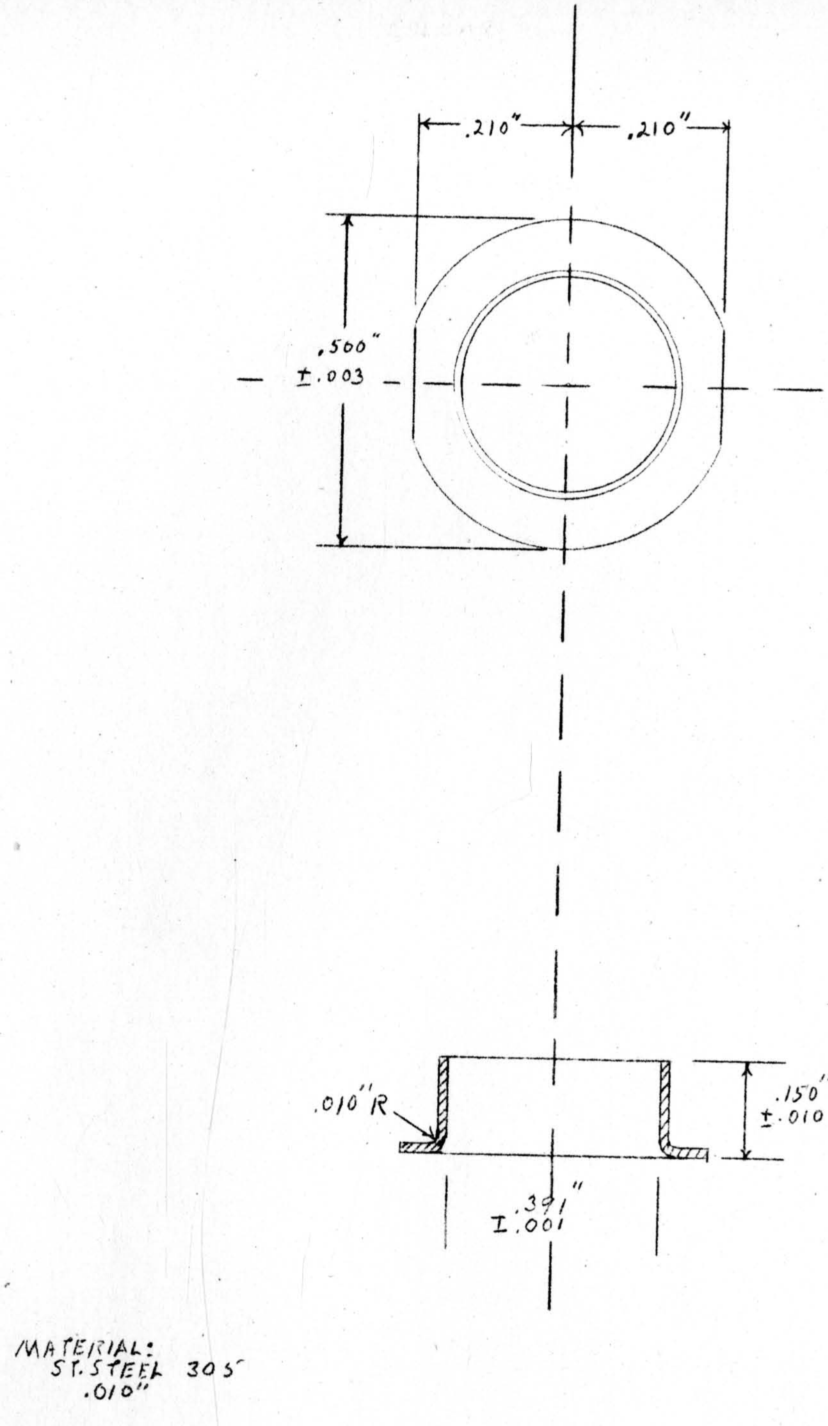


FIG. II - 16

COLLAR FOR CENTER
GUN

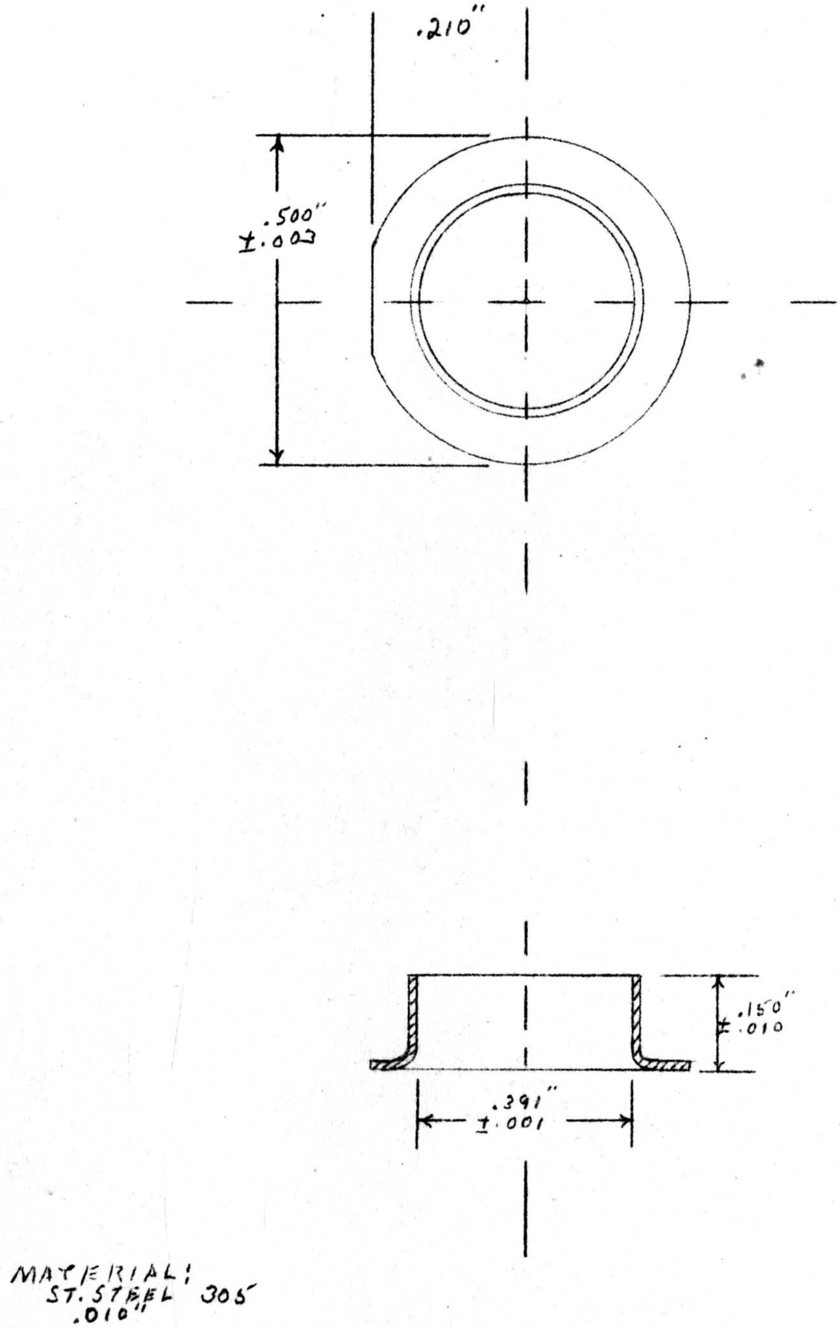


FIG. II - 17

COLLAR FOR SIDE GUNS

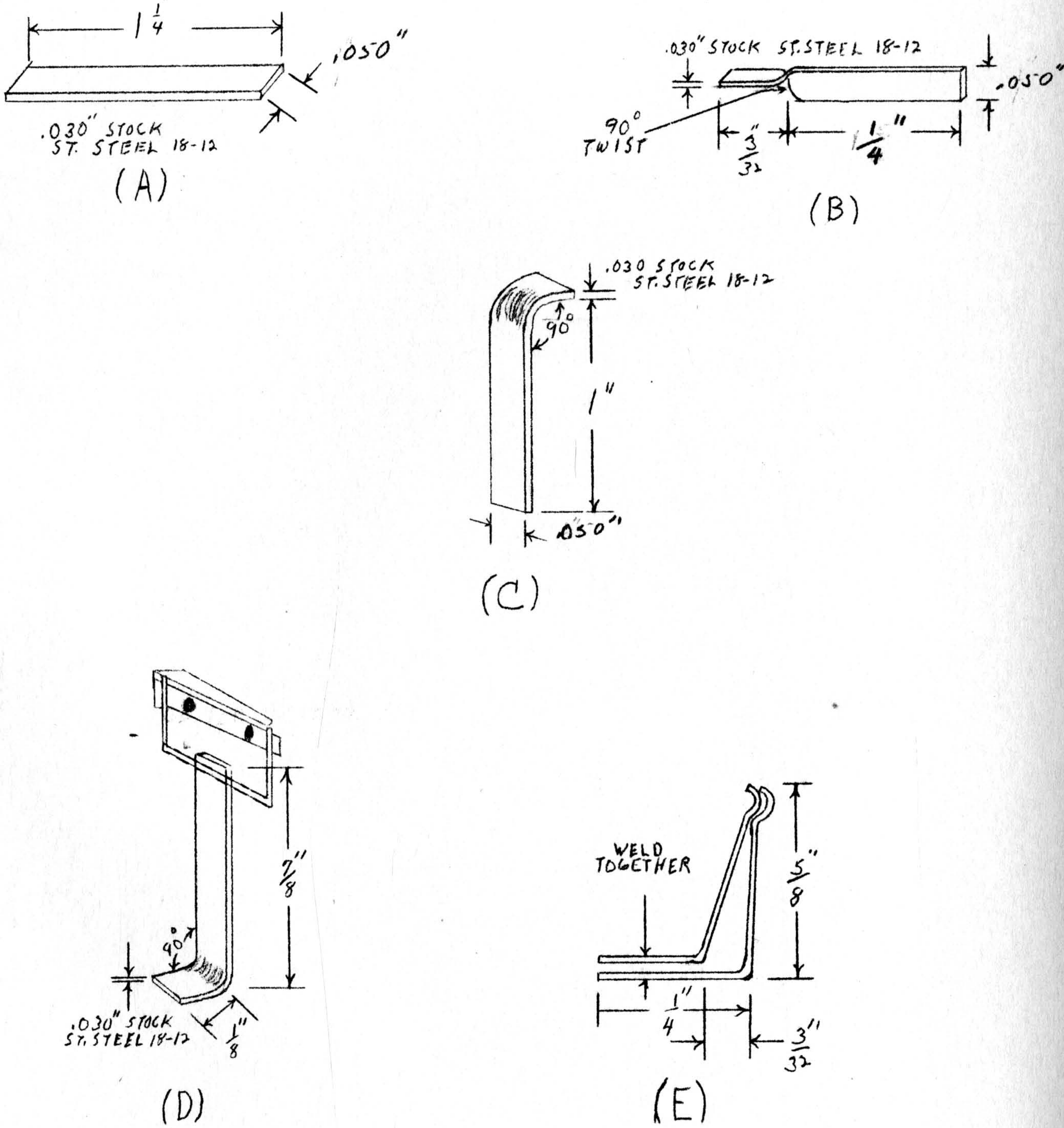
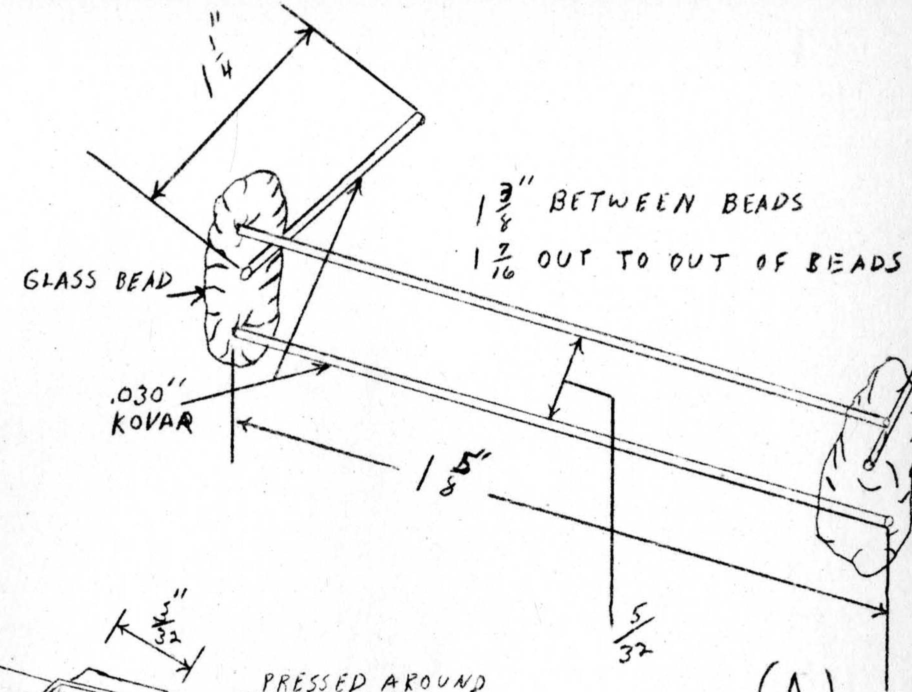


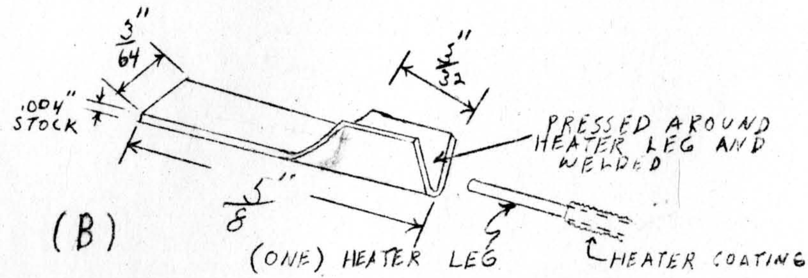
FIG. II - 18

(A), (B), (C) METAL STRIPS FOR TRI-COLOR GUN

(D) GETTER WITH SUPPORT

(E) DOUBLE SPRING





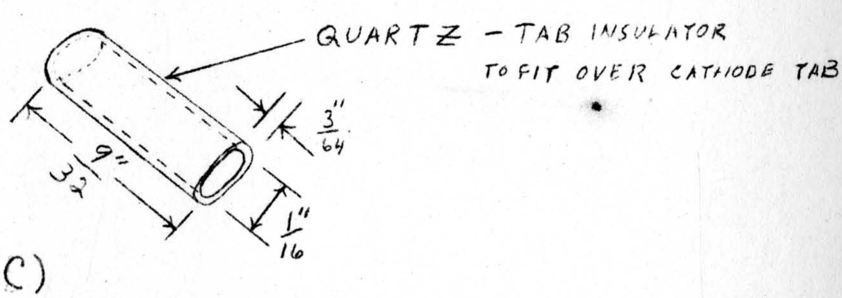


FIG. II - 19

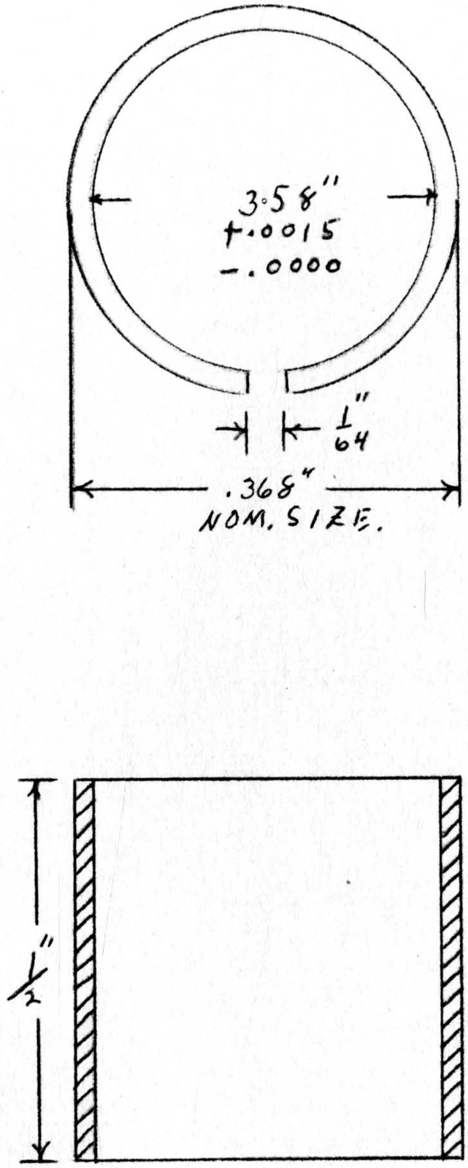
(A) KOVAR BRIDGE FOR HEATER SUPPORT

(B) HEATER NICKEL TAB

(C) QUARTZ SLEEVE FOR CATHODE TABS

P.H.GLEICHAUS

9/27/54
#7322



MATERIAL:
MU. MET. .014"

MATERIAL:
MU. MET. .014"

FIG. II - 20

MU-METAL SHIELD

P.H. GLEICHAUF

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Sept. 23-53

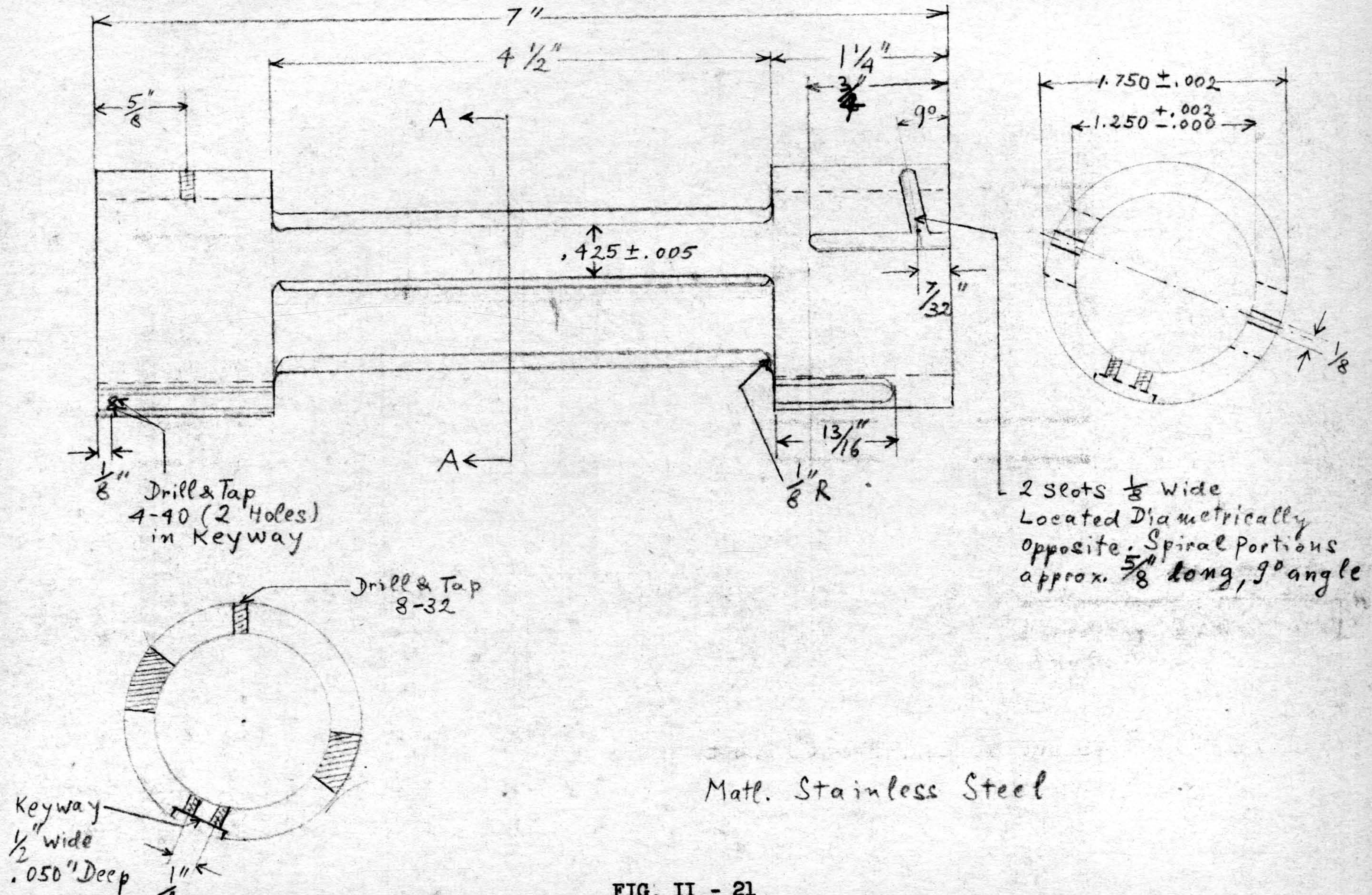


FIG. II - 21

SHELL OF BEADING FIXTURE

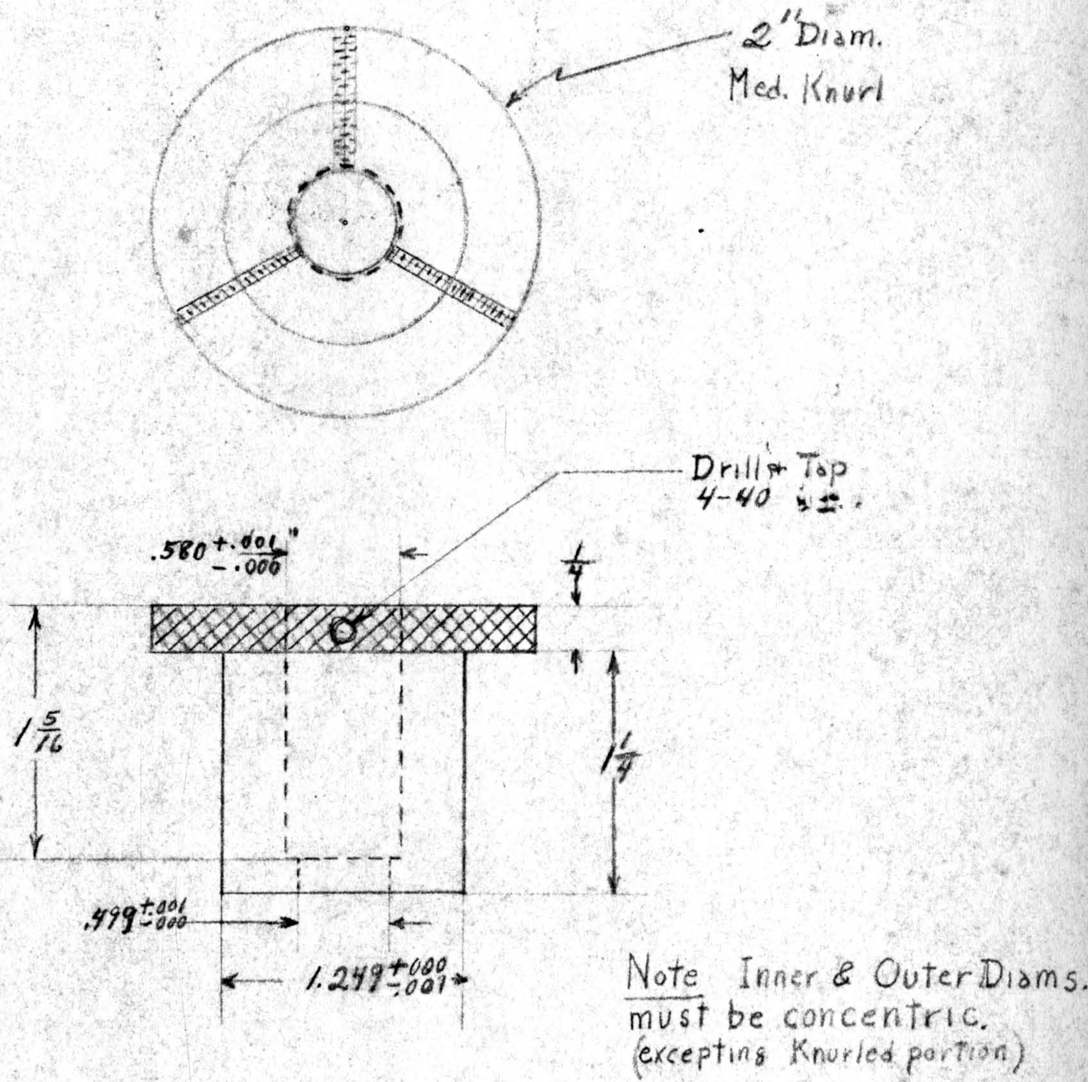


FIG. II - 22

END PIECE OF BEADING FIXTURE

Mat'l. St. Steel Hard Chrome Plated
Dwg. # 7012

Senchino
5/20/52

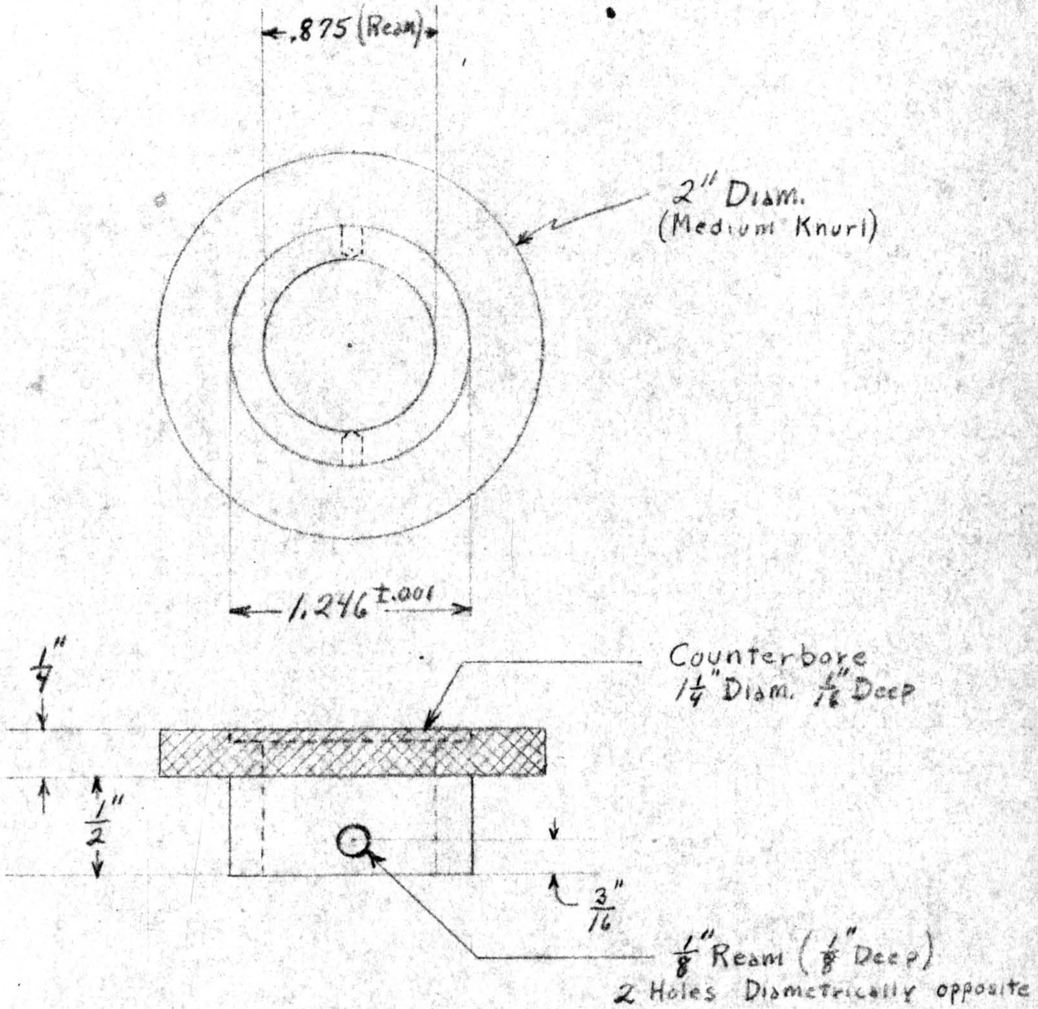


FIG. II - 23

END PIECE OF BEADING FIXTURE

COMPONENT (A)

Mat'l. St. Steel Hard Chrome Plated

Dwg. # 7017

Searchio(?)
5/20/52

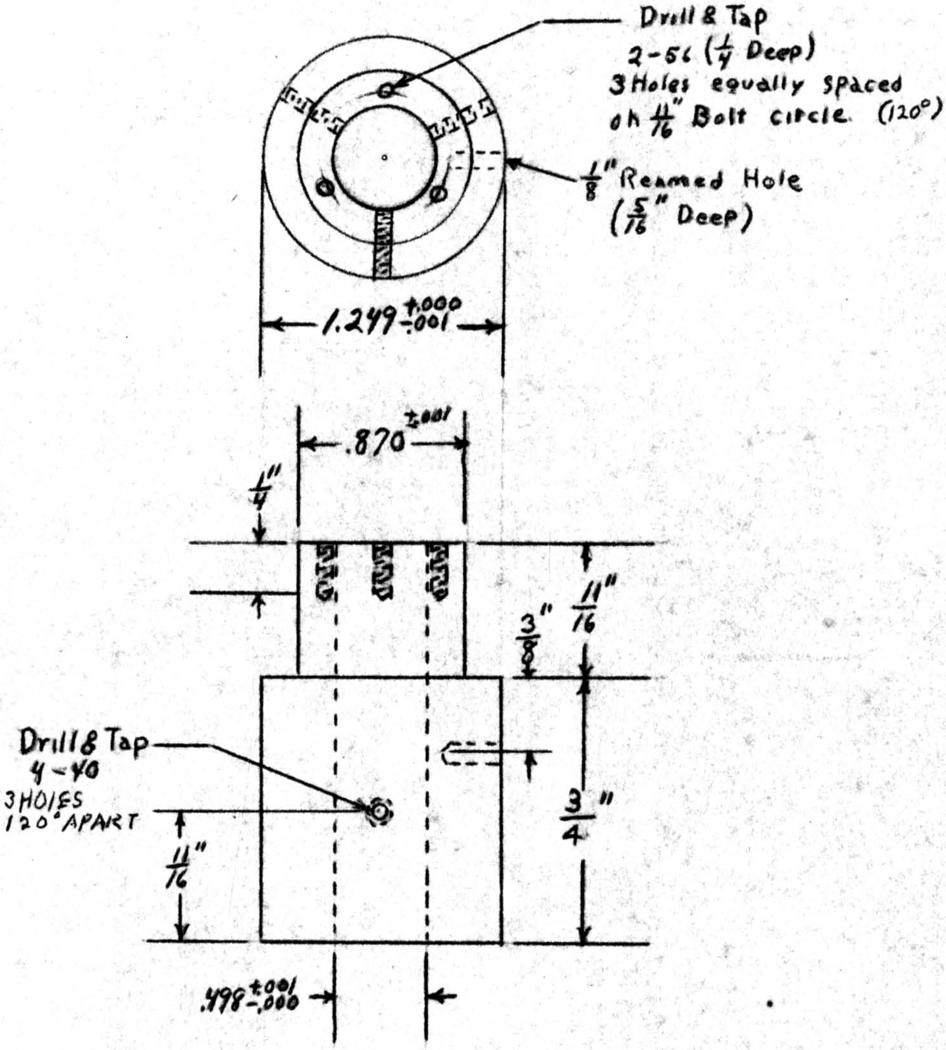


FIG. II - 24

END PIECE OF BEADING FIXTURE

COMPONENT (B)

Mat'l. St. Steel Hard Chrome Plated

Dwg. # 7014

5/20/52

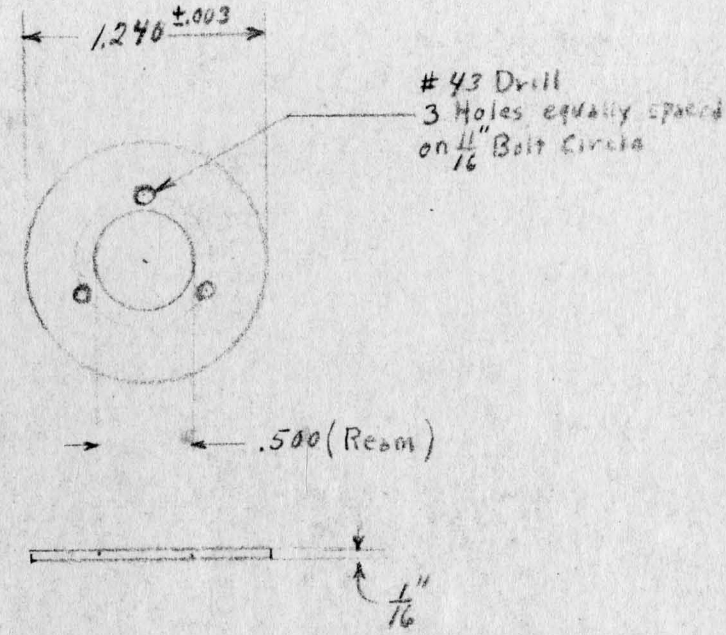


FIG. II - 25

END PIECE OF BEADING FIXTURE

COMPONENT (C)

Mat'l. St. Steel

Dwg. # 7016

5/20/52

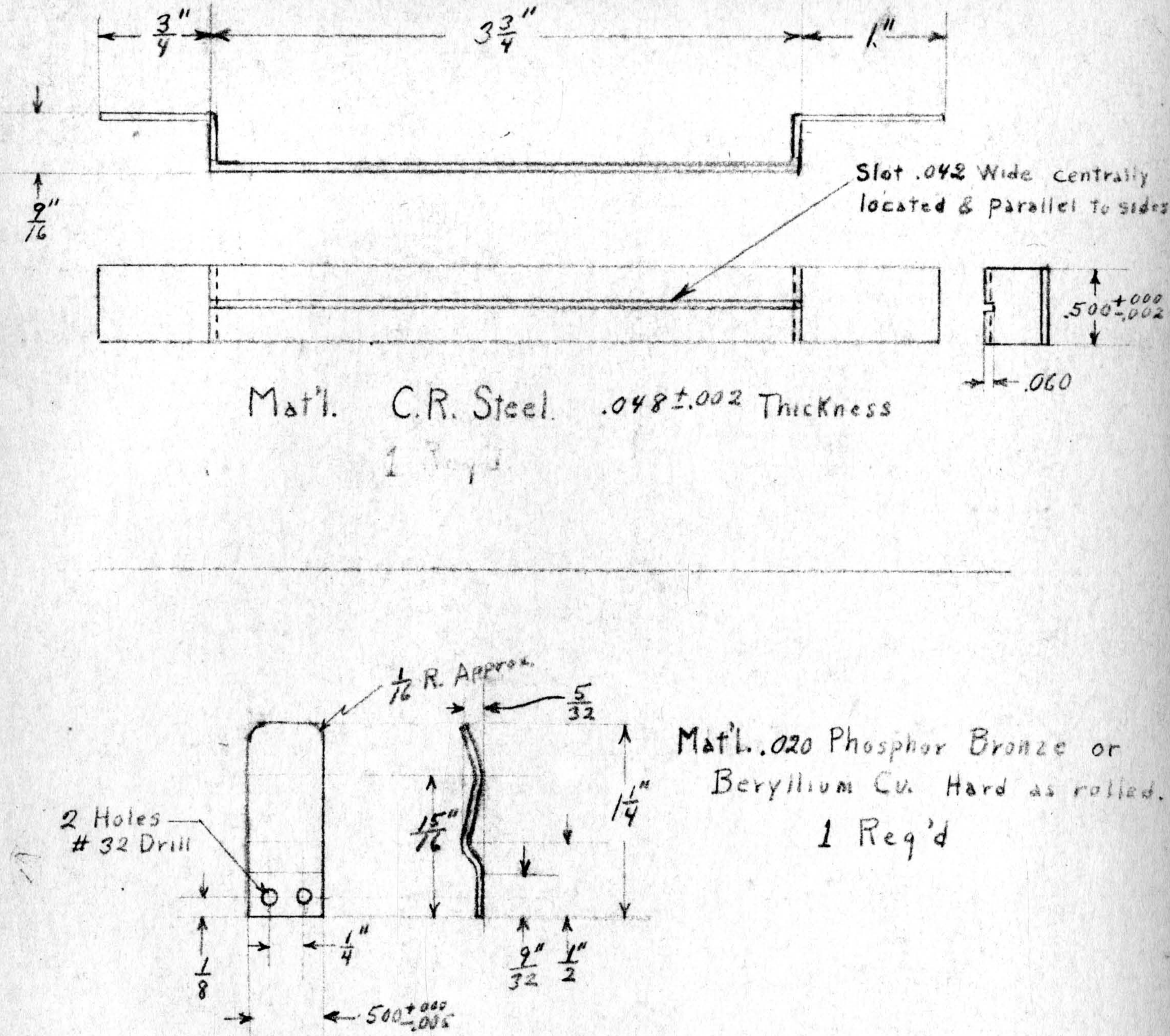


FIG. II-26

PIN ALIGNMENT STRIP AND
SPRING FOR BENDING FIXTURE

Dwg # 7018

5/20/52

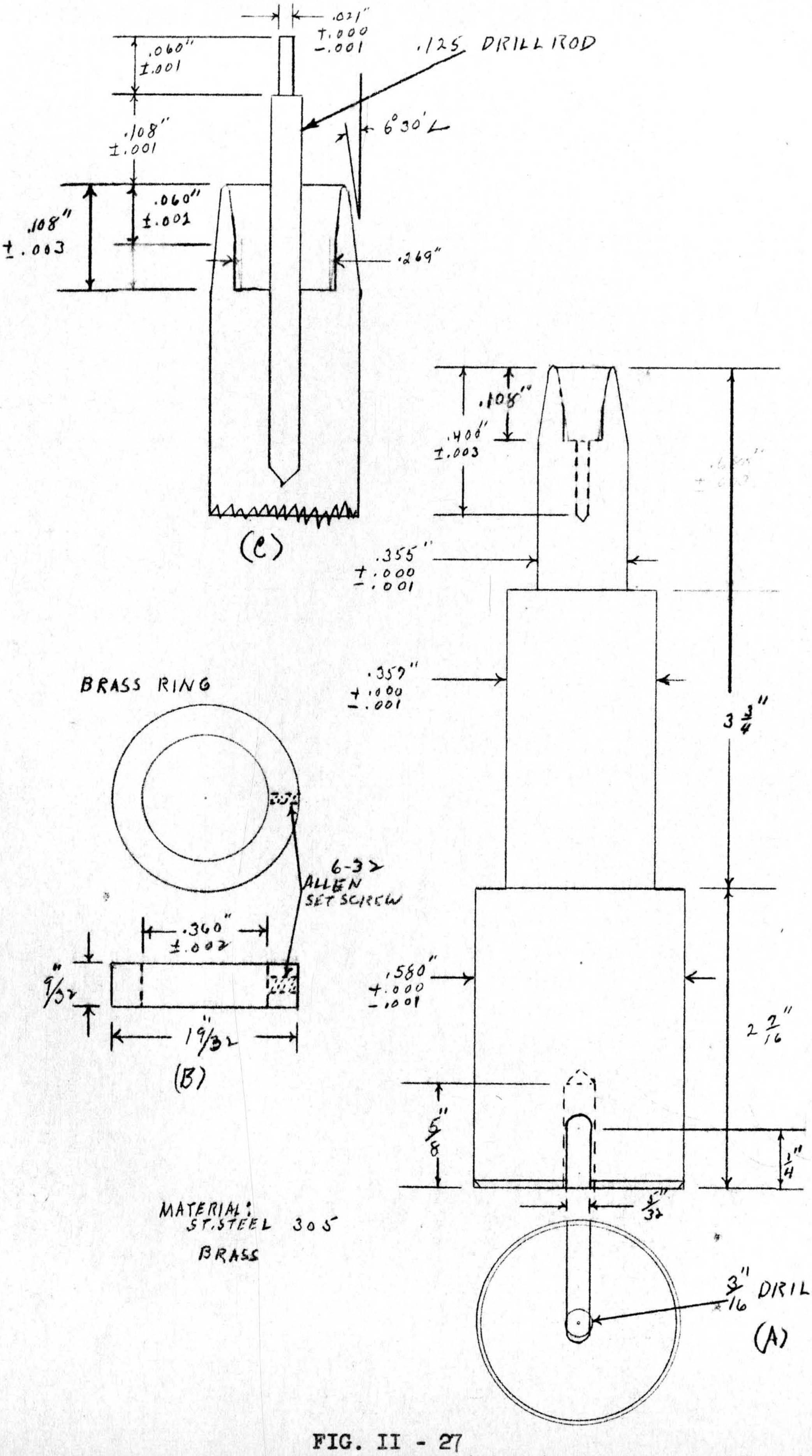
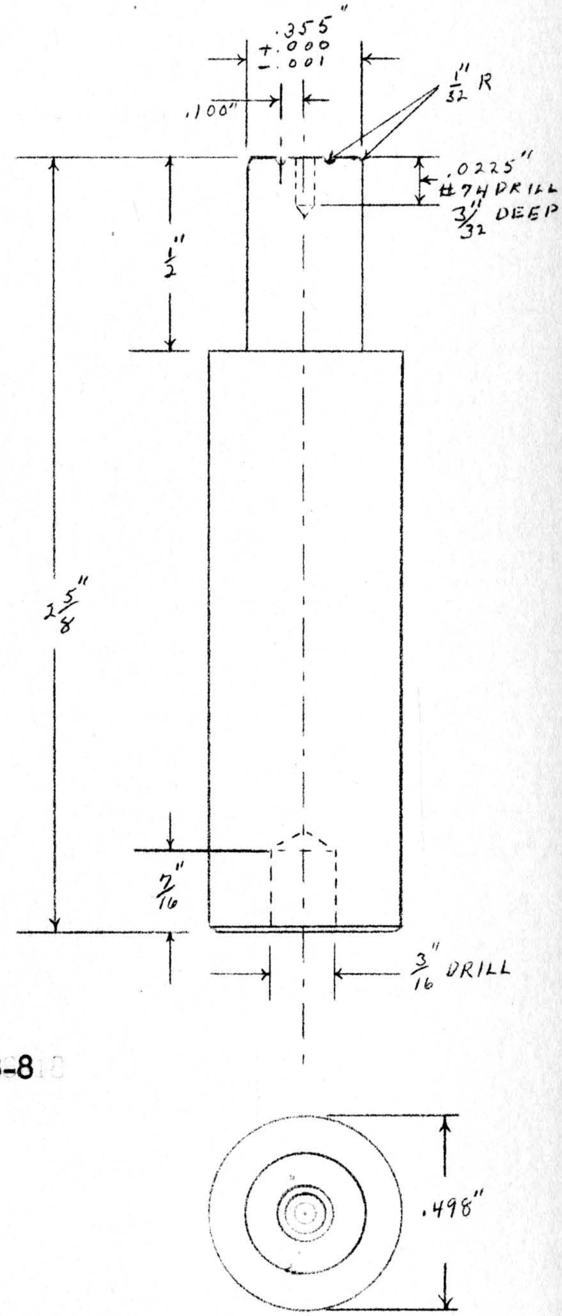


FIG. II - 27
BEADING MANDREL (male)

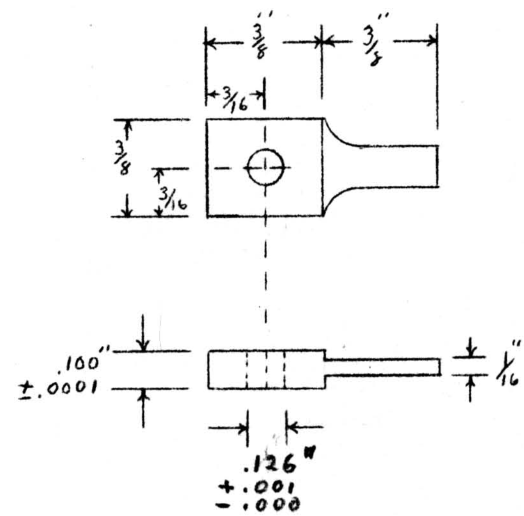


MATERIAL:
ST. STEEL 18-8

FIG. II - 28

BEADING MANDREL
(female)

SPACER



MATERIAL:
ST. STEEL

FIG. II - 29

G_1 - G_2 SPACER

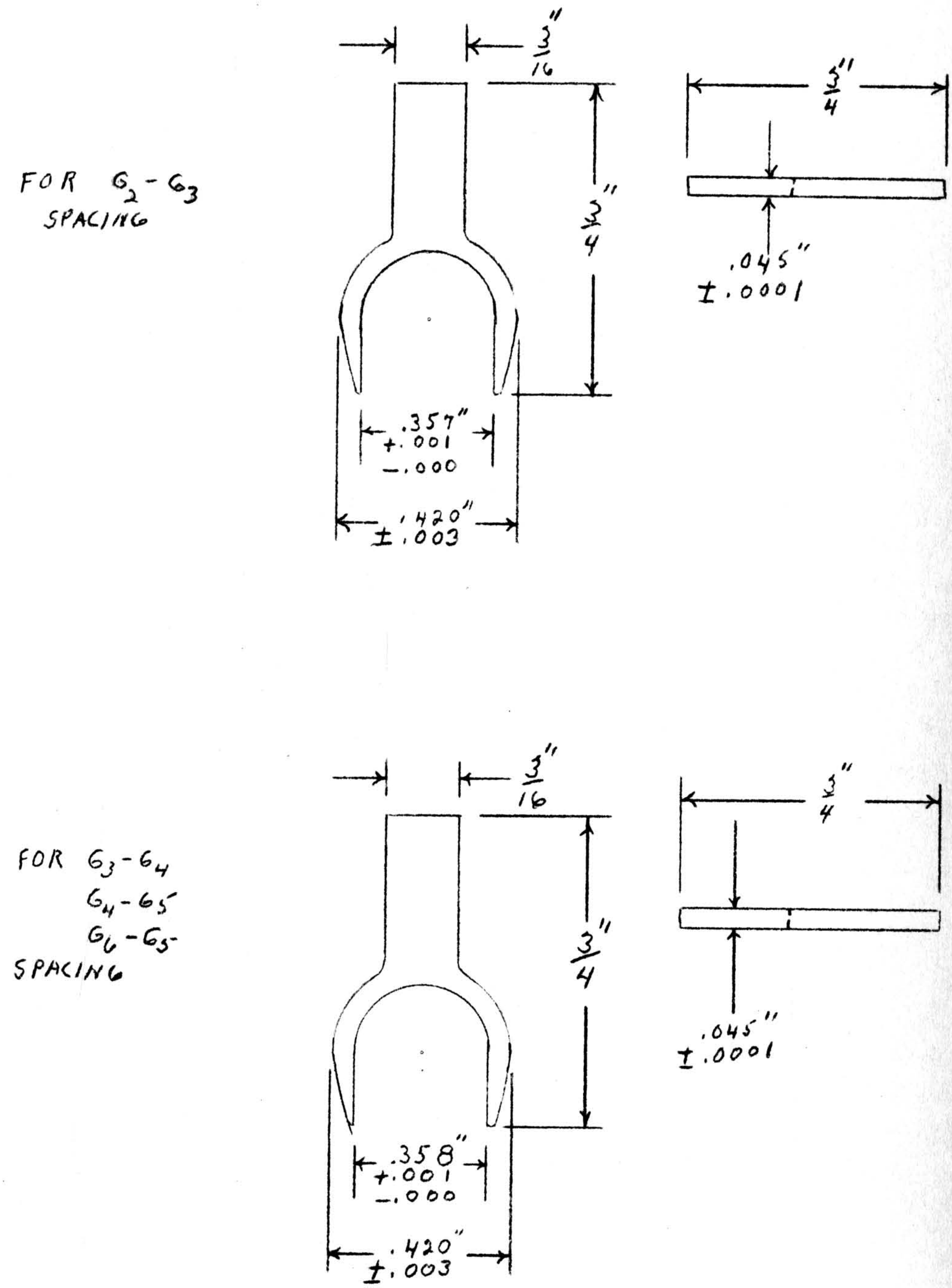


FIG. II - 30

HIGH VOLTAGE ELECTRODE SPACERS

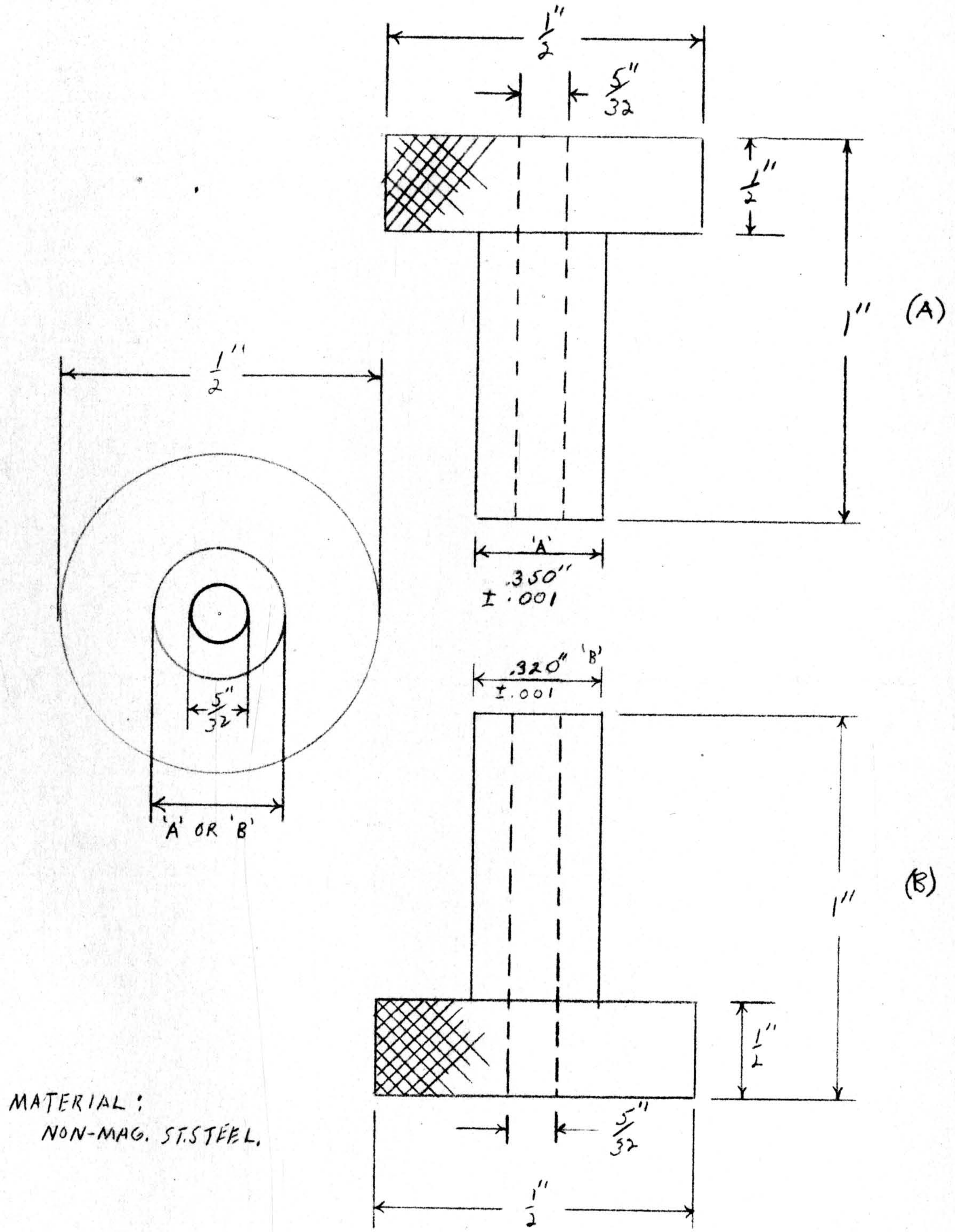


FIG. II - 31

TOOL FOR INSERTING OF SPACER RING, CATHODE AND RETAINER RING
(A) FIRST ASSEMBLY METHOD (B) SECOND ASSEMBLY METHOD

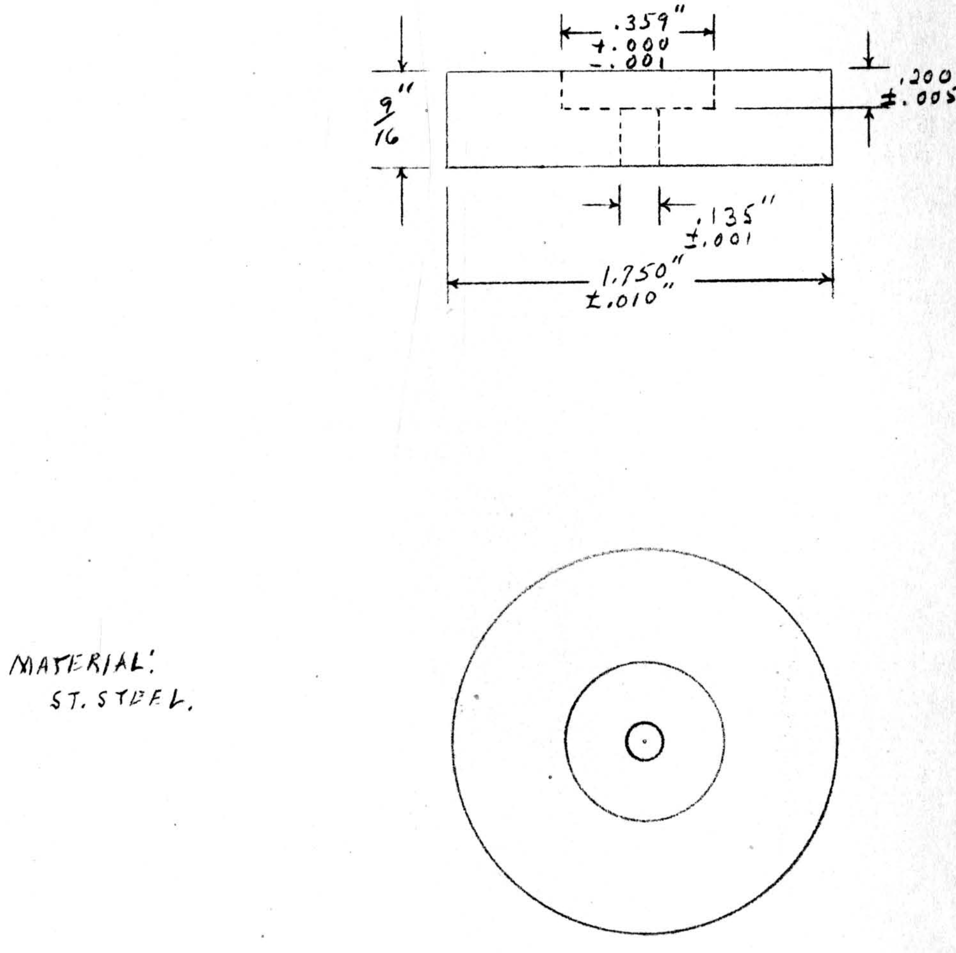


FIG. II - 32

HOLDER FOR CATHODE RETAINER
CUP

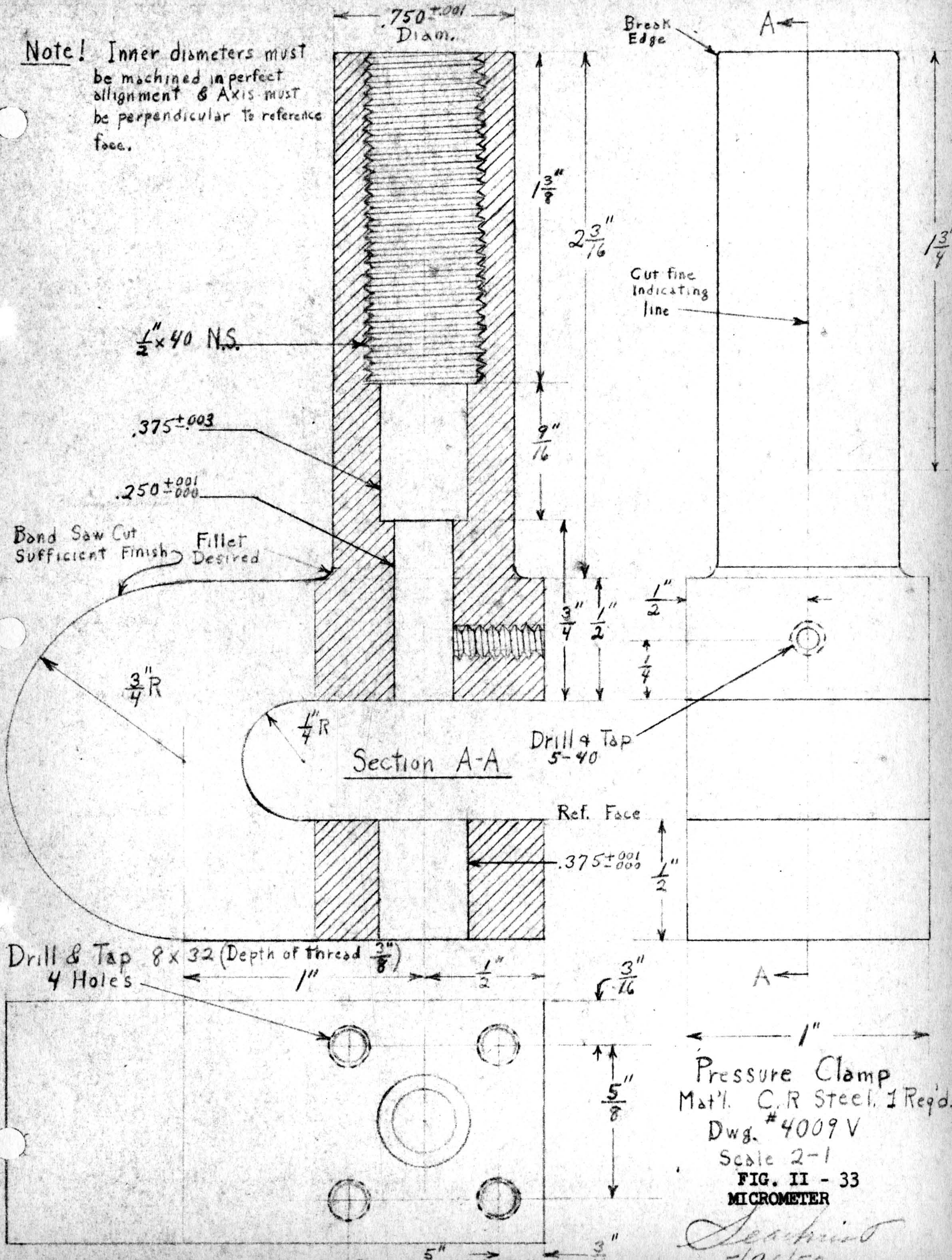


FIG. II - 33
MICROMETER

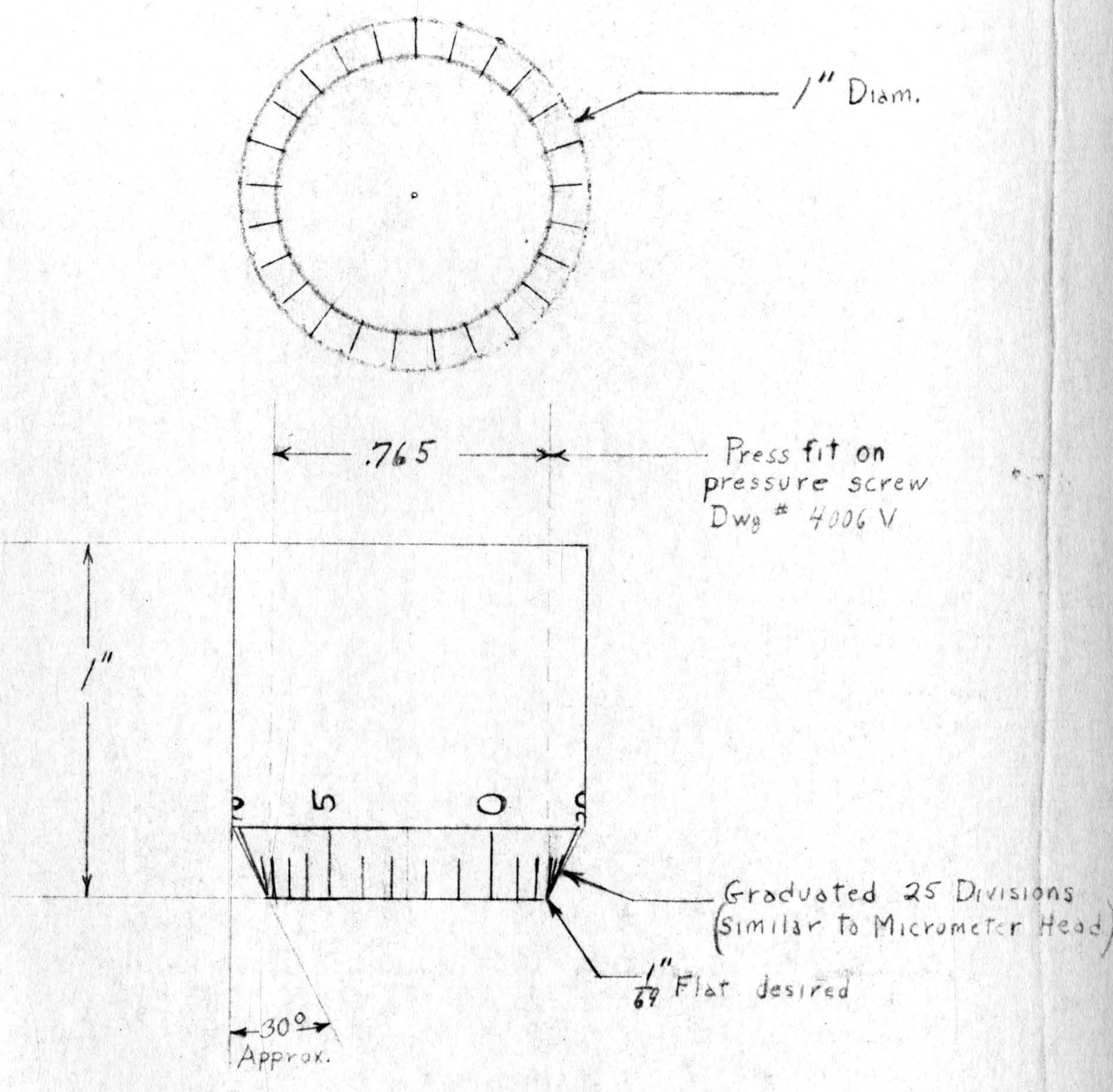


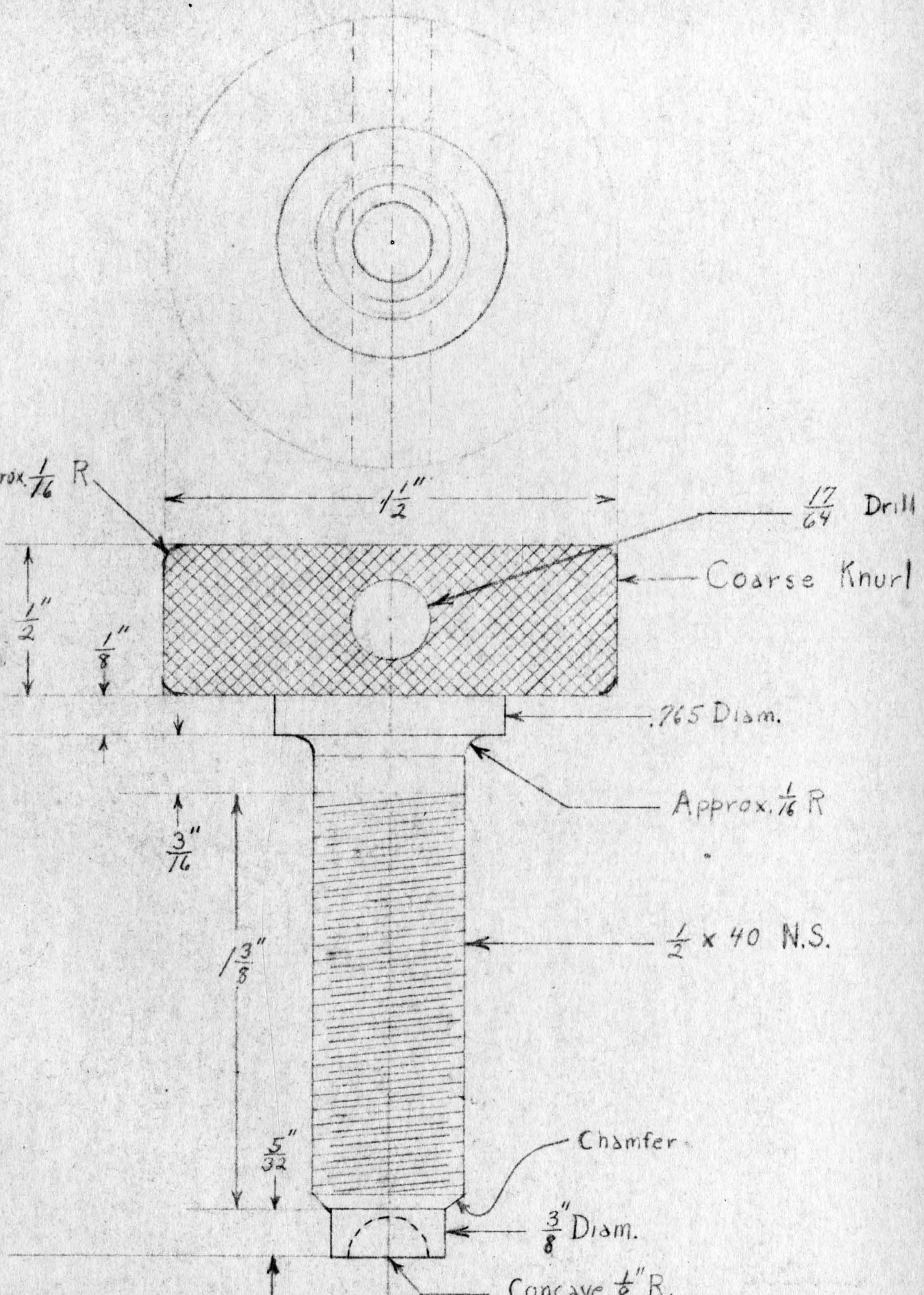
FIG. II - 34

INDICATING THIMBLE FOR MICROMETER

Material
Duraluminum
Scale 2-1
1 Req'd.

Dwg. #4007 V

5/16/52



Material
Phosphor Bronze
1 Req'd.
Scale 2-1

FIG. II - 35
PRESSURE SCREW FOR MICROMETER

Dwg. # 4006 V

Searcheit
5/15/52

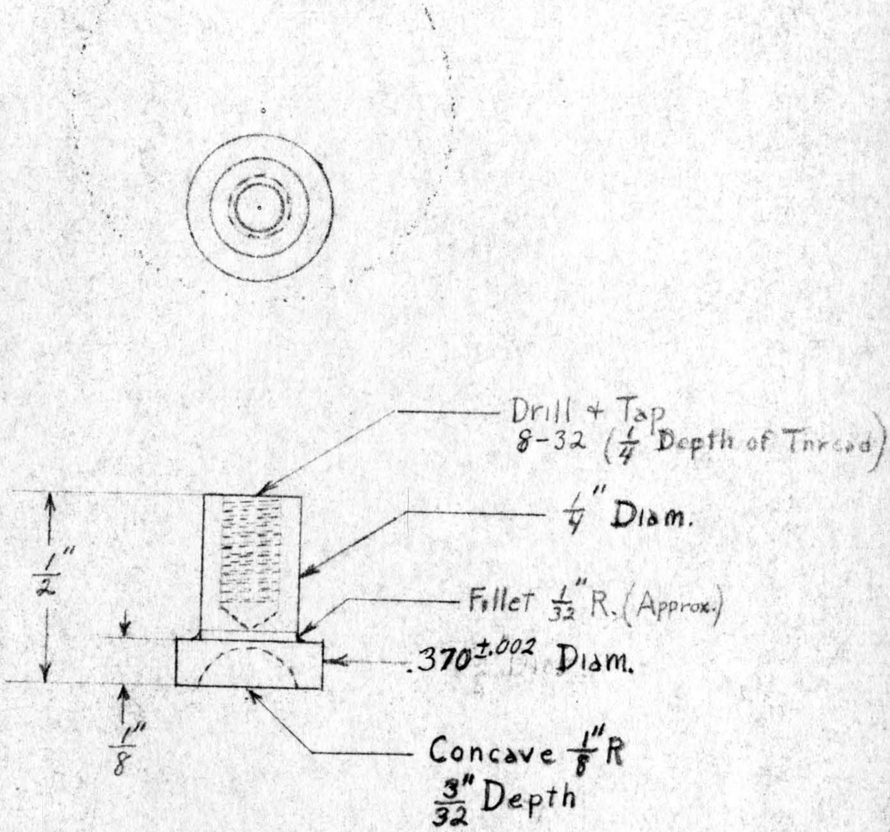


FIG. II - 36

MOUNT EXTENTION FOR MICROMETER

Dwg 4008 V

Seekins(?)
5/16/52

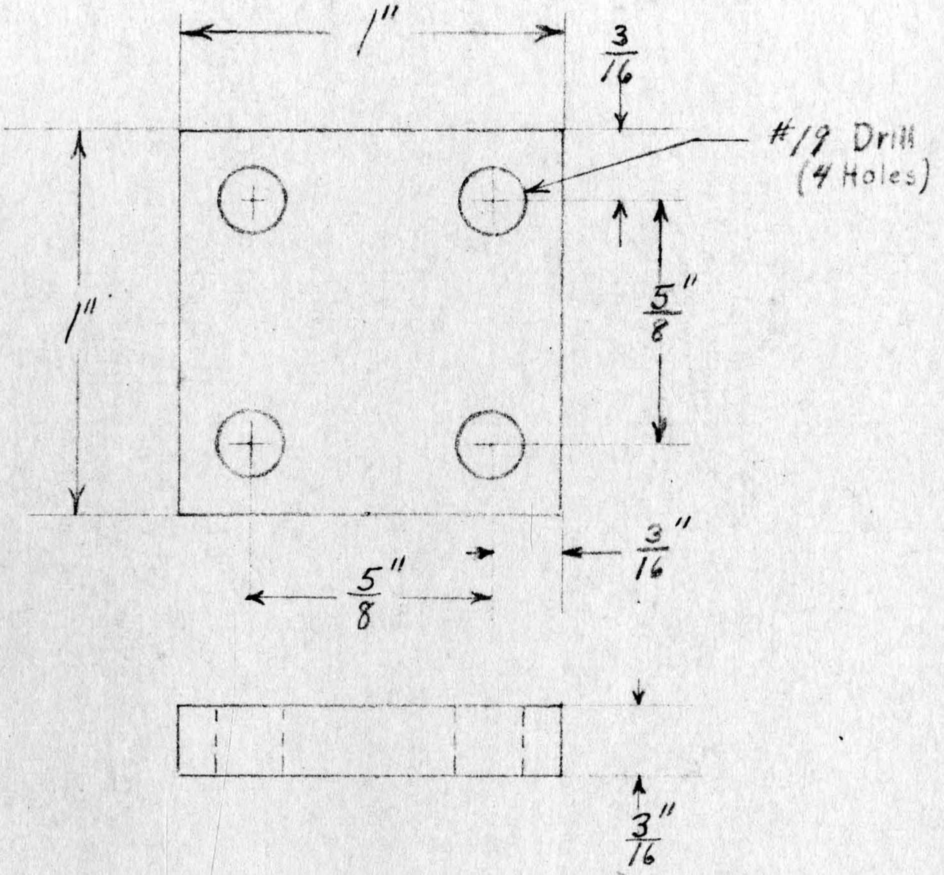


FIG. II - 37

ANVIL BASE FOR MICROMETER

Mat'l. C. R. Steel
1 Req'd.

Dwg. # 4010 V   Scale 2-1

5/27/52

Note! Faces ground parallel &
perpendicular to axis

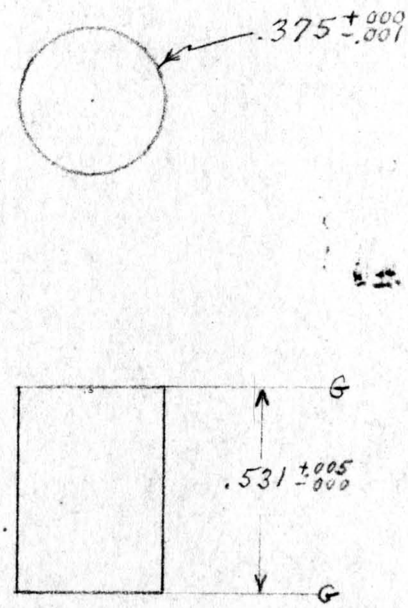


FIG. II - 38

ANVIL FOR MICROMETER

Mat'l. Drill Rod
Harden R.C. 60 min.
1 Req'd

Dwg # 4011V
Scale 2-1
5/27/52

7 Coils
.050 Diam. wire
10 Coils per inch
End coils parallel.

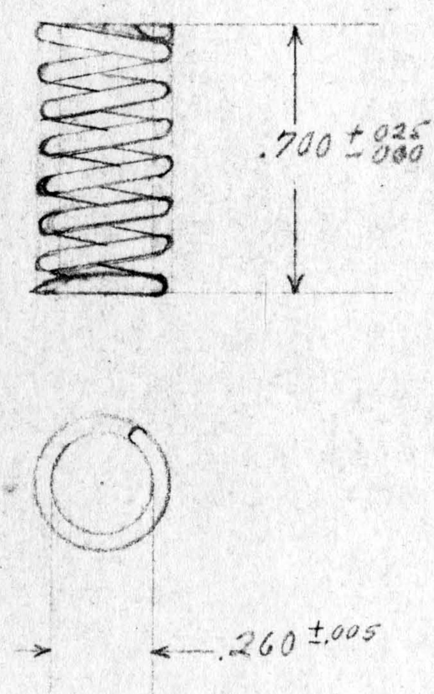


FIG. II - 39
SPRING FOR MICROMETER

Mat'l. Steel Spring Wire
1 Req'd

Dwg. # 4013 V
Scale 2-1
Seachrist
5/27/52

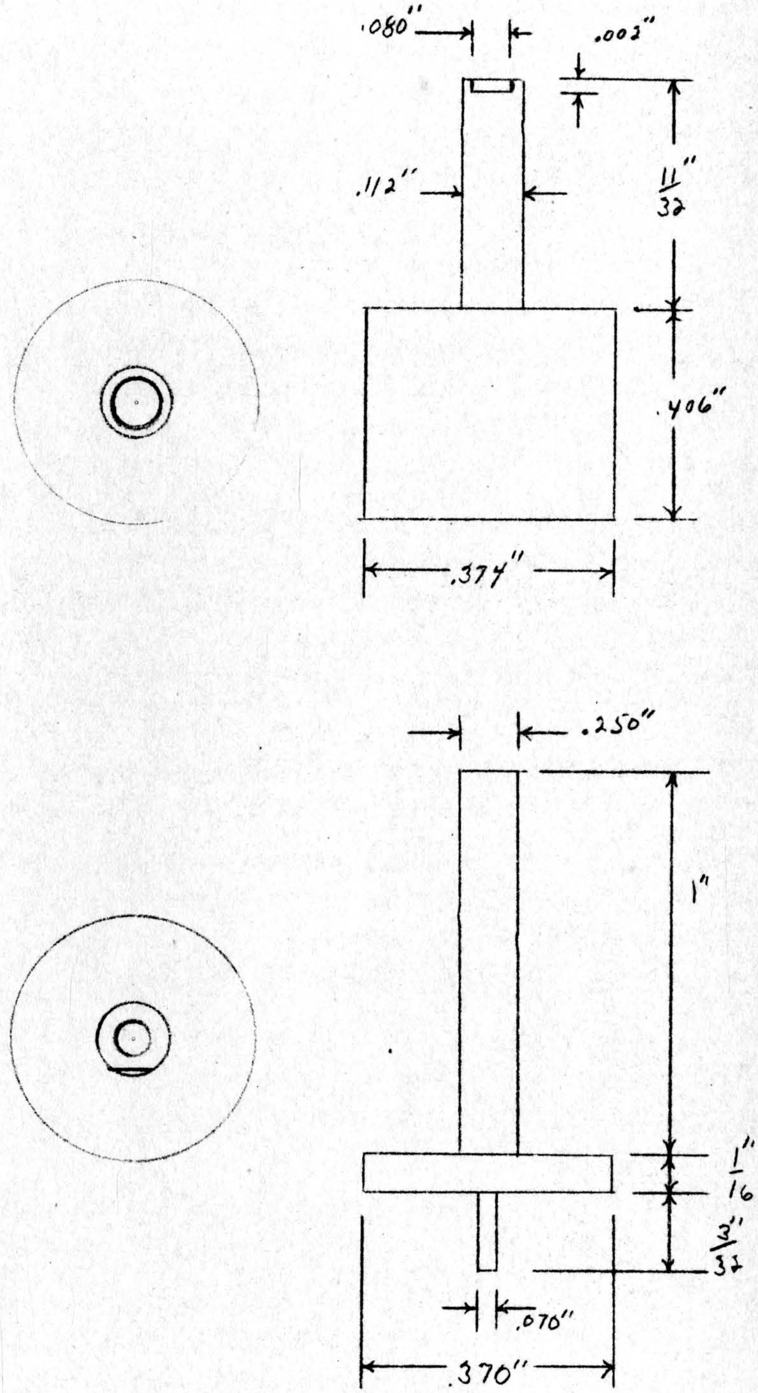


FIG. II - 40

END PIECES FOR MICROMETER

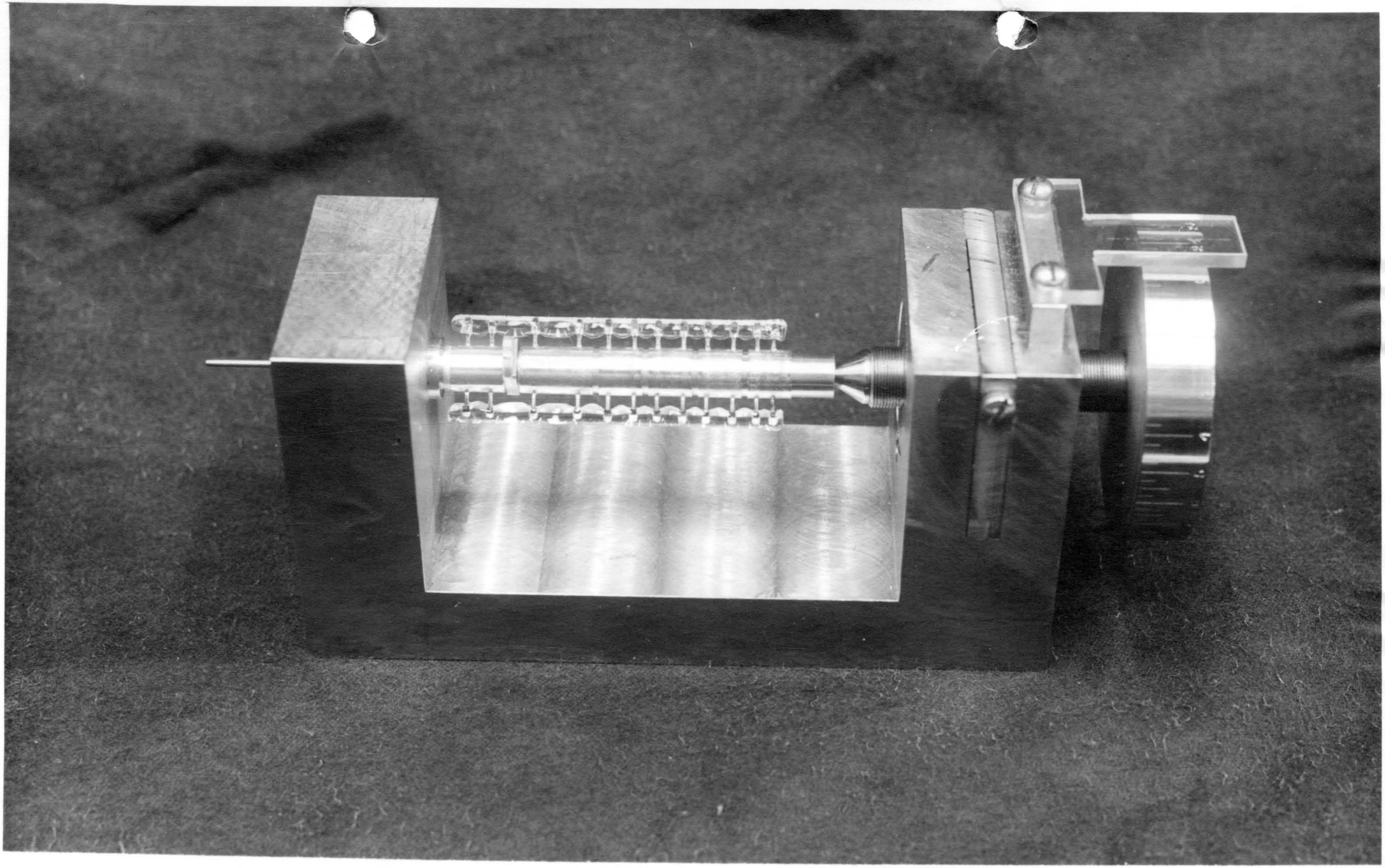


FIG. II-41
FIXTURE FOR INSERTING OF CATHODES BY THE SECOND METHOD

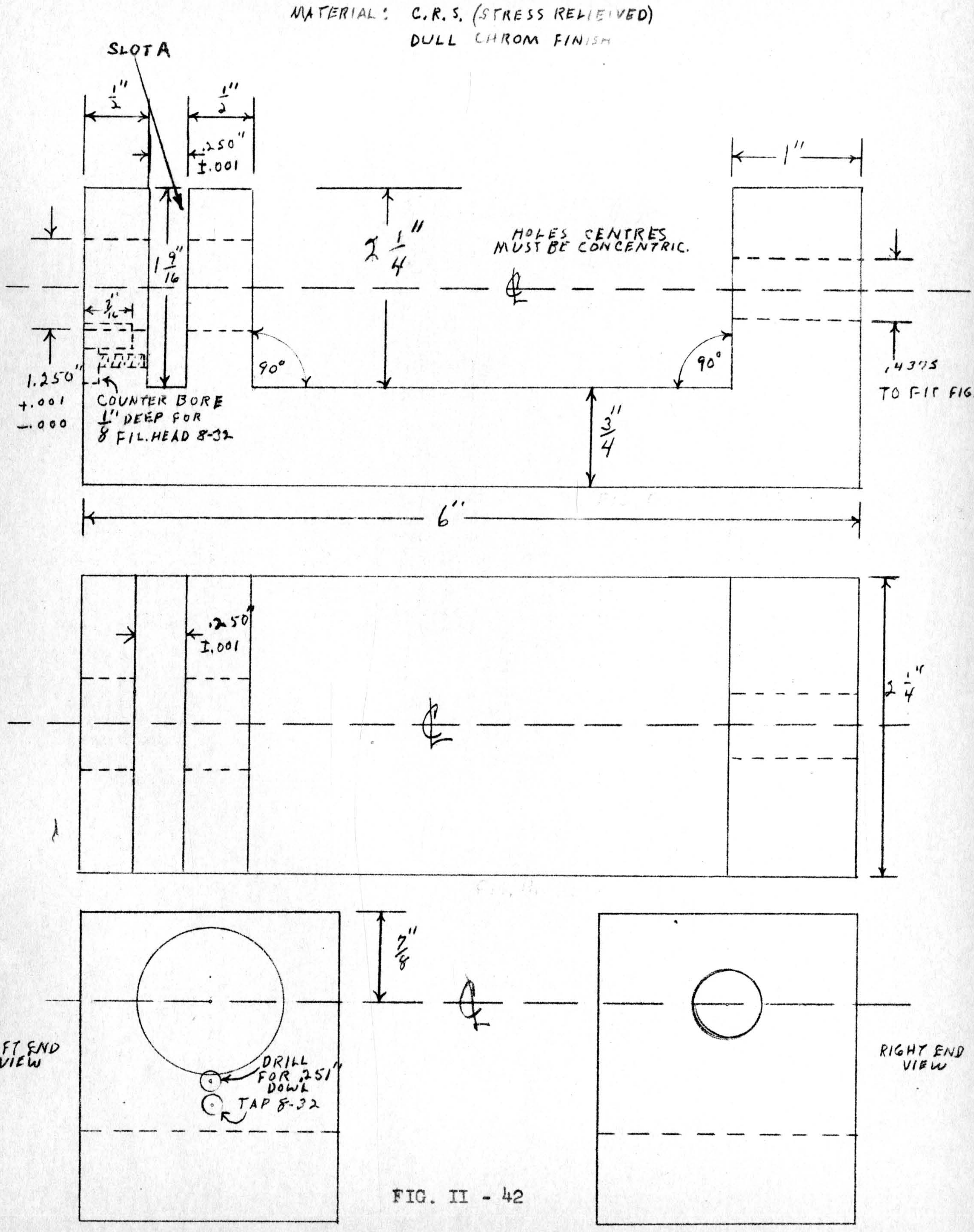


FIG. II - 42

FRAME FOR CATHODE ASSEMBLY FIXTURE (SECOND ASSEMBLY METHOD)

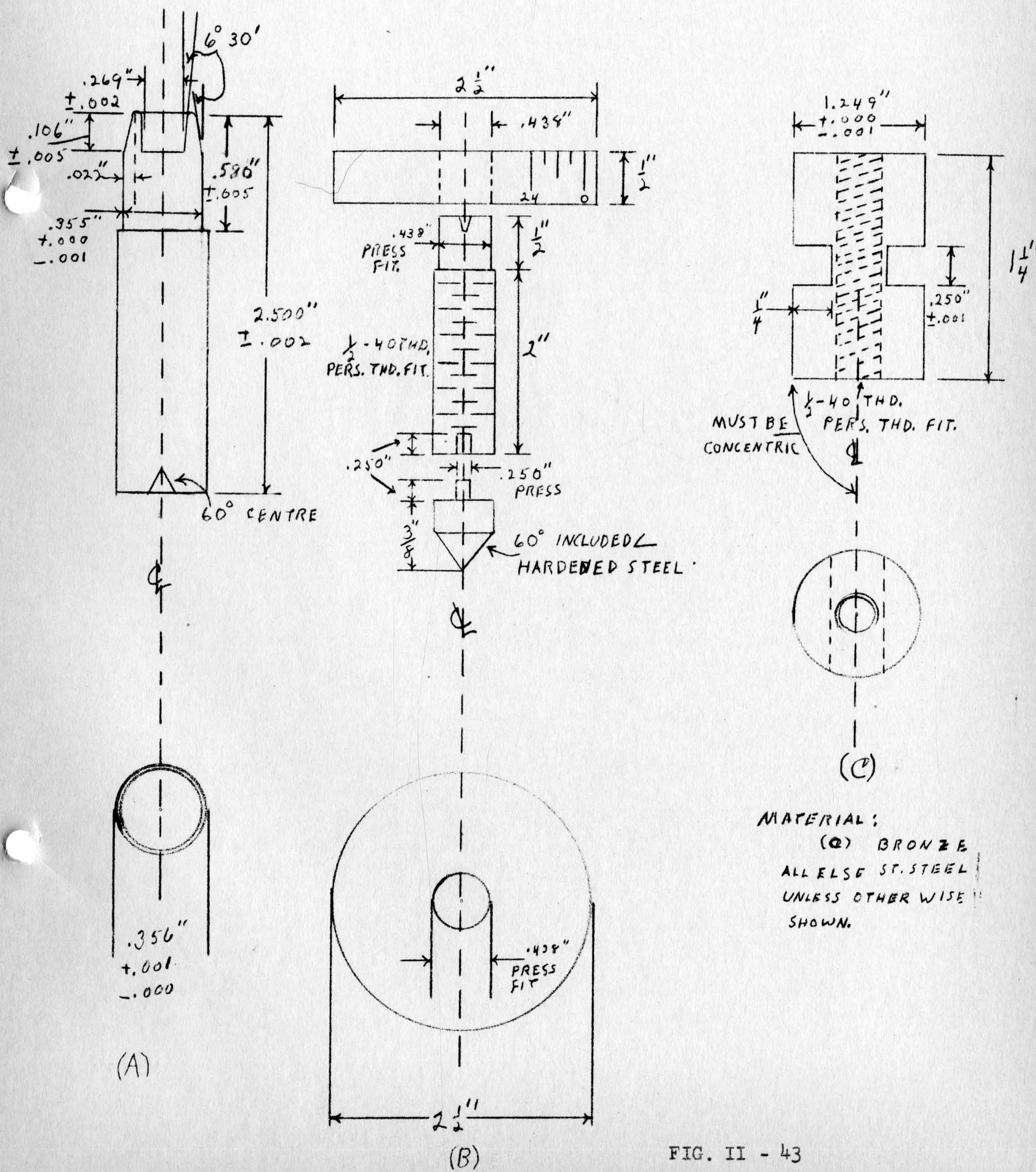


FIG. II - 43

PARTS OF CATHODE ASSEMBLY FIXTURE (SECOND ASSEMBLY METHOD)

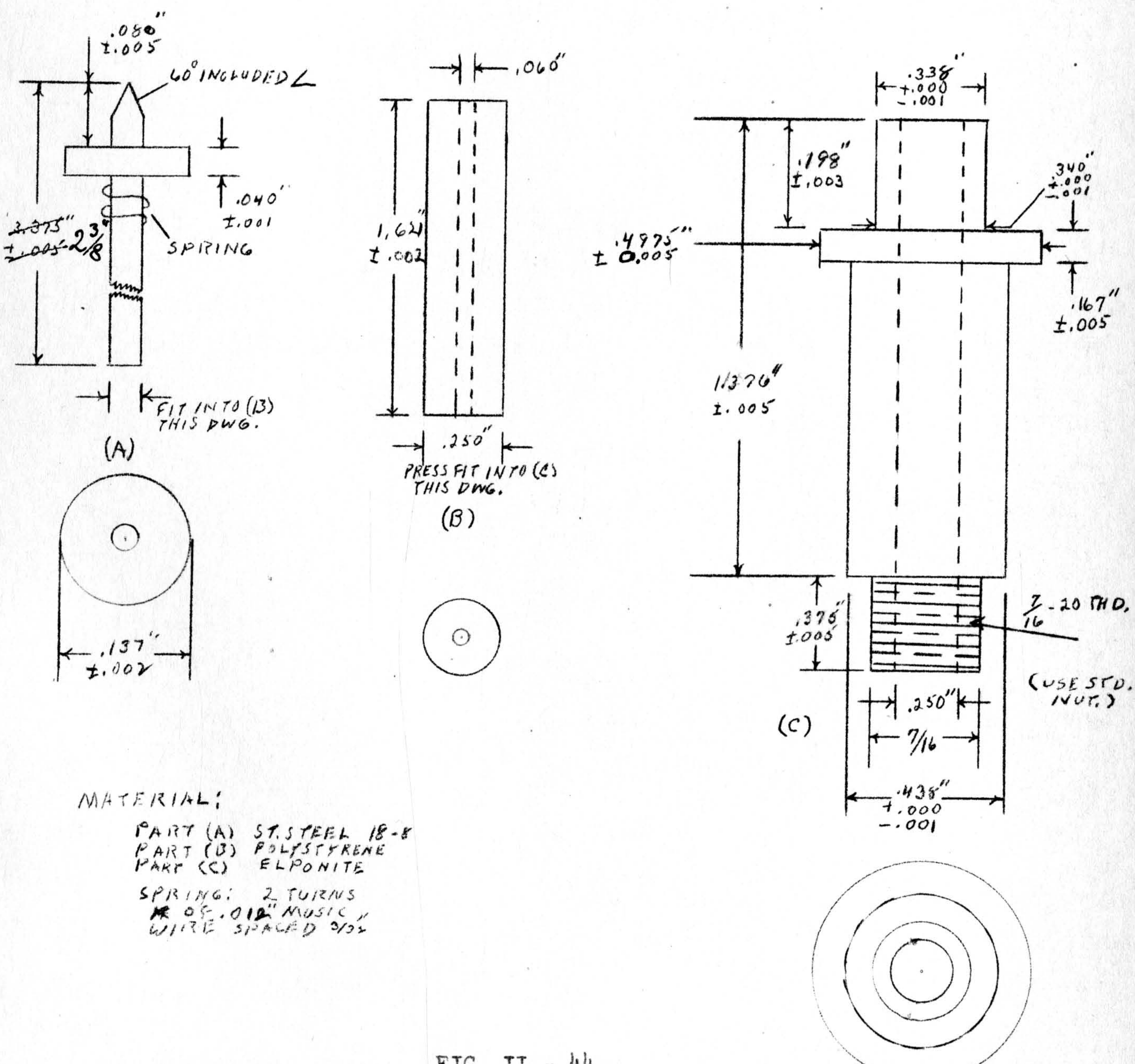


FIG. II - 44

PARTS FOR CATHODE ASSEMBLY FIXTURE (second assembly method)

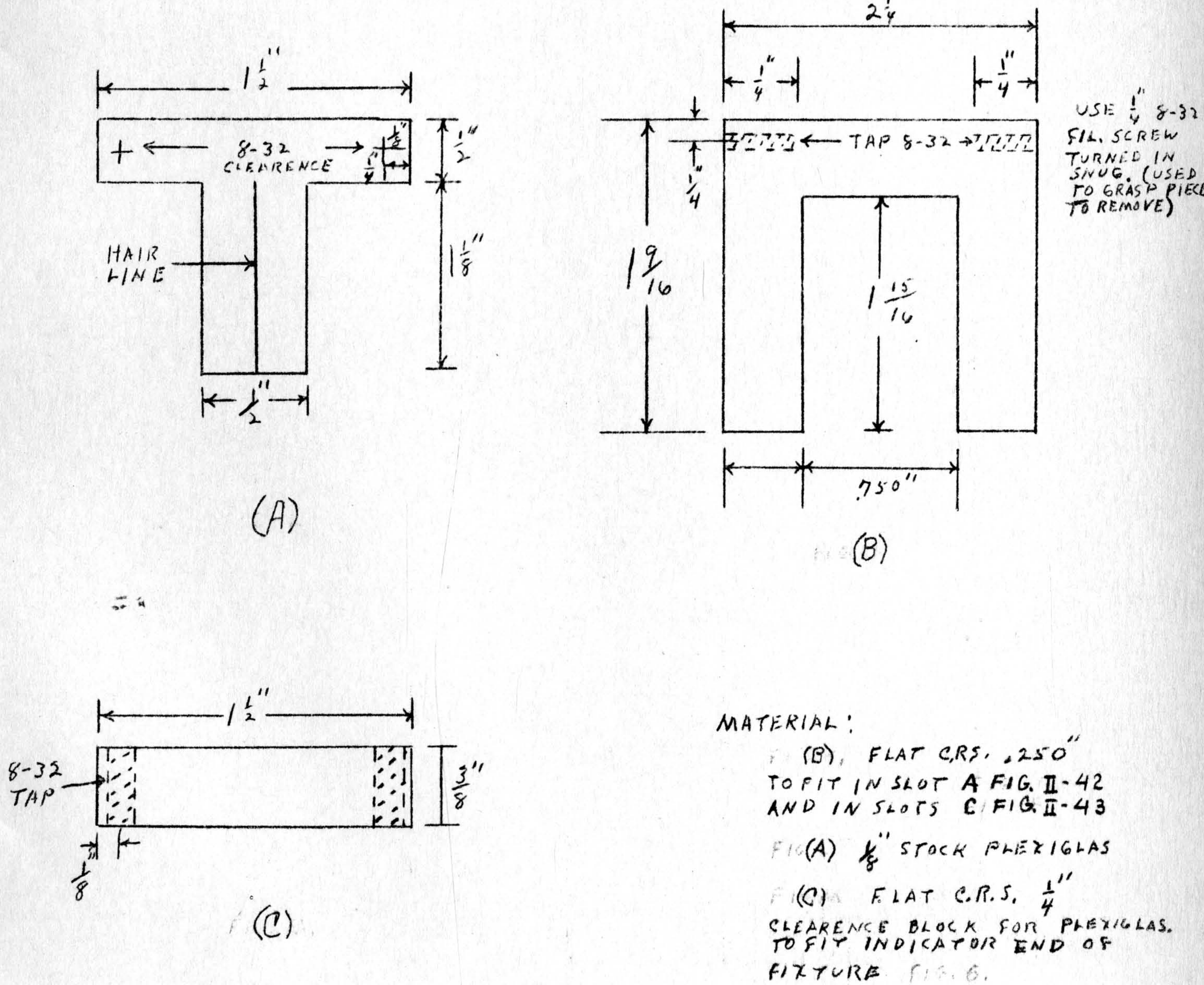


FIG. II - 45

PARTS OF CATHODE ASSEMBLY FIXTURE (SECOND ASSEMBLY METHOD)

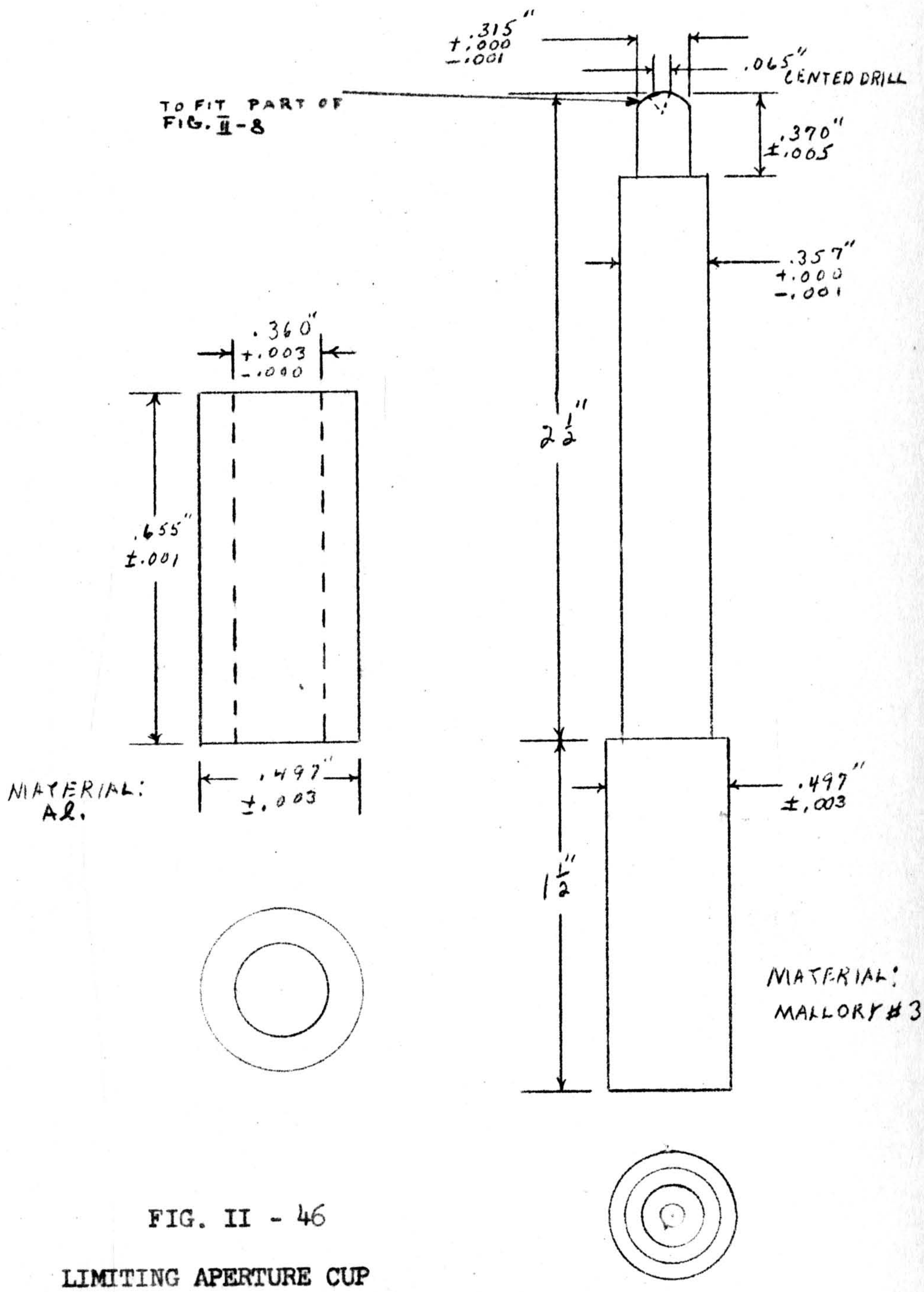


FIG. II - 46

LIMITING APERTURE CUP
WELDING MANDREL AND SPACER SLEEVE

MATERIAL:
MALLORY ALLOY #3

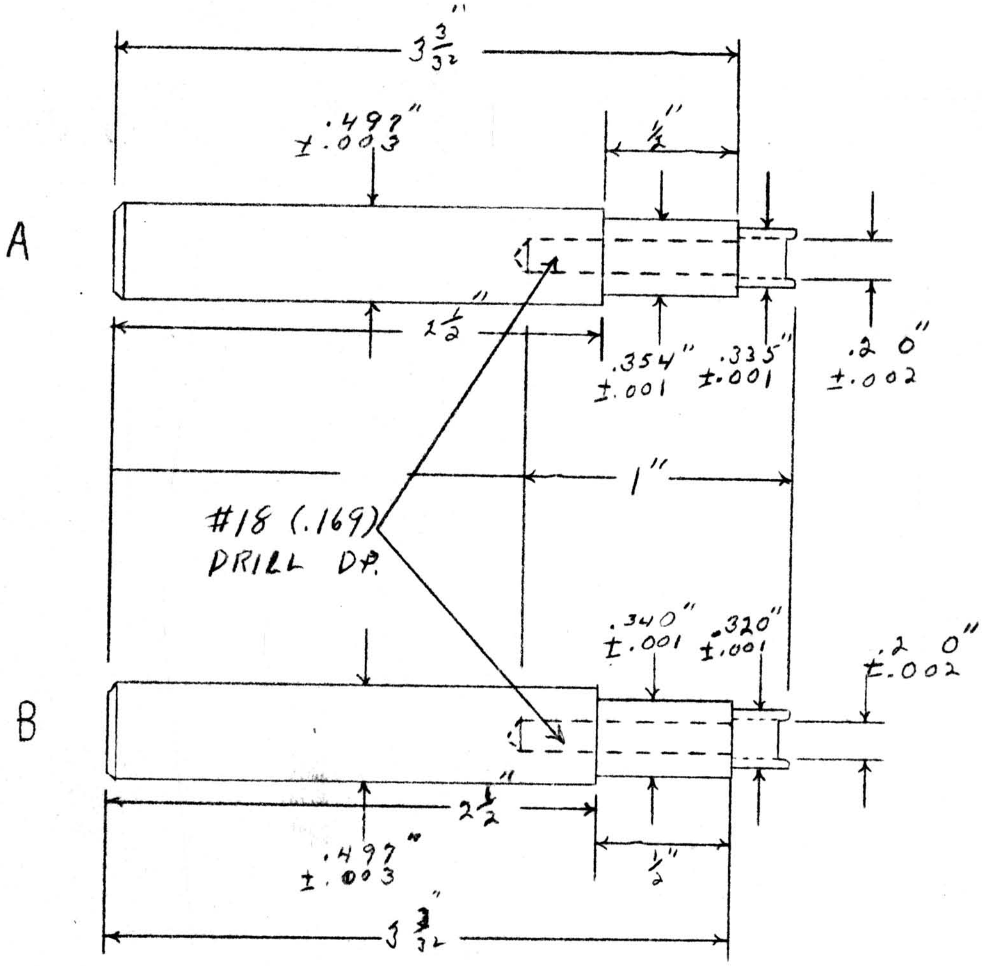


FIG. II - 47

CATHODE RETAINER RIG WELDING MANDRELS
(A) FOR FIRST ASSEMBLY METHOD
(B) FOR SECOND ASSEMBLY METHOD

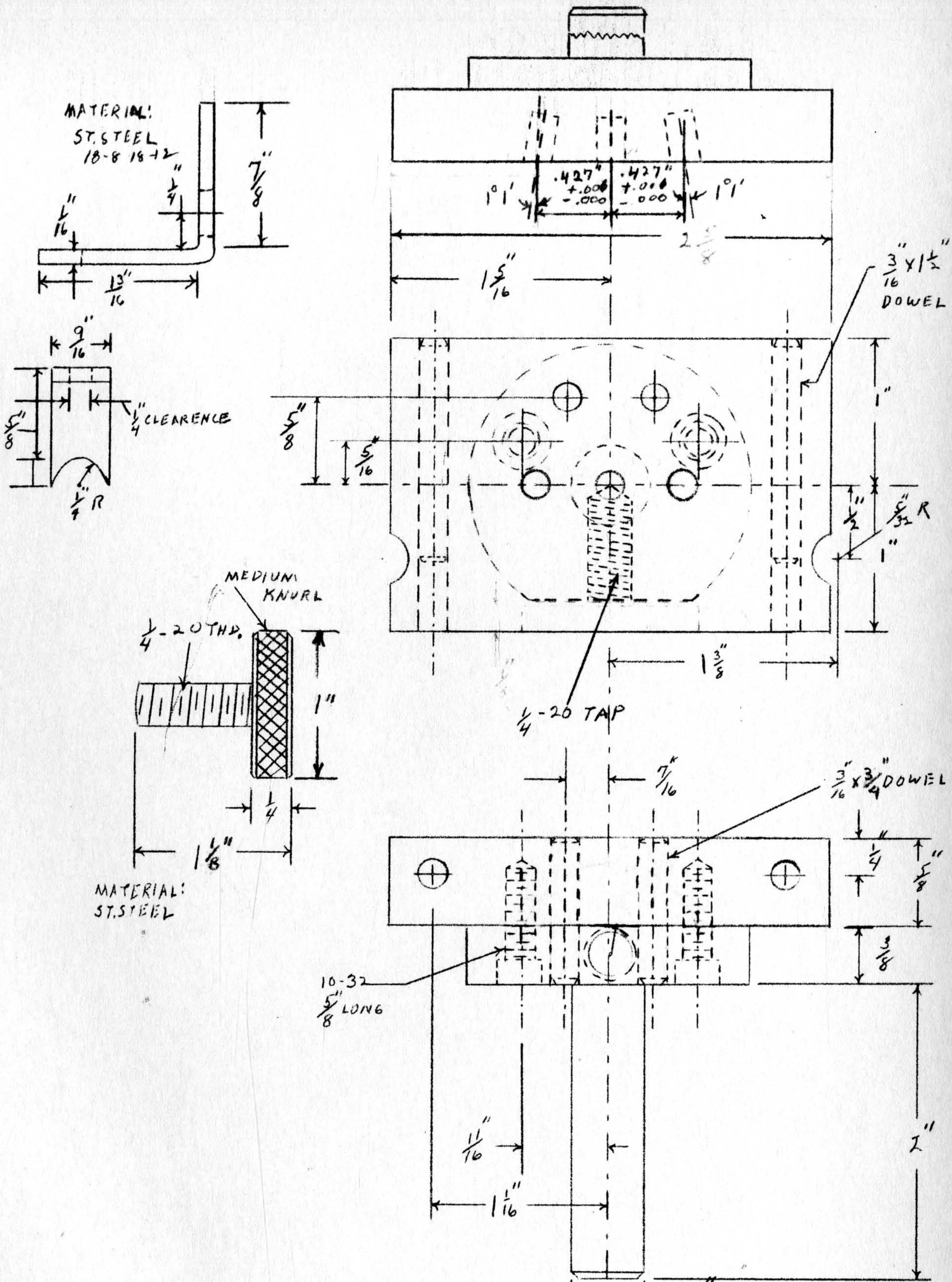


FIG. II - 48

WELDING JIG FOR TRI-COLOR
GUN ASSEMBLY

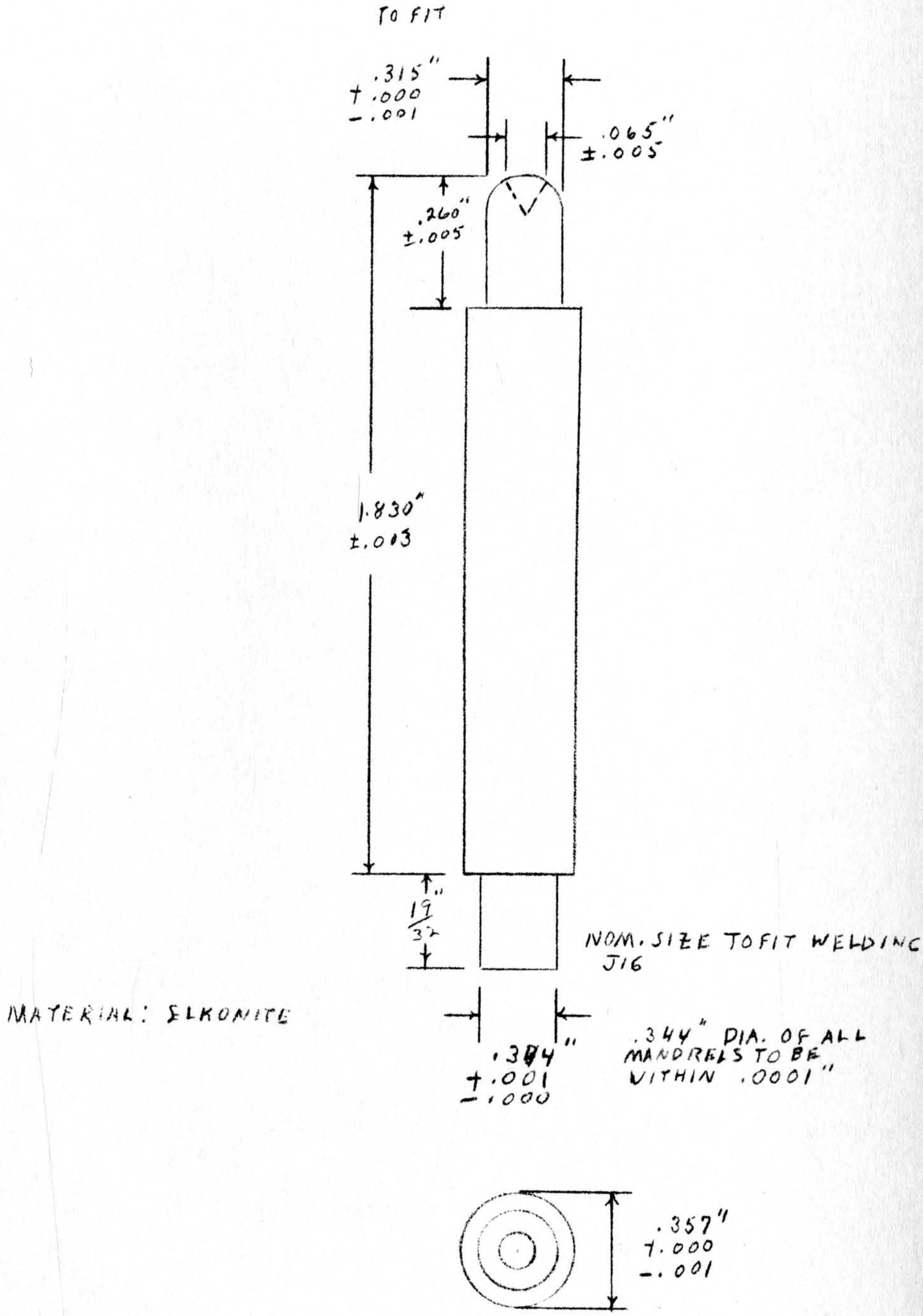


FIG. II- 49

MANDRELS FOR WELDING JIG OF FIG. 48

P.H. GLEICHAUF

Bldg 3

7240
11-11-53

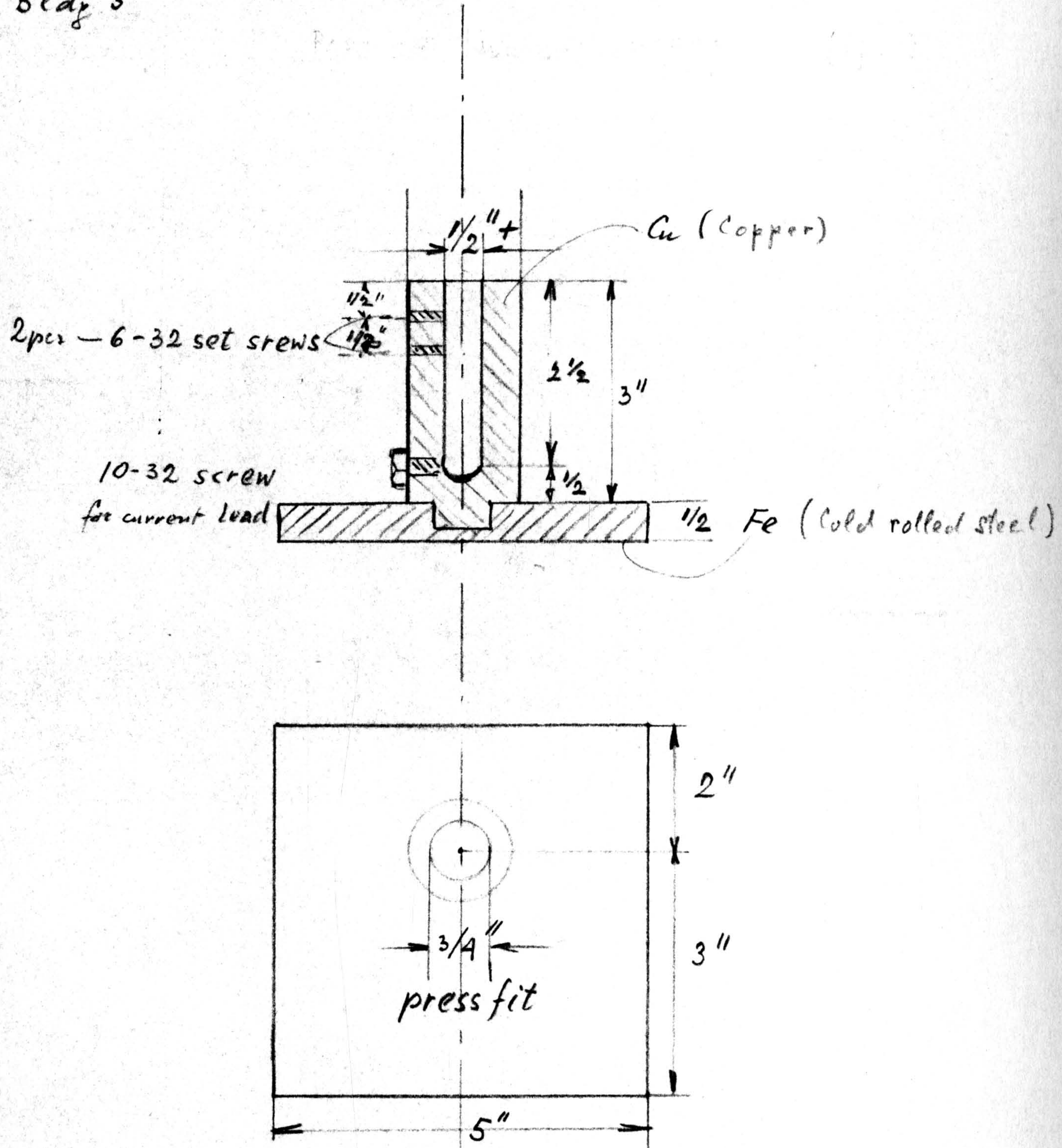


FIG. II - 50

STAND FOR WELDING JIG

P.H. GLEICHAUF

7-7-59
7300

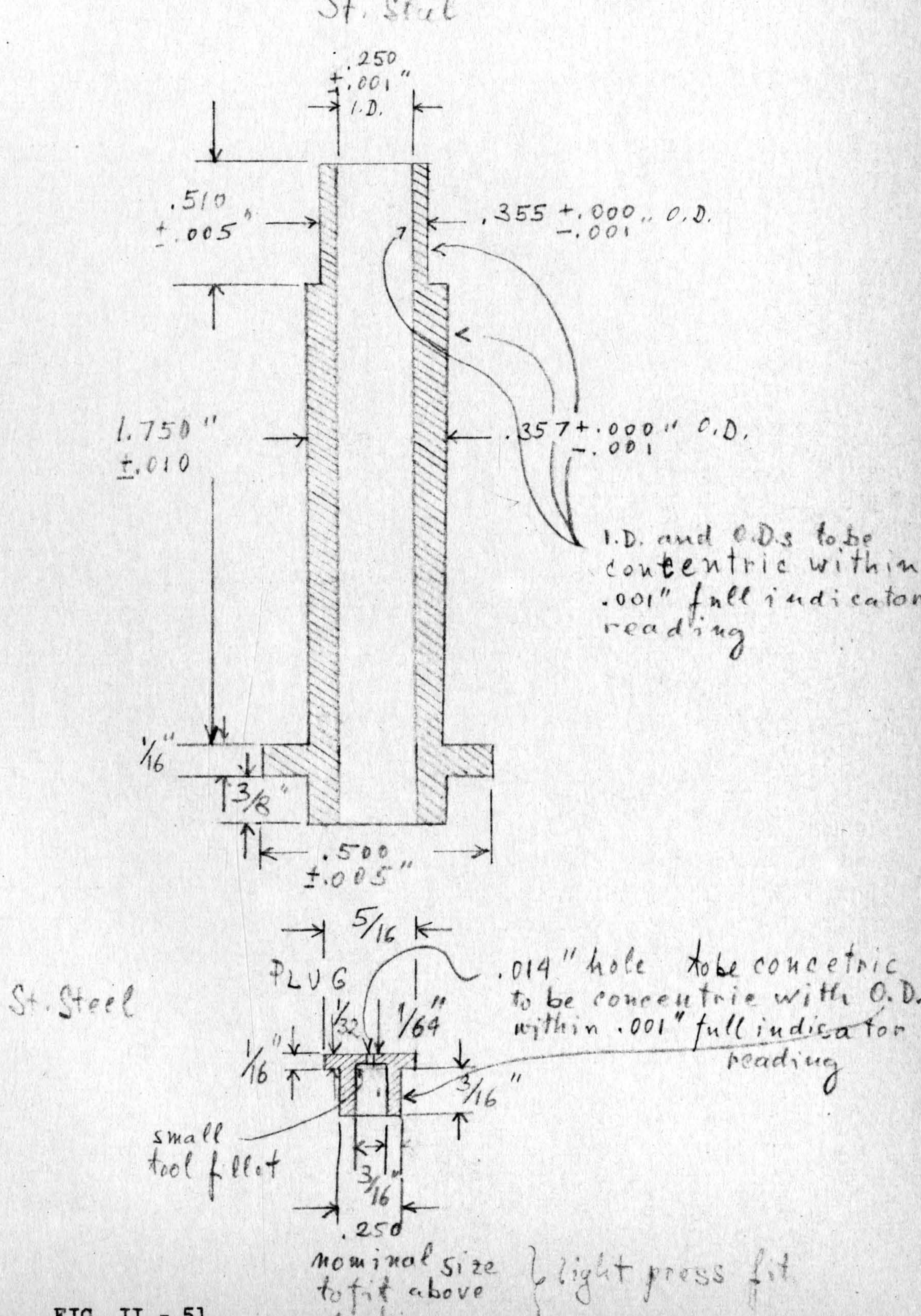


FIG. II - 51
EXTENTION OF MICROSCOBE ADAPTER FOR CHECKING OF ALIGNMENT OF G_1 WITH REST OF GUN

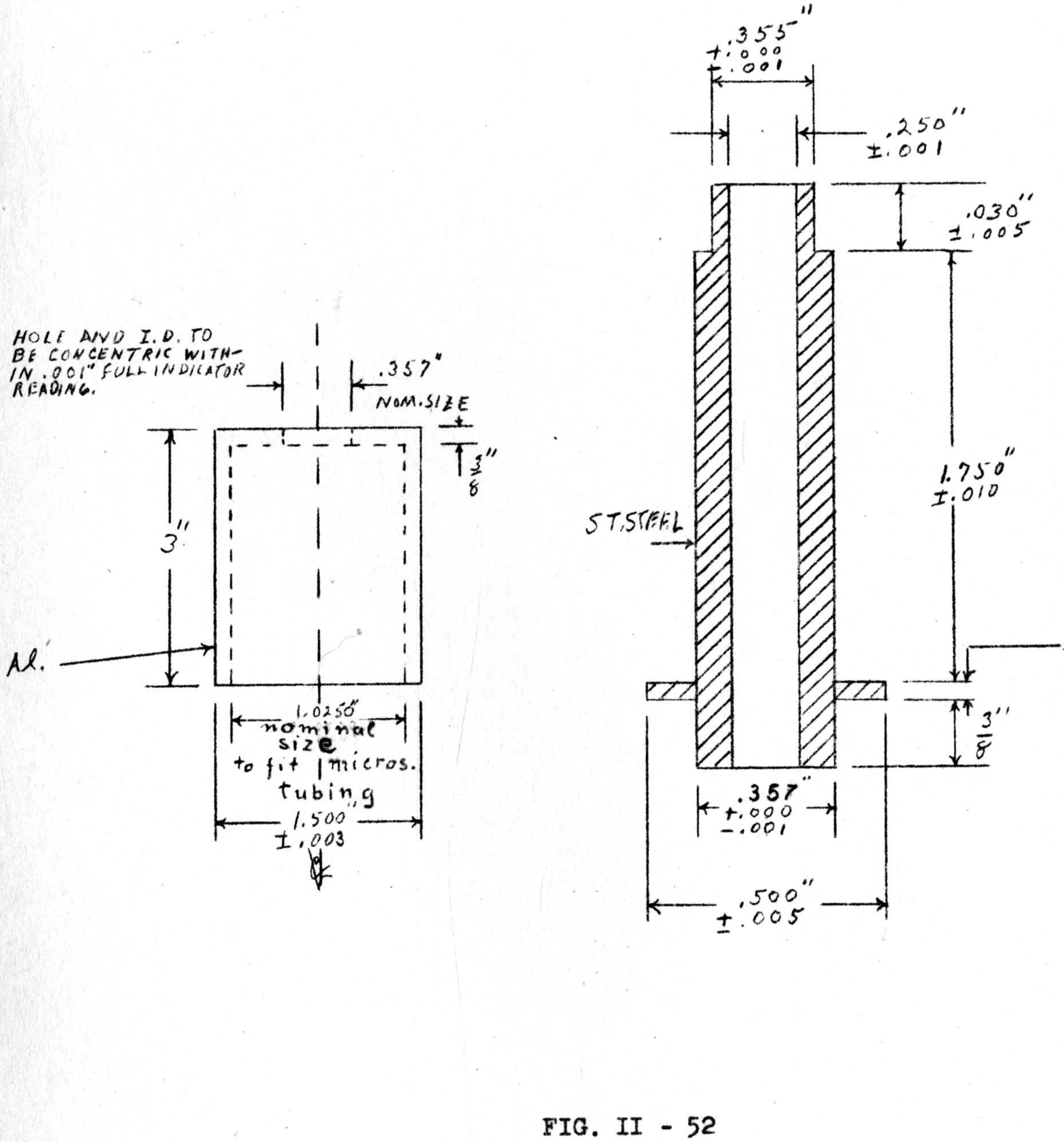
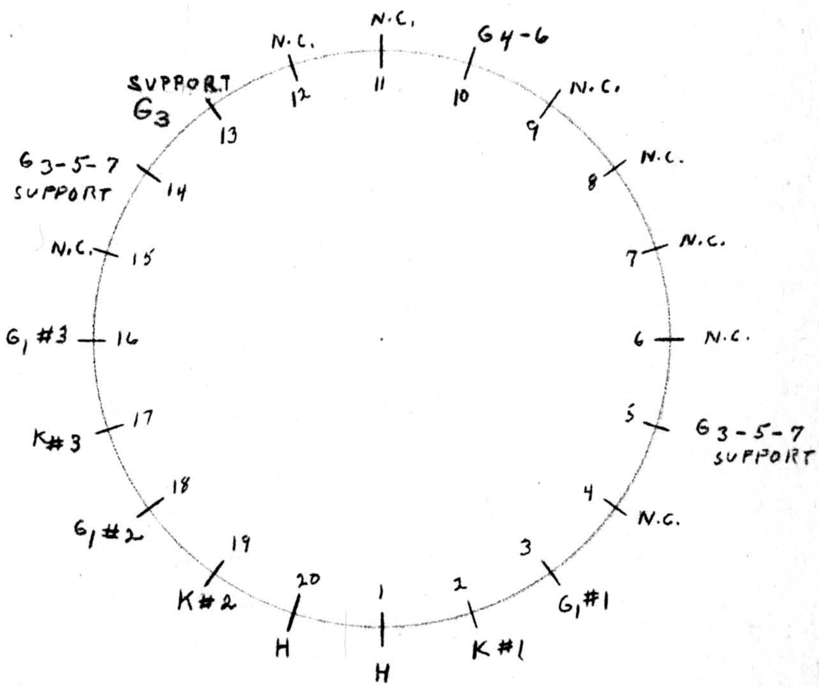
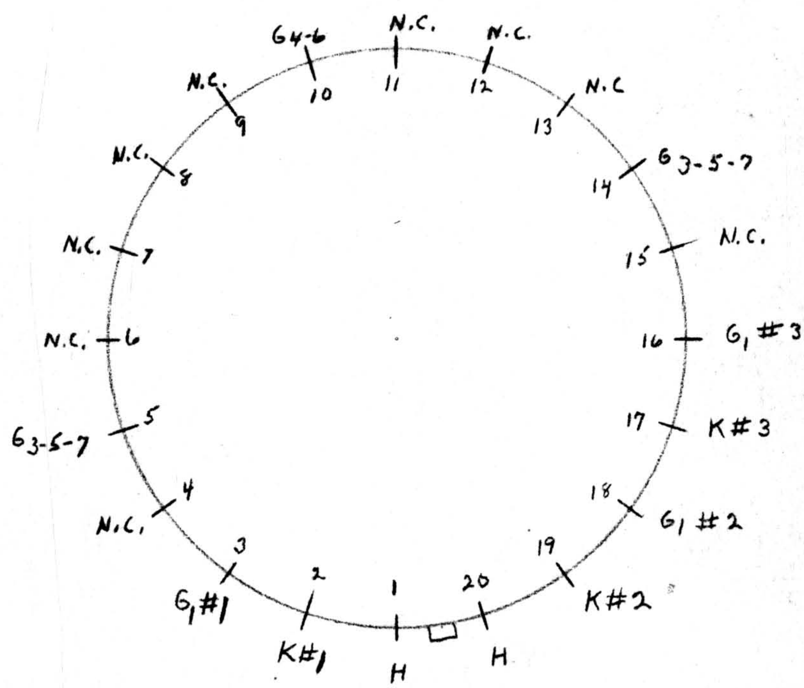


FIG. II - 52

MICROSCOPE ADAPTER FOR CHECKING OF ALIGNMENT OF G_1 AND LIMITING APERTURE



(A) STEMMING DIAGRAM



(B) BASING DIAGRAM

FIG. II - 53

Double springs to be formed (Fig. II-18(e)) and welded together.

Getters to be preassembled with supports (Fig. II-18(d)).

Heaters are preassembled with nickel tabs. Nickel cathode tabs are partly folded as shown in Fig. II-19(b), then the nickel tab is tightly folded to hold the end of the tungsten heater wire. Finally, the nickel and tungsten are welded together on a welder preset specifically for this purpose.

μ-metal shields (Fig. II-20) to be annealed in a dry hydrogen atmosphere with a dew point of -57° C. at 1100 to 1200° C. for 4 hours, cooled to a temperature of about 200° C. in about 6 hours or longer.

Stems to be annealed at 460° C. for 15 minutes, cooled at a rate of 2° per minute to a temperature of 150° C. or lower.

Cleaning Procedures

Cathode spacer rings (Fig. II-10), cathode retainer rings (Fig. II-11 or II-14), and cathode retainer cups (Fig. II-13) to be degreased, rinsed in hot water, dipped in HNO_3, rinsed in hot water, boiled in distilled water for 3 minutes or longer, and fired in hydrogen at 1100° C.

Control grids G_1 (Fig. II-4) to be degreased, rinsed in hot water, electropolished until grid hole is opened sufficiently to give close sliding fit to pin on assembly mandrel; then rinse again in hot water, dip in HNO_3, rinse in hot water, boil in distilled water for 3 minutes or longer, and fire in hydrogen at 1100° C.

First anodes G_2 (Fig. II-5) and limiting aperture cups (Fig. II-8) to be prepared as G_1 above, except the parts are not to be fitted to any mandrel when polishing.

Second and third anodes G_4 (Fig. II-6) and G_6 (Fig. II-7) respectively, and first and second focusing electrodes G_3 and G_5 (Fig. II-6) respectively, to be prepared as G_2 above. Boiling in distilled water is not required.

End plate (Fig. II-15), collars (Fig. II-16 & II-17), metal strips (Fig. II-18(a), (b), (c)), and nickel tabs for heaters (Fig. II-19(b)), and tabs for cathodes are only degreased and hydrogen fired at 1100° C.

The Kovar wire bridge (Fig. II-19(a)) for heater support is made of degreased and hydrogen-fired wire.

The quartz sleeves for cathode tabs (Fig. II-19(c)) are washed and agitated in Cyclodeine for about 3 minutes and boiled two times in distilled water for 3 minutes.

Mounting springs (Fig. II-18(e)) are only degreased.

The wire leads of the stems are deoxidized in a hydrogen flame by the conventional technique. Then the stems are checked for strains, and with a magnifying glass or microscope inspected for cracks mainly in the vicinity of the metal-to-glass seals. Then the stems, primarily the inside of the tubulators, are washed with a detergent (Calgonite) and rinsed in hot water.

Assembly of Individual Gun:

Before using a newly assembled beading fixture, check that male (Fig. II-27(a)) and female mandrels (Fig. II-28) are well centered. If not, try realignment with the three set screws in both end pieces of beading fixture (Fig. II-22 and Fig. II-24).

Compress spring on beading mandrel (Fig. II-27(a)) and tighten set screw on ring (Fig. II-27(b)) to hold spring down. Place electrodes G_6, G_5, G_4, G_3, and G_2 on mandrel. Put G_1-G_2 spacer (Fig. II-29) on mandrel above G_2, then place G_1 cup on pin. Shift female mandrel (Fig. II-28), which is mounted in end piece of beading fixture, slowly into G_1 cup, tighten fixture by turning motion. Put high voltage electrode spacers (Fig. II-30) in place, release set screw in ring (Fig. II-27(b)), and check whether all parts are tightly pressed together on mandrel. After first beading, check whether beading rack was correctly set so as to leave ample space for metal strips (Fig. II-18(a) & (b)) between glass beads and electrodes.

Before taking gun off mandrel, compress spring and tighten set screw in ring (Fig. II-27(b)). If this is not done there is danger of bending fine pin on mandrel.

After taking gun off mandrel, check hole in G_1 with magnifying glass for possible damage. Insert microscope adapter (Fig. II-52) into gun and check alignment of G_1 hole with rest of gun. The maximum acceptable misalignment is about .002" off axis.

For the first method of cathode assembly follow this procedure: Place G_1-G_2 spacer again into gun (Fig. II-29). Insert limiting aperture cup (Fig. II-8) into gun using welding mandrel with spacer sleeve (Fig. II-46). Check alignment of G_1 hole with limiting aperture using microscope with the other microscope adapter (Fig. II-52) after removing G_1-G_2 spacer. This operation can be omitted if it is found that limiting apertures are well centered in gun. Weld limiting aperture into place and then always check alignment of gun with microscope using adapter of Fig. II-52.

Clean cathode (Fig. II-9) so that no coating is left on outside rim of cathode cap. This can be done either with clean blade, which was degreased and boiled in distilled water or by wiping surface of cathode cap on the smooth surface of ashless filter paper or lens tissue (lintless paper) resting on a flat surface. The second procedure is recommended because, when using blades, sometimes chipping of the coating occurs. After all coating has been removed on the outside ring of the cathode cap, shave cathode with blade to level off center part of coating. The coating should be slightly thicker than indentation in cathode to obtain flat surface of coating.

Insert cathode spacer ring (Fig. II-10) matched with cathode into G_1 cup after placing G_1-G_2 spacer into gun, then insert cathode (Fig. II-9), after welding cathode tab to it, with the tab in the direction of one of the glass beads, and finally insert cathode retainer ring (Fig. II-11). For these operations, use tool of Fig. II-31(a). Check tight fit of cathode in G_1 cup using magnifying glass and tweezers. Then weld cathode retainer ring in place using welding mandrel of Fig. II-47(a), and check again tight fit of cathode. Check cathode for possible short with G_1 cup using ohmeter.

For the second method of cathode assembly the following procedure applies: Place cathode retainer cup (Fig. II-13) upside down into holder (Fig. II-32). Insert sprayed cathode (Fig. II-12) into cup, then insert cathode retainer ring (Fig. II-14). Use tool of Fig. II-31(b). Check tight fit of cathode in retainer cup with tweezers and magnifying glass. Weld together using welding mandrel of Fig. II-47(b), and check again tight fit of cathode. Remove sharp weld marks on cathode retainer cup with clean file. Remove cathode coating from outside rim as described above.

Place again G_1-G_2 spacer (Fig. II-29) into gun, insert mandrel (Fig. II-43(a)) into gun. Push cathode assembly slightly into G_1 cup. G_1 cup with cathode assembly fits then on female mandrel (Fig. II-44(c)) in cathode assembly fixture. Center pin (Fig. II-44(a)) in this mandrel is insulated from mandrel and makes electrical contact with cathode. Screw (Fig. II-43(b)) with hardened point fits into mandrel (Fig. II-43(a)). Bronze sleeve (Fig. II-43(c)) in which screw (Fig. II-43(b)) fits is locked into the frame (Fig. II-42) of the fixture by part (b) in Fig. II-45(b).

In another section, a circuit is described which is used with the herein described fixture. The G_1-cathode distance is being measured from the sparking potential in air. Sparking is detected by the sound of a loudspeaker and the sparking potential can be read on a voltmeter.

To determine the correct sparking potential, a sample cathode grid assembly is connected as a standard to the circuit. This assembly is of the first kind described earlier, but the cathode used here is without coating and without indentation in the cap. The G_1-cathode distance is checked on an optical comparator. To determine this distance, a .020" diameter pin with square ends is used. The thickness of the cup material around the coined area is measured with a micrometer and a special plug. The G_1-cathode distance can then be determined from the known length of pin and grid cup material thickness; the length of the pin above the cup when inserted into it is a measure of G_1-cathode spacing.

To adjust the G_1-cathode distance in a gun, the screw is slowly tightened with the electrical indicator set for a G_1-cathode distance larger than required - for example, .0065" instead of the desired .0055". An increase of the distance by .001" corresponds to an increase of sparking potential by about 120 volts. Then the correct sparking potential is adjusted for the standard with a cathode G_1 spacing of .0055", and the measuring instrument switched back to the gun into which the cathode is being inserted. The screw is finally tightened until sparking can be heard. The adjustment has to be done slowly since it is possible to push the cathode assembly too far into the G_1 cup; the cathode cannot be pulled out. The retainer cup is then to be welded to G_1 while still in the fixture. After taking gun out of fixture weld cathode tab to cathode sleeve so that it is in the direction of one of the glass beads.

<u>Assembly of Tri-Color Guns</u>

Select with sparking method, described earlier, guns with uniform cut-offs. Use this procedure for first method of cathode assembly. If desired, also recheck guns assembled with second cathode assembly method.

Prepare center gun. Connect G_2 with G_4 and G_6 with stainless steel wires .020" in diameter or thinner. This lead is to be placed on the same side as the cathode tab. Connect also G_3 with G_5. Place this lead on the opposite side of the gun from the G_2-G_4-G_6 connection. Weld so that no sharp ends of wires protrude into gaps between high-voltage electrodes. Bring wires out perpendicularly to surface of electrode about halfway between gun and neck of tube, i.e. beyond glass bead. Then bend wire so that it is parallel with glass bead, about in the midplane of the bead. Weld wire leads to all G_1 electrodes on same side as cathode tabs.

The jig for the tri-color gun assembly is shown in Fig. II-48. Place jig in stand (Fig. II-50). The end plate (Fig. II-15) is laid on the jig, then Elkonite mandrels (Fig. II-43), the ends of which have to be free from loose metal particles, are inserted through end plate (Fig. II-15) into jig. Both halves of jig are tightened together to hold mandrels (Fig. II-49) in place. Mandrels are checked for tight fit in jig. If the fit is not perfect, check whether there are any rough spots either on mandrels or in holes of jig. The alignment of the outside mandrels with respect to the central mandrel is to be checked with spacers similar to Jo-blocks.

Slip collars over mandrels. Collar of Fig. II-16 slips over center mandrel, collars of Fig. II-17 slip over side mandrels so that the sheared-off parts of flanges are toward the center mandrel. Slip guns over mandrels into collars. Keep G_1-G_2 spacers (Fig. II-29) in both side guns. The cathode tabs should be on the opposite side of the plane of symmetry, which one can imagine going through the three guns, from the small fourth hole in the end plate. Weld collars to end plate. Take jig out of stand and place into welder in horizontal position. Weld collars to gun. On side guns weld collars only on part which is away from center gun; don't weld in other places. Weld metal strips (Fig. II-18(b)) to both sides of G_2 so that short bent parts are on opposite sides of gun. To these ends, strips of Fig. II-18(c) which serve as supports will later be welded for gun stemming. Weld with tweezer welds strips (Fig. II-18(a)) across all G_2 electrodes on both sides. Weld, using welding electrodes, strips to both sides of G_3 electrodes, one strip to one side of G_4 electrodes, and strips to both sides of G_5 electrodes. Weld, using welding electrodes, short strips (Fig. II-18(b)) to both outer G_3 electrodes on opposite sides.

The bridge for heaters is welded to gun and heaters are inserted. Bend both end wires of bridge so that bridge, when mounted, is above cathode sleeves and one of the end wires can be welded to the last pin of G_1 of one of the outside guns. Cut other end wire shorter. This end is held by .020" stainless steel wire to pin on G_1 of other outside gun. The wire is used to eliminate stronger forces on G_1 cup after welding bridge to G_1 cups. After cutting end wires of bridge, grind ends off to eliminate all sharp edges. This is done before welding bridge to gun. Bend end of .020" wire so that no sharp edges point in the direction of high-voltage leads, that is to gun supports; the simplest way is to bend the end of this wire in the axial direction of the gun away from G_2.

Insert heaters with nickel tabs into cathode sleeves. Let heaters drop completely into sleeves. Weld nickel tabs with light tweezer welds to heater bridge. Check position of heaters and possible cracks of wire insulation. Take jig with gun out of welder and make final welds of heater nickel tabs to heater bridge on another preset welder used specifically for this purpose.

Place jig with gun into stand (Fig. II-50). Slip cleaned quartz sleeves (Fig. II-19(c)) over cathode tabs and hold them in place with short nickel strips welded across cathode tabs. Cut off excessively long nickel tabs of heaters. Check heater insulation for cracks with magnifying glass. If necessary, replace heaters.

To take gun off jig, release big screw, take jig apart. Pull mandrels out of guns with small pliers, one jaw of which fits into center hole in mandrel and other jaw is pressed against flat part on one side of mandrel.

Weld μ-metal shield (Fig. II-20) to collar (Fig. II-16). Insert welding mandrel into center gun, slip μ-metal shield over mandrel so that slit in sleeve points in the direction of one glass bead of the center gun. Weld collar to end plate (Fig. II-15).

Check all welds with tweezers and magnifying glass. Take G_1-G_2 spacers out of guns. Check insulation of all cathodes to G_1 electrodes and to heaters. Check with ohmeter resistance of the three heaters in parallel. Check with ohmeter continuity of all electrodes which should be connected together.

<u>Stemming of Gun:</u>

Gun is held in stemming fixture on mandrel identical with welding mandrel of Fig. II-46 which is inserted into center gun. The stemming diagram is shown in Fig. II-54(a). This view is from the top end of the gun toward the stem. Two leads are welded perpendicularly to heater bridge. Bent strips of Fig. II-18(c), which form the gun supports, are welded to bent ends of strips of Fig. II-18(b) at a 90° angle. The supporting strips are then welded to stem wires. A reinforcement strip is welded to pin #14. Welds of heater leads to stem leads are usually reinforced by two short nickel tabs welded over finished welds. After gun is taken off stemming fixture, springs (Fig. II-18(e)) and getters (Fig. II-18(d)) are welded to end plate above guns. The three springs and three getters are placed about 120° apart. Care must be taken that neither springs nor getters interfere with any of the holes in the end plate. When welding the springs, it is necessary to weld them to end plate also with one or more welds placed between the two springs forming the double spring.

Check again on finished gun all welds with tweezers and magnifying glass. Check for possible cracks on heaters. Check with ohmeter continuity of all stem leads to all corresponding electrodes. Check heater resistance. Check insulation of all leads with respect to all other leads. Bend springs so that gun is spaced symmetrically when a glass sleeve with a diameter equal to the neck diameter of the tube is pulled over the gun from the side of the stem. Adjust tension of springs so that glass sleeve rests on the spring where the bend begins. Adjust position of getters so that they do not touch glass but are close to glass to make flashing in tube easy.

Clean gun with radioactive brush to remove lint. Wash hands after handling radioactive brush. Finally, use hydrogen torch (no oxygen) to remove any remaining lint.

SECTION II DESIGN OF GUNS FOR COLOR TUBES

The post-acceleration color tube requires a low-voltage tri-color gun operating at about 5000 to 7000 volts, able to supply several hundred microamperes screen current per gun. The resolution required is about 300 by 300 lines (or 300 by 400 lines) because of the limited band width available.

To obtain 50 foot Lamberts brightness in the white highlights, the guns have to be able to supply a screen current of about 170 microamperes at 5000 volts gun voltage, or a current of about 150 microamperes at 7000 volts. Such high currents are required because of the low efficiency of the presently used red phosphor.

In the presently used tubes even higher beam currents are desired since an optical filter is placed in front of the tube to increase picture contrast. But it should be pointed out that in the highlights resolution is of little importance, and a resolution of 300 by 300 lines is not required there.

From the point of view of color purity, slender beams are desired in the plane of deflection. It is, therefore, not only the actual resolution which is of importance, but also the beam diameter in the plane of deflection has to be considered.

In this section of the report, the development of several types of guns is described. The effort was concentrated on the development of three fundamental types:

(A) Coincidence Cross-over Three Cathode Gun
(B) Modified Tri-color Guns for Post Acceleration
(C) Post-Acceleration Tri-Color Guns Arranged in One Plane

(A) Coincidence Cross-Over Three-Cathode Gun

This program was initiated on the basis of a lead obtained from the Radio Corporation of America during a trip to their Princeton Laboratories in December 1951. This gun arrangement appeared very desirable, especially when used in conjunction with the post-acceleration tube. It was only after our development work was very far advanced that we found out that RCA had discontinued a similar program because of fundamental difficulties.

In the herein described gun, three cathodes are incorporated in a single gun structure of standard dimensions (half inch inside diameter tubing), to replace the structure of three individual guns coupled together into one unit. It was expected that the simplicity of the structure would lower the manufacturing cost of the gun. Further, smaller neck diameter of about 1.5 inches seemed more desirable than the large 1.820 inches diameter precision bore tubing used then with the shadow mask type Tri-color gun.

Two approaches to the three cathode gun seem feasible. One is the coincidence cross-over principle, to be discussed in detail later, and which was followed through our project. Another scheme uses common aperture disks for the three beams, but only one system of electrodes. This is also discussed later in this report.

Description of Principle of Three-Cathode Guns

A sketch of the coincidence cross-over principle is shown in Fig. II-54. For simplicity only two cathodes are shown, instead of the three cathodes placed 120° apart. Electrons leaving the cathodes pass through apertures B in the control grid G_1. The accelerating field from the screen grid G_2 which penetrates through apertures B into cathode region is deformed by the aperture A in G_1. By the deformed field, the beams are deflected toward the axis and all three beams intersect in a common point on the axis. After passing through G_2, the electrons enter the third grid G_3. A magnetic field, the axis of which is parallel with the axis of the gun, converges the three divergent beams in the region of G_3, and focuses them simultaneously on the grille. In the color tube the image of the common intersection of the three beams is focused on the grille, which is placed in back of the screen. The grille is at a voltage which in the post-acceleration color tube is only about one-fourth to one-fifth of the screen voltage, i.e. at 4 to 5 kilovolts. Since the spot on the grille is the image of the common intersection of the three beams, it is essential to obtain minimum beam size of the three beams in their common intersection. It becomes, therefore, very desirable that the cross-overs of the individual beams coincide with the common intersection of the three beams. Screen spots of distorted shape are inherent to such an electron optical system. It should be pointed out and stressed that there are no limiting apertures in this type of gun. Another possible solution may be as follows. Instead of bringing

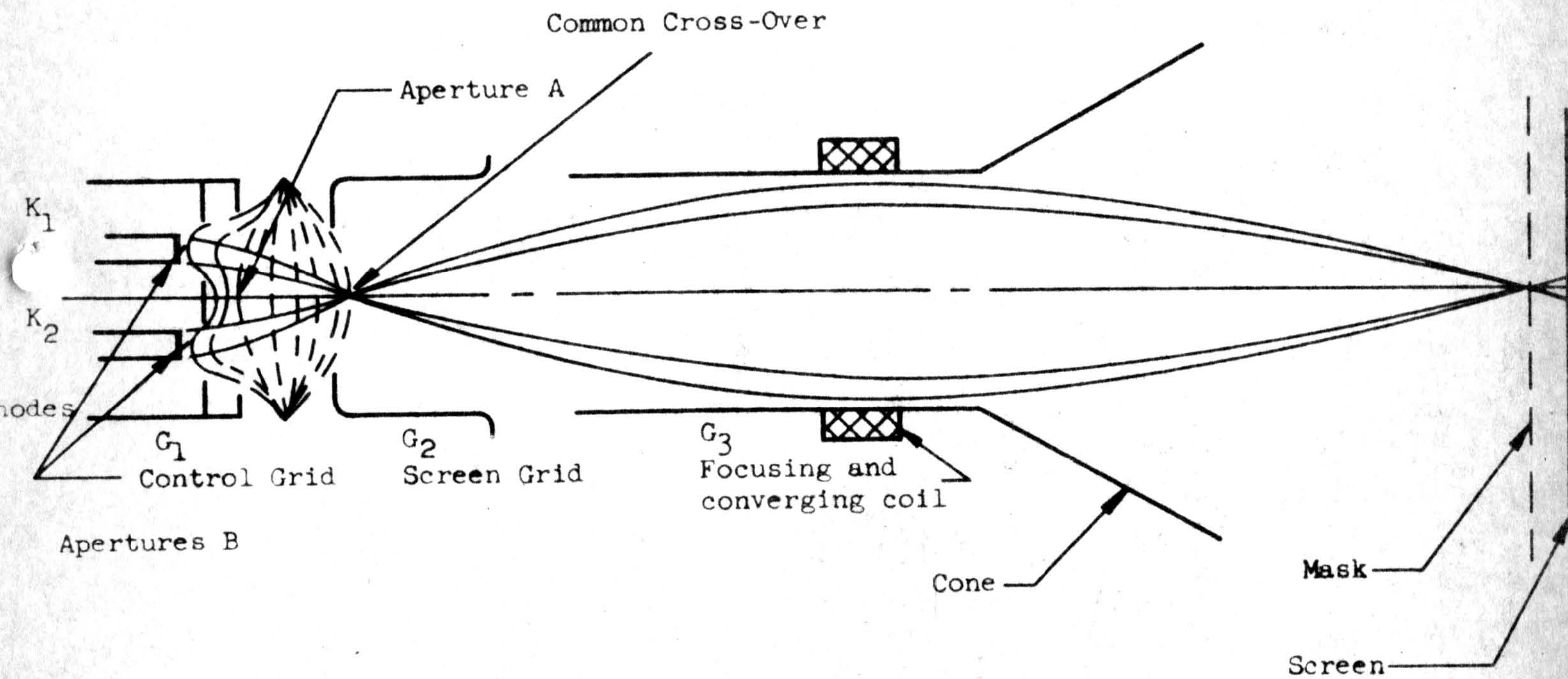


FIG. II - 54

COINCIDENCE CROSS-OVER
GUN

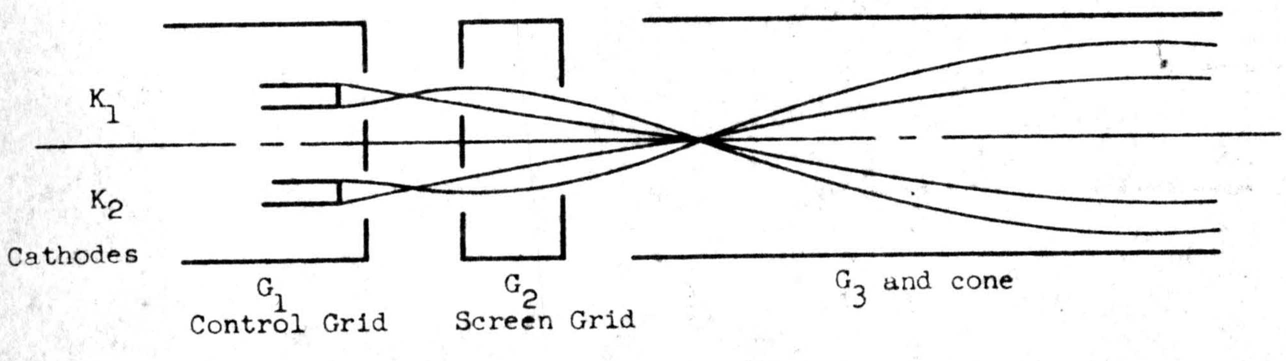


FIG. II - 55

MODIFIED THREE CATHODE
GUN

the cross-overs of the individual beams into a common intersection of the three beams, the images of the cross-overs are brought into this spot (see Fig. II-55)*. This construction would require a strong focusing lens for the formation of the first image of the cross-over.

In the other approach to the three-cathode gun, which was previously mentioned, three complete systems of apertures are used. The apertures are placed in a single system of electrodes. (See Fig. II-56). Then the design can be fundamentally the same as that of the conventional Tri-color gun used in the shadow mask tube. In the latter case, three guns are placed with their axis parallel, 120° apart. The three beams enter a convergence lens where they are deflected so as to meet in a common spot at the desired angle. The three individual guns are replaced in the three-cathode gun by three systems of apertures which form three systems of electrostatic lenses for the formation of three parallel electron beams.

Coincidence Cross-Over Gun

All the development work to be described herein was based on the principle of coincidence cross-overs. As was mentioned above, it is desirable to have the cross-overs of the individual beams coincide with the common intersection of the three beams to obtain minimum spot size.

The cross-over in front of the cathode is usually slightly beyond the control grid and moves somewhat during modulation. With conventional electron-optical means, the cross-over cannot be moved as far as required in our case, that is, into the common intersection of the three beams. By moving the control grid away from the cathode, the position of the cross-over of electrons leaving the cathode perpendicularly remains practically unchanged. The cross-over of trajectories of electrons leaving at an angle to the normal, moves in the same direction as the control grid. Nevertheless, the position of the resulting cross-over remains almost unaffected because of a nearly Gaussian electron density distribution in the beam. It should be kept in mind here that an increased cathode-control grid spacing is undesirable primarily because of resulting increased size of the cross-over, and therefore, increased spot size on the screen.

A compromise has therefore to be sought by pulling out the cross-over as far as possible and thus obtaining a minimum spreading of the beam when the three beams intersect. Even under these conditions, field plots which will be described later in detail, indicate spot sizes above 0.100 inch. Spot sizes of less than 0.060 inch are desired.

Field Plots

Because of the unconventional electron optics in the three-cathode gun, extensive plotting was made in a tilted electrolytic tank. Such field plots give only a rough indication of the position of the cross-over and

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* Patent Docket No. 4D-588 of August 5, 1954, by P. H. Gleichauf.

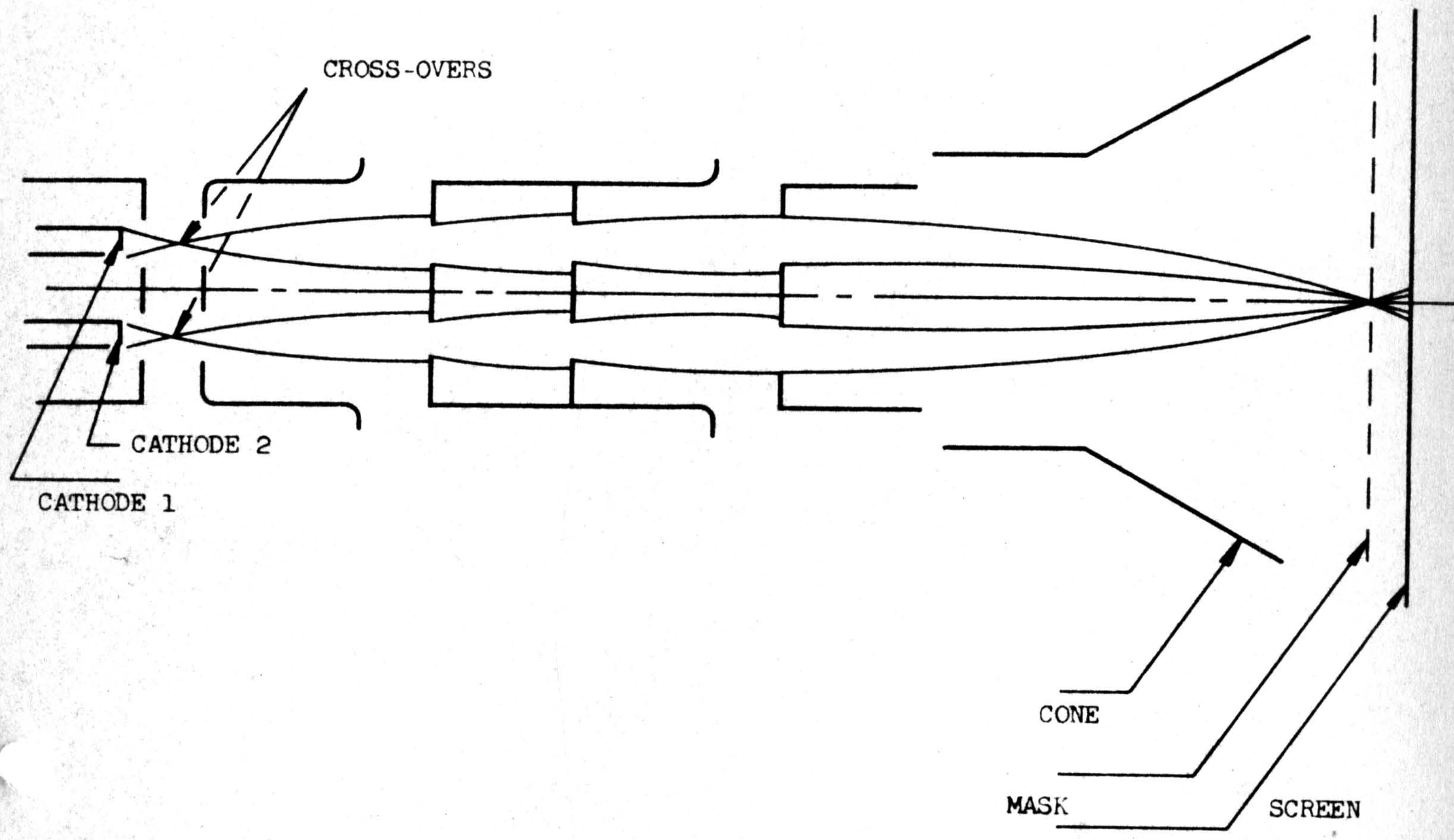

FIG. II - 56

THREE CATHODE GUN WITH
COMMON APERTURE DISKS

beam diameter primarily because of space charge effects. There are two space charge effects, the action of which can be estimated.

The space charge adjacent to the cathode increases the convergent action of the field, thus bringing the cross-over closer to the cathode than indicated by the field plots.

In the cross-over region, higher current densities lead to space charge mutual repulsion of electrons in the beam and an increased cross-over size results. The diameter of the beam in the cross-over without space charge effects can be roughly calculated from the equation*:

$$d_1 = \frac{2\,d_c}{\sqrt{\frac{V_1}{V_o}}\ \sin\theta} \qquad (1)$$

where d_1 = diameter of cross-over, d_c = diameter of emitting area, V_1 = potential at cross-over, V_o = cathode temperature in volts, θ = angle of emitting area viewed from the cross-over. The actual diameter of the beam in the cross-over and the location of the cross-over can be estimated by determining the beam spread from available curves**, using data from the field plots.

Another effect to be expected from the space charge mutual repulsion in the cross-over region is a reduction of the screen spot size as compared with the screen spot size which would result from electron trajectory tracing (or geometrical optics). The diverging angle of the trajectories after passing through the cross-over becomes smaller than the converging angle before entering it because of the higher velocities acquired by the electrons after leaving the cross-over, thus producing less mutual repulsion in the beam. For the same reason, the location of the minimum beam diameter, i.e., the cross-over, is shifted somewhat in the forward direction, after considering the earlier mentioned shift due to space charge in front of the cathode.

Electron trajectories were traced using both the parabola and the index of refraction methods. The index of refraction method was used where the angle of the electron paths with the perpendicular to the equipotentials was large, whereas for small angles the parabola method was preferred.

The electrolytic tank was tilted less than 5°. Copper sheet electrodes were used. The electrolyte was deionized water to which potassium

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* Karl R. Spangenberg, "Vacuum Tubes" - McGraw Hill Co., 1948, p. 419.
** Ibid., p. 444.

bichromate was added. To obtain a sharp edge of the electrolyte at the axis of the system, a line was drawn on the bottom of the tank with a glass marking pencil, and a wetting agent was added to the electrolyte. Measurements were made with a 300 cycle signal using an oscilloscope for null indication. The error introduced by having the electrodes resting perpendicular to the bottom of the tank was below accuracy of measurements.

First Gun Design

The size of the cathodes was reduced when compared with cathodes presently used in conventional guns. The diameter of the cathodes was only 0.062 inch as compared with almost 0.125 inch in conventional guns. This reduction of cathode area was possible since the actual emitting area is less than 0.055 inch in diameter in either case. With such small cathodes leakage paths of sufficient length on the ceramic disk supporting the cathodes were secured when placing them 120° apart on a 0.086 inch circle. The given location of the cathodes resulted from field plots as discussed later. Control grid cup G_1 consisted of two sections. The first section as shown in Fig. II-57 forms the outer cylinder with aperture A. This cylinder is of 0.010 inch stainless steel and supports the control grid assembly. The second section is of 0.004 or 0.005 inch stainless steel. Three 0.031 inch diameter apertures B are punched in this cup 120° apart with centers on a circle of 0.086 inch radius. Two lancings in this cup fit into corresponding slots in the ceramic disk, supporting the cathodes, to secure proper angular location of the cathodes with respect to apertures B.

It was desired that the angle of the beams with the axis of the tube at the grille be 1°12'. The angle of the beams passing through the common intersection of the three beams was determined from geometrical considerations. An angle between 7 and 9° was desired before entering the focusing coil. A larger angle would be desirable because of a resulting shorter gun, i.e., a shorter tube neck. But at the same time a larger screen spot would be obtained because of increased magnification.

For correct design of the gun, it was essential to have sufficient transconductance. In order to obtain convergence of the three beams, the field from the screen grid G_2 penetrating into control grid G_1 was artificially distorted by the aperture A before penetrating into the cathode region. Under such conditions nothing was known about the transconductance to be expected.

Field plots were taken at different bias voltages at the control grid G_1: 0 volt, -10 volts, and -18.2 volts. Plots at different bias voltages were taken to determine whether a noticeable change in the angle of the beam can be expected with modulation. The grid G_1 cathode region was partly shielded by the outer aperture A in G_1 from the field produced by the screen grid G_2. Therefore, a voltage of about 1000 volts on G_2 was required as compared with 200 to 300 volts in conventional guns. A field plot at 0 volts on G_1 is shown in Fig. II-58, a field plot at -10 volts on G_1 is shown in Fig. II-59, with only the central ray traced. These plots show only a part

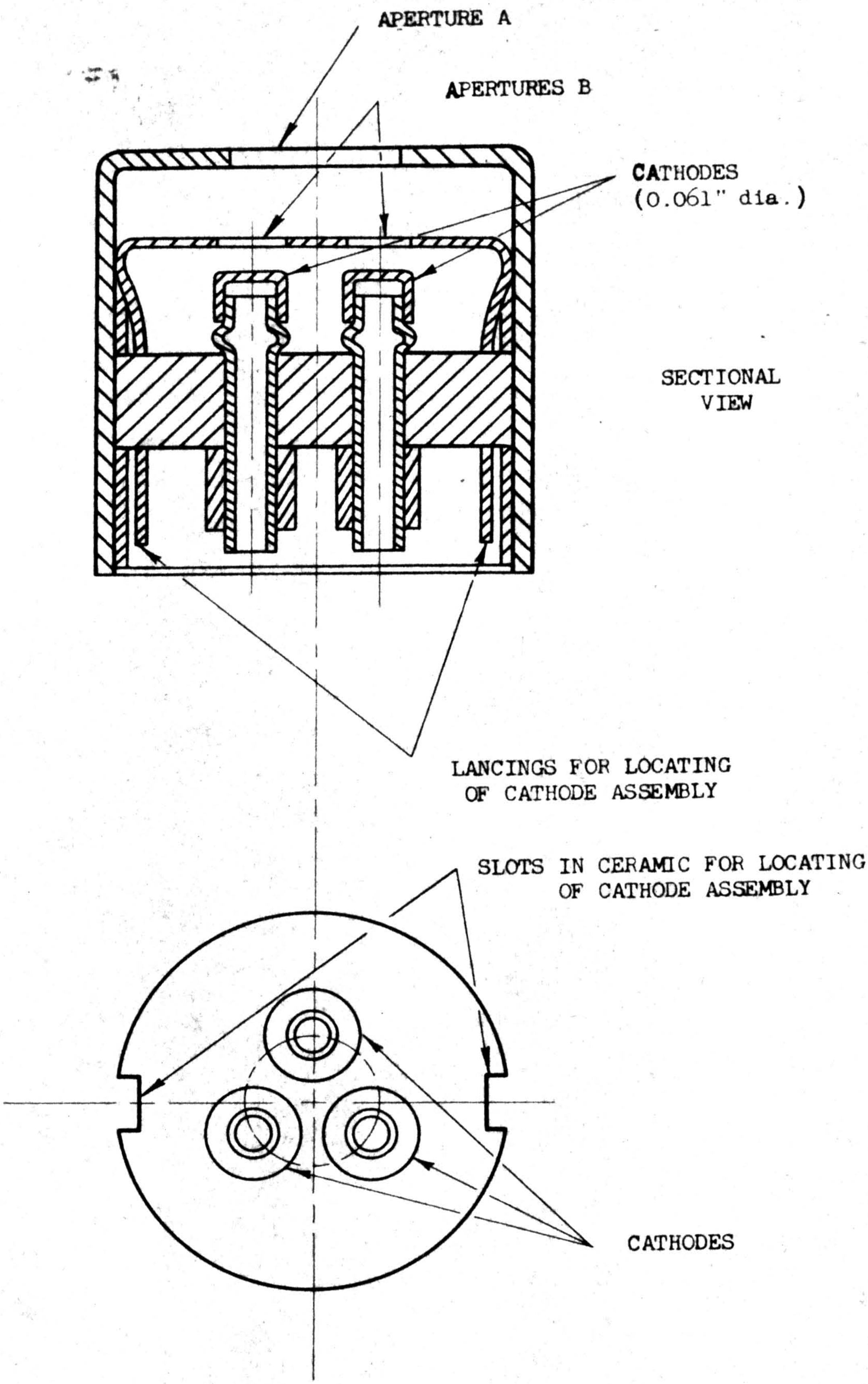

FIG. II - 57

CONTROL GRID G_1 WITH
CATHODE ASSEMBLY

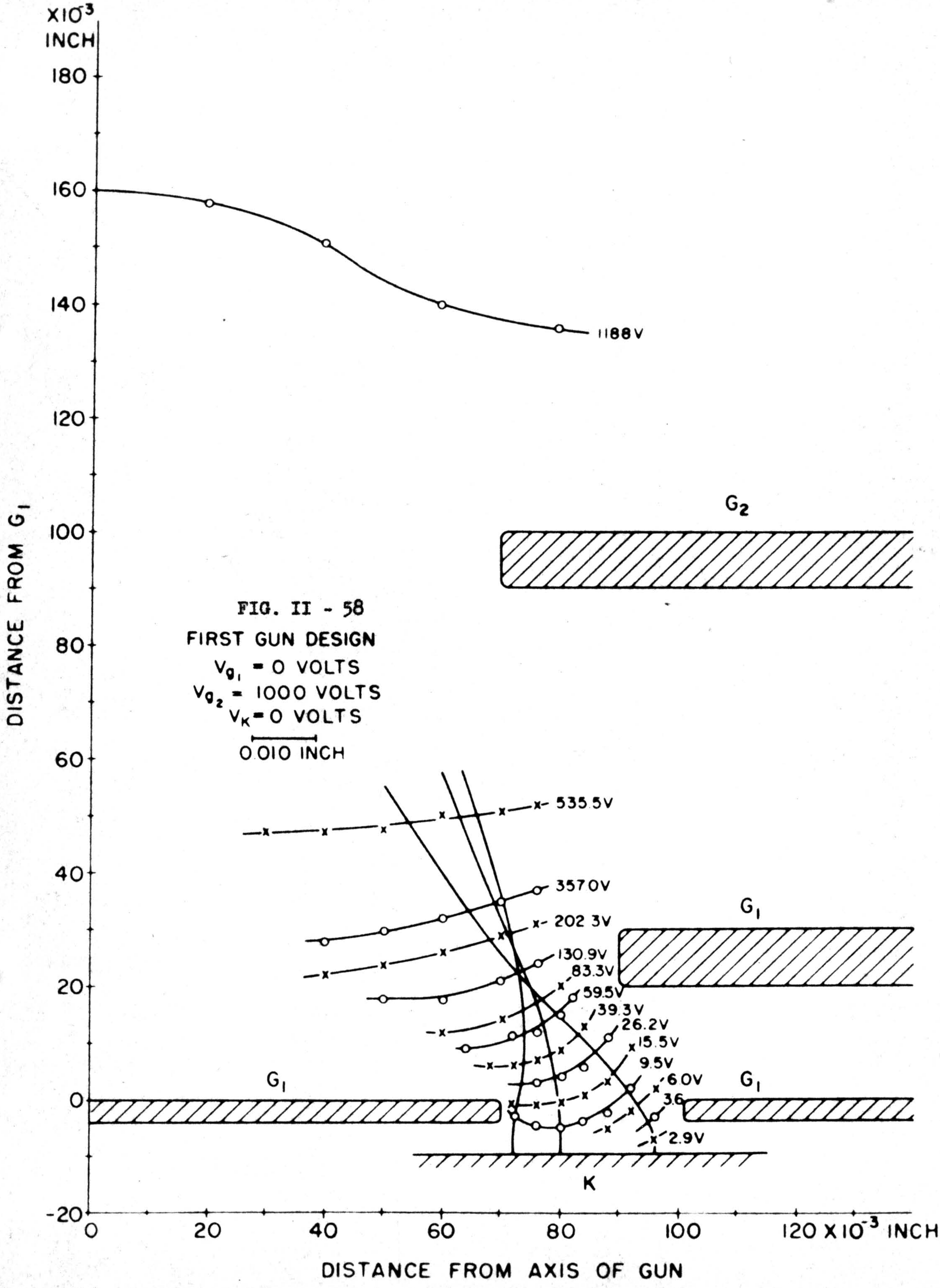

FIG. II - 58

FIRST GUN DESIGN

V_{g_1} = 0 VOLTS

V_{g_2} = 1000 VOLTS

V_K = 0 VOLTS

0.010 INCH

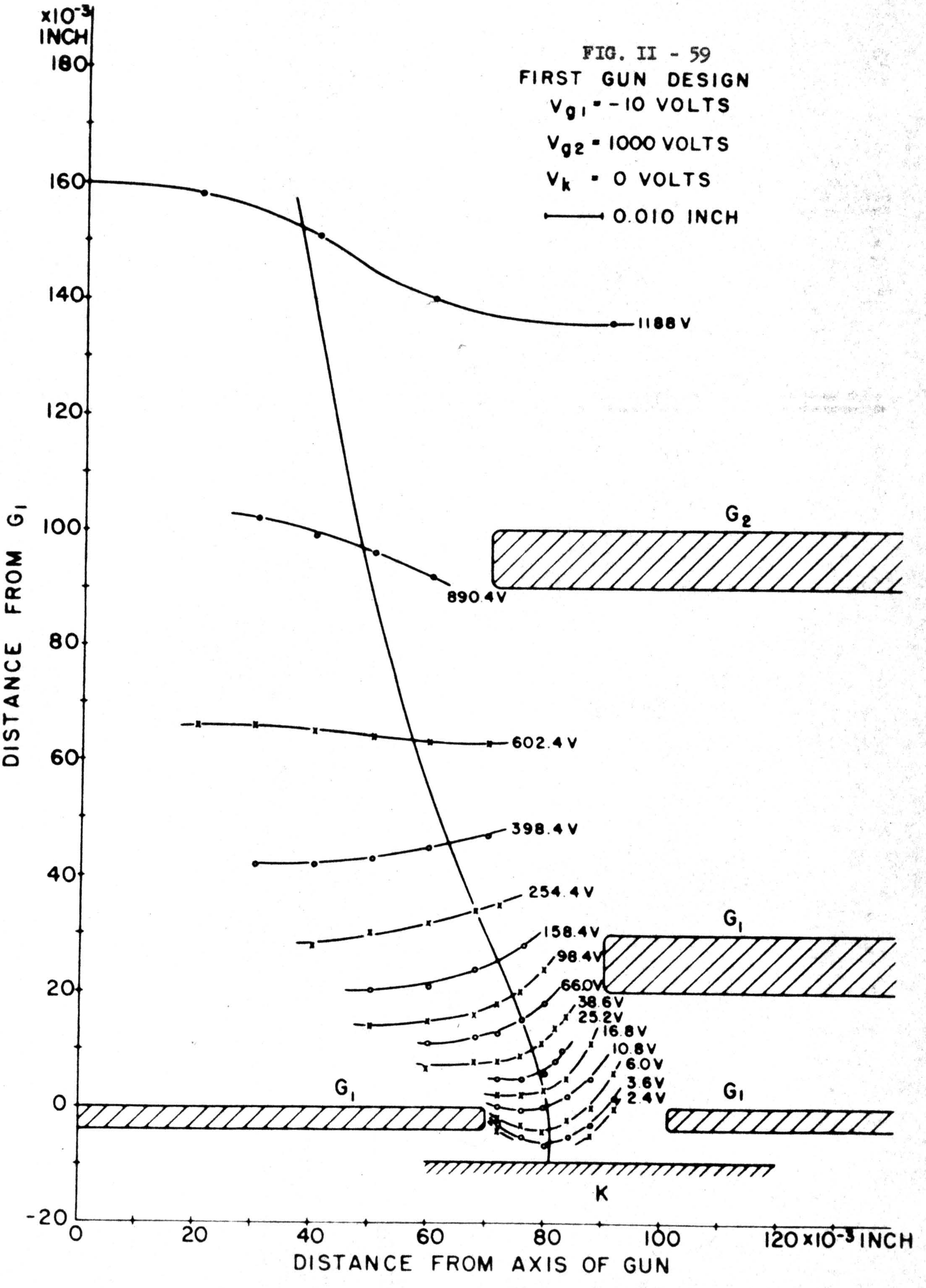

FIG. II - 59
FIRST GUN DESIGN
V_{g1} = -10 VOLTS
V_{g2} = 1000 VOLTS
V_k = 0 VOLTS
0.010 INCH
x10⁻³ INCH
180
160
140
120
100
80
60
40
20
0
-20
DISTANCE FROM G₁
0
20
40
60
80
100
120 x10⁻³ INCH
DISTANCE FROM AXIS OF GUN
1188 V
890.4 V
602.4 V
398.4 V
254.4 V
158.4 V
98.4 V
66.0 V
38.6 V
25.2 V
16.8 V
10.8 V
6.0 V
3.6 V
2.4 V
G_2
G_1
G_1
G_1
K

of the field in the gun. The section of the field shown occupied almost the whole electrolytic tank. Since it was not possible to include other electrodes into the plots, these electrodes were replaced by a tank electrode in the position of an equipotential (1188 volts). This equipotential was determined from other plots of a larger section of the gun. From these latter plots the design of the screen grid electrode G_2 was primarily determined. It was desirable that voltage changes up to 7.5% on G_3 and G_2 would not change the field appreciably in the G_1-G_2 region, and therefore, not alter noticeably the electron trajectories. The plot for the final electrode configuration is shown in Fig. II-60. Several electrode configurations were tested. By proper counter-action of the fields produced by the electrodes G_1-G_2 and G_2-G_3 a reasonable stability of the field in the region of low velocity electrons can be obtained. Although the stability of equipotentials in the final design was not the best obtainable, the configuration shown in Fig. II-60 was used since in a more desirable design, electrons would strike the screen electrode G_2. Such a case is represented in Fig. II-61 at a bias voltage of -10 volts.

In the following, an estimate is made of the maximum spot size which could be expected. The calculations were made for a 150 microampere beam. 0 volts bias was assumed, although under actual conditions, it was not expected that full grid drive would be used with a well activated cathode. The cross-over would be moved about 40%* closer to the cathode alone, because of space charge in front of the cathode and 14% in the opposite direction alone, because of mutual electron space charge repulsion in the beam; the net effect is to bring the cross-over close to the 90 volt equipotential.

Neglecting space charge mutual repulsion, the cross-over had a diameter of 3.35×10^{-3} inch according to equation (I), at a cathode temperature of 800° C. and at the corrected voltage $V_1 = 90$ volts. At the 131 volt equipotential, as indicated by the field plot before correction, the size of the cross-over would be only 3.1×10^{-3} inch. The size of the beam in the common intersection of the three beams was then estimated to be about 1.25 times the traced value, that is 32×10^{-3} inch. This includes corrections for the shift of the cross-over closer to the cathode, increased size of the cross-over by space charge mutual electron repulsion (about 4.0×10^{-3} inch) and reduced divergence in the beam leaving the cross-over. The latter correction amounted to about -13%. The screen spot size was then estimated from geometrical considerations based on a sketch shown in Fig. II-62. Further, the spread in the beam after traveling at a velocity of 4 kilovolts amounted to about 5%. The diameter of the calculated screen spot was then 175×10^{-3} inches.

Experimental Results

Fig. II-63 shows a sketch of the assembled gun. For simplicity, only two cathodes are shown. The first gun was mounted in a sealed-off 17 inch

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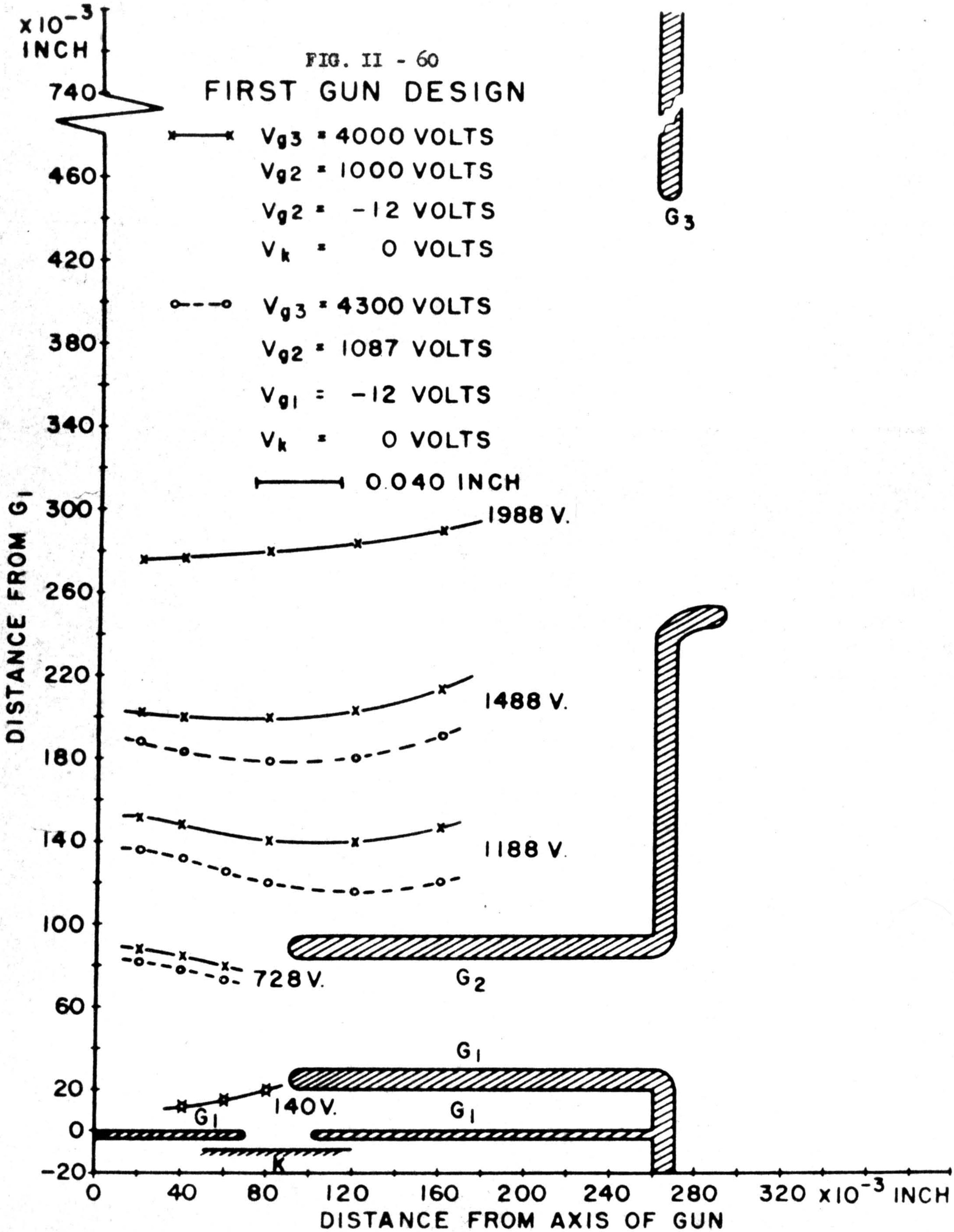
* M. Polke, "Elementare Theorie der Elektronen-Strahlerzengung mit Triodensystemen", Zs.f.ang.Phys. 4, 3, (1952).

FIG. II - 60

FIRST GUN DESIGN



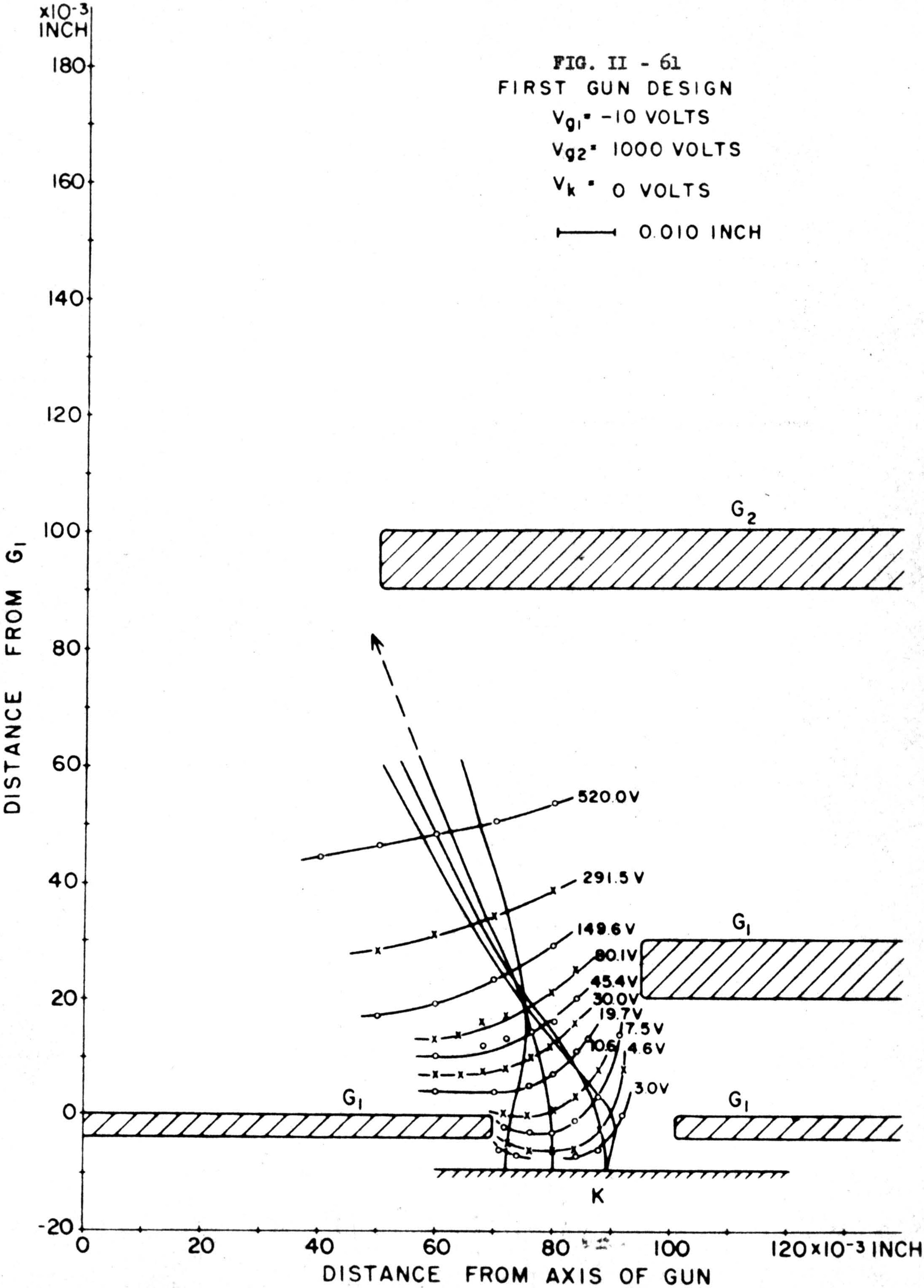


FIG. II - 61
FIRST GUN DESIGN

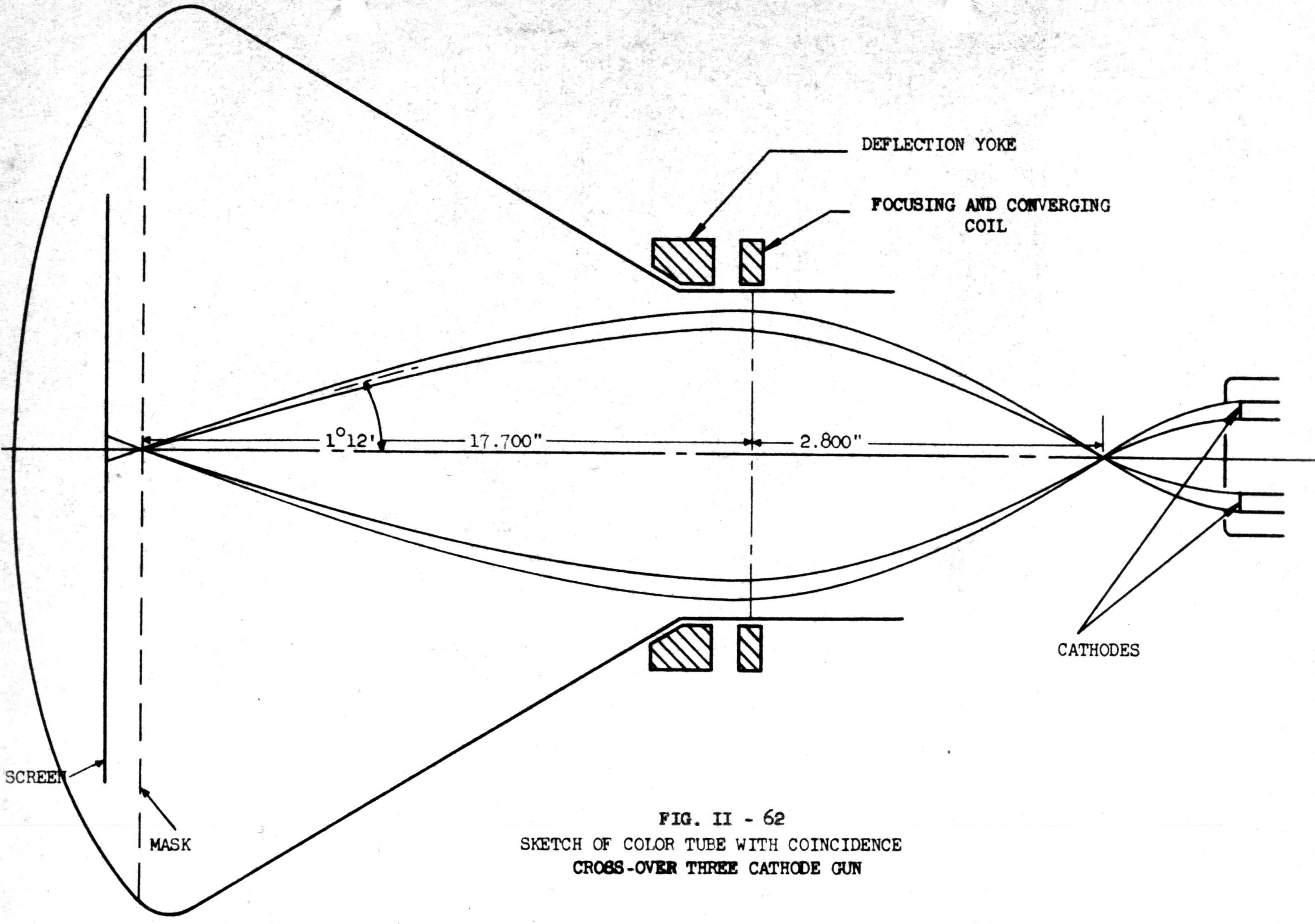


FIG. II - 62
SKETCH OF COLOR TUBE WITH COINCIDENCE
CROSS-OVER THREE CATHODE GUN

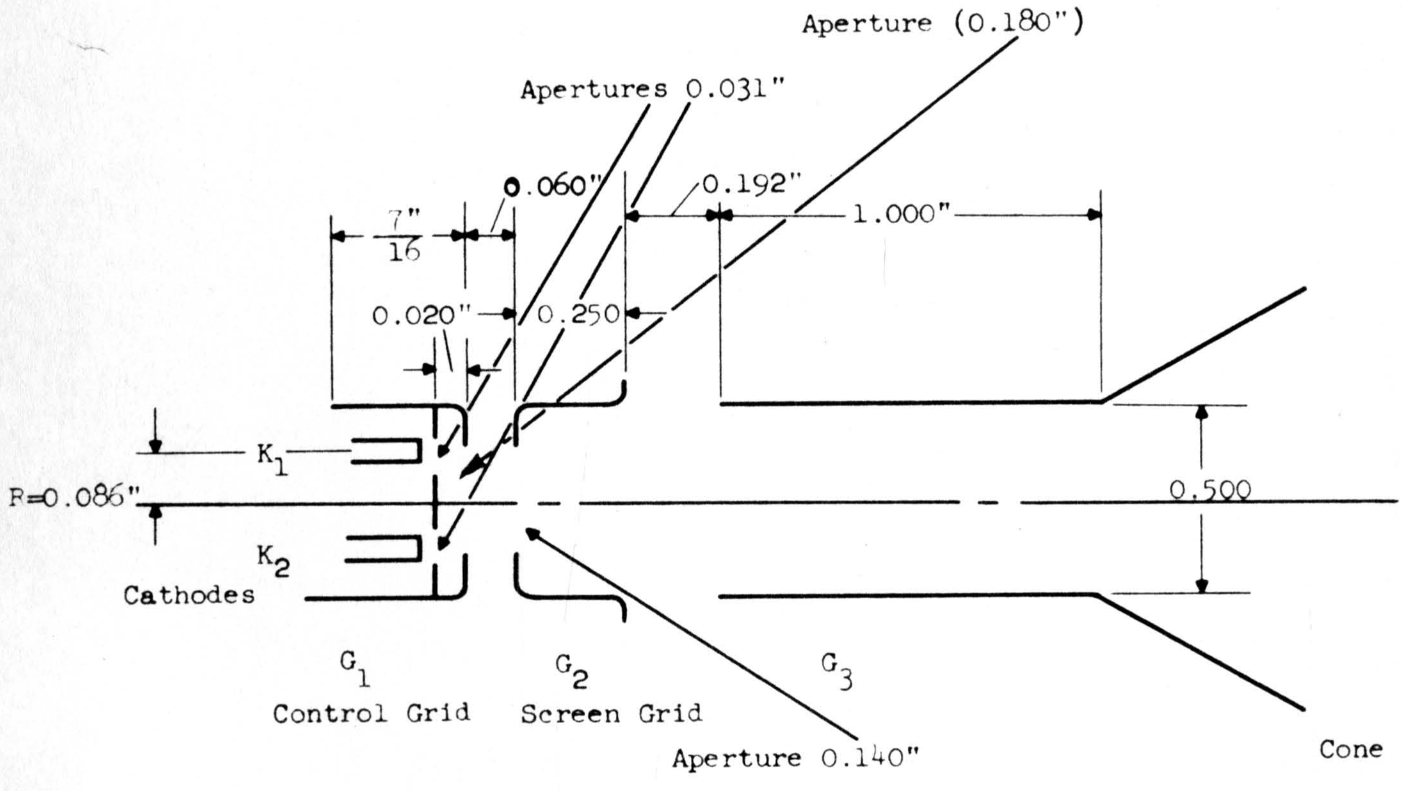


FIG. II - 63
FIRST GUN DESIGN

cathode ray tube with extended neck to simulate conditions in a color tube.

The screen voltage and, therefore, G_3 voltage was 4 kilovolts; the voltage on screen grid G_2 was varied from 300 volts to 1 kilovolt. The focusing coil had a large inside diameter of 3 inches to obtain a reasonably uniform field since the electron beams were deflected a distance of 0.300 to 0.400 inch from the axis in the center plane of the focusing coil. The coil thickness was 7/8 inch. The coil was not shielded.

To determine the activation schedule for the small cathodes which were mounted on a heavier ceramic disk than usually used, a small tube was built containing only the control grid G_1 assembly with cathodes. The cathode temperature was measured with an optical pyrometer looking through the apertures.

When best focus of the spots was obtained, the size of the undeflected spot was less than 0.040 inch close to cut-off; no limiting apertures were used. These and later experiments proved that a cross-over occurred close to control grid G_1 as indicated by the field plots. This conclusion was arrived at from the distances between screen spots, distances between apertures A in G_1 and calculated magnification of the electron optical system. The distance between the spot located on an equilateral triangle, was 0.600 to 0.800 inch. The magnification of the system was about 5. The distance between apertures B was 0.149 inch. When the three beams were converging on the screen, the spot became excessively large and distorted, or drop shaped. The dimensions were about 0.050 inch wide, 0.140 inch long.

New guns were built and tested in demountable vacuum systems. Two systems were available. One was a system with a complete mask and screen assembly of a 15 inch color tube. The other system was a specially built gun test station, resembling in design an optical bench. This gun test station is shown in Fig. II-64. The screen of the tube was 3 inches in diameter. Precision glass tubing (1.820 ± 0.001") was used for the neck which consisted, when assembled with the gun, of three parts: the neck of the tube itself, an interchangeable extension for variation of the neck length, and a short neck section sealed to the press of the gun. These parts were held together by stainless steel sleeves, one of which had a special extension for centering of the gun, and sealed together by rubber gaskets. The axial as well as the vertical positions of the focusing coil could be adjusted.

The guns tested in the demountable stations were of the same construction as the one in the sealed-off tube, except that aperture A in the control grid G_1 was interchangeable. Different aperture sizes were tested to determine the correct one for the desired convergence of the beams. A picture of a gun is shown in Fig. II-65.

The experiments showed that this gun does not give satisfactory spot size when the beams are properly converging.

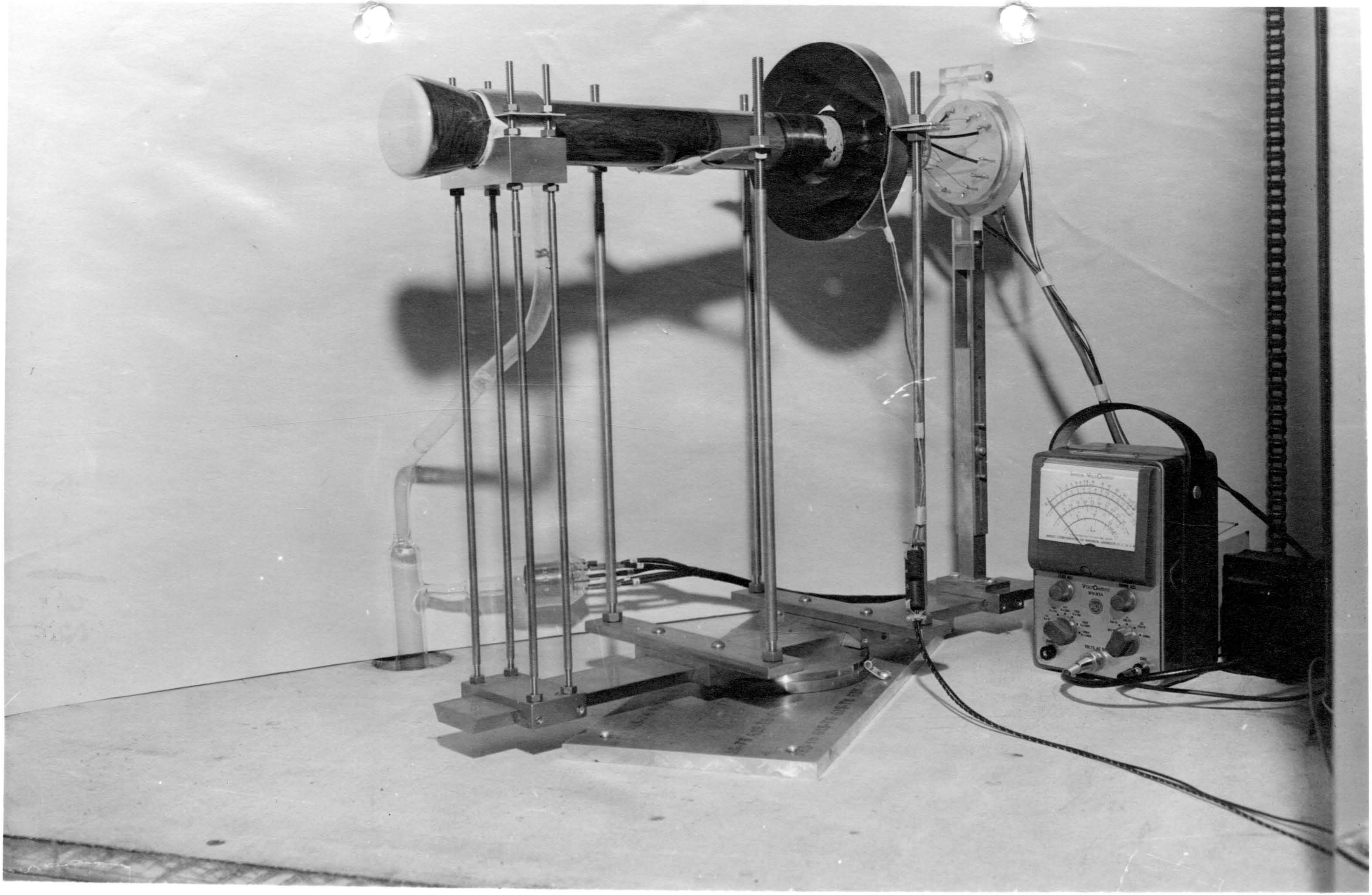


FIG. II-64
GUN TEST STATION

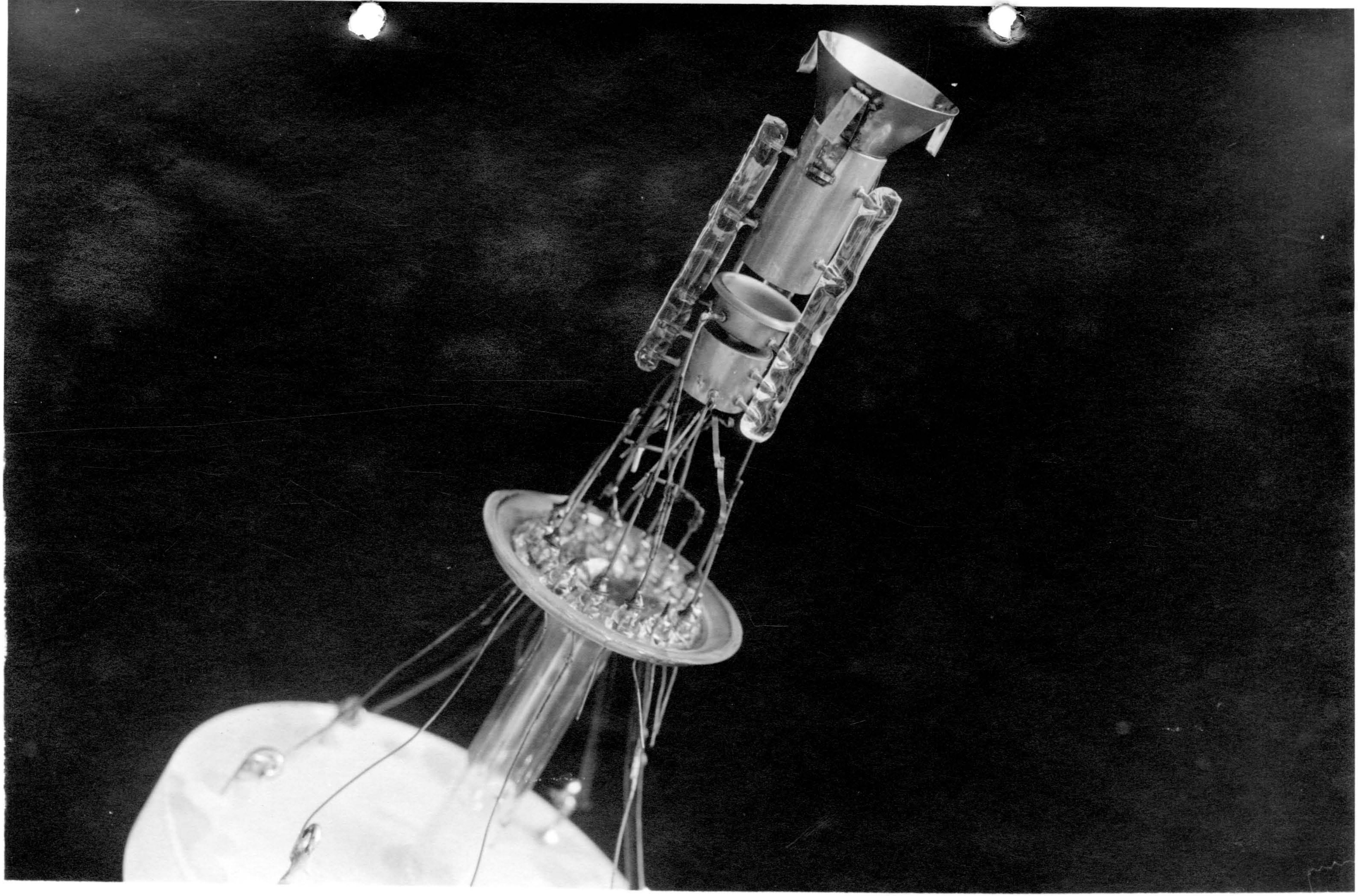


FIG. II-65
THREE CATHODE GUN

Second Gun Design

To pull out the cross-over as close as possible to the common intersection of the three beams, it was obvious that it would be very desirable to obtain in the cathode region equipotentials with little curvature and a sharp break at the edge of aperture B in G_1, which is in the direction towards the gun axis. To obtain such a shape of the equipotentials, the apertures B in G_1 were placed on a larger circle than in the first gun design. The radius was 0.1025 inch. The distance between control grid G_1 and screen grid G_2 was largely increased as compared with the first gun design. This is an undesirable feature because the electron velocities are still low in this region, and a shielding of the gun from outside fields might be required. Field plots and electron trajectories are shown in Fig. II-66 for two bias voltages: 0%, i.e., 0 volt, and 2%, i.e., about -20 volts. The cross-over in this design is far away from the cathode. However, because of the increased radial distance of the apertures B from the gun axis as compared to the first design and the smaller angle of the beams with the axis, the cross-section of the beam in the common intersection of the three beams is about the same as in the first gun. Furthermore, because of the large distance between the cathodes and the common intersection of the three beams, this intersection changes appreciably its position with drive voltage. The transconductance is smaller than in the first design.

A field plot of a larger section of the gun is shown in Fig. II-67, where G_2 is a two-aperture electrode. This shape was arrived at by minimizing bending of electron trajectories away from the gun axis before crossing it.

Other electrode configurations were plotted in an attempt to obtain similarly shaped equipotentials in the neighborhood of the cathodes without placing them (and apertures B in G_1) on an increased radius. No satisfactory solution was found.

Experimental Results

Fig. II-68 shows a sketch of the assembled gun. The gun was tested in the demountable gun station. The screen voltage and G_3 voltage was 4 kilovolts; the voltage on the screen grid G_2 was 1-1.5 kilovolts.

The size of the focused spot was less than 0.040 inch at a screen current of about 10 microamperes. The distance between the focused spots was about 0.630 inch. This indicated that the cross-overs were moved farther away from the cathodes than in the first design, but in spite of that the distance of the cross-overs from the axis is about the same as in the first design. The position of the screen spots did not change during modulation, contradictory to expectations based on field plots. When the beams were converging, the spots became drop shaped with a width of about 0.060 inch and 0.120 to 0.140 inch long.

This design did not show any improvement above the first gun design.

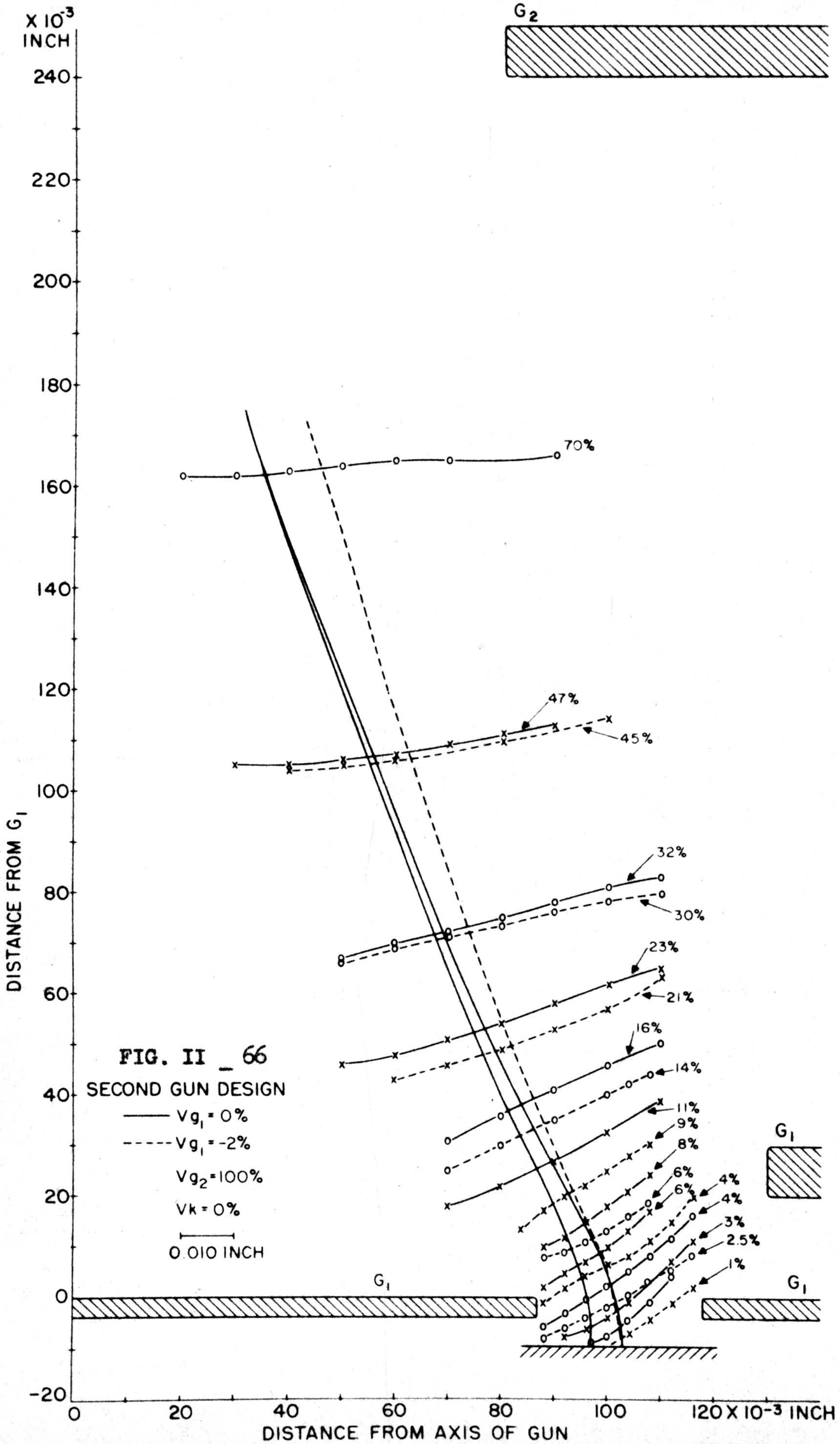


FIG. II _ 66

SECOND GUN DESIGN

—— $Vg_1 = 0\%$

- - - - $Vg_1 = -2\%$

$Vg_2 = 100\%$

$Vk = 0\%$

0.010 INCH

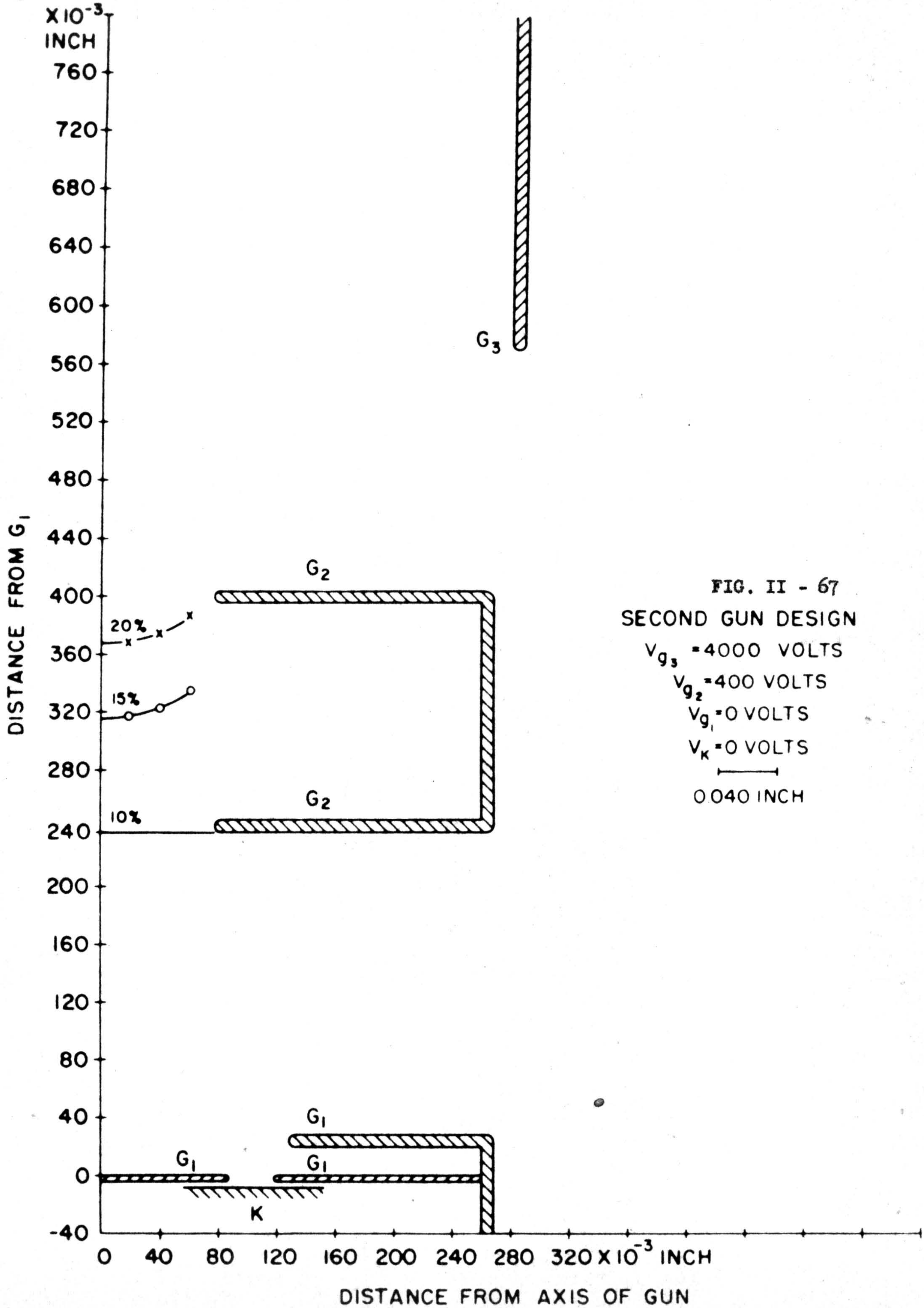


FIG. II - 67

SECOND GUN DESIGN

V_{g_3} = 4000 VOLTS

V_{g_2} = 400 VOLTS

V_{g_1} = 0 VOLTS

V_K = 0 VOLTS

0.040 INCH

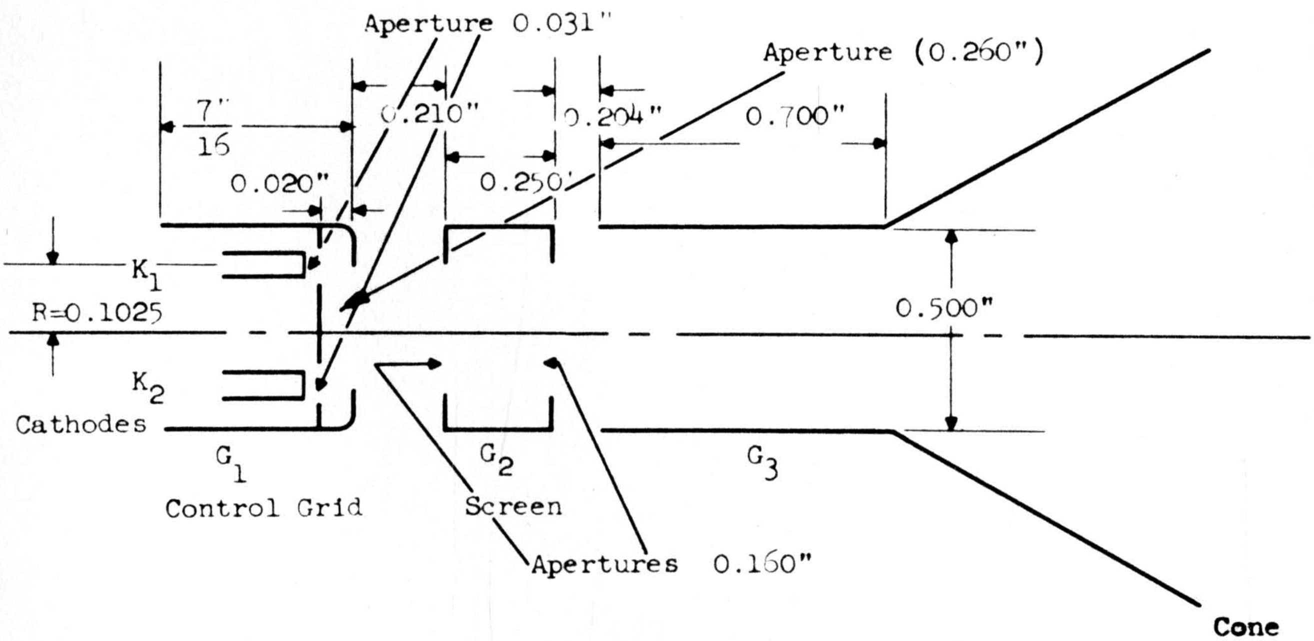


FIG. II - 68

SECOND GUN DESIGN

Guns with Wire Mesh Control Grid

Wire meshes were tried in a control grid to obtain a less converging field in the cathode region. The average field in the vicinity of the cathode produced by the control electrode becomes uniform, thus more parallelism of electron paths is obtained and the desired cross-over can be moved far away from the cathode. In general, it is difficult to obtain a good spot when wire meshes are used, because of distorted fields in the neighborhood of the wires. This can be well understood if one imagines that each spacing between wires acts the same way as a single aperture in a control grid. Then an array of "cross-overs" is formed in front of the wire mesh grid (Fig. II-69), and the electron paths in the beams emerging from the individual "cross-overs" become divergent. In the considered case, with a main cross-over of the beam desired at a voltage of the order of one thousand volts, the conditions for a reasonable spot seemed more favorable than in conventional guns. The convergence of the beam necessary for formation of the main cross-over is obtained by the action of the lens G_1-G_2; a distorted cross-over is to be expected.

Experiments and Results

Guns of this type were constructed with interchangeable wire meshes and interchangeable apertures A in G_1. The guns were of the first design described earlier. Stainless steel and nickel wire meshes were used because of their ready availability. Stainless steel grids 250 x 250 mesh per inch with 75% transparency, and nickel grids 500 x 500 mesh per inch with 70% transparency were tested.

The convergence obtained by deformation of the field produced by aperture disk A in G_1 was not sufficient. Part of the beams were striking this aperture disk. In this design, 0.160 and 0.190 inch apertures were tried. It could be shown that electrons were striking the aperture disk by using a small magnet for deflection of the beam in G_1 region, and the same was indicated by marks on the aperture disk. The spot size with the 250 x 250 mesh was about 0.120 inch at screen currents of about 10 microamperes.

Similar tests were carried out with 500 x 500 mesh grids. When finer mesh is used, the field between the mesh and the cathode should produce better parallelism in the electron paths. On the other hand, the field around the finer grid wires becomes more distorted, and the trajectories are therefore probably only little improved.

The spots showed no noticeable improvement above the spots observed in a gun with 250 x 250 mesh. To achieve more parallelism of the electron paths after emerging from the wire mesh, it would be necessary to have very much higher fields above the wires to straighten out the electron trajectories. This solution did not seem practical.

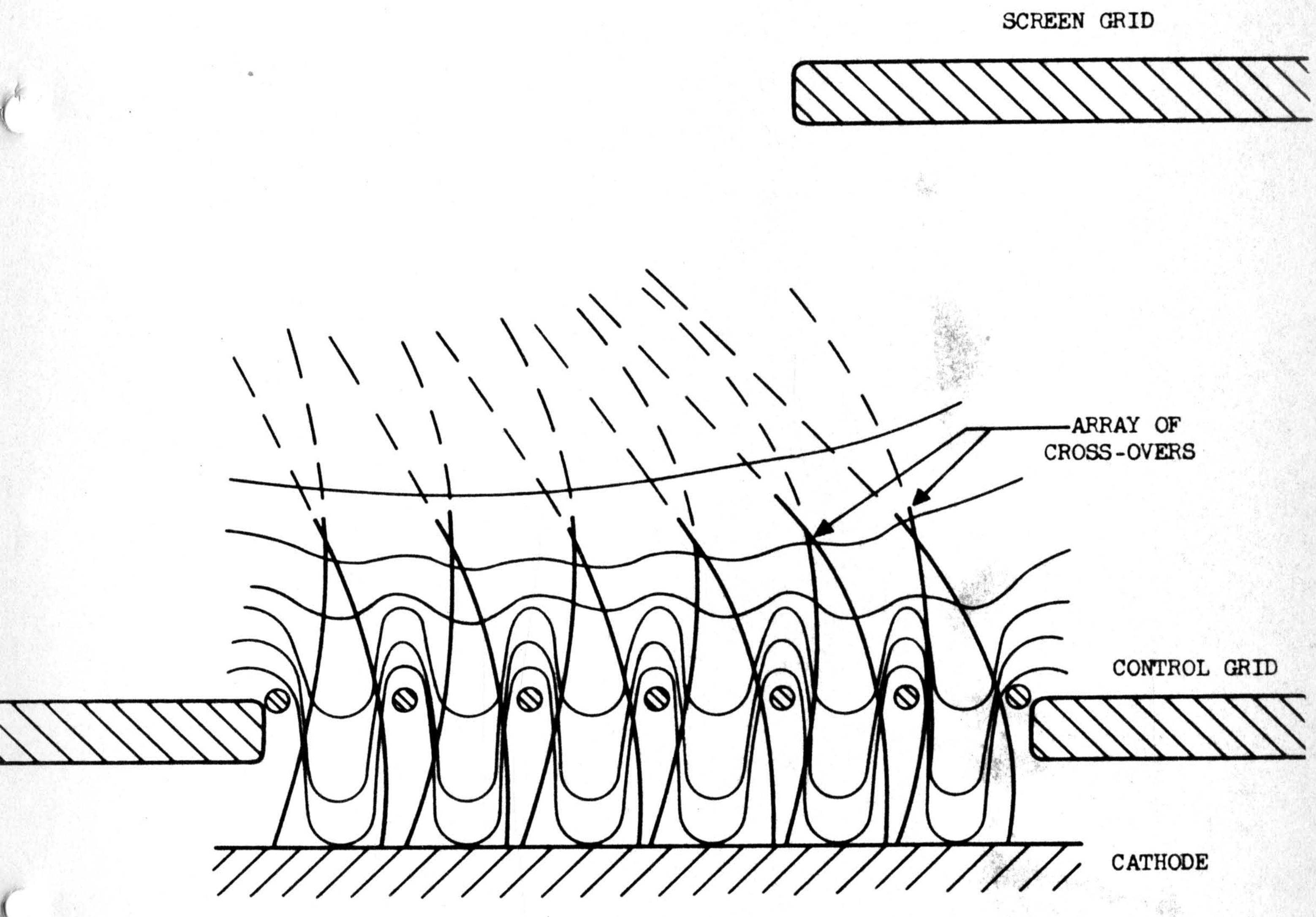


FIG. II - 69

EQUIPOTENTIALS AND ELECTRON TRAJECTORIES
IN GUN WITH WIRE MESH CONTROL GRID

Guns with Specially Shaped Cathodes

Another approach was started in order to obtain cross-overs at a distance farther away from the cathode (and the control grid). Instead of plane cathode surfaces, the cathodes were curved. By this means, the field in the neighborhood of the cathode can be modified in such a way as to move the cross-over in the desired direction. A sketch of equipotentials and electron paths for a gun with a plane electrode and a cathode, a section of which is spherically shaped, is shown in Fig. II-70(a) and II-70(b) respectively. Other conditions in the guns sketched are the same in both cases. In the case of the spherical cathode, it can be seen that the outer electron paths are first divergent, later become convergent and intersect in the cross-over. The changed position of the cross-overs may easily be seen by comparison of Fig. II-70(a) and II-70(b). By choice of different radii of curvature for the cathodes, the position of the cross-over can be changed*.

Fig. II-71 shows the field map for a cathode with a radius of curvature of 0.0315 inch. In this field map, the first gun design was maintained. A sketch of a 0.020 inch radius cathode is shown in Fig. II-72. The apertures B in G_1 had a diameter of 0.031 inch for the 0.0315 inch and 0.020 inch radius cathodes, and a 0.023 inch diameter aperture for the 0.015 inch radius cathodes. It is desirable to use as large a radius of curvature as possible on the cathode, because the alignment of apertures B with the crest of the cathodes becomes more critical when smaller radii of curvature are considered. It is estimated that the permissible tolerance in alignment is ± 0.002 inch. A compromise between radius of curvature and shifting of cross-over is therefore desired. The cross-over does not necessarily need to be shifted as far as the common intersection of the three beams if a small enough cross-section of the beam can be obtained in the common intersection.

A ceramic disk (lava) and cathode assembly is shown in Fig. II-73, and a picture of the assembly in Fig. II-74. The angular location of the cathode with respect to the apertures B in the first cup of the control grid was secured, as in earlier design, by lancings of this cup and by corresponding slots in the ceramic disks. The slots were cut into the lava disks before firing, and after firing a final grinding guaranteed very close positioning of the slots. Similarly, it was necessary to have the holes in the ceramic for correct location of the cathodes ground on a jig grinder after firing. The parallel surfaces of the ceramic disk also were ground. These operations were necessary because of non-uniform shrinkage of the lava during firing. Molybdenum cathode sleeves were used in this design because excessive evaporation of the nickel sleeves occurred in earlier constructions where heavy lava disks were used. To secure correct location, length (distance from G_1) and shape of the crest of the cathodes after welding to the molybdenum sleeves, the cathodes were reshaped in a special forming die after they were mounted in the assembly as shown in Fig. II-20 and Fig. II-21.

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* Patent Docket No. 94,533, of January 13, 1953, by P. H. Gleichauf and C. G. Lob.

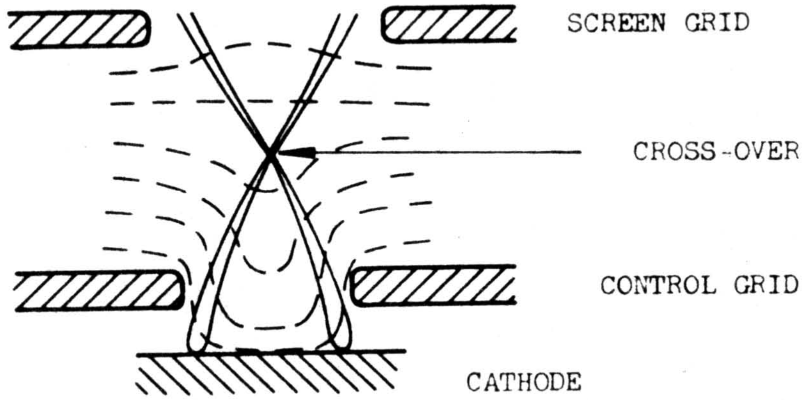

FIG. II - 70 (a)

CROSS-OVER IN GUN WITH
PLANE CATHODE

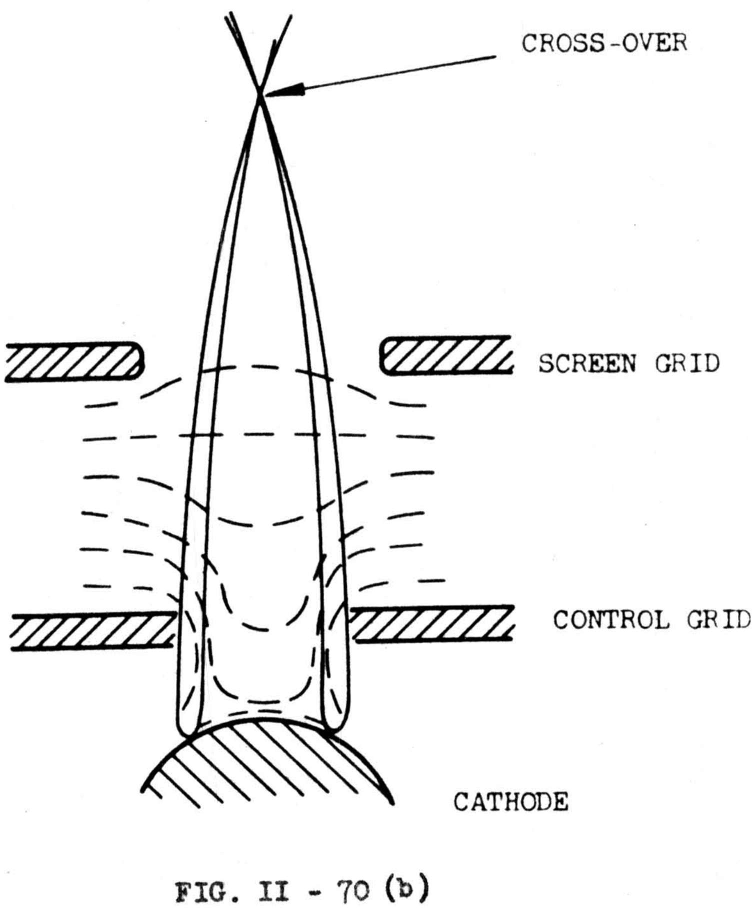

FIG. II - 70 (b)

CROSS-OVER IN GUN WITH
SPHERICALLY SHAPED CATHODE

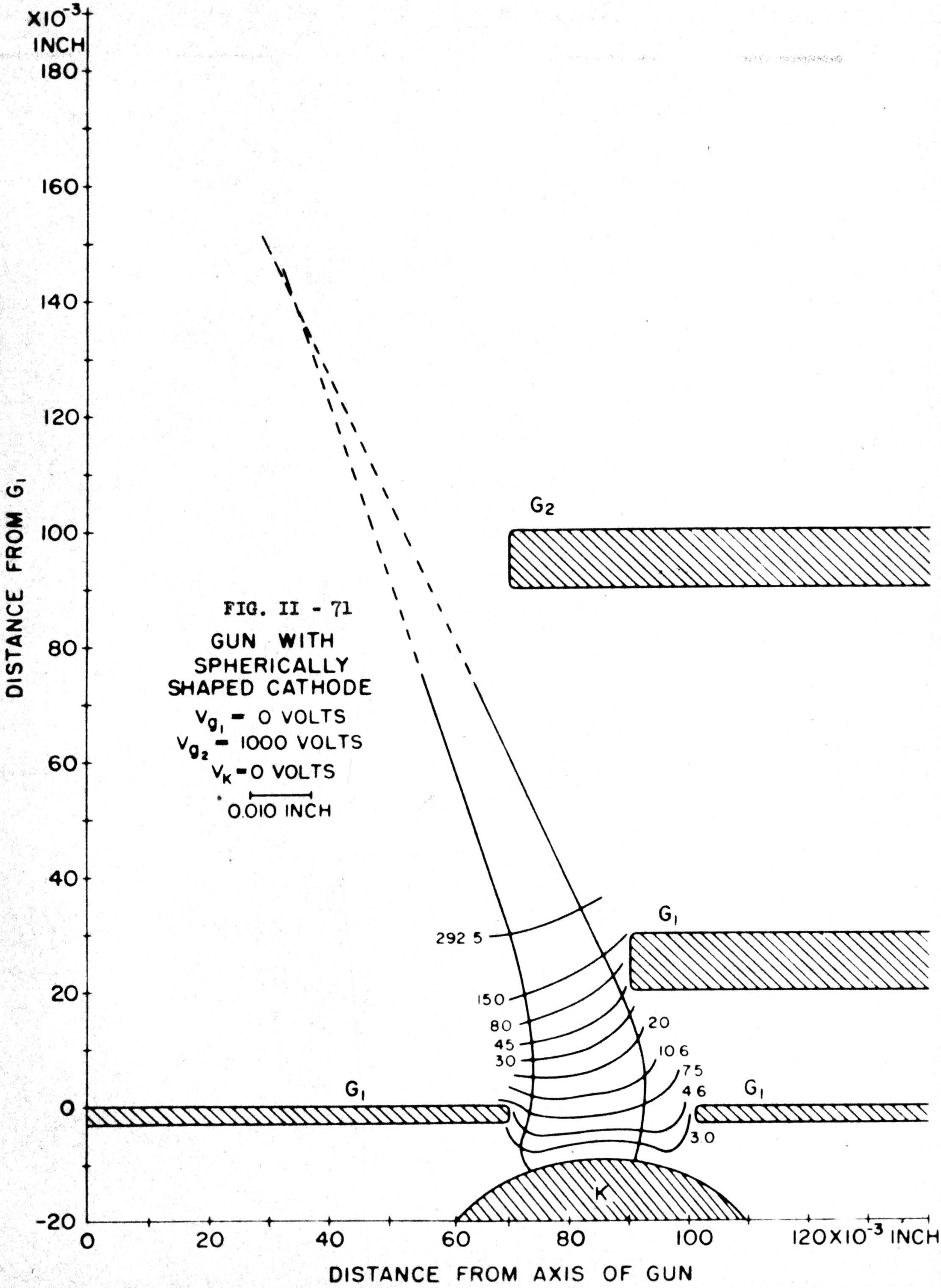

FIG. II - 71

GUN WITH SPHERICALLY SHAPED CATHODE

V_{g_1} = 0 VOLTS

V_{g_2} = 1000 VOLTS

V_K = 0 VOLTS

0.010 INCH

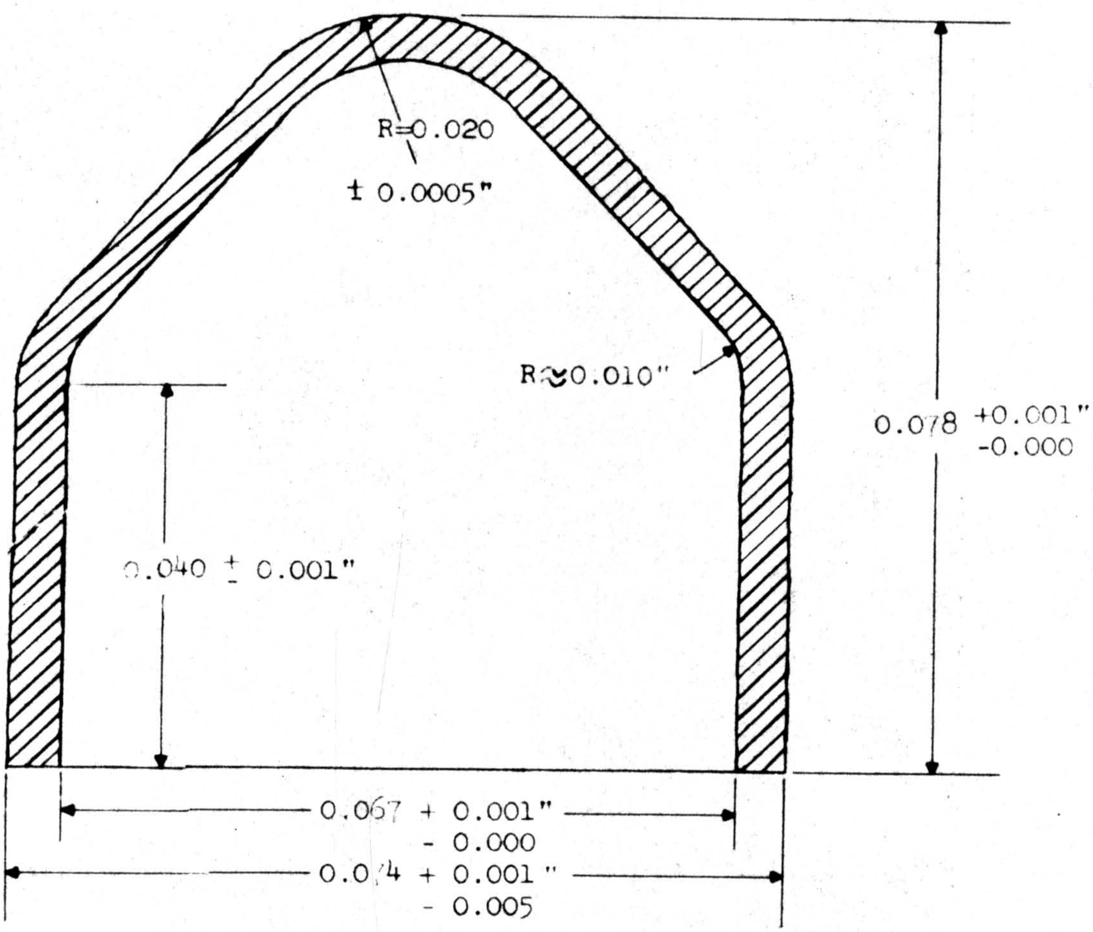

FIG. II - 72

SPHERICALLY SHAPED
CATHODE

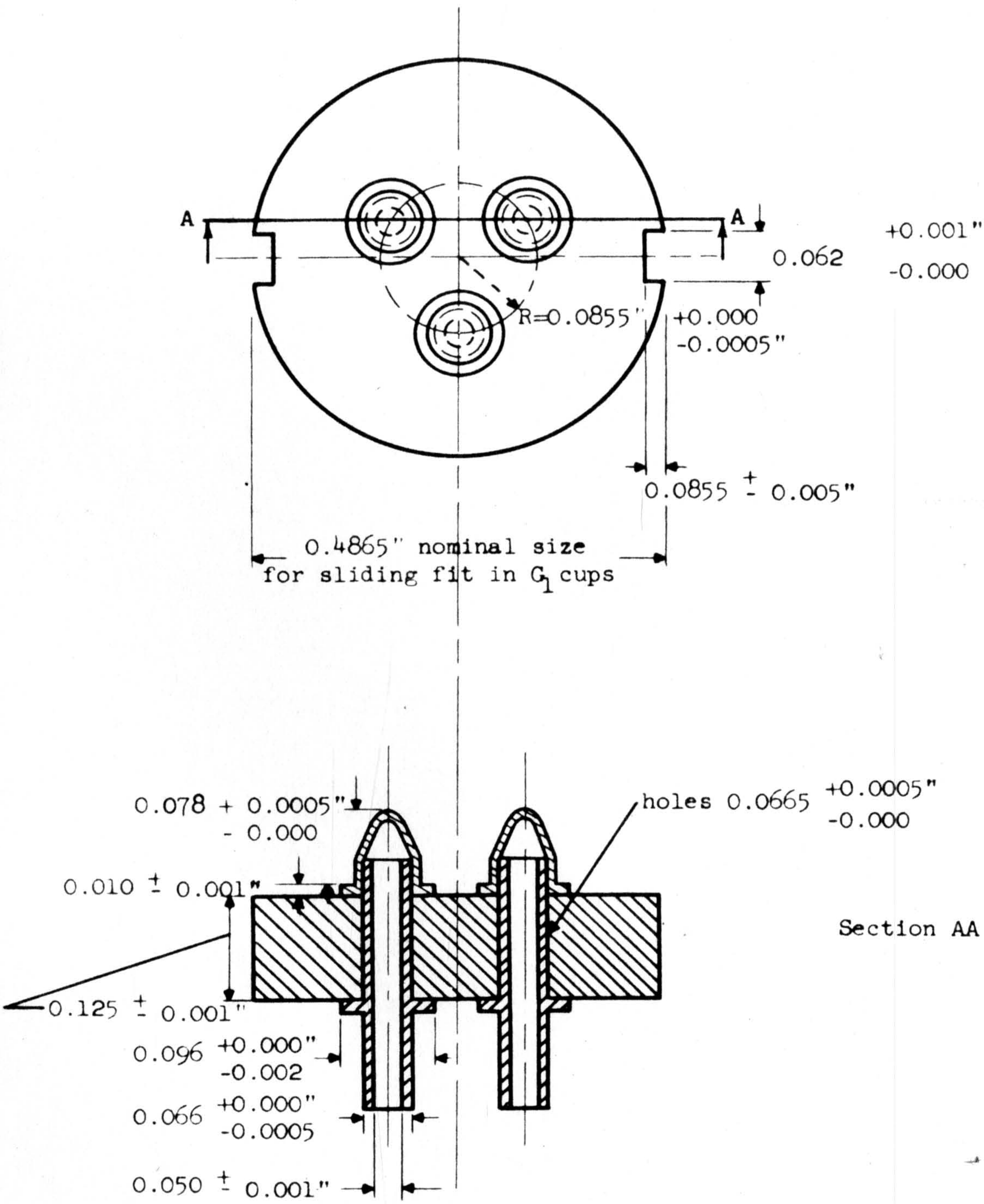

FIG. II - 73

CATHODE ASSEMBLY WITH SPHERICALLY
SHAPED CATHODES

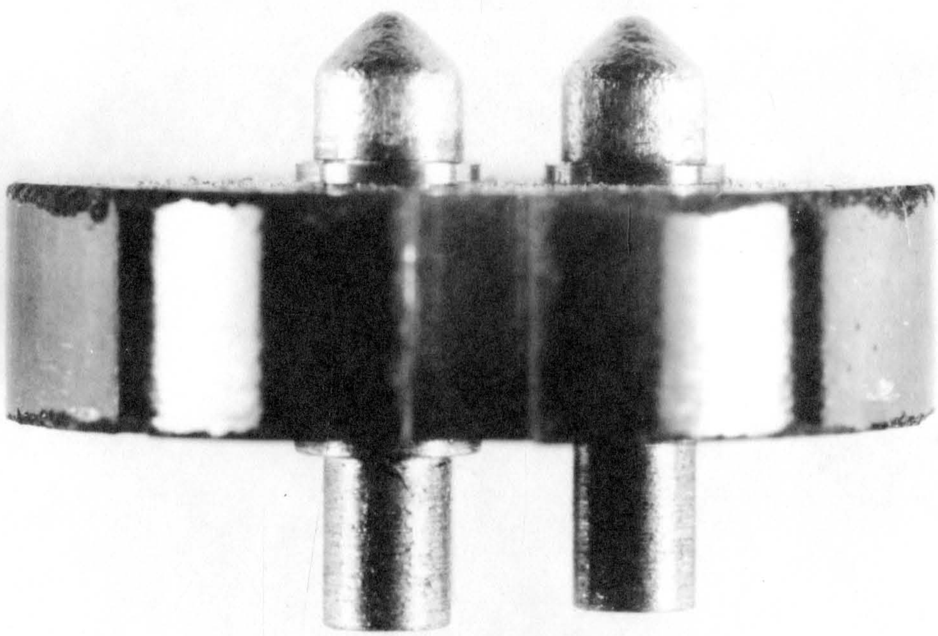

FIG. II-74
CATHODE ASSEMBLY

Experimental Results

The distance between the focused spots was decreased as expected, below 0.250 inch. But even with the precautions taken during assembly, as mentioned above, the alignment of apertures B in G_1 with the cathodes becomes difficult. The sizes of the spots when converging was still too large. A further reduction of the radius of curvature of the cathodes would have been necessary. This approach did not seem practical because even higher accuracy in assembly would be required, and the transconductance would fall far below acceptable values. The transconductance in tested guns was reduced to about one-third to one-fourth of a conventional gun. For the above reasons, work was not continued on this basic idea.

Conclusion

No satisfactory solution was found for the coincidence cross-over three-cathode gun. In all guns tested the spot size became too large when convergence of the three beams was obtained, since the cross-overs of the individual beams were not brought as far as the common intersection of the three beams. Nevertheless, it seems feasible to build a gun of this type but the expense involved in maintaining extremely close tolerances and a poor prospect for obtaining an acceptable transconductance do not justify further work.

(B) Modified Tri-Color Guns for Post Acceleration

Guns were constructed for the post-acceleration color tube and demonstrated in a demountable post-acceleration color tube. A modification of the tri-color gun used in the shadow mask tube was necessary, since the voltage at the second electrode of the convergence lens, which is at the same potential as the cone, is in the latter case reduced to about only one-fourth of the screen voltage. In the shadow mask type tube, the second electrode of the convergence lens is at screen potential.

First, a brief description of the shadow-mask type tri-color gun will be given. Three individual guns are mounted parallel to each other so that their axes are on an equilateral triangle. The axis (center) to axis (center) distances, i.e., the sides of the triangles, are 0.719". Each individual gun consists of a control grid, screen grid, focusing grid, and a final electrode by which the guns are mounted in the common convergence cup. In the convergence lens, the three electron beams are deflected at an angle of 1°12' to a common point on the mask.

Design Considerations for Modified Gun

With the reduced cone voltage, all gun voltages would have to be reduced proportionally to obtain proper convergence. The resulting voltages are too low for focusing of the beams on the mask. To obtain proper focusing and correct convergence, two alternative modifications in gun design were considered.

(1) Use smaller diameter tubing for the individual guns to obtain focus at lower voltages.

(2) Keep convergence cup at about 9 KV as in the shadow-mask type tri-color gun, in spite of the low voltage on the second electrode of the convergence lens (cone potential) and modify gun so as to obtain desired convergence.*

In the case of the first suggested modification, less than half size tubing would have to be used. This is undesirable; because of increased aberrations, it would become necessary to use small apertures which would reduce the beam current. Furthermore, it would be necessary to use thin-wall cups for the control grid to secure sufficient penetration of the field from the screen grid into the cathode region.

The second alternative was chosen for the modified gun. By applying a lower voltage to the second electrode of the convergence lens, this lens remains convergent, but the principal planes are shifted to the other side of the plane of symmetry of the lens, in the direction of the screen. In Fig. II-75 (a) and II-75(b) are shown the geometrical optical behaviours of the two lenses, and the electron paths are indicated.

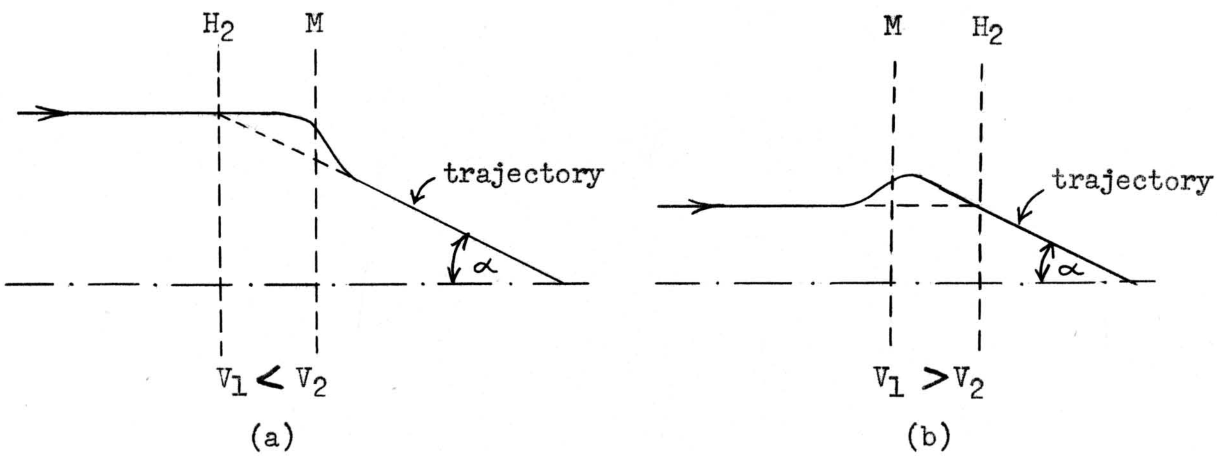

Fig. II-75

Geometrical optics and electron trajectories in electrostatic lens with increasing potential (a), and decreasing potential (b). H_2 second principal plane, M reference plane, V_1 potential on first electrode, V_2 potential on second electrode.

Fig. II-75(a) shows the optics of an electrostatic lens with increasing potential in the direction of the electron paths. Fig. II-75(b) shows the optics when decreasing potentials are applied to the electrodes. From Fig. II-75(b) it is seen that it is necessary to bring the parallel beams closer to the axis in case (b) than in case (a) to obtain the same angle of convergence.

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* Patent Docket No. 4D-181 of October 30, 1953, by P. H. Gleichauf and H. J. Evans.

It therefore becomes necessary to bring the individual guns closer together for the modified gun construction. The center (axis) to center (axis) distance of the guns was calculated using curves from K. R. Spanenberg's book on "Vacuum Tubes", McGraw-Hill, 1948. The construction of the shadow-mask type tri-color gun was checked against curves in Fig. 13.27 and 13.28 in this book. Since neither of these curves represents precisely the considered case in which the ratio of lens diameters is 1.26 instead of 1.5 as in Fig. 13.28, a correction was made for calculation of the modified gun. For the calculations, curves 13.26 and 13.27 were used. When using these curves, it must be kept in mind that the beam enters into the lens from the opposite side, i.e., from cylinder 2 to cylinder 1. The distance of the second principal plane H_2 from the reference plane in this figure then is equal to $f_1 - F_1$. The distance between the reference plane of the convergence lens and the mask is 16.394", and the angle of convergence is 1°12'. The distance (a) of the individual guns was calculated from the triangle shown in Fig. II-76. The center-to-center distance ($a \times \sqrt{3}$) so determined was 0.465"

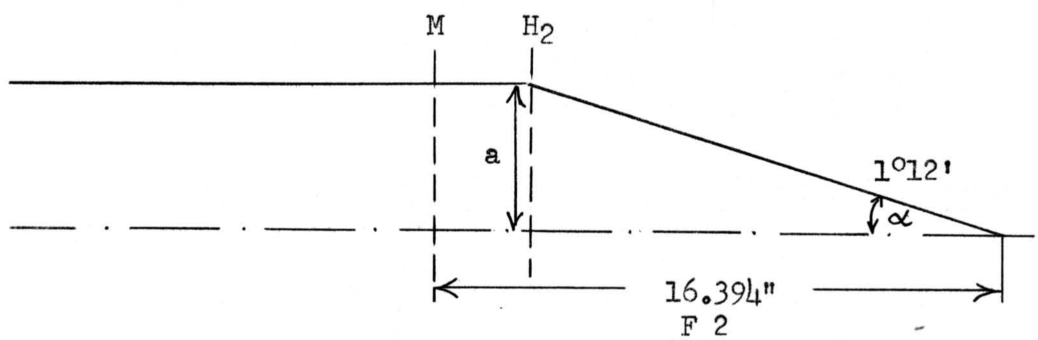

Fig. II-76

Geometrical optics in modified tri-color gun
H_2 second principal plane, M reference plane

Since the convergence lens is used for non-paraxial beams, aberrations occur, which are slightly less for the modified design than for the shadow-mask type gun. The reason for this is that, although both lenses shown in Fig. II-75(a) and (b) are convergent, the second half of the lens, in the direction of the beam, is in (a) divergent, in (b) convergent. The electron trajectories have in case (a) a negative curvature, whereas in case (b) the curvature is positive. The emerging beams which are tangential to these curves have the same final slope. Therefore, curve (b) always remains in the lens below curve (a), closer to the axis of the lens, i.e., in a region with less aberrations.

Smaller diameter tubing is used in the modified gun than in the shadow-mask type tri-color gun, making the lenses stronger. One would expect, therefore, that the long focusing electrode No. 3 could be shortened appreciably. This cannot be done because the convergence lens is weakened by the reversal of potentials, and consequently, the focusing lens also becomes weaker. Measurements made during design support this assumption.

Construction of Gun

With a center-to-center distance of only 0.465 inch, it is desirable to bring the three guns in mechanical contact to be able to use maximum diameter tubing for the electrodes. Large tubing is desirable to reduce aberrations. To reduce local gradients, the focusing grids No. 3 are equipped with a rounded flange on its end turned toward electrodes No. 4. Also electrodes No. 4 are equipped with a similar rounded flange in spite of being on a positive potential with respect to electrodes No. 3. This is done to reduce distortion in the focusing lens, which could be produced by the other two adjacent guns. The three guns are in mechanical contact, and therefore, in electrical contact by means of the above described flanges. This can be done since all three electrodes No. 3 (as well as No. 4) are being held on the same potential. It had to be considered that the close spacing of the control grids No. 1 could result in cross modulation. The capacitance was calculated to be less than 0.3 micromicrofarads which is small compared with the distributed capacitances in the circuit.

The gun parts are shown in Figures II-77 to II-85. All parts were specially machined because of unconventional dimension. The parts were electropolished.

Fig. II-77 shows the control grid No. 1 with a 0.036" aperture. It is recommended to reduce the aperture size to 0.031" for better spot size.

Fig. II-78 shows the screen grid No. 2 with a 0.036" aperture. Also here a reduction of the aperture to 0.031" is recommended.

Fig. II-79 shows the focusing grid No. 3.

Fig. II-80 shows electrodes No. 4 which are welded to the convergence cup using a flange machined on the electrode No. 4. This construction was more convenient for experimental guns than a separate flange as would be used in production. The length of this electrode can be shortened by about 0.070".

Fig. II-81 shows the convergence cup.

Fig. II-82 shows a triangular spacer keeping the three guns in alignment. The kind of support used in the conventional tri-color gun is not suited for the close spacing of the three guns.

Fig. II-83 shows aperture disk for grid No. 3; Fig. II-84 cathode mounting disk.

Fig. II-85 shows one gun assembled and mounted in the convergence cup.

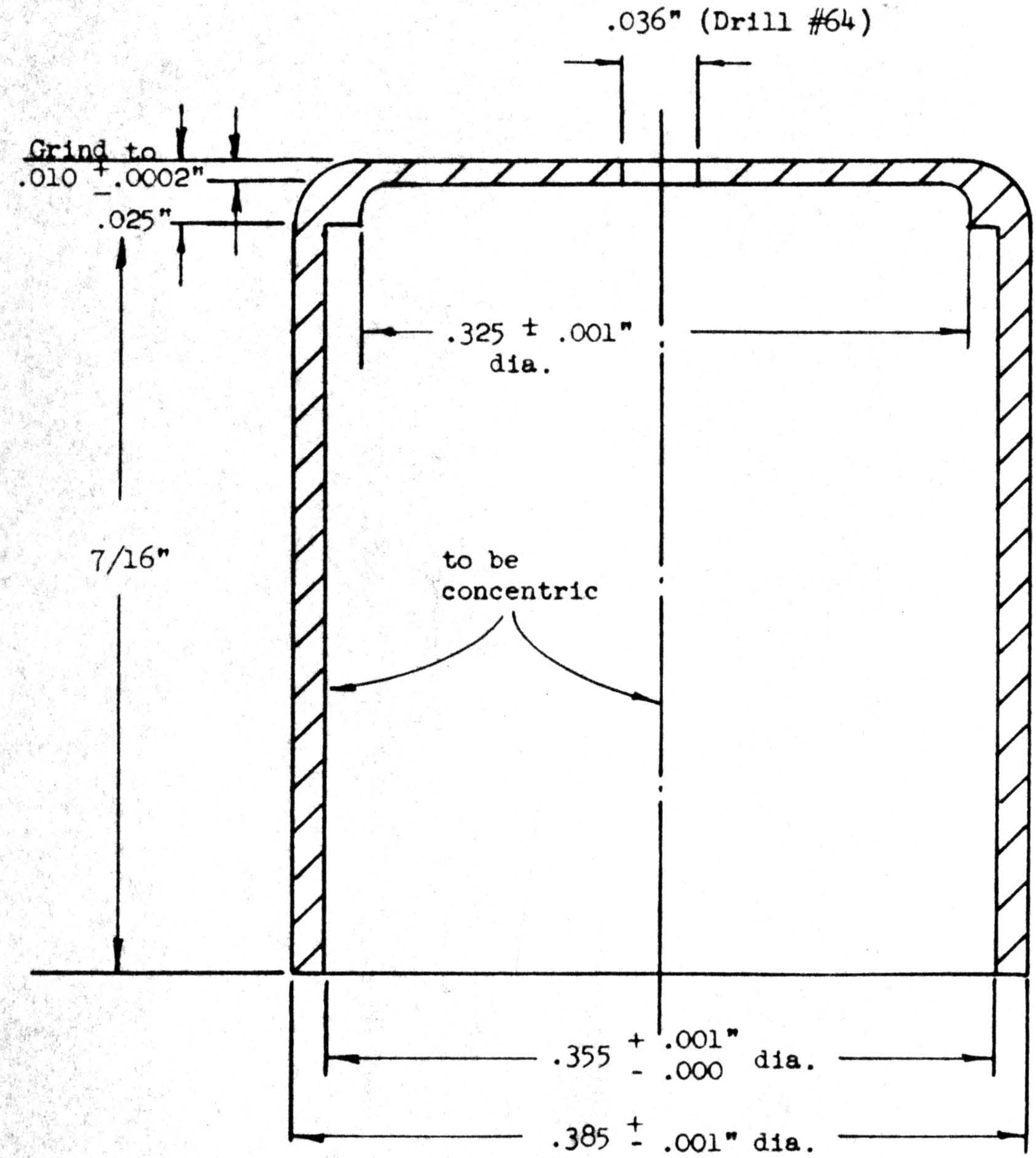

FIG. II - 77

Control grid No. 1

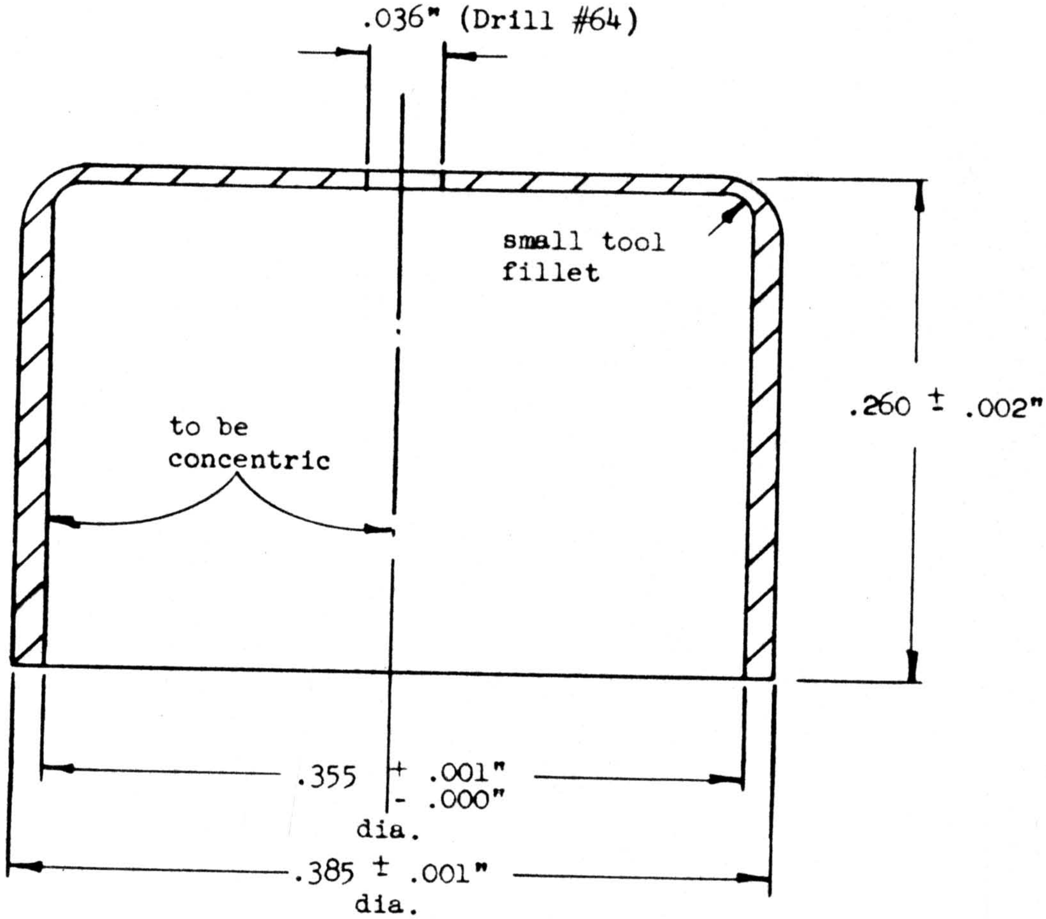

FIG. II - 78

Screen grid No. 2

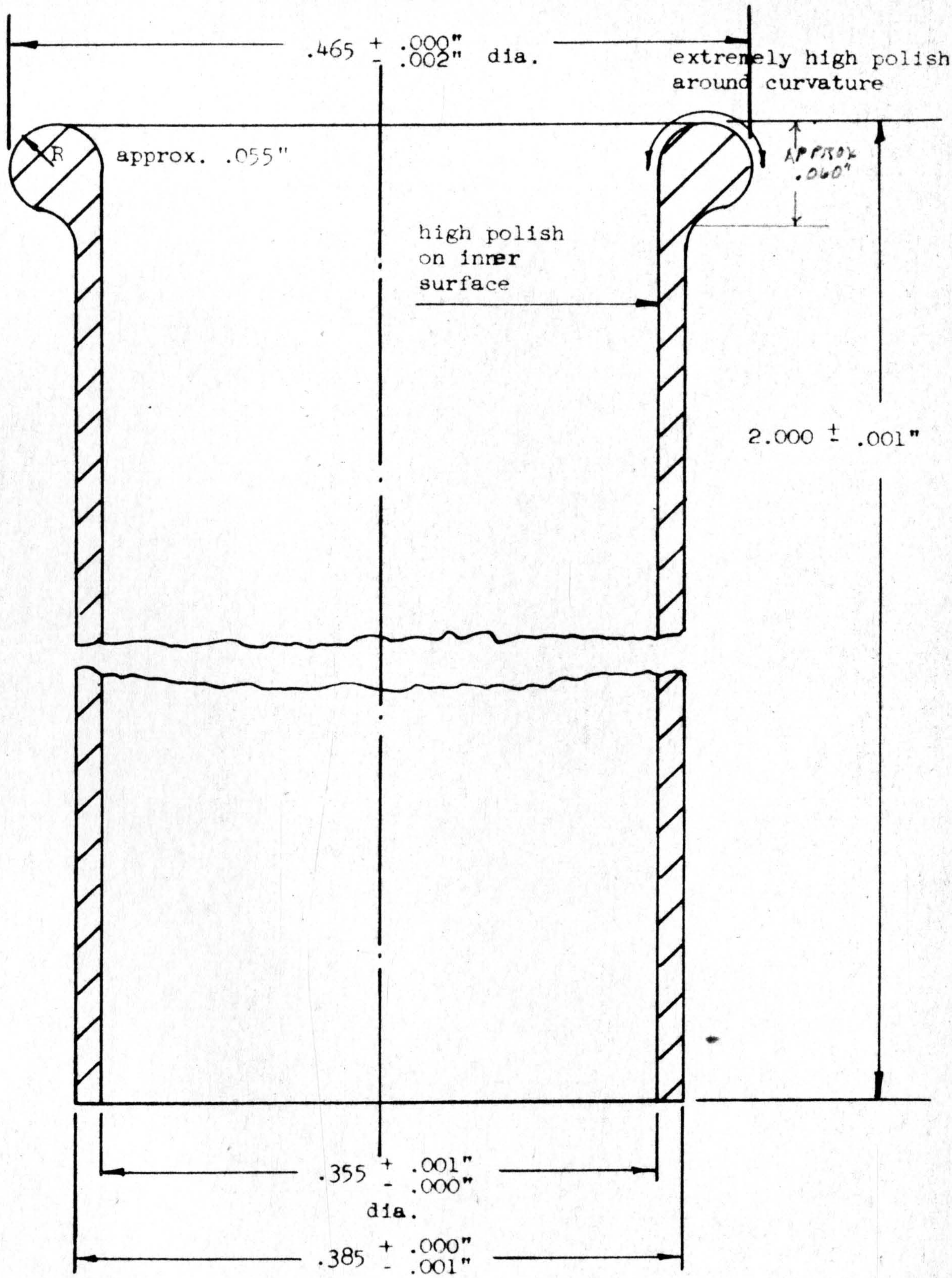

FIG. II - 79

Focusing Grid No. 3

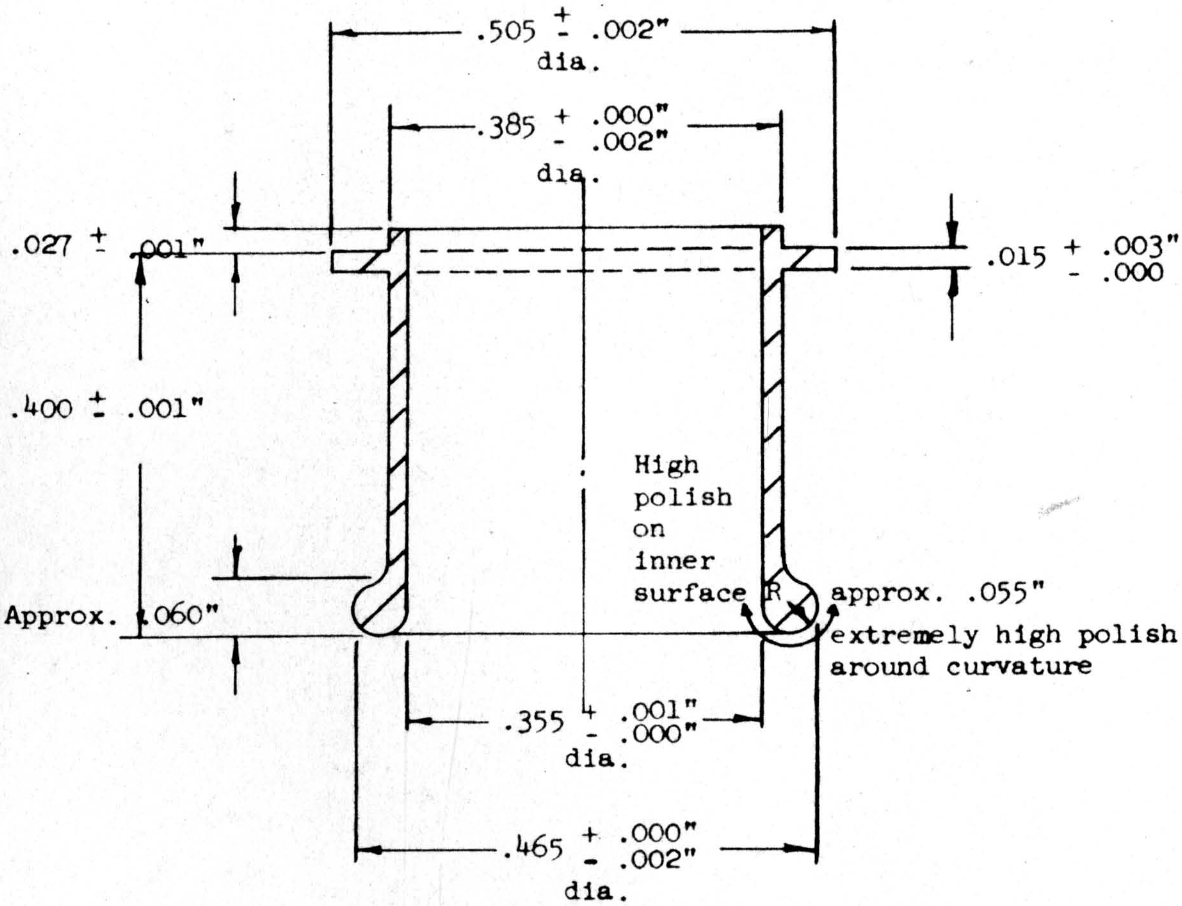

FIG. II - 80

Grid No. 4

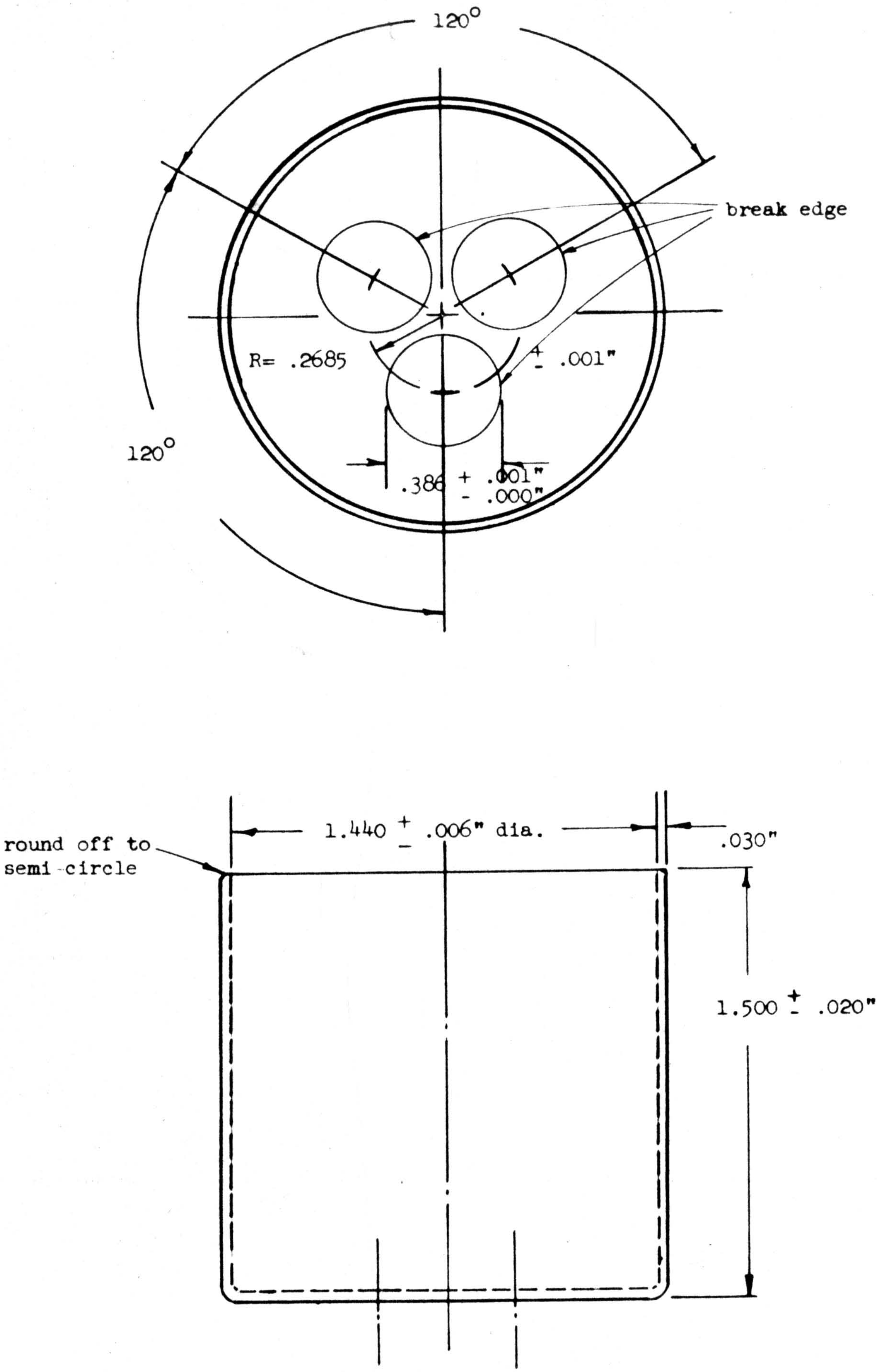

FIG. II - 81

Convergence Cup

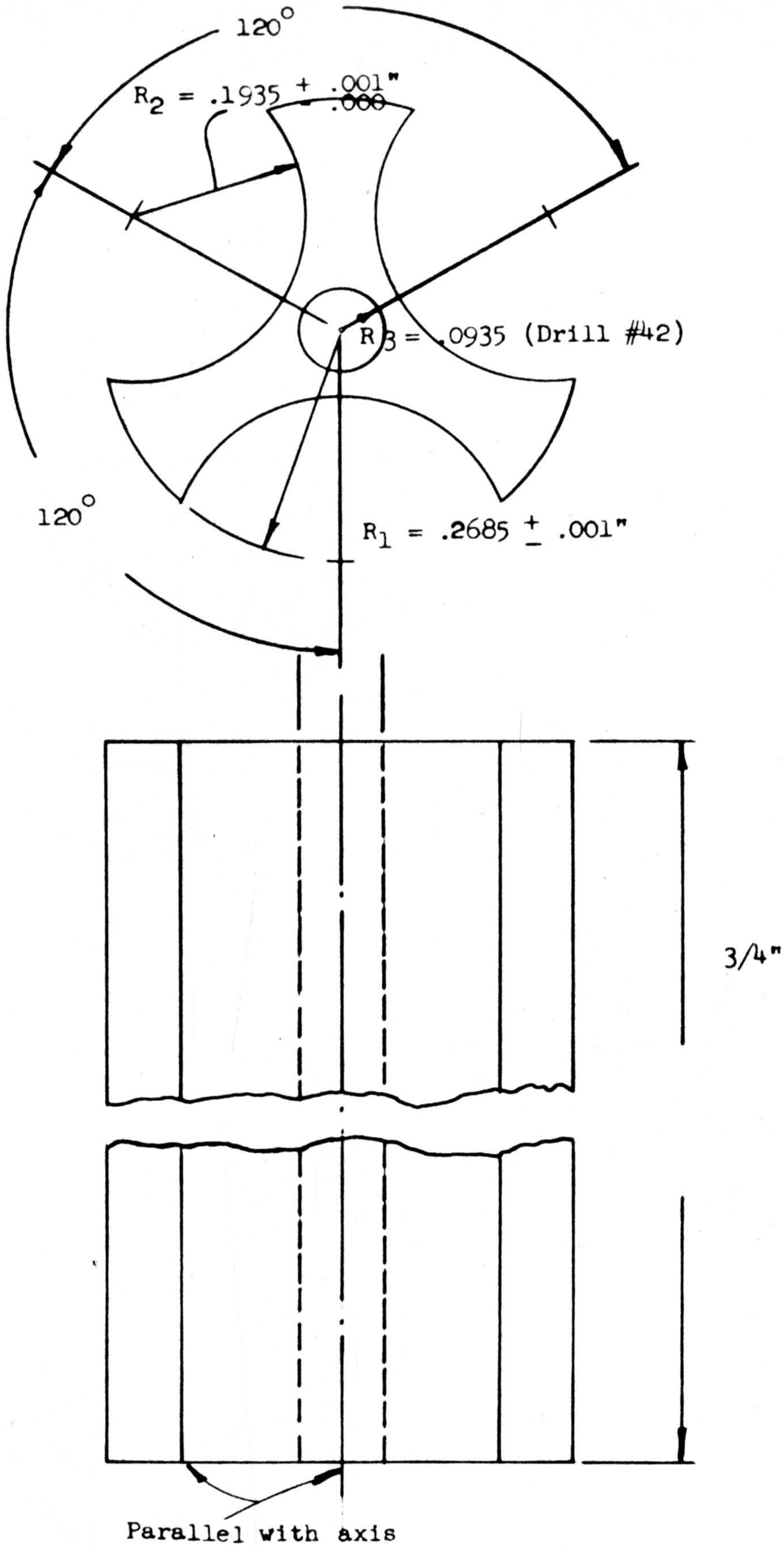

FIG. II - 82
Triangular spacer for mounting of three guns in alignment

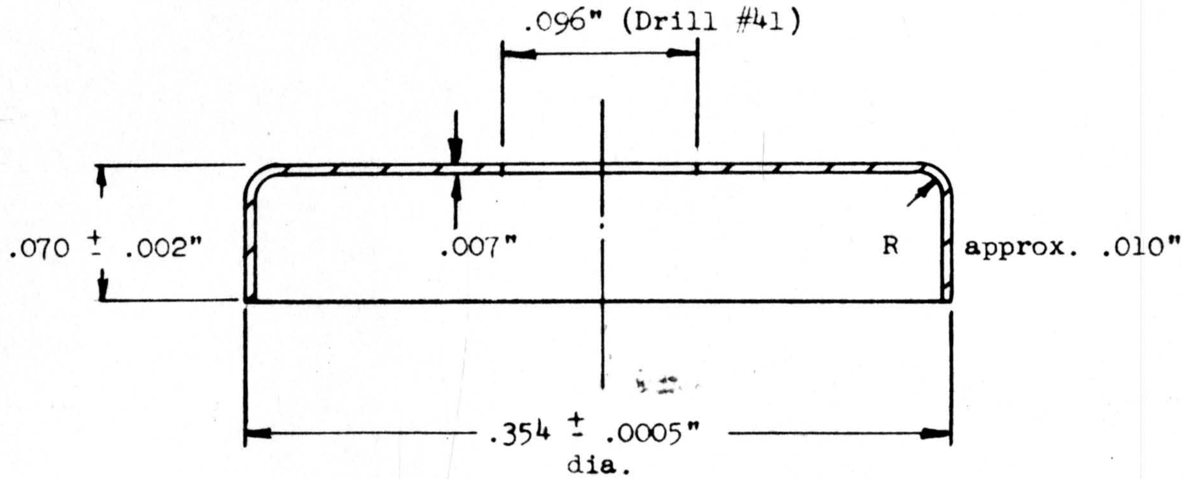

FIG. II - 83
Aperture disk for focusing grid
No. 3

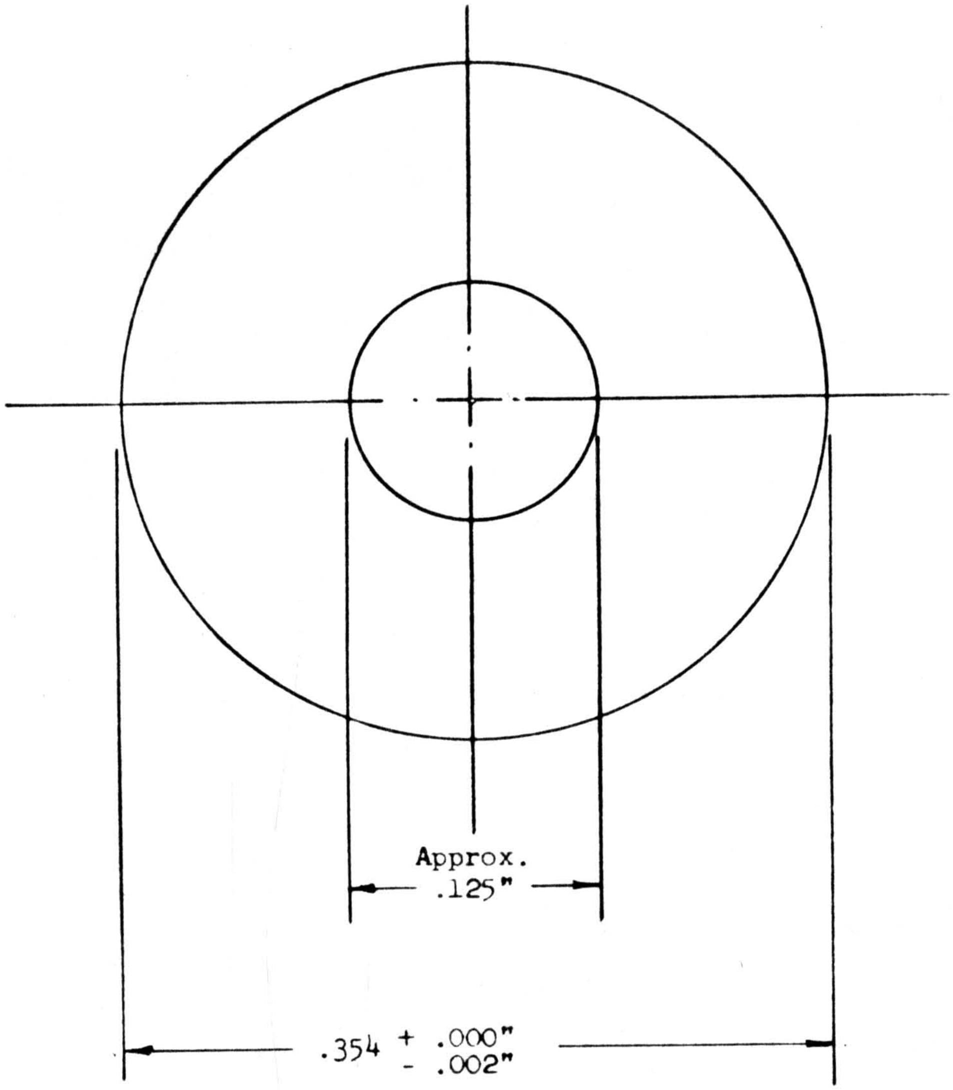

FIG. II - 84
Ceramic mounting disk for cathodes

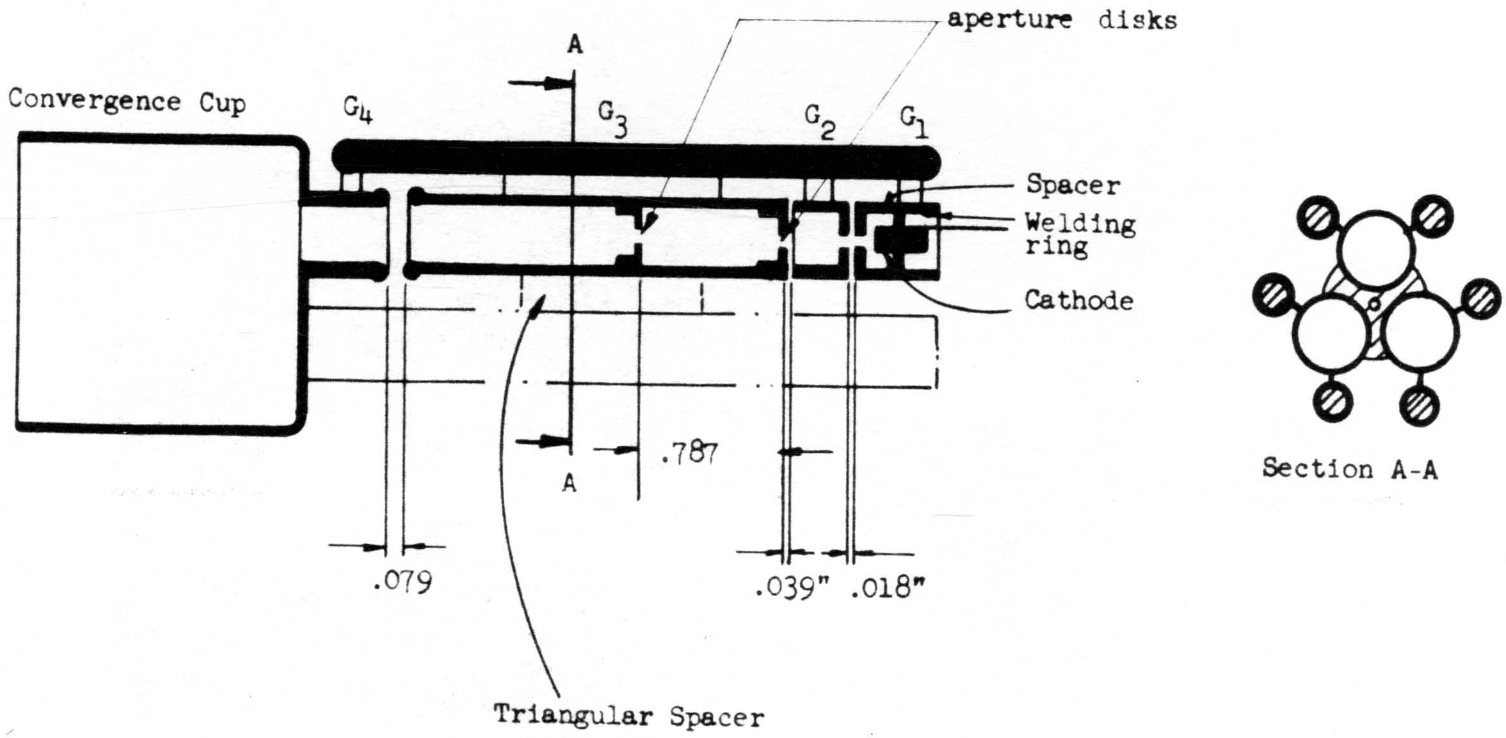

FIG. II _ 85

Assembled gun mounted in convergence cup

Oper. voltages:	Screen grid voltage	$V_{g2} \approx 250V$
	Focusing grid voltage	$V_{g3} = 3.5 - 4$ KV
	Convergence cup voltage	$V_{g4} = 9 - 10$ KV
	Cone voltage	$V_{cone} \approx 4$ KV
	Screen voltage	$V_{screen} = 19 - 20$ KV

Results and Conclusions

Two guns of this design were tested and demonstrated in a demountable color tube of the stripe type with post acceleration. The performance fulfilled the set requirements. The spot size was reasonable, but a reduction is desirable.

A reduction of the spot size can be achieved by reduction of the apertures in grids No. 1 to the conventional 0.031" size. A larger aperture, as used in the shadow-mask type tri-color gun, is not necessary because of the very high transparency of the post-acceleration tube, and no occurrence of moiré in the stripe type tube with sweep perpendicular to the color stripes.

(C) Post Acceleration Tri-Color Guns Arranged in One Plane. .260 Inch Base Guns

In the here described guns the three guns are arranged in one plane. The line connecting the centers of the three guns is aligned perpendicularly to the phosphor stripes on the screen of the tube. This was done to simplify convergence of the beams. When arranging the guns in one plane, the center-to-center distance of adjacent guns becomes smaller than when the guns are placed on a triangle, i.e., 120° apart. The center-to-center distance of adjacent guns was further reduced when a .260" color base was requested for the 15" tube; here color base is the distance between two adjacent beams in the plane of deflection.

Small diameter tubing guns had to be developed to satisfy the above requirement of short center-to-center distance of guns. The first logical step was to apply experience gained earlier with small diameter guns used in the modified tri-color gun.

The dimensioning of the gun tubing resulted from the desired distance of the gun end from the plane of deflection and from the required color base. At this point, it seems appropriate to explain the convergence scheme used for the tri-color gun since this is a determining factor for the distance of the gun from the yoke.

Convergence System

After preliminary tests with a .280" I.D. gun of the type originally used in the modified tri-color gun, electrostatic deflection was used for static and dynamic convergence using deflection plates. With such a convergence system, the gun becomes shorter than when a convergence cup is used. Deflection does not affect focusing voltage and vice versa as it does with a convergence cup, and correcting magnets can be eliminated. (Fig. II-86)

Each of the two outside guns is equipped with two pairs of deflection plates. One pair of deflection plates is for horizontal convergence. The other pair is required to correct for imperfect alignment of the three beams in the vertical direction. The center gun does not require any deflection plates. Plates F and G (also B and D) in Fig. II-86 are on gun potential and shield the center beam from any deflection fields applied to the outside guns. With this design no correcting magnets are required. This is a desirable feature since correction is usually done in the low-voltage region of the gun and leads to a reduction of the gun resolution. When magnetic fields are applied in the region of low-velocity electrons the beam becomes elliptical. Furthermore, the beam may not pass through the central part of the lenses, that means it would pass through a region of the lenses with higher aberrations, and the beam would not hit the limiting aperture centrally, thus current losses to the limiting aperture would be increased. Because of this, the spot would become not only distorted, but furthermore a higher driving voltage would be required on the control grid to obtain the same screen current, which again would result in increased spot size.

The maximum length of the deflection plates and the angle under which they are tilted is determined by the location of the gun with respect to the yoke. The plates have to be slightly tilted when the gun is placed close to the yoke to prevent the beam from striking the deflection plates. For a similar reason, the horizontal deflection plates can be only of limited length. Otherwise, they would be hit by electrons from the neighboring gun. The plates were made .330" long and the angle of tilt was 6°30'.

Gun Designs:

The gun was designed for two different positions with respect to the plane of deflection.

In the first design, the end of the gun was placed 2.755" from the plane of deflection - that is, about 1.750" from the closer end of the yoke. The resultant center-to-center distance of adjacent guns was .307". The inside diameter of the gun tubing was .247".

In the second design, the end of the gun was placed 1.280" from the plane of deflection - that is, about .280" from the end of the yoke. The resultant center-to-center distance of adjacent guns was .280". The inside diameter of the gun tubing was .220". Such close spacing of the tri-color gun from the end of the yoke* can be used when the three individual guns are placed close together and when the angle of deflection does not become large.

When calculating the correct center-to-center distance of adjacent guns for a .260" beam separation in the plane of deflection, i.e., .260" color

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* Patent Docket No. 4D-248, of December 29, 1953, by P. H. Gleichauf.

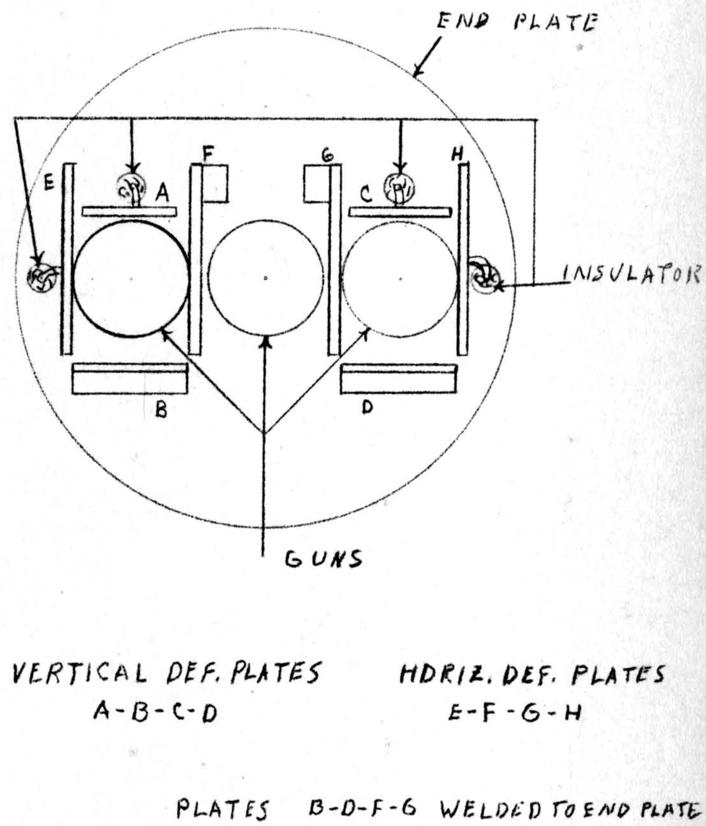


FIG. II - 86

End plate of tri-color gun with convergence plates

base, one has to bear in mind that the electrons are deflected along a parabola. Therefore, looking from the plane of deflection toward the guns, it seems that the beams originate at points which are beyond the actual centers of the outside guns in the plane of the end plate of the gun.

The main effort was put on development of the smaller gun with .220" inside radius. The reasoning was that when a gun for such small tubing can be developed, a larger gun can easily be built. The smaller diameter gun could be used in either tri-color guns for experimental purposes.

Gun Design #1:

A sketch of this gun is shown in Fig. II-87. The gun is a tetrode with progressively increasing voltages on the electrodes. The voltage on the screen grid G_2 was about 250 volts, the voltage on the first anode, the focusing voltage, was about 2200 volts, and 5000 volts were applied to the last electrode which was connected to the cone of the tube.

All parts were machined. Edges on the electrodes turned toward a high-voltage electrode had a rolled flange with a radius of .015".

The control grid G_1 was a coined grid cup with a .031" aperture. The thickness of the coined part was .004 to .005".

The screen grid cup G_2 was .180" long. This is relatively long when compared with the length of G_2 cups in conventional guns of larger inside diameter. The length was determined so as to obtain in the cross-over region equipotentials parallel to the surfaces of G_1 and G_2. By lengthening the G_2 cup a strong G_2-G_3 lens was formed which is desirable for a gun with small diameter tubing, since slender beams are required.

Designs with first anodes G_3 of different lengths and with limiting apertures in different positions were tested. The G_3 electrode was terminated on the side turned toward G_2 with a .070" aperture. The size of the limiting aperture was .055".

In the first design G_3 was 1.5" long, the limiting aperture was .910" from the open end of G_3.

In the second design G_3 was 2" long, the limiting aperture was 1.225" from the open end of G_3.

Experimental Results:

Measurements were carried out in a demountable station similar to the one of Fig. II-64, but with a bulb having a 12" screen. The distance of the screen to the plane of deflection was 14" and the distance from the plane of deflection to the closer end of the gun was 3". Such measurements in a demountable vacuum station give fast information, but the resolution of the gun is usually lower than in a sealed-off tube because of lower emission. The spot size was measured using a pulse generator. The height

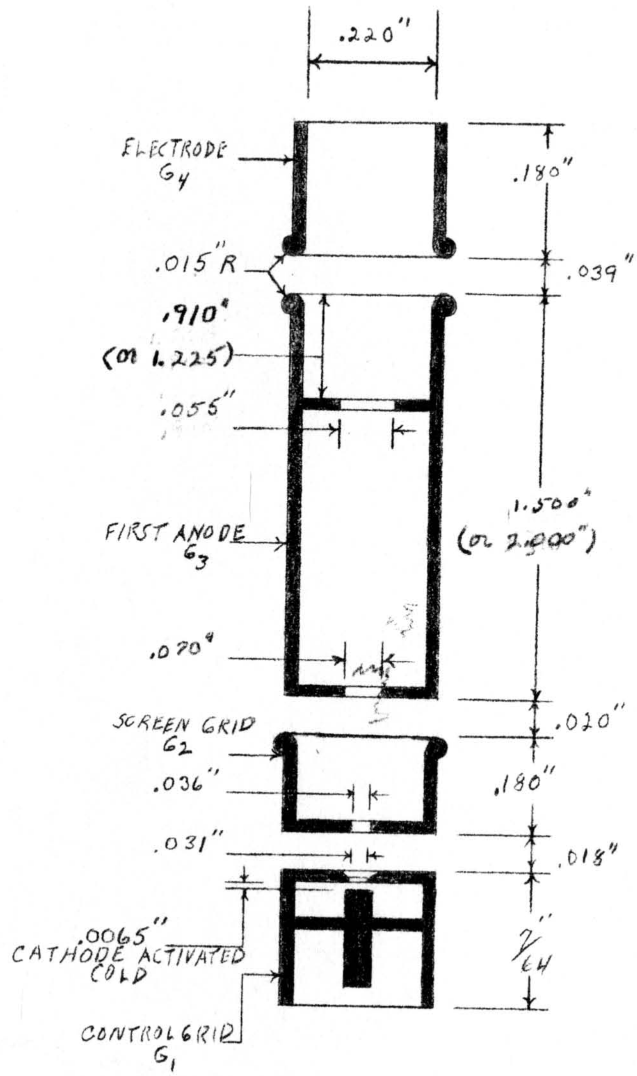


FIG. II - 87

Gun Design #1
for .260 inch Base Tri-Color Gun

of the pulses was measured with a calibrated oscilloscope; after having thus determined the bias voltage, the corresponding screen current could be measured.

(1) For guns with the first anode G_3 1.5" long, the spot size was about .080" at zero bias and at 150 to 200 microamperes screen current. The spot showed a pronounced bright core about .040" or less in diameter.

Bias Voltage in Volts	Spot Size in Inches
0	.080
-26	.060
-48	.050

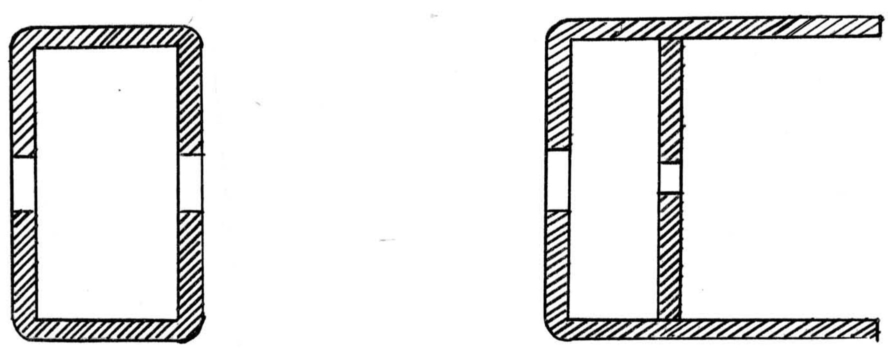
(2) For guns with the first anode G_3 2" long the spot improved and was at zero bias about .060" in diameter.

In the guns with 2" long G_3 little defocusing was observed with modulation. With G_3 1.5" long defocusing with modulation became pronounced because of larger magnification.

The cut-off in these guns occurred at -65 to -80 volts.

Modified Design:

To minimize movement of the cross-over with modulation and thus defocusing, a screen grid G_2 was built as shown in Fig. II-88*. Such a gun showed no defocusing with modulation in the range of bias voltage used. But with higher currents distortions occurred, probably because of a too small aperture in G_2. Development of such a gun was not carried further because of other urgent work.



(a) (b)

Two versions of screen grid G_2 designed for reduction of defocusing with modulation; design (b) used in test gun.

Fig. II-88

* Patent Docket No. 4D-213, of November 23, 1953, by P. H. Gleichauf.

Gun Design #2:

It seemed desirable to strengthen the lens G_2-G_3. This was done by design of Fig. II-89 where a focusing electrode G_4 on a lower potential than the first anode G_3 and a second anode G_5 were introduced. The focusing electrode G_4 was made .180" long, thus a decelerating and an accelerating lens were formed instead of an "Einzellens". Such a lens has less aberrations than an "Einzellens" as will be explained in a later section of this report. The limiting aperture was placed .910" from the upper end of G_3.

Experimental Results:

The current losses to the limiting aperture were reduced from 75% in design #1 to 30% in design #2. In both designs the limiting aperture was in the same position, .910" from the open end of G_3. The measurements were carried out on the same gun. G_4 was either used as the focusing electrode of design #2, or to obtain design #1, G_4 was brought to the potential of G_5 and G_3 served as the focusing electrode.

No defocusing of the spot with modulation was observed. The focusing voltage was about 3000 volts with 5000 volts on G_3 and G_5. The focusing voltage could be varied by ± 2 to 2-1/2% without noticeable defocusing.

Tri-Color Gun of Design #2:

Gun design #2 was used for tri-color guns demonstrated in 15" color tubes. A photograph of this gun is shown in Figure II-90(a). Small cathodes with caps only .107" in diameter were used with specially developed heaters. The heaters were mounted on a bridge made of Kovar wires sealed to glass, similar to the one shown in Section I of this Chapter, Fig. II-19(a), but of smaller dimensions. The positioning of the heater wires became very critical since the small cathode sleeves had no flared end and the coating chipped off easily. Nickel cathode tabs, as described also in Section I and shown in Fig. II-19(b), were used. Quartz sleeves shown in Fig. II-19(c) were slipped over the cathode tabs to prevent cathode-G_1 and cathode heater shorts. With the small spacings in this gun, such shorts easily occurred without the precautions mentioned above.

The focusing voltage was common to all three guns. Later it was found that because of poisoning of cathodes separate focusing voltages for three guns would be desirable. This was a temporary solution used only in a few guns.

The measured capacity of control grid G_1 to all other gun elements was 10 to 12 micromicrofarads.

Misalignment of the guns showed up easily not only because of the small gun tubing diameter, but also because of the long G_3 cylinder. A long G_3 cylinder was desirable to reduce magnification. The three guns were assembled together into one unit with spacing blocks on G_3 to secure proper separation of the guns. This spacing determines the color base of the gun. The tri-color gun was supported from these blocks on G_3 instead of from G_1 as in conventional guns to eliminate any forces on G_1 which would produce a misalignment.

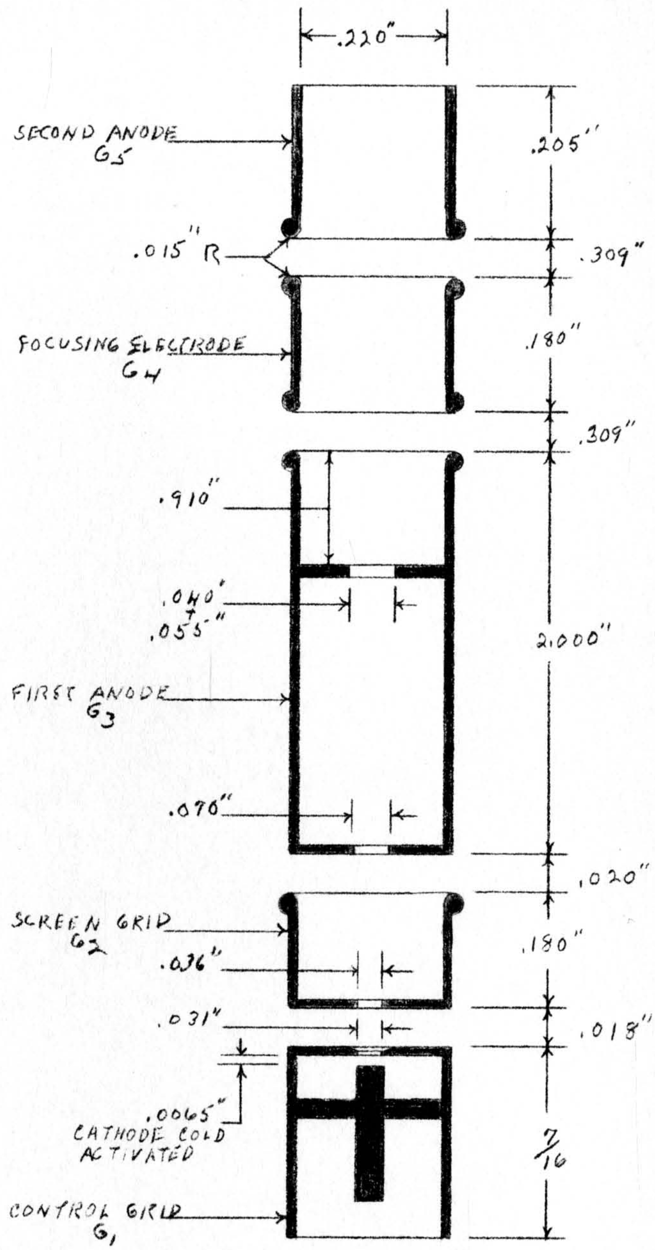
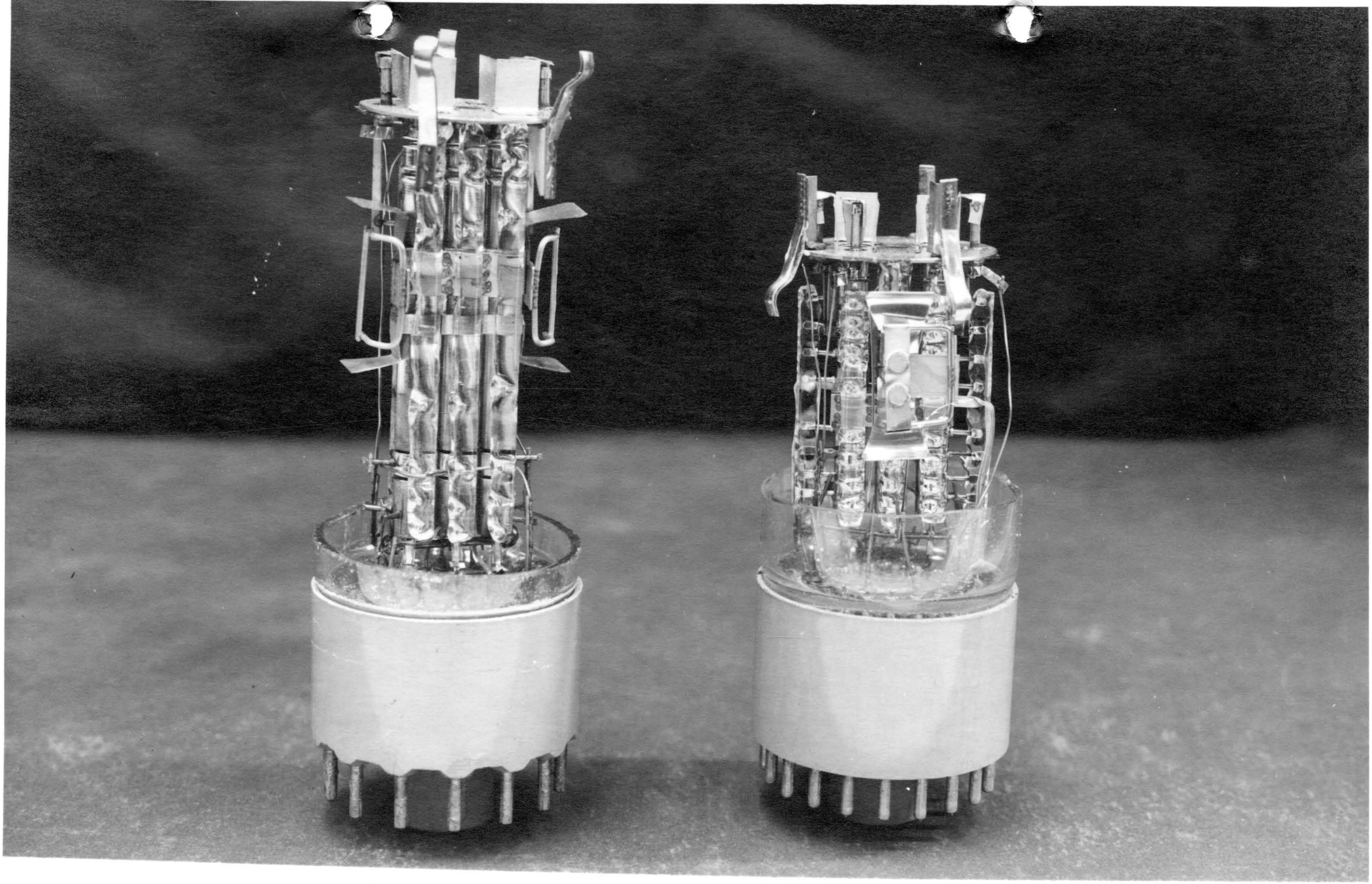


FIG. II - 89

Gun Design #2
for .260 inch Base Tri-Color Gun



A B

FIG. II-90
. 260 INCH BASE TRI-COLOR GUNS

The overall length of the 15" post-acceleration tubes was 3 or 4.5" less than of the 15" shadow-mask tubes, depending on positioning of the gun with respect to the yoke. Convergence was good and the observed divergence of the beams without dynamic convergence was in the corners of the screen about .080", in the horizontal direction maximum about .060" and in the vertical direction maximum about .040".

Other designs with common structures for the electrodes of the three guns were suggested, for example a three-cathode gun with separate cathodes but common G_1 electrode for all three guns, common G_2, common G_3, G_4 and G_5 (Fig. II-91(a)). In these guns, aperture lenses would be used. In another design only G_3, G_4 and G_5 were common to all three guns (Fig. II-91(b)). A similar construction was described in the section on the "Three Cathode Coincidence Cross-over Gun".

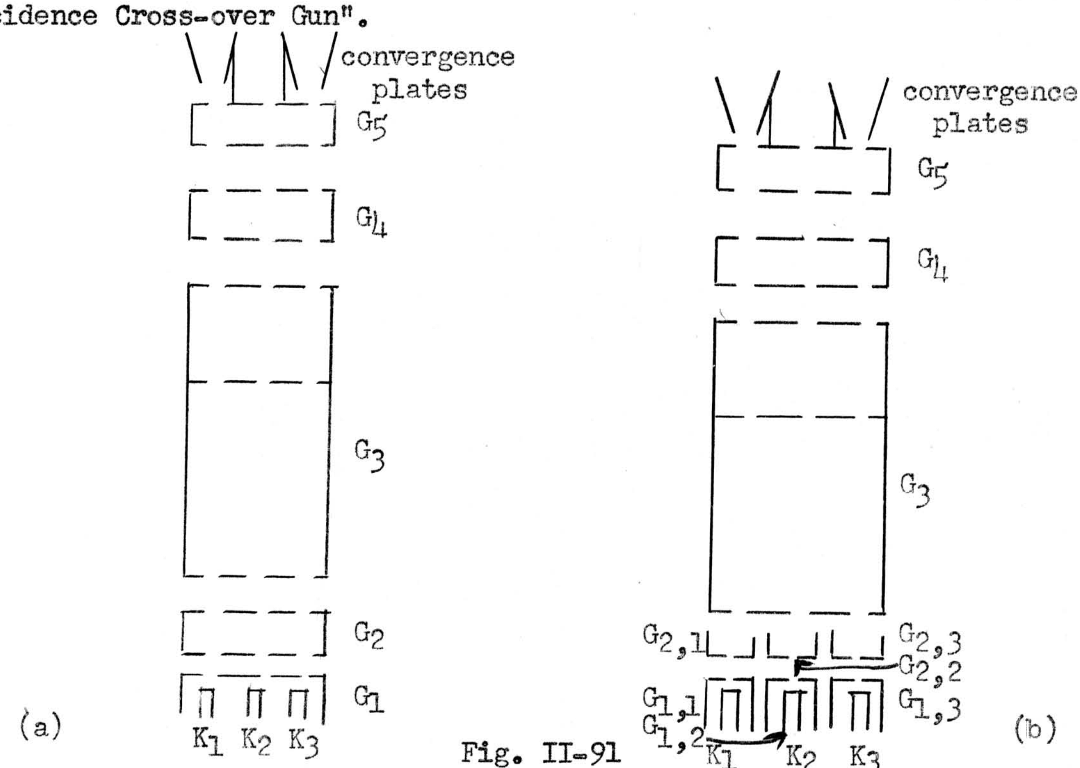


Fig. II-91
Tri-color guns with common electrode structures

<u>Gun Design #3:</u>

For further improvement of the gun there were fundamentally two approaches to be followed: (1) Improve the cross-over, (2) reduce the aberrations in the focusing lenses. Another approach is to reduce the beam angle which is practically equivalent to reduction of lens aberrations. It should be kept in mind that the guns were primarily designed for high screen currents at a resolution of at least 300 horizontal lines by 300 vertical lines. A very high resolution was not the principal aim of the design.

It seemed more desirable to start with the improvement of the focusing part of the gun, since it was found by connecting all high-voltage electrodes together that a very good spot was obtained with magnetic focusing. This indicated that a good cross-over was formed. A large magnetic lens, a focusing coil with a 2" inside diameter and without magnetic shields was used.

The focusing lenses could probably be improved by shaping. Shaping of lenses was only done in the G_2-G_3 lens where an aperture flared toward the inside of the G_3 cylinder was used. In other electrodes it did not seem to be a promising approach to shape the lenses because of their small diameter.

In the design described here and shown in Fig. II-92, it was attempted to reduce the beam angle by additional lenses placed between the control grid and the long cylindrical electrode designated in the earlier designs as G_3 (here G_5). This electrode was shortened and the aperture was made smaller since a narrower beam was expected.

Electrodes G_2, G_3 and G_4 were flat disks .020" thick. G_2 had a .036" hole, the holes in G_3 and G_4 were .070" in diameter. The G_1-G_2 spacing was .0095". The spacings between G_2, G_3 and G_4, respectively, were .040". The spacings had to be kept reasonably small to prevent the beam from becoming too wide when entering the "Einzellens". The G_5 cylinder was 1" long, with a limiting aperture of .025" placed .220" from the end.

G_2 was at 2000 volts, G_3 and G_5 at 5000 volts. An adjustable voltage was applied to G_4. G_3, G_4, G_5 formed a symmetrical "Einzellens". In other tests the "Einzellens" was formed by G_2, G_3, G_4. G_4 and G_5 were electrically tied together. In this case the "Einzellens" became unsymmetrical and the equipotentials from the G_1-G_2 region penetrate through the aperture in G_2 into the G_2-G_3 region, thus producing a less desirable field in the cross-over region.

Experimental Results:

This design showed reasonably small pulsed spot size but distortions were observed which were probably due to the beam becoming too wide in the G_3 region.

Other electrical potentials were applied. For example, G_3, G_4 and G_5 were connected together and 5000 volts were applied to the assembly of electrodes while G_2 was kept on 1500 to 2000 volts. The spot size was less than .040" at 200 microamperes screen current but the limiting aperture losses were high; only 1/8 of the total cathode current reached the screen. This structure led to another design described later.

Gun Design #4 Periodic Focusing Gun:

In this design, which led to the final construction of our gun used in the .260" base 21" tube, periodic focusing was used. The design is shown in Fig. II-93. Anodes G_3, G_5 and G_7 are tied together and the maximum potentials available (5000 to 7000 volts) are applied to them. The

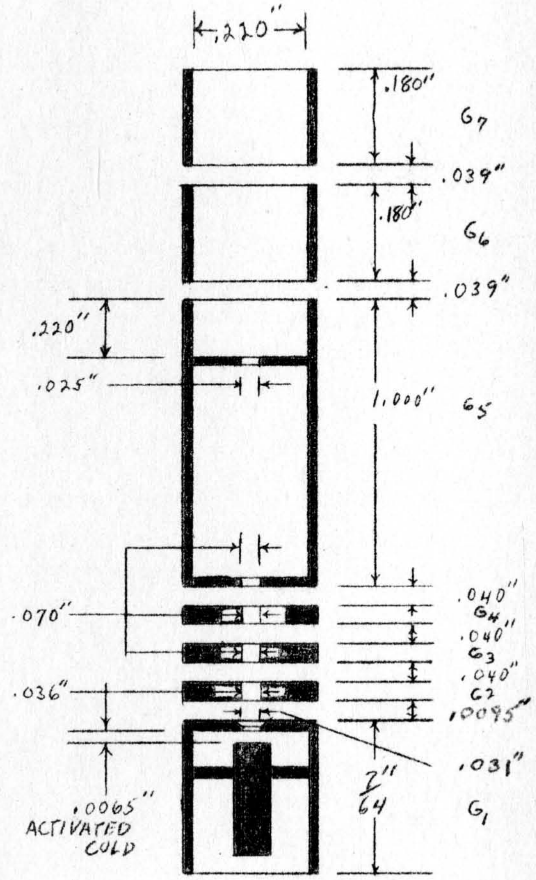


FIG. II - 92

Gun Design # 3
for .260 inch Base Tri-Color Gun

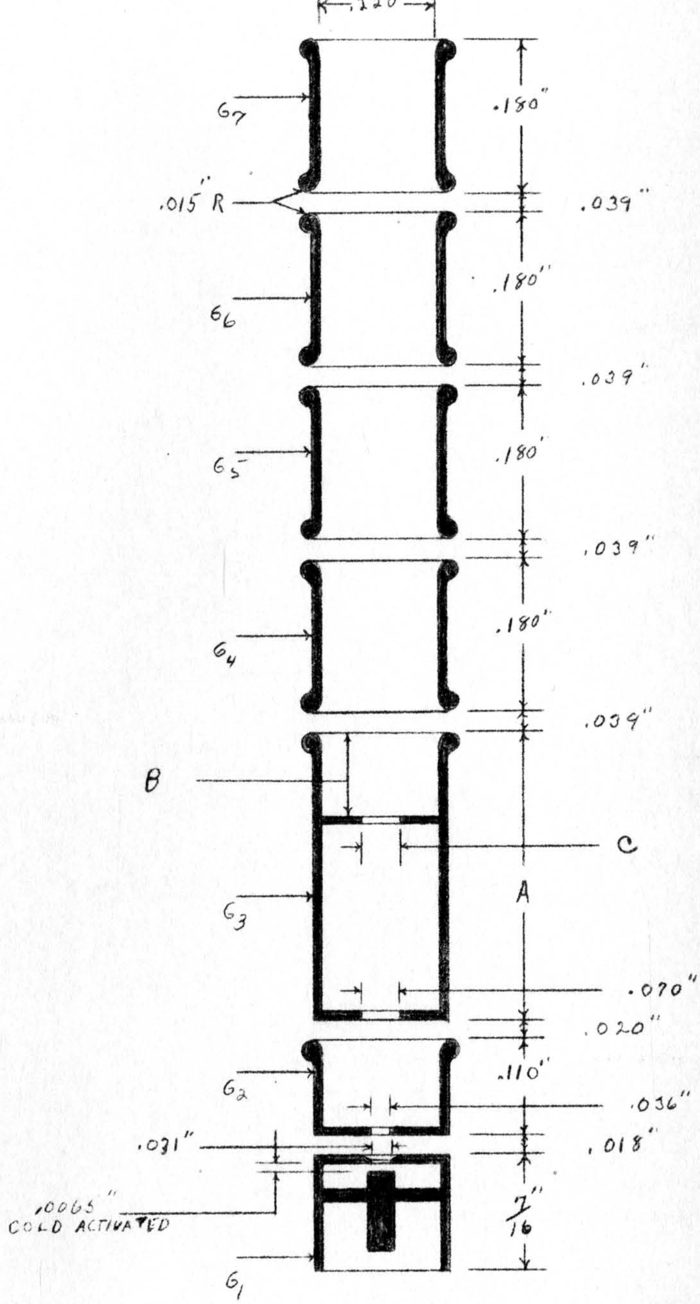


FIG. II - 93

Gun Design #4

for .260 inch Base Tri-Color Gun

electrodes G_4 and G_6 which are also connected together serve as focusing electrodes. The second focusing mode is used. Similar as in gun design #2, electrodes G_4, G_5, G_6, G_7 are about one diameter long. Thus individual lenses, instead of "Einzellenses" are formed. Periodic focusing was chosen for these reasons:

(1) In decelerating lenses, as for example in lens G_3-G_4, it is desirable not to apply too large a voltage difference between the two electrodes. With increasing potential differences on a decelerating lens electrons travel on trajectories farther away from the axis where aberrations are large. It is desirable to use only 15 to 20% of the lens diameter as measurements with different size limiting apertures showed.

(2) Large potential differences in a decelerating lens increase the effect of mutual repulsion of electrons in the beam.

(3) The principal plane of the combination of lenses is shifted farther away from the virtual object, thus magnification is reduced.

Guns with periodic focusing bloomed at currents which were 30% higher than the same guns in which the last focusing section consisting of electrodes G_6 and G_7 was omitted. The gain from adding a further focusing section, that is a G_8 and a G_9, was small, only about 10%.

The first anode G_3 was kept short so that the beam diameter in the G_3-G_4 lens remained small. Under these circumstances, the limiting aperture losses were kept low and thus the drive requirements were reduced. This too is desirable for reduction of aberrations, mainly at high currents. To keep the beam diameter small, primarily in the first focusing lens G_3-G_4, it becomes obvious that the limiting aperture is to be placed in the first anode cylinder G_3. The limiting aperture can be placed less than one electrode diameter from the end since the following electrode is on a lower potential and true secondary electrons cannot enter the lens. Close positioning of the limiting aperture to the lens was tried for shaping of the equipotentials. The results obtained were not encouraging.

Experimental Results:

The initial measurements on the periodic focusing gun were made with guns of the design shown in Fig. II-93. The length A of G_3 was .500"; no limiting aperture was used; leads to all electrodes were brought out separately to test several electrode configurations, including electrode length of G_3. Pulsed spot measurements were made. G_2 voltage was 250 volts or more.

Results obtained:

(a) G_3, G_5, G_7 at 5 KV
G_4, G_6 at $\approx$ 2.5 KV

(No aberrations, spot size close to cut-off .020", at zero bias .080")

(b) G_3, G_5 at $\approx$ 2.5 KV (Some aberrations)
G_4, G_6, G_7 at 5 KV

(c) G_3, G_7 at 5 KV (Little aberrations but larger spot)
G_4, G_5, G_6 at $\approx$ 2.5 KV

(d) G_3, G_6, G_7 at 5 KV (Good, but not as good as (a))
G_4, G_5 at $\approx$ 2.5 KV

(e) G_3, G_4, G_7 at 5 KV (Slight aberrations)
G_5, G_6 at $\approx$ 2.5 KV

(f) G_3 at 7.5 KV (No apparent improvements over (a))
G_4, G_6 at $\approx$ 2.5 KV
G_5, G_7 at 5 KV

(g) G_3, G_5, G_7 at 5 KV (Not as good as (a))
$G_4 < G_6$
($\approx$ 2 KV) ($\approx$ 2.5KV)

(h) G_3, G_5, G_7 at 5 KV (Better than (g))
$G_4 > G_6$
($\approx$ 3.5 KV) ($\approx$ 2 KV)

(i) G_3 at 7.5 KV (No improvement over (h))
G_5, G_7 at 5 KV
$G_4 > G_6$
($\approx$ 3.5 KV) ($\approx$ 2 KV)

More tests were carried out with a gun similar to the one just described but the length A of G_3 was .280", again without limiting aperture. Two electrodes G_8 and G_9 were added to study the effect of an additional pair of focusing electrodes. Only very slight improvement, about 10% smaller spot, from the added pair of focusing electrodes was found. When connecting two high-voltage electrodes together the effect of a longer electrode could be studied.

Many similar tests were carried out, but all the material cannot be presented here. Different locations of limiting apertures and different sizes were tried. With the limiting aperture in G_4 the core remained bright, but a fuzzy area around the spot wider than usual was observed. In other tests the limiting aperture was placed in the center of G_5. Or higher voltages on the screen grid G_2 were applied.

And finally, progressively increasing voltages were applied to the high-voltage electrodes. Thus a long lens was formed which should have small aberrations. Nevertheless, no improvement over (a) was found.

G_3 at 1.5 KV $< G_4 < G_5 < G_6 < G_7$ at 5 KV.

Also a smaller spacing of G_1-G_2 was tested. The spacing was .0095". The tests showed no improvement in beam angle, and at higher voltages on G_2 the spot became fuzzy. From the point of view of gun assembly, such a small separation was undesirable.

Modified Design:

After experience gained with gun design #3, the screen grid cup G_2 was replaced with a disk .020" thick. The aperture in G_2 was .036" tapered from both sides under 60°. Encouraging results were obtained, but there were large differences in resolution from gun to gun. These differences in resolution were found to be due to imperfections in the screen grid G_2. The modified design of G_2 is shown in the sketch of Fig. II-94. The electrode is a disk .040" thick with a .036" hole. The hole is tapered under a 60° full angle from the anode side to a depth of .030". The edge on the cathode side is slightly rounded off. The voltage applied to G_2 is such as to form in the G_1-G_2 region equipotentials parallel to the surface of G_2. With 5000 volts on G_3, the desired voltage on G_2 was calculated to be about 500 volts.

For smaller spot size, the aperture in the control grid G_1 was reduced to .021".

The first anode G_3 had a similar shaped hole under a 60° full angle to a depth of .040" on the G_2 side. The optimum length of G_3 was about .400". As mentioned earlier, short G_3 electrodes are desirable to prevent the beam diameter from becoming too large when entering lens G_3-G_4. The minimum length of G_3 considered was equal to one inside diameter of the electrode plus one diameter of the aperture in the end of the electrode. Measurements showed that then G_3 became too short, the resolution decreased.

Closer spacing of the limiting aperture toward the G_3-G_4 lens was tried to obtain a shaping of the lens. The limiting aperture was placed .080" from the end of G_3 (and closer to G_4), that is in a position where the lens action is still weak. A stronger lens action starts at about $Z/R = 0.7$, where R is the lens radius and Z the axial distance from the midplane of the lens*. The results were not good, aberrations were pronounced.

The wall thickness of the disk part of the limiting aperture cups was increased to .030" since it was observed that the apertures melted away when struck by the slender electron beams. It was also suggested to use titanium for the limiting apertures instead of stainless steel because of its high melting point. But the heat conductivity of titanium is low. The limiting aperture would form a convenient getter when brought to elevated temperature by electron bombardment.

From the point of view of color base a limiting aperture in the end of the gun would be desirable. But from the point of view of gun design,

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* Karl R. Spangenberg, "Vacuum Tubes" - McGraw-Hill Co., 1948, p. 343.

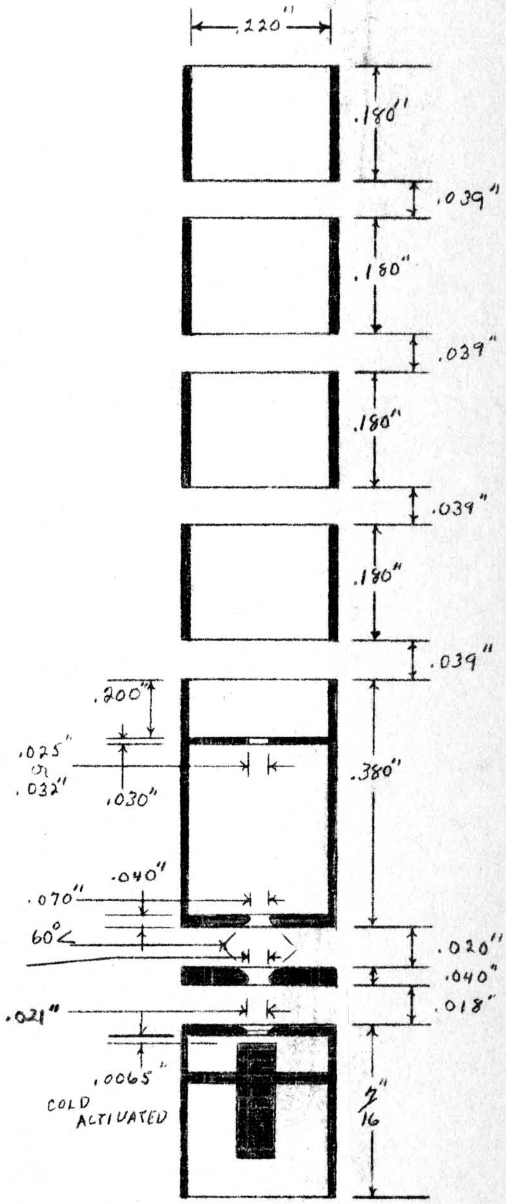


FIG. II - 94

Modified Gun Design # 4

for .260 inch Base Tri-Color Gun

this is undesirable since line-up would become difficult.

Other guns were built with electrodes without rolled flanges on edges. In these guns, the edges of the electrodes were only rounded off with full radius and a high polish was applied. No noticeable difference in performance of guns with either electrode design was found. In other guns where the electrodes were without rolled flanges, the first anode G_3 was open on the low-voltage side and had here a rolled flange.

Experimental Results:

Different electrode configurations and positions of limiting apertures were tried in the demountable test station. The measurements confirmed the earlier mentioned results. The spot size at 200 microamperes screen current was reduced to about .040" in the periodic focusing gun. 30% of the cathode current was lost to the limiting aperture.

To obtain reliable measurements, tests were made in 17" sealed-off tubes. For evaluation of the gun performance, the Indian Head test pattern obtained from a monoscope was used.

Typical results for the final design of this gun are listed below. The length of the first anode G_3 was .380". The limiting aperture was .025" and was placed .180" from the G_3 end closer to G_4. The beam was thus limited to about 20% of the G_3-G_4 lens diameters.

At 5000 volts anode voltage, 500 volts on G_4 and a focusing voltage of about 2300 volts, these guns gave screen currents up to about 110 microamperes before blooming, with a resolution of about 300 x 250 lines. The losses to the limiting aperture were 50% of the cathode current.

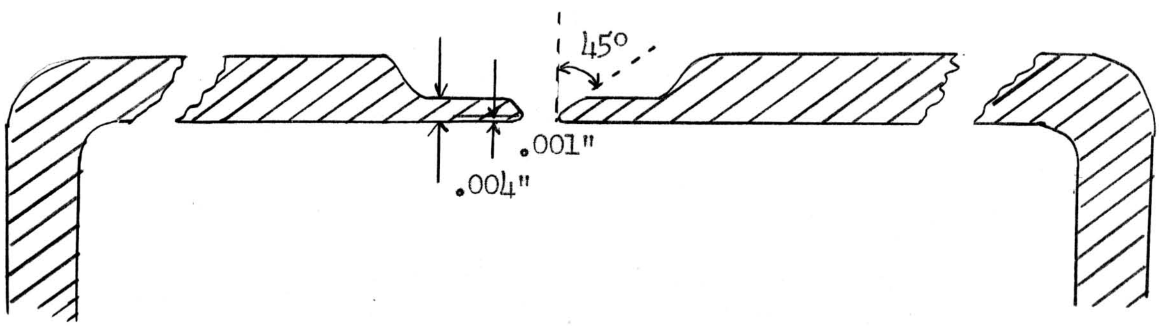
At 7000 volts anode voltage, 700 volts on G_2 and a focusing voltage of about 3100 volts, the maximum screen current before blooming was 180 microamperes, with a resolution of 300 x 280 lines. The current losses to the limiting aperture were about 50% of the cathode current.

V anode in volts	V G_2 in volts	screen cur. in microamp.	cathode cur. in microamp.	resolution in lines
5000	500	110	235	300 x 250
5000	700	125	380	300 x 250
5000	1000	105	490	300 x 250
7000	500	168	285	300 x 240
7000	700	180	370	300 x 280

From the above data it can be seen that with increasing voltage on G_2 the maximum current before blooming increases at first because the cross-over is formed at a higher equipotential and, therefore, becomes smaller. With further increasing G_2 voltage, the maximum current before blooming decreases because the voltage ratio $V_{G3}:V_{G2}$ becomes smaller and a wider beam angle results. One can see this from the above table for 5000 volts anode voltage and 1000 volts at G_2. The beam angle increased as indicated by high current losses to the limiting aperture.

Redesign of Cathode-Control Grid Region

For improved cross-over size, the control grid G_1-cathode spacing was reduced to .002 - .0025" hot. To improve further the shape of the equipotentials in the vicinity of the cathode so that side components of electron velocities acquired from the field are minimized, the apparent thickness of G_1 around the hole in G_1 was reduced by a shape shown in Fig. II-95.*



Control grid G_1 with shaped aperture

Fig. II-95

In such guns, the spacing seemed too close and frequently shorts occurred. For such close spacing finer cathode coating should be used and the cathode should be shaved to obtain flat, smooth surface. Cathodes developed later for inserting by the sparking method (see later) would be well suited. Specially well suited are L-cathodes because of their machineability.

Tri-Color Gun of Design #4:

Tri-color guns of this design were used in 21" post-acceleration tubes (with .260" base) which were demonstrated. See photograph in Fig. II-90(b). Static and dynamic convergence voltages were applied to deflection plates as in design #2 (Fig. II-86). In these color tubes, the emission was not as good as in monochrome tubes and the limiting apertures were opened to

* Suggested by C. Von Campbell.

.032" to obtain sufficiently high currents for the highlights in the pictures without losing fast resolution.

Design #5 Magnetic Focusing:

When testing the guns, magnetic focusing was applied to determine whether a good cross-over was formed. Large focusing coils with 2" radius, without shields, were used. In most measurements, the spot size was about one-half of the spot obtained with electrostatic focusing. This can be explained not only by a better focusing lens but also by magnetic leakage fields penetrating into the low-voltage region.

Although it was a questionable approach, it was tried to focus all three beams with a single large focusing coil. In spite of large inside diameter of the coil and the close spacing of the three beams, the outer two beams could not be focused.

The next step was then to use internal magnetic focus. The problem here was the interaction of the magnetic fields of the three lenses. A single gun was tested in a monochrome tube. The lower structure of gun was identical with that of design #4. The anode cylinder was 2" long with the focusing element on its end. Measurements with such a single gun were made in a monochrome tube. In this tube, it was not possible to separate screen current from limiting aperture current and the results cannot, therefore, be well compared with other available data. The resolution seemed good.

A triple gun with internal magnetic focusing was sealed into a 21" monochrome tube. It was not possible to focus any of the three spots and the spots were distorted. This was explained by the interaction of the magnetic fields. No further work was done on this gun.

Gun Design #6 Periodic Focusing Tetrodes and Triodes for Larger Color Bases

In later tube designs of the 21" tube, the color base was enlarged to .330", and in some tubes to .300". For the enlarged color base and the larger deflection angle of 65°, the gun was placed farther away from the yoke. It was, therefore, possible to use larger diameter electrodes. The center-to-center distance of the guns was .427", and the inside diameter of the tubing was .357". The measurements were again made on 17" monochrome tubes. Machined parts were used. Two types of guns were built: tetrodes and triodes.

Tetrode:

The first step was to scale up the tetrode developed earlier. A sketch of the tetrode is shown in Fig. II-96. Since there was no fundamental change made in the design when compared with the .220" inside diameter gun, the gun is not explained in detail here. Screen grid G_2 was made of .062" material instead of .040" material. Under these conditions, the field from G_3 penetrates less through G_2. The spacing between the individual guns in the tri-color gun was only

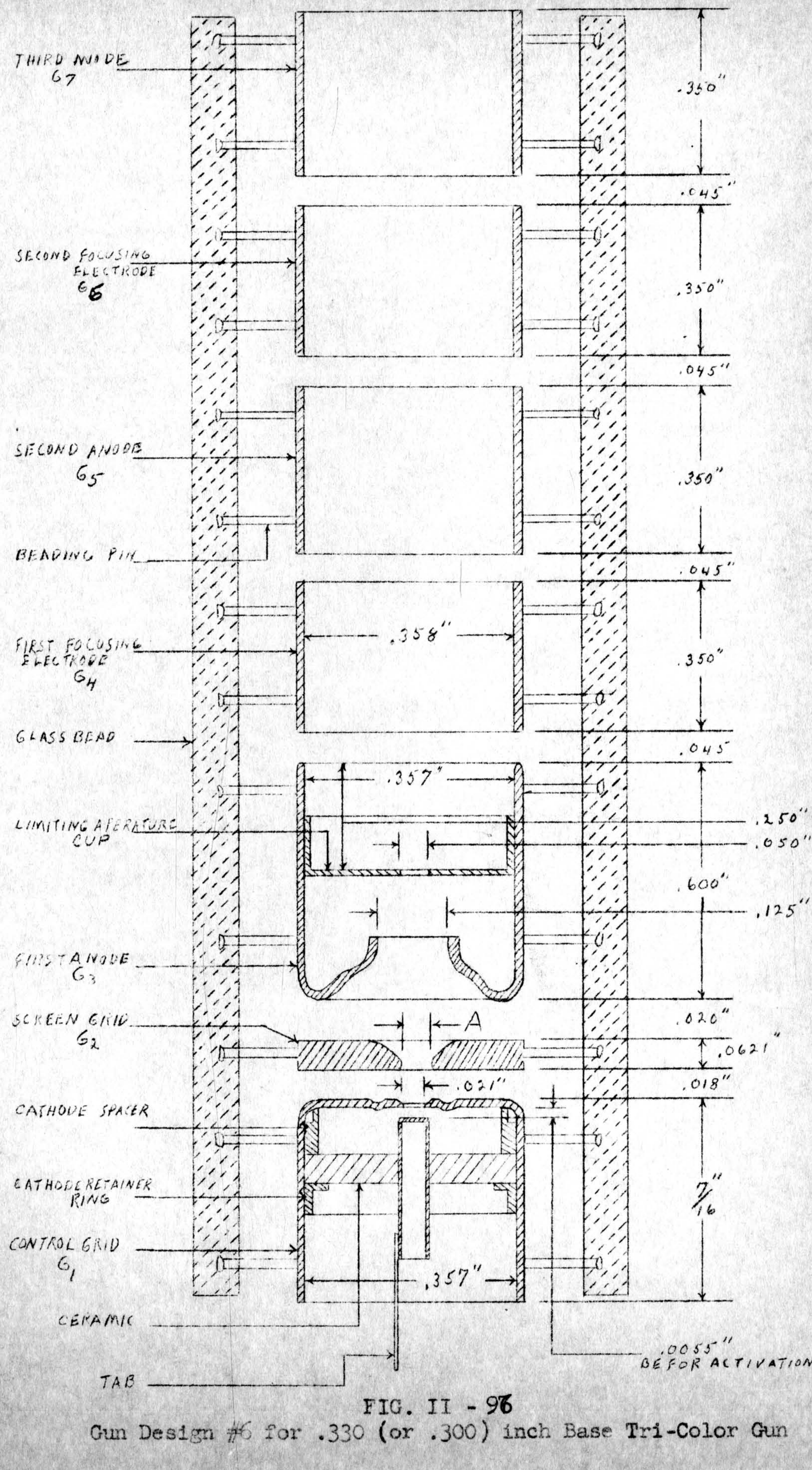


FIG. II - 96

Gun Design #6 for .330 (or .300) inch Base Tri-Color Gun

.040". Straight cylinders without rolled flanges were used for the high-voltage electrodes.

Other types of tetrodes were built. In these guns the aperture in the screen grid G_2 was opened to reduce edge effects of the aperture, that is to provide a purer field in the G_1-G_2 region. Guns with G_2 aperture diameters .052", .115" for guns with machined parts, and .125" for parts with drawn parts were tested. The guns with .115" or .125" holes in G_2 did not provide a good shielding of the first anode, nevertheless it was possible to affect the cut-off by the voltage of screen grid G_2.

Experimental Results with Tetrodes:

In the tetrodes with a .036" aperture (A) in Fig. II-96 in G_2, the screen currents at which a resolution of about 300 x 300 lines could be read were:

V anode in volts	V_{G2} in volts	Screen current in microamperes
5000	500	200
7000	700	280

The characteristic of the gun is shown in Figure II-97. Good shielding of the first anode by the screen grid was observed. For example, when changing the anode voltage from 5000 volts to 7000 volts, the cathode current - that is, the sum of screen and limiting apertures current - did not change within the accuracy of measurements. Nevertheless, with stronger limiting the screen current might increase because of smaller beam angle; that means the current losses to the limiting aperture are reduced. In color tubes with unsatisfactory cathode emission, the effect of current losses to the limiting aperture becomes a determining factor of the gun performance.

None of tetrodes was able to deliver as high screen current without blooming as the later described triodes. Work on tetrodes is continuing to bring their performance up to the level of triodes.

Triodes:

Next a triode was developed. See Figure II-1 in the first section of this chapter. With this type of gun, a very pure field free from aberrations results in the vicinity of the control grid G_1 and, therefore, a better cross-over should result. A wide open space results between G_1 and the first anode, which shall now be called G_2. It was not certain whether there would be danger of interaction of the neighboring guns in the tri-color assembly. The G_1-G_2 spacing was .100". Also guns with a spacing of only .050" were tested. In the latter guns, the cross-over would be formed at a high equipotential. No improvement was noticed.

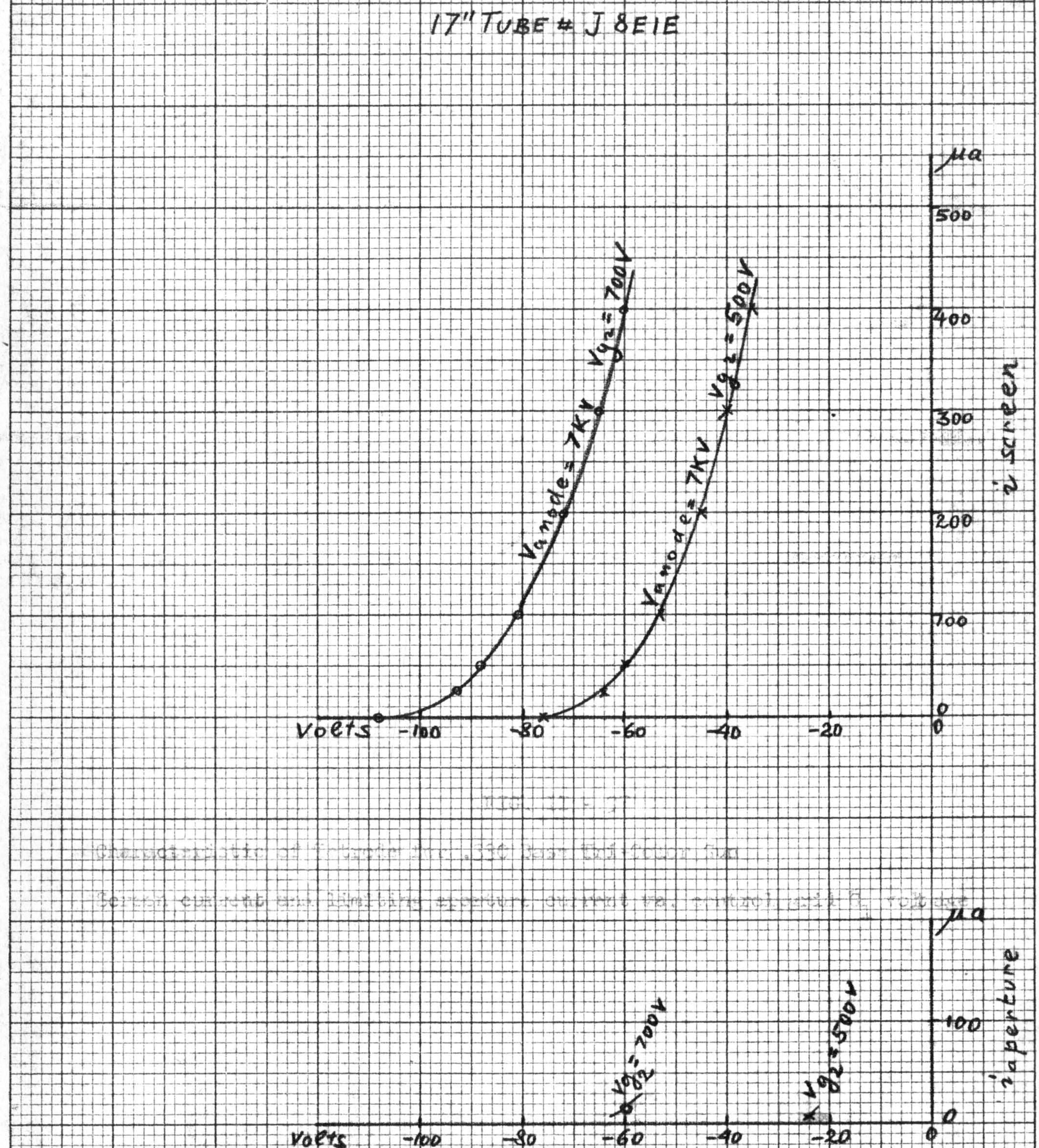


FIG. II - 97

Characteristic of tetrode for .330 base tri-color gun

Screen current and limiting aperture current vs control grid G_1 voltage

C H Claichart 11-1-54

For studying of interaction of neighboring guns in the tri-color gun, a gun was built with extensions on G_1 and on G_2 perpendicular to the axis of the gun, i.e., in the planes of the electrodes. These extensions could produce a distortion of the field in a similar manner as adjacent guns in the tri-color assembly. The maximum screen currents which could be drawn from this gun before blooming occurred were about the same as in a normal gun.

In another gun, two wide flat leads of the same kind as used for gun support were mounted along a test gun. One lead extended toward the center of the first anode in the axial direction, the other lead ran along the whole length of the gun. Both leads were brought close to the gun and did not make contact with any of the electrodes. It could be seen that there was no effect of the shorter lead extending only over the G_1-G_2 region on position of the stationary spot on the screen. Voltages as high as the anode voltage were applied. The longer lead produced a strong shift of the stationary spot on the screen and the spot was very distorted. It seemed, therefore, that there is little interaction of the guns in the G_1-G_2 region and from the electron optical point of view, there is no objection to a triode. The focusing electrodes need more careful considerations.

The spacing between the high voltage electrodes was .057" in the test guns, but later was reduced to .045". It was necessary to reduce the spacing because lenses became too wide open and fields from leads caused distortions. Also, the small curvature of the edges of the high-voltage electrodes had a more pronounced effect on lens quality. These effects were less noticeable in guns of .220" inside diameter. The effect of the electrode edges will be discussed later. A much further reduction in spacing is not recommended because lens aberrations would increase and improper alignments of the electrodes would have a more pronounced effect on the electron trajectories.

In further designs, it was decided not to use heavy supports for the gun mounting in the vicinity of any focusing electrode. Leads which go by the focusing electrodes should be kept far away from the lenses and be of thin wire with a high voltage gradient on the lead.

To obtain a gray scale at all brightness levels, the characteristics of all three guns should be in the ideal case identical. The cut-off as well as the transconductance of a gun for given voltages are determined by geometrical factors:

(a) by the control grid - accelerating electrode spacing

(b) by the control grid - cathode spacing

(c) by the aperture in G_1.

The spacing between the control grid G_1 and the accelerating electrode G_2 can be well controlled; the hole in G_1 too is quite uniform from gun to gun. In a tetrode the cut-off is adjusted by the screen grid voltage.

In a triode the cathode-control grid spacing should be held very closely from gun to gun.

For close cut-off in individual triodes of a tri-color gun, two approaches were chosen. In both methods the cathode-control grid distance is determined from the sparking potential in air. To obtain a reliable measurement, a cathode is used as shown in Figure II-9 or Figure II-12. The cathode coating fills an indentation .002" deep in the central part of the cathode and comes up to the level of the rim free from coating. Sparking occurs between the clean cathode rim and the control grid.

In one approach, individual guns with cathodes with spacers in G_1 are matched using the sparking method to obtain uniform cut-offs in the three guns of a tri-color gun assembly.

In the other approach, the cathode-control grid distance is determined by the sparking method while the cathode is welded into place. The assembly method was described in Section I of this Chapter.

Both methods are described in the first section of this chapter. By the first method in which guns are selected for uniform cut-offs, the cathode-control grid distance can be determined within about 20 volts or better of the sparking potential where a change in distance by .001" corresponds to about 120 volts according to the calibration curve of Fig. II-112. By the second method, when no further selection of finished guns is used, the cathode-control grid distance can be determined within a sparking potential difference of about 50 volts.

Experimental Results with Triode:

The characteristics of 5000, 6000, and 7000 volts anode voltage are shown in Figure II-98.

The screen currents at which a resolution of about 300 x 300 lines could be read were:

V anode in volts	screen in microamps.
5000	310
6000	360
7000	430

The screen currents in these triodes before blooming are about the same as in the latest design of the electrostatic focus guns used in monochrome tubes in spite of the small electrode diameter and low voltages.

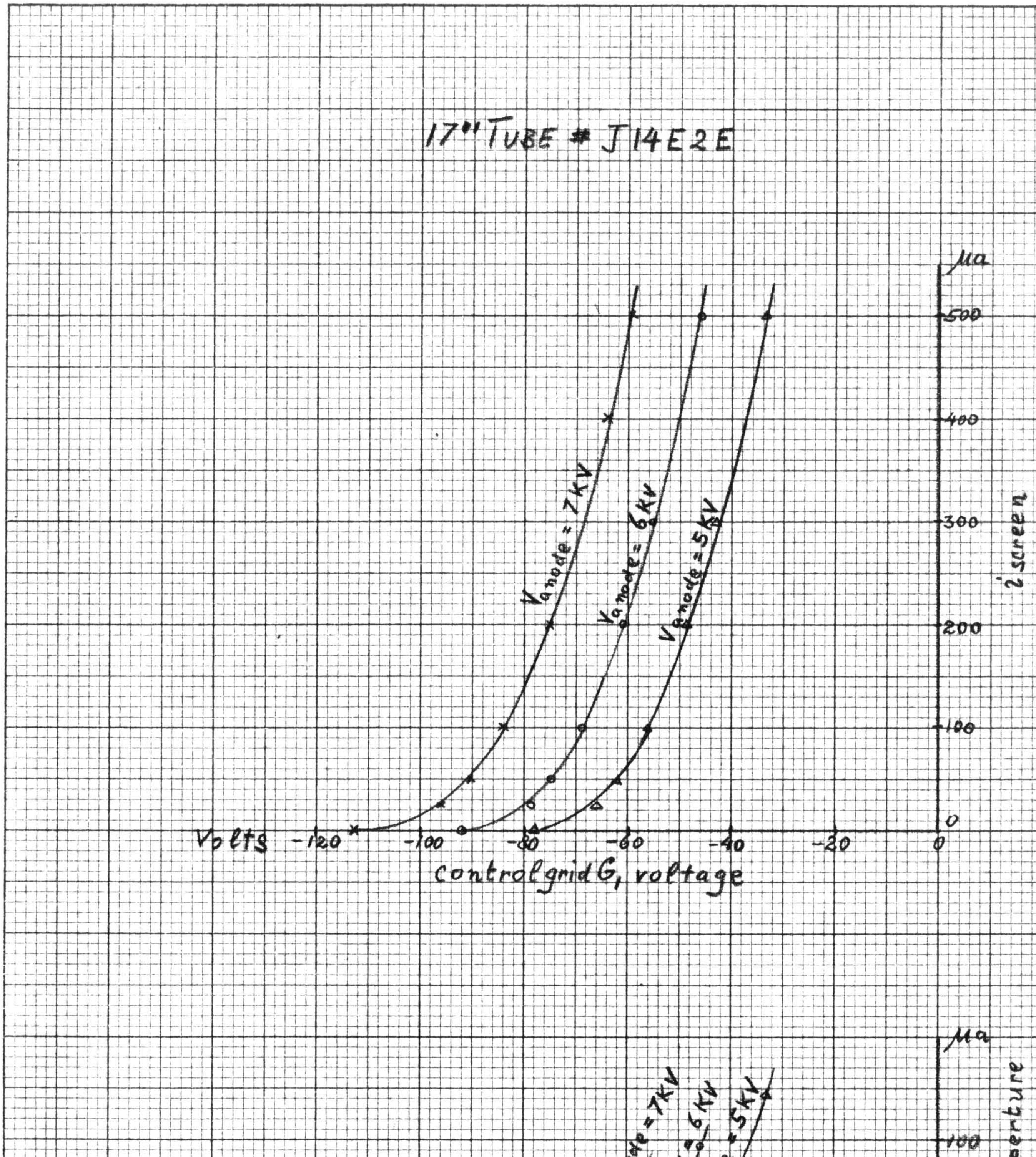


FIG. II - 98

Characteristics of triode for .330 inch base tri-color gun

Screen current and limiting aperture current vs. control grid G_1 voltage

P. H. Gleichauf 10-19-54

To obtain 50 foot Lamberts in the white highlights, 170 microamperes are required from the red gun at 5000 volts on the gun, and 150 microamperes at 7000 volts. The resolution was:

V anode in volts	i screen in microamperes	lines resolution
5000	170	400 x 420
7000	150	>500 x 500

on a 19" screen. The maximum resolution that the test pattern can indicate is 500 x 500.

To confirm earlier measurements, tests were made on a gun with one less pair of focusing electrodes, that is without G_5 and G_6. The results showed again that with periodic focusing - that is, with a G_5 and G_6 in the gun - the maximum screen currents before blooming were about 30% higher.

The maximum screen currents at which a resolution of about 300 x 300 lines could be read in this gun were:

V anode in volts	i screen in microamperes
5000	200
6000	270
7000	330

Tri-Color Gun:

Convergence Systems: The guns were originally equipped with electrostatic convergence systems similar to those of the .220" inside diameter guns. The gun is shown in Figure II-99. The deflection plates were not slanted, but were parallel with the axis of the gun since the gun was placed farther away from the yoke. In this position of the gun with respect to the yoke, no interference of the beams with the deflection plates was expected. The deflection plates were .750" long to obtain the desired sensitivity. The center horizontal convergence plates which were originally on gun potential, were insulated for more convenient circuitry.

It was found that this electrostatic convergence system was not satisfactory for the larger base - i.e., the .330" base. The main reason for unsatisfactory performance was the enlarged base requiring a larger deflection angle, and the larger deflection plate spacing. Further, the resolution of the guns was improved and defocusing became, therefore, more

FIG. II-99
.330 INCH BASE TRI-COLOR GUN

noticeable. And another reason was probably that, at the large beam currents, which were about 2 to 3 times higher than in the .260" base guns, the current densities in the slender beams were high and distortions produced by the field became more pronounced.

The deflection schemes below were considered:

(1) The deflection plates could be shaped. The desired shaping, however, could not be fully achieved because of close spacing of the three guns.

(2) The deflected spot was very little distorted when one of the deflection plates was held above and the other plate, by about the same amount, below the potential to which the electrons in the beam were accelerated (push-pull deflection). The beam passed through the field created by the deflection plates in the neighborhood of an equipotential corresponding to the electron velocity in the beam.

(3) Complete convergence could be achieved by only two permanent magnets. The distortions were high.

(4) For magnetic convergence, four pancake-type coils designed by R. Gethmann were tried. For perfect convergence, the currents through the coils could be adjusted or magnetic shunts could be used with these coils for adjustment of the fields. The performance of this system was superior to the then used electrostatic deflection system, without push-pull drive, by a factor of about two, but was inferior to the electrostatic deflection system (2) with push-pull deflection.

(5) Another magnetic convergence scheme was suggested by R. Gethmann. Permanent magnets to be used on the outside of the tube neck, and pole pieces providing a more uniform field by which the beam is deflected to be placed on the end of the gun. The two outside beams could be converged in the horizontal and vertical direction. Four magnets would be required. No tests were made to evaluate this design. It was believed that this scheme would be an improvement over the system described under (3).

Finally, it was decided to preconverge the guns in the horizontal plane by tilting them. Calculations for angle of tilt of the guns are given in Chapter III, Section II. Four convergence coils or two permanent magnets, about 1/2" from the end of the gun, were used to correct for perfect convergence. The center beam was partly shielded by a mu-metal shield 1/2" long (see Fig. II-20 in Section I of this Chapter). Dynamic convergence was obtained from the coils as described in (4). The plane of dynamic convergence is, in the latest tubes, 1.5" from the plane of deflection - i.e., the dynamic convergence coils are between the yoke and the end of the gun. In later designs, it is intended to change this distance to 1.8". The mu-metal shield is kept short to prevent the color base from becoming non-uniform when applying the color purity coil or when sweeping the beam. This would happen when the center beam would be less deflected than the two outside beams. It should be mentioned here that the color purity coil should be placed between the end of the gun and the yoke, to prevent shifting of the beams from the gun axis, which leads to distortions.

Construction of Tri-Color Gun

The construction of the gun was simplified, convergence elements were placed outside the tube. Five high-voltage leads along the gun were eliminated. This was desirable since it was found earlier that these leads can produce aberrations in the focusing lenses and change the color base. Therefore, in the presently used design, only on the center gun are leads connecting the high-voltage electrodes in the axial direction of the gun. All other connections of high-voltage electrodes were made perpendicularly to the gun axis so as not to affect the focusing lenses of the other guns.

The capacity of the control grid G_1 to all other electrodes tied together with the base on the tube was 6.5 to 7 micromicrofarads.

Other Design Considerations

Two slightly different designs of the first anode cylinder were used. The machined first anode G_2 shown in Fig. II-100 had a .115" aperture with a 60° taper which blended into the top plate of the electrode. The drawn first anode had a .125" aperture and a shape as shown in Figure II-5 of Section I of this Chapter. Beam angle measurements showed that the beam angle for both designs was about the same.

It was tried whether in the triode the wide open space between the control grid G_1 and the first anode G_2 could be reduced to eliminate possible distorting fields from the outside of the gun. On a beaded gun, a ring was slipped over the control grid G_1 and welded to it, while between this extension of G_1 and G_2 a spacing of .020" was left. By this assembly method, parallelism of the surfaces of G_1 and G_2 was not affected. This flange on G_1 itself introduced strong distortions.

Some of the guns, triodes and tetrodes, still showed aberrations, an elliptical spot. The pulsed spot showed not only ellipticity, but also a star-shaped halo around the spot. The ellipticity was, to a large extent, eliminated by reduction of the spacing between the high-voltage electrodes to .045" as described earlier. A further step to reduce aberrations in the focusing lenses was to equip the high-voltage electrodes on either end with rolled flanges for better lens shaping. The radius of the flanges in the experimental single guns was .056". Test guns of this type in monochrome tubes did not show any ellipticity, and when the spot was focused showed only slight halo. Some difficulty will occur when using rolled flanges in the tri-color gun because of the close spacing of the three individual guns. Work on this is under progress. Tri-color guns of this type are being evaluated. Results obtained so far were good.

For formation of a small cross-over not only a short spacing cathode-control grid is desirable, but also a small control grid G_1 aperture should

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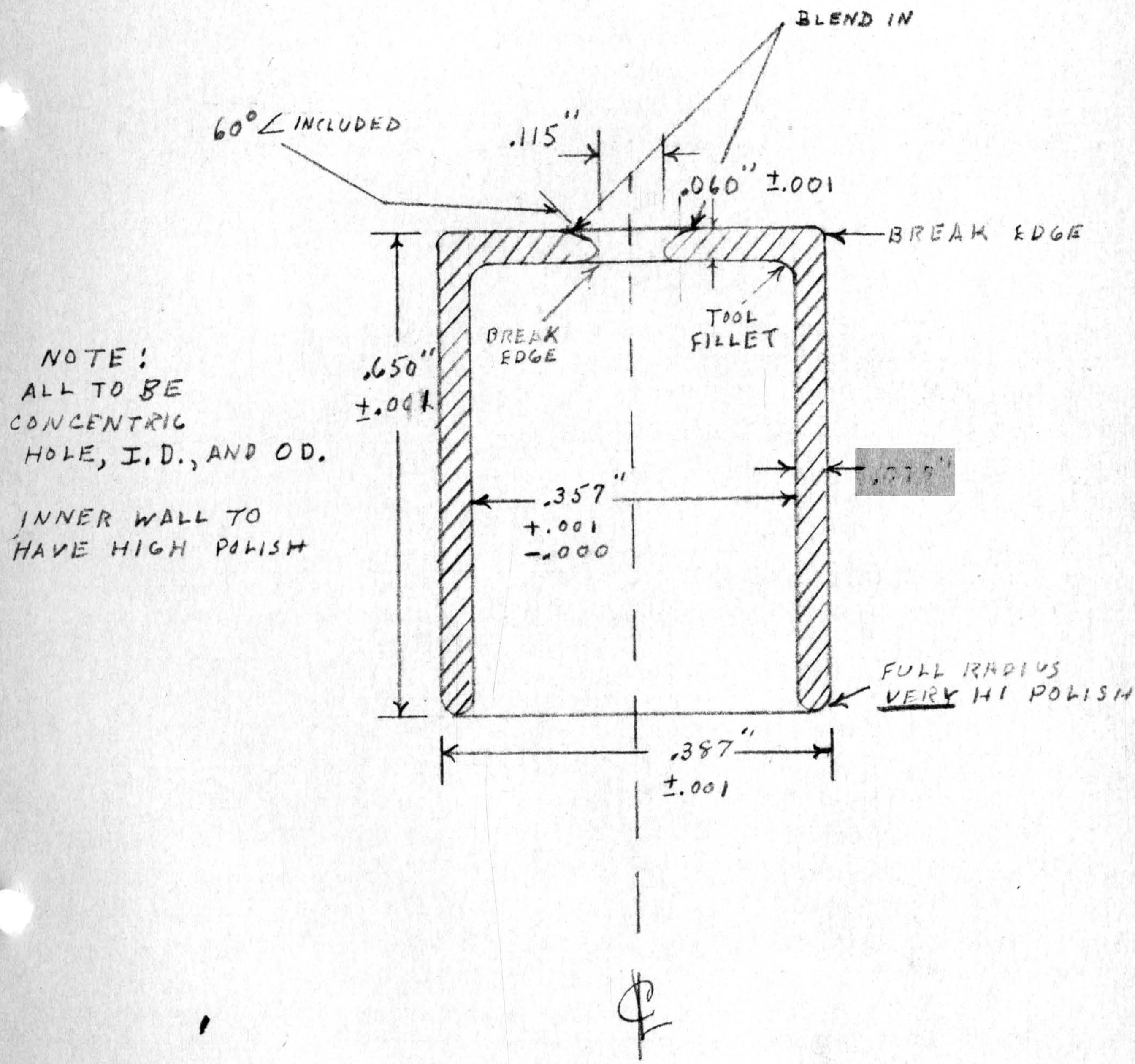


FIG. II - 100

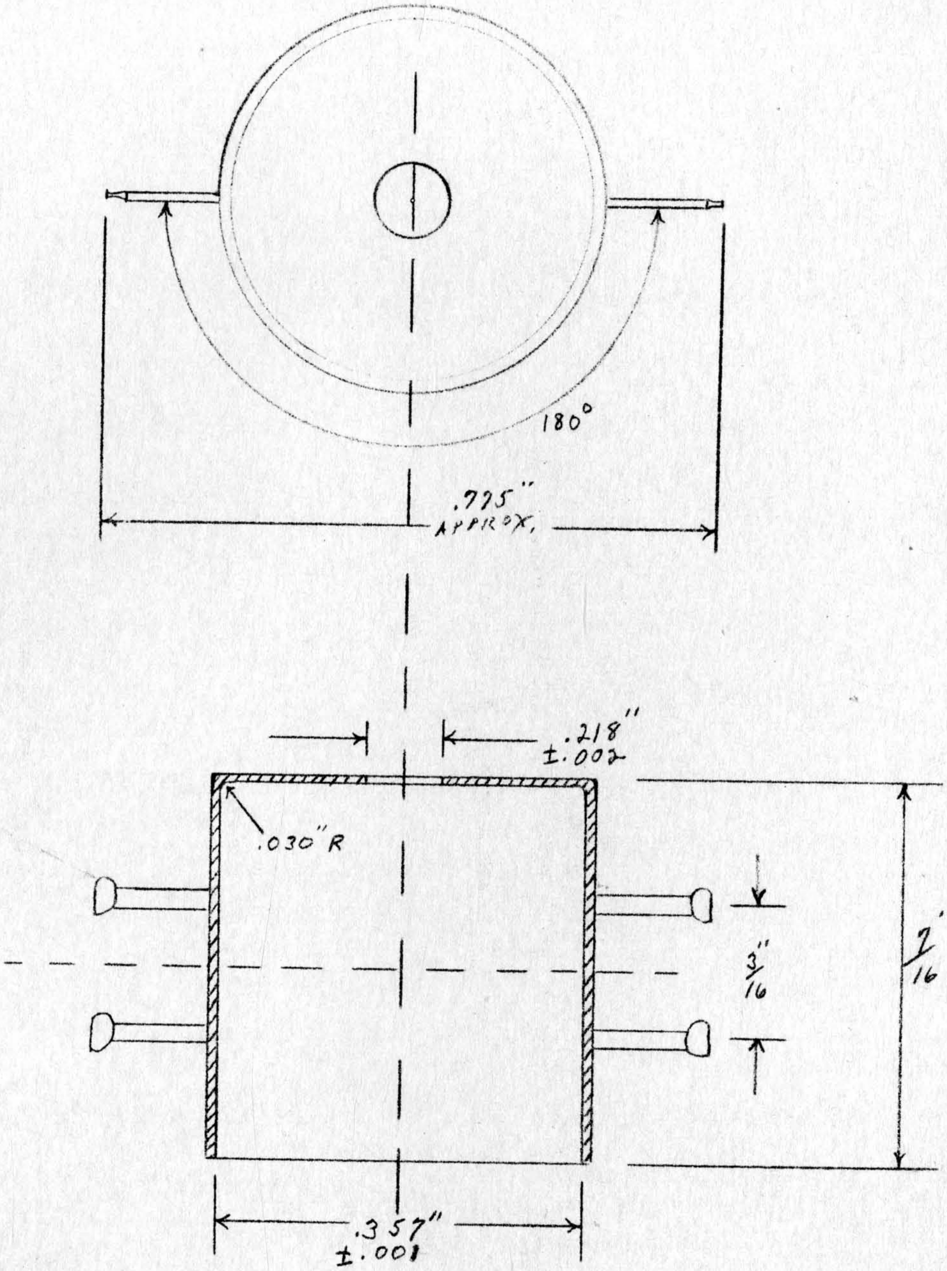
FIRST ANODE (MACHINED)

be used. In our guns, the G_1 aperture was already reduced to .021". A further reduction of this hole to .014" was tried. The resolution was high at low currents, but at high currents the spots became fuzzy. It seems that such small apertures can not be recommended in guns with electrostatic focusing for high screen currents.

The effect of insufficient cathode emission on resolution was pronounced, especially in the smaller guns with .220" inside diameter. Dead cathode areas, or areas with low emission, produced a distorted spot. When the emission of the cathode center is low, the field penetrating into the cathode region starts to draw electrons from the space charge around the central region where saturated emission is approached. Electrons from the region adjacent to the central part of the cathode acquire from the field velocity components parallel to the cathode, a wide beam angle results, and losses to the limiting aperture become high. In the color tubes, the emission was not so good as in the non-aluminized monochrome tubes pumped with a liquid nitrogen trap. Therefore, the current losses to the limiting apertures in color tubes were higher than in monochrome tubes and the resolution lower. The limiting aperture current in monochrome tubes at 7000 volts anode voltage was, for example, negligible up to 250 microamperes (see characteristic of Fig. II-98, whereas in color tubes with good emission it was about 50% of the cathode current. Originally, the tubes were pumped without a liquid nitrogen trap. This was done to work under the same conditions as on the production line. Nevertheless, our experience is that some kind of trap on the vacuum system is necessary to obtain reasonably good emission in the color tube. Even though the emission was very much improved when using liquid nitrogen trap, it was not yet up to the standard desired. Improved continuous gettering seems necessary. Titanium getters developed so far were not fully satisfactory in design. New designs are being tested. Another difficulty observed was sparking in the tubes. High-voltage breakdown, mainly over the insulators in the front end, could frequently be observed in earlier tubes. Such a breakdown usually ends up with an arc in the gun after which emission is reduced. Damaged areas can then be found on the cathodes and the resolution is lowered after arcing.

Finally, a control grid assembly is described which permits microscope alignment. The control grid consists of two parts. A cup (Fig. II-101) with a .218" opening on the top and a disk (Fig. II-102) with the control aperture. The disk is to be welded to the control grid cup in the assembled gun while using for alignment a microscope with an adapter as shown in Fig. II-51.

A modified gun was suggested using smaller diameter tubing with .327" and .328" inside diameter. The gun diameter was reduced to obtain a shorter tube neck for the .300" base color tube. The currents at which blooming would occur are expected to be 15% lower than in guns with a .357" inside diameter.



MATERIAL:
0.015" ST. STEEL
(NON-MAG)

FIG. II - 101
Control Grid Cup for Microscope Alignment of Gun

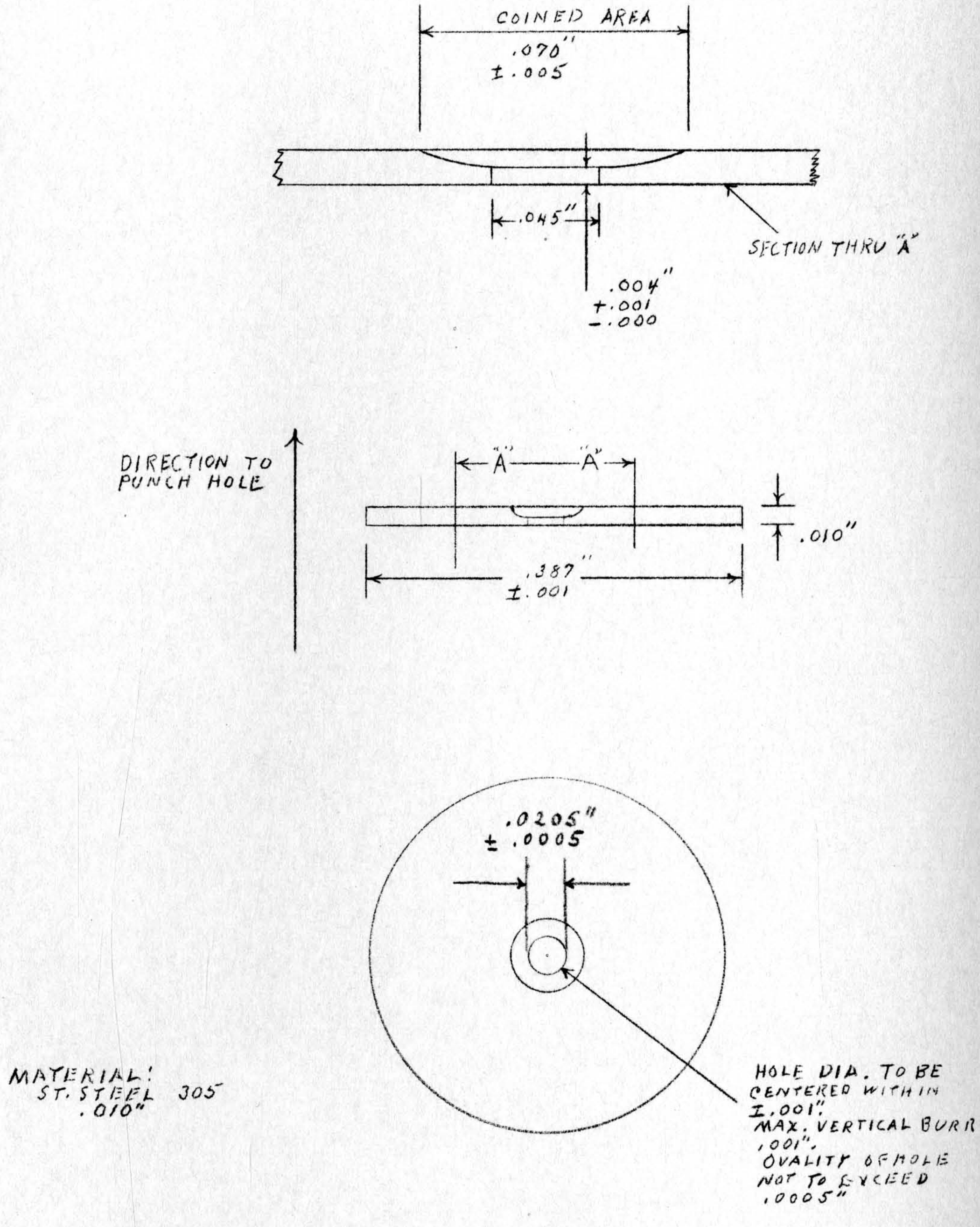


FIG. II - 102

Control Grid Disk for Microscope
Alignment of Gun

The Hollow Cathode Gun

The hollow cathode has features of special interest for the tri-color gun. The cathode is well protected from ion bombardment and arcing. The apparent cathode area is limited and, therefore, less blooming at high currents is to be expected.

The design and development of the hollow cathode itself is described in Section III of this Chapter.

Hollow cathode guns of the tetrode and triode type were built. The hole in the cathode was, in most cases, .007". The gun assembly of a triode consists of two sub-assemblies (Fig. II-103)*.

The cathode with the control grid form one sub-assembly (Fig. II-103(d)); the high-voltage electrodes form the second assembly (Fig. II-103(a)).

The control grid G_1 consists of a cup with a flange which is used for welding of the cathode-control grid sub-assembly to the high-voltage sub-assembly (Fig. II-103(e)). The grid G_1 was formed of two parts, a cup (Fig. II-104) with a .218" hole on the top and three elongated alignment holes placed 120° apart. A plate with the coined control grid aperture (Fig. II-105) is welded to the top. An embossed ring, as in Fig. II-4, is recommended for use on the top plate, but was not used in the developmental samples. For concentricity of the hole in G_1, it is recommended to pierce the hole after the top plate is welded to the cup. The hole in the hollow cathode is aligned with the G_1 hole using a microscope and welded in place, as described in another chapter. Then the elongated holes in the grid cup are covered with a stainless steel ring to prevent stray emission.

The other sub-assembly is essentially identical with previous gun designs (Fig. II-103(a)), but instead of the control grid, a bridge (Fig. II-106) is sealed to the glass beads.

Microscope alignment is used with the adapter of Fig. II-51. The flange on the control grid G_1 and the bridge (Figure II-103(b) or II-106) of the second sub-assembly serve for welding of the two sub-assemblies together.

To make structure more rigid, it is suggested to use a modified bridge as shown in Figure II-103(c).

Experimental Results: A tetrode with .220" inside diameter tubing, similar to design #3 was used in these tests. The hollow cathode had an aperture of .007", and the aperture in the control grid G_1 was .018".

The maximum current, at which a resolution of about 300 x 300 lines was read, was:

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* Patent Docket No. 4D-587, of August 26, 1954, by P. H. Gleichauf.

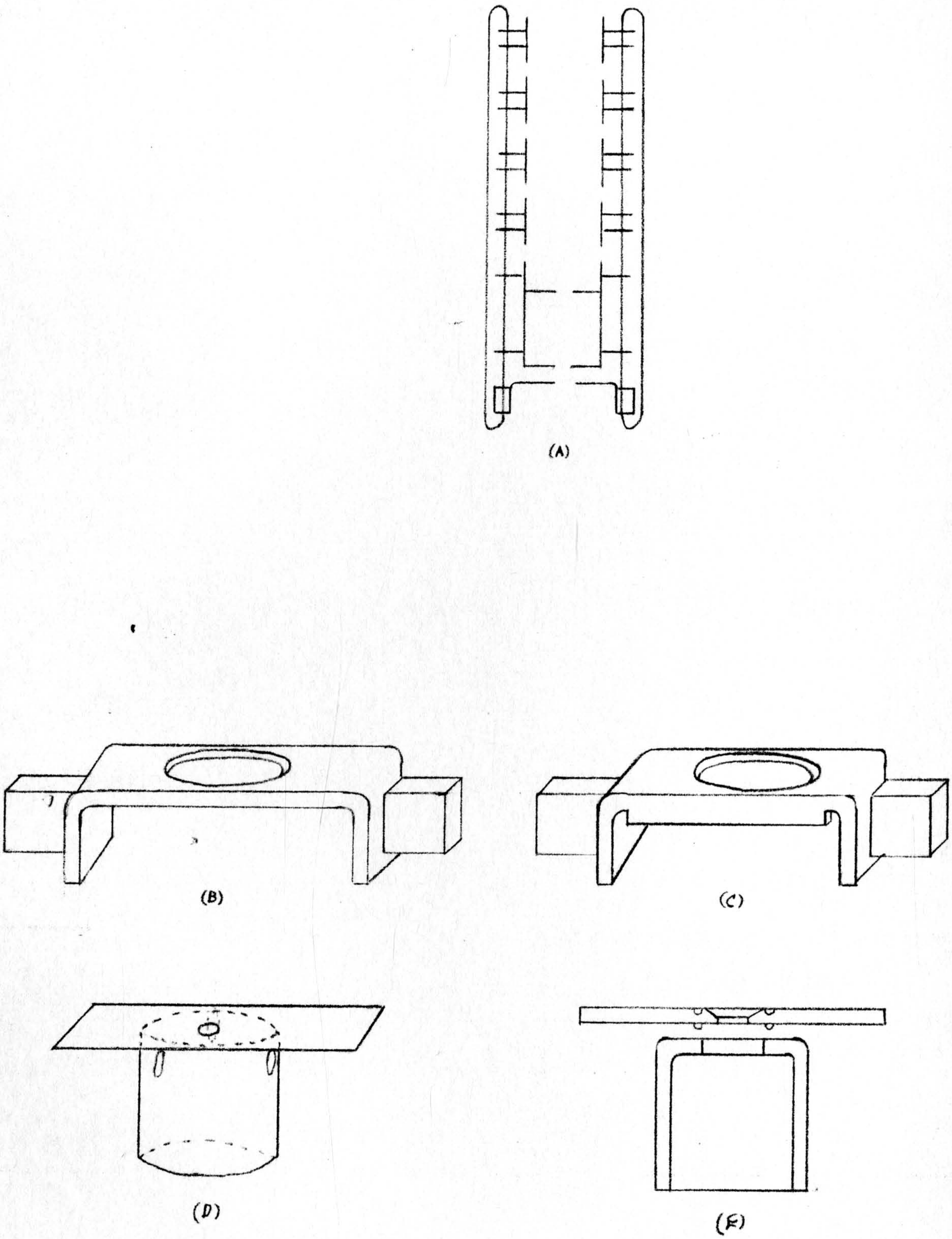

FIG. II - 103

Parts for Gun with Hollow Cathode

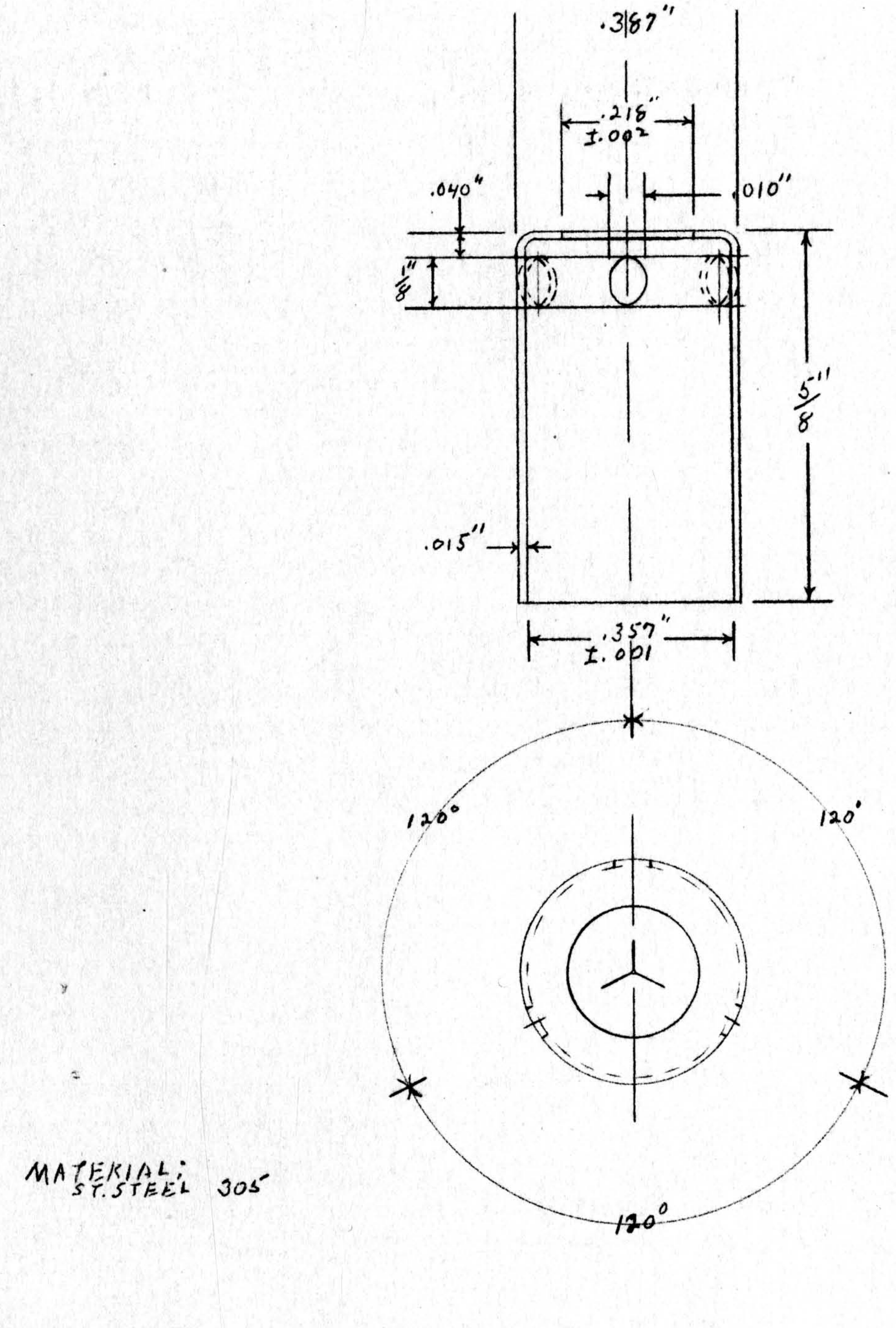

FIG. II - 104

CUP OF CONTROL GRID FOR HOLLOW
CATHODE

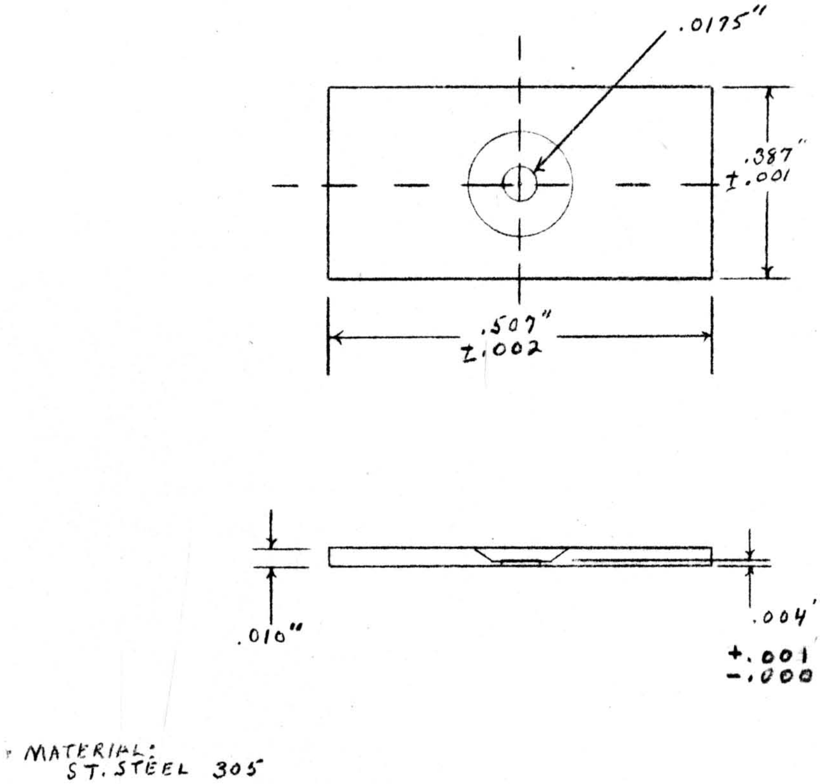

FIG. II - 105

Top of Control Grid for Hollow Cathode

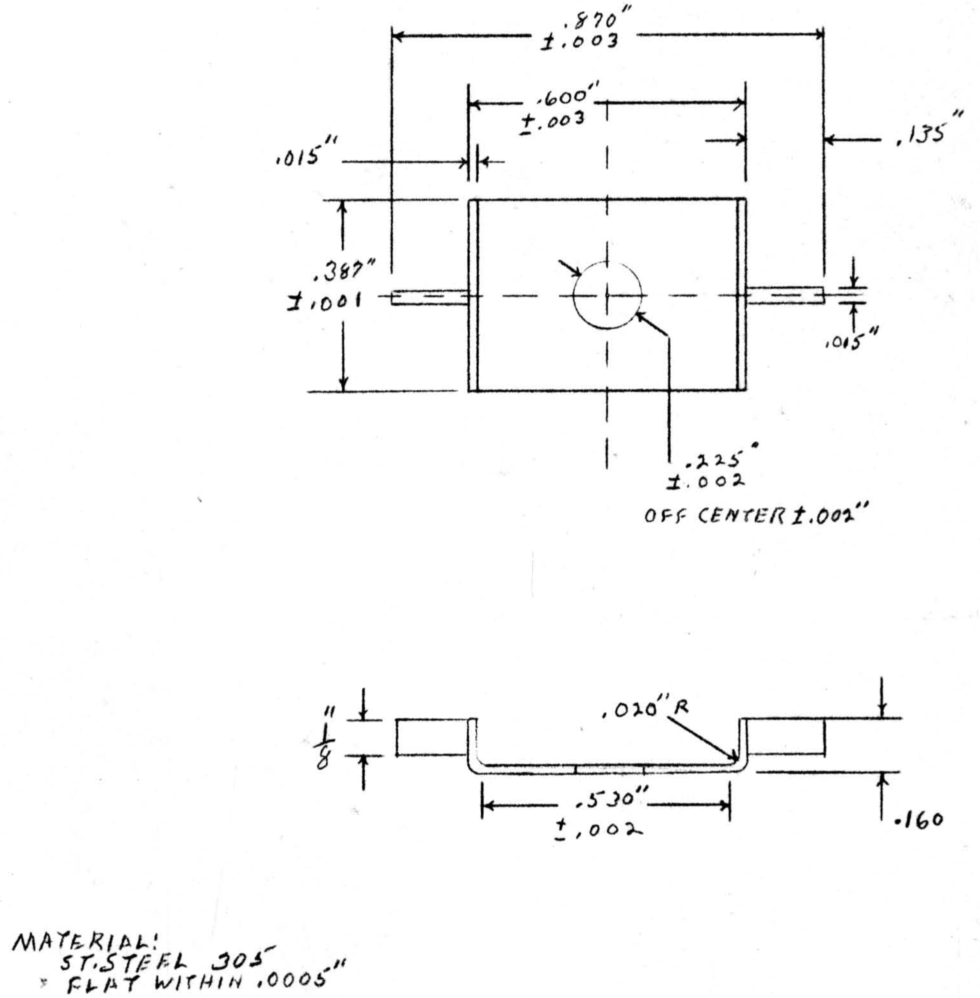

FIG. II - 106

Bridge for Mounting of Control Grid with
Hollow Cathode

Heater Voltage in Volts	Anode Voltage in Volts	Screen Grid Voltage in Volts	Screen Current in Microamperes
8	5000	500	82
8	~~6000~~	~~500~~	~~82~~
8	6000	600	98
8	6000	700	110
8	~~7000~~	~~500~~	~~75~~
8	7000	600	102
8	7000	700	120
8.5	7000	500	104
8.5	7000	600	120
8.5	7000	700	130

The results compare quite favorably with earlier results using conventional cathodes. It should be pointed out that this gun was not perfectly aligned. The alignment check was done as usually with the focusing electrodes at anode potential.

Characteristics at 5000 and 7000 volts anode voltage for different screen grid voltages are shown in Fig. II-107 and Fig. II-108.

<u>Observation of Spot</u>

The defocused spot indicated that at high currents most of the emission came from an area adjacent to the edge of the cathode hole.

In one of the triode guns with an .007" hole in the cathode and a .014" aperture in the control grid, the same picture as mentioned above was observed at higher heater power. It should be pointed out that this gun had low emission. When the heater voltage was lowered from 7.5 volts to 6.3 volts, the emission picture changed. The bright ring usually observed at the cathode hole edge contracted with lowered bias voltage toward the center of the hole, as shown in the sketch of Figure II-109. If one assumes that at low bias voltage most of the current comes from the coating adjacent to the hole on the inside of the cavity, the appearance of the emission pattern can be explaine d. At lower cathode temperature - that is, with lower emission - the field has to penetrate deeper into the cavity to extract the same amount of current as at higher cathode temperatures. The higher field and higher equipotentials in the cathode region at lower cathode temperature tends to constrict the beam as observed. It can also be seen from the characteristics in Figure II-110 that at lower heater

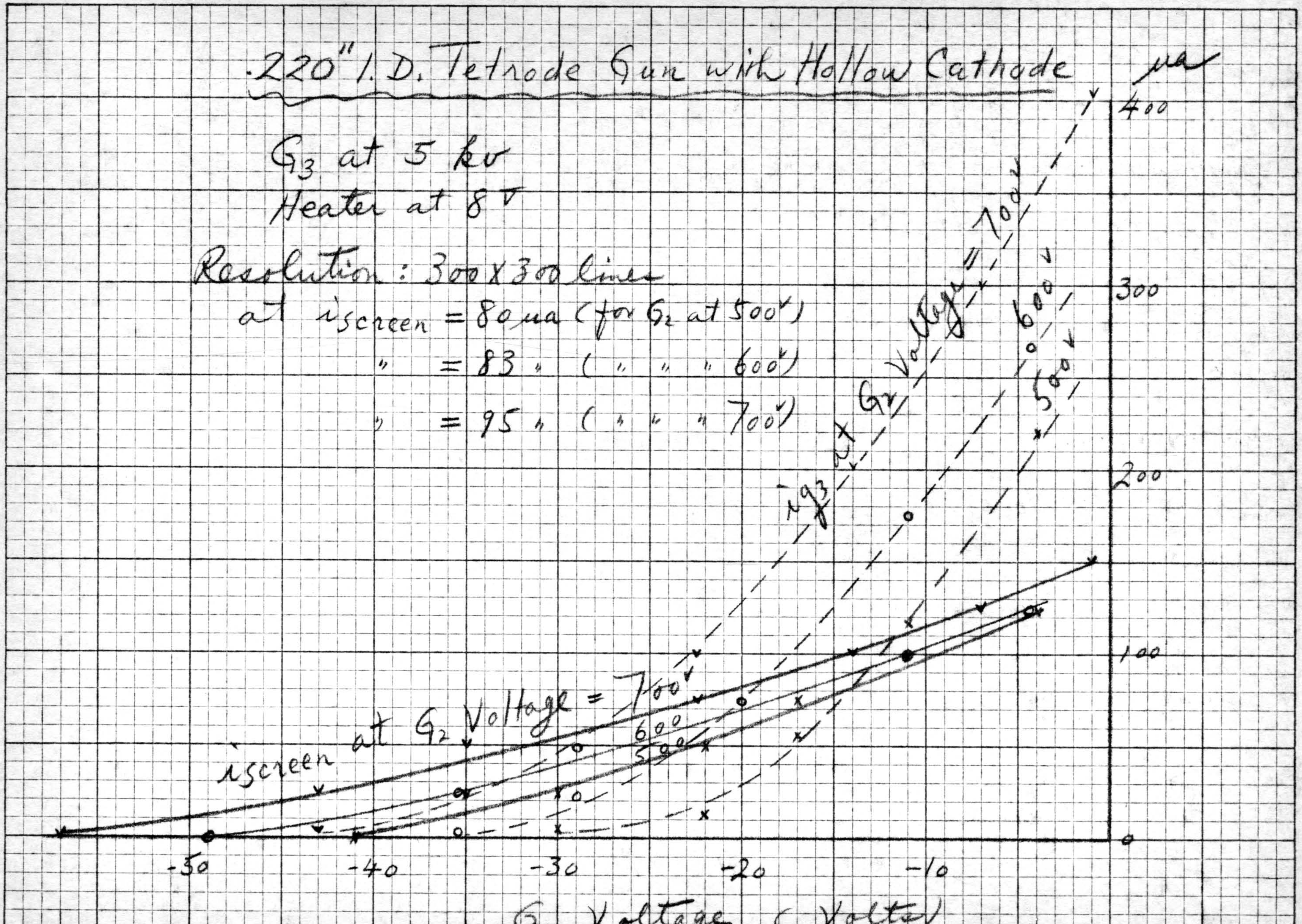
.220" I. D. Tetrode Gun with Hollow Cathode
G_3 at 5 kv
Heater at 8v
Resolution: 300 x 300 lines
at iscreen = 80 ua (for G_2 at 500v)
" = 83 " (" " " 600v)
" = 95 " (" " " 700v)
iscreen at G_2 Voltage = 700v
600
500
i_{g3} at G_2 Voltage = 700v
600v
500v
ua
400
300
200
100
0
-50
-40
-30
-20
-10
G_1 Voltage (Volts)

FIG. II - 107

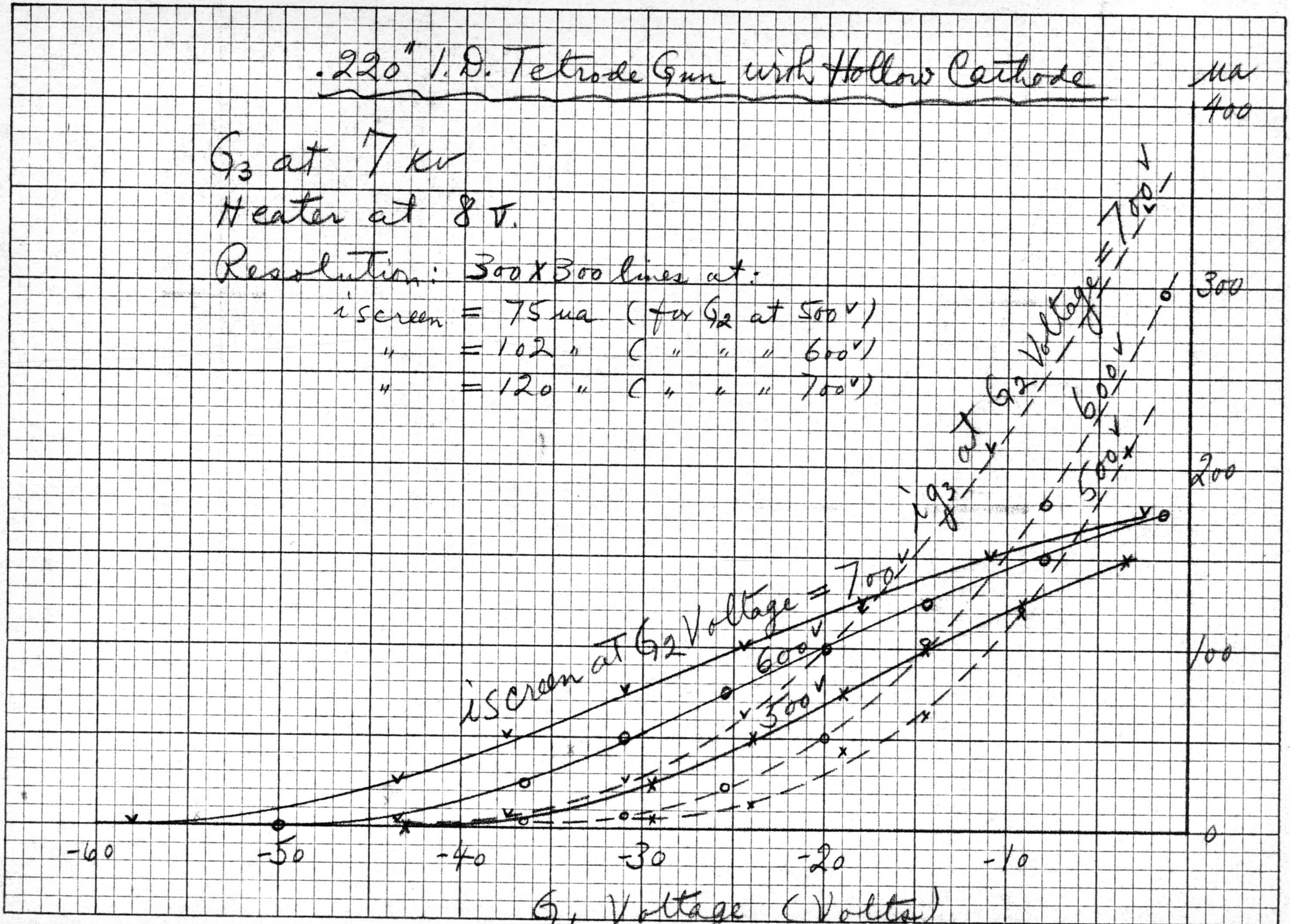

FIG. II - 108

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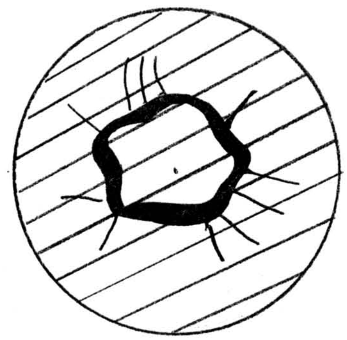

Emission picture of hollow cathode tube

Fig. II-109

voltage the losses to the limiting aperture become smaller - that is, the beam angle is reduced. Further, it can be seen that after reaching a maximum, the losses to the limiting aperture decrease with decreasing bias voltage, while the screen current increases. In guns with normal emission, i.e. about 1 milliampere or more cathode current at zero bias and 7000 volts anode voltage, the effect is less pronounced. At low currents, emission starts from a well defined ring around the aperture in the hollow cathode. With decreasing bias voltage, the ring becomes wider, i.e. spreads towards the center of the cathode aperture and tends to fill the whole aperture.

Conclusion

An electrostatic focus tri-color gun was developed for the post-acceleration color tube which is able to supply sufficient screen currents for the desired 50-foot Lamberts brightness in the white highlights. In spite of the low gun voltages available in the post-acceleration tubes, and the small gun diameter required for the color base of the tube, blooming occurred at about the same screen currents as in electrostatic focus guns for monochrome tubes.

Triodes and tetrodes were developed. The present triode is superior to tetrodes developed so far, but development on an improved tetrode design is continuing. Nevertheless, there does not seem to be need for a tetrode, since the cut-offs in triodes of a tri-color gun assembly can be held satisfactorily uniform.

Hollow cathode guns show good prospects, and much of the future effort will be directed in this direction.

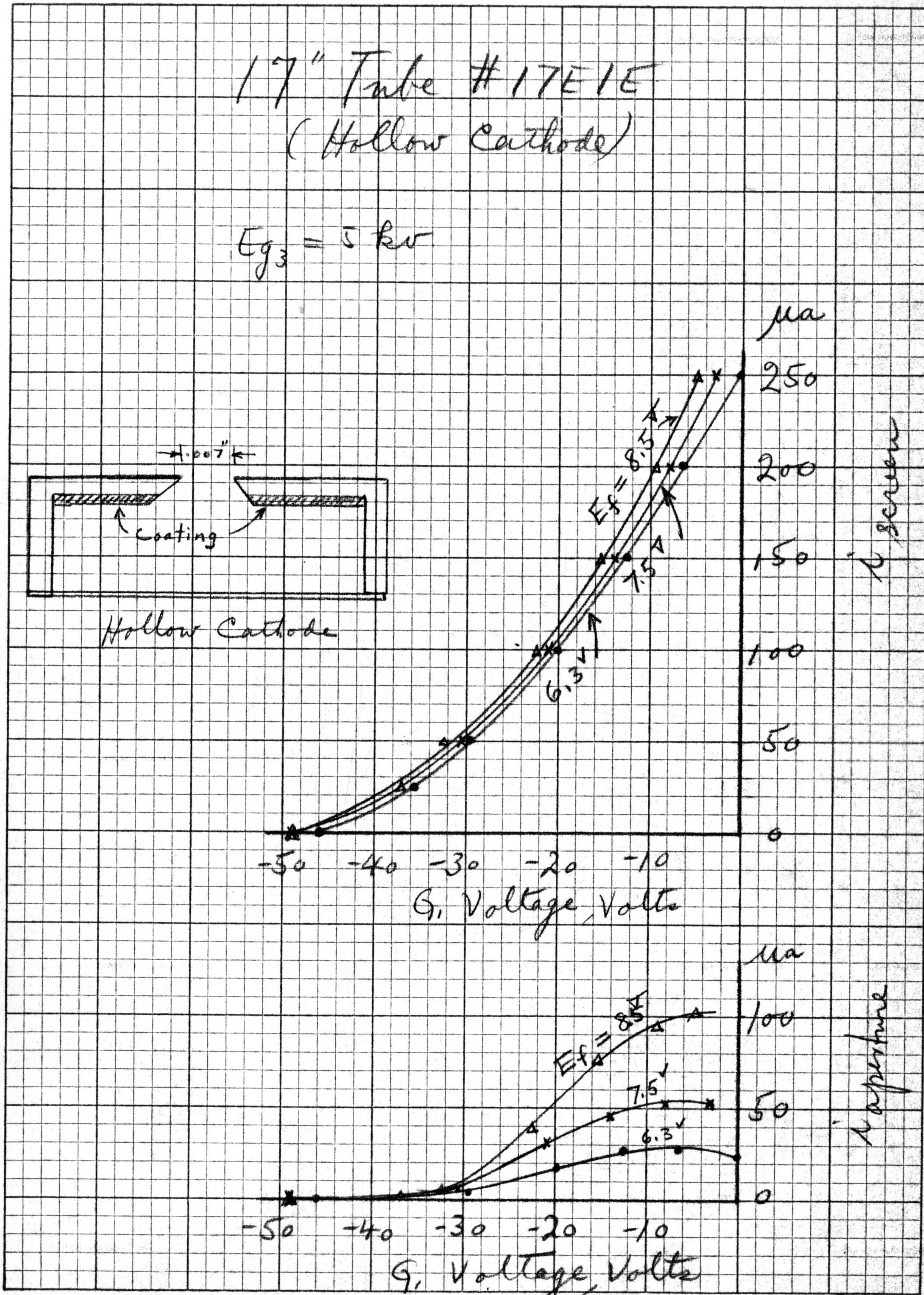

FIG. II - 110
Hollow Cathode in Triode for .330 inch Base Tri-Color Gun

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SECTION III HOLLOW CATHODES

General Remarks

Fig. II-111 shows a G_1-cathode area of an experimental gun design including a hollow cathode. In this figure,

(1) is the grid;
(2) the nickel cap of the hollow cathode;
(3) the emission coating (the bottom is not coated);
(4) the closed cathode sleeve; and
(5) the heater of the system.

A scale shows the dimensions which were used in this experimental sample measuring the cathode opening .007" and the grid aperture .013" in a distance of .005".

One of the main advantages and which primarily and basically hollow cathodes were designed for, are their life-test results excelling all life tests of planar cathode, just because of the simple fact that the emitting surface of the hollow cathode is not exposed to the ion bombardment and is less exposed to other poisoning influences.

Even if there are some discouraging results in this direction* and, in spite of the fact that our first experimental hollow cathode tubes did not achieve a very good life test, the overwhelming part of literature** for more than 20 years back shows that tubes provided with hollow cathodes have a much longer life than tubes with planar cathodes. An intensive investigation probably would discover reasons for the life test failure in our special cases.

Another advantage, aside from the longer life of the hollow cathode, is its limited effective emitting area, which, in modified gun design, can lead to smaller spot sizes and increased resolution.

A more particular study of the emission mechanism of the hollow cathode shows that there is no electron atmosphere at all inside the cavity except a very thin skin of space charge distributed all over the emitting surface. Electrons are drawn mainly around the circumference of the hole, in spite of the fact that a pulling field starts to penetrate in the center of the hole.

What we call hollow cathode is not a cathode in the regular sense, but is a cathode combined with effective electron optical features like a cavity and an aperture and their fields. Therefore, it is obvious that the basic physical laws inherent to plane cathodes, like the Child-Langmuir law,

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* Reich, T.I.S. 54E656.
** For example, Carradi, T.I.S. 53E658, or
Dobke ZS Techn. Physik 13, 432 (1932).

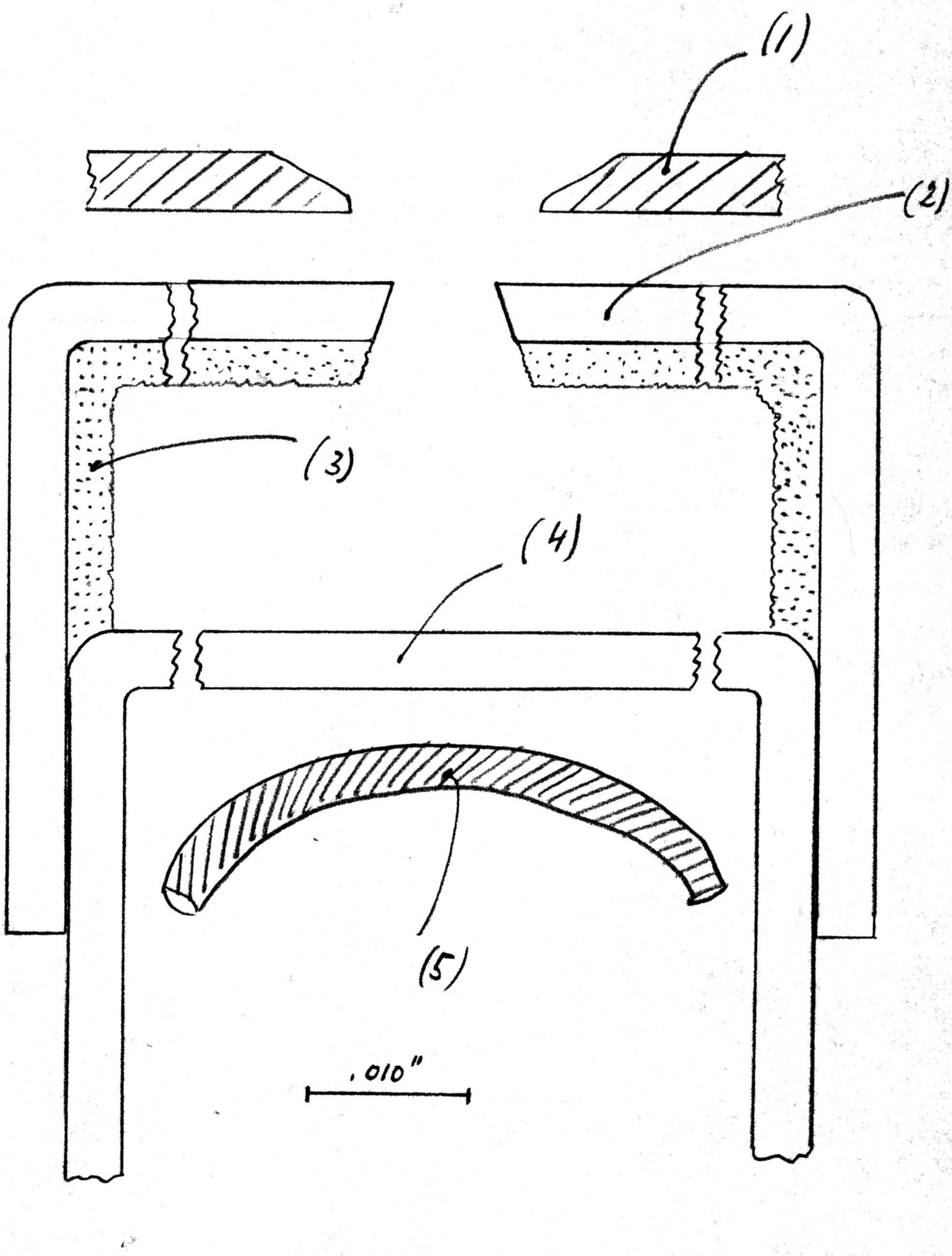

FIG. II - 111

Hollow Cathode
Control Grid 1 Cathode Region

can not be expected to be valid also for the complicated device of what we call hollow cathode. The name hollow cathode is, in itself, in this respect misleading.

There is no reason for surprise in getting discrepancies between the planar cathode and the so-called hollow cathode with respect to the Child-Langmuir law. In a similar way, one does not expect the Child-Langmuir law to be valid at any cross-over point of an electron optical system considering this point as a virtual cathode or a cathode-like region.

Publications in this field* dealing with this misleading application of the Child-Langmuir law to the hollow cathode and the comparisons with the planar cathode may raise the opinion that the hollow cathode is something which could open up completely new fields because of their properties different from Child-Langmuir law, like higher saturation currents and higher currents at low plate voltages. Our own studies** brought up a hypothesis that while drawing current a kind of diffusion of the space charge skin is going on which could explain the effects diverging from the Child-Langmuir law.

Experiments and experiences in our Laboratory**showed that all these special properties of the hollow cathode seem to get lost in the very moment we place a negative control grid into the cathode region, as it is usually done in the present gun designs. So the long life in the first approach is still the number one advantage of hollow cathode. Additional investigations, especially as to the elimination of the influences on the life tests and the improvement of gun performance, are under way.

Alignment and Tooling

In order to get good alignment between the hollow cathode and the other electrodes in the gun, a careful assembly is required. To accomplish this, it is necessary to have well designed tools.

Most of our hollow cathode samples were drawn caps having a hole in the center of the bottom and sprayed inside with an emission coating of adequate thickness. These caps fit on top of regular cathodes. In a small tool, controlling the location, these caps are put in the regular cathodes and welded to them.

Around the ceramic part of the cathode, there is an additional sleeve fastened ending in springs, as shown in Fig. II-112. These springs fit into the control grid cap, Fig. II-104, and hold the cathode within the grid temporarily allowing adjustability. An alignment ring provided with three screws in a 120° arrangement facing towards the center is put around the grid cap and these screws reach through 3 holes in the cylindrical part of

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* For example, Babcock, Halshouser and von Foerster, Phys. Review 91/3/755, Aug. 1953.

** Almasi and Fischer-Colbrie, Studies and Applications of Hollow Cathodes, not yet published.

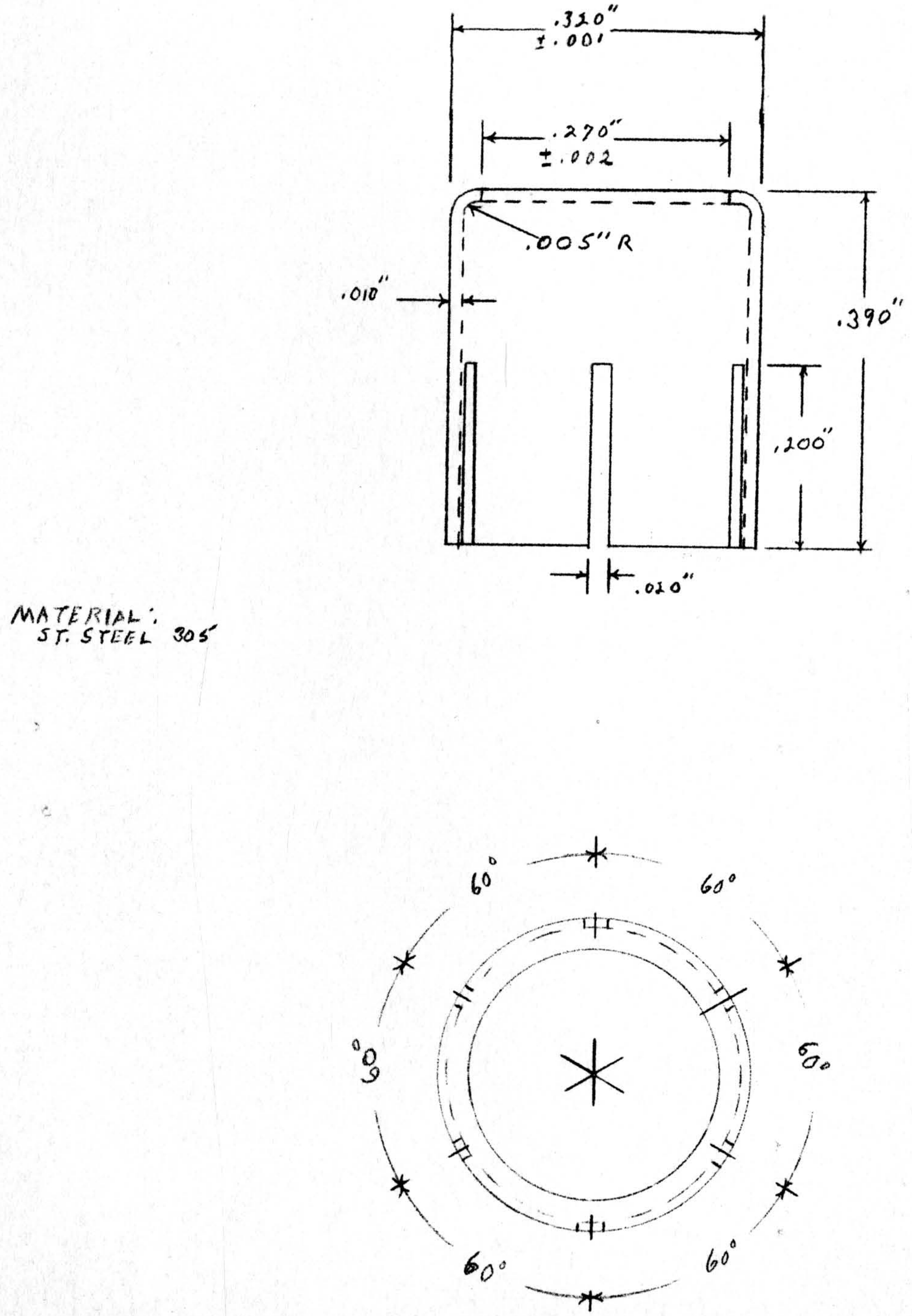

FIG. II - 112

Sleeve for mounting of hollow cathode

of the grid (see Figure II-104) to the cathode in order to align the cathode and its cavity aperture to the grid aperture. After alignment, the additional cathode sleeve is welded finally to the grid and the tool is removed.

In similar steps - i.e., provisional and adjustable placement, adjustment, and final welding - the control grid-cathode assembly is fastened to the set of the further electrodes of the gun, as described earlier in this chapter.

SECTION IV SPARKING DEVICE FOR CALIBRATION OF CONTROL-GRID TO CATHODE SPACING

This equipment is based on the idea that the sparking voltage between two electrodes in air is a function of their spacing. The criterion is to determine the critical voltage at which the sparking just starts or stops as a measure of the spacing.

In order to evaluate the idea, a test was made to measure the critical sparking voltage between two electrodes vs. their spacing. In the test, a depth micrometer head and a sheet of copper were used as the sparking electrodes. They were firmly mounted and separated by a piece of insulating plastic. The high voltage was applied to the electrodes through a 30 meg. current-limiting resistor.

The spark was detected by means of a scope. The insert of Fig. II-113 shows the connection. The same figure also gives the result of the measurement. It was observed that the curve was continuous and repeatable.

Then, a layer of oxide coating was sprayed onto the copper sheet. The same measurement was repeated. Nevertheless, the result was so irregular that the sparking voltage becomes entirely dependent on the condition of the coating instead of the actual spacing. Consequently, the sparking device can only indicate the spacing between the electrodes which are not covered with the coating. In order to use the sparking device with coated cathodes, it is therefore necessary to make an indentation on the cathode such that a reference surface with no coating can be obtained as the sparking electrode. Details of the cathode construction and the jig for indentation are shown in Section I (Fig. II-33 - II-40).

In Fig. II-114 is shown a circuit made for the sparking device. The high voltage is controlled by the 5 K 0.1 amp. potentiometer. The sparking is indicated by the "ticking" in the speaker. A relay is used for switching to measure the critical sparking voltage of either a standard control grid-cathode unit or the gun assembly to be calibrated and welded. A shorting relay is incorporated in the circuit to help discharging the high-voltage condensers as soon as the main switch is turned off.

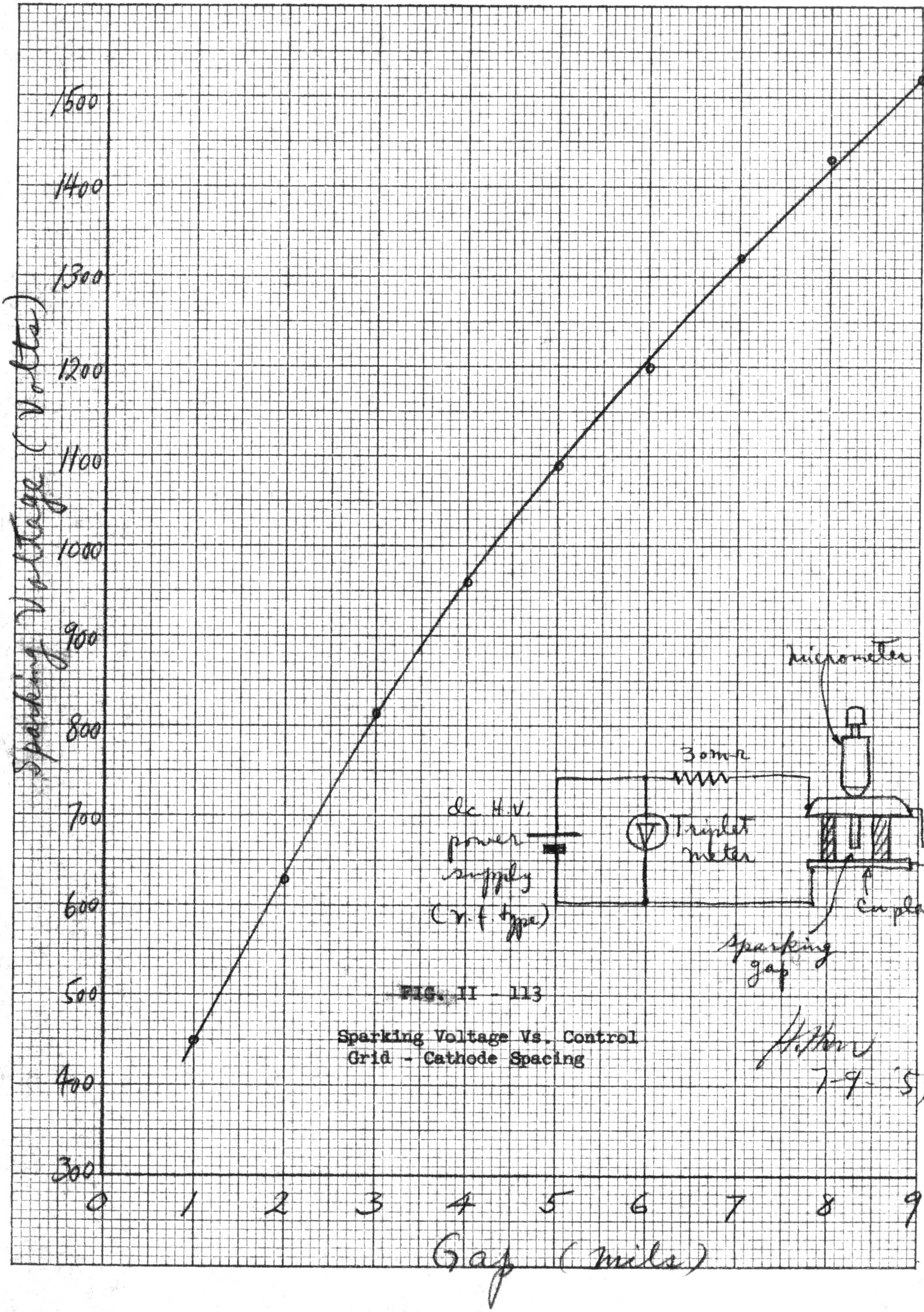

FIG. II - 113

Sparking Voltage Vs. Control Grid - Cathode Spacing

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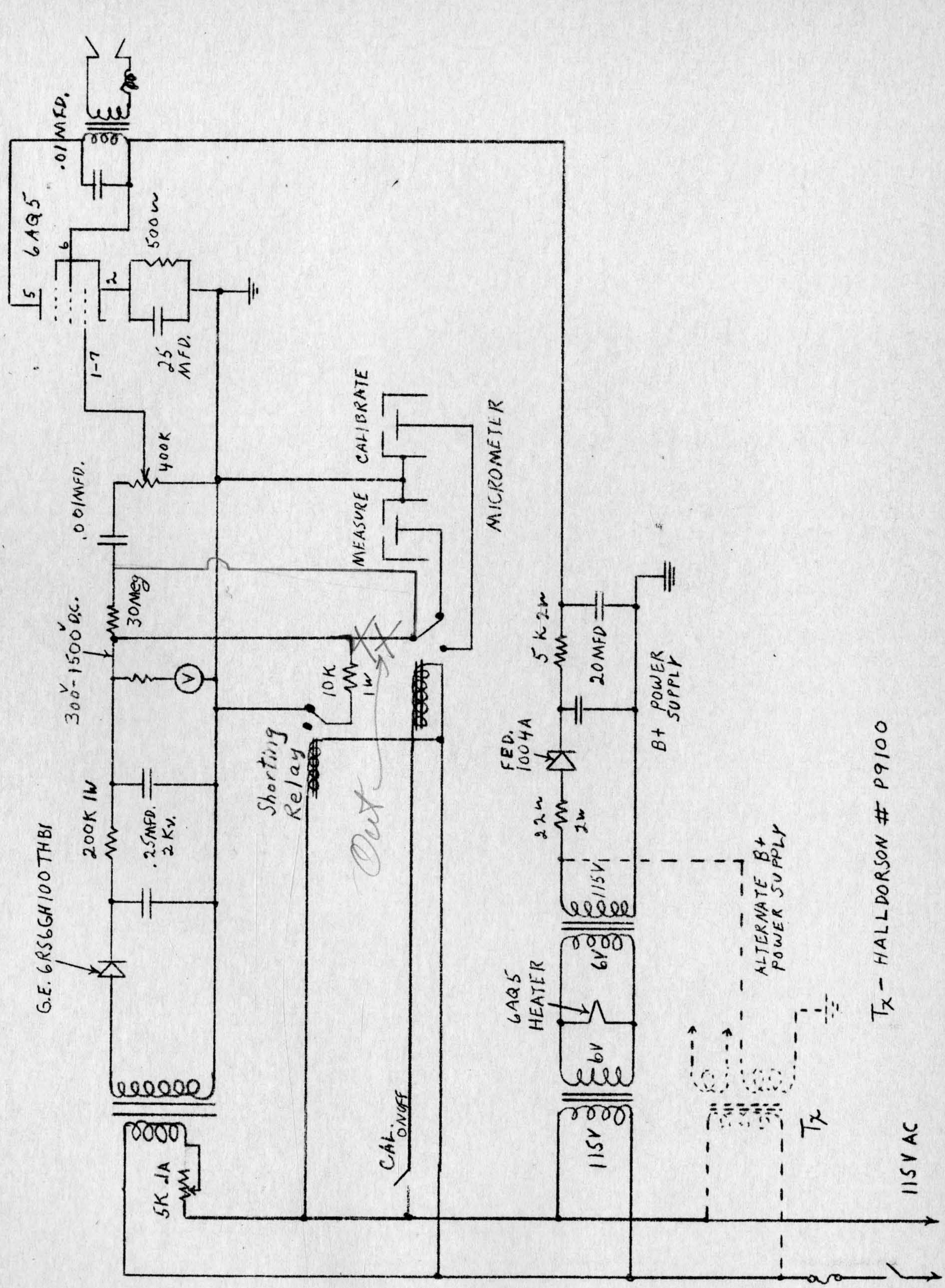


FIG. II - 114

Circuit Diagram of Sparking Device for Adjustment of Control Grid-Cathode Spacing

CHAPTER III GUN SEALING

SECTION I SEALING TECHNIQUES

The bulb which was aquadag coated according to Fig. III-1 is to be brushed to remove loose particles of the coating. After the tube has been so cleaned, a chromic oxide coating is applied around the anode button.

The tube neck is aligned with the sealing mandrel shown in Fig. III-2. The sleeve of Fig. III-3 (D_1) is pressed on part (D) in Fig. III-3. The bulb is slipped over the sealing mandrel and studs on the metal flange of the bulb are fitted into corresponding holes in the base of the sealing mandrel. The sleeve (D_1) of Fig. III-3 on the sealing mandrel is to be centered in the tube neck by placing on the studs shims between the tube flange and the base of the sealing mandrel. Lock bulb to mandrel with the three hooks of Fig. III-6, to check whether centering remains unchanged. Take bulb off sealing mandrel. Keep shims on studs. Hold shims in place on two studs with wires or plugs slipped into openings in studs. Screw shims to third stud.

Take centering sleeve (Fig. III-3 (D_1)) off mandrel. Slip gun over center mandrel (Fig. III-4 (A)) on sealing mandrel and lock end plate of gun in place with small mandrel (Fig. III-4 (C)) which fits into hole in this above plate. Fill space in two double springs with Sauerisen cement. Any two springs can be selected. No cement should come in contact with glass. Leave third spring without Sauerisen.

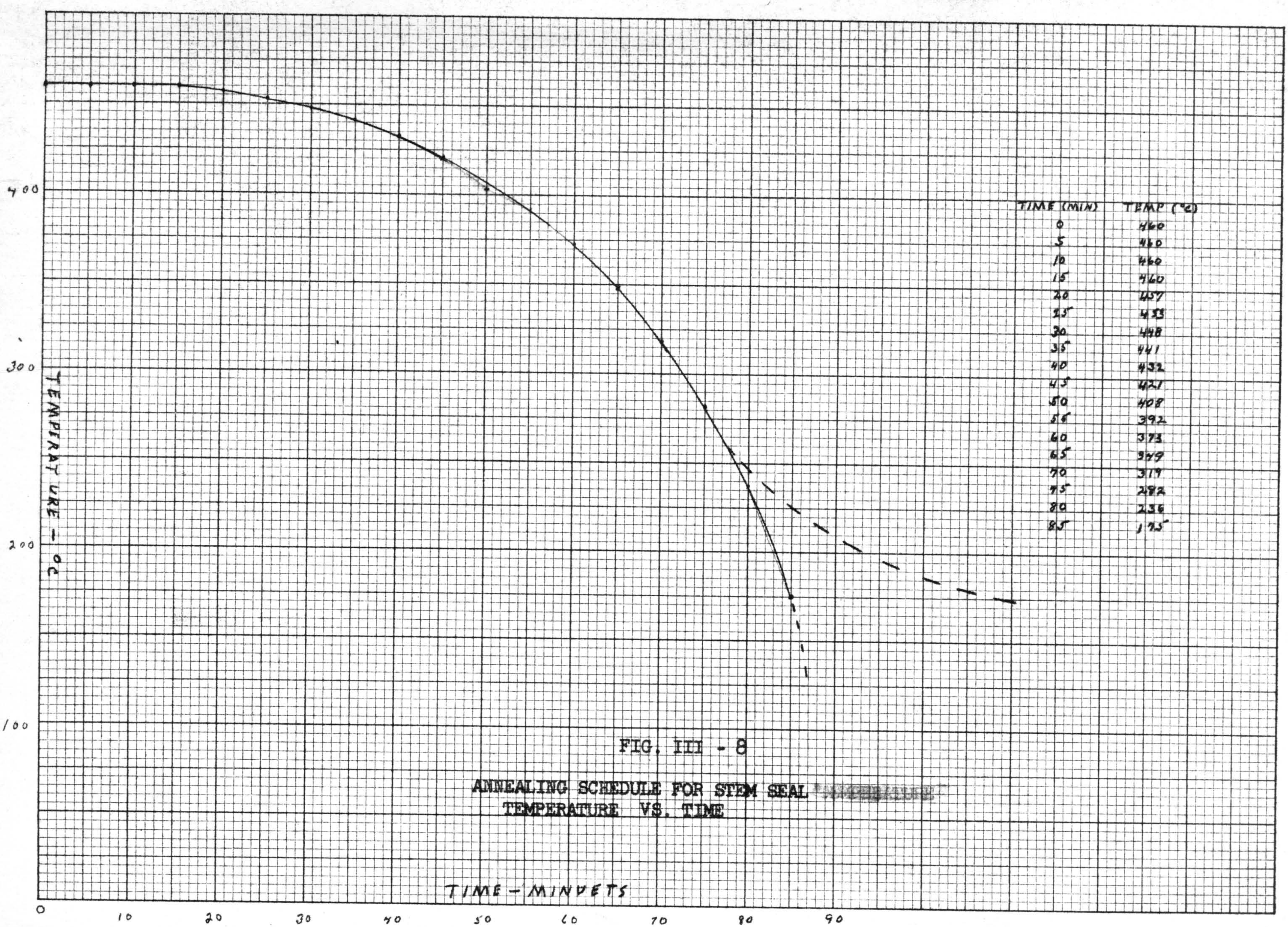
Before Sauerisen dries, slip bulb over sealing mandrel with gun. Lock bulb to base plate of sealing mandrel. Check centering of end plate of gun in tube neck. Blow out loose particles of aquadag. When using air from the line, install filter.

Sealing of Gun into Bulb on Lathe:

Place cap of tube on funnel of bulb, place several (about four) spacers between metal flanges of cup and funnel to secure openings for gas flow. Hold flanges together with masking tape, but leave openings in taping close to spacers.

After cutting neck to proper length, connect exhaust tubulation on stem of gun with soft rubber hose to tubing held in chuck of lathe for gas flow. Introduce forming gas at flow rate of 5 cfh, 92% A plus 8% H, into bulb and flush bulb for 30 minutes.

Immediately after the stem is hand sealed on the Litton EE lathe, the joint is surrounded by a preheated annealer. This annealer is of book type with the opening plane at an angle such that the opened oven can slip under the work while resting on the lathe bed. The oven is 6" in length and is so positioned axially that the seal is near the center. The oven rapidly regains its preheat temperature of 460° C. - due to its low thermal



TIME (MIN)	TEMP (°C)
0	460
5	460
10	460
15	460
20	457
25	453
30	448
35	441
40	432
45	421
50	408
55	392
60	373
65	349
70	319
75	282
80	236
85	175

FIG. III - 8

ANNEALING SCHEDULE FOR STEM SEAL [illegible]
TEMPERATURE VS. TIME

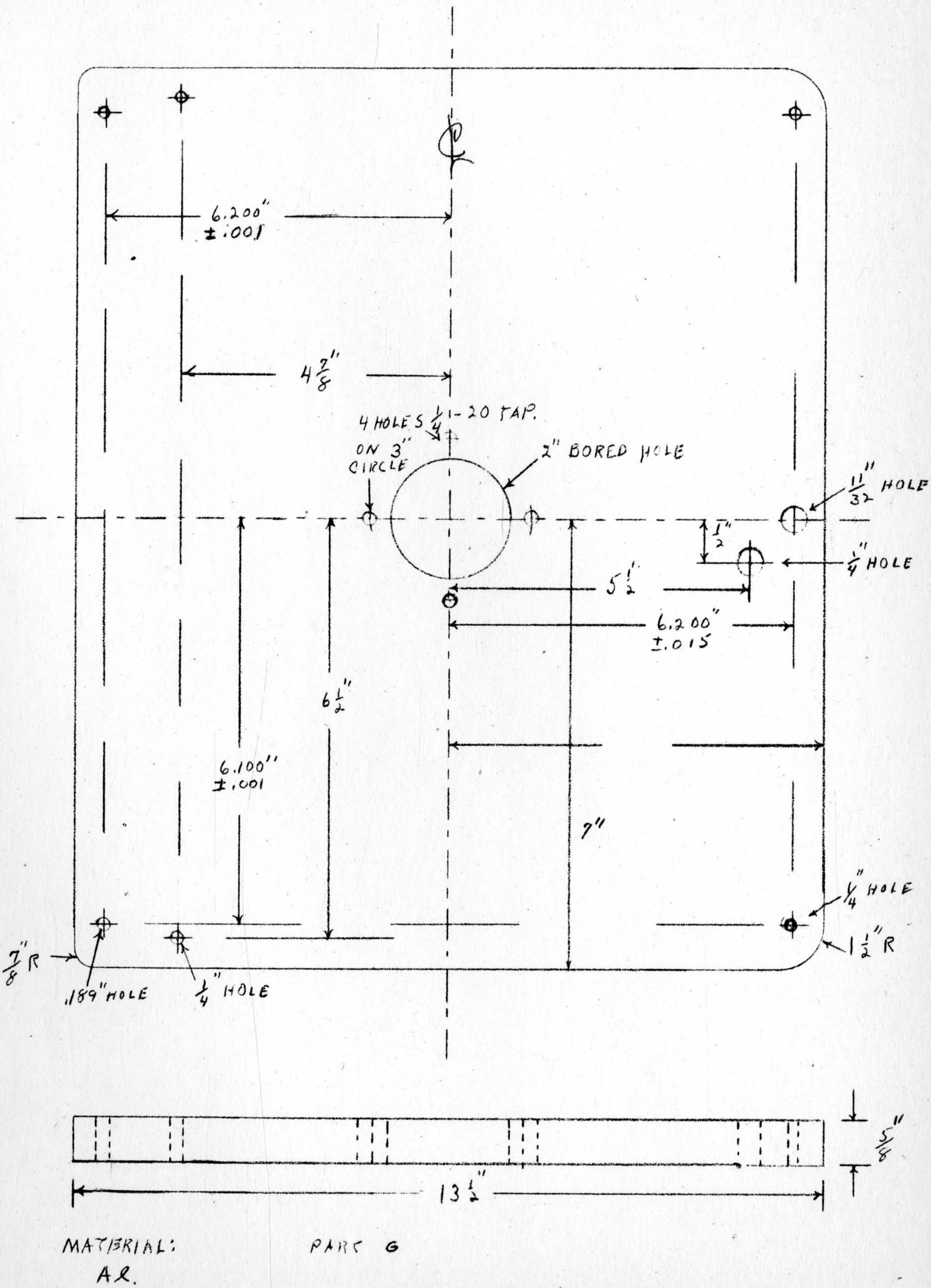


FIG. III - 7

PART FOR SEALING MANDREL

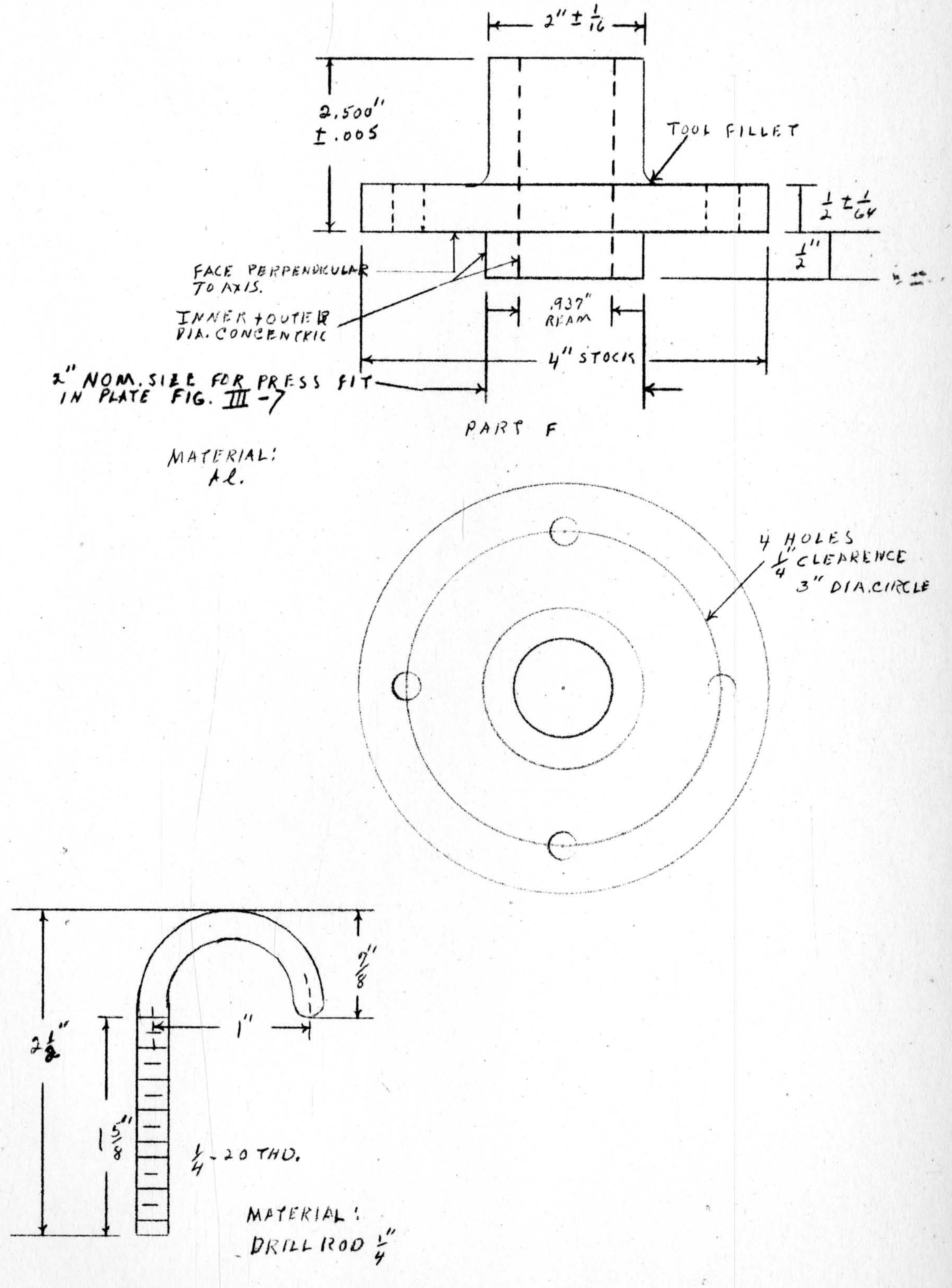


FIG. III - 6

PARTS FOR SEALING MANDREL

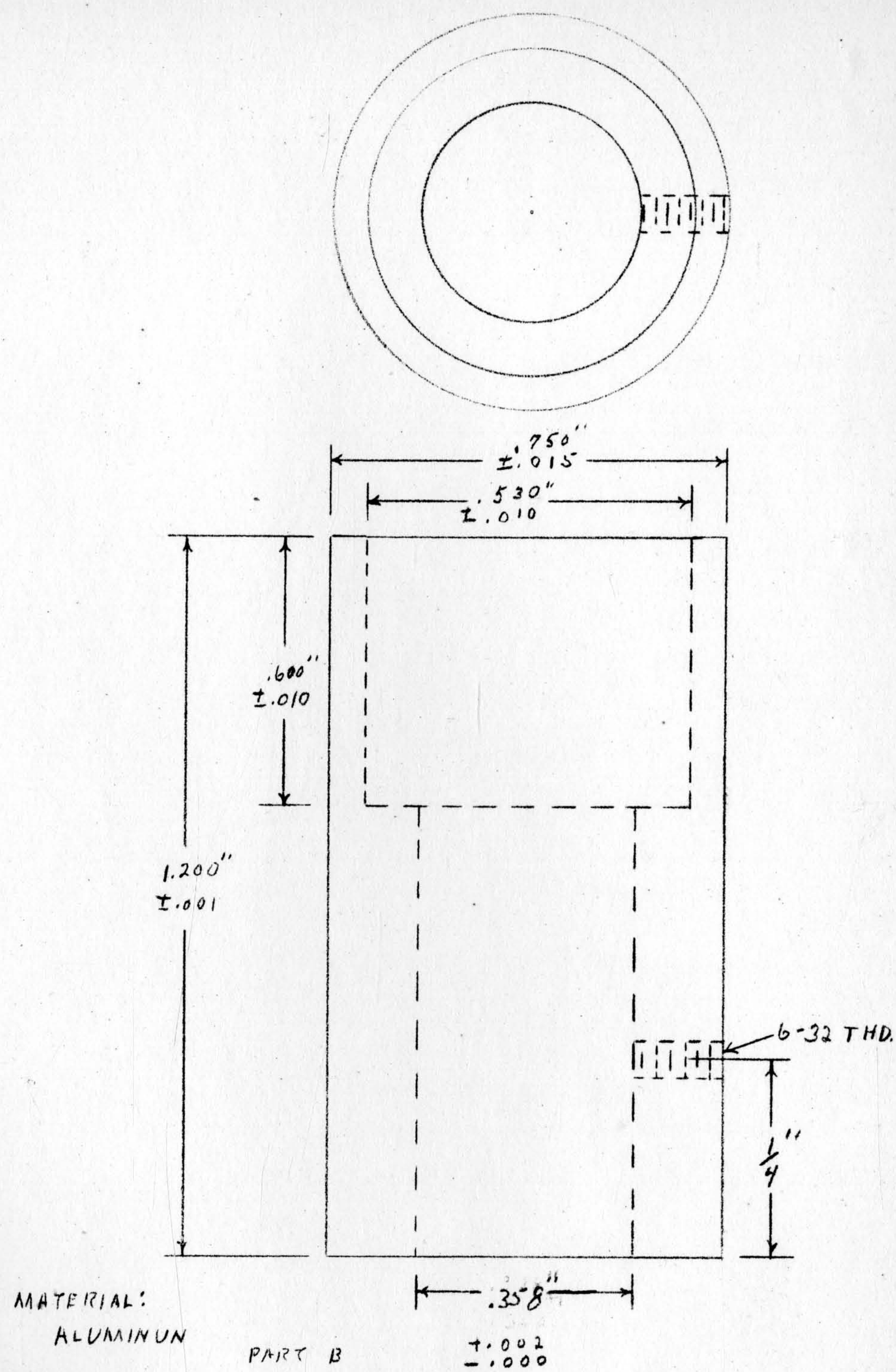


FIG. III - 5

PART FOR SEALING MANDREL

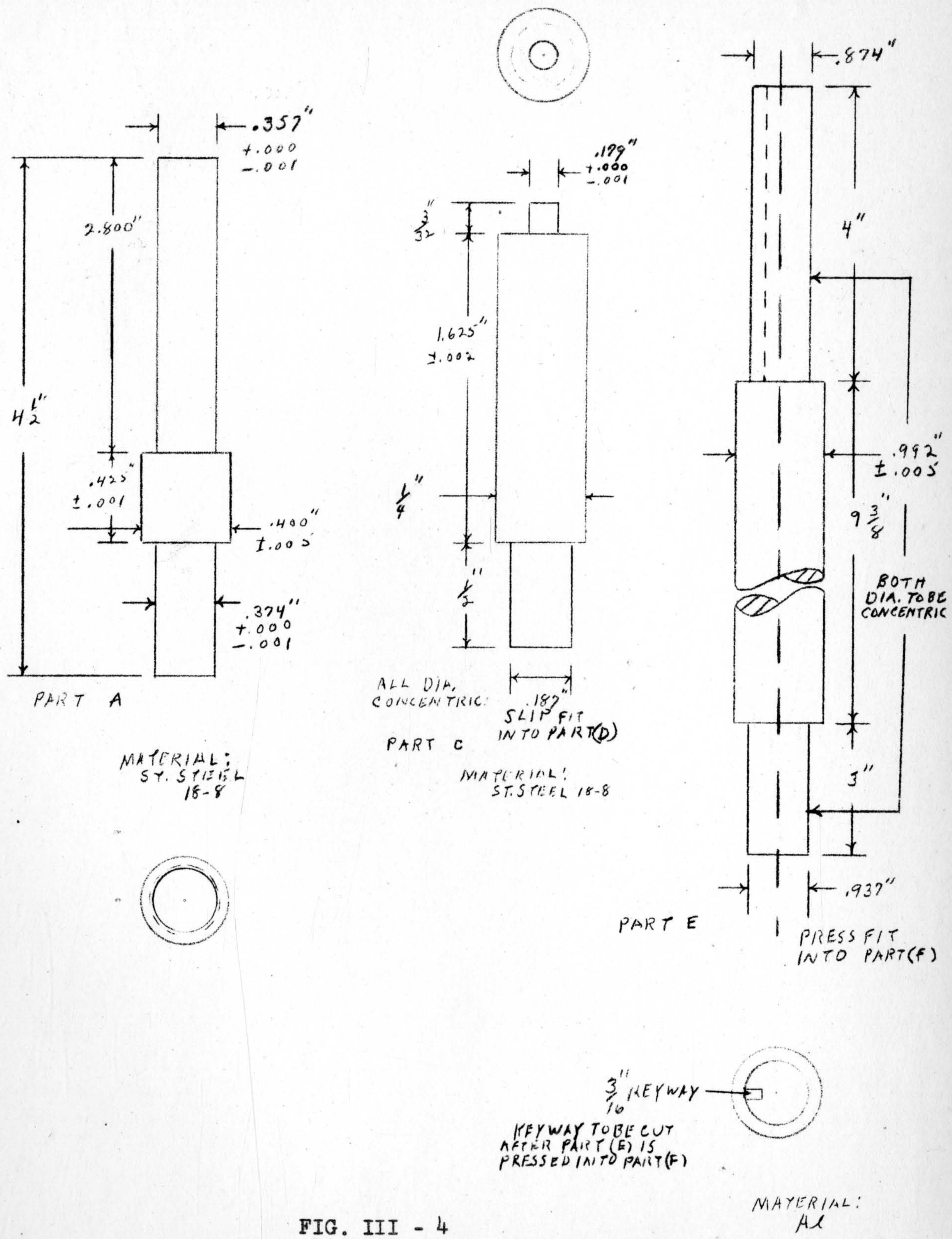


FIG. III - 4

PARTS FOR SEALING MANDREL

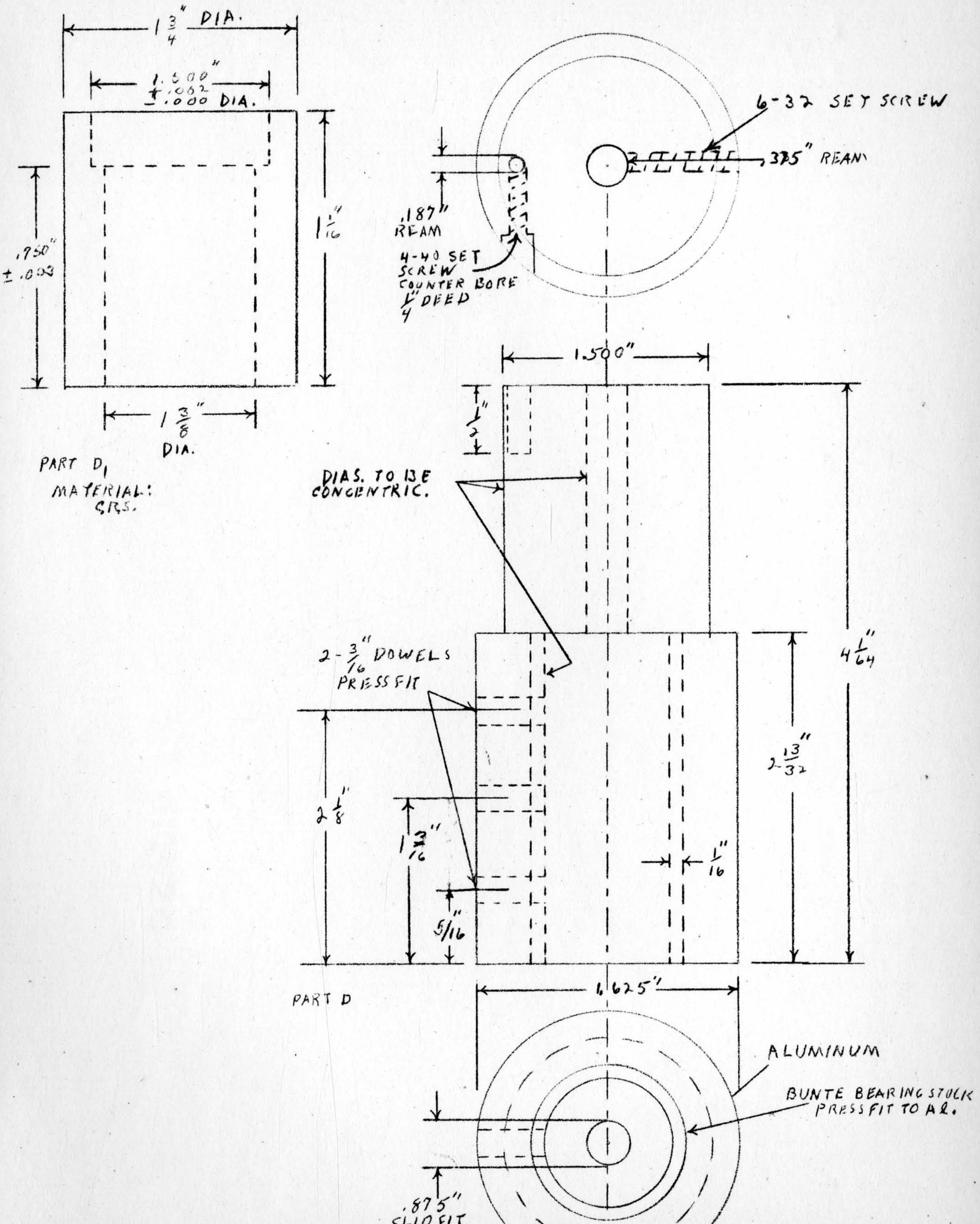


FIG. III - 3

PARTS FOR SEALING MANDREL

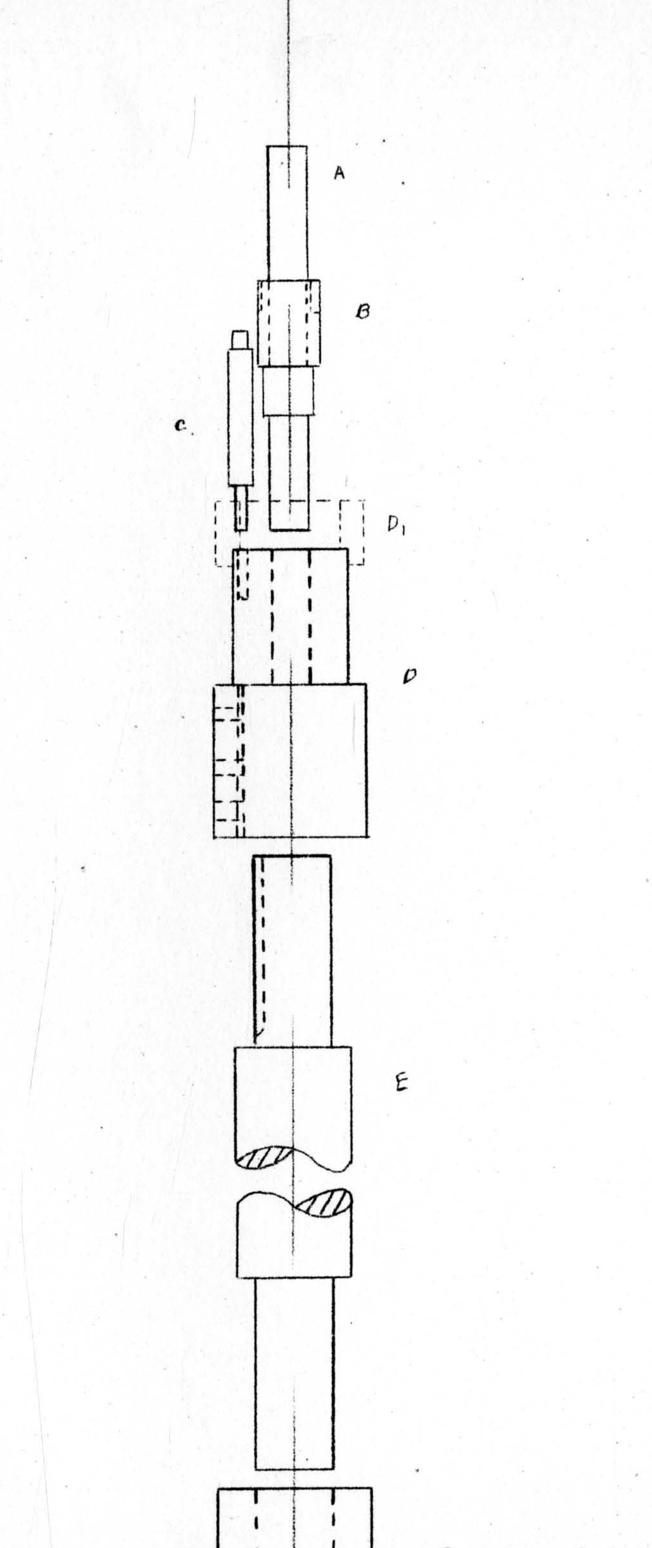


FIG. III - 2

SEALING MANDREL

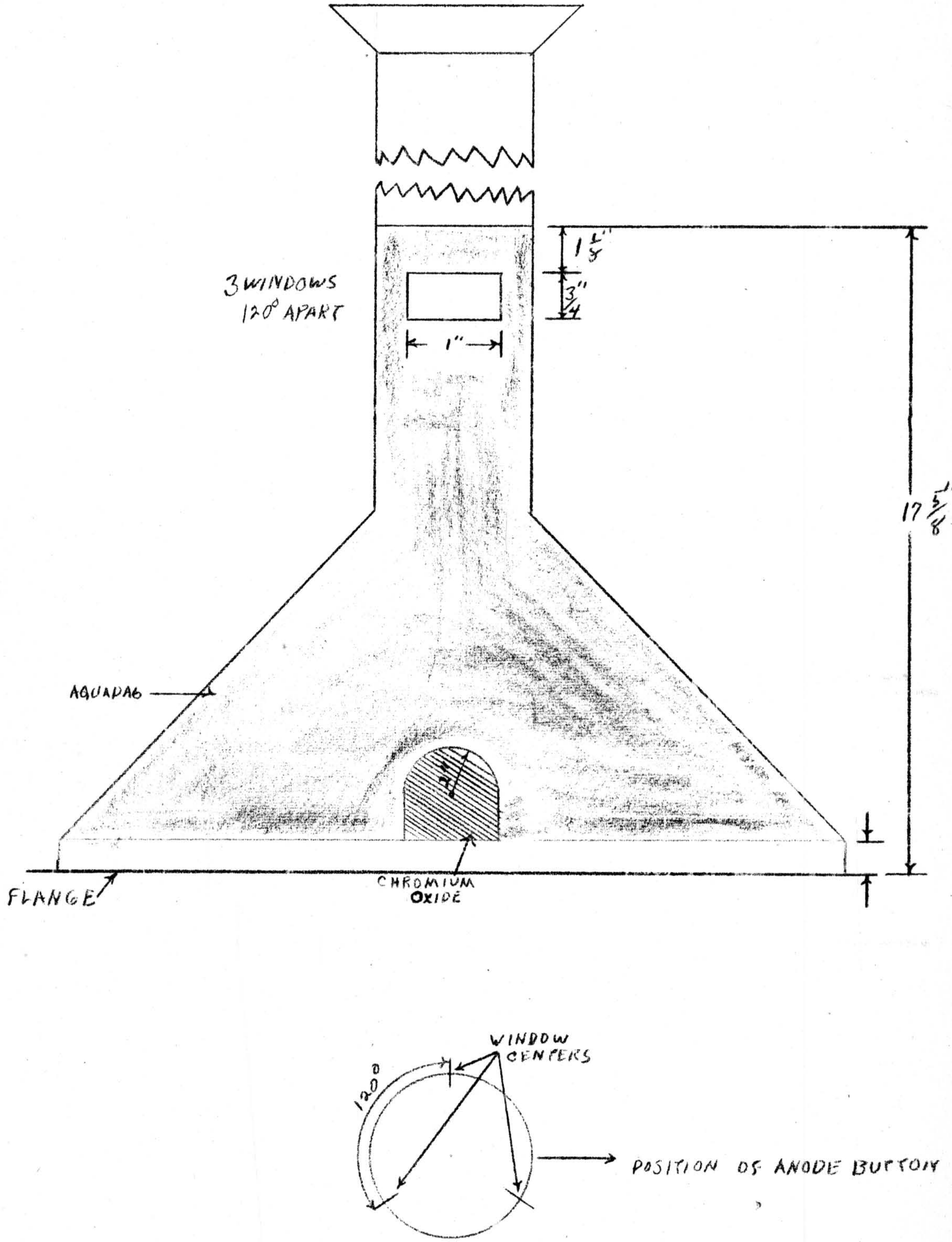


FIG. III - 1

AQUADAG COATING OF BULB

capacity and to the fact that the seal is still hot; so that there is largely a mere redistribution of heat and equalization of temperatures.

The annealing schedule adopted in the Laboratory is arbitrary and probably conservative. It is maintained by a programing unit. At some temperature, the rate of cooling will become less than that required by the annealer. The curve (Fig. III-8) will then depart as shown by the dotted line. Oven may be safely removed at 175° C.

SECTION II CONSIDERATIONS APPLICABLE TO GUN SEALING

Sealing Length of Gun:

The sealing length of the tube is determined from the distance of the end of the gun from the wires of the grille. For this calculation, one needs to know the:

(1) Distance of plane of deflection from grille D;
(2) Color base S;
(3) Center-to-center distance of adjacent guns S_o;
(4) Distance of plane of dynamic convergence from plane of deflection C_2;
(5) Distance of spots in center of screen when there is no dynamic convergence applied a_1.

The dynamic convergence coils are supplied from a transformer with an alternative current of parabolic wave form. Because of a.c. current through the coils, the beams should be divergent in the center of the screen when no dynamic convergence is applied. The required divergence of the three beams in the center of the screen was measured to be about .100".

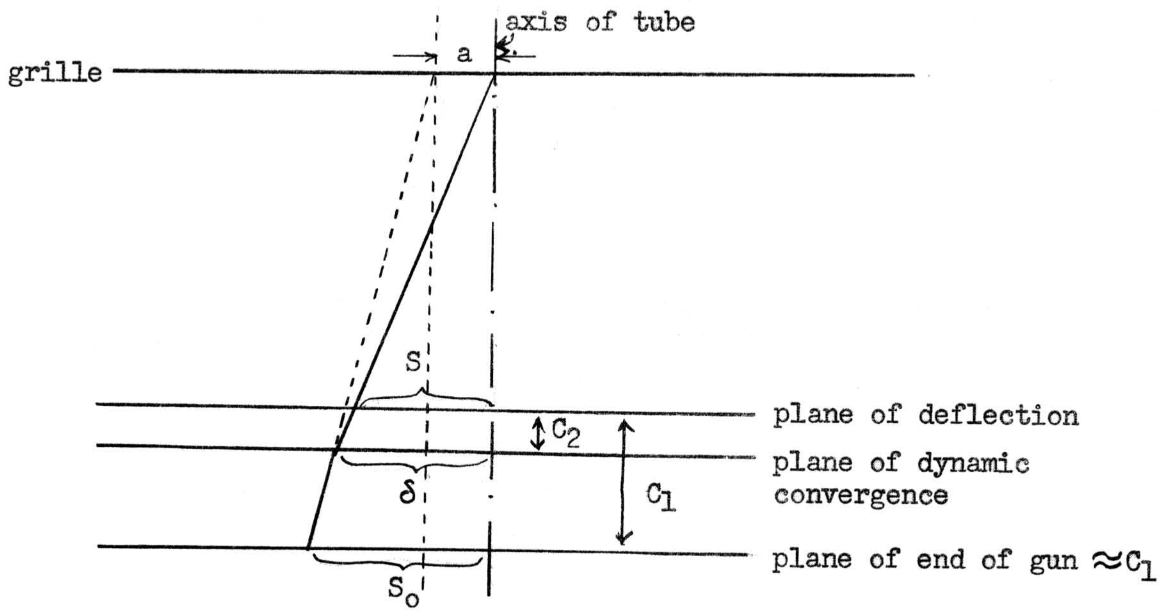
The distance of the gun from the mask can be calculated (see Fig. III-9).

$$\delta = \frac{S(D + C_2)}{D}$$

Distance from grille to end of gun

$$D + C_1 = \frac{(D + C_2)(S_o - a)}{\delta - a}$$

In the table below are given the distance of gun to grille, distance of plane of deflection to plane of dynamic convergence, and tg α , where α gives the angle under which the guns are tilted. The data are for the 21"



Tube geometry pertaining to sealing length calculation

Fig. III-9

and 22" tubes, and for guns with .357" and .327" inside diameter tubing, that is for S_o = .427" and .397" center-to-center distance of adjacent beams. The values are for a color base S = .330".

Tube	Plane of Deflection to Plane of Dynamic Convergence C_2	Center-to-Center Distance of Adjacent Beams S_o	Distance of Grille to Plane of Deflection	Distance of Grille to End of Gun $D + C_1$*	Distance of Plane of Deflection to End of Gun C_1*	$tg\alpha$
21"	1.5	.427"	13.500"	18.371"	4.871"	.0178
21"	1.8	.427"	13.136"	17.747"	4.611"	.0184
	1.8	.397"	13.136"	16.119"	2.983"	.0184
22"	1.8	.427"	13.719"	18.569"	4.850"	.0176
	1.8	.397"	13.719"	16.865"	3.146"	.0176

* Dimension a = .100" was determined experimentally, since it can not be accurately calculated. The latter dimension does result from the parabolic wave form of the alternative current through the dynamic convergence coils and from the deflection field produced by the yoke. Therefore, the accuracy of the data above is higher than required.

Mounting of Gun in Tube Neck:

It is required that the center gun of the tri-color gun be aimed perpendicularly to the screen and that the gun be located centrally in the tube neck to prevent neck shadow. For this purpose, the gun-sealing mandrel is to be aligned with the bulb, as described in Section I.

To secure proper location of the sealed-in gun, three double springs (Fig. II-18(e)) are welded to the end plate of the gun as can be seen in Fig. III-2 or on the photograph of Fig. III-3. In two of the double springs, the space between the leaves of the springs is filled with Sauereisen cement*. No cement is used on the third spring. Before the cement dries, the device acts like a spring, after hardening rigid spacers are formed. Thus the gun is held in the position determined by the centered sealing mandrel. The third spring takes care of expansion of the glass tube neck during bake-out.

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* Patent Docket No. 4D-156 of 9-22-53, by C. G. Lob.