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The redesign of a polariscope

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Lehigh University

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by William K. Aungst

ABSTRACT

The polariscope belonging to the Department of Mechanical Engineering at Lehigh University had limited usefulness due to its particular design. In this thesis the redesign of the existing polariscope is presented. The modified polariscope will enable a much wider range of investigations to be performed.

The following designs or design modifications are included:

1. A motor driven loading frame with speed control.
2. Bench modifications to increase the area of optical scanning.
3. New mountings for polaroids.
4. Water Cell modification.
5. Dynamometer for determining load values.
6. A compensator to determine fractional fringe orders.

THE REDESIGN OF A POLARISCOPE

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William Kenneth Aungst

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Certificate of Approval

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Date: August 28, 1964

Russell E. Benner
Professor in Charge

Ralph H. Long Jr.
Head of Department

ACKNOWLEDGEMENTS

I wish to thank Professor Russell E. Benner, Professor Thomas E. Jackson and Mr. Frank Pechacek for their very helpful suggestions and cooperation during the design and construction of the polariscope.

I also wish to thank Mrs. Louise E. Aungst for the typing and correction of this thesis. Her help is greatly appreciated.

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ABSTRACT

The polariscope belonging to the Department of Mechanical Engineering at Lehigh University had limited usefulness due to its particular design. In this thesis the redesign of the existing polariscope is presented. The modified polariscope will enable a much wider range of investigations to be performed.

The following designs or design modifications are included:

1. A motor driven loading frame with speed control.
2. Bench modifications to increase the area of optical scanning.
3. New mountings for polaroids.
4. Water Cell modification.
5. Dynamometer for determining load values.
6. A compensator to determine fractional fringe orders.

INTRODUCTION

To provide capability for a wider range of photoelastic studies, the polariscope, belonging to the Department of Mechanical Engineering at Lehigh University, required certain revisions in design. The object of this paper is to provide a redesign of the existing polariscope.

The items of major interest to be provided in the redesign of the polariscope are listed below:

(I) A motor driven, electrically controlled, loading system.

(II) An increased scanning area to allow the use of larger models.

(III) Optical modifications

 (a) Water cell

 (b) Polaroids in place of degraded Nicol's prisims

 (c) Compensator

(IV) Dynamometer to determine the load on the model.

(V) Central control system

(VI) Strain rate determination

In the discussion which follows, each of the above items are handled separately. A description of the existing design and its limitations is followed by the new design and the reasons for the change. Refer to Figures 1 and 27, photographs of the polariscope before and after the modification, to clarify explanations.

I. LOADING SYSTEM

The loading frame, Figure 1, consists of two beams located in the same vertical plane; the lower beam is held rigid while the upper beam can be raised or lowered. The photoelastic model is held between the beams and loaded by displacement of the top beam. The top beam is moved by columns connected to a third beam, located below the fixed loading beam, which is connected to a threaded shaft. The threaded shaft engages the threaded hub of a helical worm wheel located in the gear box. The small worm gear engaging the worm wheel presently is rotated manually by a flexible shaft connected to a handle.

This existing design does not permit photoelastic investigations requiring a constant loading rate. Hence, a method of driving the worm gear at various constant rates is needed.

To accomplish this objective, the following modifications must be made. First, in place of the hand driven flexible cable system, a variable speed motor driven system is proposed. Second, the gear box and bearings for the worm gear shaft must be modified to give a stronger more reliable system. Third, it is necessary to modify the frame upon which the gear box is mounted because the frame limits the movement of the threaded shaft.

To accomplish the above objectives, the loading frame must be changed to agree with Figure 2; the change consists of moving the gear box support angles so that the distance between them is increased. This will permit the threaded shaft, engaging the worm wheel, to move through the supports. At present, cross-head motion is limited by interference of the supports into the vertical motion of the threaded shaft. One other change on the loading frame is the addition of a one inch angle on the base as shown in Figure 2. This angle will give additional support for the motor base plate which is to be mounted on top of the cross supports.

The gear box can be changed to agree with Figure 3; the change consists of placing one inch thick steel plates at each end of the box to give it rigidity and strength. Also, the existing bearings for the worm gear shaft should be removed and replaced by pillow block bearing assemblies. Fafnir Ball Bearings, Pillow Block Rak 5/8" are used (Ref. 1). The worm gear shaft will be located as shown in Figure 3, and the front and back of the gear box will be covered with sheet metal. The gear box can be mounted on the cross supports as shown in phantom in Figure 2.

A base plate and spacer, constructed as shown in Figure 4, will provide the mounting for the motor and gear reducer. The base plate is designed so that the use of the gear reducer is optional. This provides a wider range of strain rates. The use of a gear reducer is necessary to provide adequate torque for very slow strain rates. The range of cross-head movement is 0 to 1.750 inches per minute; the corresponding strain rate, based on a two inch gage length, is 0 to 0.875 inches per inch per minute. See Appendix 4 for the calculations.

The motor and gear reducer were purchased from the Boston Gear Company, motor Model R50 and gear reducer Model LC. When assembled the motor and gear reducer are connected by a flexible coupling. The spacer, mentioned above and shown in Figure 4, is necessary to bring the motor and gear reducer shaft heights to the same level.

The drive element between the worm gear shaft and the motor or gear reducer shaft is a roller chain. Identical sprockets are placed on the drive shaft and the worm gear shaft. The reduction gear output shaft must be modified as shown in Figure 26. This change will make the gear reducer's output shaft the same diameter as the motor's output shaft, thus making interchange ability much easier. See Figure 27 for assembled motor and gear reducer system.

II. <u>SCANNING AREA</u>

The present design of the optical bench allows 3-5/8" vertical and 11¼" horizontal movement of the optics relative to the photoelastic model. This allows approximately 41 square inches of usable area for photoelastic studies. An increased scanning area is desirable.

The vertical scanning distance is limited by the interference of the triangularly shaped beam, which supports the optics and the bottom loading beam. See Figures 1 and 1a. To eliminate this interference a redesign of the bench frame is necessary. The triangularly shaped beam at present is the only connection between the two halves of the optical bench. See Figure 1. Thus, if it is cut to allow free vertical movement of the bench, other means of support are necessary.

To accomplish these objectives, maximum vertical scanning and support between the two halves of the optical bench, several changes are proposed. First, the triangular shaped support beam is cut to agree with Figure 5. Also, its mounting axis is changed to coincide with the center line of the optical bench. This change will maximize the horizontal scanning distance. The optical bench frame is modified to agree with Figures 6 and 7. This change allows the supporting members for the two sides of the optical bench to pass around the loading frame, thus there is free vertical movement.

One other change is necessary to obtain the maximum horizontal scanning distance: the two lower connecting beams of the frame must be made as shown in Figure 8 to provide the maximum scanning area for the polariscope.

The new scanning distances will be 13" vertical and 18" in the horizontal direction. This gives an area of 234 square inches or 5.7 times the original area.

The addition of a counter weight system for the bench as shown in Figures 9 and 27 allows it to be raised or lowered easily.

III. OPTICAL MODIFICATIONS

Optical systems of polariscopes are used to produce polarized beams of light and to interpret the photoelastic effect in terms of stress. In general, the optical system consists of a light source, a polarizer, the photoelastic model, a second polarizer which is sometimes called an analyzer. In addition, there may be a system of lenses, a compensator, a water cell, and a viewing screen or camera for photographic recording (Ref. 2). See Figure 28 for a schematic drawing of the optical system.

(A) Water Cell

An existing water cell is to be changed as shown in Figures 10, 10a and 11 to accommodate it to the bench. The purpose of the water cell is to eliminate the infra red light rays to protect the polaroids.

(B) Polaroid Holders

Holders made as shown in Figures 12 and 12a can be used to hold the polaroids in the existing fixtures. The fixtures had previously held Nicol's prisms which were in a degraded condition.

(C) Coker Compensator

The compensator design is shown in Figures 13, 14, 15 and 16. The part per Figures 13 and 14 is inserted into the part per Figures 15 and 16. This will allow the determination of fractional fringe orders very accurately in photoelastic studies by placing a small strip of photoelastic material in series with the light passing through the photoelastic model. The normal procedure used is to orient and load the photoelastic tensile strip in such a manner that the relative retardation produced in it just neutralized the effect at the point being investigated in the photoelastic model (Ref. 3). The compensator has a metal tension dynamometer which will experience the same axial load as the photoelastic sample (see Figure 13); a strain gage attached to this metal tensile strip will enable the force or load to be determined. The electrical strain gage circuit for determining the load is shown in Figure 17.

To calibrate the compensator, fringe order versus millivolts output from the strain gage circuit can be plotted to give a calibration curve. For the approximate formulas and calculations see Appendix 1. Note, that for a typical photoelastic sample the range of fringes is from zero to fifty-five fringes.

IV. DYNAMOMETER

To determine the load exerted on the photoelastic model, a dynamometer is placed in series with the model. The dynamometer is connected to the top loading beam. The top of the photoelastic model is connected to the dynamometer, and the bottom of the model to the lower fixed loading beam.

A dynamometer constructed as shown in Figure 18 will enable one to measure the range of loads this particular loading frame is capable of producing. The calculations exhibited in Appendix 2 show that the maximum allowable load the frame can produce without danger of failure is 1970 pounds force.

To determine the proper dimensions for the dynamometer, various widths and thicknesses were used to calculate a length which would be compatible with the maximum allowable load of 1970 pounds; see Appendix 3. The final dimensions of 5/8" thick, 3" wide and 3.5" long, using 1020 steel, are being used to construct the dynamometer. A load of 1900 pounds can be applied and will give a deflection of 0.0127 inches per beam; see Appendix 3 for calculations.

The electrical system, including strain gages, amplifier, millivoltmeter or recording instrument, is given in schematic form in Figure 19. Before using the dynamometer it must be calibrated. Data of force versus millivolts can be plotted to give a calibration curve. Calibration conditions should be recorded to ensure that the dynamometer is used under the same conditions.

V. CENTRAL CONTROL SYSTEM

The central control system will consist of the motor controls, the polariscope light source switch and transformer, the strain gage amplifiers for the dynamometer and compensator, and two millivolt meters to indicate the output of the amplifiers. This equipment is to be mounted on a push cart as shown in Figures 20 and 21. The electrical connections for the motor and motor control shall be made as shown in Figure 22 (Ref. 4). The switches labeled S-2 and S-3 should be mounted on the loading frame as shown in Figure 23. These switches will limit the movement of the loading bars by cutting off the power to the motor when they are activated.

The dynamometer and compensator strain gage - amplifier systems shall be built as shown in Figures 19 and 17 respectively (Ref. 5). Also, the dashed line connections indicate where recording instruments can be used to get a permanent record of the loading conditions.

VI. STRAIN RATE DETERMINATION

To determine the rate of strain on any photoelastic model being investigated, the Decker Delta Unit and Monitor is employed (Ref. 6). This commercial equipment converts a change in electrical capacitance into a convenient meter reading. By using a capacitor made as shown in Figure 24 and mounted as shown in Figure 25, it is possible to convert the vertical movement of the loading frame into a meter reading. The capacitor and its associated equipment should be calibrated by plotting distance versus voltage so that a calibration curve can be produced. Calculations used in the design of the capacitor are given in Appendix 6.

VII. CONCLUSION

The redesigned polariscope has three major advantages over the old polariscope. They are summarized below:

(A) Increasing the polariscope's usefulness by allowing a wider range of photoelastic investigations to be performed.

1. Investigate behavior of photoelastic materials subjected to various strain rate histories by providing a controlled, power driven loading frame.
2. Increased scanning area which will allow the investigation of larger and more complicated photoelastic models.

(B) Improved optics which will enable photoelastic investigations to be carried out with more accuracy.

1. Polaroids replacing degraded Nicol's prisms.

2. Use of water cell to protect the polaroids from infra red light.

3. A Coker compensator which will allow the determination of fractional fringe orders.

(C) Improved mechanical alignment.

1. The structure is redesigned so that the optical beam no longer serves as an integral load bearing part of the bench structure.

2. Added counter weights to allow the optical bench to be raised and lowered without strenuous physical effort.

FIG. 1. . POLARISCOPE BEFORE MODIFICATIONS

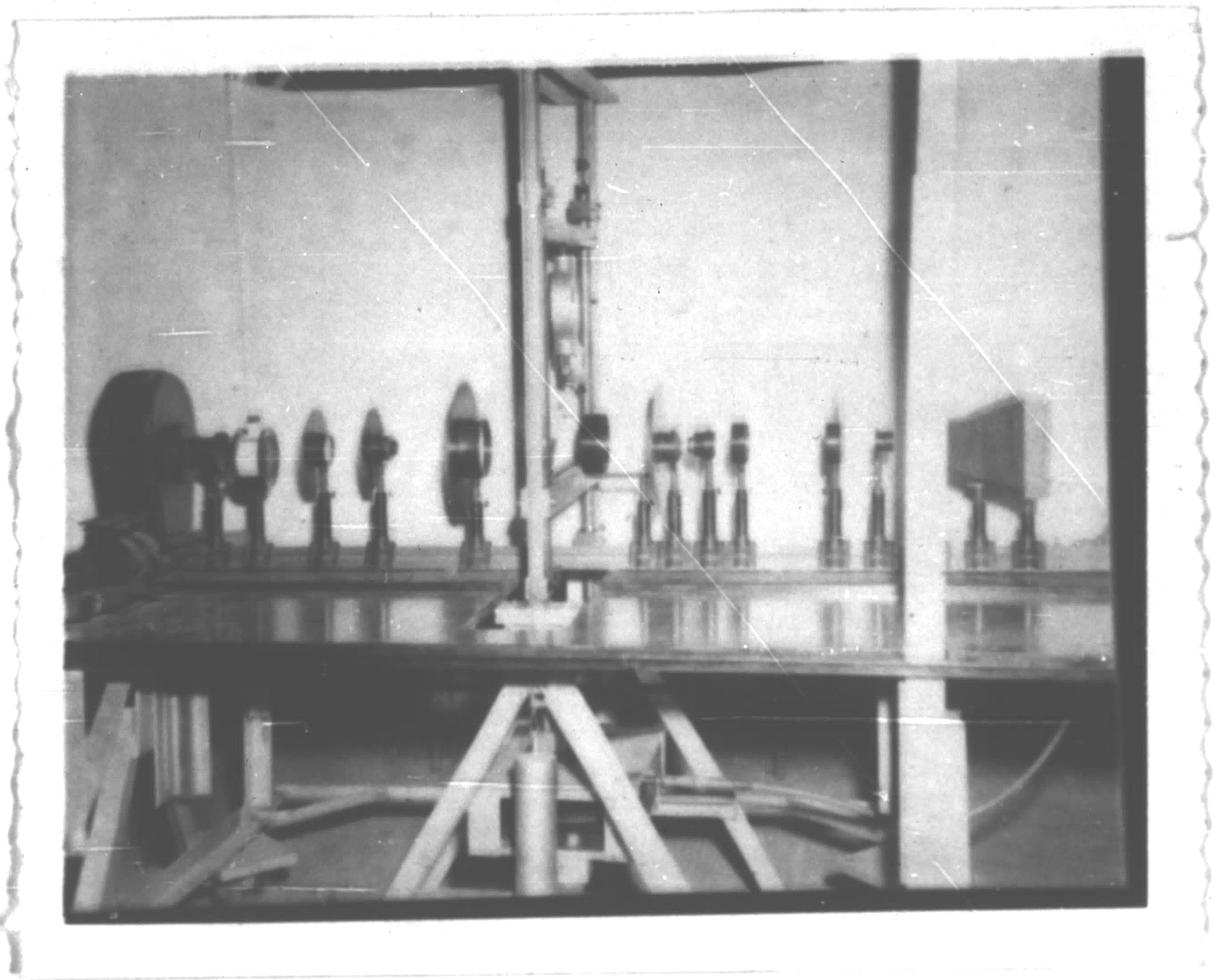
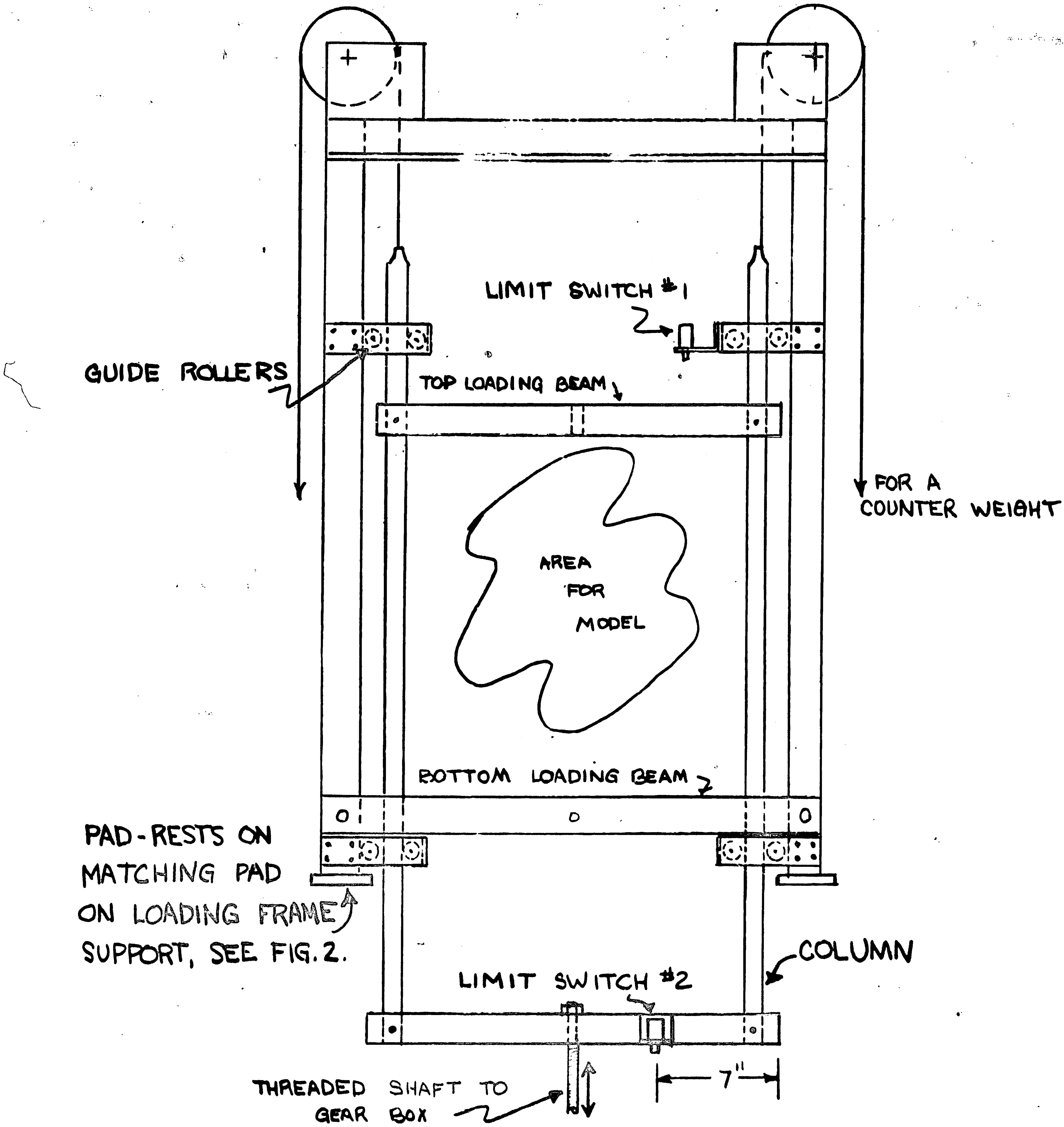


FIG: 1A LOADING FRAME



SCALE: 1/8" = 1"

WKA 7-20-64

FIG. 2 LOADING FRAME SUPPORT

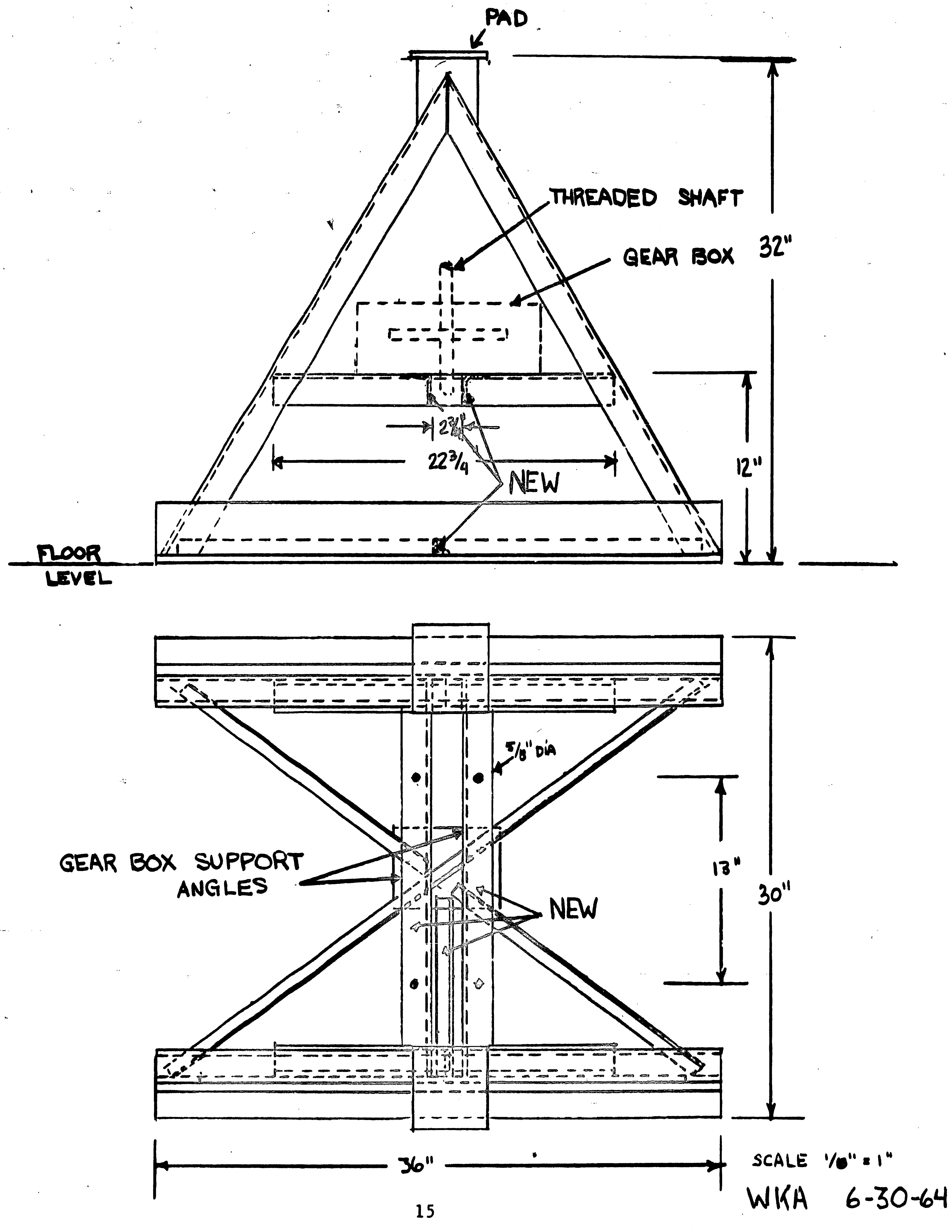
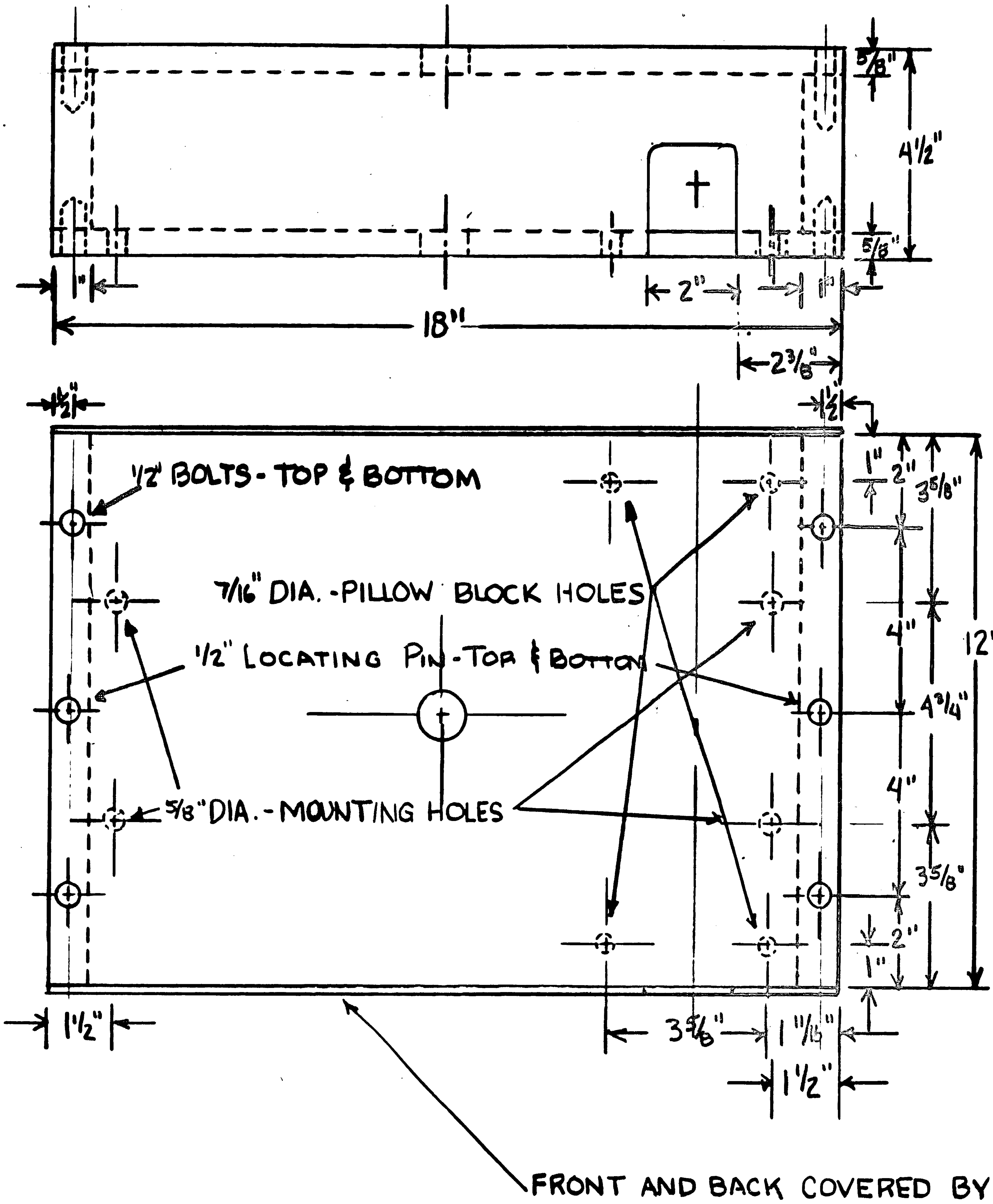


FIG. 3 GEAR BOX



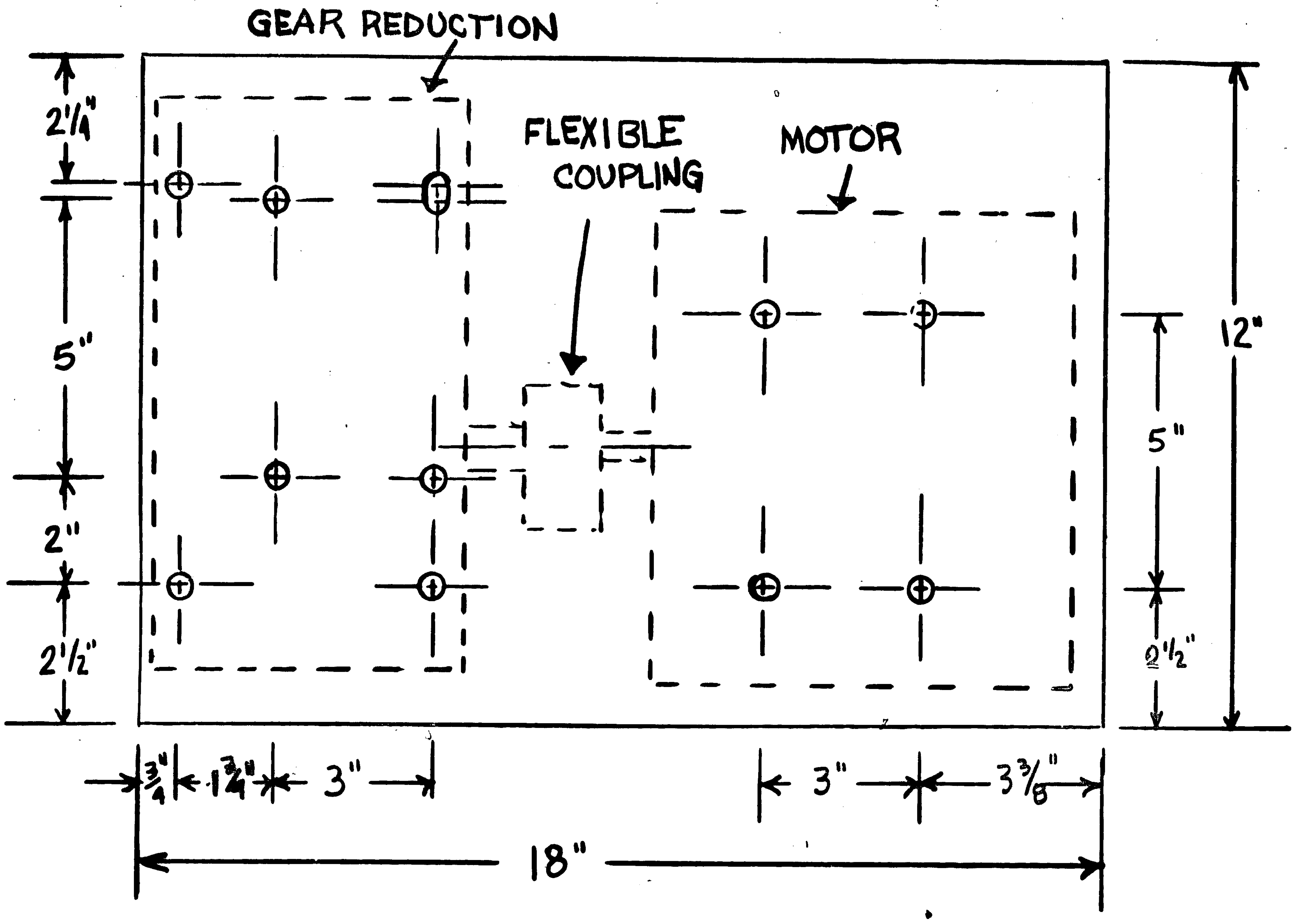
FRONT AND BACK COVERED BY 1/8" SHEET METAL - SLOT ONLY ON FRONT USE METAL SCREWS TO ATTACH.

NOTE: ALSO MAKE A NEW SHAFT FOR THE WORM GEAR - 5/8" DIA., 13 1/2" LONG; USE STEEL AND PUT 1/8" KEY WAY IN ONE END.

SCALE: 1/4" = 1"

WKA - 6-29-64

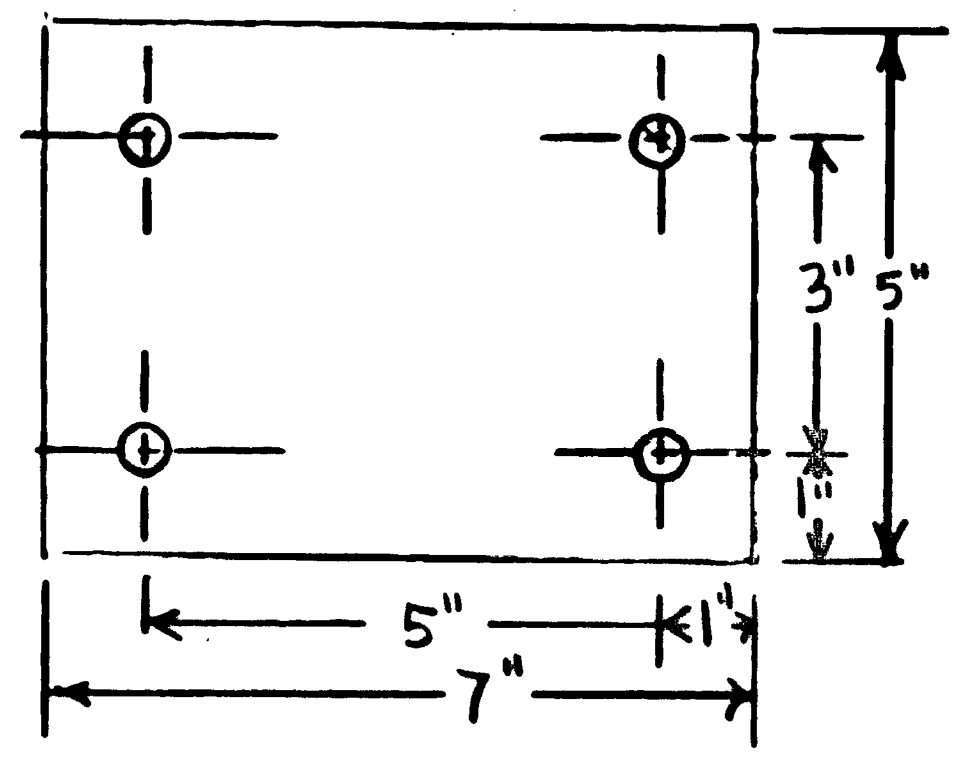
FIG. 4A BASE PLATE FOR MOTOR



USE 1/2" THICK STEEL PLATE - ALL HOLES 25/64" DIA.

FIG. 4B

SPACER FOR MOTOR



USE 1/4" THICK STEEL PLATE - ALL HOLES 25/64" DIA.

SCALE : 1/4" = 1"

WKA - 6-29-64

FIG. 5 SUPPORT BEAM FOR OPTICS

NOTE: CUT THE TRIANGULAR BEAM INTO TWO SECTIONS WITH LENGTHS PER THIS DRAWING.

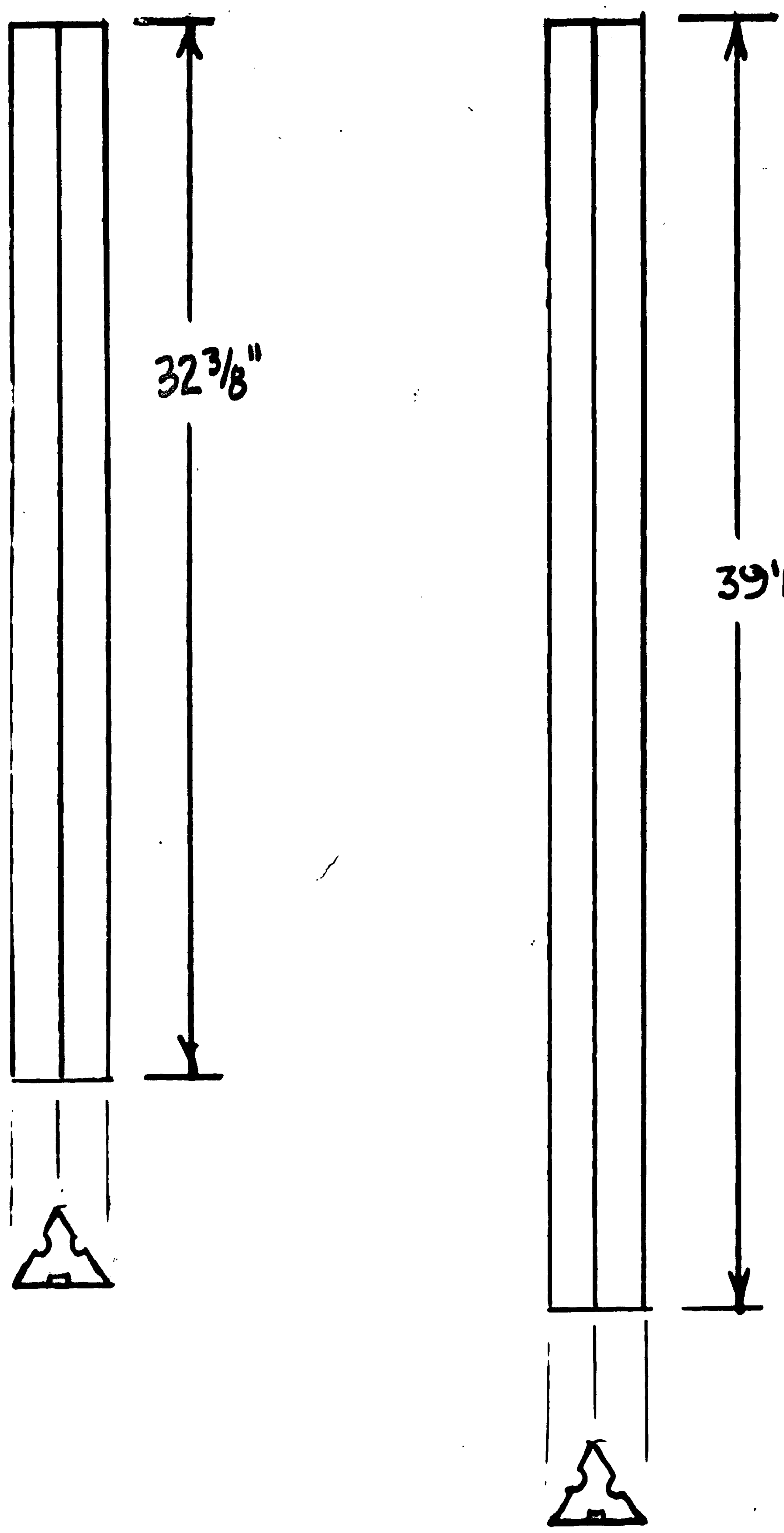


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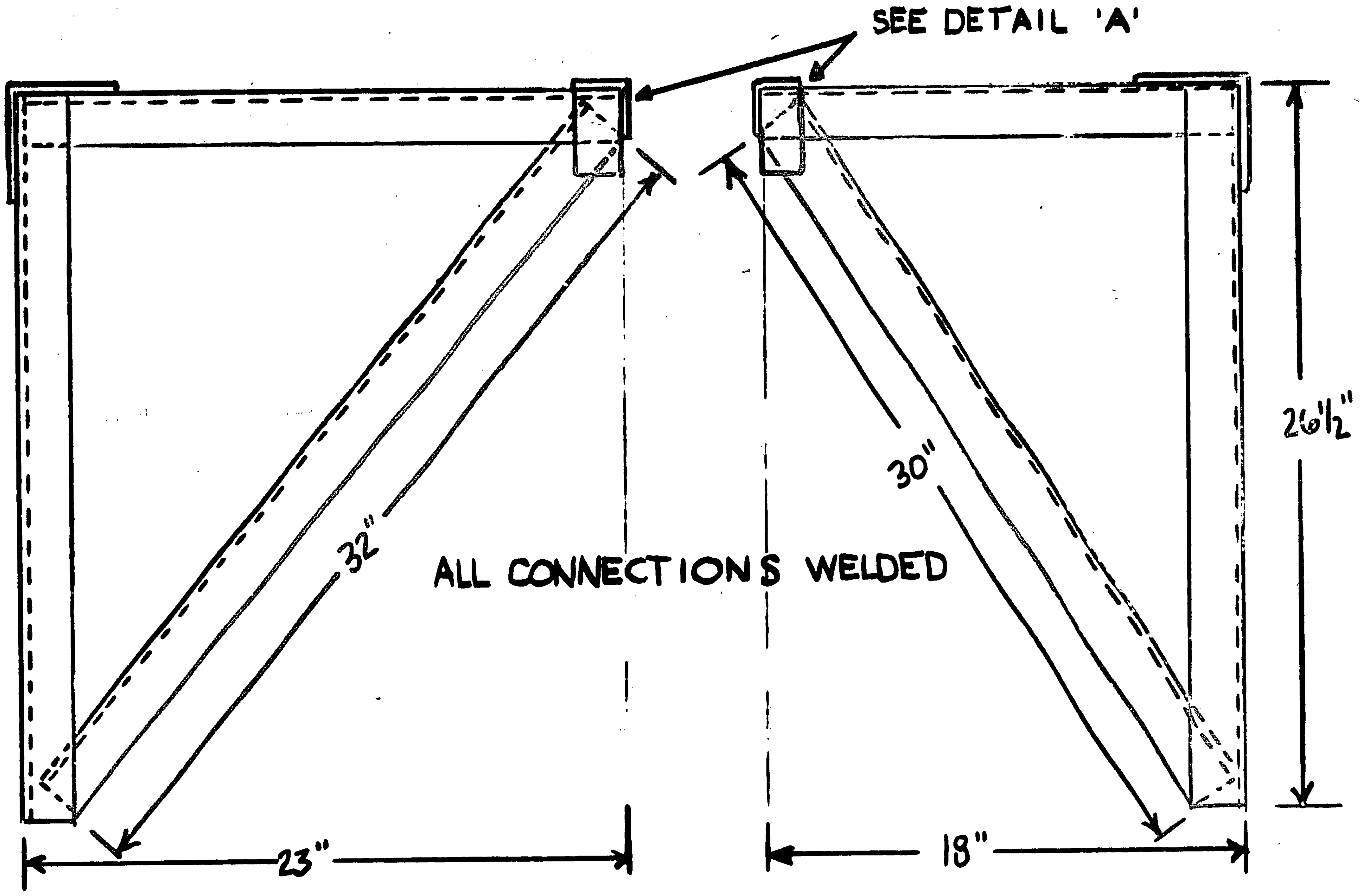
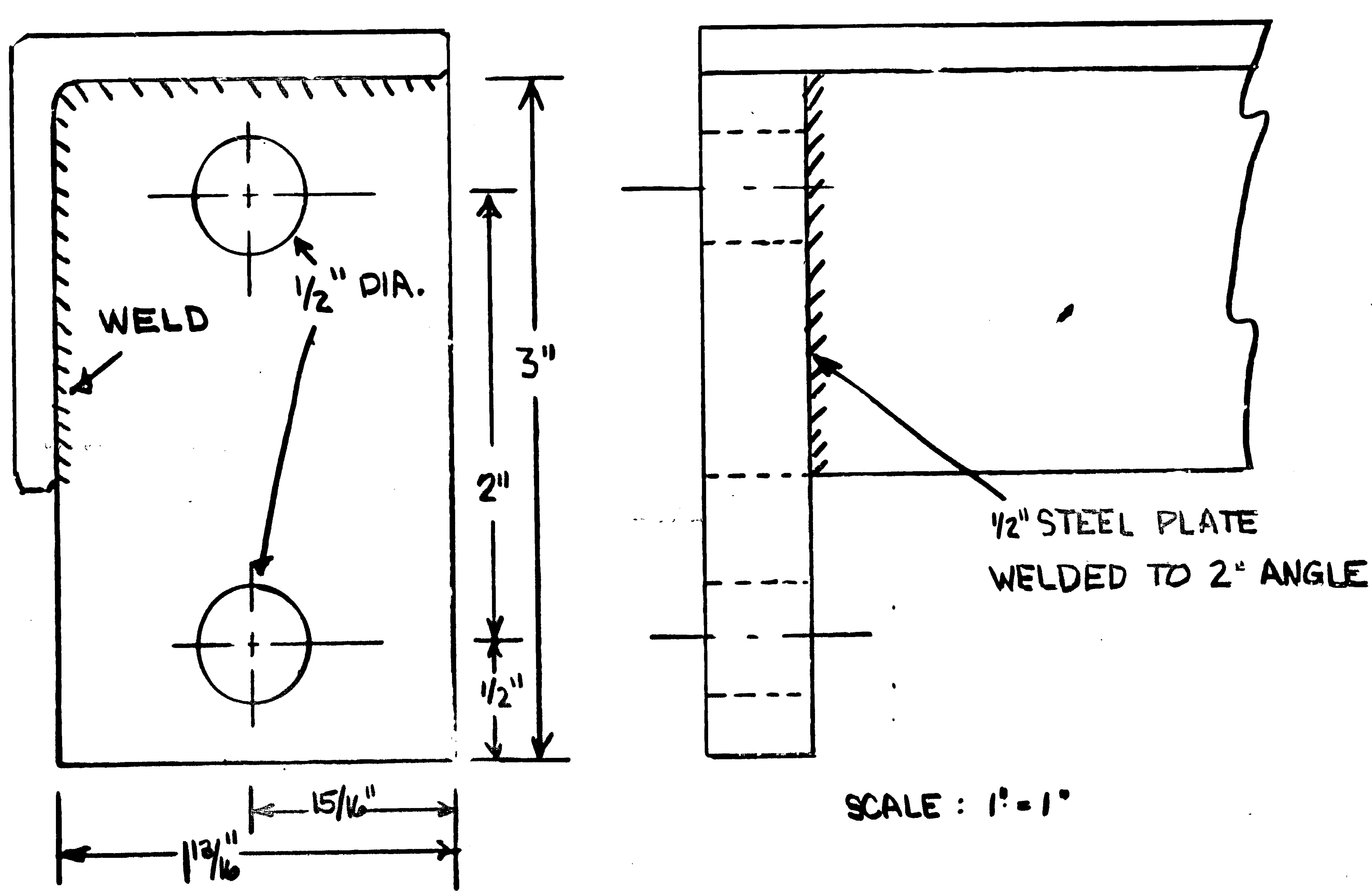
FIG. 6 BENCH FRAME SUPPORTS

FOR ASSEMBLED DRAWING SEE FIG. 7



SCALE 1/8" = 1"

DETAIL 'A'



SCALE : 1" = 1"

WKA 7-9-64

FIG. 7 BENCH FRAME ASSEMBLY

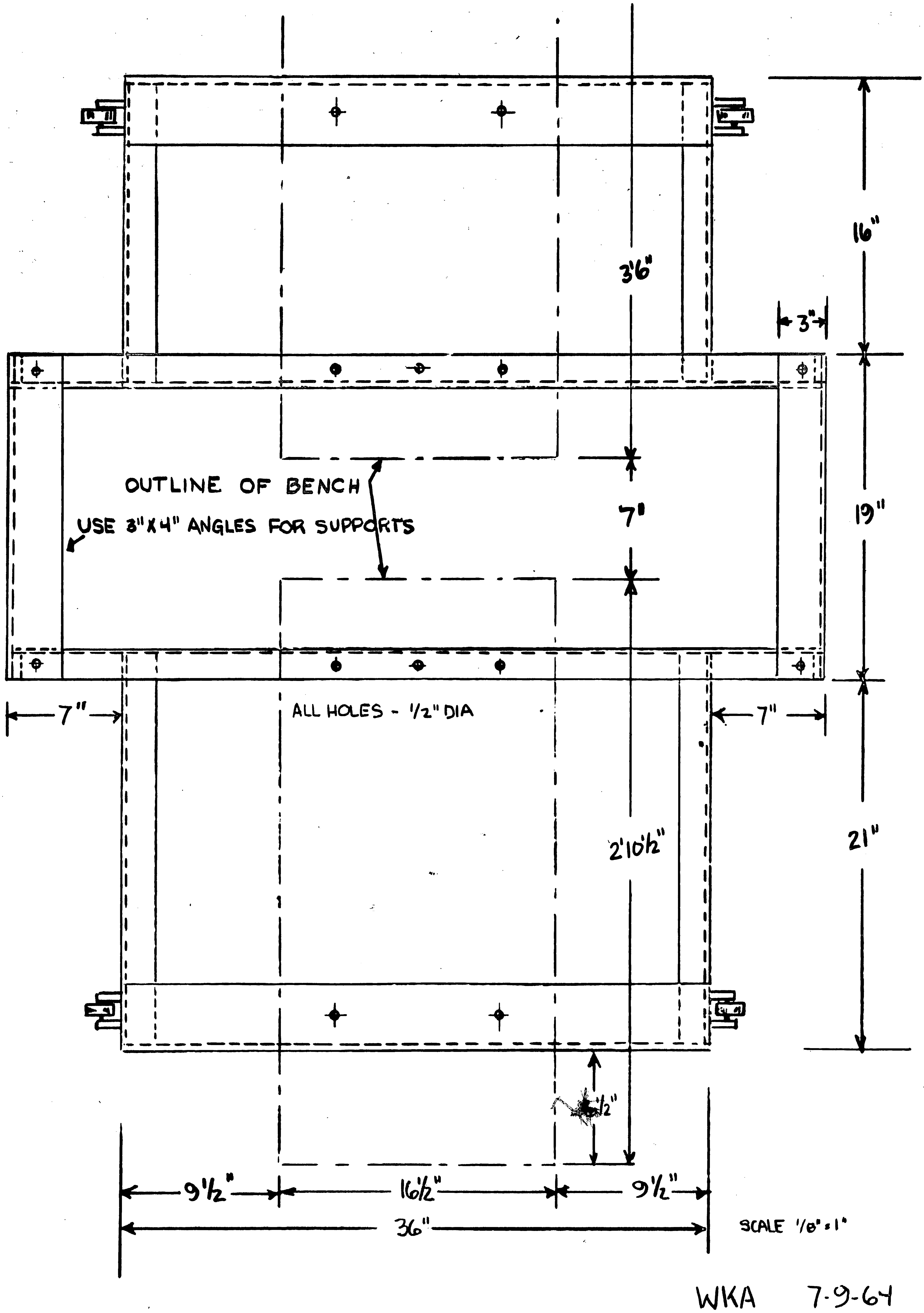


FIG. 8 CONNECTING BEAM

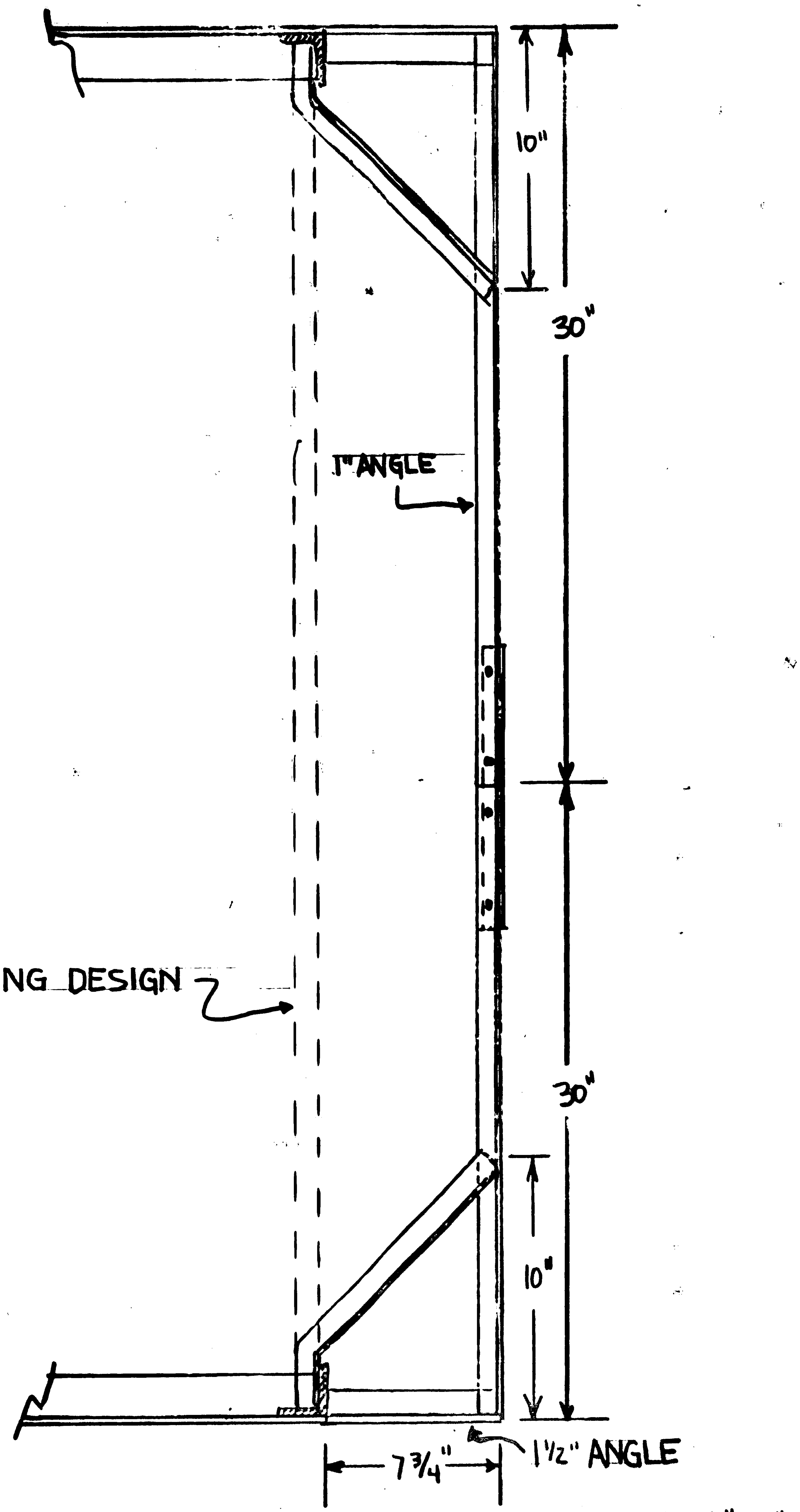


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FIG. 9 PULLEY MOUNTS

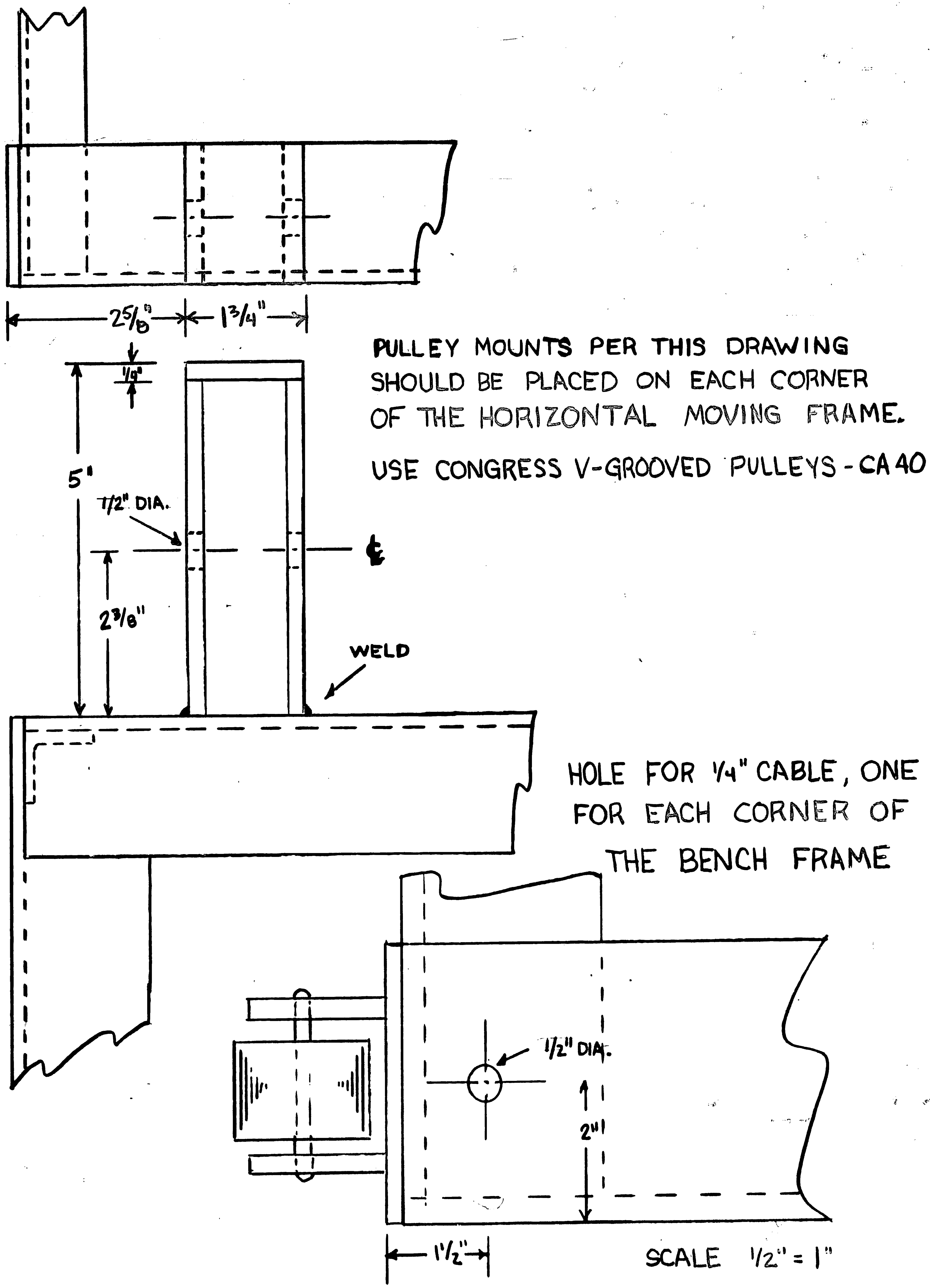

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FIG. 10. WATER CELL PHOTOGRAPH

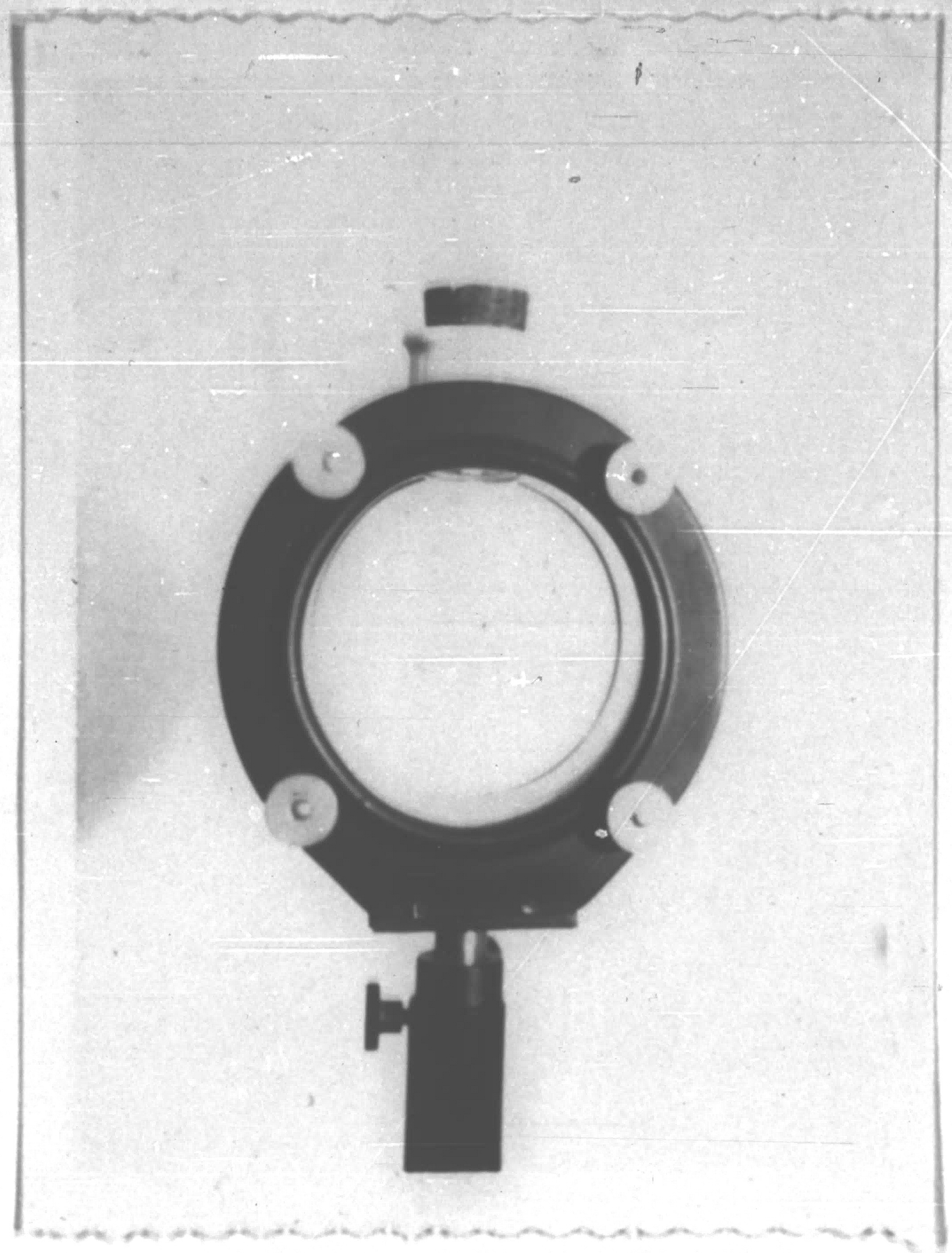
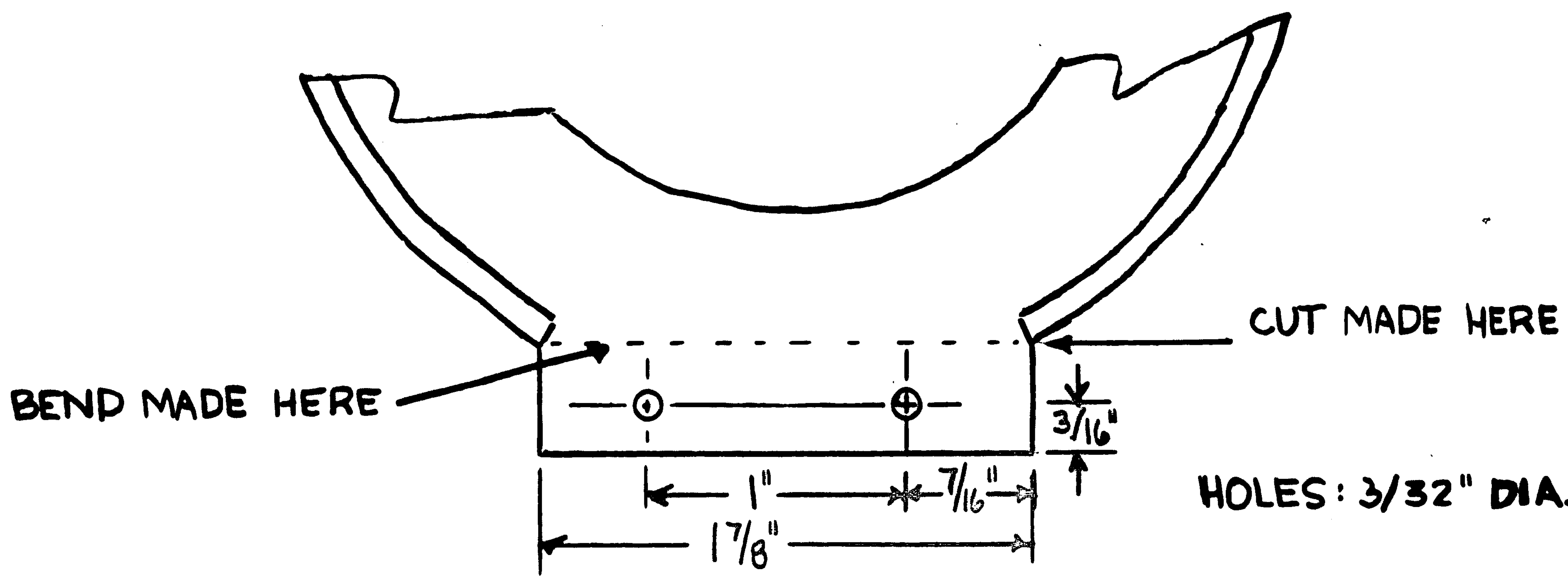


FIG. 10A WATER CELL MODIFICATION

(1) DISASSEMBLE THE WATER CELL AND CLEAN PARTS BY SANDING, WASHING, ETC.

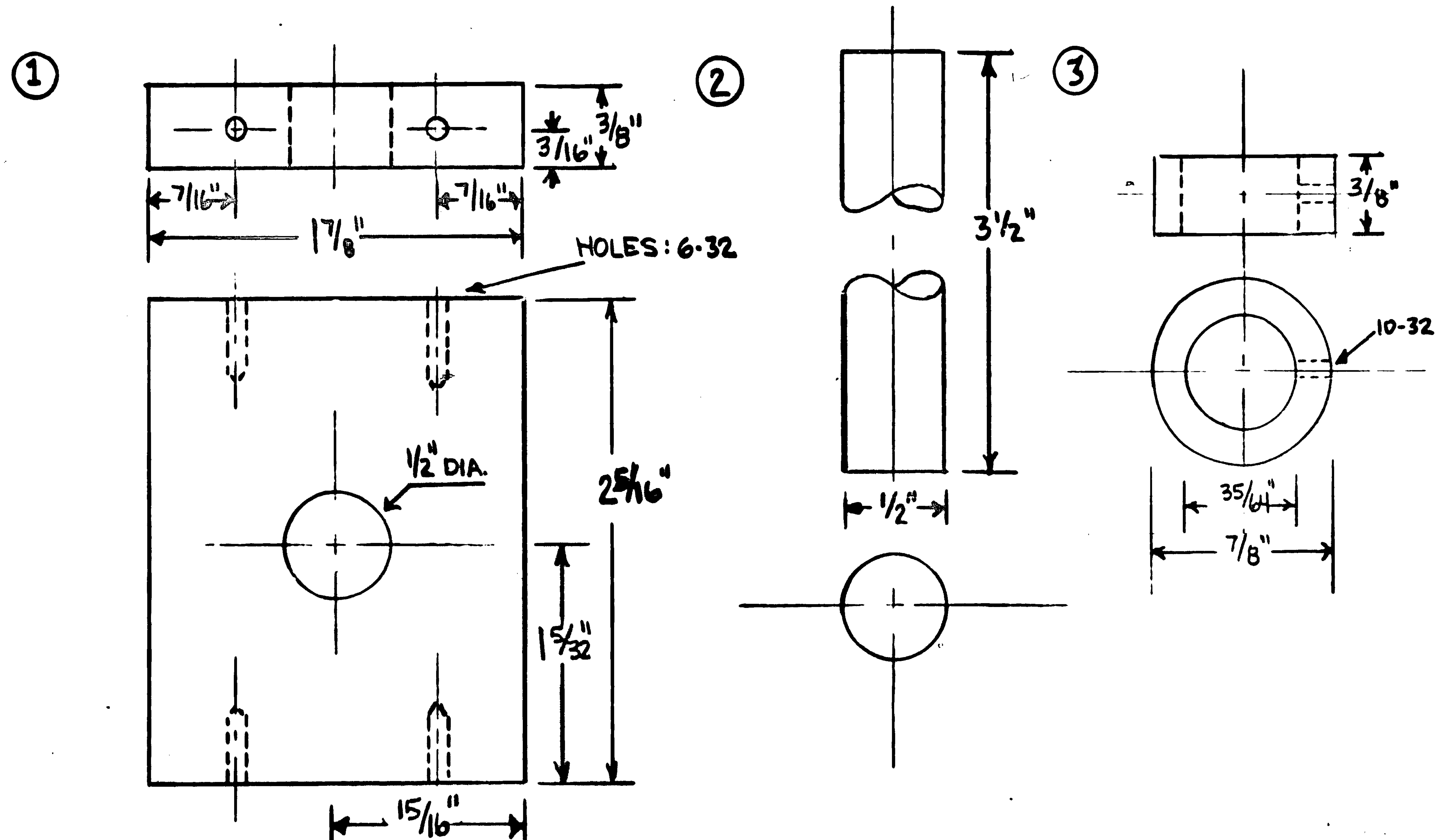
(2) MAKE CUTS IN SIDES AT THE CORNERS OF THE STRAIGHT PORTION, AND BEND THE STRAIGHT PORTION FLAT.

(3) DRILL TWO HOLES IN EACH SIDE PER THE SKETCH BELOW.



(4) REPAINT PARTS USING FLAT BLACK PAINT.

(5) USING BRASS - MAKE THE FOLLOWING PARTS.



(SCALE 1:1)

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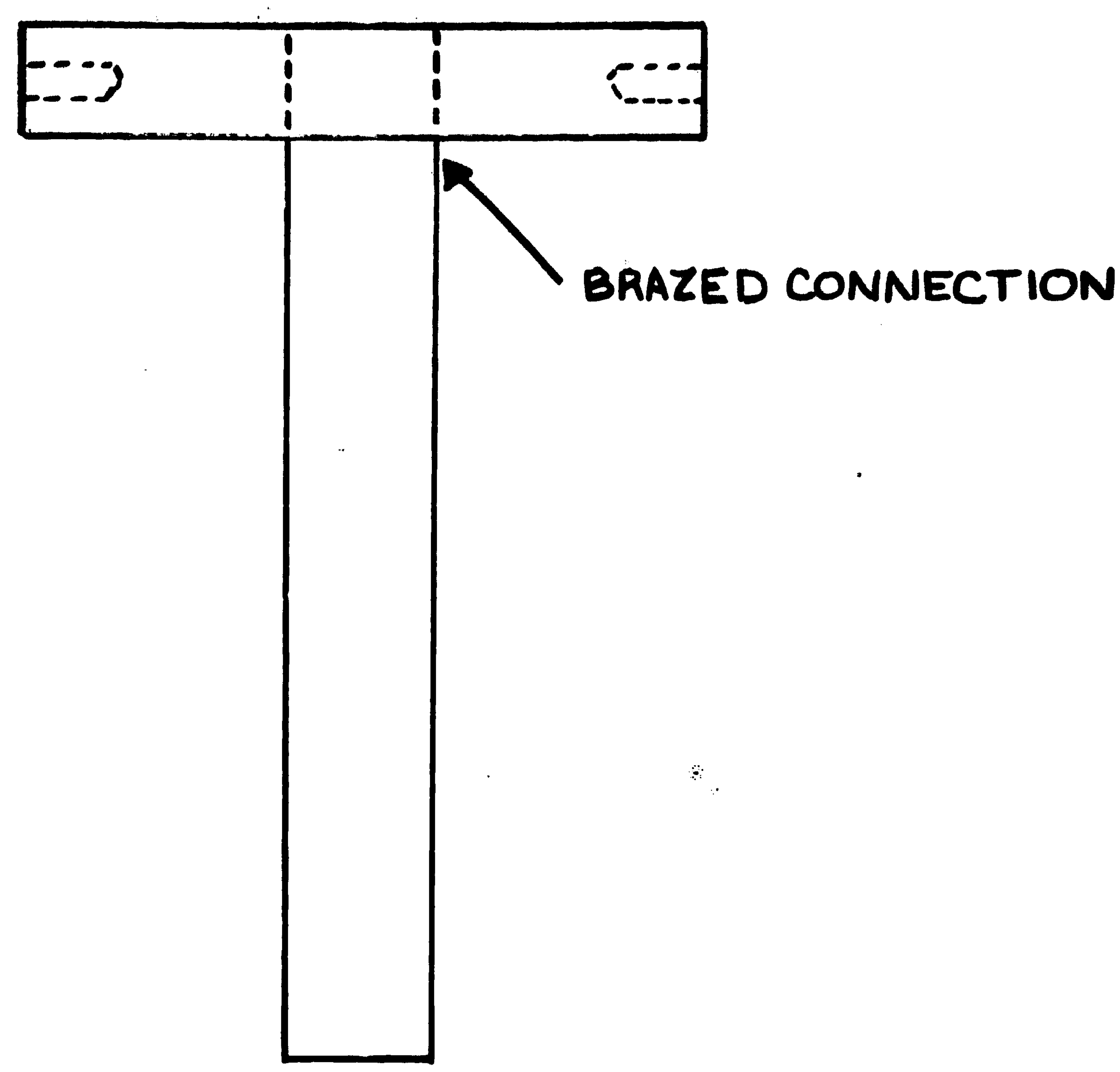
FIG. 11 WATER CELL MODIFICATION - CONT.

(6) BRAZE ② INTO ① TO GIVE THE FOLLOWING:



(7) ASSEMBLE THE WATER CELL, USING NEW O-RINGS AND D.I. WATER.

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FIG. 12. POLAROID HOLDER PHOTOGRAPH

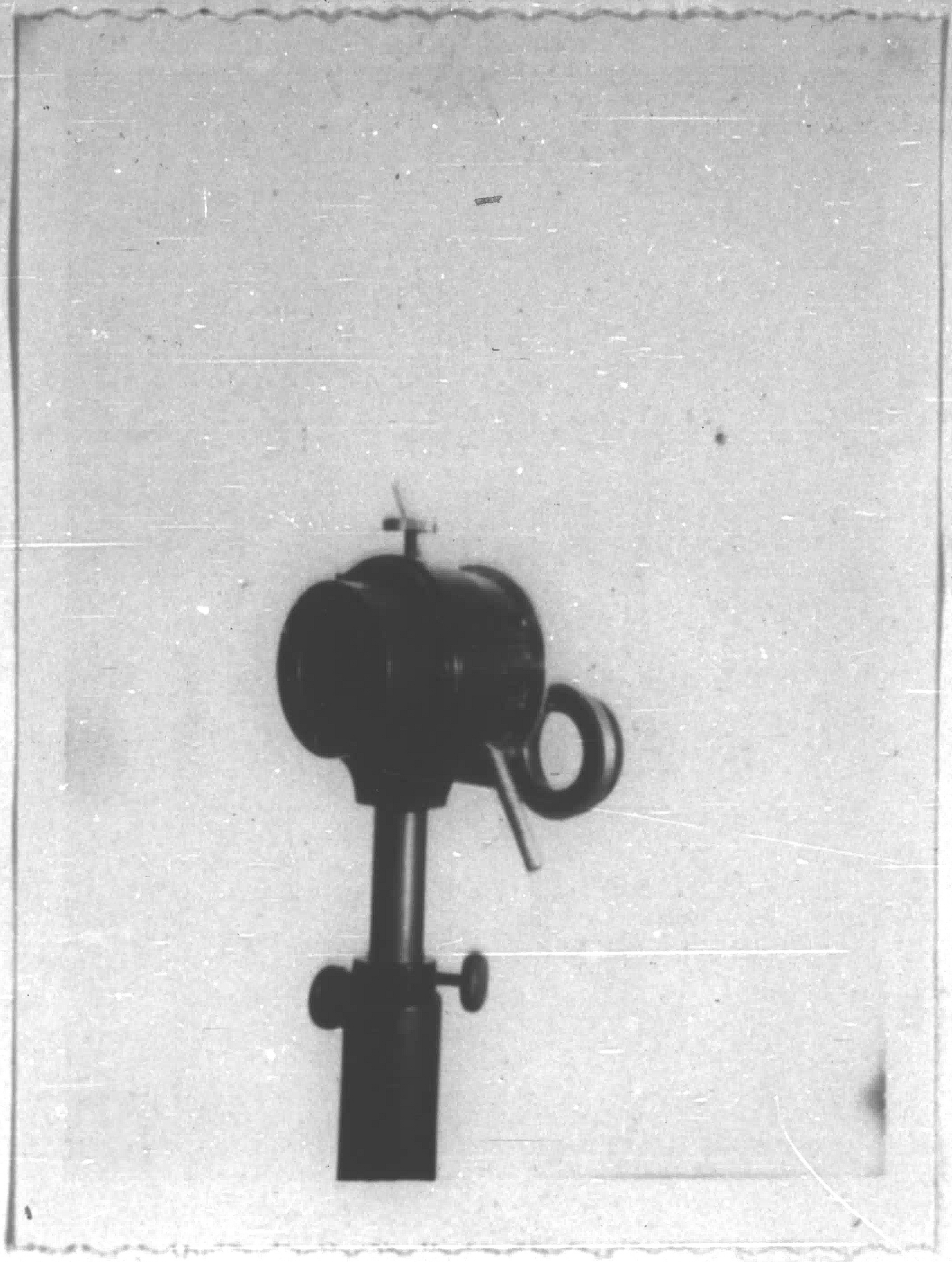
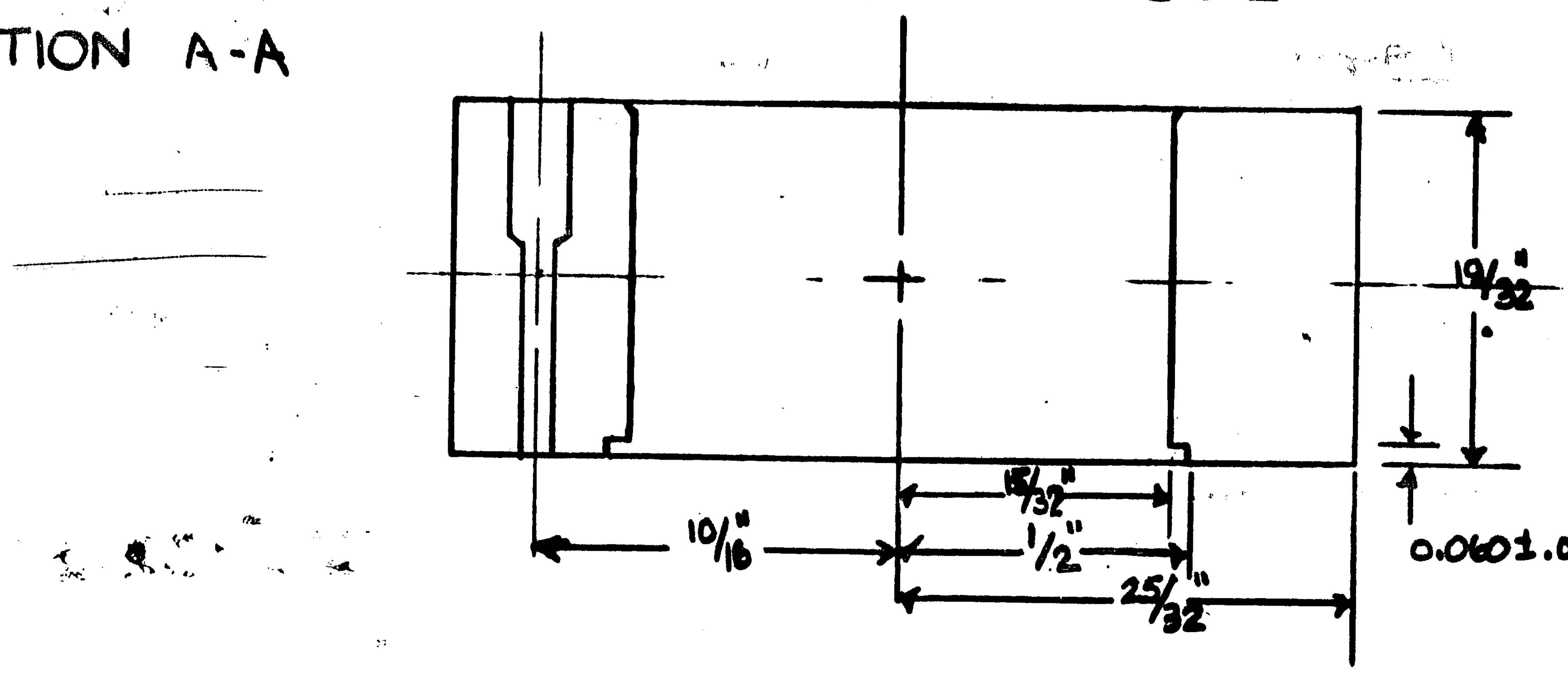
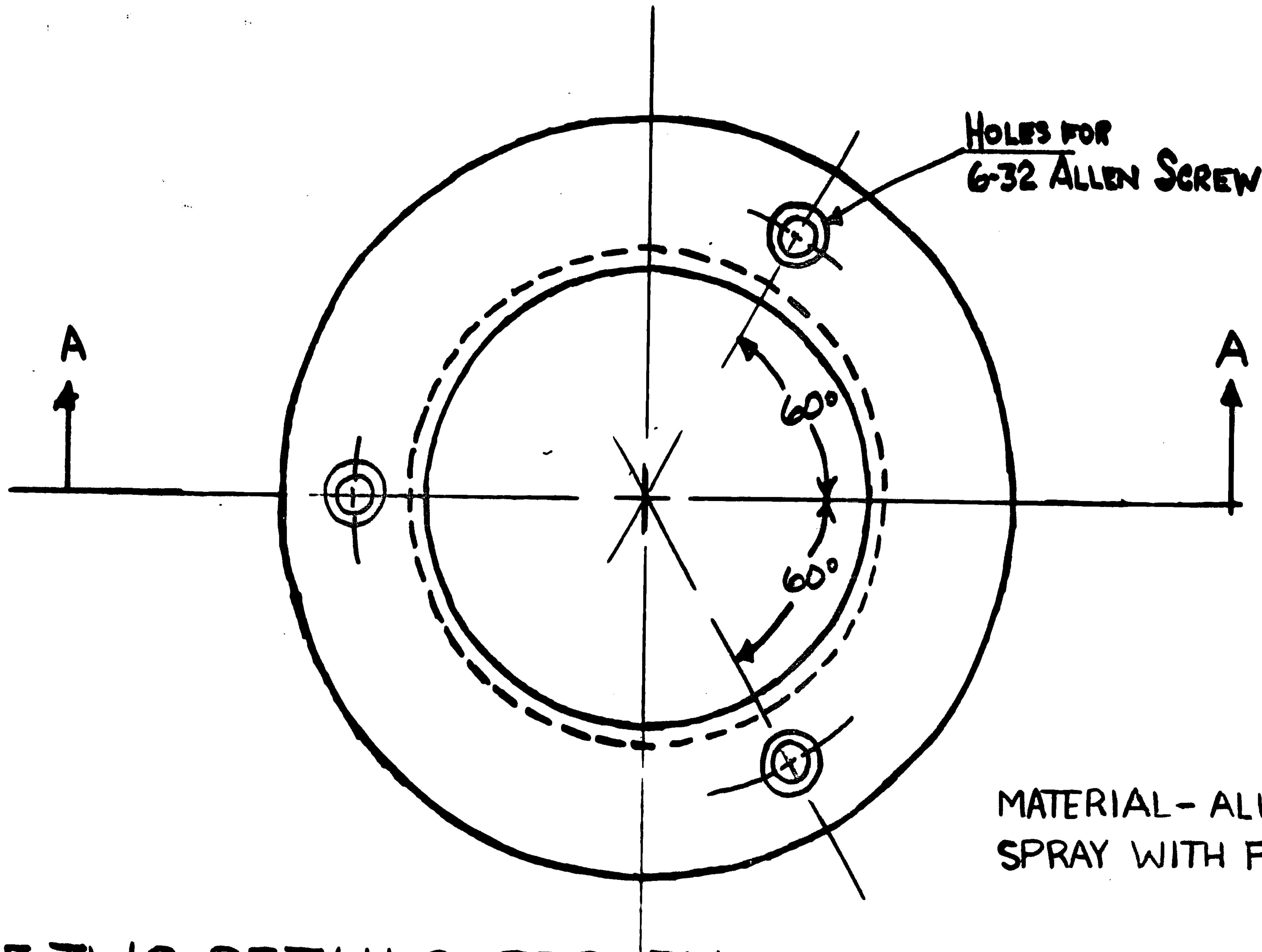


FIG. 12A POLAROID HOLDER

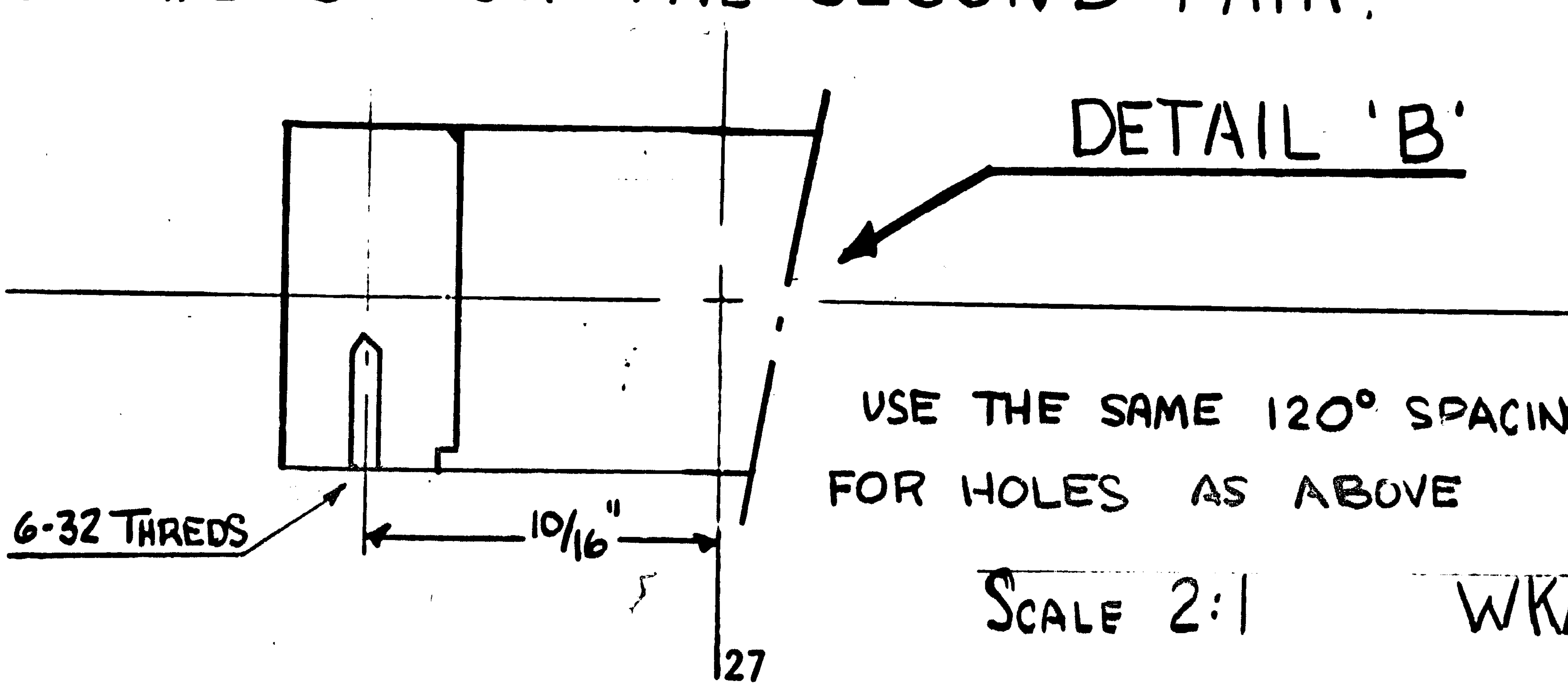
SECTION A-A





MATERIAL - ALUMINIUM
SPRAY WITH FLAT BLACK PAINT

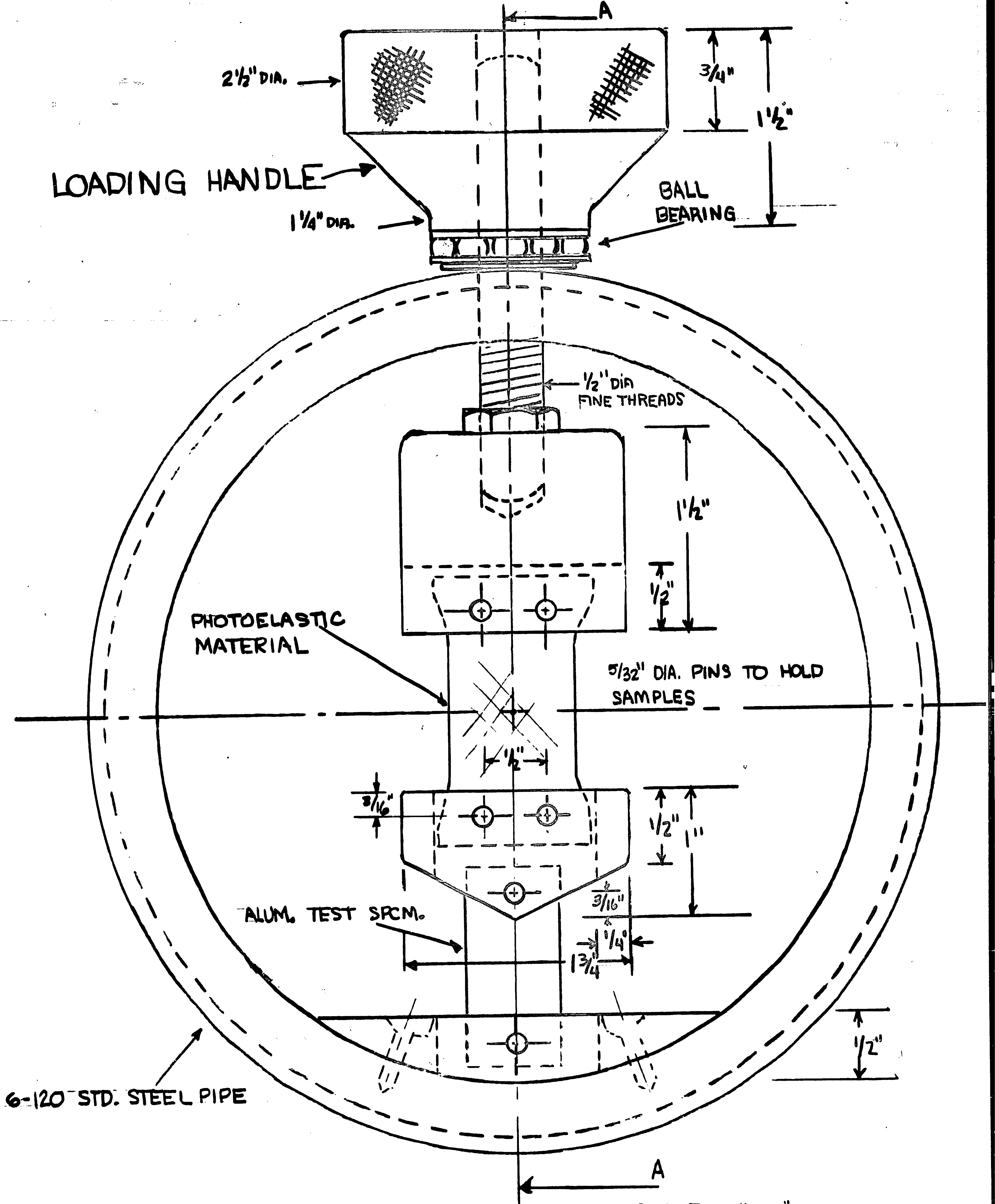
MAKE TWO DETAILS PER THIS DRAWING AND TWO PER THIS DRAWING EXCEPT FOR SCREW HOLES, USE DETAIL 'B' FOR THE SECOND PAIR.



USE THE SAME 120° SPACING FOR HOLES AS ABOVE

SCALE 2:1 WKA - 6/15/64

FIG. 13 COMPENSATOR

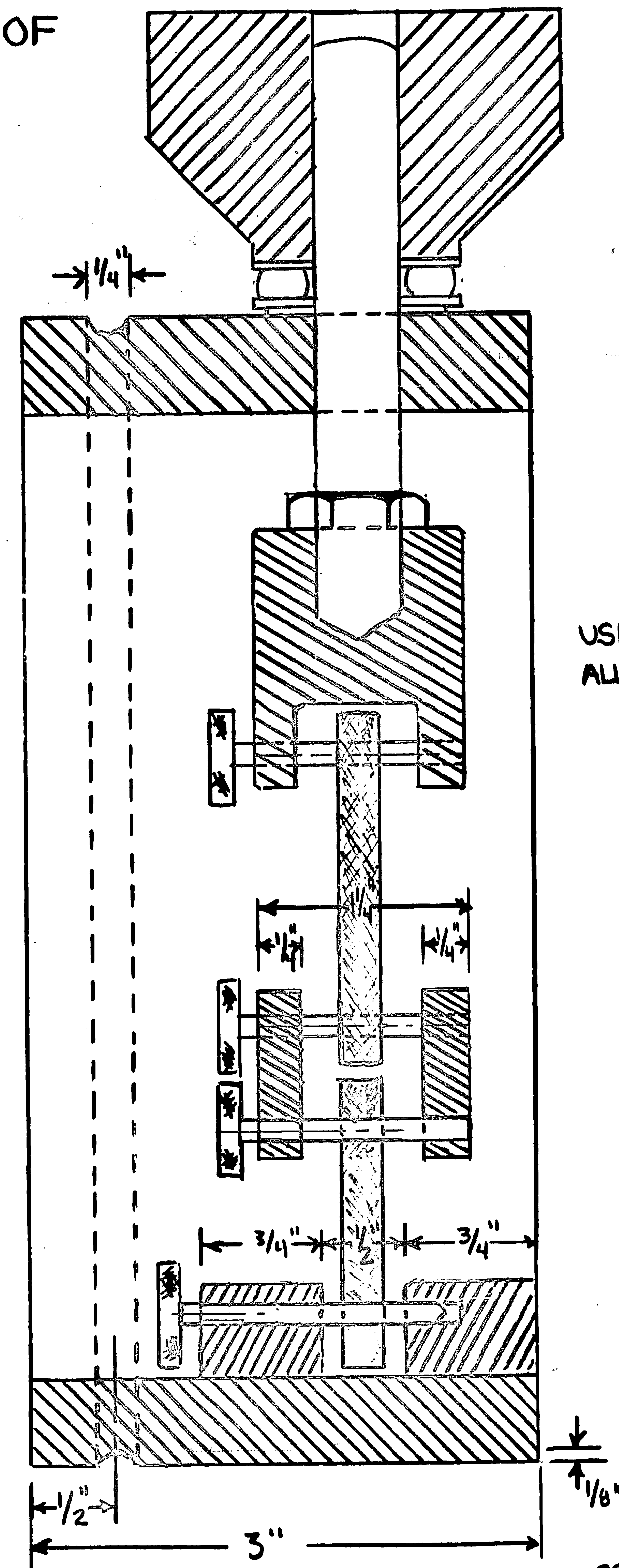


SCALE 1" = 1"

WKA 7-22-64

FIG. 14 COMPENSATOR CONT.

SECTION A-A OF
FIG. 13



USE 1020 STEEL FOR
ALL PARTS

SCALE 1"=1"
WKA 7-22-64

FIG. 15 COMPENSATOR FIXTURE

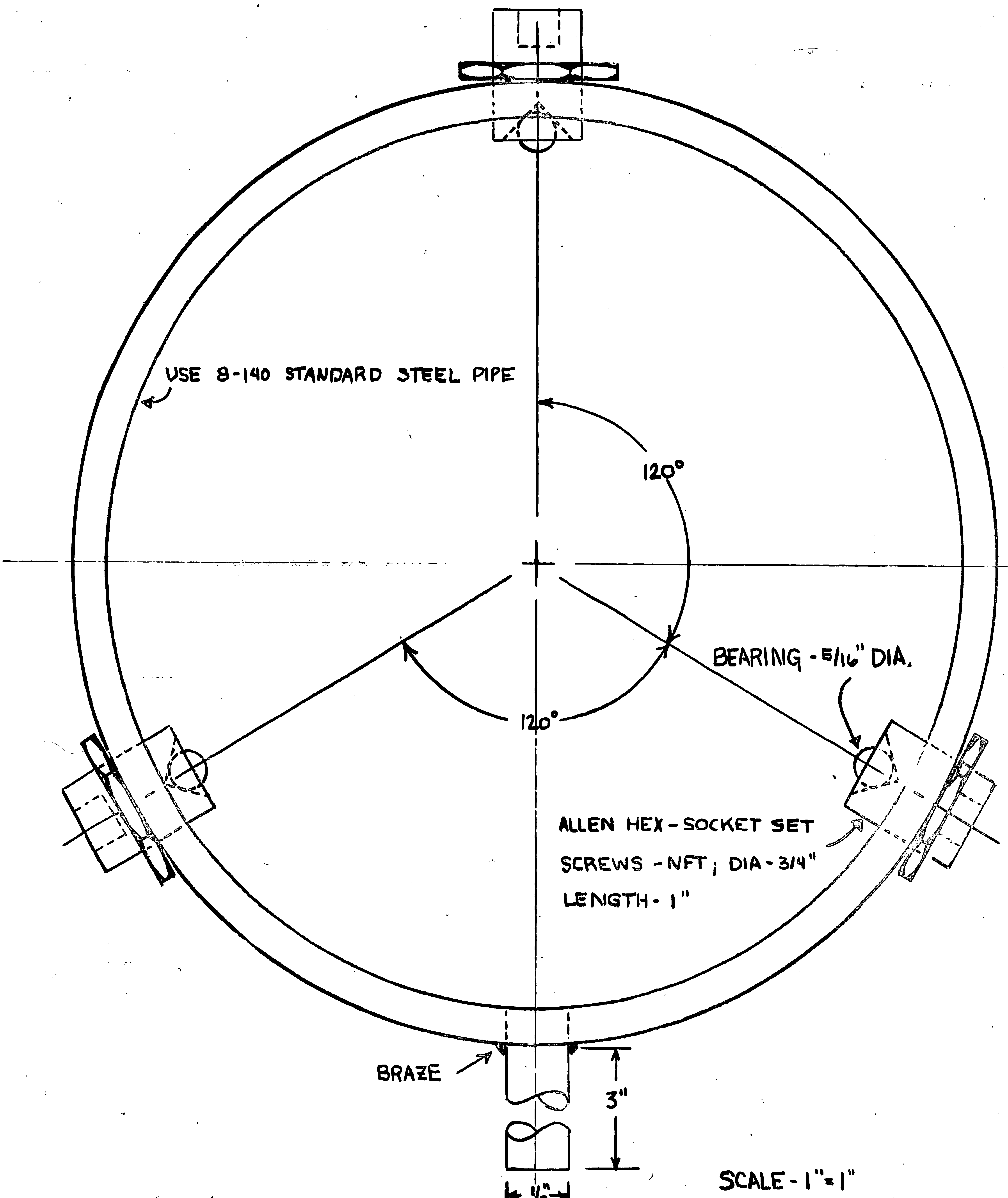
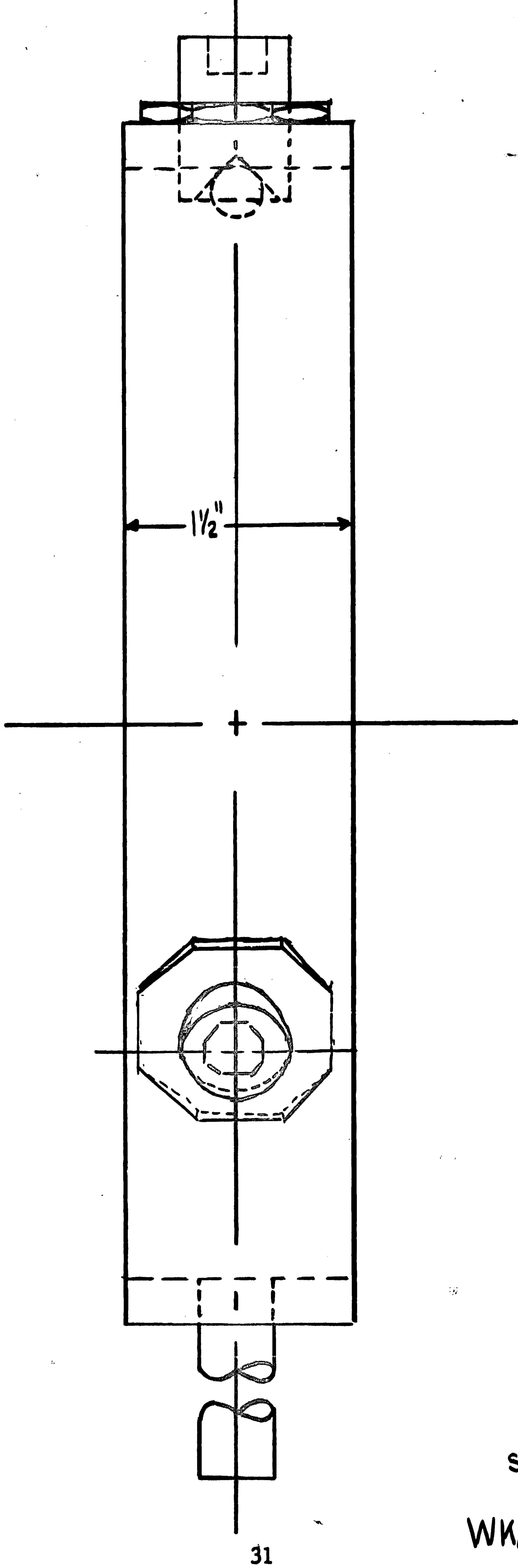


FIG. 16 COMPENSATOR FIXTURE - CONT.



SCALE : 1" = 1"

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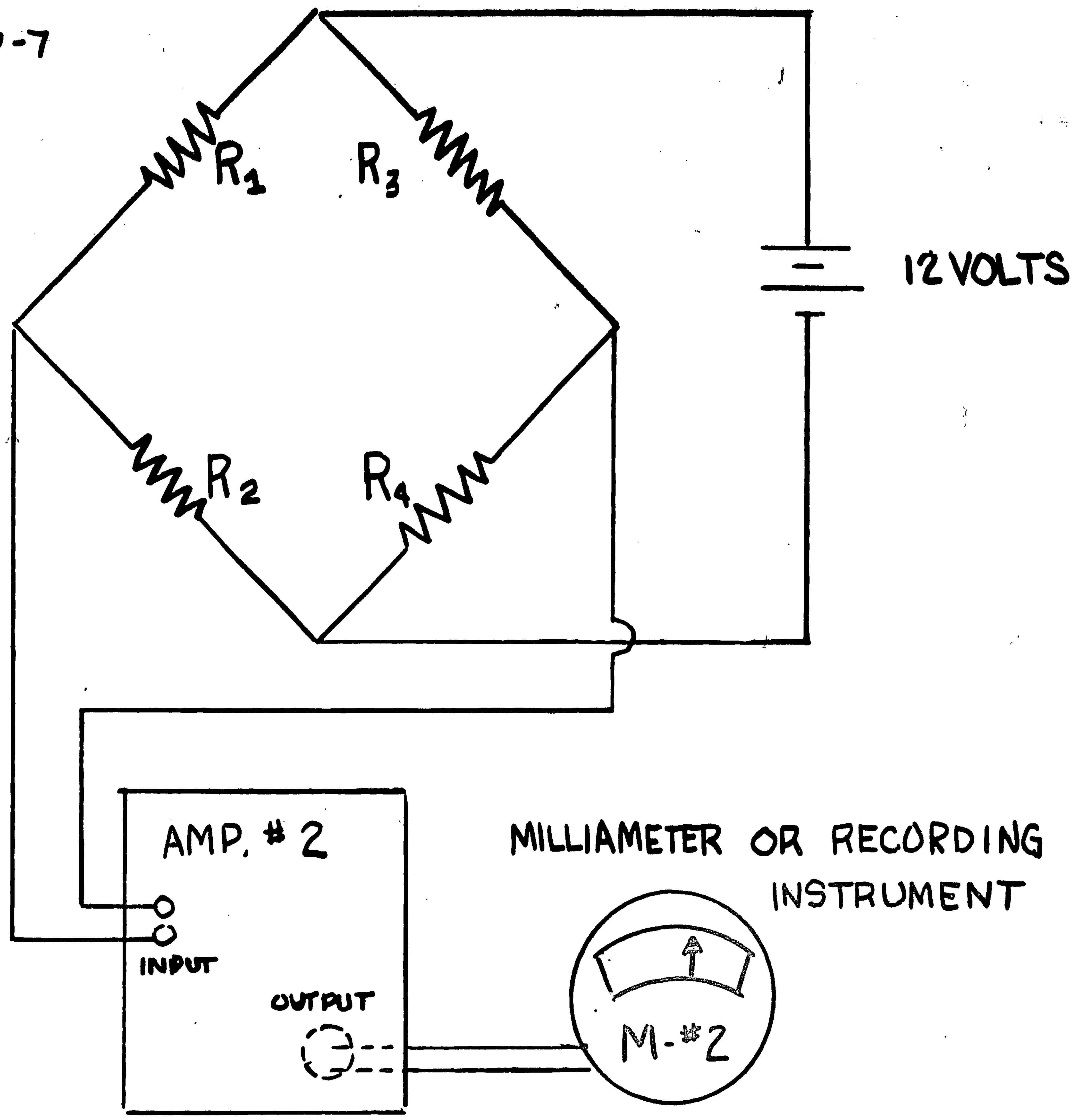
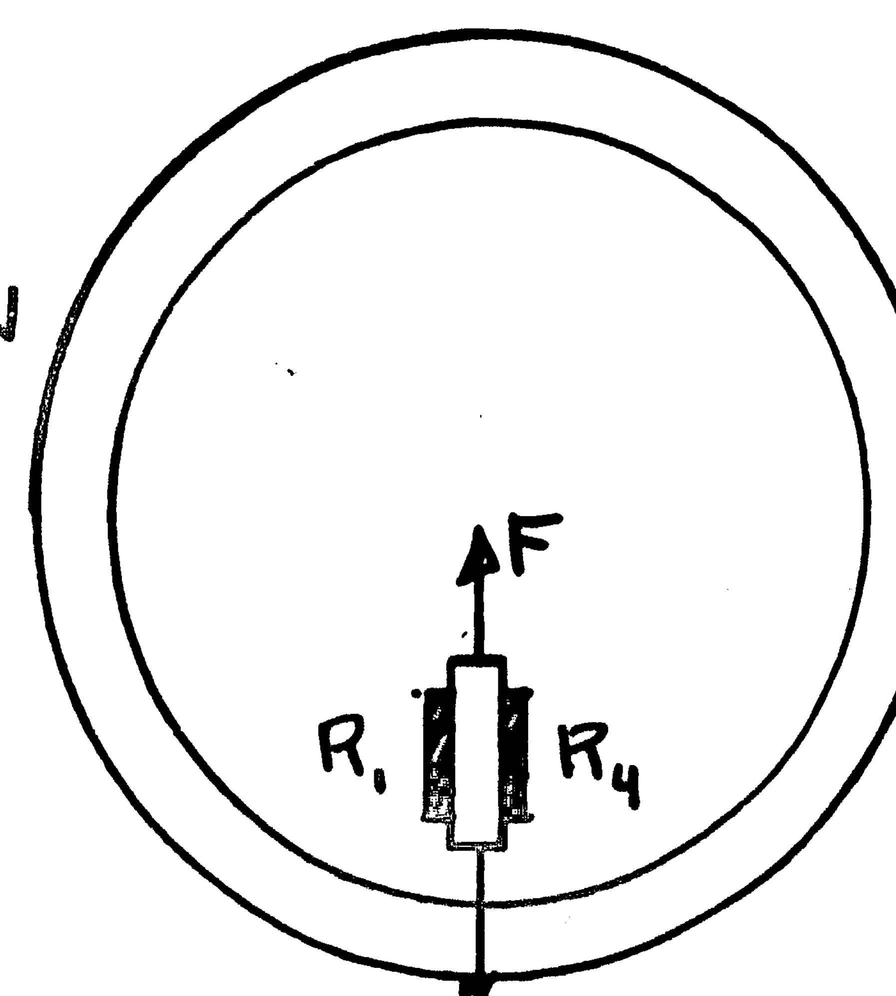
FIG. 17 ELECT. SCHEMATIC FOR COMPENSATOR

USE STRAIN GAGES -
SR-4 TYPE AD-7



STRAIN GAGE
MOUNTING ON
COMPENSATOR



NOTE: GAGES R_2 AND R_3 ARE DUMMY GAGES IN THE BRIDGE CIRCUIT.

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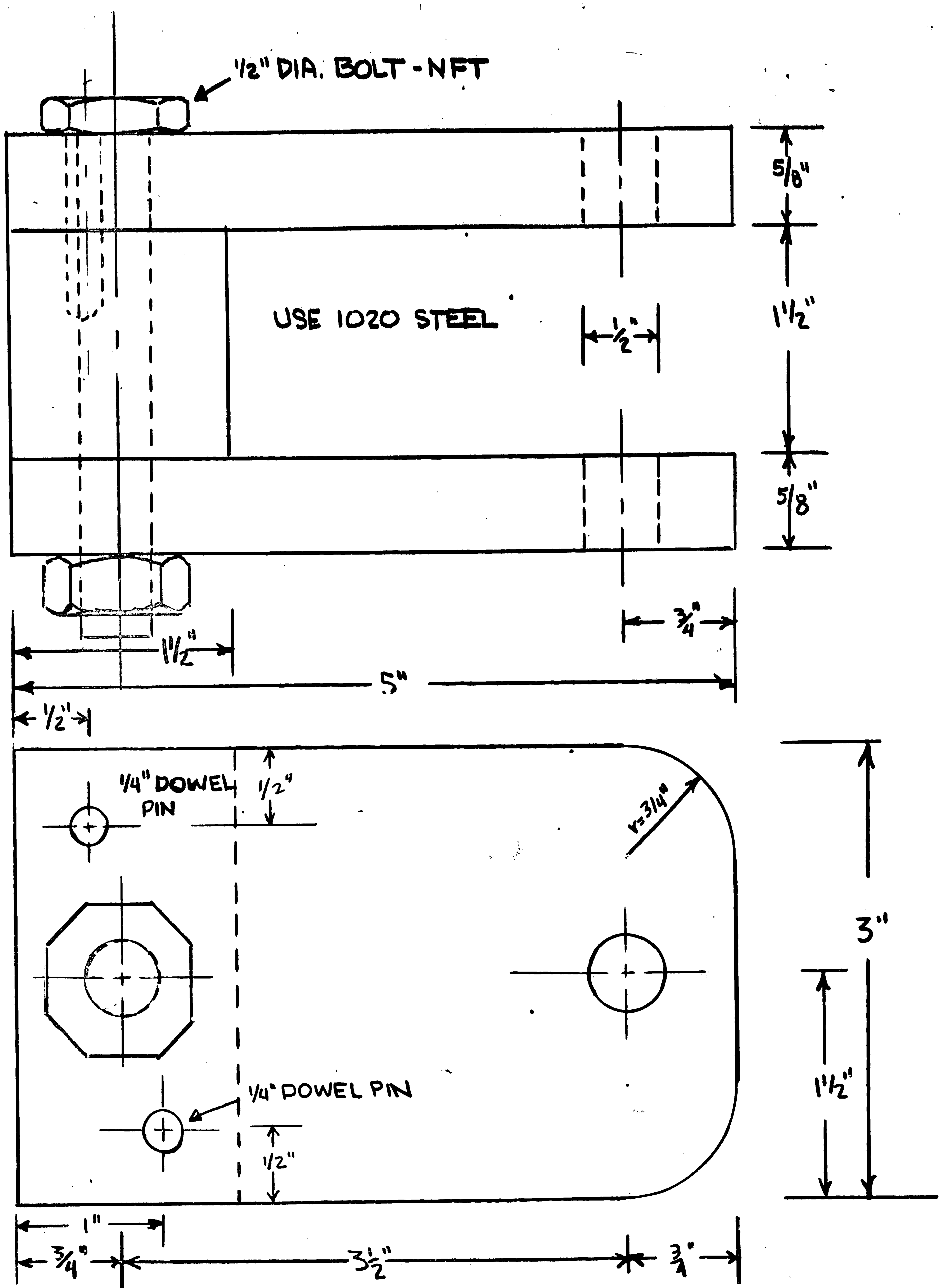
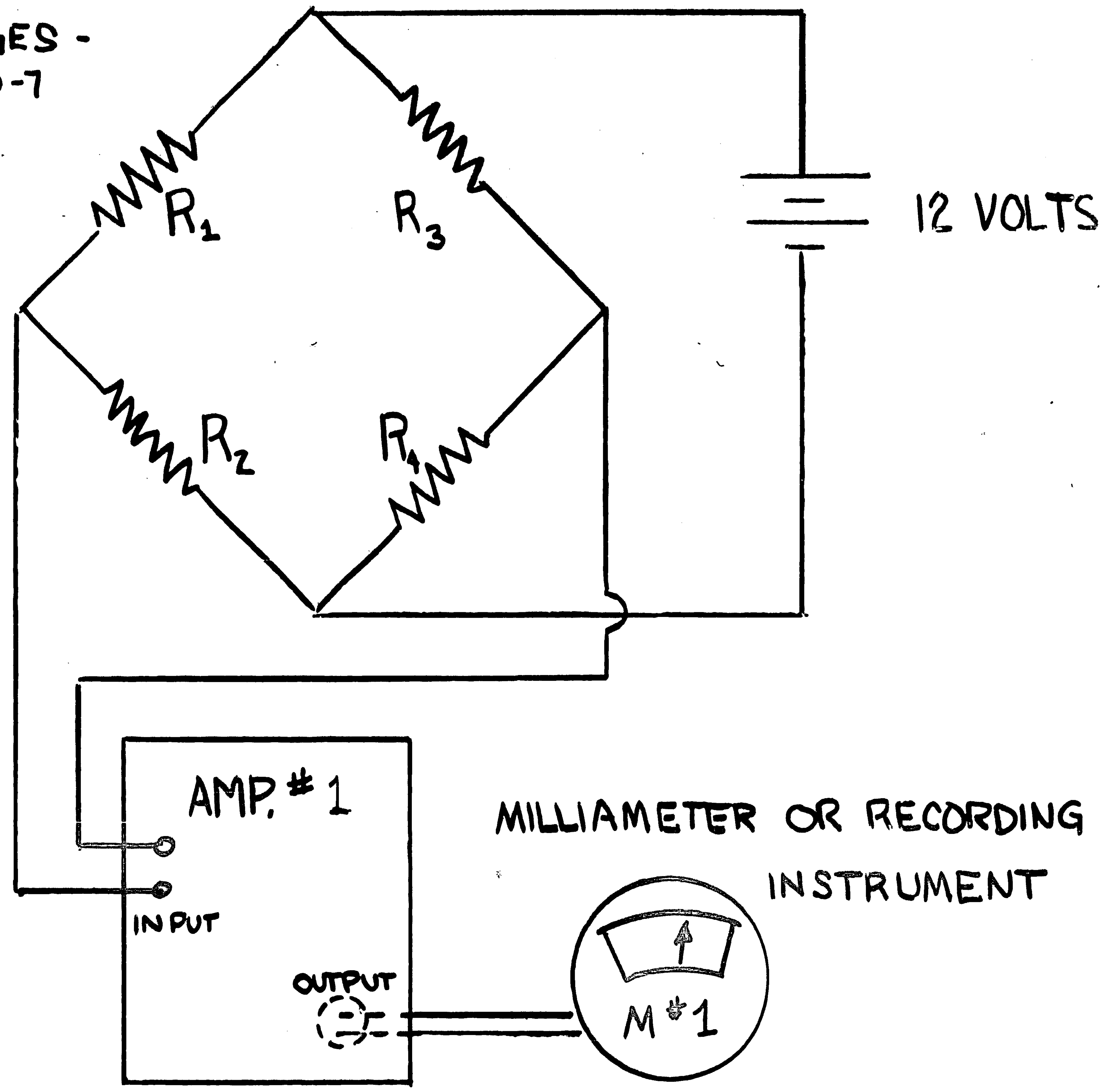
FIG. 18 DYNAMOMETER

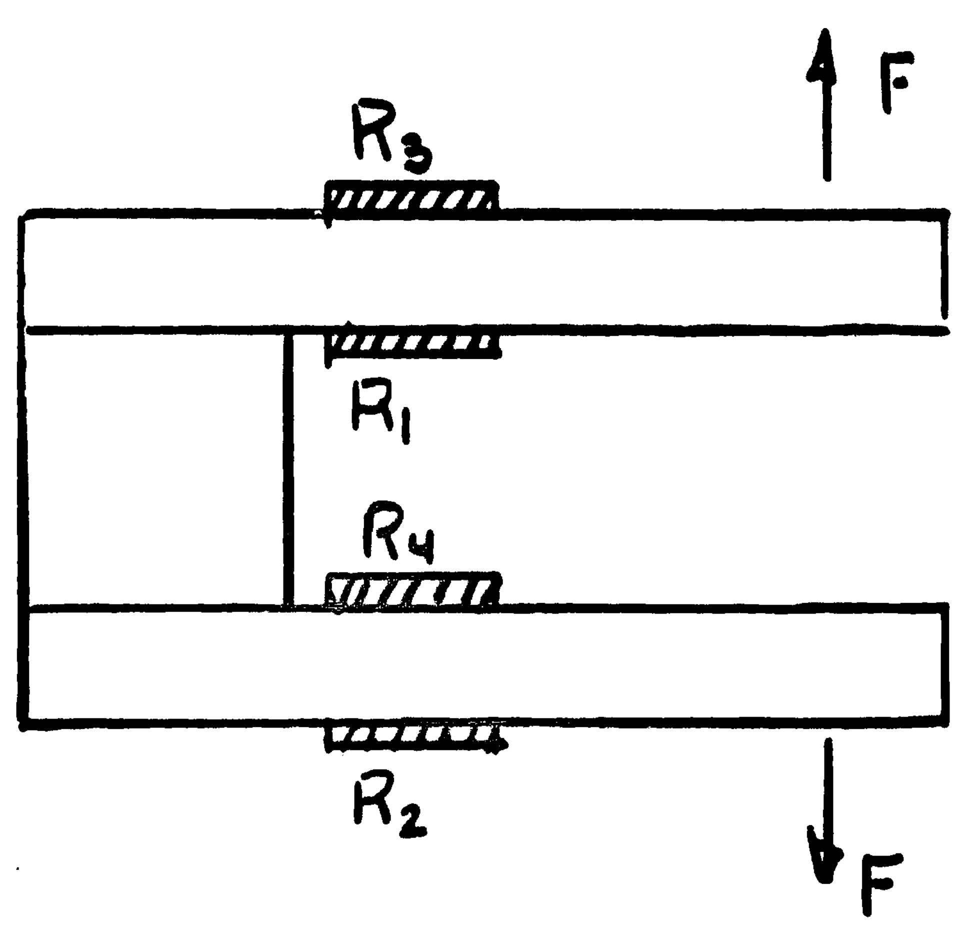


SCALE 1" = 1"
WKA 7-20-64

FIG. 19 ELECT. SCHEMATIC FOR DYNAMOMETER

USE STRAIN GAGES -
SR-4, TYPE AD-7





STRAIN GAGE MOUNTING
ON THE DYNAMOMETER

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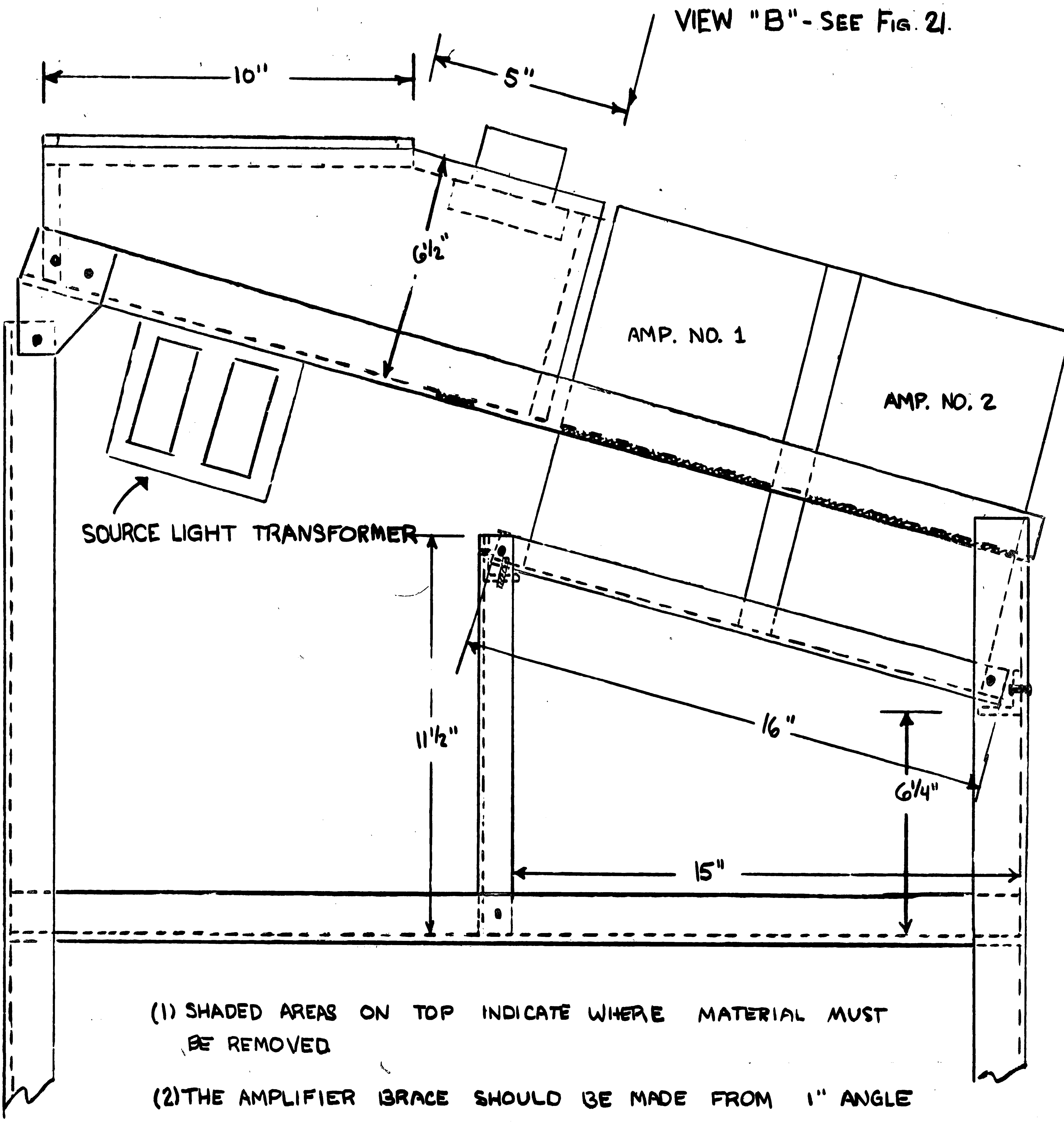
FIG. 20 CONTROL CONSOLE



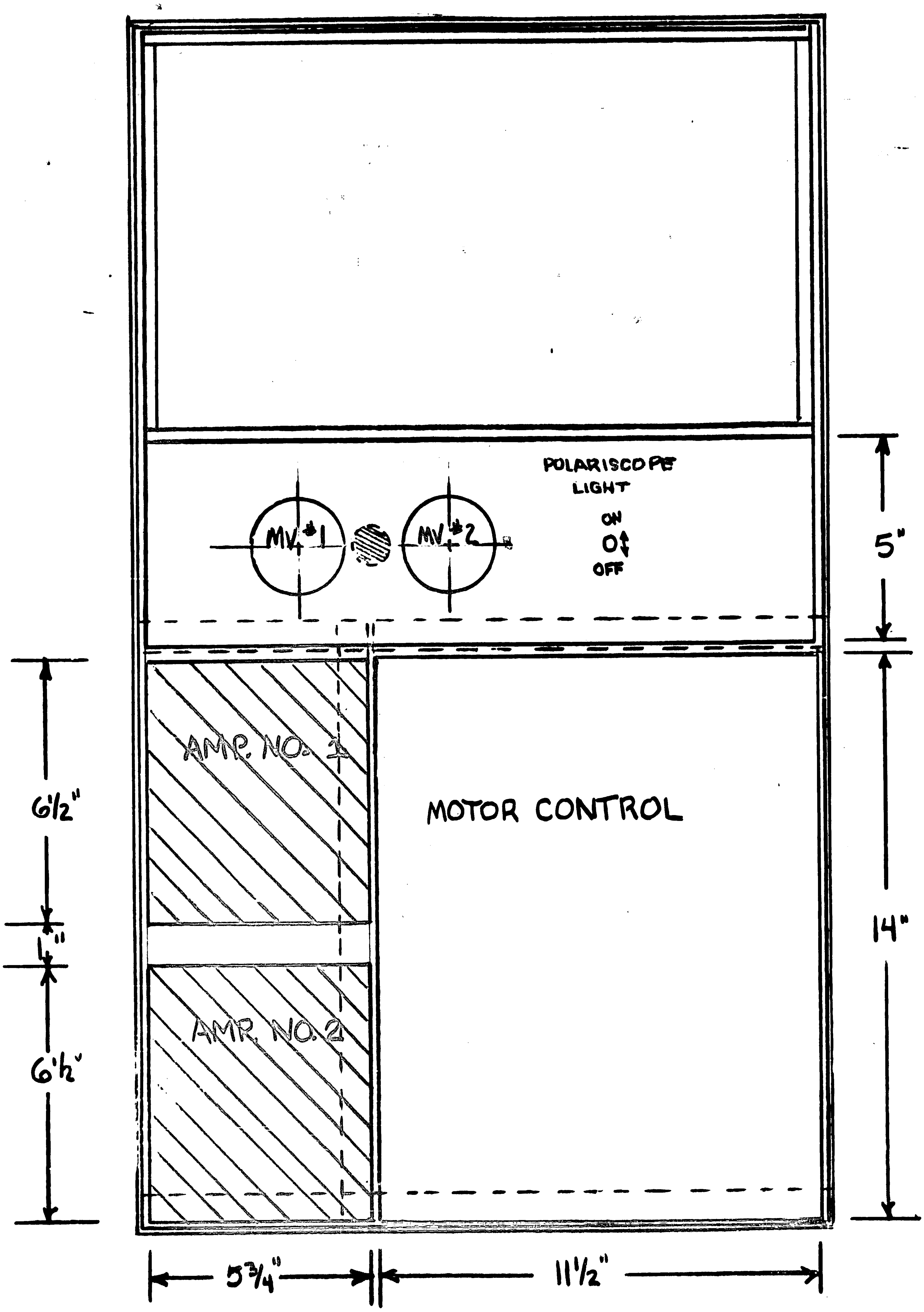
(1) SHADED AREAS ON TOP INDICATE WHERE MATERIAL MUST BE REMOVED

(2) THE AMPLIFIER BRACE SHOULD BE MADE FROM 1" ANGLE

(3) USE 1/2" OR 3/4" PLYWOOD FOR PLATFORM.

SCALE : 1/4" = 1"
WKA 7-20-64

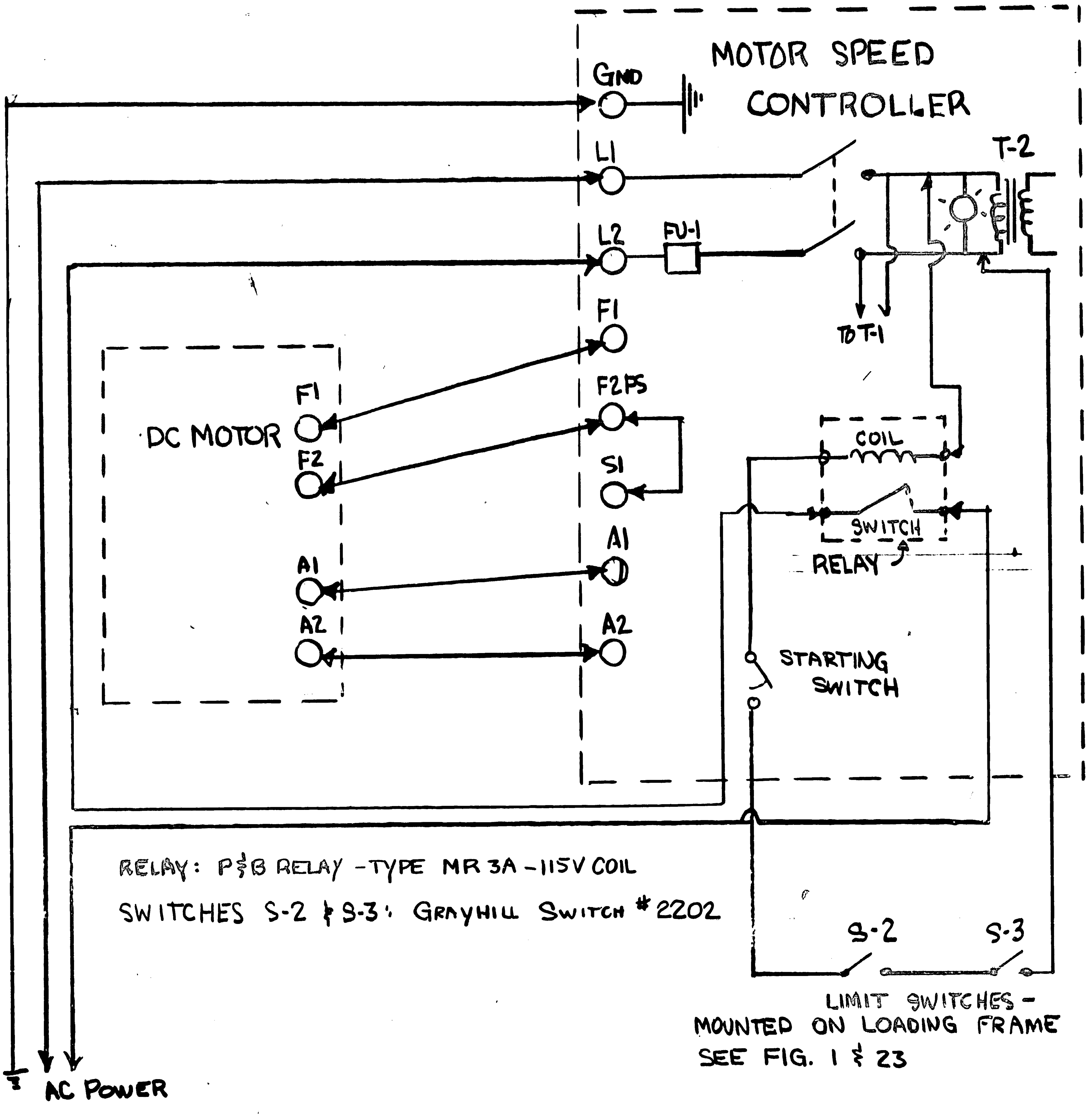
FIG. 21 CONTROL CONSOLE - VIEW B OF FIG. 20



SCALE: 1/4" = 1"

WKA 7-20-64

FIG. 22 ELECT. SCHEMATIC FOR MOTOR AND CONTROL



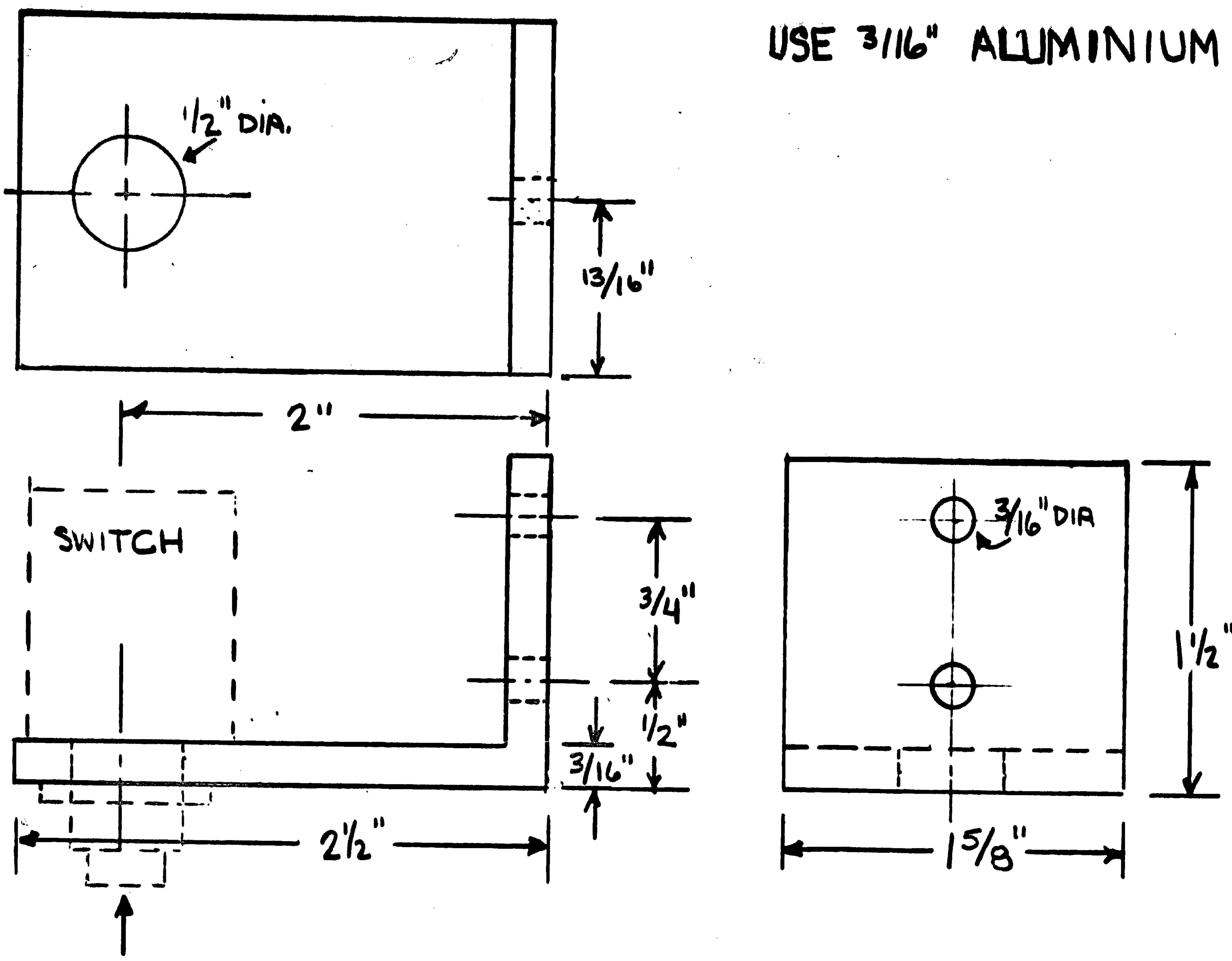
RELAY: P&B RELAY - TYPE MR 3A - 115V COIL

SWITCHES S-2 & S-3: GRAYHILL SWITCH # 2202

WKA 7-20-64

FIG. 23 MOUNTING OF LOAD LIMIT SWITCHES

(1) MOUNTING FIXTURE



(2) CONSTRUCT TWO FIXTURES PER THE ABOVE DRAWING.

(3) MOUNT FIXTURES AND SWITCHES AS INDICATED ON FIGURE 1.

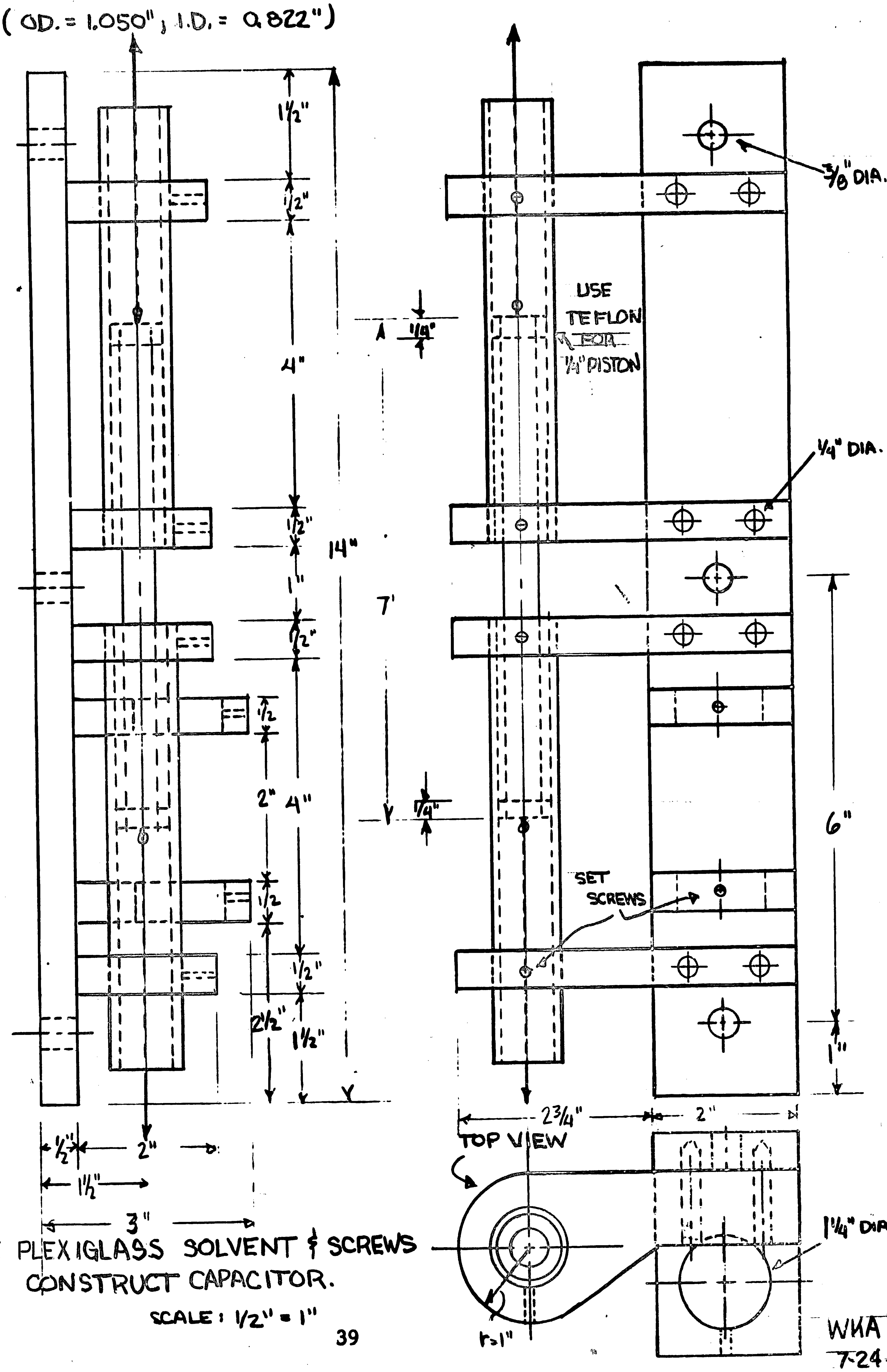
(4) CONNECT SWITCHES ELECTRICALLY PER FIGURE 22.

SCALE · 1" = 1"

WKA 7-22-64

FIG. 24 CAPACITOR

USE PLEXIGLASS FOR ALL PARTS EXCEPT THE CAPACITOR WHICH IS MADE BY INSERTING A 1/2" DIA. COPPER ROD INSIDE A 3/4" SPS COPPER PIPE. (O.D. = 1.050", I.D. = 0.822")



NOTE: USE PLEXIGLASS SOLVENT & SCREWS TO CONSTRUCT CAPACITOR.

SCALE: 1/2" = 1"

WKA
7-24-64

FIG. 25 CAPACITOR MOUNTING

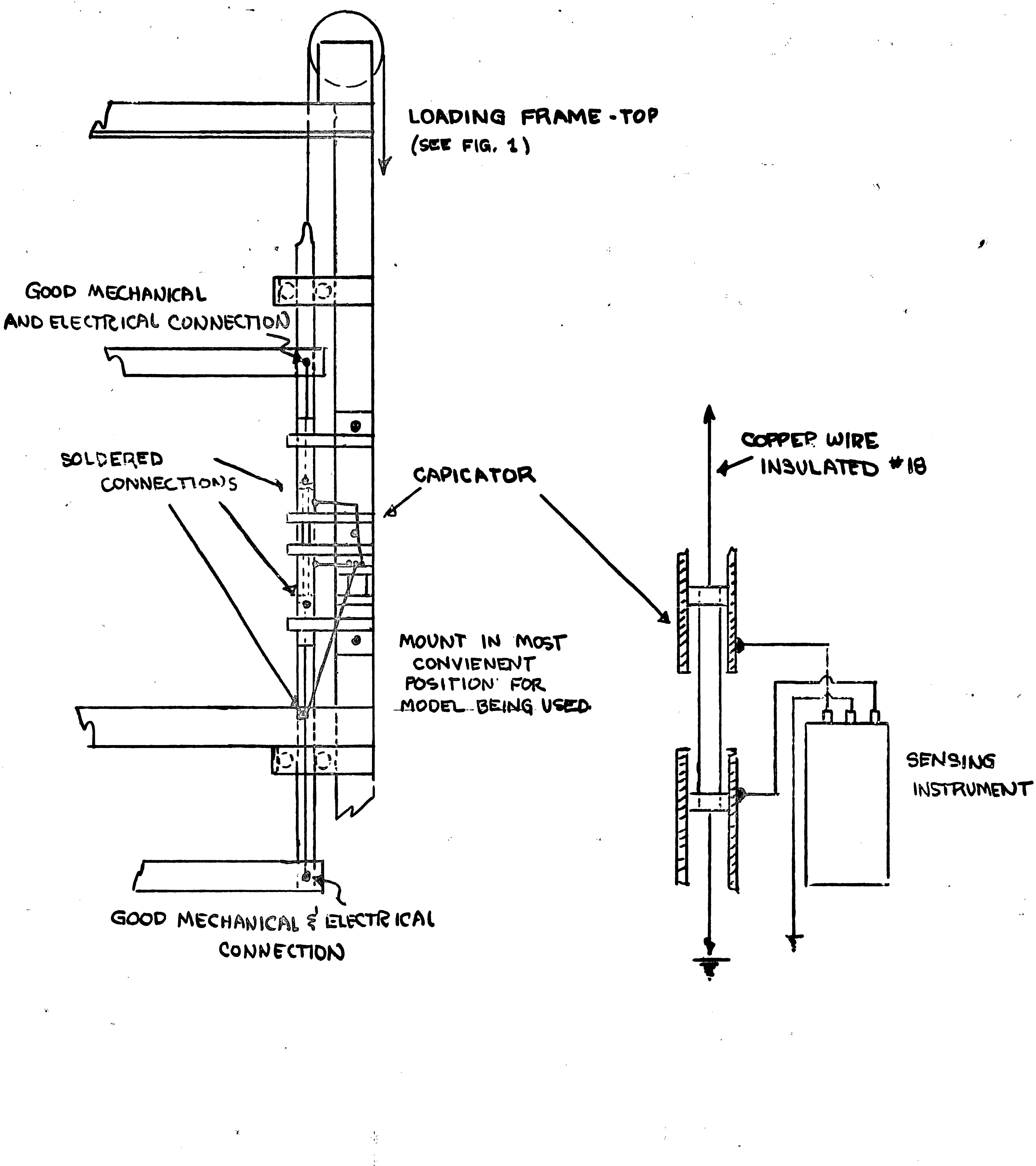


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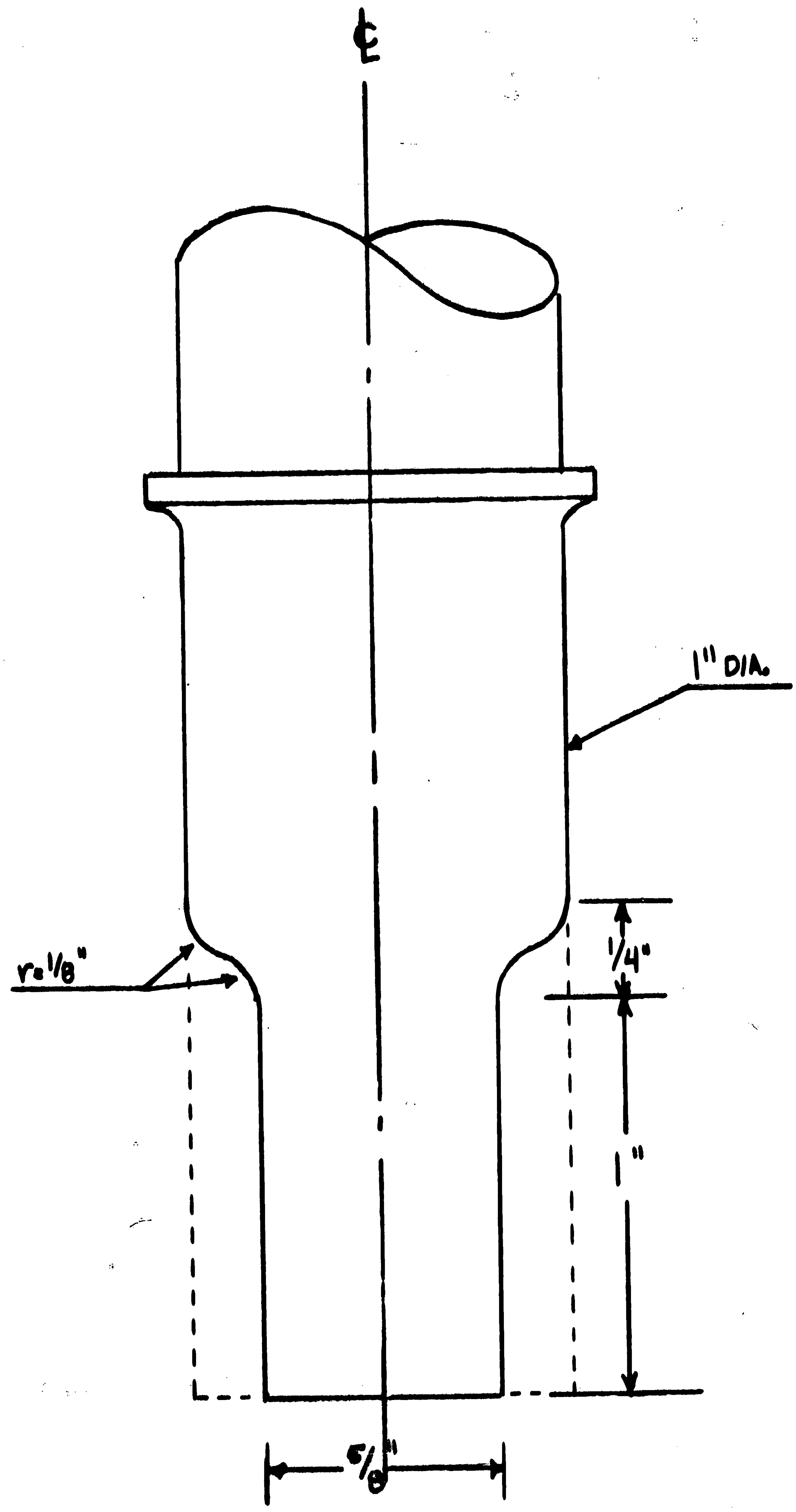
FIG. 26 GEAR REDUCTION DRIVE SHAFT - MODIFICATION



NOTE: DOTTED LINES SHOW ORIGINAL SHAPE

SCALE: 2:1
WKA 6-17-64

FIG. 27. POLARISCOPE AFTER MODIFICATIONS

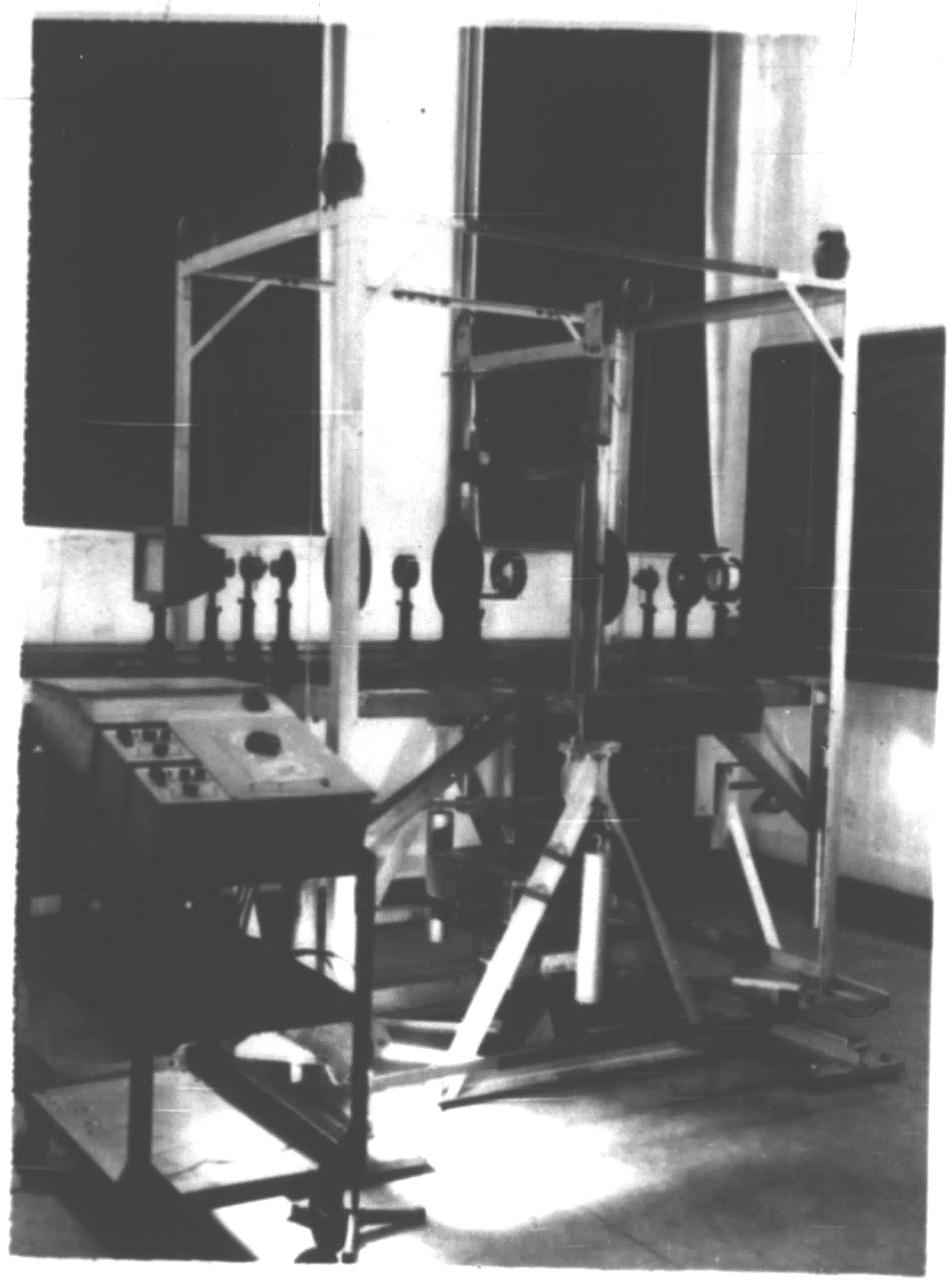
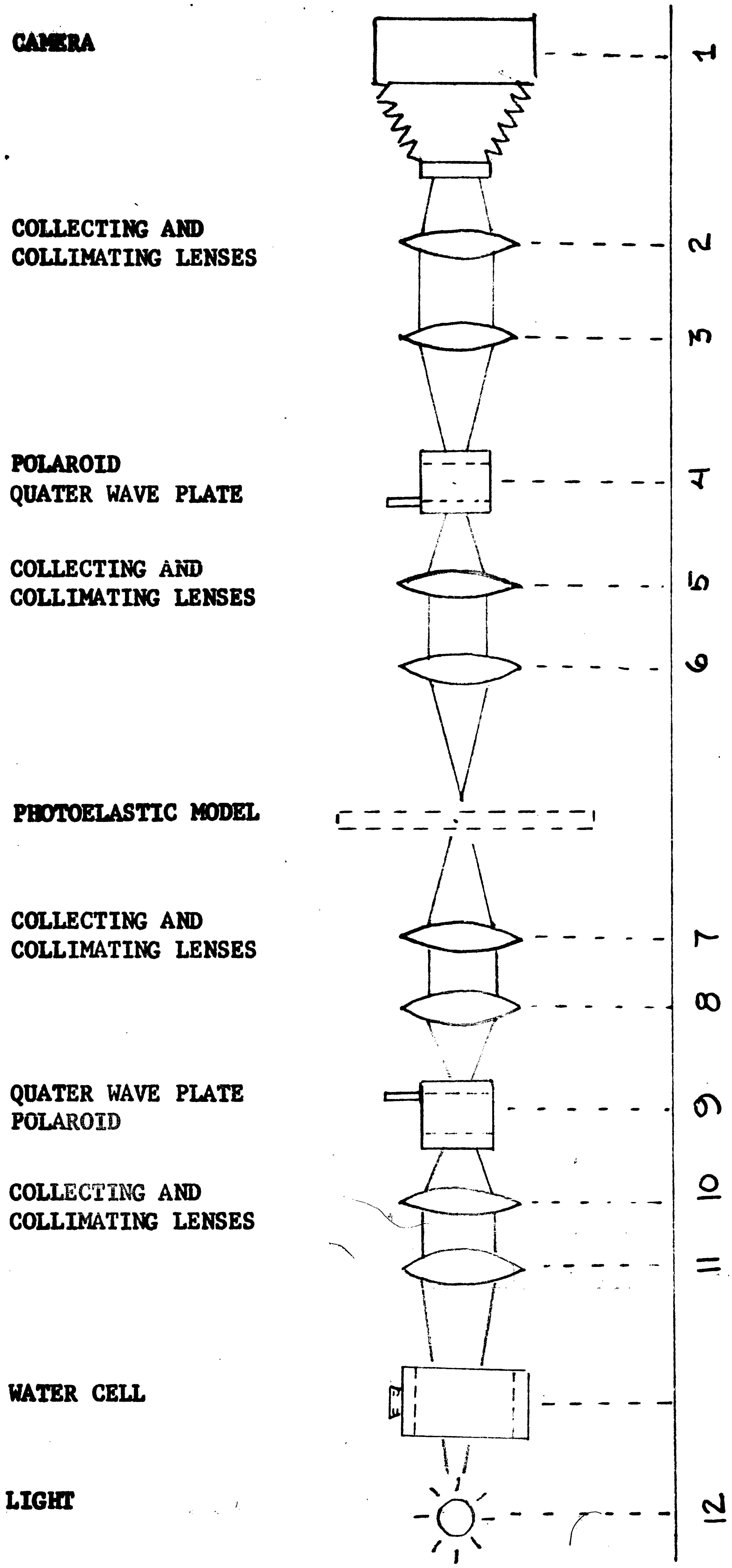


FIG. 28. SCHEMATIC OF POLARISCOPE OPTICS.



APPENDIX 1

STRESS AND FRINGE CALCULATIONS FOR COMPENSATOR

Photolastic sample: Tensile strength range: 400-16,000 psi

Maximum area: $1'' \times \frac{1}{2}'' = \frac{1}{2}$ sq.in.

$$F = \sigma A = 16,000 \left(\tfrac{1}{2}\right) = 8,000 \text{ lbs.}$$

(1) Metal Section:

Using Aluminum alloy 51ST, $\sigma_T = 48,000$ psi

Area: $\left(\frac{1}{4} \times 3/4\right) = 3/16$ sq.in.

$$\sigma = \frac{8,000}{3/16} = 42,750 \text{ psi which is less than } \sigma_T$$

(2) Pipe Section:

Dimensions of 6-120 pipe: od = 6.625"; id = 5.501"; t = .562"

for a pipe (Ref.7): $M_{Max} = 0.3183\ FR$

$$\sigma_{Max} = \frac{Mc}{I} = \frac{(0.3183)(8000)(.562)(12)}{(2)\ (3)\ (.562)^3} = 16,200 \text{ psi}$$

Since the allowable stress is 20,000 psi, the pipe section is in no danger of failing.

(3) Holding Pins:

Using steel pins with $\pm$20,000 psi maximum stress in tension or compression and 13,000 psi maximum stress in shear, the allowable forces the Coker compensator can safely carry are:

Shear:

$$\frac{F}{A} = 13,000$$

$$F = 13,000 \times \left(\frac{1}{8}\right)^2 = 640 \text{ lbs.}$$

or <u>1280</u> lbs. because there are two pins.

Bending:

$$\frac{Mc}{I} = 20{,}000$$

$$F = \frac{20{,}000\left(\frac{\pi}{2}\right)\left(\frac{1}{8}\right)^4}{(1/4)(1/8)} = 246 \text{ lbs.}$$

or 492 lbs. because there are two pins.

(4) Fringe Range:

Using the 492 lbs. as the maximum force that the Coker compensator can safely produce, the number of fringes on a typical photoelastic sample will be: (Ref. 9)

using $f = 9.0$ lb/in/order

$b = 1$ inch

$$n = \frac{P}{bf} = \frac{492}{1 \times 9} = 54.8 \text{ fringes}$$

Thus, the Coker compensator has a range of 0-55 fringes.

APPENDIX 2

DETERMINATION OF MAXIMUM ALLOWABLE LOAD ON LOADING FRAME

(A) Loading Screw:

$d_o = 1''$; $d_r = 7/8''$

direct axial load on screw:

$$F = \sigma_{MAX} A = \frac{20,000 \cdot (7/8)^2}{4} = 12,000 \text{ lbs.}$$

shear strength of threads:

$$F = \tau_{MAX} A = 18,000 \cdot \frac{(7)(1)}{(8)(8)} = 8,850 \text{ lbs.}$$

(B) Top Loading Beam:

dimensions: $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times 20''$

$\sigma_{ULT} = 35,000$ psi ; $M = 10F$

$$F = \frac{\sigma_{ULT} I}{10c} = \frac{35,000 \cdot (1.5)^4}{(120)\ (.75)} = 1,970 \text{ lbs.}$$

(C) Bottom Loading Beam:

dimensions: $2'' \times 3/4'' \times 25\frac{1}{2}$; $M = 12.75\ F$

$$F = \frac{\sigma_{ULT} I}{12.75c} = \frac{35,000\ (3/4)(2)^3}{12.\ 12.75} = 1,330 \text{ lbs.}$$

However, since there are two lower bars of the above strength which can be used together, the lower loading bar can withstand 2660 lbs.

Thus, the maximum safe allowable load would be 1970 lbs.

APPENDIX 3

DYNAMOMETER DESIGN CALCULATIONS

Using 1970 lbs. as the load, a beam thickness of 5/8", and a beam width of 3", the length can be:

$$\sigma = \frac{Mc}{I} = \frac{12(F)(x)c}{bh^3}$$

$$x = \frac{35{,}000 . bh^3}{12\ Fc} = \frac{35{,}000(3)(5/8)}{(12)(1970)(5/16)} = 3.50''$$

thus, a length of 3.5 inches is allowable.

The deflection will be:

based on 1900 lbs. force

$$Y_{Max} = \frac{Fx^3}{3EI} = \frac{(1900)(3.5)^3(12)}{3(30x10^6)(3.5)(5/8)^3} = 0.0127''$$

APPENDIX 4

STRAIN RATE CALCULATIONS

Maximum Motor RPM = 1750

Reduction Gear Ratio = 20.03

Gear Box Ratio = 100:1

Threads per Inch on Shaft = 10

Minimum Travel Rate of Loading Bar = 0 inches/minute

Maximum Rate Using the Reduction Gear:

$$\frac{1750 \text{ RPM}}{20.03 \times 100} \times \frac{1}{10} \frac{\text{Inch}}{\text{Revolution}} = 0.351 \text{ inches/minute}$$

Maximum Rate Using Motor but not Reduction Gear:

$$\frac{1750}{100} \frac{1}{10} = 1.750 \text{ inches/minute}$$

The strain rates, based on the above rates of moving the loading bar and a sample two inches long are:

Minimum = 0

Maximum strain rate using reduction gear:

$$\frac{.351}{2} = 0.176 \text{ in/in/minute}$$

Maximum strain rate using motor alone:

$$\frac{1.750}{2} = 0.875 \text{ in/in/minute}$$

APPENDIX 5

DETERMINATION OF APPROXIMATE STRAIN GAGE OUTPUT

The electrical output of a strain gage is a function of its gage factor, excitation voltage, strain level and electrical circuit. When arranged in a Wheatstone bridge circuit with all four arms active, the bridge output can be expressed as (Ref. 8):

$$E = KVN \text{ (micro-volts)}$$

where:
- E = output of bridge
- K = manufacturer's gage factor
- V = excitation to bridge (volts)
- N = unit strain (E) micro inches/inch

Thus, using a Wheatstone bridge circuit in the case of the dynamometer, assuming a load of 500 lbs., and using SR-4 Bonded Wire Strain gages of Type AD-7 (K = 1.9, R = 120 ohms),

$$E = \frac{\sigma}{E} = \frac{Mc/I}{E} = \frac{(500)(3.5)(5/16)(12)}{(30\times10^{6})(3)(5/8)^{3}} = 298.6 \times 10^{-6} \text{ in/in}$$

Using a gage current of 50 milliamperes (safe value so that no excess heat is produced to change the gage factor) and the 120 ohm gages, the excitation voltage will be:

$$V = (R_1+R_2)I - R_1I_1 - R_2I_2$$

$$V = (120+120)(100 \times 10^{-3}) - 120(50 \times 10^{-3}) - 120(50 \times 10^{-3})$$

$$V = (240)(.1) - 2(120)(.05) = 12 \text{ volts}$$

Thus, the output from the circuit will be:

$$E = KVN$$

$$= (1.9)(12)(298.6) = 6{,}820 \text{ micro-volts} = 6.82\times10^{-3} \text{ volts}$$

Using the maximum gain of the Amplifier which is 30,000;

A maximum signal of:

$$E_{signal} = 6.82x10^{-3}x30x10^{3} = 20.46 \text{ volts}$$

can be obtained to drive a meter.

Note:

The above example shows that a signal of considerable size can be produced using the SR-4 strain gage and Invertor-Amplifier. Therefore, it is important to select the proper gain on the amplifier so that the meter available or recording instrument available can be used to their best advantage. It is recommended that the instruction manuals of each piece of equipment are consulted before operating the equipment.

APPENDIX 6

CAPACITOR DESIGN CALCULATIONS

Requirements for Capicator (Ref. 6):

1 - 50 mmf usable

5 - 20 mmf optimum

Formula for the capacitance of Concentric Cylinders:

$$C = 0.2171 \epsilon_r l / 9x10^5 \log R_2/R_1 \;;$$

or $$l = \frac{C(9x10^5 \log R_2/R_1)}{.2171\ \epsilon_r};$$ where: ϵ_r = dilelectric constant

l = length (cm.)

C = μf = 10^{-6} farad

Calculations: (using air with E_r = 1.0)

$$l = \frac{(5 \rightarrow 20x10^{-6})(9x10^5)(\log R_2/R_1)}{.2171\ (1)}$$

$$l = (4.15)(5 \rightarrow 20) \log R_2/R_1 = (20.75 \rightarrow 83.0)(\log R_2/R_1)$$

Using a ¼" copper rod inside a 3/4" S.P.S. copper pipe O.D. = 1.050"

i.D. = .822"

$$\frac{R_2}{R_1} = \frac{.822}{.250} = 3.288$$

Thus:

$$l = (20.75 \rightarrow 83.0)(.51693) = 10.75 \rightarrow 43 \text{ cm.}$$

Using a ½" copper rod inside the same copper pipe:

$$\frac{R_2}{R_1} = \frac{.822}{.500} = 1.644$$

Thus:

$$l = (20.75 \rightarrow 83.0)(.16613) = 3.45 \longrightarrow 13.8 \text{ cm.}$$

The 3.45 → 13.8 cm. lengths are reasonable; therefore, a ½" diameter rod inside a 3/4" S.P.S. copper pipe is recommended.

The lengths used for the design used will be ¼ inch to 6" which is roughly ½ cm. to 15 cm's.

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VITA

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