THE DESIGN, CONSTRUCTION, AND CALIBRATION OF A GENERATING VOLTMETER FOR A TWO MILLION VOLT ELECTROSTATIC ACCELERATOR

by

Robert L. Bowden, Jr.

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APPROVED: APPROVED:

Director of Graduate Studies Head of Department

Dean of Academic Science and Business Administration Supervisor or Major Professor

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INTRODUCTION

Recent completion of the Virginia Polytechnic Institute electrostatic accelerator makes possible the production of a beam of protons with a maximum energy of two million electron volts. It is of particular convenience to be able to read directly the voltage with which the protons are accelerated. This of course is also an indication of the energy of the beam. Measurement of electrostatic potentials can be accomplished with a generating voltmeter. The purpose of this thesis is to describe the design, construction, and calibration of a generating voltmeter used with the electrostatic generator. The final value of energy is determined by a magnetic analyzer.

The generating voltmeter is a rotating grounded shutter type developed for electrostatic generators operating under pressure. It essentially consists of two sectored vanes located in the electrostatic field. One of the vanes is grounded. It is rotated, alternately shielding the other vane, generating an alternating charging current which is proportional to the potential of the high voltage source creating the electric field. This current passes through a rectifier circuit and the voltage developed across a resistance is measured by a vacuum tube voltmeter. The meter was calibrated in place utilizing energies of known nuclear resonances obtained by gamma-ray yields from bombardment of fluorine with protons.

REVIEW OF LITERATURE

Many generating voltmeters have been described in the literature. The original generating voltmeter was developed independently by Gunn[6] and by Kirkpatrick and Miyake.[15,16] It was developed in order to have a rugged portable instrument for measuring electrostatic fields. This type of instrument proved very valuable in measuring electrostatic potentials which were too high or where measurement by other means was impractical.

With the advent of the high voltage electrostatic accelerators the problem of obtaining a convenient and reliable measurement of this high potential received considerable attention.[24,25] Several methods could have possibly been used. Among these are the methods of high resistance, attracted disk, proton range, generating voltmeter, and magnetic and electrostatic deflection of ions. The high resistance method requires a resistance difficult to construct and shield from corona, and probably results in non-linear response because of the size of the apparatus and the magnitude of the voltage involved. An attracted disk is subject to large calibrating errors because of the squared scale and the relatively low available calibrating voltages. The magnetic and electrostatic deflection and proton range were felt to be more complicated than at first thought to be necessary.

Because it had been used with good results for a variety of purposes[6,9,15] and because of the advantages offered by its relative simplicity and its independence of the ion beam, the method utilizing a generating voltmeter was tried with good results.[11,24] Consequently, voltmeters of linear scales and accuracies ranging from 5 percent to 0.2 percent have evolved for use with electrostatic generators. The generating voltmeter has remained the primary means of measuring the voltage on many of the generators for several years. With the addition of concentric electrodes on the electrostatic generators some other means of obtaining the absolute voltage have had to be devised since the generating voltmeter would only measure the potential of the outer electrode. Also, the desire for more accurate energy measurements dictated the use of other methods. Accurate measurements are made today by electrostatic analyzers or calibrated magnetic analyzers. The generating voltmeter remains a very useful tool with the electrostatic generators, especially during initial focusing, because of its continuous scale reading.

Because of its usefulness, it is well to review the type of generating voltmeter developed with respect to choice of parameters, difficulties found, methods of calibration, and the advantages found from the use of this type of meter. The review is by no means complete, but contains references to some typical voltmeters.

The parameters involved in generating voltmeters as will be shown in the next section include the size and shape of the vanes and the speed of rotation of the grounding vane. An early attempt by Van Atta, Northrup, Van Atta, and Van de Graaff[25] was to shape the vanes as to generate a sine wave current. However, the most expedient shaped vanes have been sector shaped. The University of Kentucky[14] and The California Institute of Technology[17] electrostatic accelerator groups built voltmeters consisting of semicircular pole pieces. Herb, Parkingson, and Kerst[5,11,19] of Wisconsin and Williams, Rumbaugh, and Tate[27] of Minnesota built voltmeters of two pole sectored vanes. The current from these voltmeters was commutated by a synchronous mechanical rectifier and displayed on a sensitive galvanometer. Trump, Safford, and Van de Graaff[22] reported a four pole voltmeter the output of which was rectified by a full-wave-bridge vacuum tube rectifier and displayed on a microammeter. An innovation of the shutter type voltmeter is the one developed by Haxby, Shoupp, Stephens, and Wells[8,26] using the principle of compensating voltages described by Harnwell and Van Voorhis.[7] In this voltmeter, the generating voltmeter itself is used only to detect the absence of inhomogeneities in the field behind a voltage plate. Voltage is applied to this plate until it coincides with an equipotential surface of the field from the high potential electrode. This condition is detected by the absence of pick-up in the generating voltmeter part. The high voltage is then proportional to the voltage on the voltage plate and is measured by means of precision resistors and a milliammeter. The size of the vanes of these various voltmeters ranges from about twelve inches to three inches depending on the size of the generator. In most cases the rotating vane is spun by either an 1800 r.p.m. or a 3600 r.p.m. synchronous motor.

Difficulties arising with these voltmeters are those usually associated with location. Difficulty has been noted when the voltmeter was located so that it might "see" a charged insulated surface or where the field is large enough to permit sparkover.[25] Some comments have been made on the effect of corona current. Trump, Safford, and Van de Graaff[22] showed that the effect of corona current in their design was negligible for the pressure insulated generator. Herb, Parkingson, and Kerst[11] found that the sensitivity of the voltmeter changed radically if the vanes were changed slightly with respect to the tank wall.

The most expedient way of calibrating the voltmeter is to apply to the high voltage electrode a potential which can be measured by some other means. Since the voltmeter is linear a relatively small voltage can be applied and measured by a previously calibrated high resistance. From this a voltage sensitivity can be established. This is the method used by Trump, Safford, and Van de Graaff.[22] Another standard method is to compare the voltmeter reading with the value of the terminal voltage at known nuclear resonances. This method has been used by a number of groups.[8,11,17,27] The linearity has also been checked by utilizing the double and triple energies needed for diatomic and triatomic ions to undergo the same reactions as monatomic ions.

The main advantages of the generating voltmeter have been found to be as follows. The voltmeter is independent of the ion beam. The voltmeter drains no current from the source of high voltage. It has a continuous scale reading. It is relatively rugged. The indicating meter is at or near ground potential and can be located at a distance from the generator.

DESIGN

Principle of Operation

The generating voltmeter consists essentially of an insulated stator member mounted in the ground plane of the tank facing the high voltage terminal from which it is periodically shielded by the rotation at constant speed of a grounded sectored disk. The stator-to-terminal capacitance is thus caused to vary periodically and the induced stator current, which is a measure of the terminal voltage, passes through a rectifier giving rise to a voltage across a resistance R. The d.c. potential developed across this resistance is measured by a special vacuum tube voltmeter. A simplified circuit for a generating voltmeter is given in Figure 1. In this figure and in the analysis below V is the constant potential to be measured; C is the periodically varying capacitance between the high voltage terminal and the stationary stator, the maximum variation of which is C_v.

The cycle of operation is as follows. As C increases from its minimum value, the stator is charged through the rectifier T_1 by the influence of the potential V until C reaches its maximum value. Then as C decreases, the stator discharges through the rectifier T_2 and the resistance R until C again reaches its minimum value, whereupon the cycle is repeated. It is evident that the current in R is unidirectional and is independent of the polarity of V. It is of interest to note that the total charge transferred over one cycle is zero. Therefore, the voltmeter draws no current from the high voltage source, but rather the power used for the cyclic transfer of charge is supplied by the mechanical force varying the capacitance C.

The circuital relation during the last half of the cycle is

$$V = \frac{q}{C} + iR,$$

where: q = the charge at any time on C,

i = the instantaneous current,

V = the high voltage potential,

C = the stator-to-terminal capacitance, and

R = the voltage dropping resistance,

assuming negligible rectifier voltage drops. This equation is difficult to solve since C is a function of time. If, however, it is noted that iR is very small in comparison with V (a departure of about two parts in one million for the present voltmeter) the relation may be written with good approximation as

$$V = \frac{q}{C} .$$

Differentiating with respect to time,

$$\frac{dq}{dt} = \frac{dC}{dt} V,$$

or,

$$i\ dt = dC\ V.$$

Integrating over one half period, T/2, the equation becomes

$$\int_{T/2}^{T} i\ dt = \int_{C_V}^{0} dC\ V.$$

The left side of this equation is simply the total charge, Q, which flows through the resistance R during this half cycle. Therefore,

$$Q = -C_V V.$$

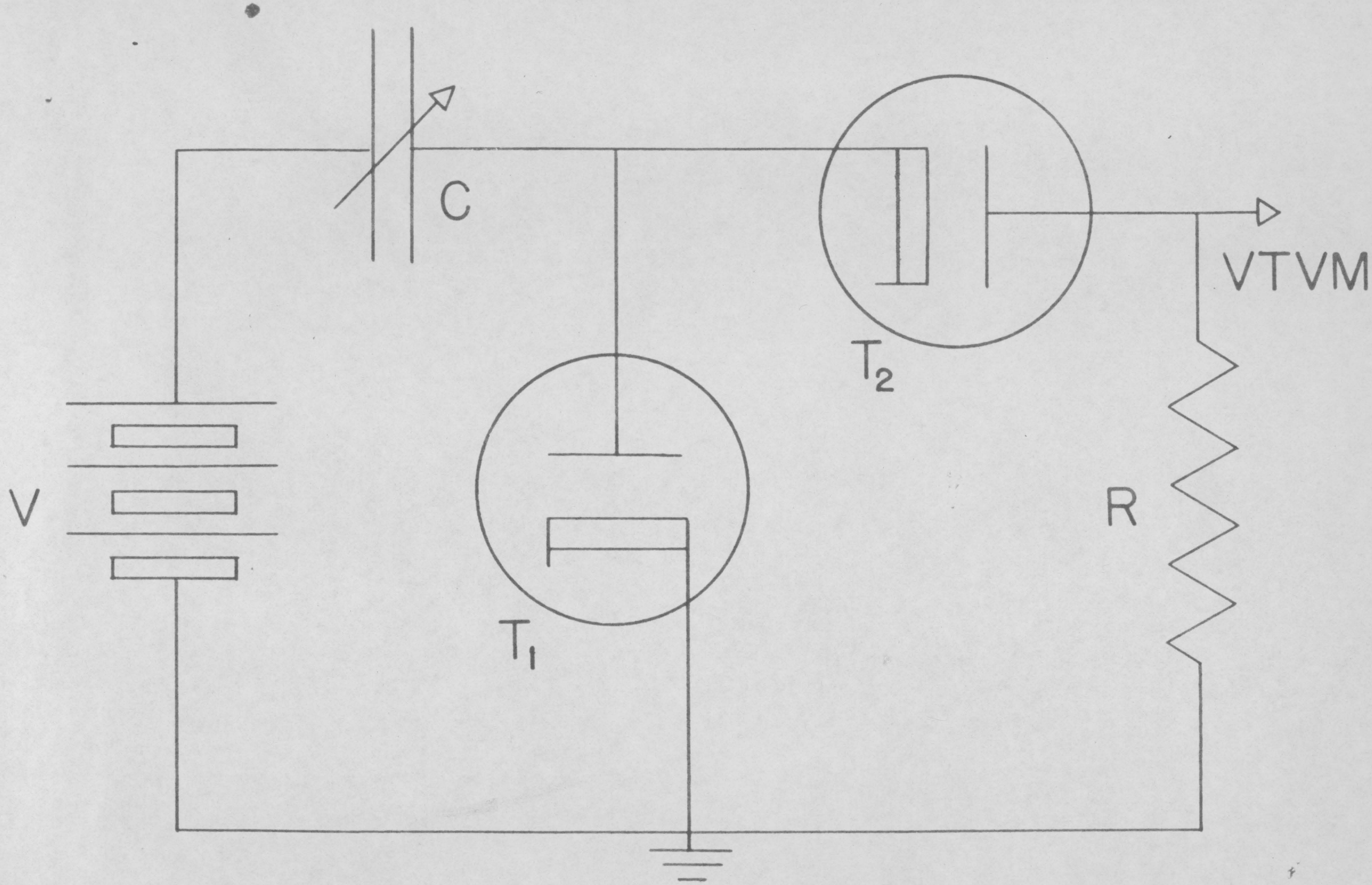
But because the circuit is essentially a half-wave rectifier, this is also the total charge through R during a complete cycle of operation. Then dividing by T,

$$\frac{Q}{T} = -\frac{C_V V}{T}.$$

Since Q/T is the current, I, in R during one cycle and $1/T = f_c$, the variation frequency of the capacitance C, the voltage across the resistance R is

$$IR = -Rf_c C_V V.$$

This relation shows that the voltage across R is proportional to f_c and for constant frequency is proportional to the poten-

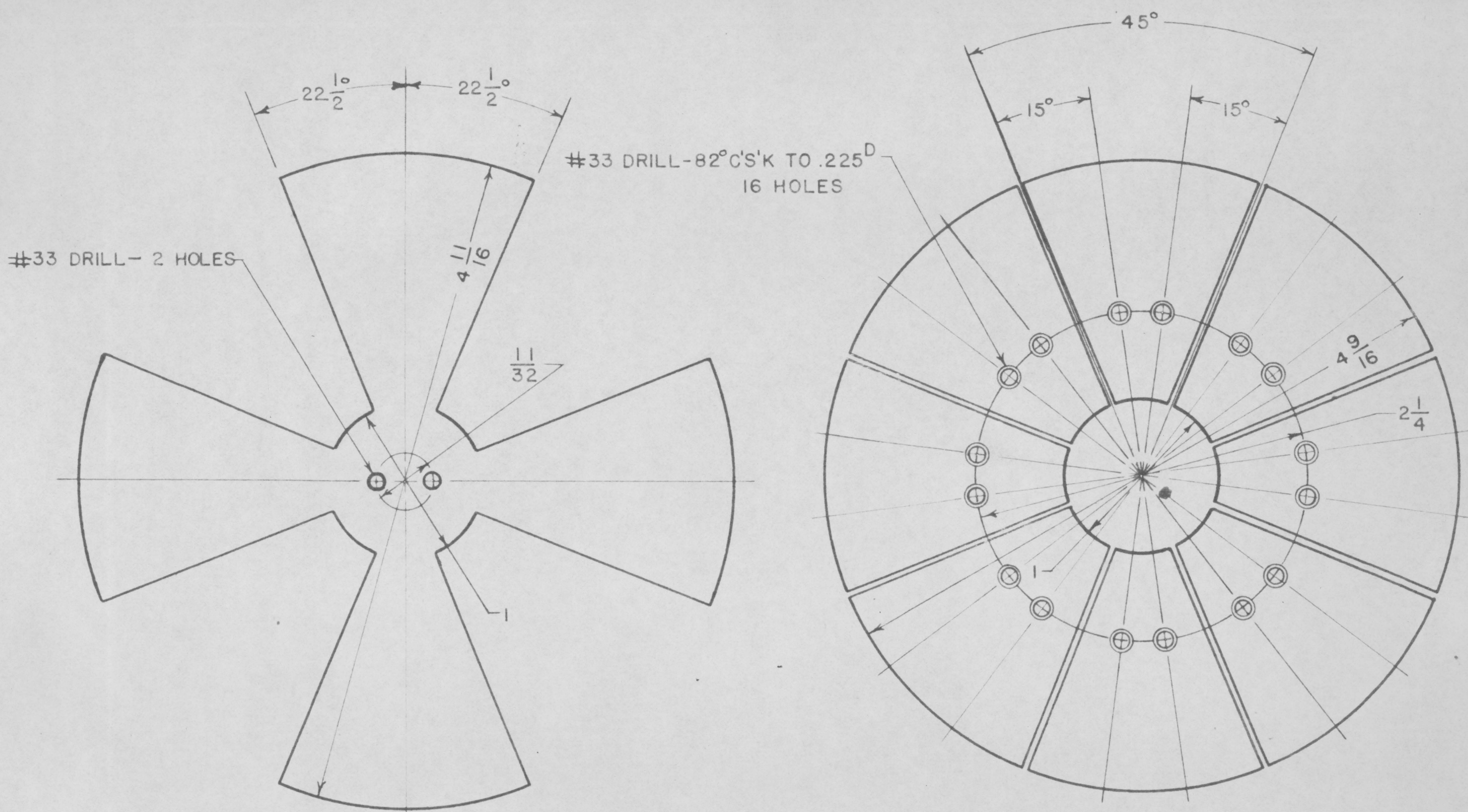


SIMPLIFIED GENERATING VOLTMETER
FIG. 1

tial V. By reading this voltage directly with an appropriate vacuum tube voltmeter, the high voltage potential V can be read directly.

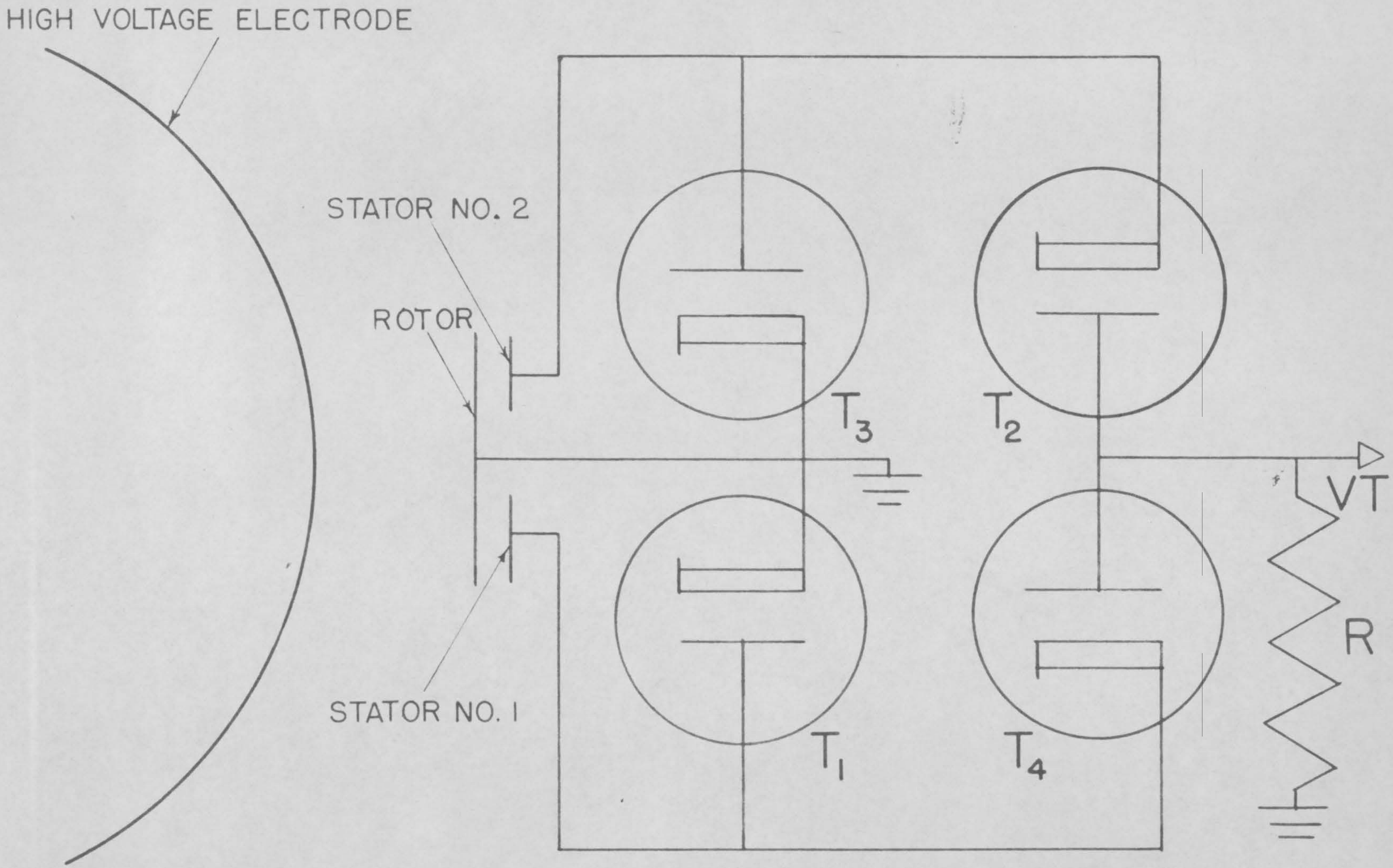
Rotor and Stator Assembly

Since the induced stator current is proportional to the frequency of the variation of C, it is desirable to divide the stator member into several poles so as to increase the magnitude of the induced currents for a fixed speed of the rotor. The period of variation of the capacitance should of course be large in comparison with the relaxation time of the circuit. The stator of the present voltmeter is divided into eight 45° sectors. Alternate stator sectors are electrically connected to form two stator groups of four poles 180 electrical degrees out of phase with each other. The four pole rotor is a complement to each of these stator groups. Figure 2 shows a detail drawing of the rotor and stator. It may be noted that the induced stator current will be essentially a periodic rectangular wave of 180 electrical degrees. With each stator group provided with an independent rectifier system as shown in Figure 3, a substantially constant rectified current flows in the resistance R. Since the frequency of variation of the capacitance is essentially twice that of the previous analysis the current output is doubled.



ROTOR STATOR

ROTOR AND STATOR DESIGN
FIG. 2



SIMPLIFIED GENERATING VOLTMETER OF PRESENT DESIGN

FIG. 3

It is also desirable to make the stator-to-terminal capacitance as large as possible to increase the magnitude of the current generated. The capacitance is determined primarily by the size (area) of the stator and its distance from the high voltage terminal. These two parameters, however, were fixed by the geometry of the pressure tank and high voltage terminal. The distance to the stator from the high voltage terminal was determined by the relative distance between the accelerator electrode and the ground plane of the apex of the tank. The size of the stator was limited by the 4.9 inch diameter recess aperture in which the stator is located.

Rotor Drive and Pressure Housing

It has been noted that the generating voltmeter output is proportional to the high voltage potential only if the frequency of the periodic stator-to-terminal capacitance is constant. This is accomplished by spinning the rotor with a synchronous motor. For the present voltmeter a Bodine, 1/20 h.p. 1800 r.p.m. synchronous motor is used. Since a motor of this capacity will not fit into a three inch welding well opening to the pressure tank, it was necessary to design a rotor drive in which the motor is located outside of this well. In order to completely pressurize the entire generating voltmeter, the motor is located in a flange and pipe pressure chamber which bolts onto the flange of the welding well. The rotor is affixed to the end of a double ballbearing shaft arrangement which is located down the length of the well. The shaft is driven by the synchronous motor, being coupled by a flexible coupling. A cross-sectional detail drawing of the voltmeter is shown in Figure 4. Complete detail drawings of the generating voltmeter are inserted in a pocket in the back cover.

Rectifier and Vacuum Tube Voltmeter

Since it is desirable to take advantage of the linear scale of a direct current meter, it is necessary to rectify the generated signal from the voltmeter. Referring again to Figure 3, it can be seen that the rectifier circuit is simply a full-wave-bridge type. A full-wave-bridge rectifier was designed utilizing the high reverse resistance of a vacuum tube diode. Two twin 6H6 diodes were used with the heater current limited to about one half rated value to inhibit the flow of emission current during the non-conducting part of the cycle. The filament supply to the rectifier is controlled by the vacuum tube voltmeter power switch. Figure 5 shows the diagram for the rectifier.

The vacuum tube voltmeter shown in Figure 6 is based on a difference amplifier circuit. The voltmeter power supply is a conventional full-wave VR tube regulated supply.

The output is read on a meter between the plates of the two triodes of a 6SN7. The 5000 ohm variable resistance in the plate circuit serves to balance the plate voltage of the two tubes so that no current is indicated by the meter. The rectified output signal from the generating voltmeter is developed across a 3.14 megohm resistance. This resistance is connected to a switching arrangement so that either all, one half, or one fourth of the total voltage drop across the resistance is applied to the grid of one triode giving relative voltage ranges of one, two, and four respectively. An identical resistance switching arrangement is in the other grid circuit so that in switching from one range to another the zero drift is minimized. The application of the signal to the grid causes an unbalance between the plates and the differential plate current is given by

$$i = \frac{\mu e}{R_m + r_p(2 + R_m/R_l)},^{4}$$

where:

μ = gain of vacuum tube,

e = voltage applied to grid,

R_m = resistance of meter,

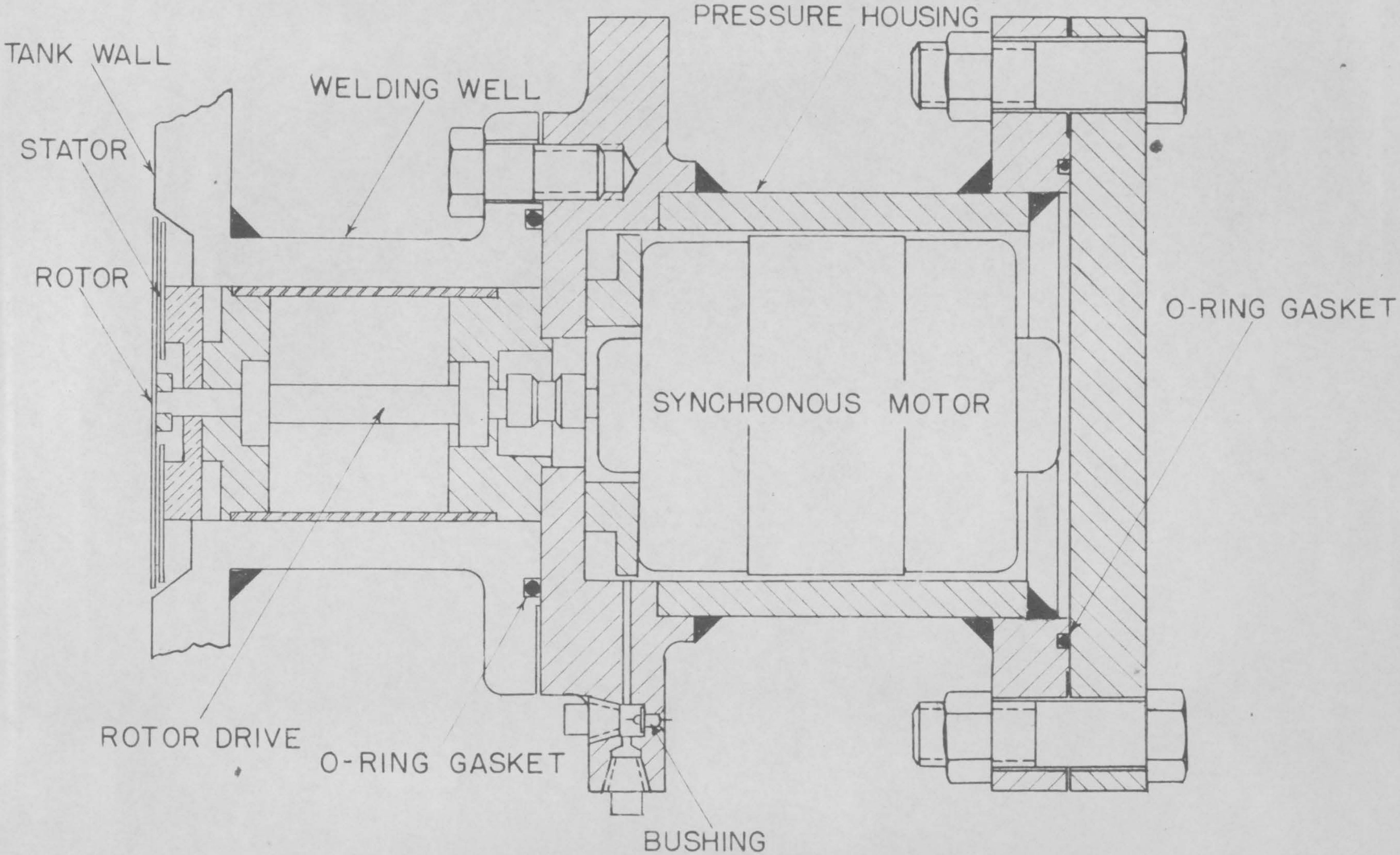
r_p = plate resistance of tube, and

R_l = load resistance.

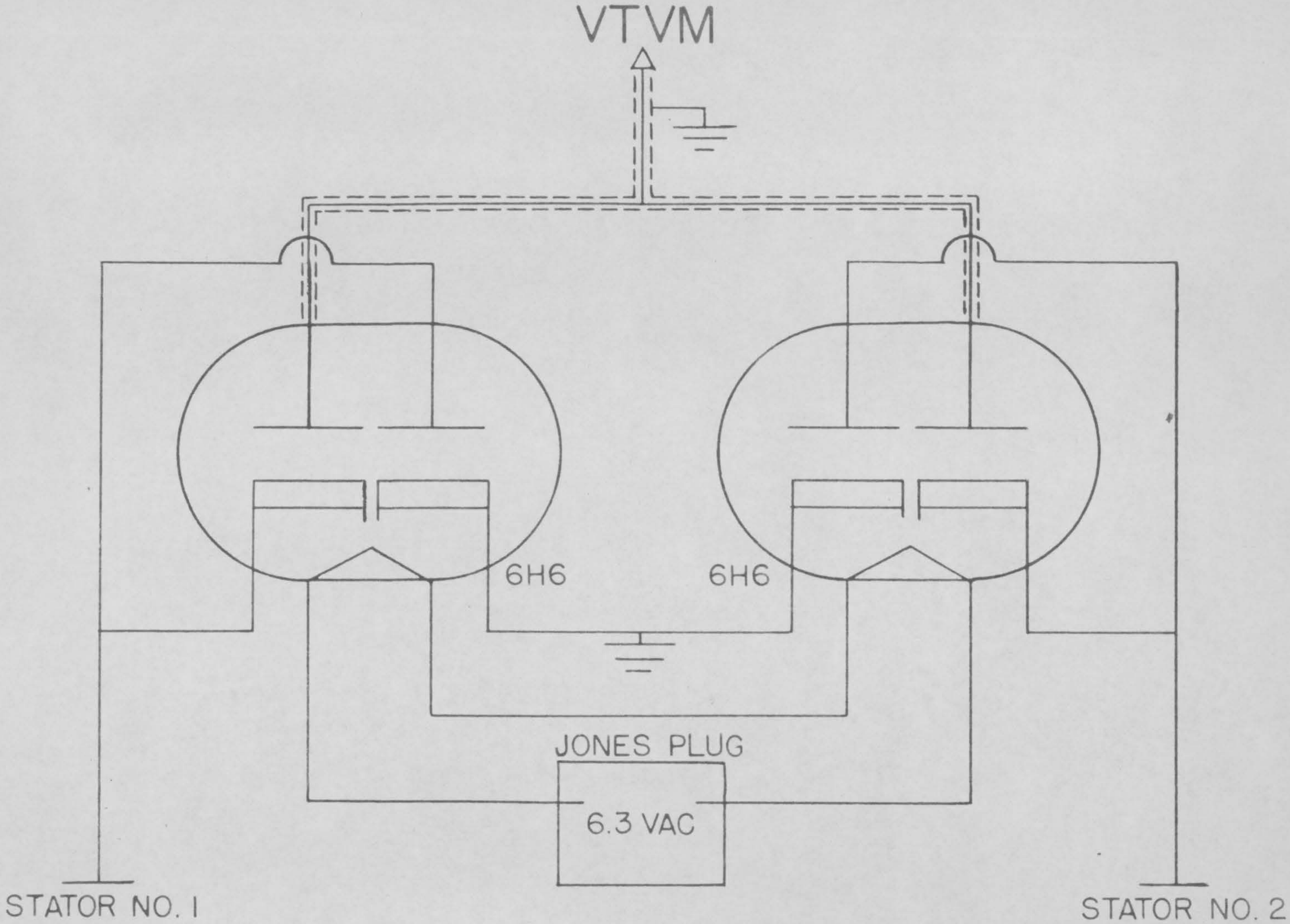
This shows that under proper operating conditions the output of the vacuum tube voltmeter corresponds directly to "e" and hence by previous analysis to the potential of the high voltage electrode.

The meter between the two plates is a 0-100 microammeter movement shunted so the output ranges correspond closely to one, two, and four million volts. Further calibration is achieved with the adjustable resistances marked "Cal C" and "Cal F". Since it is not known which setting corresponds to one, two, and four million volts full scale, the meter circuit contains a switching arrangement so that two different calibrating resistances may be placed in the circuit. With the "Scale Selector" switch in the "Cal" position, the resistance "Cal C" is adjusted until the output is thought to be such that a full scale reading will correspond to one million volts. It is in this position that the voltmeter is calibrated. After calibration, the "Scale Selector" is switched to the "Full" position and the resistance "Cal F" is adjusted until full scale deflection corresponds to one million volts.

It was noted that the rectifier developed a contact potential and that a constant signal across R was always present. This small current is compensated by with the zero adjustment. However, this makes it impossible to have a conventional zero check by simply interrupting the signal from the generating voltmeter. A zero check is provided by a switch in the voltage supply to the synchronous motor.

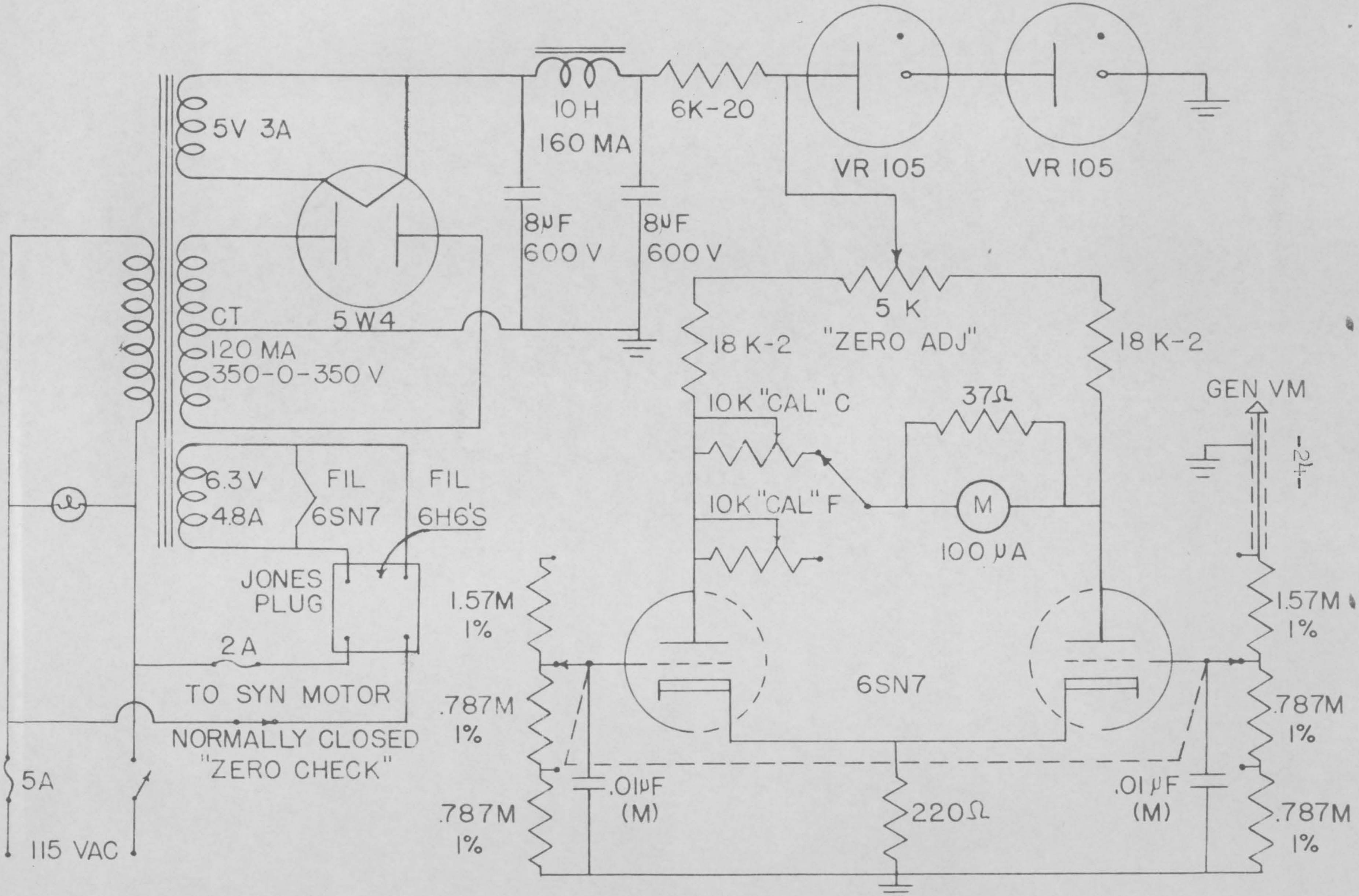


VOLTMETER ASSEMBLY DESIGN
FIG. 4



RECTIFIER DESIGN

FIG. 5



VACUUM TUBE VOLTMETER DESIGN

FIG. 6

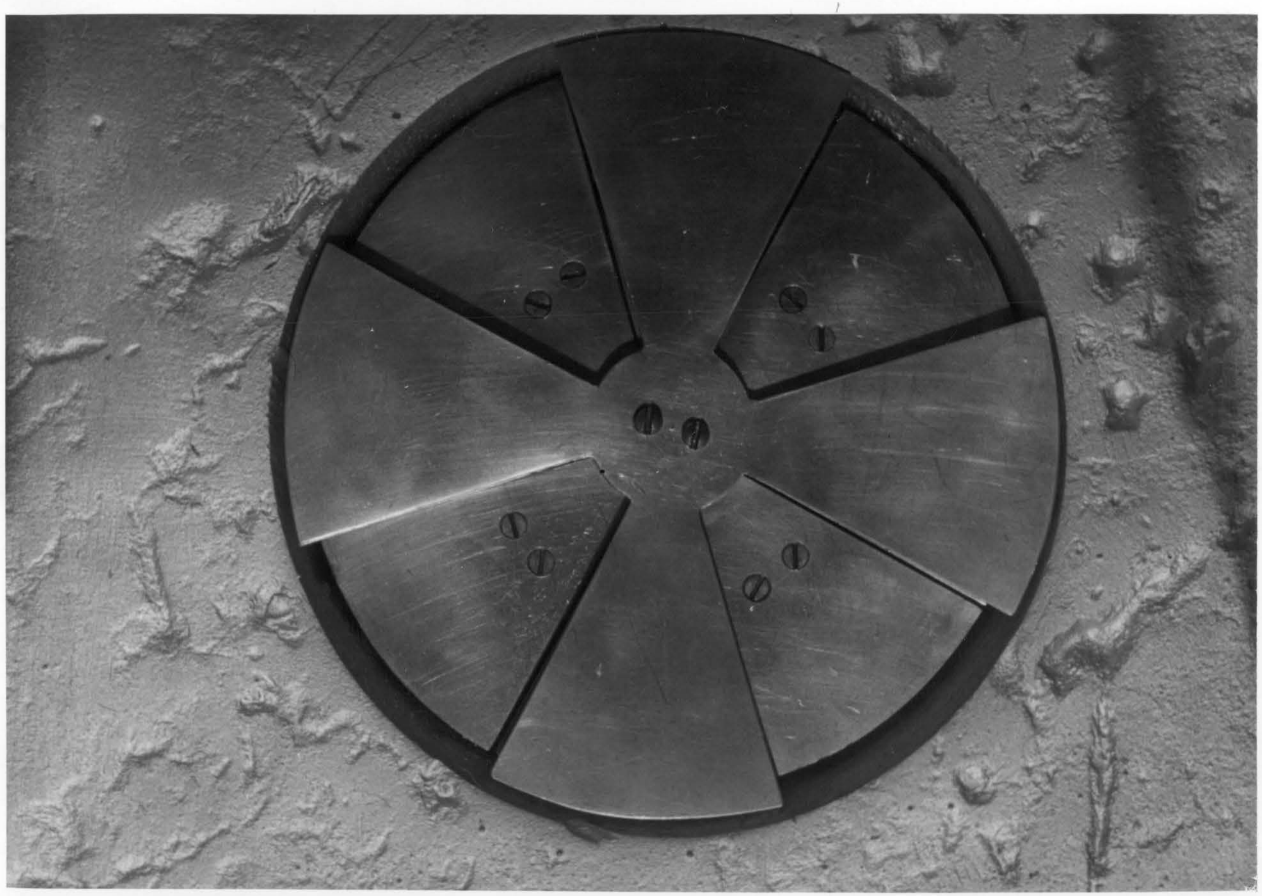
CONSTRUCTION

Rotor and Stator Assembly

The rotor and stator are made of 1/16-inch aluminum. The eight members of the stator are fastened to a 1/2-inch bakelite insulator by two screws each. These screws serve also as electrical contacts with every other member connected and two leads away from the stator. The bakelite insulator is secured to the front bearing housing of the rotor drive by four screws. The rotor is affixed to the shaft by a removable collar. The rotor is adjusted until the rotor is slightly behind the ground plane of the tank wall. The spacing between the stator and rotor is about 0.1 inch. The whole rotor and stator assembly is recessed in an opening in the apex of the tank. Because of this recess the rotor and stator must be mounted from inside the tank. Figure 7 shows the rotor and stator in this recess. Figure 8 shows the relative position of the stator and the high voltage terminal.

Rotor Drive and Pressure Housing

The rotor drive and pressure housing as were all the other parts of the voltmeter were machined in the Virginia Polytechnic Institute Physics Department shop. The rotor driving shaft and bearing housings are made of steel. The bearing housings are separated by a thin wall brass cylinder.



ROTOR AND STATOR IN TANK RECESS
FIG. 7

RELATIVE POSITION OF ROTOR AND STATOR WITH TERMINAL

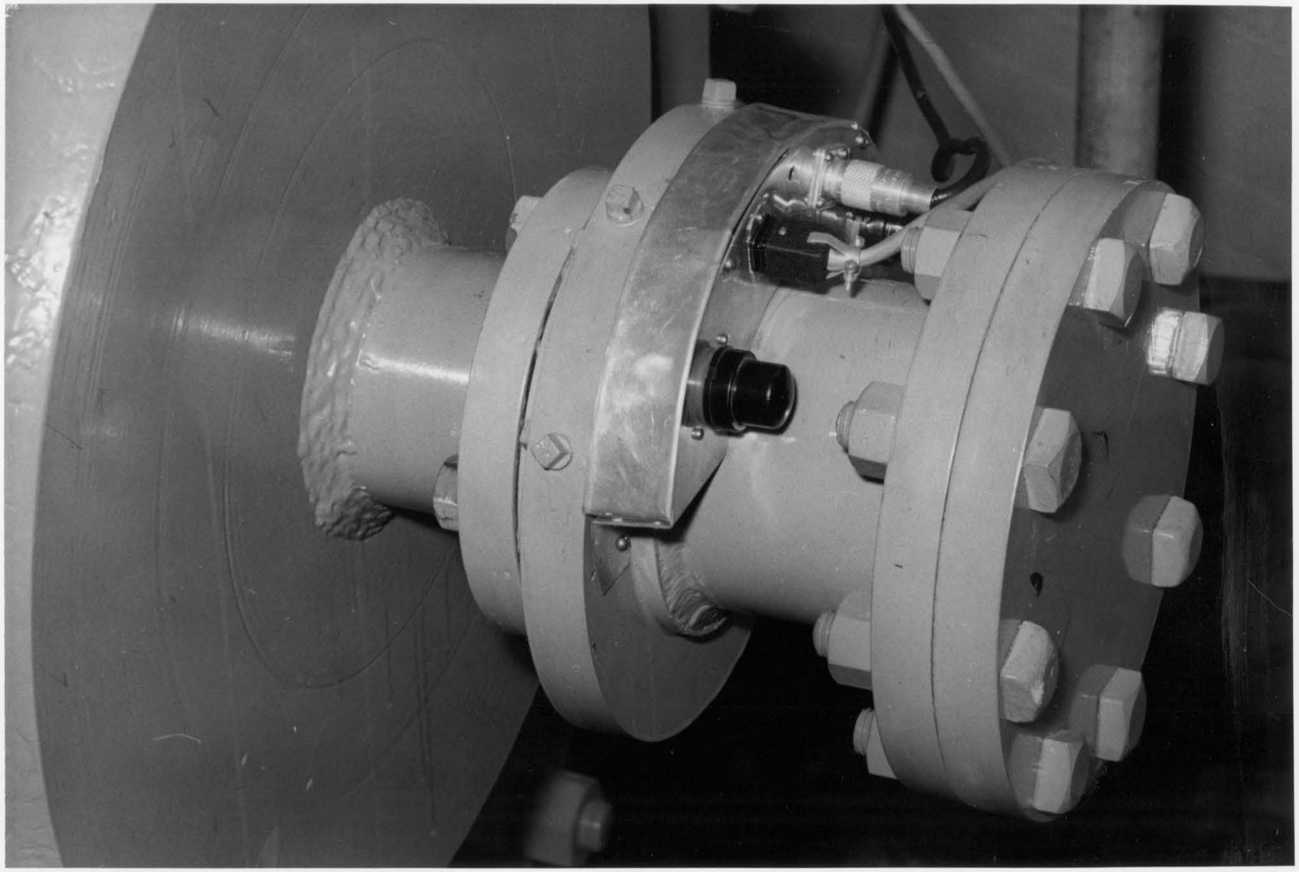
FIG. 8

The synchronous motor is enclosed by a welded steel pressure chamber. The chamber is fastened to the tank by four 3/4-inch cap screws. Pressure seals are achieved with "O" ring pressure gaskets. Figure 9 shows the voltmeter assembled and bolted to the tank. Four electrical connections are brought out through the front plate of the pressure chamber. These bushings were soldered into place after welding by preheating the complete plate. Access to the bushings is made by 1/4-inch pipe plugs.

Rectifier and Vacuum Tube Voltmeter

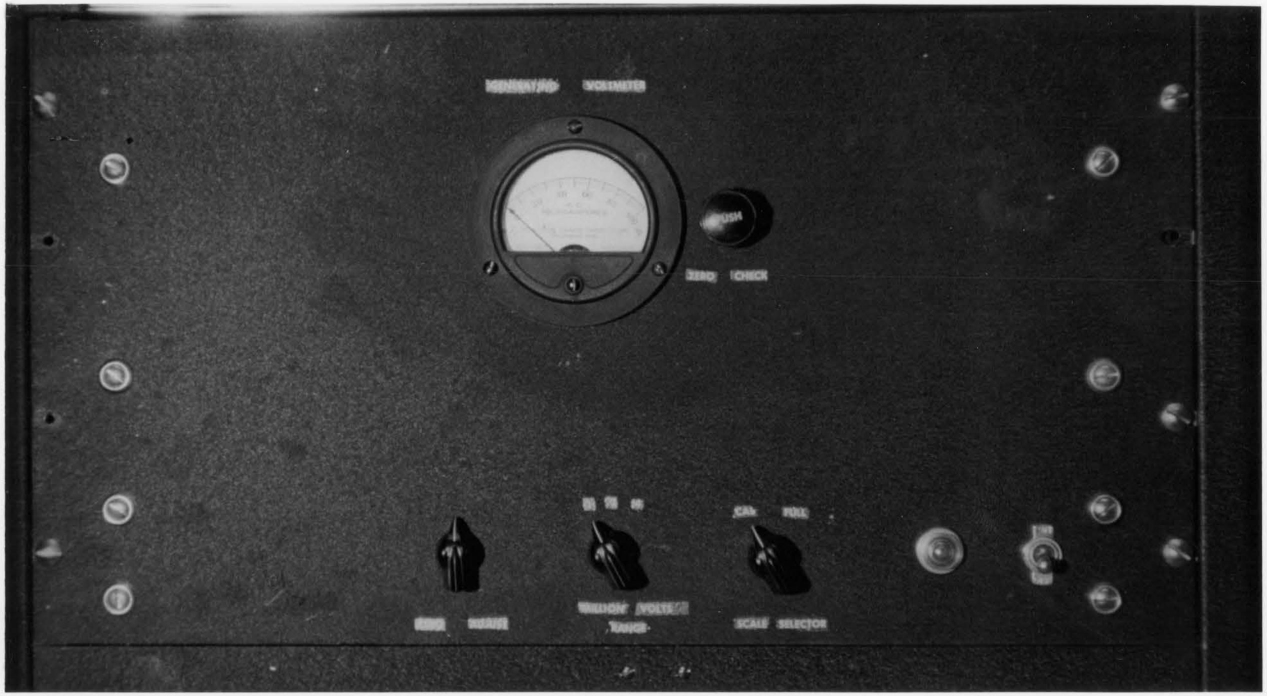
The rectifier is mounted on a semicircular chassis located on the pressure chamber. The signal from the rectifier is carried to the vacuum tube voltmeter by a low loss coaxial cable. The power supply for the synchronous motor and filament supply for the rectifier are brought from the vacuum tube voltmeter located on the remote control console. A view of the rectifier may be seen in Figure 9.

The vacuum tube voltmeter is located on a control console so that the meter may be read easily by the operator. It is of conventional panel and chassis construction and is rack mounted. The range selector, scale selector, zero adjust, and zero check are located on the front of the panel for easy use. Figure 10 shows a view of the console panel of the generating voltmeter. The calibrating resistors are located on the chassis and can be adjusted from the top of the rack.



GENERATING VOLTMETER BOLTED TO TANK

FIG. 9



GENERATING VOLTMETER PANEL
FIG. 10

Assembly

Because of the unique construction of the generating voltmeter the following assembly procedure is used. The motor is provided with a clamping ring and is end mounted. The motor is mounted first, making sure the two leads to the stator are brought out the front of the chamber and the two leads to the motor are brought back around the motor. The flexible coupling during this time should be secured to the shaft of the motor. The rear bearing housing is next fastened to the chamber, shaft inserted into the coupling, and the cylinder and front bearing housing secured in place. The coupling now may be tightened with an Allen-head wrench at the opening provided in the rear bearing housing. The voltmeter may now be bolted to the tank and the rotor and stator attached from inside the tank. The voltmeter should be disassembled in reverse order.

CALIBRATION

Operation of Accelerator

Although the generating voltmeter reading is independent of the ion beam, it is necessary for calibration purposes to bombard a target with protons. For this reason a brief description of operation of the equipment is given.

The first step in putting the accelerator into operation is to initiate a discharge in the ion source. The ions produced are extracted by application of a "probe" voltage in the discharge vessel. The spray voltage is now raised until a predetermined voltage between terminal and ground is brought to equilibrium, with the amount of charge being brought to the terminal by the charging belt equal to the charge being lost by the terminal. The ion beam is now being accelerated down the tube with the chosen energy. The beam is allowed to fall upon a quartz disk where it is focused by an electrostatic lens at the high voltage end of the accelerating tube. The beam must now be analyzed, that is, separated into mass one, mass two, etc, components. This is done with the magnetic analyzer.[18] With proper adjustment and a reasonable current through the magnet so that the desired mass number will be bent by the magnet, the beam should now be at the slit box. With the beam impinging on the slit jaws the corona feedback stabilization[1] holds the beam on target with the desired energy. The spread of energy on the target is now a function of the slit width through which the beam passes and the distance from the magnet to the slit. The approximate energy of the beam is now known from the knowledge of the magnetic field as determined by the current.[18] It is now desired to determine more exactly the energy corresponding to the generating voltmeter reading at this voltage.

Counting Apparatus

When the protons fall upon the target a reaction may take place which results in the emission of gamma-rays. It is desired to find the "relative yield" of this reaction, that is, a number proportional to the ratio of the gamma-rays emitted from the target to the number of bombarding protons. It is then necessary to measure a quantity proportional to the number of gamma-rays emitted and also a quantity proportional to the number of protons impinging on the target.

A scintillation counter was used to detect the gamma-rays. This counter consisted of a sodium iodide crystal[13] and a 6292 Dumont photomultiplier tube. The scintillations caused by the gamma-rays are amplified by the photomultiplier tube and the output pulse, after suitable amplification, was applied to a decade scaler. The discriminator of the amplifier was set so that the x-ray background of the accelerator was not detected. Therefore, the "background" radiation was reduced essentially to that due to cosmic radiation.

A quantity proportional to the number of bombarding protons was obtained with the use of a "current integrator". The "current integrator" was of the neon glow type. It consisted of a 150 micromicrofarad capacitor, a 1.2 megohm resistor and a neon glow lamp. The charge which accumulated on the target charged the capacitance until the breakdown potential of the neon lamp was reached. The glow tube then "fired", discharging the capacitor through the resistance, giving rise to a pulse which was proportional to the charge accumulated. The cycle was then repeated. The output pulse was fed through a preamplifier into a decade scaler.

To obtain the relative yield, it was only necessary to allow the pulses from the scintillation counter and current integrator to register simultaneously for a specific length of time. By dividing the number of scaled scintillation counts by the current integrator counts, the relative yield is obtained.

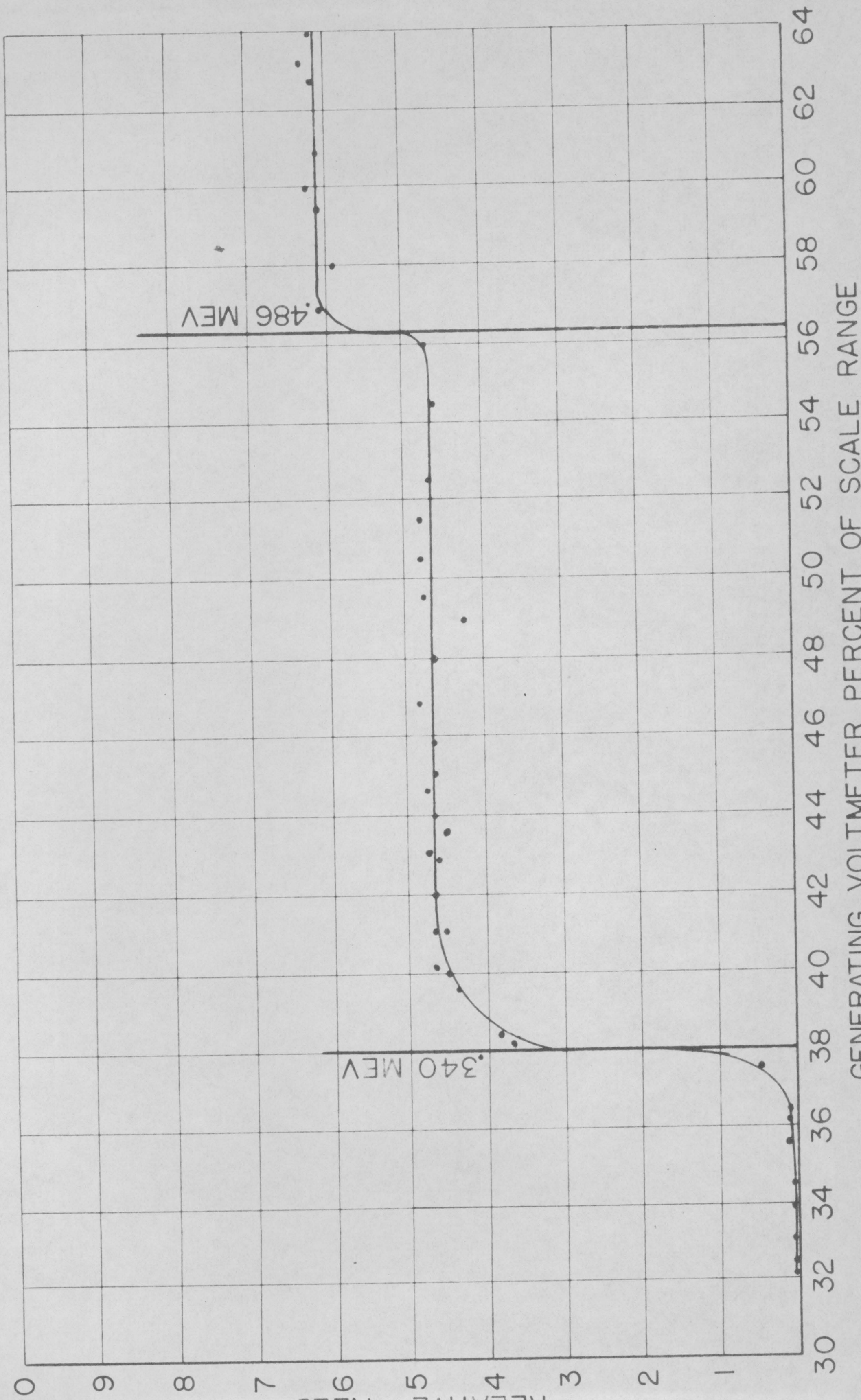
Calibrating Experiment

Most of the light elements are known to yield gamma-rays when they are bombarded with protons. The intensity of gamma-ray radiation from most light elements exhibit resonance phenomena; near resonance the amount of gamma-ray radiation is much greater than for neighboring energies. For example, in the bombardment of fluorine with protons, resonances are known to occur at energies of .340 Mev and .486 Mev in addition to other well known resonances.[22] To illustrate further, examining the yield from protons on fluorine, it would be expected that the yield would increase with increasing energy until the energy of .340 Mev was reached. Increasing the energy beyond this would result in decreasing yield until the next resonance is approached. This of course is the case if the target is a thin target. Let us consider what would happen if the target is thicker. If a proton having an energy slightly greater than .340 Mev impinges on such a target it will have a lower probability of being captured by the first layer of atoms than one of energy of .340 Mev. But as it penetrates the target it will lose energy by collisions with electrons and the probability of capture increases. The net result then is a shifting of the maximum of the yield curve to higher energies. If the target is thick enough to stop all the protons the yield curve will exhibit no maximum at all but will level off at the highest value of the yield. The position of resonance is taken to be half way up the yield curve. These so called "thick target" yields are well known and are suitable for calibration purposes.

Thick target yields of fluorine were obtained and the calibration of the generating voltmeter made from them. A typical yield run was made in the following manner. The generating voltmeter selector switch was placed in the "Cal" position. After a definite recycling pattern of the magnet to minimize hysteresis effects the magnet current was brought to a desired current to bend the mass one component of the beam with approximately a predetermined energy. The voltage of the accelerator was raised until the beam was seen to be impinging on the target. Simultaneous counting of gamma-ray and integrator counts were made for two minutes and the relative yield calculated. The generating voltmeter was read during the time period. The magnet current was read by reading the potential drop across a standard .01 ohm resistance in series with the magnet with a Leeds and Northrup type K-1 potentiometer. The magnet current was then raised .05 amperes and simultaneous reading taken again. This process was repeated until the desired yield spectrum was obtained.

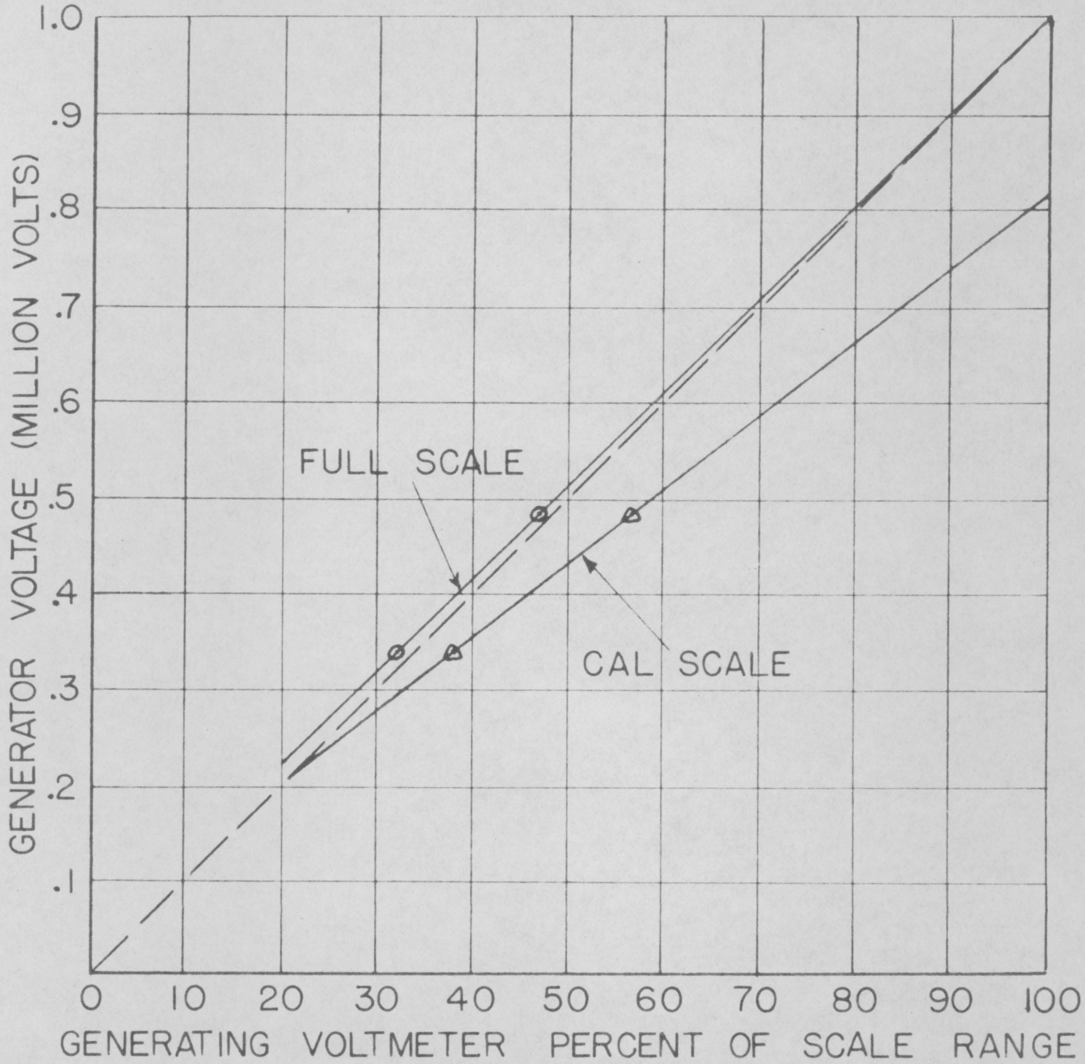
__Results__

The .340 Mev and .486 Mev resonances of fluorine were obtained. The yield curve may be seen in Figure 11. The .340 Mev and .486 Mev resonances correspond to generating voltmeter readings of 38.0 and 56.3 percent of scale range on the one million volts range. Since the voltmeter should be linear it was felt that it was only necessary to obtain two points to establish calibration. The calibration curve of the generating voltmeter may be seen in Figure 12. By use of this curve a reiteration process was made by switching from the "Cal" position to the "Full" position of the scale selector and the meter was adjusted until full scale deflection in the "Full" position should correspond to one million volts. This curve may also be seen in Figure 12. The dotted line from the origin to one million volts is the idealized calibration curve. The distance between the calibrated "full scale" curve and this idealized curve represents the actual error reading interpreting the voltage from the meter directly. This error should amount to within five percent in half scale deflection with decreasing error for higher reading on the one million volts range. On the two million volts range the error should not exceed plus or minus three percent being a minimum near half scale. If it is necessary to recalibrate the meter, good results should be obtained in the following manner. With the beam on target and the current in the magnet 5.04 amperes, the generating voltmeter should read 38 and 32 percent scale reading on the "Cal" and "Full" positions of the scale selector respectively on the one million volts range.



GAMMA YIELD FROM FLUORINE

FIG. 11



CALIBRATION OF VOLTMETER

FIG. 12

SUMMARY

A generating voltmeter capable of measuring one, two, or four million volts has been designed and constructed for use with the Virginia Polytechnic Institute electrostatic accelerator. The voltmeter is a grounded shutter type, the rectified output of which is measured by a vacuum tube voltmeter. The voltmeter was calibrated by known nuclear resonances of fluorine. The calibration showed the meter to be accurate to within five percent at half scale deflection on the one million volts range and less than plus or minus three percent on the two million volts range.

ACKNOWLEDGMENTS

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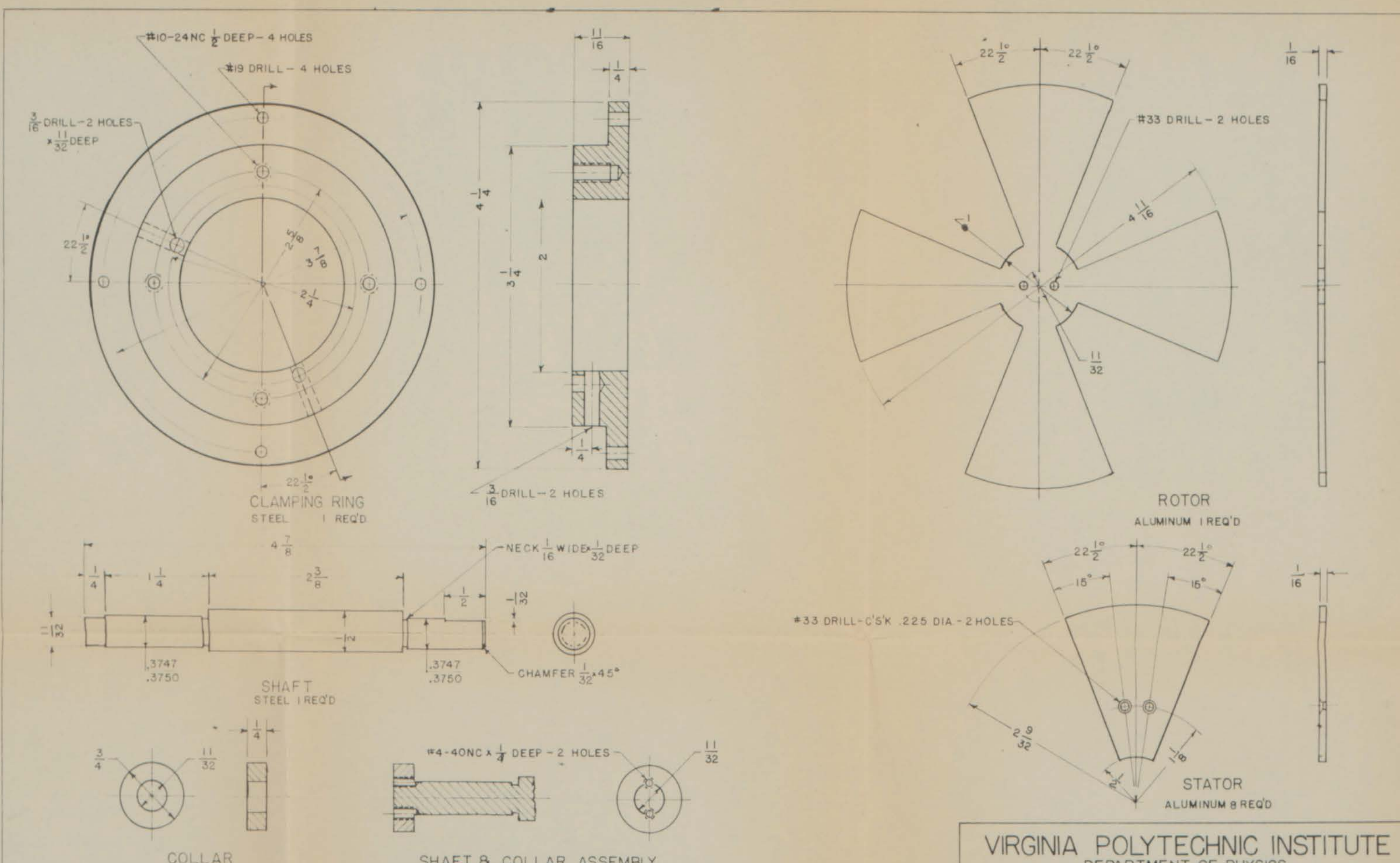
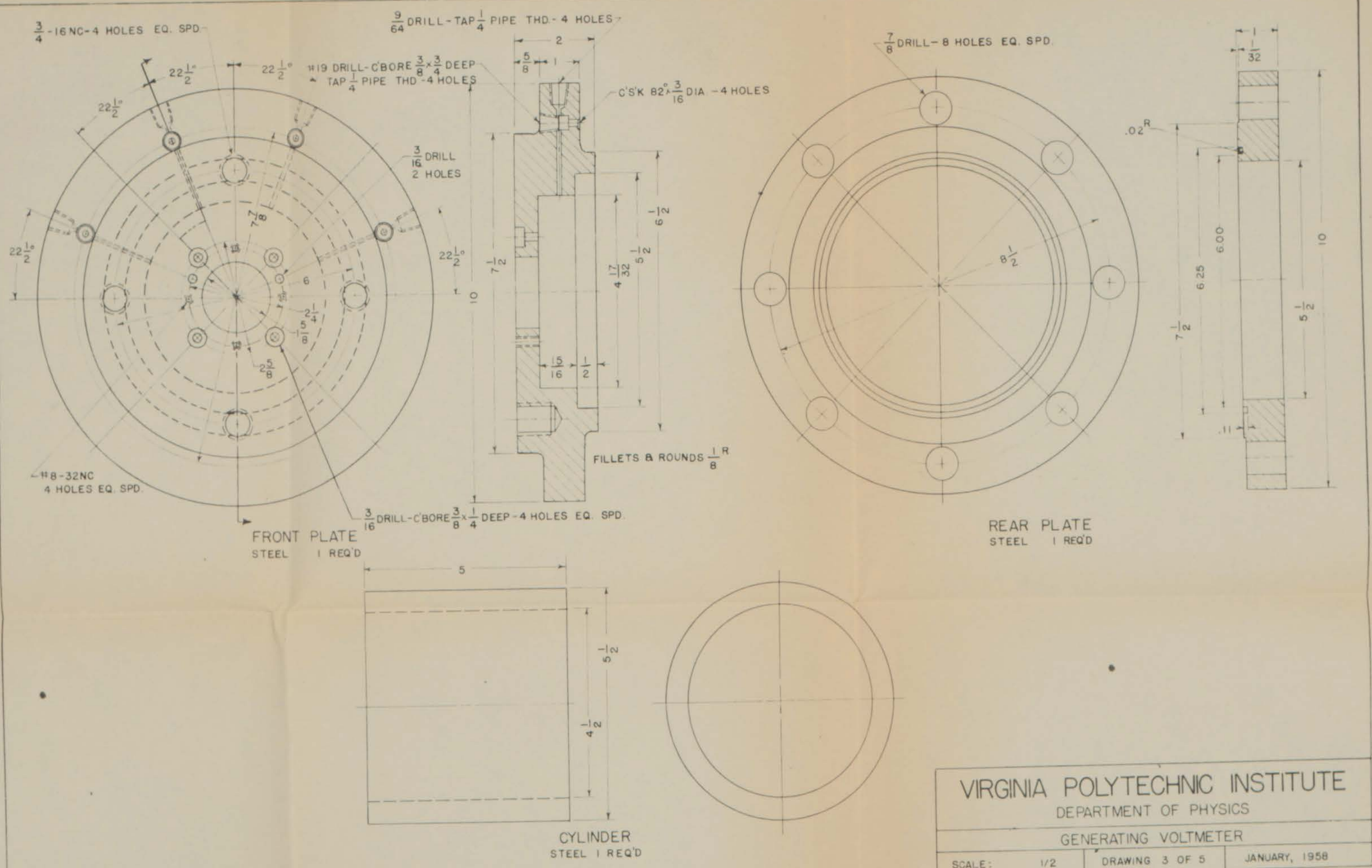


#10-24NC 1/2 DEEP - 4 HOLES
#19 DRILL - 4 HOLES
3/16 DRILL - 2 HOLES x 11/32 DEEP
CLAMPING RING
STEEL 1 REQ'D
3/16 DRILL - 2 HOLES
ROTOR
ALUMINUM 1 REQ'D
#33 DRILL - 2 HOLES
NECK 1/16 WIDE x 1/32 DEEP
CHAMFER 1/32 x 45°
SHAFT
STEEL 1 REQ'D
#33 DRILL - C'S'K .225 DIA - 2 HOLES
STATOR
ALUMINUM 8 REQ'D
COLLAR
STEEL 1 REQ'D
#4-40NC x 1/4 DEEP - 2 HOLES
SHAFT & COLLAR ASSEMBLY
NOTE: DRILL & TAP COLLAR AND SHAFT AT SAME TIME.
VIRGINIA POLYTECHNIC INSTITUTE
DEPARTMENT OF PHYSICS
GENERATING VOLTMETER
SCALE: FULL
DRAWING 2 OF 5
JANUARY, 1958



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GENERATING VOLTMETER

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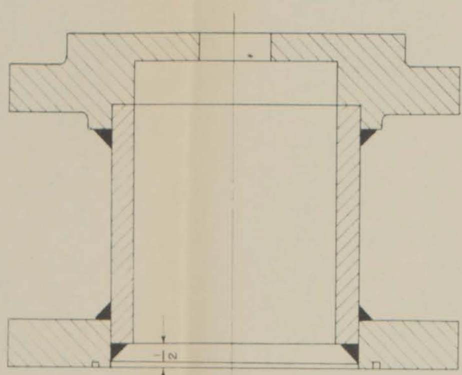
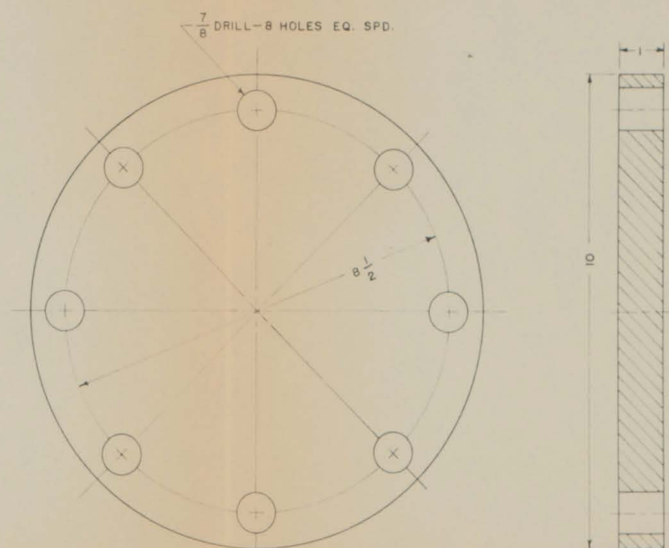


PRESSURE HOUSING ASSEMBLY



TOP PLATE
STEEL 1 REQ'D

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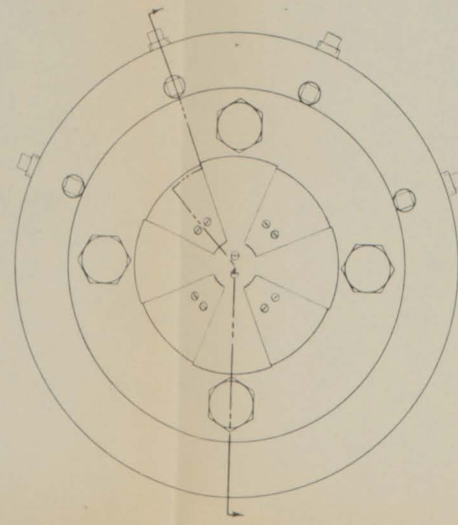
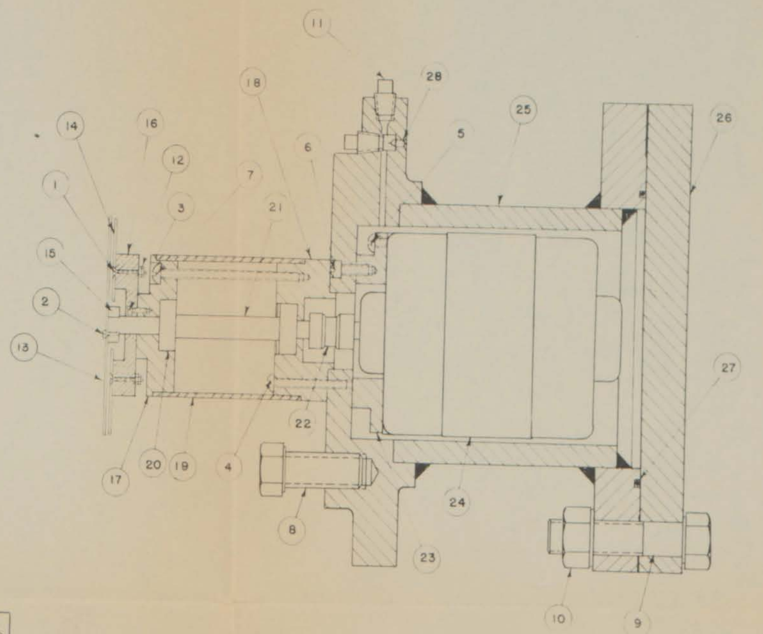
GENERATING VOLTMETER

SCALE: 1/2	DRAWING 4 OF 5	JANUARY, 1958





PART NO.	NAME OF PART	NO. REQ'D	PART NO.	NAME OF PART	NO. REQ'D
1	NO. 2-56×5/8 FLAT HD. SCREW	16	15	COLLAR	1
2	NO. 4-40×1/4 FIL. HD. SCREW	2	16	INSULATING RING	1
3	NO. 4-40×1/2 FIL. HD. SCREW	4	17	FRONT BEARING HOUSING	1
4	NO. 8-32×1 5/8 RD. HD. SCREW	4	18	REAR BEARING HOUSING	1
5	NO. 8-32×1 1/8 RD. HD. SCREW	4	19	CYLINDER	1
6	NO. 10-24×5/8 FIL. HD. SCREW	4	20	BALL BEARING	2
7	NO. 10-24×3 RD. HD. SCREW	4	21	SHAFT	1
8	3/4-16×1 3/4 HEX. HD. CAP SCREW	4	22	COUPLING	1
9	3/4-16×3 HEX. HD. BOLT	8	23	CLAMPING RING	1
10	3/4-16 HEX. HD. NUT	8	24	SYNCHRONOUS MOTOR - 1/20 H.P.	1
11	1/4 PIPE PLUG	8	25	PRESSURE HOUSING	1
12	NO. 2-56 HEX. HD. NUT	32	26	TOP PLATE	1
13	ROTOR	1	27	O-RING GASKET	1
14	STATOR	8	28	BUSHING	4

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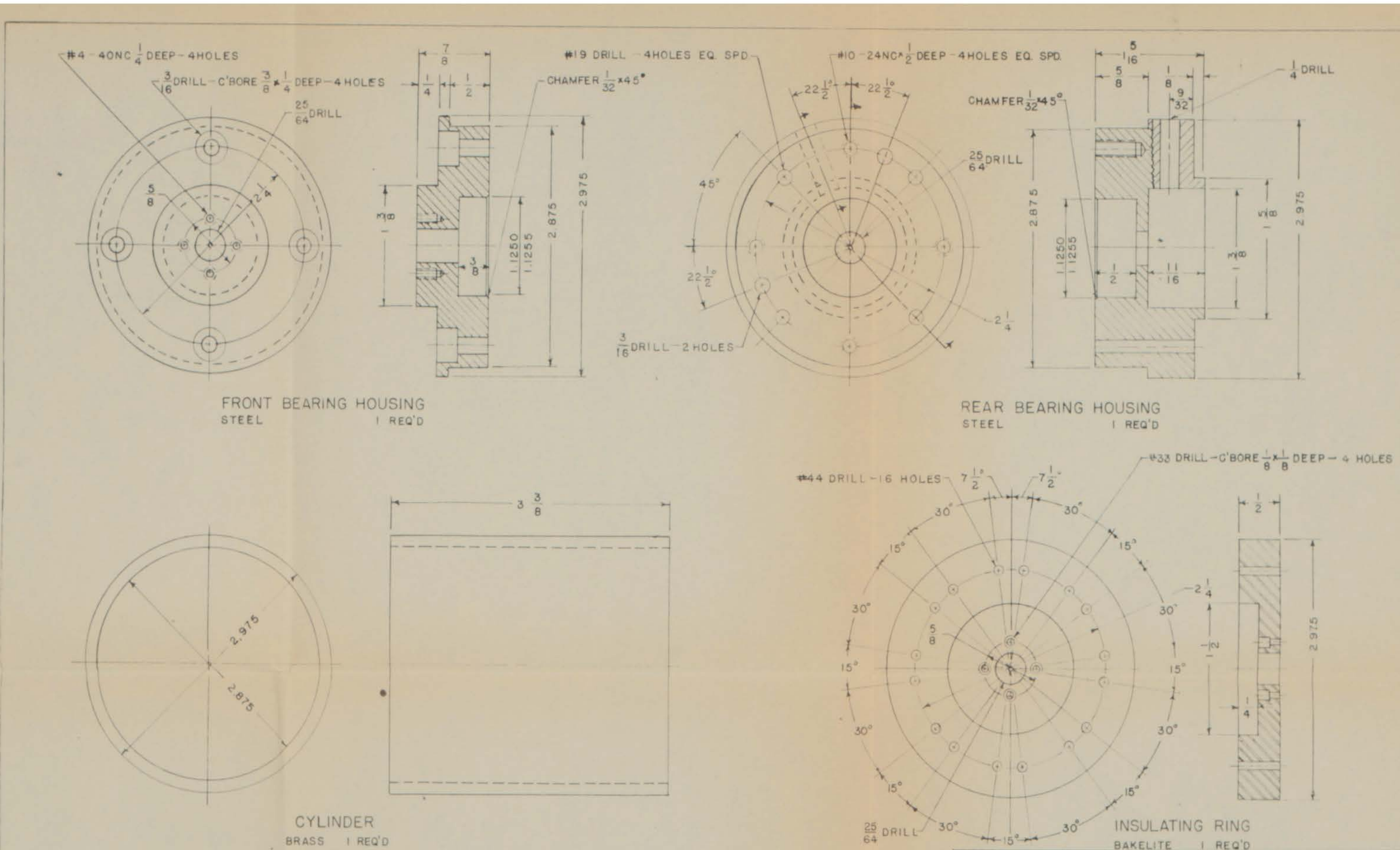
GENERATING VOLTMETER

SCALE	1/2	DRAWING 5 OF 5	JANUARY, 1958



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GENERATING VOLTMETER

SCALE: FULL	DRAWING 1 OF 5	JANUARY, 1958