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ENERGY STABILIZATION OF THE BERKELEY PROTON LINEAR ACCELERATOR

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Abstract

A device is described which stabilizes the energy of the 32 Mev linear accelerator to within ± 40 kev. Energy control is obtained by slightly detuning the rf cavity with a rotating paddle.

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INTRODUCTION

During some preliminary experiments on the reaction C^{12} (p, a)B^9 with 32 Mev protons from the Berkeley linear accelerator, it became apparent that small variations in the proton energy were creating serious difficulties. The high reaction threshold and the low mass ratio of the product nuclei acted together to cause the laboratory energy of the alpha particle to vary by an amount almost equal to the variation of the proton energy, when the alpha particle was counted at angles less than 30°. Because differential range analysis of the alpha-particle energy spectrum was used in order to discriminate against scattered protons, and the differential range element was quite thin (0.75 mg/cm^2) to provide for good resolution, a shift of 100 Kev in the beam energy (1/3%) caused a shift of almost one range channel. Under these conditions, it was impossible to resolve the first excited level of B^9 (at 2.37 Mev) over the continuum[1] of alpha particles which begins under the ground state peak of B^9.

Beam energy variation at the 32 Mev linear accelerator has been observed before, but usually was an insignificant effect compared to the instrumental resolution, which was largely determined by the proton straggling in differential range experiments, or by the scintillator response spread in pulse-height analysis methods. These effects are both of the order of 4%. The energy change was therefore not well understood, and consequently a study of its probable causes was made. Of the observable parameters, the following were found to be the most significant:

(a) The plate voltage at the oscillator power supplies, which has occasionally been observed to change spontaneously by about 250 volts from a mean value of 14.5 kilovolts. Crude measurements indicated that a change of this size would produce 75 kev change in the beam energy, in the same direction as the plate voltage variation.

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[1] J. B. Reynolds, Phys. Rev. 98, 1289 (1955).

(b) Temperature changes of the machine itself may cause small variations in the geometry of the copper liner and consequently change the local rf tuning of the cavity. These temperature changes may be induced by a sudden load on the cooling system, by an increase of ambient temperature in the building, and, possibly, by rf sparking inside the liner. Energy changes almost always appeared after sparking had occurred. No correlation of temperature variation with the direction of beam energy change could be made.

(c) The position of the exit "end tuner" (last half-drift tube) was found to be a powerful control on the beam energy, which increased as the end tuner was pushed in (i.e., as the cavity was capacitively loaded) and decreased as it was pulled out. The end tuner position is normally not changed except when the cavity is being retuned after it has been opened, but it was in this instance being considered as a control device. However, severe backlash in the control gearing made this impossible.

Certain other possible causes of energy variation were found to have little or no effect. For example, extreme variation of the Van de Graaff injection energy appeared to have no effect on the exit energy of the protons from the linear accelerator tank.

It was clearly impracticable to use temperature as a servomechanism control, and it proved to be very difficult technically to servo-control the plate voltage (although inverse-feedback plate voltage regulation with simultaneous maintenance of constant temperature might ultimately be the best solution). These two parameters were believed to be responsible for most of the trouble, because energy variation was observed to occur in a sudden discrete step, rather than as a drift. It was therefore decided to install a separate control device which would be totally independent of the normal operation of the machine and powerful enough to compensate such energy variation as one would normally encounter.

APPARATUS

General-Feedback Circuit

The model for the energy stabilizer was that designed by Schrank[2] for the Princeton cyclotron. As in the case of the Princeton instrument, an argon-filled ionization chamber collects positive ion currents on two electrodes. When the terminal peak of ionization from a sample of coulomb-scattered protons is centered

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[2] G. Schrank, Rev. Sci., Instr. <u>26</u>, 677 (1955).

between the electrodes by changing the absorber in front of the ionization chamber, the two currents (each of the order of 10^{-11} amp) are matched in a difference amplifier. The output of the difference amplifier is then connected to an energy-correcting device and the servo loop is completed.

Certain modifications in the Princeton stabilizer were needed, the most obvious of which was in the energy-correcting device. It was suggested by Dr. L. W. Alvarez that a paddle in the side of the rf cavity would load it inductively and thus reduce the energy of the beam slightly. If the normal to such a paddle is parallel to axis of the cavity, (at the "0° position") the paddle lies along an equipotential and has no effect, but if it is rotated 90°, it interferes with the peripheral magnetic field and thus reduces the central electric field that performs the acceleration. This method proved to be quite successful.

The ionization chamber is positioned outside the scattering chamber and below the beam, 9.5° from the incident direction. (Schrank put his ionization chamber inside the scattering chamber.) The platinum scattering foil is taped to the aluminum exit foil of the scattering chamber. It does not scatter any particles into the alpha detector, an advantage somewhat offset by the necessity of passing the proton beam through a few inches of air as part of the total range, thereby introducing some uncertainty into the energy measurement.

The difference amplifier design makes use of a standard electrometer technique to eliminate input cable capacitance and can therefore be placed in the counting area for convenient adjustment. Its long time constant (ten seconds) introduces an oscillation in the main servo loop unless its output is attenuated. The attenuation is performed on a "master energy-control panel" before the output is fed into the chopper-amplifier that controls the servomotor which drives the paddle. The master energy-control panel also carries the absorber-wheel control. Figure 1 shows the important components of the energy stabilizing feed back loop.

Because the paddle is not powerful enough to control all energy variations encountered, limit switches (not shown on Fig. 1) are provided at the 0° and 90° positions. These are to keep the paddle out of a positive feedback condition. Closing either of the limit switches automatically disconnects the input to the chopper-amplifier. The experimenter must then throw the main switch from "Ionization chamber" position to the "Manual" position, (thus going over to another servo loop) and then momentarily reset the broken connection until the paddle rotates out of the extreme position. The second servo loop is also indicated on Fig. 1. It compares the voltage taken from a potentiometer geared to the paddle to another voltage taken from a potentiometer on the master panel. The latter voltage opposes the first in polarity and both voltages are read through voltmeters whose dials are calibrated to read directly in degrees of paddle position. At all times the true paddle position is indicated by the meter, reading the voltage from the paddle box. The other voltmeter shows the position to which the paddle can be set when the main switch is in the "Manual" position. Direct control of the paddle is thus provided.

The "main switch" is actually two relays with coaxial cable connections, and the transfer from "Manual" to "Ionization chamber" can be performed automatically by a 110 v signal from the flip gate of the linear accelerator, so that the paddle is controlled either by the beam if the flip gate is open or by the manually set potentiometer if the flip gate is closed and the beam is interrupted. Such automatic transfer of control is a great convenience to the experimenter, whose attention is required elsewhere when the beam is interrupted.*

Components

Paddle.

The paddle was made of 1/4 inch copper and is 3 inches wide by 4-1/2 inches long. The width is limited by the diameter of the aperture through which it is introduced into the cavity, and the length by the necessity of staying within about 5 inches from the edge of the cavity. Beyond this limit it would begin to have a serious detuning effect on the cavity, unless some rather inconvenient compensating adjustments are made. It was inserted into the next-to the last oscillator port on the south side of the machine. All rf oscillators are now on the north side and the unused south ports are blanked off by threaded copper plugs screwed into ports which are soldered to the rf liner. One of these plugs was drilled to receive the

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*The servomotor used was a Minneapolis-Honeywell Unit No. 76750-3, Serial 6-51 (13.5 watts) controlled by a Brown "Electronik" Amplifier Unit No. 356358-1. If the input is disconnected, the great sensitivity of the latter unit accepts very small stray currents and the servomotor tends to autorotate slowly. If left very long in this condition, the servomotor might damage the indicating potentiometer because of the large mechanical advantage of the reduction gearing. It is therefore always desirable to have one of the feedback loops completed. The input interruption when a limit switch is closed is always corrected at once and does not constitute a danger to the system.

paddle shaft, and the paddle grounded to the liner by a set of rf fingers cut into one end of an "Everdur" bearing sleeve which is tightly fastened to the copper plug. The fingers make contact with the outside of the paddle hub and are silver plated, as are the paddle and hub. A small collar is fastened by a set-screw to the 1/2 inch stainless steel shaft and keeps the paddle, plug and bearing assembly together; it also prevents the paddle from being pulled in when the tank is evacuated. The paddle, bearing and copper plug can thus be pre-assembled and then screwed to the rf liner with a special wrench. A Wilson seal, soldered to the solid brass plate which is then sealed to the existing vacuum tank port, provides a vacuum seal for the paddle shaft and a second bearing surface. A crude set of copper rf fingers are next fastened to the shaft outside the Wilson seal and make contact with the latter. This is necessary because the shaft length is almost 1/4 wave length (14.6 inches) and in the event of failure of the internal ground, some protection must be given to the electrical equipment. A frame containing the gears, servomotor, recording potentiometer and limit switches is then bolted to the brass plate, and finally the driving gear is fastened by a set-screw securely to the paddle shaft, after it has been rotated to the correct position with respect to the potentiometer. Finally, the gear frame is covered with a copper shield (to keep out stray currents and dust) and the paddle assembly is complete. Water cooling was originally provided through the hollow paddle shaft but proved to be unnecessary. The paddle and its associated equipment are shown in Fig. 2.

Ionization Chamber

The relatively large straggling spread of the ionization peak of 32 Mev protons near their mean range required that a considerable "thicker" ionization chamber be used than was possible in the case of 17 Mev protons. Space in the scattering chamber is limited, and therefore the ionization chamber was placed outside where it accepts protons elastically scattered from a 0.25 mil Pt foil taped to the exit foil of the scattering chamber. Since the beam was to be subsequently integrated in a Faraday cup which had to be positioned just beyond the ionization chamber and its mounting, and the Coulomb scattering from the platinum foil spreads the beam size in direct proportion to the distance of the Faraday cup, it was decided to "condense" the ionization peak by pressurizing the argon gas in the chamber to about 30 psig, thereby roughly tripling the S. T. P. density of the argon. The ionization chamber is approximately 10 inches long, with the accepting aperture 10 inches from the platinum foil, so that the Faraday cup could be brought to within two feet of the exit end of the scattering chamber. At this distance the beam is spread to approximately 7/8 inch in diameter, or about one quarter of the aperture of the cup used, so that no significant part of the beam was expected to be lost. This was experimentally verified.

The chamber was constructed primarily of 3/16 brass plate, which is thick enough to keep out any protons which might be back scattered from the Faraday cup, and strong enough to meet the positive pressure requirement. The apertures collecting and collimating the Coulomb-scattered protons are slit-shaped rather than round, in order that a large current can be collected while restricting the vertical size of the chamber so that it can be positioned at a small angle to the beam. The first slit was milled in the front plate of the chamber (to which a carefully measured aluminum plate was sealed with an O-ring) and the second slit is located in a 1/2 inch polystyrene block which is an integral part of the electrode support.

The collector electrodes are each about one inch long in the beam direction and two inches wide. The two collectors are separated from each other by an intermediate grounded guard electrode in order to increase the sensitivity of response to beam energy shifts, and a similar grounded guard electrode is at either end. The vertical separation between the high voltage plate and the collectors is one inch, which is enough to keep the primary protons away from the collectors. The internal geometry of the ionization chamber is shown in Fig. 3, and is predicated on an argon density of exactly 5.00 mg/cm^3. Figure 4 is a plot of the calculated ion density per proton together with the end-point probability, using a gaussian end-point probability distribution with a standard deviation of 22.0 mg/cm^2 in argon. This value is derived from the inherent 100 kev total beam energy spread (σ_E=3.50 cm argon at 15° C and 1 atmosphere) and a standard deviation of range straggling equal to 1.38%[3] with an 866 cm range in argon (σ_R = 12.0 cm argon). The resulting total standard deviation is about 12.8 cm or almost 22 mg/cm^2 of argon. The ionization density is calculated from a numerical fold of the individual proton Bragg curve with the end point probability, as described by Schrank. At mean range, the ionization density is 78% of the maximum ionization density, in excellent agreement with the analytically calculated value of 82% presented by Mather and Segrè.[4]

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[3] G. Millburn and L. Schecter. "Graphs of RMS Multiple Scattering and Range Straggling for High Energy Charged Particles." University of California Radiation Laboratory report, UCRL-2234.

[4] R. Mather and E. Segrè, Phys. Rev. 84, 191 (1951).

All electrodes are made of polished stainless steel. They are positioned by a polystyrene frame and the whole electrode assembly is mounted on the cover plate. High resistance electrical connectors for the high voltage electrode and the two collectors were made through machined plugs of cast Epon which were pressure-sealed to the chamber by modified 3/8 inch UCRL "water fittings", as shown in Fig. 5. Such connections are mechanically much stronger than Kovar insulators, and permit preliminary evacuation of the chamber, followed by a filling to two atmospheres positive pressure. The wires are led to electrometer cable connectors inside a copper shield. The high voltage electrode is normally operated at + 1000 v, which was found experimentally to be well above the saturation voltage.

Evacuation and filling of the chamber is performed through a manifold connected to an argon bottle and a mechanical vacuum pump, A calibrated refrigeration gauge and a blowout foil are always in direct contact with the chamber. By consulting a thermometer and a barometer an attempt has been made to adjust the argon density to 5.00 mg/cm^3 at each filling, and to maintain this density. However, it has proved to be very difficult in practice and the argon thickness is the least reliable component of the total range measurement.

The argon amounts to about 20% of the proton range. All of the rest of the range is in aluminum, except for the platinum scattering foil and the 10 inches of air. The aluminum plate which is sealed to the front of the chamber comprises almost all of the aluminum absorber, and is augmented by a few pieces of 5 mil aluminum foil taped to the outside. The variable absorber is mounted on two wheels placed just in front of the ionization chamber. Both wheels have eleven positions, one in tens of mg/cm^2 from 0 to 100 mg/cm^2 and the other in units of mg/cm^2 from 0 to 9 mg/cm^2, with the eleventh position holding approximately 700 mg/cm^2. This latter position keeps all direct protons out of the chamber and permits an examination of background induced currents from the collectors when the beam is on. (The small "dark" currents which have been observed are probably caused by 4.43 Mev gamma rays coming from the carbon beam stopper in the Faraday cup. A few inches of lead between the cup and the ionization chamber substantially reduces the dark currents.)

Difference Amplifier

Initial attempts to use a replica of the difference amplifier in operation at Princeton failed because of its lack of stability. A modified circuit was designed, which has proved to be very satisfactory. (See Fig. 6). Its basic form is substantially that of Schrank's ingenious circuit. The new difference amplifier has the following properties:

1. The first stage is necessarily an electrometer tube because of the need for a very low grid current. By using each input CK5886 as a cathode follower, it is possible to feed back essentially 100% of the voltage on the grid to the intermediate shield of a double-shielded cable, whose center wire carries the signal from the corresponding collector of the ionization chamber. In this way the cable capacitance is eliminated and the cable can be made as long as is necessary to put the difference amplifier in the counting area, in which location it can be adjusted while the beam is entering the target area. The uncompensated capacitance of the electrodes and wires in the ionization chamber itself is of the order of 5 μμf and may be ignored.

2. The 10-second time constant that is required to smooth out rate fluctuations in the ionization chamber can be kept constant while the grid resistor is varied, by switching both CK5886 grids to any of the three sets of capacitors and resistors. In the low cross section (p, α) experiment described, the 10^9-ohm or 10^{10}-ohm resistors, were normally used, but the present amplifier can be used with a beam reduced by a factor of 50 or more.

3. The first stage of difference amplification takes place in the CK5755 twin triode, which is a premium tube (manufactured by Raytheon) whose two sides are remarkably similar. It is not necessary to select two input tubes of nearly equivalent characteristics, which is a very tedious process.

4. As constant-current devices, the two sides of the 12AD7, another relatively new premium twin triode, are notably stable. The 12AD7's can be replaced by 12AX7's, which are identical, except in quality.

5. The input-stage filament supplies and their screen-grid biases are provided by small mercury batteries. The filament batteries can be used for a month of steady operation. For electrometer-tube filaments, batteries are belived to be far superior to any transformer supply, however well regulated.

6. Provision was made for a set of test input equals (see Fig. 7 for the circuit of the test unit) with which the operation of the circuit can be quickly checked. The

microammeter in the output line was added to facilitate adjustment to a balanced condition, so that the difference amplifier can be zeroed without external connections.

7. The response curve is shown in Fig. 7. The gain along the linear portion of the curve is about 0.30 μa/mv of difference in input signals, and the response to common mode is approximately 2.5 μa/v of common input, so that the common-mode rejection is about 100. With input resistors of 10^{10} ohms on the CK5886 grids, the amplification factor of the current difference is 3×10^6. It should be noted that the response saturates at about 8.5 μa output in either direction. However, the amplifier-servomotor system, which is the next stage in the servo loop, reaches its maximum output at an input current of about 6 μa.

Master Energy Control Panel

The circuit diagram for the energy control panel (excluding the absorber wheel controls) is shown in Fig. 8 along with the connecting paddle-box circuits. It should be noted that the "ground" connections at the paddle are not made to the gear frame (which is at the potential of the linear accelerator tank) but through one strand of a five-wire cable to ground to the rack potential in the counting area. Occasional large ground currents near the machine are thus kept out of the circuit.

OPERATION

In practice, the paddle is first manually positioned at about 30°, the beam turned on, and the absorber wheels rotated until balance of the ionization chamber currents is observed. The paddle is switched to ionization chamber control and the damping adjustment used to reduce oscillations. From mean position the absorber wheels are then rotated 3 mg/cm^2 in either direction (the proton energy equivalent is ± 45 kev) and the motion of the paddle examined to make sure that all components are interlocked properly. If the energy shifts enough so that the paddle control (about 250 kev) is inadequate, a new absorber value is put in position. Care is taken to run all important features of the differential range distribution at the same absorber value.

An absolute range measurement of the beam was not possible because proton ranges in this energy region are not known very well, and also because of the previously mentioned uncertainty in the density of the argon. However, relative changes of the proton energy (as calculated from the $C^{12}(p, \alpha)B^9$ alpha particle peak) agreed very well with the same changes as measured by the absorber wheels, if done with the same filling of argon.

Routine checks were made every few hours on the argon density, and, about twice a day, on the balance of the difference amplifier. The latter was very stable, and often stayed in balance for two days without adjustment.

DISCUSSION

The stabilization obtained can be read from the paddle position meter. The estimated stabilization of the beam energy is within ± 30 kev. Some unavoidable common-mode response to beam intensity fluctuation may cause a 20 kev shift in the stable position of the paddle. The resultant stabilization is certainly good to ± 40 kev.

No attempt has been made to improve the stabilizer because it has so far been used only on the alpha-particle experiment, and it was adequate for the needs of this experiment. For example, the first excited level of B^9 was readily detected at small angles after the introduction of the stabilizer.

Certain improvements are indicated for a really precise instrument. The new proton range-energy values of Bischel et al[5] should be extended experimentally to the 32 Mev energy region. Following a suggestion by Bichsel,[6] the writer would insert the bulk of the range between the two ionization chambers, thus comparing the proton ionization density at essentially full energy with the ionization density somewhat beyond the mean range. Such an arrangement would, allow the ionization chambers to be at atmospheric pressure (with less resulting uncertainty in argon density and also a much smaller fraction of the range in argon), and, have only one stable position (the present system might possibly be brought to balance if the variable absorber is much less than the mean range so that the ionization curves is relatively flat). It would also be more compact, although the collected currents would be smaller by a factor of almost ten.

Another change indicated is the use of a larger paddle, with consequently greater energy control. To do this, it would be necessary to insert it from inside the linear accelerator when the tank is open. A paddle with 400 to 500 kev control would handle almost any normal energy change encountered. The existing paddle might be slightly more effective if it were moved closer to the exit end, i.e., the last port, but this has not been tried.

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[5] H. Bichsel, R.F. Mozeley, and W.A. Aron, Phys. Rev. 105, 1788 (1957).

[6] H. Bichsel, The Rice Institute, Private communication (1956).

ACKNOWLEDGMENTS

The writer would like to express his gratitude to Dr. L. W. Alvarez and Mr. J. D. Gow for their initial suggestions and assistance on the problems. Mr. Thomas H. Rogers and Mr. William G. Richards were instrumental in the design and construction of the paddle. Mr. James B. Robinson and Mr. J. A. G. Russell assisted greatly in the design of the difference amplifier, and Mr. Louis B. Edwards and the Accelerator Technicians under Mr. Walter E. Stockton fabricated the various components of the ionization chamber with great ingenuity. Thanks are also due to Mr. H. Paul Huish, who did the tedious and exacting absorber foil measurements and assisted in all other phases of the experiment and to Dr. Robert Silver, for his work on beam-energy changes. Dr. Schrank communicated much information and the writer is most grateful to him.

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Figure Captions

Fig. 1. Energy stabilizer in schematic form.

Fig. 2. Paddle and its associated gearbox, mounted in position.

Fig. 3. Internal geometry of the ionization chamber.

Fig. 4. Ionization density and end-point probability for 32-Mev protons stopping in argon. I_1 and I_2 represent the currents from collectors No. 1 and No. 2 (respectively) in the balanced condition, assuming an argon density of 5.00 mg/cm^3.

Fig. 5. High resistance connectors for the ionization chamber.

Fig. 6. Difference amplifier.

Fig. 7. Difference amplifier response at one meg ohm output resistance.

Fig. 8. Master energy control panel and associated circuits. The component values are given below.

R_1, R_2	100 Ω (5W) "Helipot"
R_3, R_4	50 Ω (2W) potentiometer
R_5, R_6	150 Ω (2W)
R_7, R_8	10 KΩ WW
R_9, R_{10}	1 MΩ WW
R_{11}, R_{12}	10 MΩ potentiometer
R_{13}, R_{14}	1 MΩ
C_1, C_2	500 μfd (electrolytic)
C_3, C_4	1000 μfd (electrolytic)
M_1, M_2	0 - 1 ma ammeter
M_3, M_4	10 - 0 - 10 μa ammeter
S_1, S_2, S_3	"Coaxwitch"
S_4	N.C. pushbutton switch
T_1	110 v/27 v C.T. transformer.

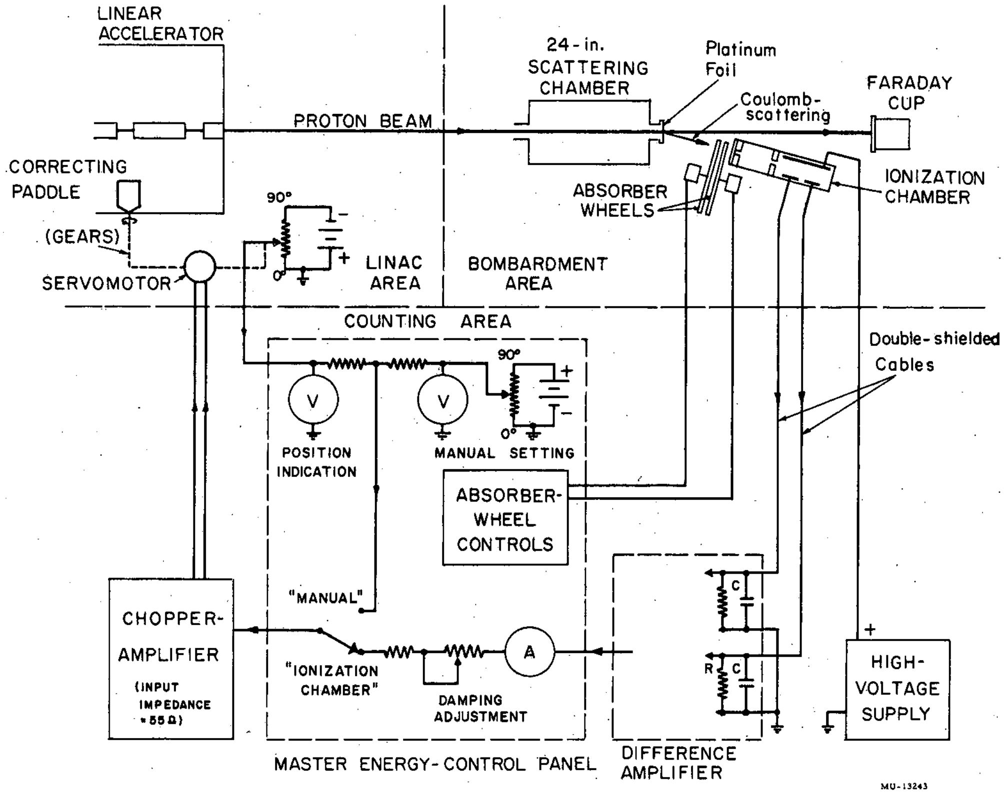

LINEAR ACCELERATOR
PROTON BEAM
CORRECTING PADDLE
(GEARS)
SERVOMOTOR
90°
0°
+
-
LINAC AREA
BOMBARDMENT AREA
24-in. SCATTERING CHAMBER
Platinum Foil
Coulomb-scattering
FARADAY CUP
ABSORBER WHEELS
IONIZATION CHAMBER
COUNTING AREA
Double-shielded Cables
V
V
POSITION INDICATION
90°
0°
+
-
MANUAL SETTING
ABSORBER-WHEEL CONTROLS
"MANUAL"
"IONIZATION CHAMBER"
A
DAMPING ADJUSTMENT
CHOPPER-AMPLIFIER
(INPUT IMPEDANCE ≈55Ω)
MASTER ENERGY-CONTROL PANEL
C
R
C
DIFFERENCE AMPLIFIER
+
HIGH-VOLTAGE SUPPLY
MU-13243

Fig. 1

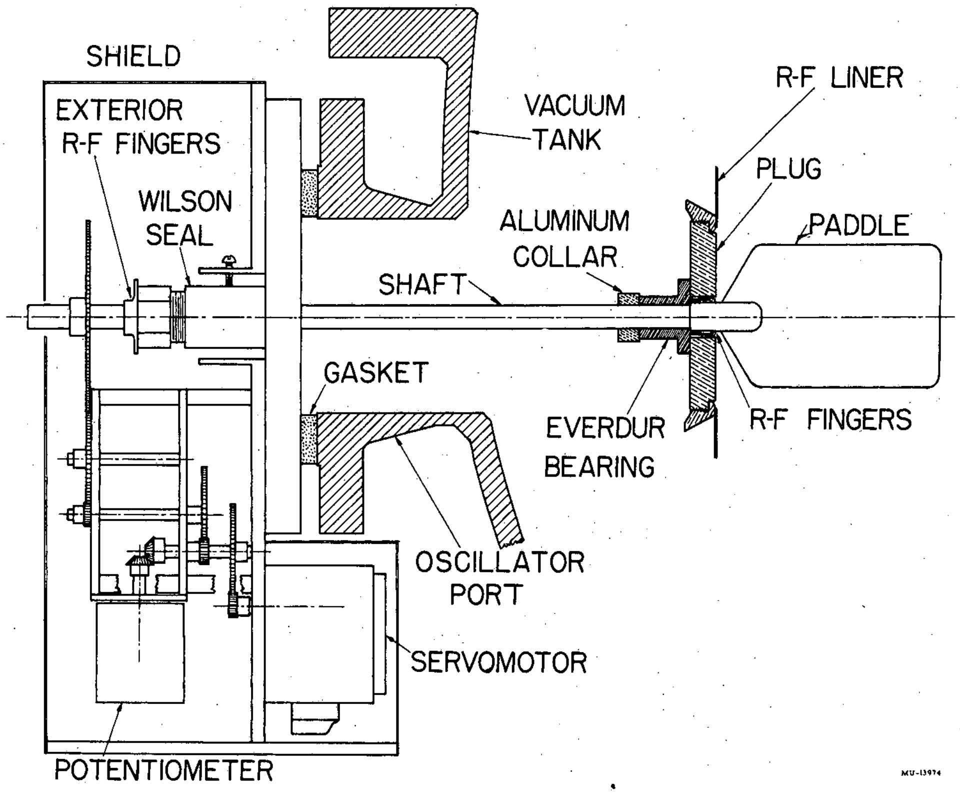
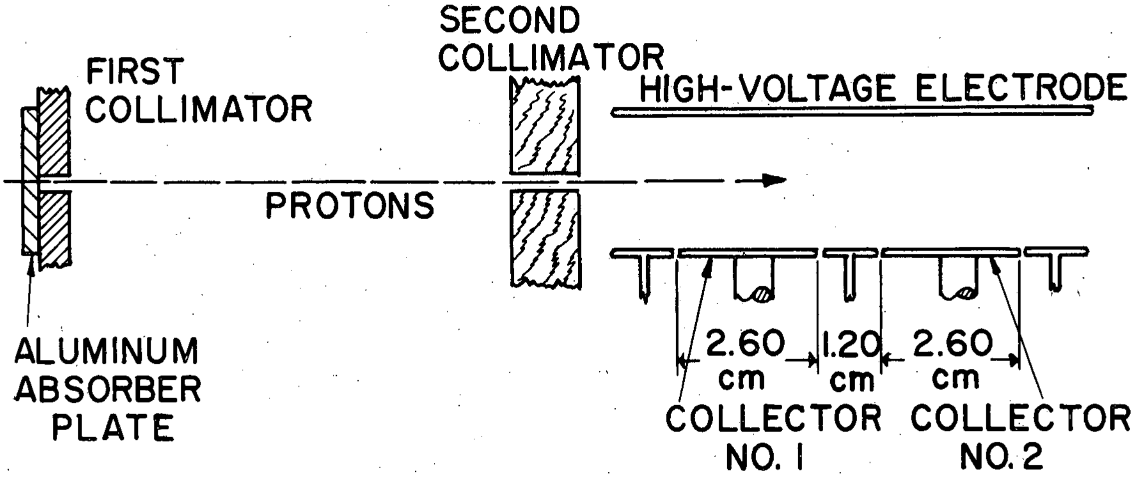

SHIELD
EXTERIOR R-F FINGERS
WILSON SEAL
VACUUM TANK
R-F LINER
PLUG
PADDLE
ALUMINUM COLLAR
SHAFT
GASKET
EVERDUR BEARING
R-F FINGERS
OSCILLATOR PORT
SERVOMOTOR
POTENTIOMETER
MU-13974

Fig. 2



MU-13975

Fig. 3

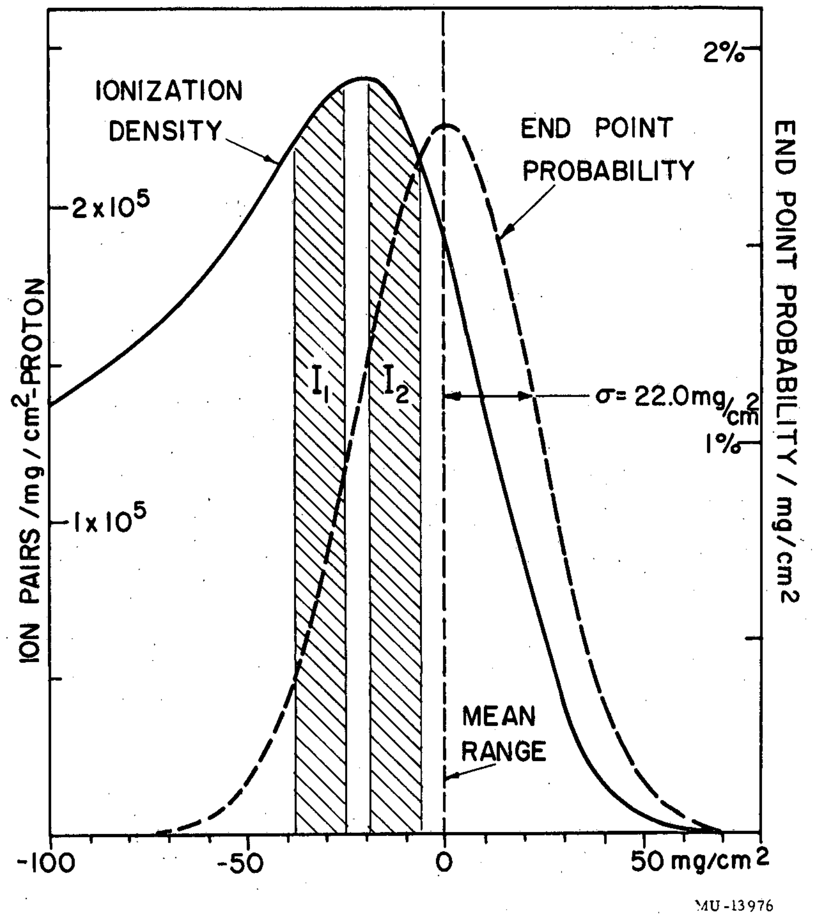
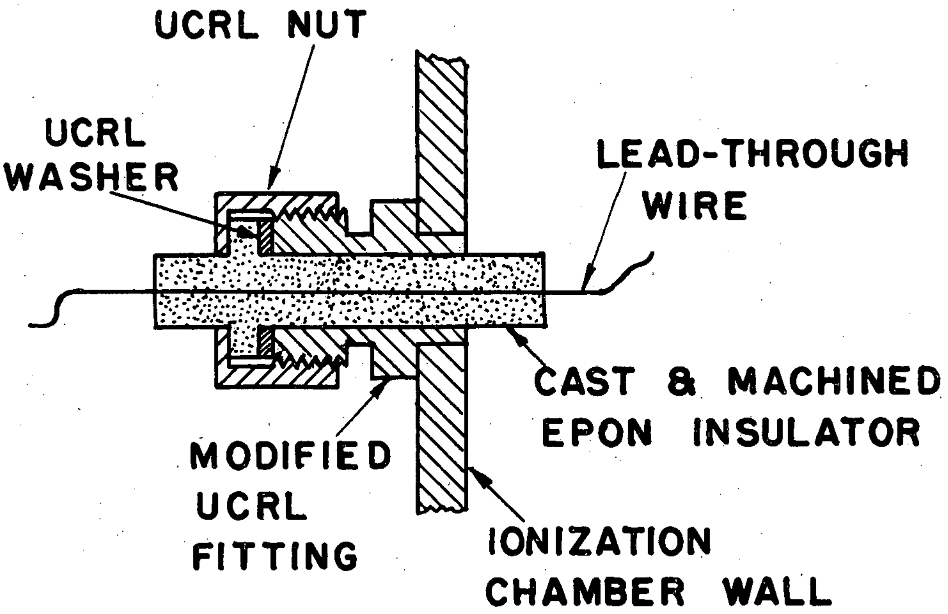

IONIZATION DENSITY
END POINT PROBABILITY
2%
1%
2 x 10^5
1 x 10^5
ION PAIRS / mg / cm² - PROTON
END POINT PROBABILITY / mg/cm²
I₁
I₂
σ = 22.0 mg/cm²
MEAN RANGE
-100
-50
0
50 mg/cm²
MU-13976

Fig. 4



MU-13977

Fig. 5

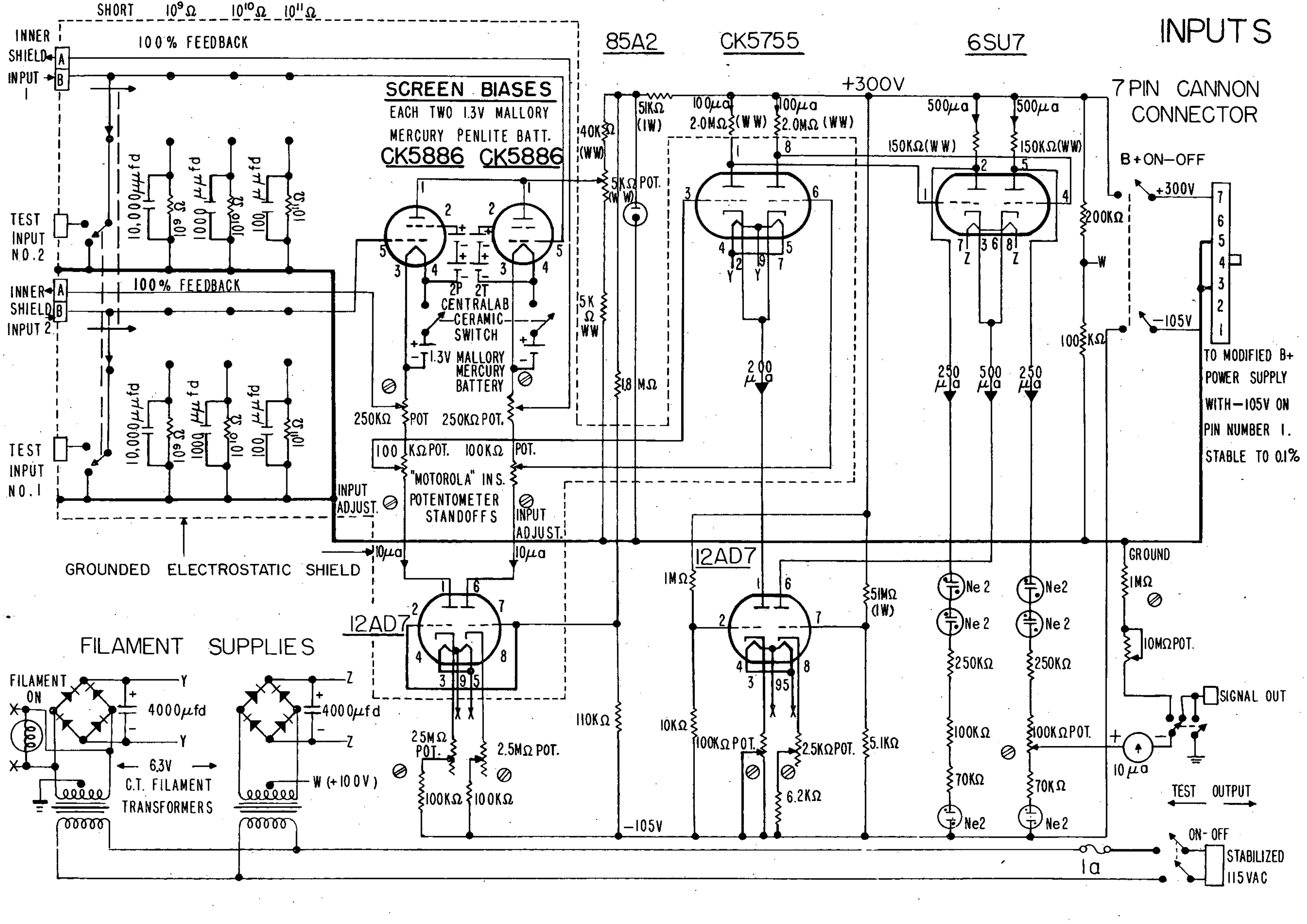

INPUTS
7 PIN CANNON CONNECTOR
B+ON–OFF
+300V
–105V
TO MODIFIED B+ POWER SUPPLY WITH –105V ON PIN NUMBER 1. STABLE TO 0.1%
85A2
CK5755
6SU7
+300V
SHORT 10⁹Ω 10¹⁰Ω 10¹¹Ω
INNER SHIELD A
INPUT 1 B
100% FEEDBACK
TEST INPUT NO.2
INNER SHIELD A
INPUT 2 B
TEST INPUT NO.1
10,000μμfd
10⁹Ω
1000 μμfd
10¹⁰Ω
100 μμfd
10¹¹Ω
SCREEN BIASES
EACH TWO 1.3V MALLORY MERCURY PENLITE BATT.
CK5886 CK5886
2P 2T CENTRALAB CERAMIC SWITCH
1.3V MALLORY MERCURY BATTERY
250KΩ POT
250KΩ POT.
100 KΩ POT.
100KΩ POT.
"MOTOROLA" INS. POTENTOMETER STANDOFFS
INPUT ADJUST.
10μa
GROUNDED ELECTROSTATIC SHIELD
40KΩ (WW)
51KΩ (1W)
5KΩ POT. (WW)
5K Ω WW
1.8 MΩ
100μa
2.0MΩ (WW)
150KΩ (WW)
500μa
200KΩ
W
100KΩ
200 μa
250 μa
500 μa
12AD7
12AD7
1MΩ
51MΩ (1W)
5.1KΩ
10KΩ
110KΩ
–105V
100KΩ POT.
2.5KΩ POT.
6.2KΩ
2.5MΩ POT.
25MΩ POT.
100KΩ
Ne 2
250KΩ
100KΩ POT.
70KΩ
GROUND
1MΩ
10MΩ POT.
SIGNAL OUT
10μa
TEST OUTPUT
ON-OFF
STABILIZED 115VAC
1a
FILAMENT SUPPLIES
FILAMENT ON
4000μfd
Y
Z
6.3V
C.T. FILAMENT TRANSFORMERS
W (+100V)
MUB-123

Fig. 6.

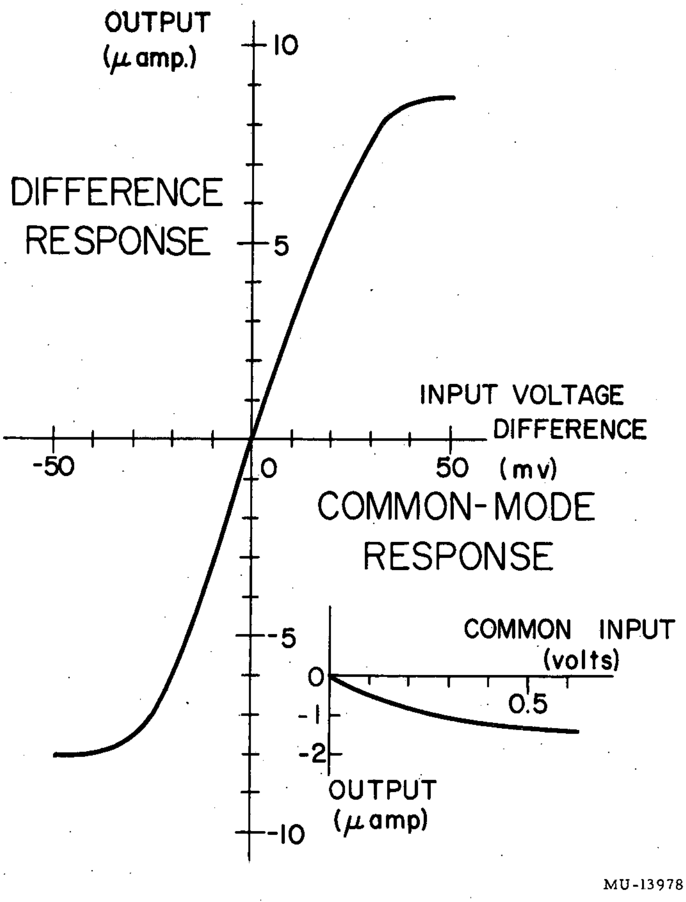

OUTPUT
(μ amp.)
10
DIFFERENCE
RESPONSE
5
INPUT VOLTAGE
DIFFERENCE
(mv)
-50
0
50
COMMON-MODE
RESPONSE
-5
COMMON INPUT
(volts)
0
0.5
-1
-2
OUTPUT
(μ amp)
-10
MU-13978

Fig. 7

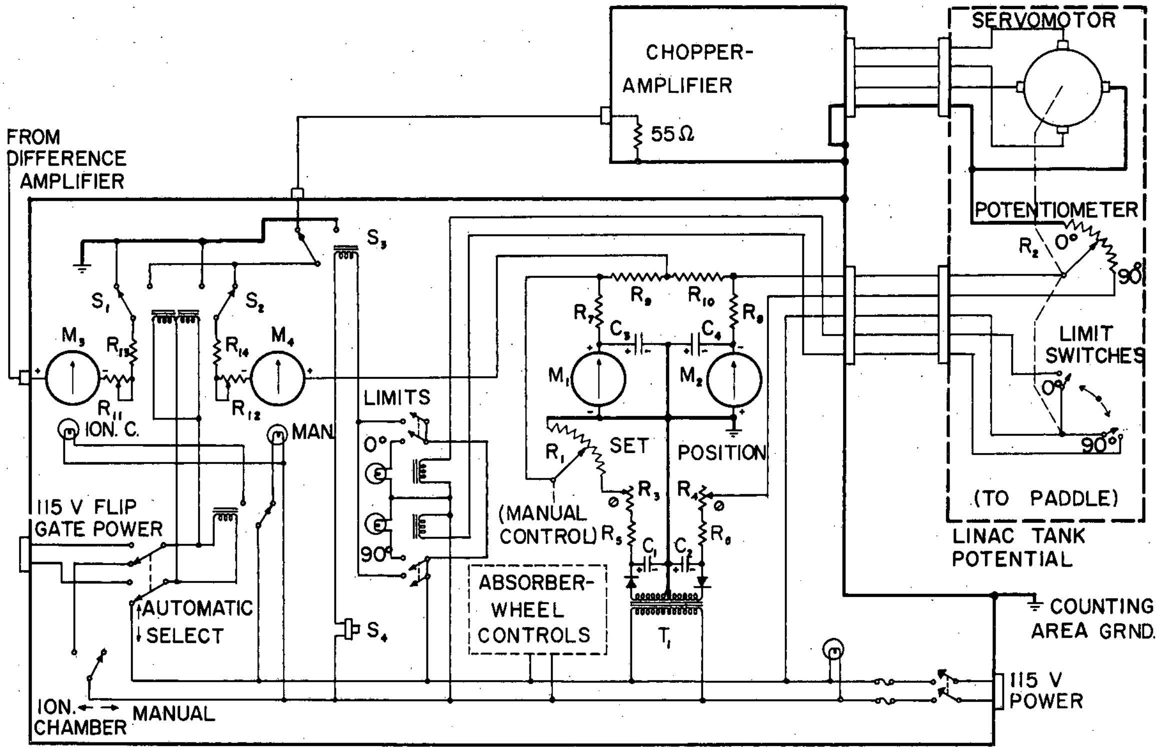

CHOPPER-
AMPLIFIER
55 Ω
SERVOMOTOR
FROM
DIFFERENCE
AMPLIFIER
POTENTIOMETER
R2
0°
90°
S3
S1
S2
M3
R13
R11
R14
M4
R12
ION. C.
MAN.
R9
R10
R7
R8
C3
C4
M1
M2
LIMIT
SWITCHES
0°
90°
LIMITS
0°
90°
R1
SET
POSITION
(MANUAL
CONTROL)
R3
R4
R5
R6
C1
C2
(TO PADDLE)
LINAC TANK
POTENTIAL
115 V FLIP
GATE POWER
AUTOMATIC
SELECT
ABSORBER-
WHEEL
CONTROLS
S4
T1
COUNTING
AREA GRND.
115 V
POWER
ION.
CHAMBER
MANUAL
MU-13979

Fig. 8