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THE PROTON DEUTERON R-F SYSTEM FOR THE BERKELEY SYNCH!CYCLOTRON

Author

MacKenzie, K.R.

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K. R. MacKenzie

August 15, 1950

Berkeley, California

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K. R. MacKenzie

Department of Physics, University of California, Los Angeles
and
Radiation Laboratory, University of California, Berkeley

August 15, 1950

ABSTRACT

An r-f system is described which allows the acceleration of either 190 Mev deuterons or 350 Mev protons in the Berkeley 184-inch cyclotron. The dee is connected to a large cross section line, which is in turn connected, through a rotating condenser, to a short section of grounded line of approximately the same cross section. At the upper frequency limit of 23.2 megacycles the dee and dee stem oscillate as a half wave line, while the grounded line, which is about one-quarter wave long, oscillates in the opposite phase. At the low frequency limit of 9.5 megacycles, the whole system looks like a quarter wave line. The oscillator which feeds the system is described.

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K. R. MacKenzie
Department of Physics, University of California, Los Angeles
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Radiation Laboratory, University of California, Berkeley

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In December 1948, an r-f system was installed on the 184-inch Berkeley cyclotron which made possible the acceleration of either 350 Mev protons or 190 Mev deuterons.[1] As the system has operated since that time with no essential changes, it can be considered to be in its final form. Original plans called for a power input of 200 kw and a dee voltage of 30 kv. However, other factors have kept the dee voltage in the range from 15 to 20 kv, with a power input of 50 to 80 kw. With this dee voltage, a circulating beam of one microampere is obtained both with deuterons and protons. In the model stage it appeared that the change from deuterons to protons could be made by not more than two simple changes of external capacity. The changeover now involves five external changes and the operation of an internal vacuum switch. This, however, can be done in about five minutes, so that the cyclotron can be switched from deuterons to protons as fast as the target can be changed.

The frequency range required is 22.9 to 15.8 megacycles for protons and 11.5 to 9.8 megacycles for deuterons. Experiments were carried out on the previous deuteron system for the 184-inch cyclotron[2] which showed that the beam was not affected by eliminating the "excess" range on both high and low ends of the frequency swing. It is interesting to note that the ion

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[1] Wide Range Frequency Modulation, K. R. MacKenzie, Phys. Rev. 74, No. 1, 104-105, July 1, 1948.

[2] Design of the Radiofrequency System for the 184-inch Cyclotron, K. R. MacKenzie, F. H. Schmidt, J. R. Woodyard and L. F. Wouters, R.S.I., 20, 126-133, February 1949.

catching efficiency of the cyclotron was apparently not affected by the slope of the frequency time curve. The slope in this case was varied from essentially zero to the point where the frequency time curve was almost concave upward (the curve being almost a sine curve). Consequently, in the new system, provision was made for only a few percent extra range on either end. The frequency limits therefore range from 23.2 to 9.5 megacycles.

The present arrangement has been called the "three-quarter wave system".[3] It was chosen because it appeared to solve the problem of obtaining a wide frequency variation with a rotating capacitor that could be placed outside the magnetic field. The only other practical solution seemed to be a rotating condenser mounted near the dee edge, and involved the problem of eddy current heating due to rotation in a magnetic field. Since it was apparent that a range greater than three to one could be obtained theoretically with the external rotating capacitor, thus permitting the acceleration of deuterons, there was no argument against its adoption except bulkiness. A further argument was that the design of the dee already in operation in the 184-inch cyclotron for deuterons[2] could be used unchanged.

The first tests were performed during the summer of 1947. A half scale model was built and excited by two 304TL tubes with padding condensers to simulate 9C21 tubes. Various oscillator coupling schemes were tried and abandoned. These are described in a previous progress report.[3] The full scale system was started as soon as dimensions on the model were reasonably definite. It was built as a complete unit, including new faceplate and even a new dee. The new dee was identical with the old dee in the deuteron system, so the old dee became a "spare". Dummy liners were made to simulate

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[3] Preliminary Report on the "Three-Quarter Wave" R-F System for Frequency Modulated Cyclotrons, Kenneth MacKenzie, AEC Report AECD-1850, September, 1947.

the magnet pole surfaces. This allowed the whole system to be tested before removing the old deuteron f-m system. The tests had to be made in air, and limited the dee voltage to 3 kv, at which point the rotary capacitor gaps broke down. The new system, including dee, face plate, new vacuum sections, rotary condenser, and oscillator, were supported on a truck system which allowed the insertion of the dee into the cyclotron vacuum tank. When the change-over was made, the whole apparatus, including the truck system, was set in place by the crane. The change-over required an elapsed time of five weeks from the time the 190 Mev deuteron beam was turned off until a 350 Mev proton beam was obtained. About two weeks later the 190 Mev deuteron beam was again obtained with the new system.

Electrical Features

The name, "Three-quarter wave system," arose because the dee is connected to ground by a transmission line which is three-quarters of a wave in electrical length at the high frequency end of the range. At the low frequency end of the range it is a little longer than an electrical quarter wave. In fig. 1(a) the system is shown in schematic form, with the voltage distribution shown for various frequencies throughout the range (fig. 1(b)). The oscillator tubes are coupled to the system by resonant lines, whose lengths are chosen in such a way that the dee voltage remains relatively constant regardless of frequency variation.

The diagram in fig. 1 is over-simplified, but can be used to explain why the oscillator coupling scheme was adopted. A grounded grid oscillator was chosen, due to its inherent freedom from parasitic troubles. The main oscillating system, in which we find most of the r-f energy, consists of the section connected to the dee, which will be referred to as the "dee stem", and the grounded section which will be called the "stub" line. The rotating condenser connects the dee stem with the stub line. This arrangement has two fundamental modes of oscillation, shown in fig. 1(b), by the voltage distribution in full and dashed lines. The mode in which there is no voltage across the condenser (dashed lines) is useless, of course, and must be prevented. It is therefore necessary that power be fed into the system on the opposite side of the capacitor from the point at which excitation for the oscillator is obtained. With proper orientation of the excitation loop (connected to the filament), the right mode will present the correct voltages at the oscillator tube, while the wrong mode will present voltages 180° out of phase. The graphs V(f) and V(p) in fig. 1(a) represent the voltage distributions along the filament and plate lines in the correct mode.

With a frequency range of 2.4 to 1, suitable coupling is more difficult to obtain with a loop than a direct tap, since some of the voltage is lost due to back e.m.f. in the loop. In addition, the loop reactance changes with frequency. Accordingly, advantage was taken of the fact that the plate line could be directly connected to the stub line. The plate line current does not appreciably affect the voltage at the tap, because of the relatively low impedance of the "stub" section. With constant dee voltage, the voltage on the stub line varies considerably as the frequency is changed (fig. 1(b)).[3] It is, of course, desirable that a constant plate voltage (and therefore a relatively constant plate r-f voltage) produce a constant dee voltage. With a constant plate r-f voltage it is possible to choose a length and impedance for the plate line so that the voltage at the other end (as a function of frequency) is very nearly the same as the variation in voltage on the stub line. When connected together we have a system in which a constant d.c. plate voltage means relatively constant dee voltage. Slight changes in line length about this point will result in a dee voltage that either rises or falls throughout the range. As will be seen later, the optimum length of line to achieve an absolutely constant dee voltage could not be used, since it was necessary to "dodge" numerous overtones of the system.

It was possible to choose the length of the plate coupling line so that the same length could be used over both deuteron and proton ranges. With the filament line however, it was necessary to add capacity to ground at the tube and part way along the line when changing from protons to deuterons (shown dotted in fig. 1). This difference between the lines is due to the loop coupling scheme instead of a direct tap as used on the plate line. A direct tap cannot be used since the voltage on the dee stem side of the capacitor changes phase as the frequency is varied. The current flowing in the dee stem is always in the same direction however, so magnetic coupling is all right. In order to minimize the loss in voltage due to loop reactance and also the variation of this reactance with frequency, four 2-inch diameter loops were used in parallel. These loops are shown in the pictorial sketch (fig. 2).

Mechanical Features

Many of these features are shown in figs. 2 and 3. The main oscillating system consisting of dee, dee stem, rotary capacitor and stub line are all in vacuum. The dee and dee stem are supported by two 15-inch diameter zircon insulators. They are 18 inches long with one-half inch thick walls, and are the same insulators used to support the dee in the previous deuteron system.[2] The dee, which is 15 feet 3 inches across at the edge, is much heavier than the dee stem which is about $3\frac{1}{2}$ by $4\frac{1}{2}$ feet in cross section, resulting in a very "front heavy" mechanical arrangement. The weight of the dee is balanced by two "tie rods" at the end of the dee stem (shown in fig. 2). They are set at 41° to the vertical to give lateral stability. These tie rods are one inch in diameter and six feet long and consequently look like a very high inductance when compared with the $3\frac{1}{2}$ by $4\frac{1}{2}$ ft. section. The voltage across these rods at the high frequency end is around 15 kv. and a current of over 100 amperes flows. They are, of course, water cooled and consist of copper plated steel tubes. The inductance of these rods reduces the frequency range about two percent, which seems small compared to the mechanical convenience realized. As shown in fig. 2, these rods go to ground through short sturdy insulators consisting of zircon rings 10 inches in diameter and 3 inches long with 1 inch wall thickness. The tie rods are then grounded for r-f through a one turn inductance consisting of a 5/8 inch copper tube in an 8-inch circle (which carries water to the tie rods), and a mica condenser. A d.c. bias can thus be put on the dee.

The rotor of the capacitor (shown in fig. 4) weighs about one ton. There are six rows of teeth or blades, and seventy-two blades to a row. The gap between blades when meshed is 100 mils. The blades were machined from steel disks (6 blades and a large central hole), and copper plated to a thickness of 5 mils. The 72 rings were then shrunk onto a central steel tube ten inches in diameter which is water cooled. Water flows into the tube through the drive shaft. The rotor is supported on a framework consisting of two inch steel tubes (copper plated). The ball bearings are packed with grease and covered. Brushes, consisting of a continuous set of flexible tantalum fingers (one-eighth strips separated by saw cuts) bear on the circumference of a rotating polished steel cylinder. The r-f current is thus by-passed around the bearings. There is a brush on each side of the rotor which conducts current from the rotor to the support frame. The current flow is not symmetrical on both sides, since there are two support rods on one side and two supports and a drive shaft on the other. The drive shaft supplies lateral stability. Another brush conducts current from the support frame to the drive shaft and a fourth brush carries this current from the drive shaft to ground through a condenser. Since a d.c. sweeping bias must be applied to the rotor, the ground ends of the rods are held on short insulators similar to the dee stem tie rod insulators. The ground end of the drive shaft is held in the same way. Ground for r-f is achieved through a one turn inductance and condenser except in the case of the drive shaft, where a condenser is connected directly between ground and a point next to a set of V pulleys. A 15 h.p. motor supplies power to the drive shaft through V belts. The condenser to ground prevents r-f from burning the belts.

Mode Problems

The inductance of the support rod structure for the rotor is much lower than the inductance of the tie rods on the dee stem, and cannot be neglected. As shown in fig. (1)c it introduces another tuned circuit and therefore another mode. The mode in which most of the energy can be found in this new circuit cannot be excited because of relatively high losses. It can, however, alter the voltage distribution in the useful mode. The rotor would normally float two-thirds of the way between dee stem and stub line, since there are two sets of teeth on the stub line and only one set on the dee stem (see fig. 2), but due to the effect of this extra circuit, which is tuned above the cyclotron frequency, it is even closer to stub line potential (see fig. 1(b)). If this new circuit could be tuned below the lower limit of the frequency swing, it would allow the rotor to float more nearly half way between dee stem and stub line. A large external inductance is required to do this, however, with the result that voltages of about 10 kv appear at certain frequencies across the support rod insulators. This voltage was considered excessive, inasmuch as an insulator fracture with the one ton rotor revolving at 1000 rpm could cause a lot of damage. With the circuit tuned above the frequency range, the actual rotor voltage to ground goes as high as 15 kv, but most of the drop occurs along the support rods in vacuum and the voltage across the insulators is rarely over 2 kv.

The unequal gap voltage introduced by this tuning procedure is not too desirable, since the breakdown point will be reached at a lower dee voltage. The higher rotor to ground voltage also increases the current through the brushes. This is a more serious limitation. With 15 to 20 kv on the dee the latest set of bearings and brushes have lasted over six months. In a recent test the dee voltage was raised to 24 kv, and the power input to well over 100 kw, with the result that one of the brushes failed in a few hours. The heavy experimental nuclear program precludes the possibility of making many tests of this sort, or even testing improved forms of brushes.

The extra set of teeth on the stub line was necessary in order to reach the lower limit required for deuterons. If these extra teeth had been put on the dee stem instead of the stub line, the rotor to ground voltage could have been reduced by almost a factor of two. However, it was not possible to reach the upper frequency limit with this extra capacity on the dee stem.

Only one other important mode in the region of the fundamental was encountered. When fully meshed, the rows of blades can be considered as a parallel plate transmission line of very low impedance. If there are sufficient teeth per row, the extended length of this line can be a half wave at the fundamental frequency. This happened just above the lower limit of the deuteron range, and since it was a very low Q circuit, it absorbed a lot of power. The trouble was fixed by removing a few stator teeth from the ends of the row. This raised the frequency of the mode. As the teeth are unmeshed, the frequency of this mode rises faster than the frequency of the fundamental, so they never overlap. The removal of these teeth from the ends of the row made it necessary to add the extra row mentioned above.

The Deuteron Range

It appeared at first that both the proton range and deuteron range could be covered by adjustment of the lines to the oscillator, with no changes in the main resonant system. The frequency range would have to be 23 to 9.8 mc. The actual range achieved was 23.2 to 10.1 mc, and no amount of minor adjusting would get the lower limit any lower. Theoretically, the range can be much greater, and in the limit it can be made to approach the square root of the capacity ratio. This is done by providing a large volume around the rotary capacitor, which reduces capacities to ground, thus raising the upper limit. At the same time, this volume provides a lot of inductance when the teeth are meshed, and thus lowers the lower limit. Modifications were made in going from scale model to full size, with the result that plenty of volume was provided above and below the rotor, but the clearance to the sides was small. The r-f current then hugged the sides, rendering the large volume rather ineffective. This also resulted in excess heating on the ends of the rotor. Much of this was corrected by cutting away some of the sides of the stub line, but the amount of correction that could be accomplished was limited. It is unfortunate that the rather obvious bad effects of the small side clearance were not appreciated until after the structure was finished.

In order to distribute the current evenly, the volume above the rotor was greatly reduced by a liner (fig. 2). This causes most of the current to flow on the top side of the dee stem and not so much on the lower side.

However, it was a vast improvement over the current concentration on the sides, and reduced the heating of the ends of the rotor to the point where it was of little concern. This of course raised the lower limit. In order to achieve the lowering effect, this liner was made discontinuous. This causes current to flow through the opening and back along the upper side of the liner, then back through the opening again. The current is thus forced to flow in the region it formerly dodged, and results in a lower frequency. This frequency is lowered even more if there is considerable capacity across the gap. The inductance and capacity of course form a tuned circuit and the result is considerable voltage across the gap - in fact, almost equal to dee voltage. Fortunately, this voltage as well as the extra losses introduced could be tolerated. The addition of this liner lowered the lower limit from 10.1 mc to 9.6 mc. It also lowered the upper limit of the proton range far below 22.9 mc. In the proton range a vacuum switch, consisting of a large number of short spring loaded copper bars, shorts out the gap. This switch (marked S), and the liner are shown in fig. 2. No attempt has been made to show the actual form of this switch, which must be operated through a vacuum seal.

The Oscillator

The oscillator is built around two parallel 9C21 tubes in a grounded grid circuit. The grid ring seals fit in two holes in an oval sheet of copper. The grounding of the grid for r-f potential is accomplished by an oval ring of sixteen 100 μμf vacuum condensers around the edge of this sheet (see fig. 2). These condensers must stand the plate plus grid voltage to ground (which at present does not exceed 11 kv) and pass about 30 amps of r-f. Recently some vacuum condensers have been replaced by equivalent ceramic condensers.

The two tubes are supported in separate copper plated steel jackets which reduce the stray magnetic field at the tube filaments. These jackets are connected together at the bottom (see fig. 2) and a 50 ohm resistor connected across the top. This effectively prevents any push pull parasitic. Since some extra capacity to ground, in addition to the plate to grid capacity is desirable, no special effort was made to reduce the jacket capacity to ground. The water connections are made inside the connecting box between anodes and the water goes to ground through six feet of seran tubing. The absence of d.c. on the plate removes the electrolysis problem.

The filament line enters the back of the oscillator house and connects to the tube through four 0.004 μμf mica stand-off type condensers which block the d.c. plate potential. The filament current comes in through four chokes mounted over the tubes. Extra filament to ground capacity was added by plugging in vacuum condensers.

Although the oscillator is coupled to the system by lines around three-eighths of a wavelength long, the size of components restricts the location of the oscillator house within a few feet. With this restriction it was fortunately still possible to locate the oscillator in a region of minimum magnetic field strength. A minimum occurs since the leakage flux is in the reverse direction to the useful flux, and so a point can be found fairly close to the magnet, where the field is close to zero. As a further precaution the oscillator house was made of one-fourth inch steel and lined with copper.

Adjustment of Transmission Lines.

The calculation of transmission line lengths is made on the following basis. The relative values of voltage and current along a transmission line are determined solely by the impedance at the end of the line. The plate line is terminated by the plate to grid and ground capacity in parallel with a negative resistance. The assumption of a negative resistance is legitimate if we restrict our calculation to the fundamental component of the plate current pulse. In the same way the filament line is terminated by the filament to grid and ground capacity in parallel with a positive resistance. The resistive component can be neglected in the calculation of magnitudes. The voltage distribution along the plate line, for a fixed value of plate r-f voltage, is shown in fig. 5 with the assumption that we use a uniform line of 80 ohms characteristic impedance with a capacity of 200 μμf at the end. The plate to grid capacity of two 9C21 tubes plus the jacket capacities is approximately 200 μμf. The voltage distribution is shown for 23, 18, 12.5 and 9.5 mc. If we consider a length of 21½ feet, we see that the voltage at the end (which will be the voltage at the tap on the stub line), is slightly lower than the plate voltage at 23 mc. Then it rises to a maximum of about twice plate voltage and finally falls to about one-half plate voltage at 9.5 mc. This is a variation of over four to one. For constant dee voltage, the voltage variation on the stub line is around two and one-half to one, and it is not desirable to make the ratio much larger since it must be done by increasing the gap voltage somewhat, so the best approach was to reduce the variation at the end of the plate line. The manner in which the characteristic impedance and length of stub line affect the voltage variation throughout the range has been calculated in a previous progress report.[3] Some provision was made for changing the stub line variation by installing movable ground liners which would vary Z_0.

When first set up, the plate line would not work, since, instead of being uniform, there was considerable lumped capacity around the feed through insulator (see fig. 2). This capacity occurs right at the voltage maximum at 23 mc and effectively lengthens the line, which is the wrong thing to do. The shield box around the insulator was replaced by a very large box.

The result is a section of high impedance line with low capacity and large inductance. At 23 mc the voltage maximum occurs at this point, and the low capacity makes the line effectively shorter, which is the effect desired. At 9.5 mc the node is very close to the insulator. Since high currents flow at the voltage node the high inductance makes the line appear longer. With this modification it was possible to empirically adjust the length, and get a voltage variation to match the stub voltage variation. The large box around the insulator can be seen in fig. 6.

The voltage variation along the filament line was handled in the same manner. Before starting any calculation it was necessary to assume added capacity from filament to ground of about 200 $\mu\mu f$ in the proton range and 400 $\mu\mu f$ in the deuteron range. This is done to insure that the circulating current is about eight times the current due to the electron pulses. A ratio much less than this results in a serious phase shift between the filament grid voltage and the plate grid voltage[3] with a consequent loss in efficiency. This added capacity for phase shift correction is achieved by the extra vacuum condensers between filament and ground (50 $\mu\mu f$ in the proton range and 150 $\mu\mu f$ in the deuteron range) plus the capacity of the flexible filament leads and supporting structure. Unfortunately not much voltage is picked up by the loop, so the loop terminal must also be very close to the node on the filament line, and it was not possible to match voltages by simply changing line length. The matching was accomplished by locating vacuum condensers very near the node. The change in voltage with frequency at the coupling loop end of the transmission line can be accentuated or decreased, depending on which side of the node the condensers are placed. These condensers have the same effect as the non-uniform section in the plate line. The adjustment was made empirically, and a set of condensers in "suitable locations" was determined for each range. These condensers are indicated in fig. (1) (dotted lines). On the proton range one 100 μμf condenser was located about 2 feet on the loop side of the node. In the deuteron range eight 100 μμf vacuum condensers were located about one foot on the loop side of the node and three 100 μμf condensers about one foot on the tube side of the node. This peculiar distribution appeared to give the minimum excitation of higher modes. The excitation of these higher modes at various frequencies throughout the range will cause dips in the dee voltage. It should be possible to locate condensers so that the filament line would work over both ranges without adjustment. Unfortunately any such setting either did not provide enough excitation or resulted in the excitation of overtones in certain frequencies in the range.

Parasitics

The foregoing discussion gives the impression that much of the adjustment was empirical. This is very true, since it is almost impossible to account for the behaviour of the very numerous overtones of a complex system. These overtones are troublesome even over 100 megacycles. The wavelength is short, so small adjustments of line lengths have drastic effects on the overtones. Recognizing that the final adjustment would be empirical, the calculations were used merely to obtain approximate overall dimensions and also to determine the "trend" that would result from an adjustment. Most of the "adjustments" were very time consuming and expensive, usually requiring refabrication of parts, so it was very desirable to keep them to a minimum. By observing the change caused by an "adjustment", it was then easily possible, by comparison with theory, to determine the changes necessary for optimum operation. The theory thus served the purpose of eliminating much of the usual time consuming process of successive approximation. Very often the optimum setting would favor the excitation of a parasitic. In such cases a compromise setting was used if the parasitic could not be eliminated in other ways.

The most troublesome parasitic occured around 90 megacycles at the beginning of the deuteron range (12.5 megacycles). It was finally eliminated by a thyrite resistor to ground near the plate line node (for the fundamental). This resistor absorbs some power and changes the dee voltage amplitude versus frequency somewhat. Other parasitic oscillations of unmeasured frequency were discouraged by a thyrite resistor near the filament line node, and also by empirical placement of the above mentioned padding condensers near the node. These parasitics are just higher order modes of the system which present the right voltages at the plate and filament. The grounded grid circuit eliminates only those parasitics which are normally excited by coupling through the tube.

Another effect, related to parasitic trouble but of a distinctly different nature, occurs whenever one of the overtones or stray tuned circuits can be excited by either the fundamental or a harmonic of the fundamental. Various such circuits were located and either eliminated or detuned, e.g., two high voltage 0.005 μμf mica capacitors connected in parallel by flat plates, will resonate around 20 megacycles, so all commercial condensers were used singly. The by-pass condensers at the ground end of the dee tie rods and rotor supports have to carry r-f currents of 100 amps and over, and no single commercial condenser will stand up. By-pass condensers were made by clamping 10 mil sheets of mica, 6 inches square, between water cooled plates (fig. 2). Four of these in parallel approximate 0.004 μμf and have an inductance so low that the resonant frequency is far above 23 megacycles. They stand 10 kv d.c. and carry over 100 amps r-f, and so have some margin of safety, as the bias voltages are kept below 2000 volts. In the deuteron range it was necessary to add external inductance in series with the dee tie rods to reduce the current through these condensers and in addition gain about one percent extra frequency range. In the proton range most of this inductance is shorted out to prevent excessive voltage on the tie rod insulators. This also raises the upper frequency slightly.

Dee Bias

In oscillators of this type, the oscillations build up slowly at first and allow plenty of time for discharges to develop due to electrons that oscillate in the r-f electric field. It is possible to get enough electrons oscillating back and forth to change the frequency several percent. The effect is inductive because of the mass of the electrons. The principle effect is that the oscillator loads down and the voltage stops rising. A d.c. sweeping field on the dee removes these electrons. The dee tie rods must therefore be insulated for d.c. as well as the rotor supports. The stub line is grounded however, so the spaces are swept clear of electrons by wires at a potential of around 1500 volts. One of these "wires", consisting of a one-fourth inch rod, is shown in fig. 2 (marked R). The sweeping voltages applied to the dee and rotor are over 1000 volts, but seldom over 1500 volts. The voltage is negative, since a positive voltage allows a discharge similar to the discharge in the "Philips" type vacuum gauge.

The Pulser

The oscillator is pulsed over the desired range by keying the grid leak. If operating on deuterons it must be shut off over the proton range since the oscillator will drop out of the right mode and find some parasitic. The turn on signal is obtained from small magnetic bars set in a disk attached to the rotor shaft, and the turn off signal from an adjustable tuned circuit. The signals are amplified and fed through an r-f link to two 304 TL tubes which alternately open and close the grid leak circuit. In the open circuit condition, cut off is insured by applying a high negative bias. The pulsing system will be described in a paper by R. Mack.

Acknowledgments

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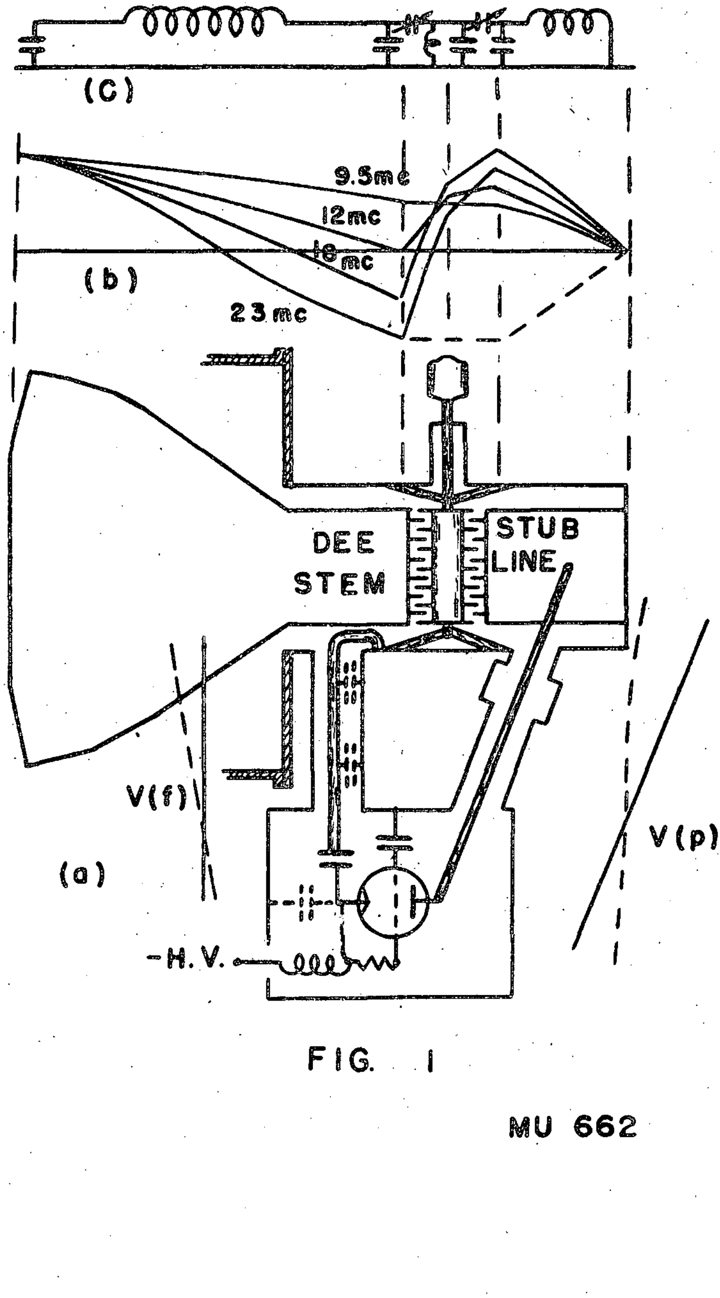

FIG. 1

MU 662

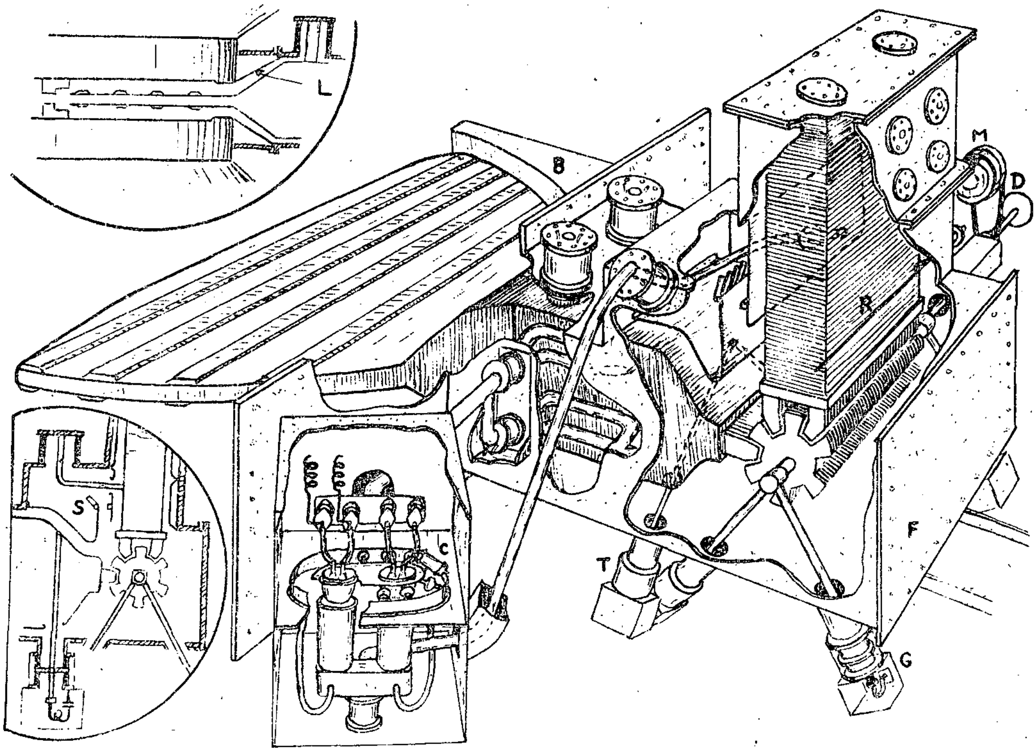

FIG. 2

MU 661

B- ground shield to reduce volume available for electron oscillation; C- vacuum condenser from filament to ground to reduce phase shift; D- disk containing small magnetic bars which generate the turn on signal; F- faceplate for removal of rotor; G- insulator, inductance and capacitor at end of rotor support; L- copper liner; M- motor; R- bias rod; S- vacuum switch; T- insulator, inductance and capacitor at end of tie rod.

FIG. 3

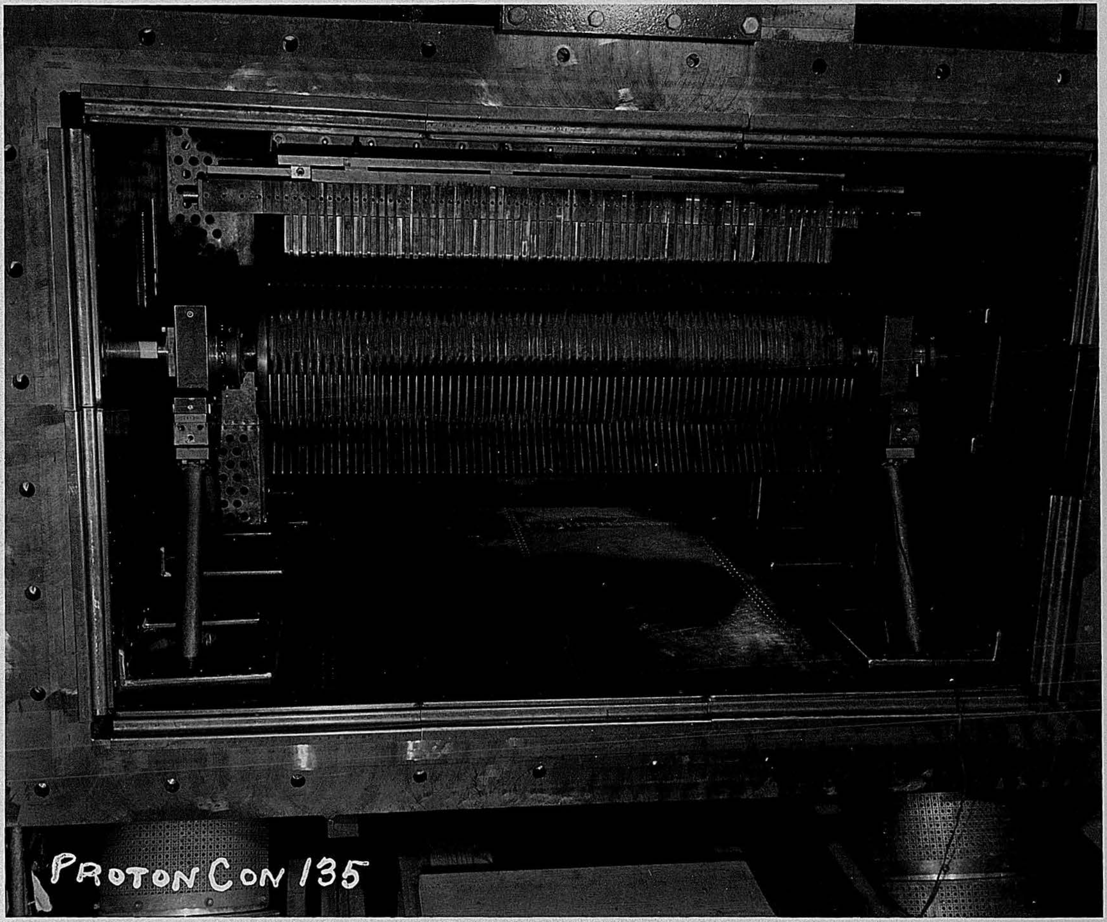

FIG. 4

VIEW OF ROTOR AS SEEN WHEN FACEPLATE F (SHOWN IN FIG. 2) IS REMOVED.

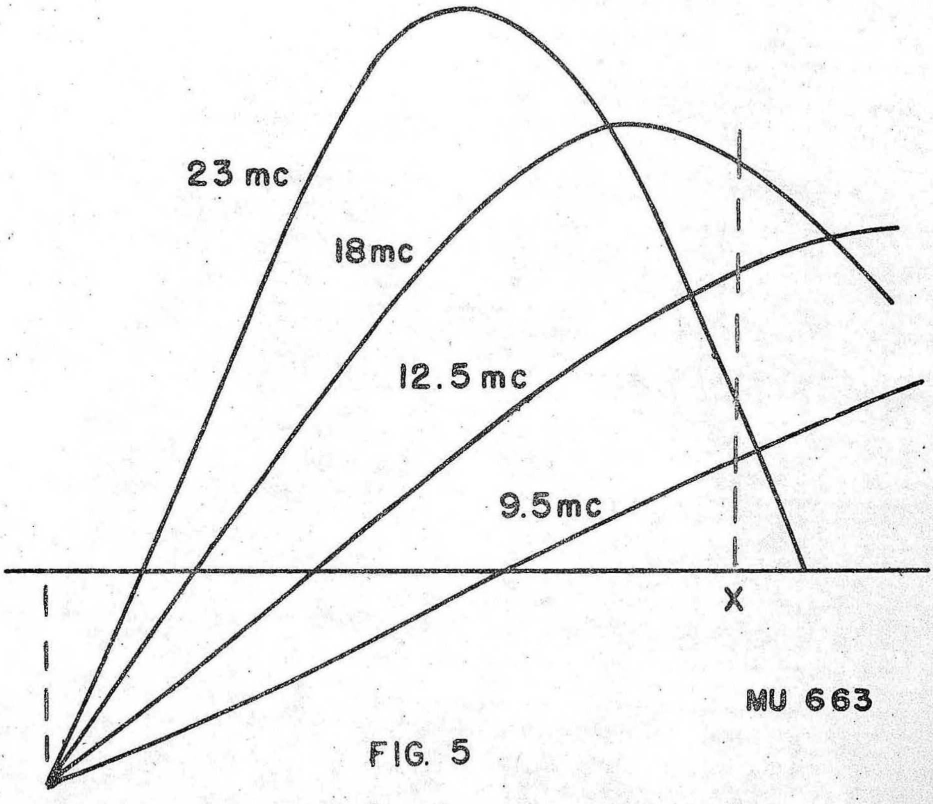

FIG. 5

The graph assumes constant r-f voltage at the plate of the tube (at the left). The line voltage at the tap on the stub line is shown at X.

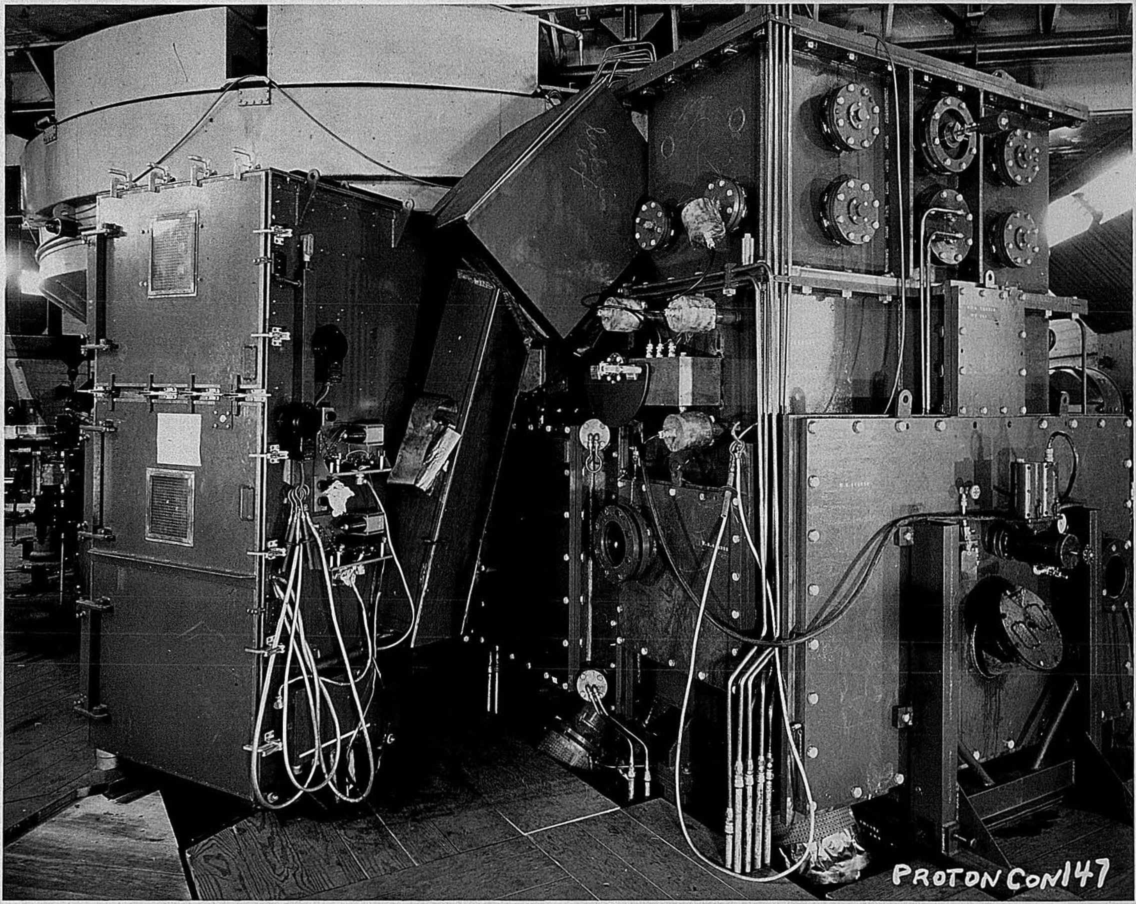

FIG. 6