

**CONSIDERATIONS IN THE
DESIGN OF ELECTROSTATIC
ACCELERATOR COLUMNS**

By

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requirements for the degree of

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Abstract

Several generations of acceleration columns have been tested for use in the electrostatic electron accelerator at Houghton College. Early designs allowed charge to build up in the column causing the beam to be deflected. The previous design, which used a series of alternating of plastic and aluminum rings held together and sealed with vacuum epoxy, was too fragile and was prone to leak when evacuated. A new design eliminates many of these problems. An alternating series of 50.8 mm OD high-density polyethylene and stainless steel rings are compressed by six pre-stretched, 1/4-inch threaded nylon rods. Glands machined into the plastic rings hold Viton o-rings that provide a good vacuum seal. The high voltage is supplied by a Van de Graaff generator mounted in-line with the accelerator column and electron gun. The entire assembly is supported by an insulating acrylic base, with rigid but adjustable joints.

Thesis Supervisor: Dr. Mark Yuly

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Chapter 1

INTRODUCTION

Particle accelerators have been used for years to investigate the atom and the forces within. The electrostatic accelerator is a low cost design for researchers desiring to construct a particle accelerator able to provide particles with enough energy to probe the nucleus. Houghton College is in the process of completing an electrostatic accelerator that has been under construction for a number of years by students.

1.1 Description of an Electrostatic Accelerator

An electrostatic accelerator uses electric forces to accelerate charged particles. Energy is given to the particle through coulomb interaction with the high voltage terminal, which is held at a large electric potential. The particle is introduced into the electric field generated by the high voltage terminal via an ion source. Coulomb's law, $\vec{F} = \frac{kq_1q_2}{r^2}\vec{r}$ where k is the Coulomb Force Constant, and r is the

distance between the two charges q , states that the force a charged particle experiences is dependent on the distance between the charges and the magnitude of each charge. Therefore, as the charge of the high voltage terminal increases, more force is exerted causing more energy to be given to the charged particle.

1.2 History and Motivation

1.2.1 History of Particle Accelerators

Particle accelerators have long been a major tool for physics research into the structure of the nucleus. Since Rutherford first investigated the disintegration of the nitrogen nucleus when impacted with alpha particles from radium [1], it was obvious that there was a need for further investigation. While using naturally radioactive elements as sources for high-energy physics did provide alpha and beta particles, electrostatic accelerators were able to provide high-energy electrons at a much higher current [2]. Alpha particles from radium were the highest energy particles known with energy of 8

MeV, but the usefulness of an apparatus that could be used to generate higher and varied energy particles at higher currents would allow for more precise measurements of the nucleus.

Figure 1 shows how the maximum energy of particle accelerators has increased over time as improvements are made and new types are developed. As higher energies were developed, more was learned about the dimensions and makeup of the nucleus.

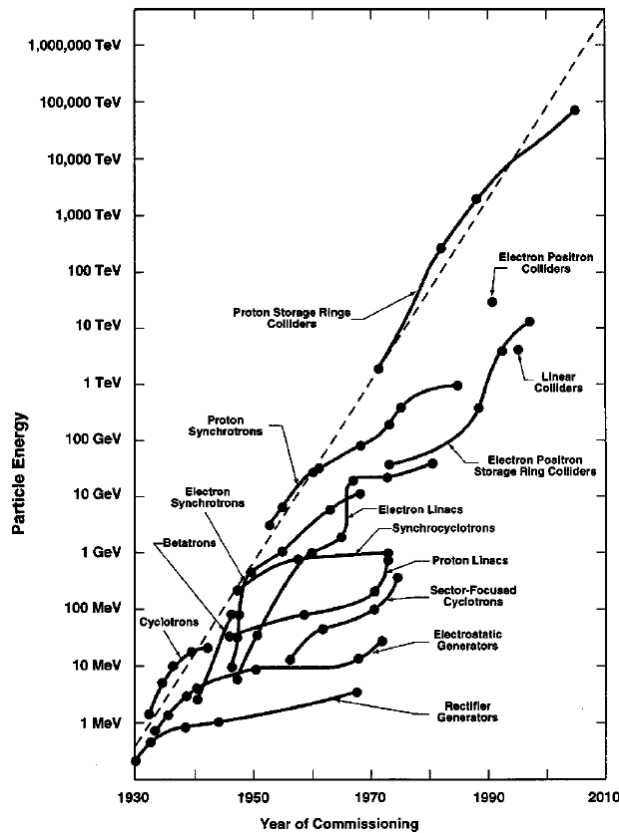


Figure 1. A graph of various accelerator maximum energies versus the years of their use.
Figure taken from Ref. [3].

Electrostatic accelerators use a highly charged terminal to accelerate charged particles. To achieve the high potential needed, the same forces that allowed for the accelerating of charged particles needed to be overcome. Researchers needed to develop a method of generating large stable potentials. An early design by Lord Kelvin used drops of water through a nozzle to slowly acquire

large potentials [3]. The drops became charged by friction in passing through the nozzle and fell into a metal pool causing a buildup of charge and therefore a high potential. Another design by Vollrath in 1932 used a powder as the charge carrier [4]. The powder, when blown through an injector, became charged by friction and traveled through a glass pipe into a spherical conductive terminal. The powder transferred its charge to the terminal through copper tubes electrically connected to the terminal. Potentials of a million volts and currents of up to one milliamp were reported [4].

Three major methods have been used to supply the high voltages to electrostatic accelerators: the Tesla coil, the voltage multiplier circuit, and the Van de Graaff generator. A Tesla coil uses multiple resonant circuits to cause a large pulsing potential. During research with Tesla coils at the Carnegie Institution of Washington in 1930 [5], the breakdown potential for glass accelerator tubes was discovered to be approximately 300,000 V. At this potential, arcing causes punctures in the tube or caused the tube to become conductive, discharging the high voltage terminal. While leading to advances in accelerating tube design [5], the pulsing potential of the Tesla coil caused it not to be used in favor of the Van de Graaff generator. The potential of a Tesla coil oscillates at high frequency and if used to power the high voltage terminal of an electrostatic accelerator, it would result in a pulsed accelerated beam.

The voltage multiplier uses a multiple capacitor circuit, charging them in parallel with an AC voltage and discharging them in series with the result of a high potential DC voltage. The system was used by J.D. Cockroft and E.T.S. Walton to achieve the first nuclear disintegration with artificially accelerated 400 keV protons and lithium in 1932 [6].

Van de Graaff generators have proved to be the most useful way to generate large potentials, as they are the most stable and safest for use with an accelerator tube. After a number of small-scale successes, Van de Graaff, K.T. Compton, and L.C. Van Atta built two large generators in 1933 [7]. The two generators had spherical terminals 15 feet in diameter with a supporting column 22 feet long and 6 feet in diameter. The generators used two insulating belts each, to carry charge from the bases into the terminals above. Figure 2 shows the charging system for each generator, one achieving a potential of positive 2.4 megavolts and the other, negative 2.7 megavolts [8]. When an

accelerator tube was placed between them, a total potential gradient of 5.1 MV was used for acceleration.

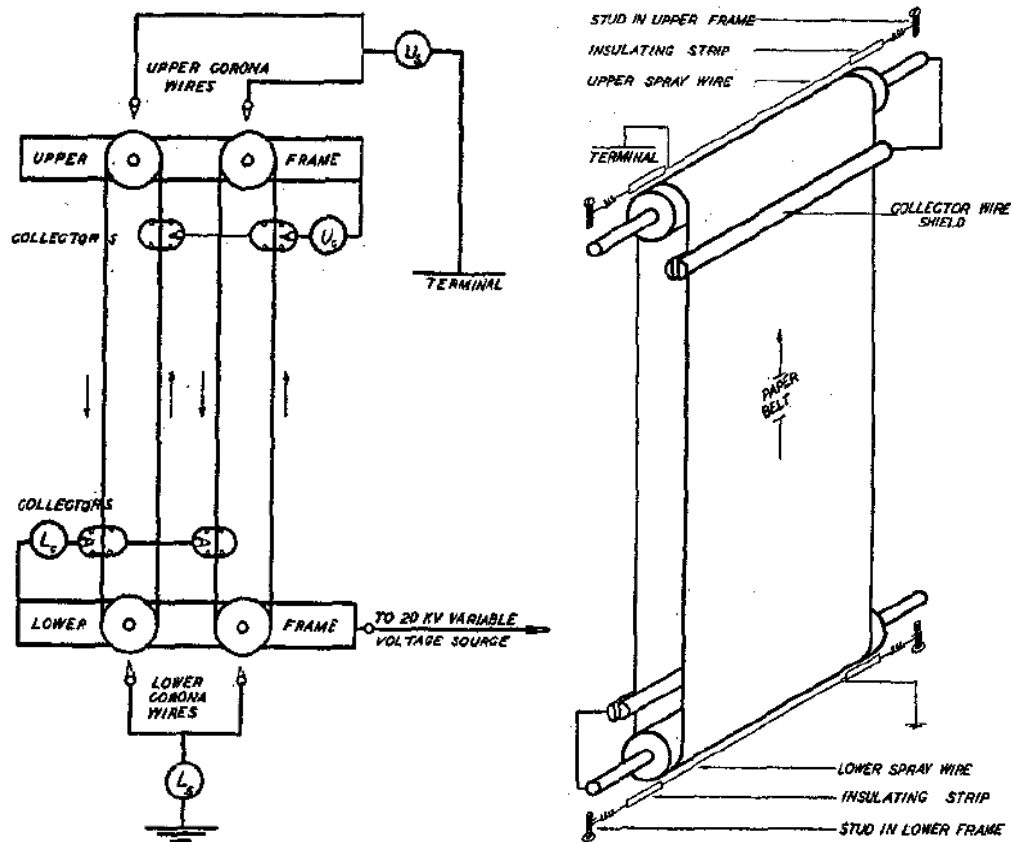


Figure 2. Two drawings of the belt charging system used by de Graaff, K.T. Compton, and L.C. Van Atta in their two large generators at Round Hill. These generators use a two-way charging system. Charge is sprayed on at the bottom, brought to the top by the belt, and collected for conduction to the terminal. Opposite charges are then sprayed onto the descending belt and collected below, effectively doubling the charging current. Figure taken from Ref. [8].

Van de Graaff generators provided a simple and cheap method of supplying the large potentials used by electrostatic accelerators to accelerate charged particles. Van de Graaff accelerators can be made using common scrap. F.B. Lee writes of an electrostatic accelerator using a Van de Graaff generator that he built using scrap and salvage parts in 1959 [9]. The simplicity of the electrostatic accelerator makes it a favorite among amateur scientists.

Van de Graaff accelerators originated as Van de Graaff generators with glass accelerating tubes. To increase the maximum potential and the stability of the potential on the high voltage terminals, researchers added more electrodes to lower the potential gradient. As advancements made it possible to generate very large potentials, air at standard pressure was too conductive and Van de Graaff accelerators had to be encased in pressure tanks allowing compressed air, which is a better insulator, to be used to insulate to ground. After further increases in energy, compressed air was replaced with gasses that are even better insulators such as SF_6 . Van de Graaff generators are often used as ion injectors in very large accelerators, as well as being able to accelerate particles to an energy of 25.5 MeV by themselves.

1.2.2 History of the Houghton College Electrostatic Accelerator

The Houghton College electrostatic accelerator is a student project that has been under construction for years. It was built to carry out low energy electron scattering experiments as well as provide a source of x-rays and in the future, a neutron beam. The initial design originated at Eastern Nazarene University under Professor Mark Yuly. It used a glass accelerator tube and electrodes formed from copper wire. The spherical high voltage terminal was supplied with high voltage from a Van de Graaff generator that was in contact with the high voltage terminal. The next design improved on the previous by increasing the number of electrodes on the accelerator tube formed by alternating high-density polyethylene and aluminum rings glued together with epoxy. The electron gun was taken from a cathode ray tube and modified for use. The accelerator tube proved to be too fragile and a more durable and easily repaired design was then explored. By using o-rings between the conductive and nonconductive rings that are compressed together, the accelerator tube is able to maintain a vacuum after handling. The electron gun initially had no control for intensity, focus, and aiming, and after five different electron guns were constructed, the current gun provides all these capabilities.

1.3 Original Concepts

A few conditions must be met in any design of an electrostatic accelerator. The setup must be capable of maintaining a vacuum of the order of 10^{-6} torr and the high voltage terminal must be

held at a constant potential, which determines the final energy of the accelerated ion. Many electrostatic accelerators use the basic design shown in Figure 3.

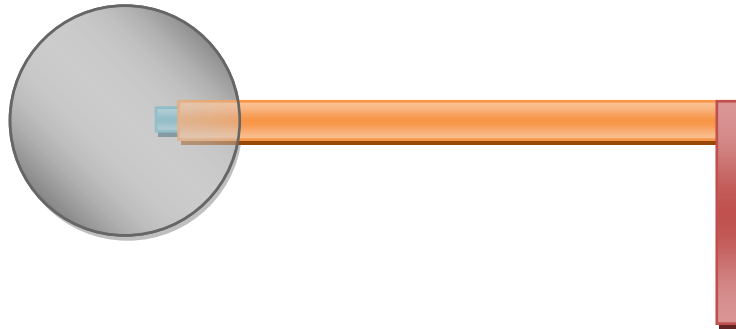


Figure 3. Simple Representation of an Electrostatic Accelerator. The grey circle is the high voltage terminal. An ion source or electron gun located within the high voltage terminal provides the charged particles for acceleration. The orange tube is the accelerator column that provides an evacuated path for the accelerated particle. The red tube connects to the vacuum pump.

1.3.1 *Voltage Terminal*

Many researchers have used Van de Graaff generators to supply high voltage [10]. Van de Graaff generators provide a steady potential while allowing the potential to be adjusted by altering the belt speed, charge density of the belt, or by placing a grounded electrode at various distances from the terminal such as Barshcall [11]. This in turn allows the operator of the accelerator to change the energy of the accelerated particles.

A Van de Graaff generator uses a belt to carry charge up an insulating support column to a conductive terminal. The belt is rotated over two pulleys, one in the high voltage terminal and the other located within the base. The problem that the Van de Graaff solves is how to move an electron towards a highly charged negative terminal to increase its negative charge. In a Van de Graaff generator, this is done by causing an electron to stick to an insulating belt. As the belt is turned on the pulleys by an electric motor located in the base, the electron is brought within the high voltage terminal and extracted onto the conductive terminal.

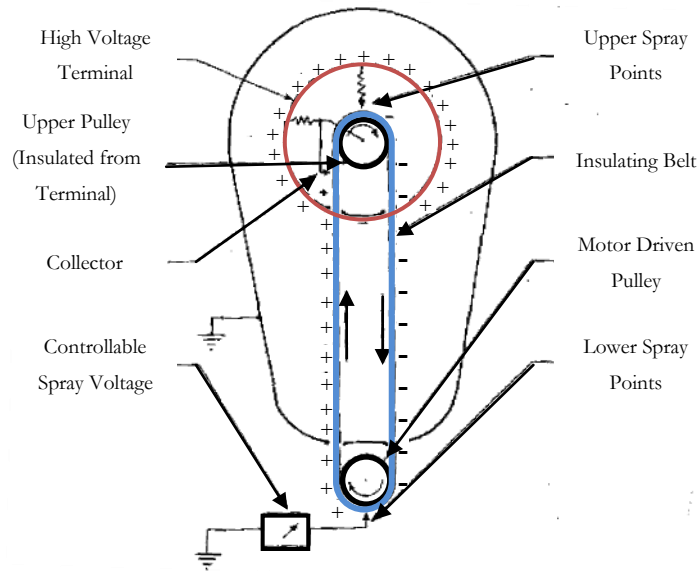


Figure 4. Simple schematic of a Van de Graaff generator. The pulleys are shown in black with the rotation direction. The terminal is shown in red. The bottom pulley is connected to a drive motor. Charge is sprayed on the belt at the bottom and as the belt turns, the charge is brought into the terminal where it then flows to the surface.

1.3.2 *Accelerating Tube*

The accelerating tube is the component of an electrostatic accelerator through which the particle travels. It must be with able to maintain a vacuum of about 10^{-6} torr or the accelerated particles will collide with air molecules. One very crucial property of the accelerating tube is that it must be non-conductive. A conductive accelerator tube would short the high voltage terminal. The more conductive the accelerator tube, the lower the maximum potential of the high voltage terminal. The earliest electrostatic accelerator designs used a glass tube [9]. Glass is an insulator up to 300,000 V [7] and can be formed into tube. Glass does not absorb water and does not outgas much, making it capable of maintaining the required vacuum.

When a high potential is reached and a glass accelerator tube is being used, the glass does not allow enough current to flow down the tube [10]. This causes the terminal potential to grow until the air around the terminal discharges by arcing to ground. This requires the potential must be built back

up, which takes some time and results in a pulsed beam. The glass can also be cracked by the arcing electricity, causing the tube to implode.

To account for this flaw in what is called the two-electrode design (the two being the high voltage terminal and ground); more electrodes are introduced at equally spaced intervals along the tube as shown in Figure 5. The tube then acts as a voltage divider, with each electrode having a lower potential than the electrode before it. The high voltage terminal is charged up, and through corona discharge, each electrode along the accelerating tube becomes charged. This allows the potential difference between any two sequential electrodes to be less than a two-electrode system and the arcing between electrodes is eliminated. The electrodes are commonly constructed from a metal and the insulating sections between the electrodes are glass.

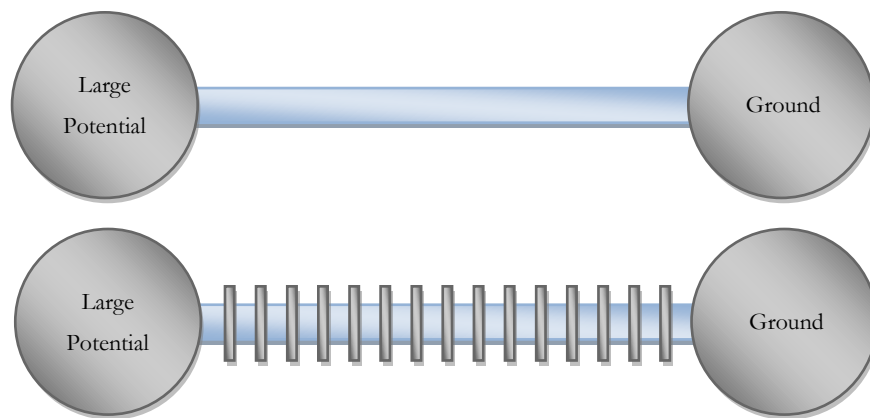


Figure 5. Drawing of two accelerator tube designs. The top design is the two-electrode design. The only electrodes are the high voltage terminal and ground. The bottom design introduces 15 electrodes evenly spaced along the accelerator tube between the two previous electrodes.

Chapter 2

THEORY

An electrostatic accelerator has three major components, the high voltage terminal, the ion source, and the accelerator tube. In this chapter, the mechanics of each component will be discussed.

2.1 High Voltage Terminal

The high voltage terminal maintains a high steady potential by using a Van de Graaff generator. The early designs of the high voltage terminal used a spherical terminal in contact with the spherical terminal of the Van de Graaff generator. A Van de Graaff generator has three components: a belt, an insulating column, and a conductive terminal. A Van de Graaff generator can be altered to be negative or positively charged and since electrons are being accelerated at Houghton College, the generator is negative. To achieve such a high negative potential, electrons must be placed on the terminal by transporting them on the belt. The belt is usually made from silk or rubber. The belt is rotated on two pulleys, one at the bottom of the insulating column in the base and the other within the terminal. The electrons are stuck to the belt and then removed onto the terminal causing a buildup of negative charge on the terminal where the charge evenly spreads out over the surface.

To make the transfer of electrons to and from the insulating belt, Van de Graaff generators make use of combs or spray points. Some Van de Graaff generators use a rubber belt and felt covered motor driven pulley located within the base to start the charging process. As the rubber rubs the felt, the felt becomes positively charged. The lower spray point is connected to ground and electrons are attracted to the positive felt. Other designs use a lower spray point connected to a power supply applying a negative potential and lower pulleys that have a positive potential. The electrons leave the spray point and stick to the insulating belt that carries them to the terminal where they are extracted by a comb. Since the electrons are removed from the belt inside the terminal, they are not affected by the potential on the terminal.

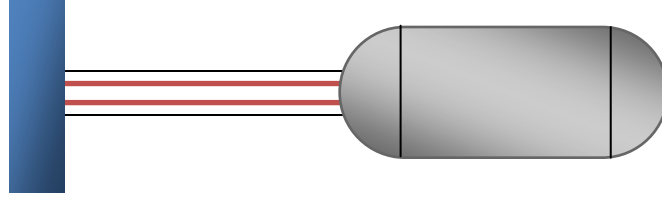


Figure 6. Side view of a Van de Graaff generator. Charge is carried from the base (blue) by the belt (red) into the high voltage terminal (grey) which is supported by an insulating column.

When the current flowing in and the current flowing out of the high voltage terminal reaches equilibrium, the maximum potential of the Van de Graaff generator is achieved. The terminal acts as a capacitor with the other electrode being ground and air acts as an insulator. In the case of an electrostatic accelerator, the grounded electrode is located at the opposite end of the accelerator tube. For simplicity, the terminal can be treated like a sphere, which has a capacitance of

$$C = 4\pi\epsilon_0 r \quad (1)$$

where r is the radius of the spherical electrode and ϵ_0 is the permittivity of free space. The terminal potential (V) is given by

$$V = \frac{Q}{C} \quad (2)$$

where Q is the stored charge and C the capacitance of the terminal to ground. By differentiating Equation 2 with respect to time, the change in potential is given by

$$\frac{dV}{dt} = \frac{1}{C} \frac{dQ}{dt} = \frac{I}{C} \quad (3)$$

where I is the total current flow into the terminal. The current into the terminal depends on belt speed and charge density on the belt, but the current flowing out of the terminal depends on the resistance between the terminal and ground. Therefore, to increase the maximum potential of the terminal, the charge density on the belt, the belt speed, or the resistance to ground must be

increased. Many researchers increase resistance to ground by surrounding the terminal in an insulating gas such as compressed nitrogen or SF₆.

The electric field for a sphere is given by

$$\vec{E} = \frac{Q}{4\pi\epsilon_0 r^2} \vec{r} \quad (4)$$

where r is the distance from the center of the sphere, for any r (radius) greater than the radius of the sphere. By using Equation 1 and Equation 4 to substitute for C and Q in Equation 2, the potential

$$V = Er \quad (5)$$

is found allowing the calculation of the maximum potential for a spherical terminal of radius r in a dielectric capable of supporting an electric field E . Since the maximum potential gradient that air is able to withstand without breakdown is approximately 30,000 V/cm [12], the maximum voltage of the High Voltage Terminal is 30,000 multiplied by the radius of the spherical high voltage terminal in cm. The reason for the spherical approximation is that a sphere provides the consistent electric field at the surface of the conductor. As shown in Figure 7, the charge builds up and causes a stronger electric field at points with smaller radii of curvature. This stronger electric field causes the potential of the high voltage terminal to decrease, because air can no longer insulate it and current leaks through corona discharge. Most Van de Graaff generators are found to operate at about 50% of their maximum potential due to environmental conditions such as humidity.

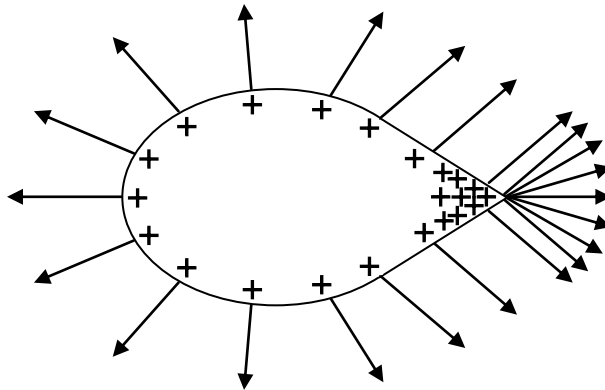


Figure 7. The charge distribution along the surface of a conductor and resulting electric field lines. The electric field lines are perpendicular to the surface of the conductor at the surface. Notice that there is more charge located near the sharp edge and therefore a stronger electric field shown by the higher concentration of field lines.

2.2 Electron Gun

The electron gun provides the electrons for acceleration. Since it is located within the high voltage terminal, it is not affected by the high voltage on the terminal. A simplified drawing is shown in Figure 8. First, a filament is supplied with a low voltage AC causing it to heat up. This in turn causes a cathode, held at about -1000V relative to the potential of the high voltage terminal, to be heated, stimulating thermionic emission. The electrons released initially have an energy of approximately 0.2-0.3 eV with the energy dependent on the temperature of the cathode. The electrons then encounter with the control grid that is slightly negative with respect to the cathode potential. By altering the potential difference between the cathode and the control grid, the intensity of the beam may be adjusted. The control grid is more negative than the cathode and therefore the electrons are repelled by it. The control grid is shaped like a cup with a small hole in the bottom. Only electrons with enough energy to overcome the repulsion pass through and are then attracted to the accelerating grid. The cylindrical accelerating grid is held at 0 V and the electrons pass through, exiting with an energy of 1,000-2,000 V depending on the cathode voltage. To apply focusing control, a grid is added between the two halves of the accelerating grid. By adjusting the potential to be slightly negative on the focusing grid, the beam can be focused on to the phosphorescent screen.

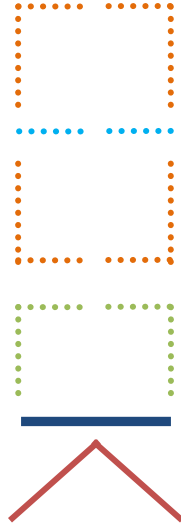


Figure 8. Simplified drawing of the electron gun. The filament (red) heats the cathode (dark blue) causing electrons to be emitted. The electrons are repelled by the control grid (green) and only those with enough initial energy pass through the pinhole in the control grid. Electrons are then attracted to the accelerating grids (orange). The potential of the focusing grid (light blue) is adjusted slightly higher or lower than the accelerating grid.

2.3 Accelerator Tube

The accelerator tube provides a uniform electric field along the direction of acceleration from the voltage terminal to the target that is at ground. At high voltage a tube made of an insulator, would provide no protection from arcing between the terminal and ground as discussed previously. Current flows down the accelerating tube from the high voltage terminal by corona discharge with air acting as a resistor. Once the potential difference between the high voltage terminal and ground is sufficiently large, the system will arc and the arc could damage the tube. This is known as a two-electrode system, the two electrodes being the terminal and ground. By adding more electrodes, the accelerator tube acts as a voltage divider. Instead of the potential decreasing from the potential of the high voltage terminal to ground through the length of the accelerator tube, adding electrodes allows the potential to decrease in smaller steps and over shorter lengths. This allows the potential difference between two consecutive electrodes to be greatly decreased and therefore decreases the possibility of arcing. The addition of electrodes also causes the electric field within the tube to be collimated and provide acceleration in only one direction. The electric field is given by $\vec{E} = -\vec{\nabla}V$ where V is the potential. If the electrodes are closer together, then the field within the accelerator

tube is directed in more of a straight line from one electrode to the next than if the electrodes were farther apart. This allows the accelerated particles to only experience forces in a single direction, toward the phosphorescent screen.

The accelerator tube has 49 electrodes including the terminal and ground. The estimated maximum potential of the high voltage terminal is 250,000 V making the potential difference between any two consecutive electrodes to be approximately 5,000 V. The length of the insulating sections is 0.6 cm and the maximum electric field that air is able to support is approximately 30,000 V/cm. Therefore the maximum voltage air is capable of supporting between two consecutive electrodes is 18,000 V, well over the actual potential difference.

Chapter 3

PAST DESIGNS

In this chapter, a description of past designs and problems associated with those designs will be discussed. The original design used an accelerator tube made from glass and wire. The next designs accelerator tube used a series of aluminum and high density polyethylene rings epoxied together. The epoxy caused trouble with durability and a design using a compressed assembly of steel washers and Teflon was then built. The electron gun went through revisions as well. Initially the electron had only intensity controls, but the need for focus, aiming, and some initial acceleration was realized.

3.1 Initial Considerations

The initial design, shown in Figure 9, used a Van de Graaff generator, a glass tube, and rings of copper wire wrapped around the tube formed the additional electrodes between the high voltage terminal and ground and decreased the potential gradient. The design is very similar to the design of Lee [9]. He used a Van de Graaff generator to supply a spherical high voltage terminal, which accelerated electrons through a 2-inch diameter Pyrex tube 3 feet long. The equipotential rings consisted of copper wire wrapped around the tube and spaced at 3-inch intervals.

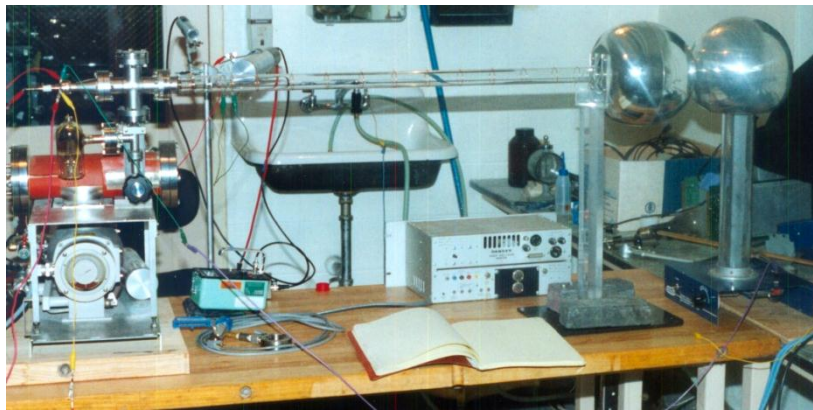


Figure 9. Photograph of the first design. The Van de Graaff generator (right) provides the high voltage to the high voltage terminal (sphere). A single glass tube with copper wire rings for the electrodes forms the accelerating tube. The filament is located within the high voltage terminal. The vacuum pump is shown in the lower left.

3.1.1 *Van de Graaff Generator*

The Van de Graaff generator used to supply the negative high voltage was a Winsco N-100V. The high voltage terminal has a diameter of 25 cm and the entire generator has a height of 76 cm. The maximum potential the generator can achieve is 375,000V calculated using Equation 5, but due to current leaks and humidity, it was believed to be operating at 50 % of the maximum. Since the high voltage terminal is not a perfect sphere, the calculated maximum potential is a high approximation. Air composition also affects the maximum electric field that air can insulate. Changes in humidity will change the maximum electric field of air and change the maximum potential of the Van de Graaff generator. The capacitance of the generator was calculated to be 14.5 pF resulting in a charge of 5.92 μC with a charging (belt) current of 8 μA [13]. The current was measured by an ammeter connected to the faraday cup.

3.1.2 *Accelerating Tube*

A 99.4 cm glass tube that extended from inside the high voltage terminal to a flange connecting it to the vacuum system formed the accelerating tube. The assembly was supported on an acrylic base. Thirteen copper rings were formed using uninsulated copper wire spaced at approximately 10 cm intervals.

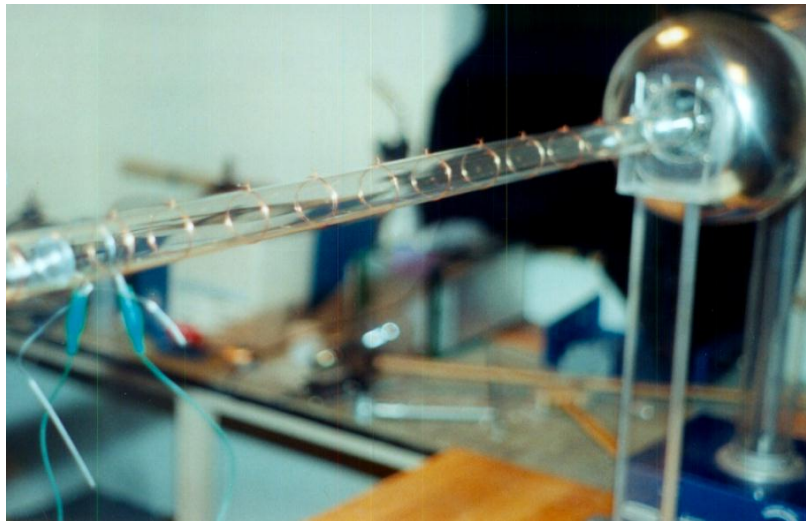


Figure 10. Photograph of the glass tube that forms the accelerating tube with copper wire for the electrodes. The Faraday Cup is on the left side of the tube. The electrons are accelerated from right to left.

3.1.3 Electron Gun and Faraday Cup

The electron gun was constructed by taking a RCA 3RP1 cathode ray tube and the phosphorus screen as well as the deflection plates. Figure 11 shows the circuit that provides the potentials for each component. The cathode is connected to the high voltage terminal as well as one side of filament with the other side connected to a battery. The control grid is also connected to the battery, keeping the potential slightly larger than the potential of the cathode. As the electrons are released from the cathode, they must overcome the attractive force of the control grid to pass into the accelerator tube. The intensity is controlled by altering the voltage between the cathode and the control grid.

To test the electron gun, the high voltage terminal was connected to a power supply set at -4000 V. The cathode was then connected to the terminal and the accelerating grid was connected to a battery that was connected to the terminal. The current of electrons emitted from the cathode was measured to be 1-2 μA . An aluminum cylinder filled with a scintillating material formed the faraday cup.

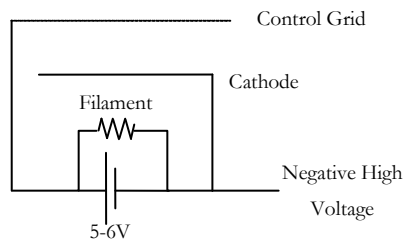


Figure 11. Schematic of the circuit for the electron gun for the initial design. The filament heats the cathode stimulating the emission of electrons. The control grid is at a slightly higher potential than the cathode and only electrons with enough initial energy continue into the accelerator tube.

3.1.4 Results

With the electron gun placed within the high voltage terminal and the faraday cup placed 90cm from the cathode, a beam current of 4-6 μA was measured. Using a Bicron BC400 plastic scintillator and an Amtek 8000A 512-channel multichannel analyzer (MCA), the bremsstrahlung x-ray spectrum was measured and are shown in Figure 12. The maximum energy is between 300 and 400 keV. Due to

the gain of the amplifier, the resolution of the 300-400 keV was not high enough to provide an accurate measurement of the actual energy of the beam. In addition, the sparking at the cathode caused the beam to have a range of energies causing the spectra to not have well defined end points.

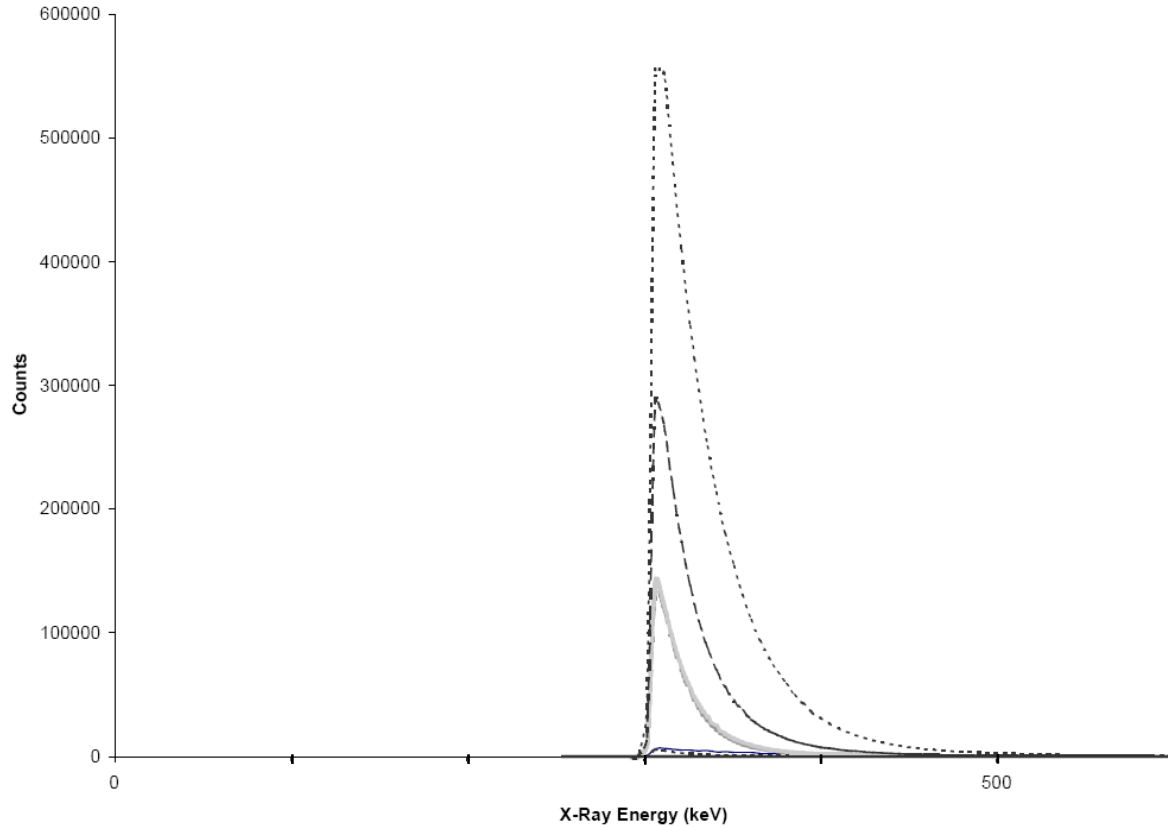


Figure 12. Bremsstrahlung x-ray spectra measured using the first tube. Energy spectra at 25° (thick), 43° (dark thick), 66° (top dashed), 86° (bottom dashed), 111° (dotted) and background (solid) for 100 seconds collection period, displaying the relative intensities of the bremsstrahlung x-rays at each position. The 25° and 43° energy spectra overlap. Figure taken from Ref. [13].

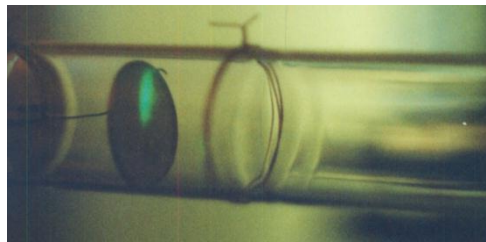


Figure 13. Photograph of the beam spot on the phosphorescent screen. The electrons are accelerated from the right. A copper equipotential ring is shown.

As electrons traveled down the tube, stray electrons would stick to the glass wall of the tube. The buildup of charge deflected the beam until it discharged, causing a drifting electron beam. The beam would start centered on the screen and as the charge built up on the wall, the beam spot would be deflected increasing as the charge on the accelerator tube wall increased. Once it discharged, the beam spot would return to center and repeat the process. Due to the location of the electron gun, there was sparking at the cathode. It was determined that the electron gun was not far enough into the voltage terminal. The inside of the terminal is an electric field free region since there is no electric field within a conductor. Since the electron gun experienced sparking at the cathode, the electron gun was not in the field free region and was being affected by the high voltage. As shown in Figure 13, the beam spot was large due to the electrons sparking from the high voltage terminal to the cathode. The electron gun provided no way to focus or aim the electron beam. In addition, the potential of the control grid could not be adjusted while running the accelerator. The vacuum system was composed of a rotary forepump, liquid nitrogen cold trap, and a diffusion pump.

3.2 Second Design

The second design aimed to improve on the first design by eliminating the buildup of charge on the glass accelerator tube wall. This was done by making impossible for a stray electron to contact the insulating sections between the equipotential rings. In the previous design, copper wire rings outside the glass tube formed the equipotential rings and allowed for a smaller voltage gradient between consecutive electrodes. If the equipotential rings extended into the accelerator tube with an inner diameter smaller than the inner diameter of the insulation rings, the electrons will not be able to strike the insulation rings. Electrons striking the conductive rings are conducted to the outside of the tube and can then flow down the tube through corona discharge.

A new electron gun was also designed to provide the electrons with a small amount of acceleration. The same Winsco N-100V Van de Graaff generator was used to supply the high voltage.



Figure 14. Photograph of the second accelerator tube with the high voltage terminal attached. The accelerator tube was made of alternating aluminum and high-density polyethylene rings. The Van de Graaff generator is located on the left. The supporting base was machined from acrylic. The faraday cup is on the right. The vacuum system is located below the table. Figure taken from Ref. [14].

3.2.1 Accelerator Tube

The accelerator tube was a series of 51 alternating 5052 aluminum and 51 high-density polyethylene rings glued together using Hysol Epoxi-Patch EPK 1C [14]. The aluminum rings had an outer diameter of 10.16 cm and an inner diameter of 3.81 cm with a thickness of 0.3 cm. The plastic rings had an outer diameter of 9.14cm and an inner diameter of 5.08 cm with a thickness of 0.6 cm. There were also four 0.64 cm diameter holes at 90-degree intervals approximately centered between the inner and outer diameters of all rings. These holes were used to align the assembly with delrin rods. The epoxy was applied to the face of each ring and then allowed to cure. Once the tube was assembled, epoxy was added to the outside surface where the plastic rings contacted the aluminum rings while being careful not to form an epoxy bridge between any two sequential aluminum rings. Since the conductivity of the epoxy is different from the conductivity of the high-density polyethylene, epoxy forming an electrical connection between sequential aluminum rings would have caused an inconsistent potential gradient on the accelerator tube. As shown in Figure 15, two C9504 aluminum-bronze flanges were epoxied unto the two ends of the tube, providing a connection for

the tube to the vacuum system and for the tube to the electron gun. The flange on the high voltage side was flared to provide a smooth transition from the terminal to the tube, reducing any current leaks off the terminal and the chance of sparking.

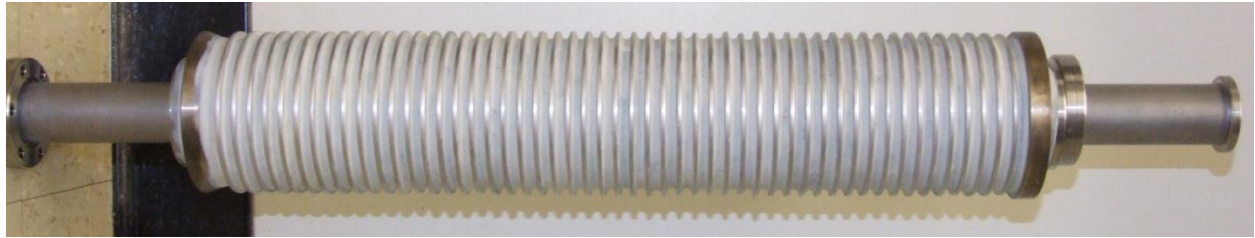


Figure 15. Photograph of the accelerator tube. The electron gun would be attached to the left and the vacuum system would be connected to the right. The brass flange on the left was flared to decrease currents leaks and sparking.

3.2.2 *Electron Gun and Target*

The electron gun was redesigned to add the capacity to supply a small amount of acceleration by way of an accelerating grid. An accelerating grid was made using $\frac{1}{2}$ -inch copper pipe and the previous electron gun from a RCA 3RP1 cathode ray tube. Figure 16 shows the finished electron gun and Figure 17 shows the bias voltages. The high voltage supplied to the electron gun 100 V and therefore the energy of the electrons was 100 eV.

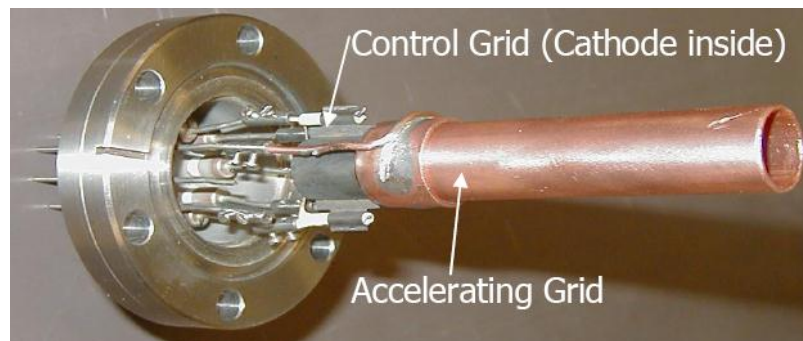


Figure 16. Photograph of the assembled electron gun. The copper tube is the accelerating grid and provides a field free region for the electrons to move from the voltage terminal into the accelerating tube while also supplying the electrons with 100 eV. The filament and cathode are located within the control grid. Figure taken from Ref. [14].

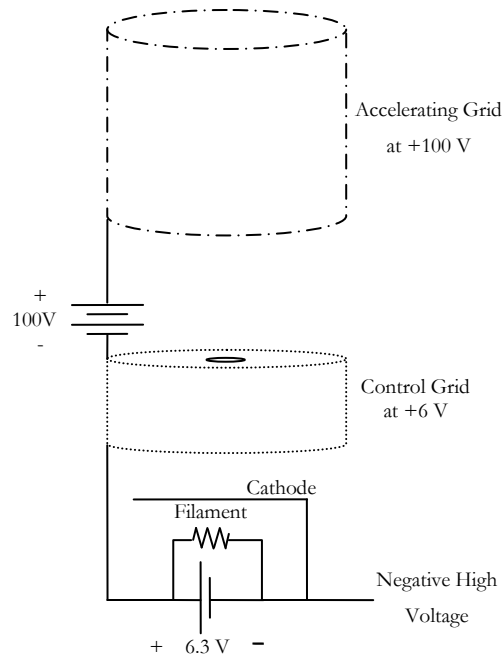


Figure 17. Circuit diagram for the new electron gun. The control grid controls intensity by providing a potential barrier that electrons having enough initial energy can overcome. Batteries located within the high voltage terminal supply the potentials.

The beam traveled down the accelerator tube, then through an insulating glass tube, and finally struck the faraday cup. The electrons were then conducted through a micro ammeter connected to ground.

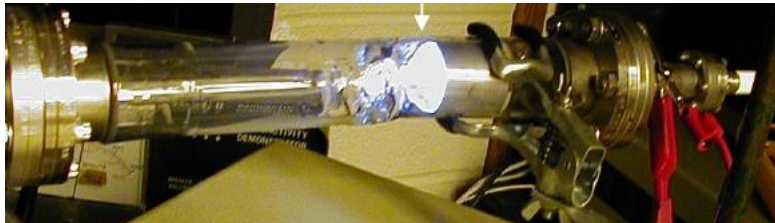


Figure 18. Photograph of the faraday cup. It is insulated from ground by a glass section of tube. The beam enters from the left and electrons hitting the faraday cup are conducted to ground through an ammeter providing a beam current measurement.

3.2.3 Results

With the Van de Graaff generator on, a beam current of approximately $0.4 \mu\text{A}$ was measured at the faraday cup. Using a NaI scintillator and a multichannel analyzer, the Bremsstrahlung spectrum was measured to determine the energy of the accelerated electrons.

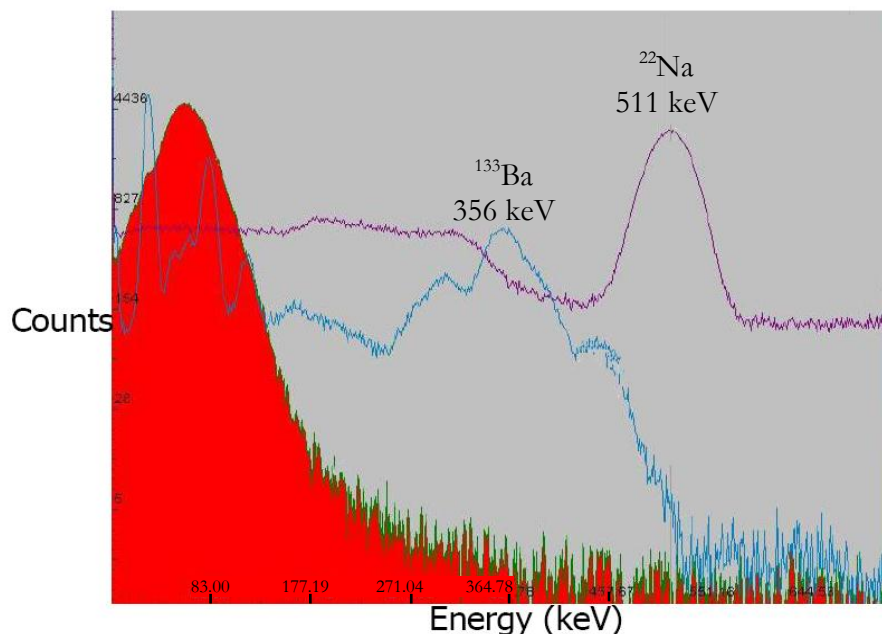


Figure 19. A plot of the bremsstrahlung x-ray energy spectra for two gamma-emitting calibration sources and for the electrostatic accelerator. A ^{22}Na source (purple) and a ^{133}Ba source (blue) were used for calibration. The spectrum for the accelerator (red) has a bremsstrahlung endpoint at about 180 keV. Figure taken from Ref. [14].

The epoxy joints initially provided a good seal capable of 10^{-5} torr, however, the tube was fragile, and any handling created leaks. The tube was leak checked and repaired with more epoxy numerous times. Any epoxy that created an electrical bridge between consecutive aluminum rings was sanded down to preserve a uniform potential gradient. After applying epoxy multiple times without being able to achieve a good vacuum, a new accelerator tube was designed.

The electron gun, while it provided intensity control and a small amount of acceleration, still had no focus or aiming control. A new electron gun was constructed by taking a RCA 3RP1 cathode ray tube and cutting it in half lengthwise. The deflection plates were removed because they did not fit in

the steel tube the electron gun was mounted to. The deflection plates contacted the interior of the steel tube.

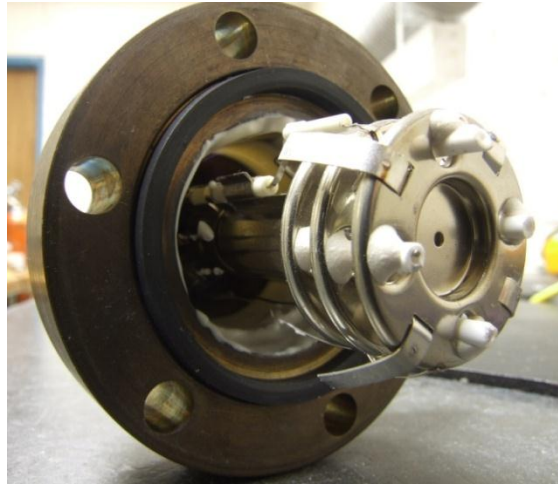


Figure 20. Electron gun taken from a RCA 3RP1 cathode ray tube. The three disks in the foreground are the accelerating grids and the middle disk is the focus grid. The glass was epoxied to a brass flange allowing it to be connected to the accelerator tube. The control grid and cathode are located behind the accelerator grids.

The gun was then mounted on the accelerating tube and sealed with a Viton o-ring. This gun provided focusing and intensity controls. The other half of the CRT, which contained the phosphorescent screen, was also mounted to a brass flange using epoxy. The glass section of insulating tube was removed and replaced with the short ceramic piece shown in Figure 21. The circuit used in testing this gun is shown in Figure 22 except pins 6, 7, 9, and 10 that control the deflecting electrodes were removed. This gun was never used with an accelerator tube. During test runs without an accelerating tube or high voltage terminal, the gun was found to be crooked. It showed the need for the deflection grids to be left on the electron gun to compensate for a cocked mounting on the brass flange.



Figure 21. Photograph of the ceramic tube insulating the phosphorescent screen from ground.

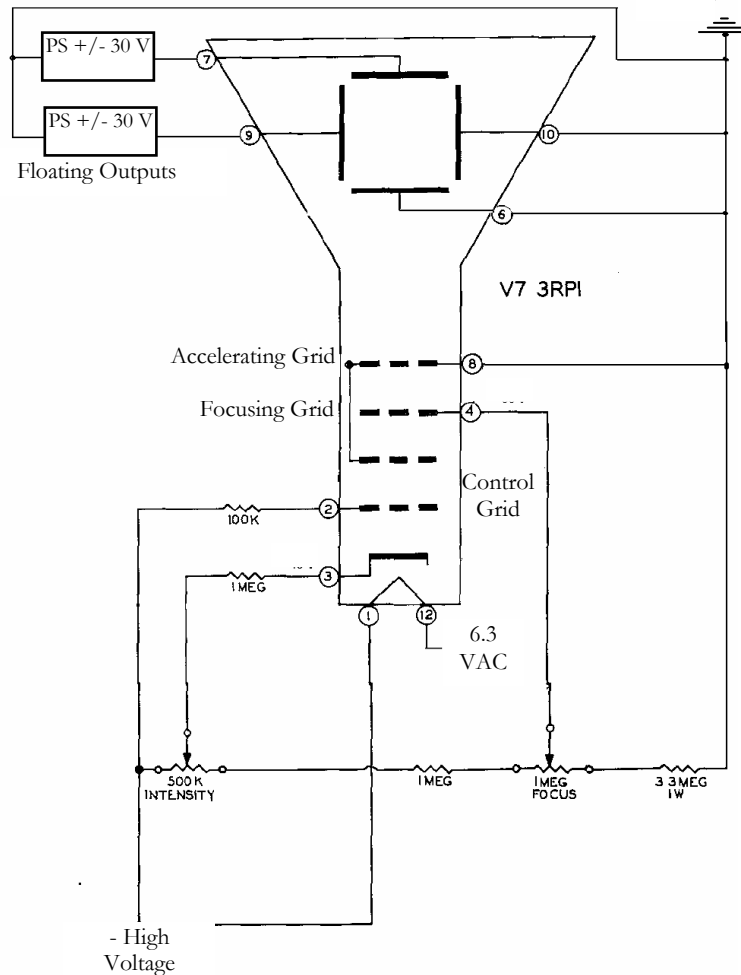


Figure 22. Schematic for biasing the 3RP1 electron gun. The filament (pin 1) heats the cathode (pin 3) causing it to release electrons. The electrons must overcome the more negative potential of the control grid (pin 2) and then are accelerated by the accelerating grid (pin 8). The beam may be focused by adjusting the potential of the focusing grid (pin 4). The beam can be deflected in two directions by the deflection grids, which operate in pairs (pin 6&7 and pin 9&10).

3.3 Third Accelerator Tube

Due to leaks in the previous accelerator tube design, the third design aimed to provide an accelerator tube that maintained a vacuum seal and was reasonably durable allowing it to be handled. The goal was to incorporate all that had been learned from the previous designs to construct a working accelerator tube. The new accelerator tube was a series of Teflon washers with o-rings at the outer circumferences compressed by stainless steel washers.

3.3.1 Materials

The conductive disks were stainless steel 18-8 washers. The washers had an outer diameter of 5.08 cm, an inner diameter of 1.36 cm, and a width of 0.152 cm. Stainless steel outgases very little, making it useful in vacuum systems.

The insulating discs were Teflon washers with a 3.81 cm outer diameter, a 1.905 cm inner diameter, and a thickness of 0.236 cm. Teflon, while being a good electrical insulator, is porous, making it not capable of providing a good seal in a vacuum [15].

3.3.2 Design

To seal the Teflon washers, a Viton o-ring was placed around the circumference of the Teflon and two washers were used to compress the o-rings on both sides as shown in Figure 23.



Figure 23. Ring design of the third accelerator tube. The Teflon washers (black) were sealed by Viton o-rings (red) and compressed between two stainless steel washers (orange).

Six threaded nylon rods compressed the entire assembly of 50 washers. The accelerator tube was assembled using a 1.36 cm diameter threaded rod long enough to hold the uncompressed array of discs and o-rings. Conflat full nipples were placed at both ends to allow the tube to be connected to the vacuum system and electron gun. Nuts at both ends of the threaded rod compressed the accelerator tube, and then the six nylon rods were inserted into the holes of the Conflat flanges to hold the compression.

3.3.3 Results

The assembly was difficult to align due to the different inner and outer diameters of the washers. There was no way to make sure that the centers were aligned. When the assembly of 50 stainless steel washers was put together and compressed using steel rods, a pressure of only 10^{-2} torr was achieved. This was caused by a distortion of the o-rings under compression causing to slip out from between the steel washers. Another attempt was made using larger S.A.E. Standard steel washers, but suffered similar sealing problems due to the roughness of the washers' surface that was in contact with the o-rings.

Chapter 4

CURRENT DESIGN AND CONSTRUCTION

The current design is similar to the previous design except high-density polyethylene (HDPE) was used to make the insulating rings, and grooves were machined into the face of the HDPE rings to provide seats for o-rings. The assembly is compressed by six pre-stretched nylon rods. A new electron gun was taken from a RCA 3RP1 cathode ray tube, leaving all electrodes intact. The new electron gun has focus, intensity, and aiming control capability. A horizontally mounted Van de Graaff generator powers the high voltage terminal. A schematic drawing of the electrostatic accelerator is shown in Figure 24. The conductive discs have a smaller inner diameter than the insulating discs, making it impossible for stray electrons to stick to the walls of the accelerator tube causing a buildup of charge. The outer diameter of the conductive discs is the same as the outer diameter of the insulating discs to allow for easy alignment.

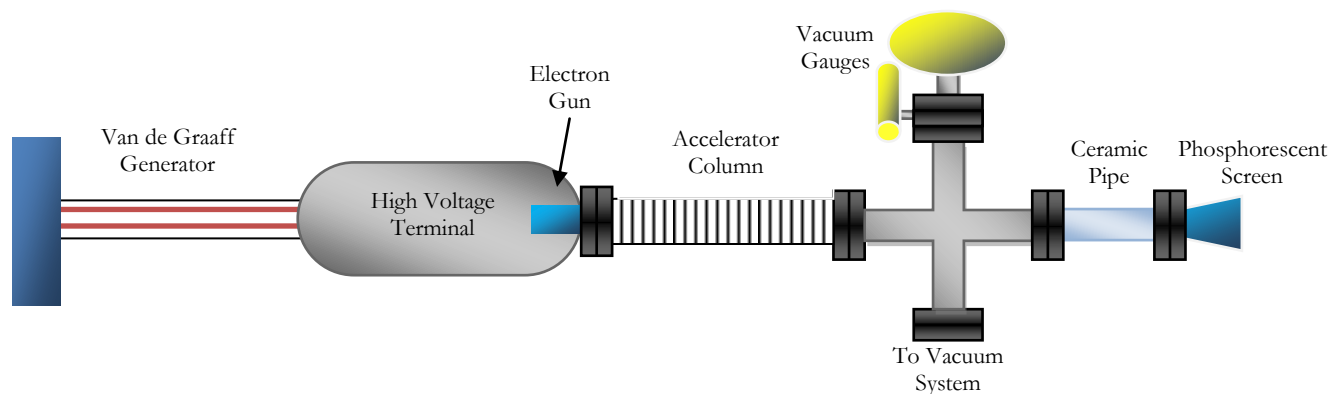


Figure 24. A schematic of the current electrostatic accelerator. The Van de Graaff generator (left) provides the high potential to the high voltage terminal. The electron gun located within the high voltage terminal releases electrons and provides focus and intensity control, while also providing a small amount of initial acceleration. The electrons are accelerated through the accelerator column. The electrons then strike the phosphorescent screen (right) which is insulated from ground with a ceramic pipe to allow for the current striking the screen to be measured. The system is maintained at a pressure of $\sim 10^{-6}$ torr by vacuum pumps (not shown).

4.1 Design

A series of alternating conductive stainless steel and nonconductive high-density polyethylene discs are arranged into a tube 5.1 cm wide and 38.9 cm long and compressed using six $\frac{1}{4}$ inch threaded nylon rods of 20 threads per inch at 60-degree intervals around the outside of the assembly. The Winsco N-100V Van de Graaff generator is mounted in line with the accelerator tube and a capsule shaped aluminum shell (Figure 6 & Figure 24) approximately 35 cm long forms the high voltage terminal. The two end hemispheres have a radius of 12.5 cm and the cylindrical center has a radius of 12.5 cm. The high voltage terminal contains the controls for the electron gun that allows aiming, intensity, and focus control of the beam. The beam is controlled through a fiber optic link between a control terminal computer and a BASIC Stamp 2 microcontroller. The target is the previously stated phosphorescent screen, made from a RCA 3RP1 insulated from ground by a ceramic section of pipe as shown in Figure 26.

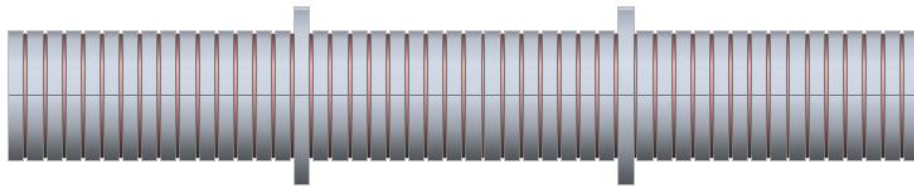


Figure 25. A drawing of the current accelerator tube. The light discs are the high-density polyethylene rings and the red discs are the stainless steel washers. The two larger plastic rings provide lateral support for the compression rods (not shown). Between all discs, are o-rings providing the seal for the vacuum.

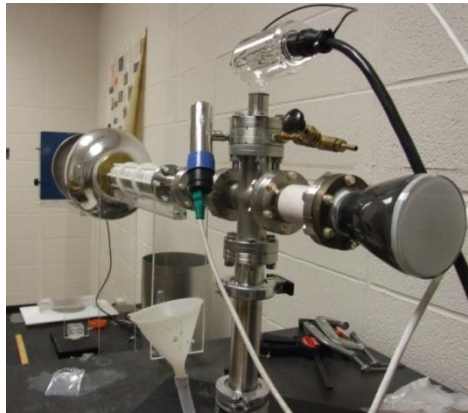


Figure 26. Photograph of the most recent design. The Van de Graaff generator is located in the back with the accelerating tube in front of it. The phosphorescent screen is in the foreground insulated from ground by the white section of ceramic pipe. The vacuum system is below the table.

4.1.1 Discs

The insulating discs are made out of high-density polyethylene and the conductive discs are made out of 18-8 stainless steel washers. All but two of the plastic rings have a 5.08 cm outer diameter and all the plastic rings have a 1.91 cm inner diameter and are 0.62 cm thick. The stainless steel washers have an outer diameter of 5.08 cm, an inner diameter of 1.27 cm, and are 0.15 cm thick. The smaller inner diameter of the conducting rings causes it to be impossible for stray electrons to come in contact with the insulating rings and cause a beam deflecting charge buildup on the accelerator tube wall as in the initial design.

To seal the assembly, the plastic rings have a 2 mm deep circular groove on each face in which a Viton o-ring is seated. The o-ring has an outer diameter of 3.33 cm, an inner diameter of 3.31 cm, and a thickness of 0.16 cm. As the accelerator tube assembly of 48 stainless steel washers and 48 HDPE rings is compressed, an o-ring seals against each side of the stainless steel washers well enough to reach a pressure on the order of 10^{-6} torr. The construction technique is discussed later.

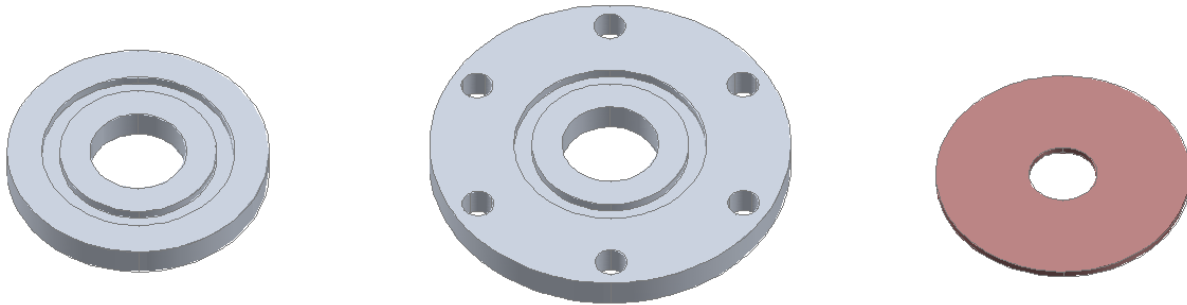


Figure 27. 3D view of the accelerator tube components, showing (from left to right) the plastic ring that serves as the insulation between the equipotential rings, the larger ring is used to prevent twisting of the nylon compression rods, and the stainless steel equipotential ring.

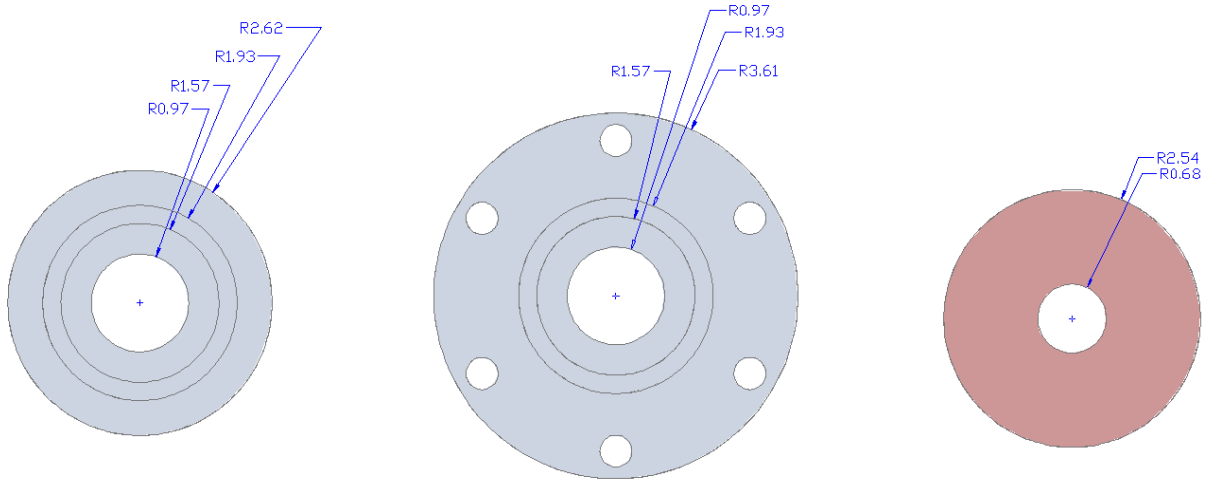


Figure 28. Top view of the accelerator tube components, showing (from left to right) the plastic ring that serves as the insulation between the equipotential rings, the larger ring is used to prevent twisting of the nylon compression rods, and the stainless steel equipotential ring. The units of all dimensions are cm.



Figure 29. Side view of the accelerator tube components, showing (from left to right) the plastic ring that serves as the insulation between the equipotential rings, the larger ring is used to prevent twisting of the nylon compression rods, and the stainless steel equipotential ring. The units of all dimensions are cm.

4.1.2 Electron Gun

The electron gun was taken from a RCA 3RP1 cathode ray tube, this time leaving all electrodes intact as opposed to previously when some were removed. The electron gun allows the focus, intensity, and deflection to be adjusted. The electron gun has a twelve-pin connector that allows the necessary electrode voltages to be applied. Pin 12 provides a connection to the filament.

The filament is supplied with 6 V causing it to heat up the cathode. The cathode (pin 3), is supplied with a potential between 0 and 2000 V to accelerate electrons. The control grid (pin 2) is also supplied with a potential between 0 and 2000 V. When the control grid is more negative than the cathode, the electrons emitted at the cathode must overcome this potential to continue to the

accelerator grid. Not all electron emitted can accomplish this and therefore the intensity of the electron beam can be controlled by adjusting the voltage between the cathode and the control grid.

The accelerating grid (pin 8) accelerates electrons to 1,000 – 2,000 eV depending on the potential supplied. The focusing grid (pin 4) is located between the two accelerating grids. To focus the beam, the potential of the focusing grid is adjusted slightly positive or negative relative to the accelerating grids. Pin 6 and 7 allow for deflection of the beam. By connecting one to ground and the other to a variable floating power supply, an electrode will attract or repel the beam allowing for aiming adjustments. Pin 9 and 10 are identical to the deflection plates connected to pins 6 and 7 but oriented perpendicular.

4.2 Construction

The techniques of construction will be discussed in this section. The control circuit for the electron gun is also discussed.

4.2.1 Accelerator Tube

The high-density polyethylene rings were cut out of sheets using a hole saw, drilled out for the inner diameters and grooved for the o-ring seats using a lathe. The rings, 48 stainless steel washers and 48 HDPE discs, were then stacked on a 1.27 cm diameter steel threaded rod through the center holes with o-rings between all rings. Nuts on each end were then used to compress the assembly until the o-rings were no longer visible. Then the six rods that would provide the compression during acceleration were inserted as shown in Figure 31. Initially the rods chosen were 0.634 diameter cm threaded nylon rods, but when inserted to keep the assembly compressed with the central rod released, after a night, the rods had stretched, no longer providing compression. The next choice for the rods was 0.634 cm acrylic rods but they are not available pre-threaded. Acrylic has the highest tensile strength, 6820-11500 psi, of any plastic. It is also nonconductive, a requirement of these rods. Acrylic while having high tensile strength is brittle, making it very difficult to thread the rods. A 1/4 - 28 die was used to cut threads in the acrylic using WD-40 as lubricant. The choice to use pre-stretched nylon rods was made and proved to work well. By stretching the threaded nylon rods by 2-3 cm, they were able to maintain the necessary compression force for a good seal. The rods were

stretched by inserting one into each of the six holes of two Conflat flanges with nuts on the ends of each nylon rod. A nut and washer was placed on the steel threaded rod used to compress the accelerator tube assembly on the opposite side of the Conflat flanges as the nuts on the nylon rods. With the accelerator tube compressed, the nylon rods were stretched by turning the nuts on the steel rod in opposite directions. Once the rods were stretched 2-3 cm, the nuts on the nylon rods were tightened to the accelerator tube. Figure 31 shows the final assembly with the two larger plastic rings that the six nylon rods run through. These larger rings provide lateral support for the rods.

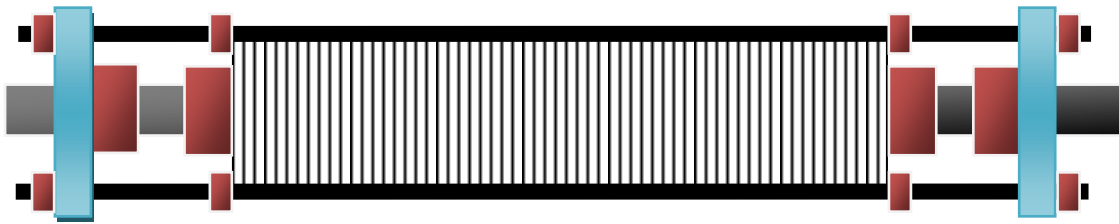


Figure 30. Drawing of the setup used to compress the accelerator tube and stretch the nylon rods. A nut was placed at each end of the nylon rods. The nuts on the steel rod were then turned in opposite directions causing the Conflat flanges to move away from each other. Once the rods were stretched 2-3 cm, nuts were tightened to the accelerator tube to keep the compression. Threaded rods are shown in black, nuts in red, Conflat flanges in teal, and the accelerator tube is in black and white stripes. Only two nylon rods are shown for simplicity.

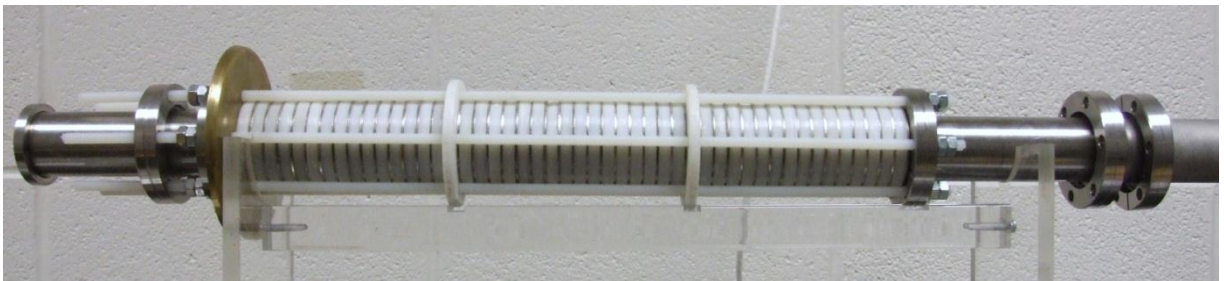


Figure 31. Photograph of the final assembled accelerator tube. The brass ring on the left provides a smooth transition from the voltage terminal to the accelerator tube. The electron gun attaches to the left and the vacuum system attaches to the right.

4.2.2 *Electron Gun and Target*

A RCA 3RP1 cathode ray tube shown in Figure 32 was used to make the electron gun and target. A hole was first drilled into the CRT at the midpoint of the side to equalize the pressure. Then it was

scored with a file at about a centimeter from the flare towards the screen and cracked along the scored line by tapping it with the file. Using vacuum epoxy, each side was then attached to brass Conflat flanges. The screen is coated with a conductive film. A wire was soldered to the brass flange and coiled along the interior wall to provide a path for accelerated electrons to leave the target so charge does not build up in the target.



Figure 32. Photograph of the RCA 3RP1 cathode ray tube from which the electron gun and target were taken.

4.2.3 *Electron Gun Control Circuit*

A method for remotely controlling the electron gun has been built. Past methods of supplying the potentials to the electron gun electrodes have been by placing a circuit within the high voltage terminal powered by batteries. The circuit was turned on and the high voltage terminal was assembled. The drawback of such a system was the inability to tune the potentials while the accelerator was operating. The new system allows for full control of the potentials from a computer terminal located outside the room where the accelerator is operated.

Inside the high voltage terminal, the potentials of the electron gun electrodes are controlled by a BASIC Stamp 2 microcontroller, powered by a 9 V battery. It has a 2-kByte memory and is capable of approximately 4000 instruction/sec. It also provides 16 input/output pins that are used to control the potentials. The microcontroller communicates with a Burr-Brown DAC7625 digital-to-analog converter through a 12-Bit data bus. The DAC has an output range of 0-2.5 V at 1.25 mA and is powered by a 5 V battery supply. The DAC connects to a transistor circuit capable of supplying the

filament with 6 V. Three other outputs of the DAC connect to transistor amplification circuits powered by a 12 V battery supply. Each amplification circuit is identical and one controls the intensity, one controls the accelerating grid, and the other controls the focus grid. To achieve a high potential on the grids, the circuit uses an EMCO G20 HVDC Converter. It has an input range of 0-12 V at 275 mA and an output range of 0-2000 V at .75 mA.

Figure 33. Schematic of the electron gun control circuit located within the high voltage terminal. The focus, accelerating, and intensity circuits are identical; only one is shown for simplicity Figure taken from Ref. [16].

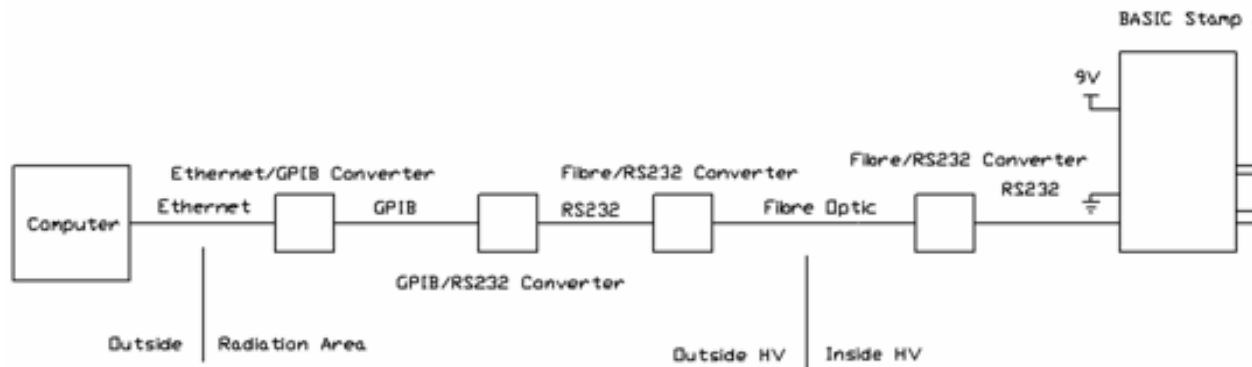


Figure 34. Schematic of the connection to the electron gun control circuit. Figure taken from Ref. [16].

4.2.3 Support Stand

The support stands for the accelerator tube and Van de Graaff generator are made out of acrylic. Both stands are mounted on the adjustable points shown in allowing for adjustments in 3 axes. The adjustemnets allow for the tube to be positioned straight, making it easier to aim the electron beam at the phosphorescent screen. The Van de Graaff gerenator supprot is shown in Figure 35. The base of the generator screws into the left side and the insulating column of the generator rests in the circular cutout on the left with the capsule shaped high voltage terminal projecting from the right side.

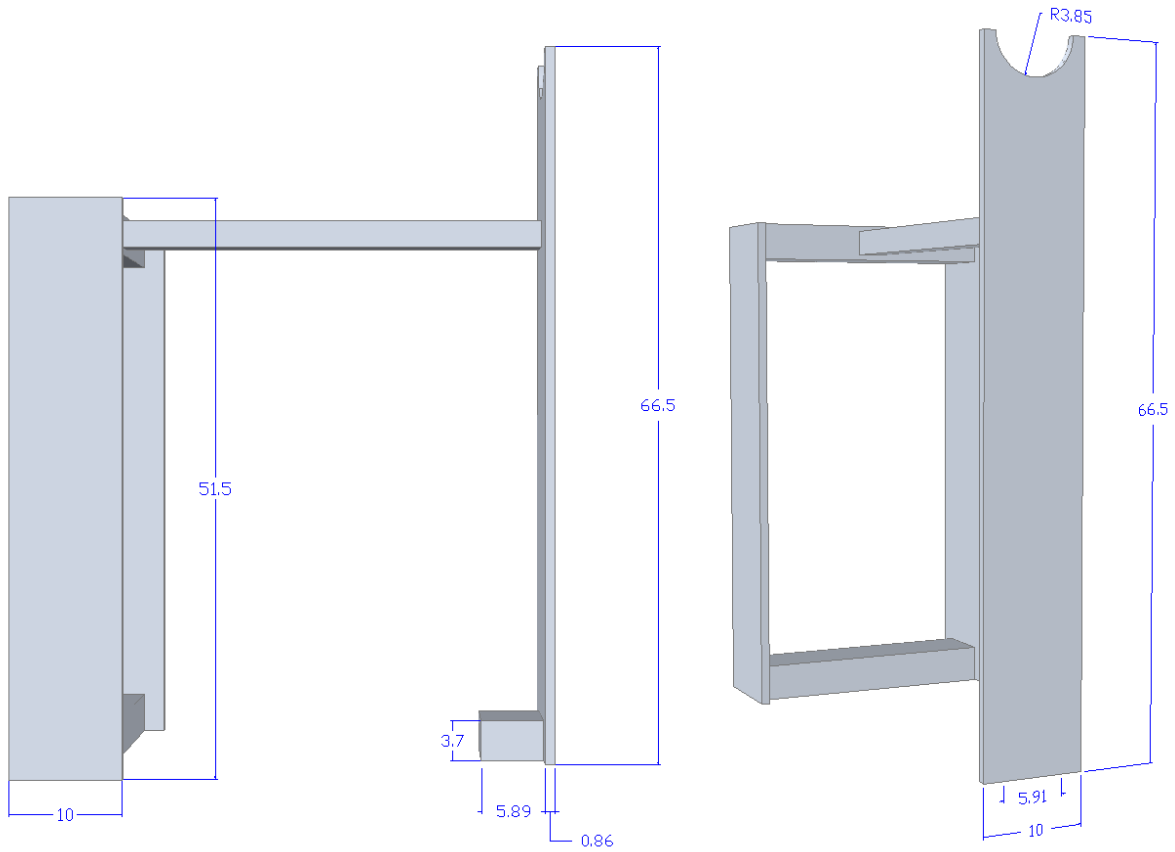


Figure 35. Drawings of the Van de Graaff generator support stand. The left view is a side view and right view is for perspective. The base screws into the left side and the insulating column of the generator rests in the circular cutout on the left. The units of all dimensions are cm.

The accelerator column support is shown in Figure 36. The electron gun side of the accelerator tube would rest on the left and the vacuum system side on the right with the high voltage terminal projecting from the left side. To prevent sagging, the accelerator column rests on the horizontal member in the center.

Chapter 5

CONCLUSIONS

5.1 Summary

The design and construction of a 250 keV electrostatic accelerator was described in this thesis. The current design uses an alternating assembly of 48 stainless steel washers and 48 high-density polyethylene rings to form the accelerating tube. A Van de Graaff generator capable of maintaining a constant 250,000 V powers the capsule shaped high voltage terminal. The vacuum system composed of a cold trap, diffusion pump, and rotary forepump, keeps the system at a pressure of approximately 10^{-6} torr. The electron gun and phosphorescent screen were taken from a RCA 3RP1 cathode ray tube.

5.2 Current Results

The accelerator tube and electron gun were attached to the vacuum system for a test run. The high voltage terminal was not attached so the electron gun's acceleration grid provided the total acceleration of 2500 eV. The pressure was pumped down to approximately 4×10^{-6} torr. A test circuit shown in Figure 22 was connected to the electron gun. While a current was measured off the cathode, the beam of approximately 2500 eV electrons did not strike the phosphorescent screen. The voltages across the deflection plates were varied in an attempt to find the beam spot. The focus controls were also varied with the thought that the beam spot was too diffused to see on the screen. The beam was not found.

The accelerator tube was disconnected and the electron gun was connected to the vacuum system at the cross, shown in Figure 40, to see if the electron gun was misaligned and to record the voltages of the deflection plates when the beam struck the center of the screen. The beam hit close to center on

the screen. The focus control of the test circuit might not be adequate and needs further investigation. The shape of the beam spot also needs investigating and might be related to the focus control. The electrons had an energy of 870 eV. The cathode was supplied with -870 V, the control grid was supplied with -838 V, the focusing grid was supplied with -596 V, and the accelerating grid was supplied with 0 V. The current from the cathode measured 89 μA and the current striking the screen measured 0.05 μA .

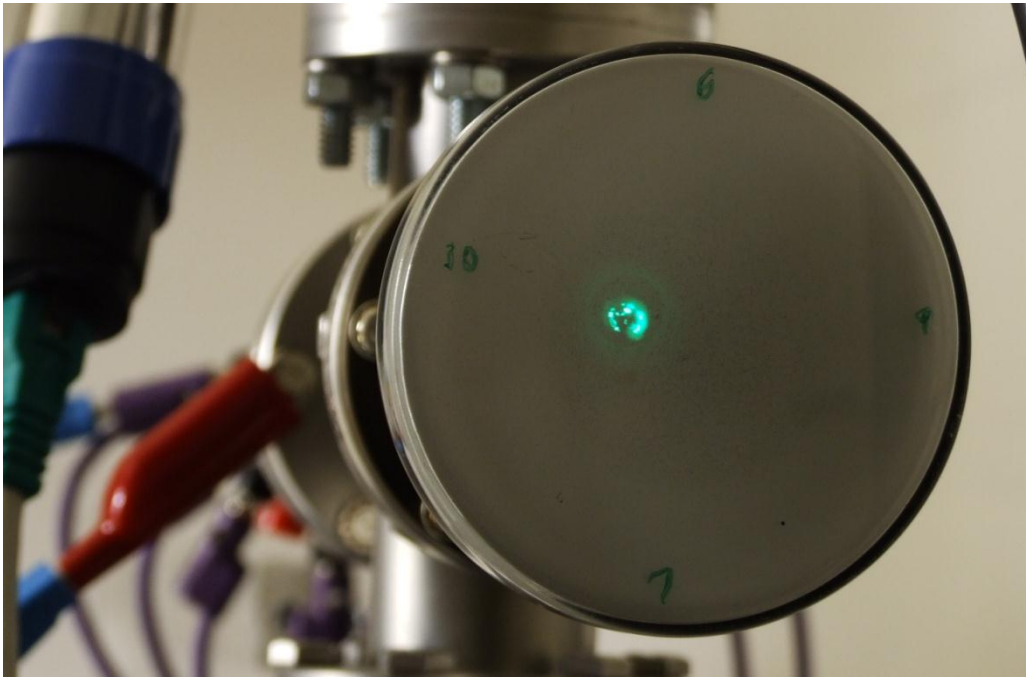


Figure 38. Photograph of the phosphorescent screen while a test was performed to check the alignment of the electron gun without the accelerator tube. The green dot is caused by the electrons impacting the screen. The shape of the beam spot is strange and being investigated.

5.3 Future Plans

The accelerator has yet to be turned on while fully assembled. The control circuit needs to be tested and a program needs to be written that allows easy communication to and from the microcontroller. The electron gun alignment must first be corrected or compensated for by the deflection plates. The electric field inside the accelerator tube generated by the high voltage terminal having a potential of 200 kV, will correct any misalignment of the electron gun. The maximum potential of the capsule-

shaped high voltage terminal is unknown and needs to be measured. The beam current and energy of the accelerator also needs to be measured. There are plans for increasing the charging current by adding a second spray comb to the Van de Graaff allowing for positive charges to be transferred from the high voltage terminal, doubling the charging current and allowing for higher potentials to be reached. The accelerator already has the ability to accelerate ions allowing for the acceleration of more massive particles than protons.

Appendix

VACUUM SYSTEM

A vacuum system must be attached to the accelerator to provide a pressure on the order of 10^{-6} torr. Many vacuum systems have similar components to the system constructed at Houghton College that contains a rotary pump, diffusion pump, and cold trap. Three gauges, one ion gauge and two convection gauges monitor pressure. All components are connected using either 2.75-inch OD Conflat or Kwik-Flange connections connected to 1.5-inch OD stainless steel tube and sealed with Viton gaskets. The lowest pressure attained by this setup has been 2.0×10^{-6} torr without the accelerator tube and 4.9×10^{-6} torr with the accelerator completely assembled.

Forepump

The Alcatel rotary forepump used in the Houghton College system is powered by a Franklin Electric motor rated at 0.5 horsepower and 1725 RPM. A schematic of the pump is shown in Figure 39. The pump is a positive displacement pump. As the rotor rotates, the empty space at the intake is increased. The cavity is then filled due to pressure within the system. The vanes are tensioned such that they remain in contact with the outer wall. Once a vane crosses the exhaust, the cavity containing air begins to shrink forcing the air out of the exhaust port. The forepump is able to maintain a pressure of 6-8 millitorr.

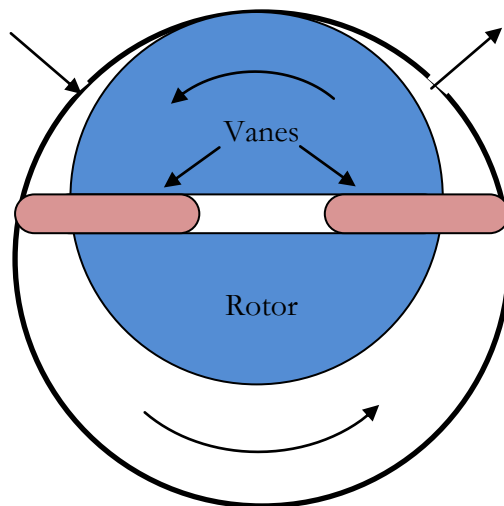


Figure 39. Drawing of a rotary vane pump. As the rotor (blue) rotates, the vanes (red) are in constant contact with the walls. As a vane passes the intake port, the volume that air can enter through the intake port increases. Once the other vane passes over the exhaust port, the volume is then decreased forcing air through the exhaust port.

Cold Trap

To reduce the pressure further, a liquid nitrogen cold trap is used. By adding liquid nitrogen into the Kurt J. Lesker Company TLR6XS150QF cold trap, the temperature of molecules within the system is lowered and the forepump is able to extract them. Since the temperature is lowered, the average kinetic energy of the air molecules is less and the forepump is able to overcome the lower kinetic energy and remove the air molecules.

Diffusion Pump

Once the pressure is low enough, the diffusion pump is turned on. The diffusion pump has no moving parts, unlike the forepump. 50 cc of 704 Diffusion pump oil, low vapor pressure oil, is boiled and the oil vapor is directed through a downward jet. As the vapor falls downward towards the boiler, it causes air molecules to move in a downward direction where the exhaust is located and connected to the forepump that removes the air molecules. The outside of the pump is cooled by water or air, as in this setup. As the oil contacts the outer wall, it condenses and returns to the boiler. The diffusion pump used is a Varian 0159 with an output of 350 watts and an oil capacity of 50 cubic centimeters. A Dayton centrifugal fan provides cooling. The diffusion pump benefits from the

cold trap because any oil vapor that contacts a baffle in the bottom of the cold trap condenses and returns to the boiler. The pressure of the fully assembled accelerator shown in Figure 40 is lowered to approximately 4.2×10^{-6} torr by the entire system.

Measuring Pressure

Two convection gauges track the pressure, one above the cold trap and one after the forepump, down to a pressure of 10^{-3} torr. Both gauges are ConvecTech Gauge Tubes from Duniway Stockroom Corp. CVT-275-101. Below this pressure, an iridium filament ion gauge from Duniway Stockroom Corp. I-100-K provides more accurate measurement of pressure of this order. The ion gauge has an operation pressure from 1×10^{-3} torr to 2×10^{-10} torr. All gauges are connected to a Stanford Research Systems IGC100 ion gauge controller. This provides digital readouts for all gauges as well as a safety for the ion gauge which automatically shuts down if the pressure rises to a level in which the filament is capable of burning out.

Valves

A butterfly valve made by Key High Vacuum Products INC. QBV-150-AL-40 is located above the cold trap and allows the ability to disassemble the accelerator tube, electron gun, or target without the entire vacuum system being taken off line. A valve allows the forepump to be isolated during shutdown and prevents forepump oil from contaminating the diffusion pump. The third valve allows air to be introduced into the system.

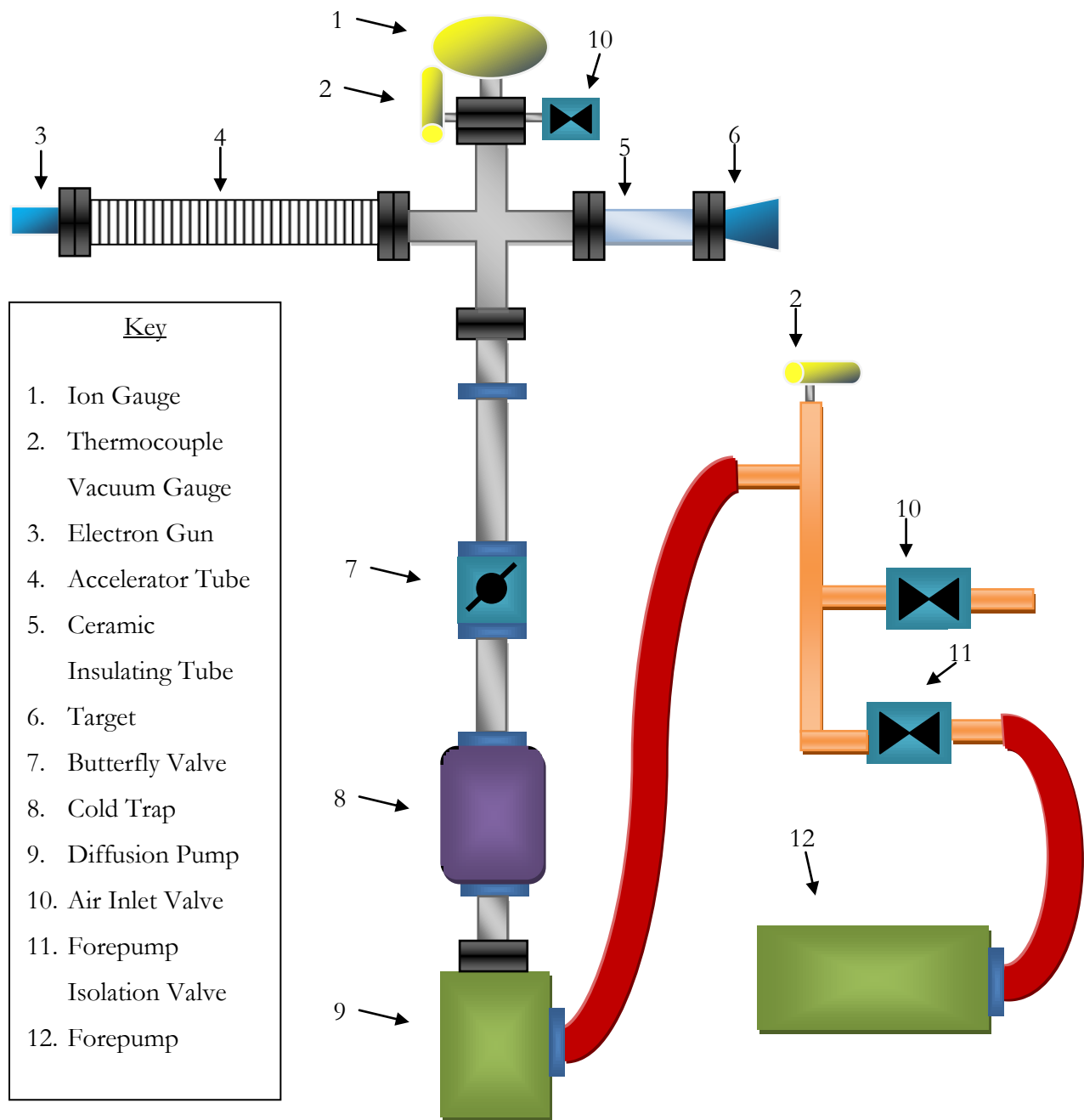


Figure 40. Drawing of the Vacuum System. All stainless steel tubes are shown in gray with the Conflat flanges shown in black and quick flanges in blue. Rubber Tubing is shown in red and copper piping and solder joints are in orange. The forepump and diffusion pump are shown in green and the cold trap is shown in purple. Valves are shown in teal and pressure gauges are shown in yellow. The electron gun and target are shown in blue.

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