Richard Stephens

University Physics II

Section: H2

Honors Project- Van de Graaff Generator

April 20, 2010

Van de Graaff Generator

Abstract

This paper is written to describe possible designs for building a Van de Graaff generator and the flaws in an attempted assembly of a Van de Graaff. It is concluded that the problems experienced from the attempted Van de Graaff construction could be remedied by either a lower output motor or a more tightly fitting belt assembly. Information describing the basic physics behind a Van de Graaff generator and a short history will also be included. There are diagrams and images to help explain the physics and construction of the device itself.

Introduction

The central basis for the functionality of a Van de Graff generator is charge separation. This is the result of an imbalance in the quantity of positive and negative charges on the surface of an object. The electronegativity (how well an atom holds onto its electrons) of atoms varies, and how well a material holds its electrons determines its location in the tribo-electric series (A. J. Martins).

(Tribo-electric series)

- Human hands (very positive)
- Glass
- Human hair
- Silk
- Paper
- Steel (neutral)
- Wood
- Hard rubber
- Nickel, Copper
- Gold, Platinum
- Silicon
- Teflon (very negative)

The greater the distance between two materials on the tribo-electric series table the greater the charge separation occurs, when the two materials are brought together. The charge created by the friction (rubbing) of two materials together is called charging by friction. Another important fact when dealing with electrostatics and particularly Van de Graff generators is humidity. Since air can act as a conductor it is important that the air be as dry as possible, because increased humidity increases the conductivity of air. Increased conductivity of air will result in a decreased ability to store charge on the sphere of the Van de Graff generator (A. J. Martins).

A typical Van de Graff generator has several essential parts. The first of which is a round high-voltage terminal held up off the ground by some type of dielectric (insulating) material. The spherical shape of this terminal is very important. The sphere allows for a maximum surface area for the charge to be placed on, and a sphere has no sharp edges. Sharp edges are bad when trying to hold a charge, because they tend to allow charge to be lost to the air more easily. A belt of dielectric material should be extended up the column supporting the high-voltage terminal into the sphere. The belt should be placed around the roller inside the sphere and the roller on the ground. An electric motor is typically used to turn the roller on the ground, which provides the torque to turn the belt and create friction (A. J. Martins).

The lower grounded roller builds a negative charge as it turns the belt. This negative charge on the grounded roller induces a positive charge on the outside of the belt. This induced charge on the belt and the later induced charge of the sphere are referred to as charging by induction. There is a conducting comb on the inside of the sphere that removes the positive charge from the belt as it passes. Since the high-voltage terminal is a sphere, the positive charge removed from the belt will be evenly distributed over the entire outer surface of the high-voltage terminal (A. J. Martins).

The sphere (terminal) will continue to build up a charge until the voltage breakdown point for air is reached. When the breakdown point for air is reached the charge will jump from the sphere (terminal) in the form of a spark in the air (A. J. Martins). A diagram of a Van de Graaff generator is shown below in figure.1:

Figure 1. (Wikipedia, 2010)

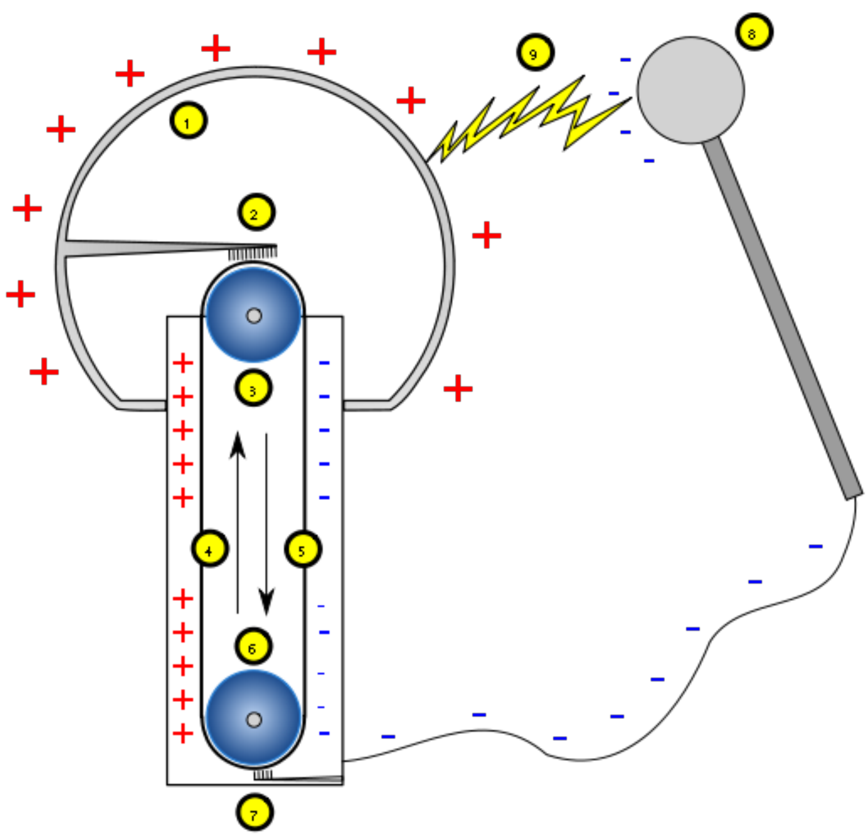


Figure 1. Labels:

1. **(1) hollow metal sphere**
2. **(2) upper electrode (comb)**
3. **(3) upper roller**

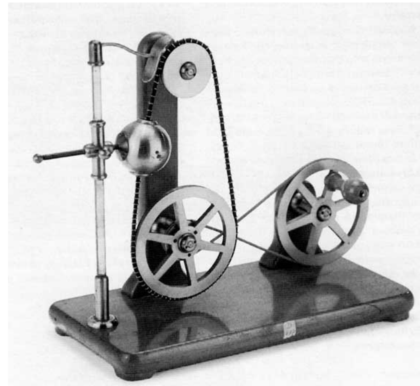
(4) side of belt with positive charges
(5) opposite side of belt with negative charges
(6) lower roller
(7) lower electrode
(8) spherical device with negative charges, used to discharge the main sphere
(9) spark produced by the difference of potentials

Jamison Van de Graaff (USA) constructed the first Van de Graaff generator in 1929. Van de Graaff designed the generator with the purpose of using it to generate high voltages to be used with experiments in nuclear physics. Van de Graaff patented his design in 1935. Van de Graaff generators have the capability to produced incredibly large voltages if designed properly. While most typical Van de Graaff generators will usually produce 100,000 V to 500,000 V some extreme designs can produce millions of volts (A. J. Martins).

Van de Graaff's design was built on the research and designs of many scientists before him. Otto von Guericke (German) built the first known electrostatic generator in 1660. Guericke's design used a sulfur globe (figure 2) that was charged by friction by hand, and then used as a source of electricity for experiments. In 1872 Augusto Righi described an "induction electrometer" (figure 3) in his PhD thesis work. The "induction meter" he described was a Van de Graaff generator. However, these early designs would be made antiquated by later disk induction generators like a Holtz generator (A. J. Martins).

Figure 2 (Magnet Lab, 2008) **Figure 3 (Brenni, 2007)**

Von Guericke Sulfur Globe
(circa 1660)



Theoretical Procedures 1 & 2

This section will describe two separate Van de Graaff generator designs. The first of which is a relatively complicated high output model of Van de Graaff generator, and the second is an ultra simplistic version. The basic information for the high output model is as follows:

Parts List:
2 @ 80mm dia(o/d) PVC flanges
2 @ 270mm x 75 mm stainless steel bowls
1 @ 600mm x 80mm dia(o/d) PVC pipe tube
1 @ 2m natural rubber chair webbing
3 @ 300mm x 300mm x 20mm compressed wood or ply timber
2 @ 25mm x wooden dowel
1 @ PVA wood Glue
30 @ 2.5 mm x 12mm screws
1 @ tube contact cement (Glue)
4 @ pop rivets
2 @ sealed roller bearings
1 @ nylon66 material (50mm dia x 60mm)
1 @ nylon food cutting board.
2 @ 30mm x 70mm metal tin strips
1 @ 25mm x 25 mm shim steel
1 @ 30mm x 120 mm tin strip
1 @ 100mm x 6mm booker rod
1 @ 4 or 6mm steel shaft cut to length
4 @ 6mm nuts & washers

The sphere of the Van de Graaff is to be composed of two stainless steel bowls placed on top of one another. The bottom bowl is to have a hole cut into it to allow it to accommodate the 80mm diameter PVC shaft. The sphere itself will rest on the PVC flange that is attached to the PVC shaft. A 75mm piece of shaft should extend up into the sphere. This piece of PVC should be cut to allow an opening around the top roller so the comb on the interior of the sphere can have easy access. The comb inside of the sphere should be made of a very sharp conducting metal and placed as close to the belt as possible without touching it. A second PVC flange should be used to anchor the PVC shaft into the box that will house the lower (grounded) roller. This particular design calls for nylon rollers with sealed bearings. The belt is to be constructed from non-stretch rubber upholstery webbing using sand paper and contact cement. The box to house the electric motor and lower roller is of fairly basic design. It is simply a top, bottom, back, and two front supports that make the box sturdy, but still allow all the interior parts to be visible. The electric motor required varies from 12V ac/dc to 240 V ac motor depending on the desired revolution speed. The design calls for the bottom comb to be mounted to the motor itself. This design was found online, and a much more detailed version of the construction process is available. For convenience only a short description of the total procedure is listed above, since the original procedure was 20 pages long (Mutch, 1995).

A second ultra simplistic design was also found:

Parts List:
Some wires
1 @ plastic tupperware (the oven safe kind)
1 @ nail
1 @ small dc motor
1 @ piece of PVC pipe (roughly 4cm diameter)
1 @ broad rubber band
1 @ wooden skewer
1 @ plastic bag
1 @ roll of tape
1 @ soft drink can
1 @ mineral water bottle

2 @ 3V batteries
1 @ battery holder (optional)

A hole should be drilled into the bottom of the Tupperware container. The electric motor should be placed in the center of this hole and taped down securely. Three holes should be drilled into the side of the Tupperware container. Two of the holes will be used to run the (+) and (-) wire for the electric motor, and the other hole will be for the grounding wire (figure 4). The piece of PVC should be placed on top of the Tupperware container and should be directed straight up. At the top of the PVC shaft place the skewer to act as the roller, and cover the center of the skewer in scotch tape (figure 5). Place the rubber band over the taped portion of the skewer and over the driveshaft of the electric motor. The top and bottom of the water bottle should be cut off and placed over the PVC pipe. Make sure the bottle is taller than the piece of PVC pipe. Remove the top of the soda can and place this on top of the water bottle, with the open end facing down. The wire should be threaded through the soda can and run just above the rubber band. This creates a rather crude but functional Van de Graaff generator (figure 6) (Tan).

Figure 4 (Tan)

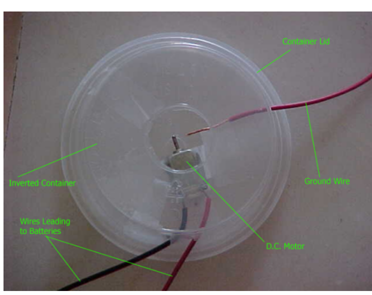


Figure 5 (Tan)

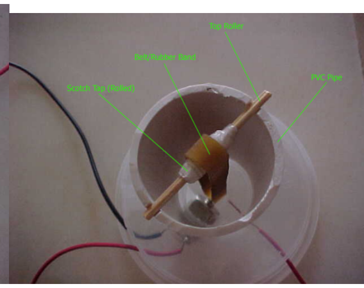


Figure 6 (Tan)

Attempted Procedure

The Van de Graaff generator that was attempted in this experiment was based on the large scale Van de Graaff design described above. The materials used in the failed attempt are listed below:

Parts List:
2 @ large pieces of MDF (medium density fiberboard)
20 @ small wood screws
1 @ bottle of wood glue
2 @ corner L-brackets
1 @ 80mm diameter PVC pipe
2 @ 80mm diameter fitting PVC flanges
2 @ large stainless steal mixing bowls
2 @ piece of thin sharp metal (to be used as a electrode comb)
1 @ large electric motor with switch from vacuum cleaner (120V ac/dc)
1 @ large rubber belt (vacuum belt, lawn mower belt, car radiator belt)
1 @ wood spool
1 @ large bolt
2 @ washer to fit large bolt
1 @ nut to fit large bolt
4 @ small bolts
4 @ small nuts
1 @ spool of electrical tape
1 @ spool of solder

Tools:
1 @ Jigsaw
1 @ Circular saw
1 @ power drill

The base of the Van de Graaff was constructed from 5 pieces of MDF. The bottom, back, and top pieces cut to measure 64cm x 33cm. The two side pieces of the base measure 32cm x 30cm. The front of the base was left open to allow for easy manipulation of the components and for observation purposes. The five pieces of MDF are held together by a total of 16 wood screws and wood glue. 10 of the 16 screws were drilled from the outside of the box and 6 were anchored from inside. The 10 exterior were placed at what is assumed to be the best structural locations. The 3 screws were placed in the two bottom corners using the L-brackets.

The electric motor is placed in the middle of the back board composing the base. Once the motor is centered, it should be anchored into the board using the four small bolts and nuts. A hole to allow for the belt should be placed directly over the drive shaft of the electric motor in the top of the wooden base (remember to be centered over the driveshaft and not the motor). A second small hole should be drilled in the right wall of the box to allow the power cords to conveniently exit. The switch that was also removed from the vacuum should be attached to the right wall.

One PVC flange needs to be placed on top of the box directly over the hole. This flange should be anchored using four small wood screws. The PVC shaft needs to be cut to a length that corresponds with the length of belt that is used. A wedge shape should be cut out of the top of the PVC shaft to expose the belt as it is turned. A hole needs to be drilled above the wedge cut, and will be used later for the large bolt. The PVC shaft is placed inside the flange and should fit tightly enough that no added anchoring is needed. The second PVC flange should be placed just below the wedge cut, and this flange should also fit securely enough that no added anchoring is needed.

The large bolt should be placed through the hole drilled in the top of the PVC shaft. A washer should be placed on the outside of both sides of the PVC shaft. The bolt needs to be securely fastened using the large nut. However, before securing the bolt the wood spool must be placed on the bolt inside the shaft, and the belt must be placed over the spool.

The conducting sphere placed on top of the Van de Graff will be composed of two stainless steal mixing bowls. One of the bowls must have a hole cut into the bottom of it big enough to accommodate the PVC shaft. Since the PVC shaft is 80mm it is highly recommended that the hole be slightly bigger, but not too big. Drilling a starter hole in the steel bowl with a power drill and then using a jigsaw should accomplish the task. As long as the hole is not too large the bowl will slide down nicely over the shaft and rest on top of the PVC flange, with no added anchoring needed. One piece of thin sharp metal should be attached to the interior of the sphere and the end placed as close to the belt as possible without touching. If a good connection between this piece and the sphere is in question it may be necessary to solder the sharp metal to the sphere. A second metal piece should be placed on the electric motor and extended as close as possible to the belt at the bottom. The final assembly step is to place the second mixing bowl on top of the first and attach it using tape of some kind.

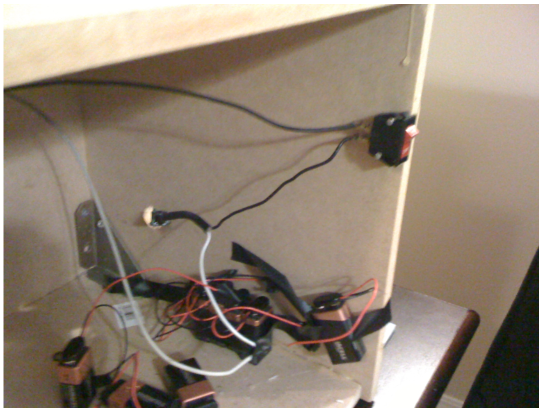
Data/Error Analysis

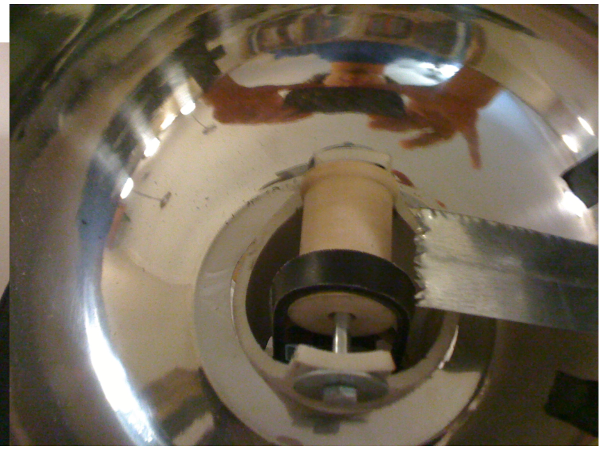
Originally the electric motor and entire electrical system from the vacuum were kept intact. The idea behind this was to achieve more friction than would be necessary, so that a very strong charge would be created. It was quickly discovered that the wall outlet provided far too much power to the electric motor. Everytime the motor was engaged while plugged into the wall it would apply so much power/torque that it would either throw off the belt or almost burn through it.

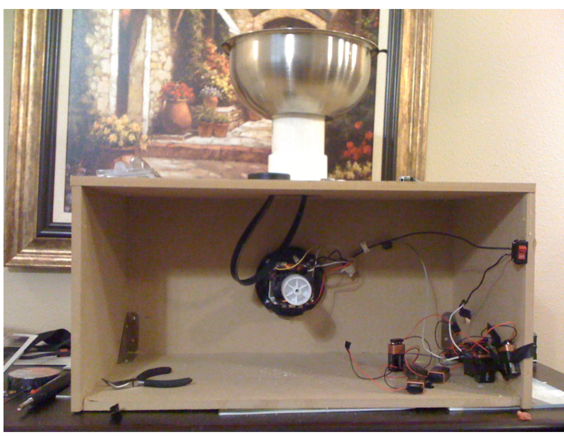
After multiple failed attempts with various belts, it was decided that reducing the voltage to the motor was the only viable option. At this point 9V batteries were placed in a series using parts from radio shack. A series of 9V batteries allows the motor’s output to be dialed down and more accurate control of the voltage through the motor by simply adding another batter to series. Regrettably the 9V batteries are not strong enough to power the electric motor that was used. After placing nine 9V batteries in series and being unable to run the motor the design was dubbed a failure. On a small side note, the 9V batteries were enough to run the electric motor by itself just not with a belt placed on it.

Conclusion

The Van de Graaff generator is a great tool for building up large voltages to either be used in high energy experiments, or simply teaching the principles/laws of charge. The experimental design that was attempted did not function as it was hoped. However, if a smaller motor is utilized along with a controllable power source it should work beautifully. Only three designs for a Van de Graaff generator are listed, but there are countless different designs and construction materials that can be used to build a Van de Graaff.







References

A. J. Martins, H. M. (n.d.). *BSCW shared workspace.* Retrieved April 9, 2010, from ORBI Team: http://www.clab.edc.uoc.gr/2nd/pdf/36.pdf

Brenni, P. (2007). *Bulletin of the Scientific Instrument Society* . Retrieved April 9, 2010, from Bulletin of the Scientific Instrument Society : http://pagesperso-orange.fr/Lyonel.Baum/sis.html

Magnet Lab. (2008). Retrieved April 9, 2010, from Magnet Lab: http://www.magnet.fsu.edu/education/tutorials/timeline/1600-1699.html

Mutch, G. D. (1995). *How To Build A Vendegraff Generator.* Retrieved April 9, 2010, from How to Build A Vandegraff Electrostatic Generator: http://www.gocs1.com/gocs1/Psionics/Vandegraff+Generator.htm

Tan, A. (n.d.). *High Voltage*. Retrieved April 9, 2010, from Alvans Van de Graf Generator: http://web.singnet.com.sg/~sengam/construction.htm

Wikipedia. (2010, April 19). Retrieved April 9, 2010, from Wikipedia: http://en.wikipedia.org/wiki/Van_de_Graaff_generator