VAN DE GRAAFF GENERATOR

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Abstract: A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high electric potentials. It produces very high voltage direct current electricity at low current levels. The potential difference achieved by modern Van de Graaff generators can be as much as 5 megavolts. A tabletop version can produce on the order of up to 100,000 volts and can store enough energy to produce a visible spark. Small Van de Graaff machines are produced for physics education to teach electrostatics, larger ones are displayed in some science museums. The principle of corona discharge action of sharp points, electric discharge takes place in air or gases readily,at pointed conductors. . There is a large spherical conductor having a few meters of radius. It is placed on two pillars at a certain height from the ground. One is P1 and other is P2. A belt made up of insulating material is moving over two pulleys P1 and P2. The pulley P2 is present at the center of the spherical conductor S and the pulley P1 is present near the ground. A motor is used whose main function is to create a spin in the belt. Spray Comb and collecting comb are the names of B1 and B2 respectively. A discharge tube D is used in which the acceleration of ions is done. The point from where the ions originate is present at the head end of the discharge tube. But the other end of the tube is earthed.

Index Terms: **generators, spherical conductor, pulley, discharge tube**

I. INTRODUCTION

A **Van de Graaff generator** is an electrostatic generator which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high electric potentials. It produces very high voltage direct current (DC) electricity at low current levels. It was invented by American physicist Robert J. Van de Graaff in 1929. The potential difference achieved by modern Van de Graaff generators can be as much as 5 megavolts. A tabletop version can produce on the order of 100,000 volts and can store enough energy to produce a visible spark. Small Van de Graaff machines are produced for entertainment, and for physics education to teach electrostatics, larger ones are displayed in some science museums

The Van de Graaff generator was developed as a particle accelerator for physics research; its high potential is used to accelerate sub atomic particles to great speeds in an evacuated tube. It was the most powerful type of accelerator of the 1930s until the cyclotron was developed. Van de Graaff generators are still used as accelerators to generate energetic particle and X-ray beams for nuclear research and nuclear medicine.

Particle-beam Van de Graaff accelerators are often used in a "tandem" configuration: first, negatively charged ions are injected at one end towards the high potential terminal, where they are accelerated by attractive force towards the terminal. When the particles reach the terminal, they are stripped of some electrons to make them positively charged and are subsequently accelerated by repulsive forces away from the terminal. This configuration results in two accelerations for the cost of one Van de Graaff generator, and has the added advantage of leaving the complicated ion source instrumentation accessible near ground potential.
The voltage produced by an open-air Van de Graaff machine is limited by arcing and corona discharge to about 5 megavolts. Most modern industrial machines are enclosed in a pressurized tank of insulating gas; these can achieve potentials of as much as about 25 megavolts.

II. DESCRIPTION

A simple Van de Graaff generator consists of a belt of rubber (or a similar flexible dielectric material) moving over two rollers of differing material, one of which is surrounded by a hollow metal sphere. Two electrodes in the form of comb-shaped rows of sharp metal points are positioned near the bottom of the lower roller and inside the sphere, over the upper roller. Comb 1 is connected to the sphere, and comb 2 to ground. The method of charging is based on the triboelectric effect, such that simple contact of dissimilar materials causes the transfer of some electrons from one material to the other. For example, the rubber of the belt will become negatively charged while the acrylic glass of the upper roller will become positively charged. The belt carries away negative charge on its inner surface while the upper roller accumulates positive charge. Next, the strong electric field surrounding the positive upper roller induces a very high electric field near the points of the nearby comb . At the points, the field becomes strong enough to ionize air molecules, and the electrons are attracted to the outside of the belt while positive ions go to the comb. At the comb 1 they are neutralized by electrons that were on the comb, thus leaving the comb and the attached outer shell with fewer net electrons. By the principle illustrated in the Faraday ice pail experiment, i.e. by Gauss's law, the excess positive charge is accumulated on the outer surface of the outer shell, leaving no field inside the shell. Electrostatic induction by this method continues, building up very large amounts of charge on the shell.

In the example, the lower roller is metal, which picks negative charge off the inner surface of the belt. The lower comb 2 develops a high electric field at its points that also becomes large enough to ionize air molecules. In this case, the electrons are attracted to the comb and positive air ions neutralize negative charge on the outer surface of the belt, or become attached to the belt. The exact balance of charges on the up-going versus down-going sides of the belt will depend on the combination of the materials used. In the example, the upward-moving belt must be more positive than the downward-moving belt. As the belt continues to move, a constant "charging current" travels via the belt, and the sphere continues to accumulate positive charge until the rate that charge is being lost (through leakage and corona discharges) equals the charging current. The larger the sphere and the farther it is from ground, the higher will be its peak potential. In the example, the wand with metal sphere is connected to ground, as is the lower comb 2; electrons are drawn up from ground due to the attraction by the positive sphere, and when the electric field is great enough (see below) the air breaks in the form of an electrical discharge spark. Since the material of the belt and rollers can be selected, the accumulated charge on the hollow metal sphere can either be made positive (electron deficient) or negative (excess electrons).

The friction type of generator described above is easier to build for science fair or homemade projects, since it does not require a high-voltage source. Greater potentials can be obtained with alternative designs (not discussed here) for which high-voltage sources are used at the upper and/or lower positions of the belt to transfer charge more efficiently onto and off the belt.

A Van de Graaff generator terminal does not need to be sphere-shaped to work, and in fact, the optimum shape is a sphere with an inward curve around the hole where the belt enters. A rounded terminal minimizes the electric field around it, allowing greater potentials to be achieved without ionization of the air, or other dielectric gas, surrounding. Outside the sphere, the electric field becomes very strong and applying charges directly from the outside would soon be prevented by the field. Since electrically charged conductors do not have any electric field inside, charges can be added continuously from the inside without increasing them to the full potential of the outer shell. Since a Van de Graaff generator can supply the same small current at almost any level of electrical potential, it is an example of a nearly ideal current source.

The maximal achievable potential is roughly equal to the sphere radius R multiplied by the electric field E_{max} at which corona discharges begin to form within the surrounding gas. For air at standard temperature and pressure (STP) the breakdown field is about 30 kV/cm. Therefore, a polished spherical electrode 30 cm in diameter could be expected to develop a maximal voltage $V_{max} = R{\cdot}E_{max}$ of about 450 kV. This explains why Van de Graaff generators are often made with the largest possible diameter.

III. PRINCIPAL & WORKING

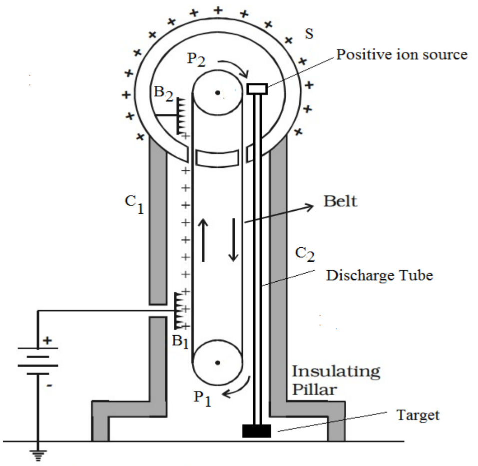
PRINCIPAL

Basic principle on which Van de graaff generator works are

1. Discharging action of sharp points, ie., electric discharge takes place in air or gases readily, at pointed conductors.
2. If the charged conductor is brought in to internal contact with a hollow conductor, all of its charge transfers to the surface of the hollow conductor no matter how high the potential of the latter may be.

WORKING

The generator is simple to operate. Place the unit on a plastic or wooden table. Attach the red wire from the discharge wand to the grounding terminal using the black plastic nut. Make sure the drying lamp switch is "Off". Plug in the power cord to a grounded 110 volt outlet and the generator belt will begin to rotate (there is no on/off power switch). Within 30 seconds the dome will become charged. Move the discharge wand toward the dome until you get a spark. When the discharge wand is close to the dome the sparks are short and frequent (about one spark per second). As you move the discharge wand further from the dome, the sparks become longer and less frequent. Unplug the generator to turn it off. When operating properly under the right conditions, your generator will consistently produce 1-2" sparks every second and 5-6" sparks every 3-5 seconds. Under ideal conditions 8-12" sparks can be produced. However, there are several variables that affect the performance of your generator including air humidity, cleanliness of the rollers and belt, and adjustments on the generator. Carefully read the Maintenance and Troubleshooting sections if your generator is not performing fully.



The potential outside is that of a point charge; and inside it is constant, namely the value at the radius R. We thus have:

Potential inside conducting spherical shell of radius R carrying charge Q = constant and is given by,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$$

Let a small sphere be placed at the center of the large one such that the radius of the smaller sphere is r and the charge over its surface is q. The potential energy thus generated due to the smaller surface at different points in the system can be given as the following values,

At the surface of the small sphere:

$$V_{r1} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

At the large spherical shell of radius R:

$$V_{r2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

If we consider the total charges in the system, that is, q and Q, then the total potential energy due to the system of charges can be given as,

$$V_R = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{R} + \frac{Q}{R}\right)$$

$$V_r = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r} + \frac{Q}{R}\right)$$

$$V_R - V_r = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{R} - \frac{1}{r}\right)$$

Assuming that q is positive, the inner sphere is always at a higher potential and is independent of the charge Q that is accumulated on the larger surface. The difference in potential given by the value V(r)-V(R) is positive. The potential due to Q is constant up to radius R and thus, the difference gets canceled out.

IV. CONSTRUCTION

ALLOY STEEL SPHERE

A **sphere** is a perfectly round geometrical object in three-dimensional space that is the surface of a completely round ball (viz., analogous to the circular objects in two dimensions, where a "circle" circumscribes its "disk"). Like a circle in a two-dimensional space, a sphere is defined mathematically as the set of points that are all at the same distance *r* from a given point, but in a three-dimensional space. This distance *r* is the radius of the ball, which is made up from all points with a distance less than *r* from the given point, which is the center of the mathematical ball. These are also referred to as the radius and center of the sphere, respectively. The longest straight line through the ball, connecting two points of the sphere, passes through the center and its length is thus twice the radius; it is a diameter of both the sphere and its ball. While outside mathematics the terms "sphere" and "ball" are sometimes used interchangeably, in mathematics the above distinction is made between a sphere, which is a two-dimensional closed surface, embedded in a three-dimensional Euclidean space, and a ball, which is a three-dimensional shape that includes the sphere and everything inside the sphere (a closed ball), or, more often, just the points inside, but not on the sphere (an open ball).

FLEXIBLE BELT

A **belt** is a loop of flexible material used to link two or more rotating shafts mechanically, most often parallel. Belts may be used as a source of motion, to transmit power efficiently or to track relative movement. Belts are looped over pulleys and may have a twist between the pulleys, and the shafts need not be parallel. In a two pulley system, the belt can either drive the pulleys normally in one direction (the same if on parallel shafts), or the belt may be crossed, so that the direction of the driven shaft is reversed (the opposite direction to the driver if on parallel shafts). As a source of motion, a conveyor belt is one application where the belt is adapted to carry a load continuously between two points.

Types of belts: Flat belts, Rope drives, Round belts, V belts, Multi groove belts, Ribbed belts, Film belts, Timing belts, Specialty belts

PULLEYS

A **pulley** is a wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and cable or belt. In the case of a pulley supported by a frame or shell that does not transfer power to a shaft, but is used to guide the cable or exert a force, the supporting shell is called a block, and the pulley may be called a sheave. A pulley may have a groove or grooves between flanges around its circumference to locate the cable or belt. The drive element of a pulley system can be a rope, cable, belt, or chain. Hero of Alexandria identified the pulley as one of six simple machines used to lift weights. Pulleys are assembled to form a block and tackle in order to provide mechanical advantage to apply large forces. Pulleys are also assembled as part of belt and chain drives in order to transmit power from one rotating shaft to another.

Classifications of Pulleys: Immovable or fixed pulley, Movable pulley, Combined pulley

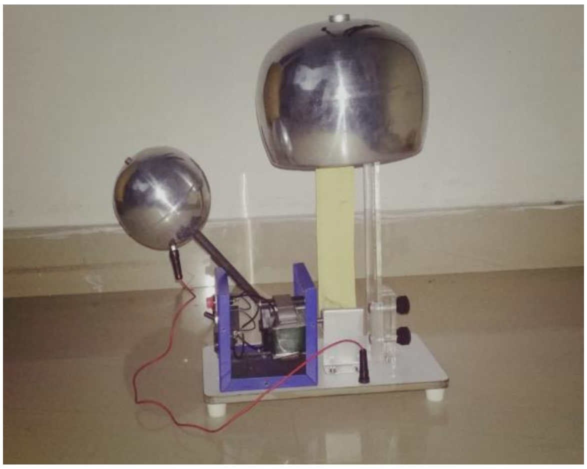
V. EXPERIMENTS & DEMONSTRATIONS

LIGHTNING

You can create sparks, or "lightning," using the discharge wand that came with your generator. Attach the red wire from the discharge wand to the grounding terminal with the black grounding nut. Plug in the generator on and let it run for one or two minutes. Holding the plastic handle of the discharge wand, slowly move the ball towards the dome. Depending on humidity conditions, you should see a large, bright blue spark when the wand is anywhere from one to six inches away from the dome. The sparks that can be made are very quick like lightning. When the spark is produced, you should also hear a loud crack or pop. This demonstrates a lightning electrical discharge which is accompanied by a bright flash and loud cracking sound. It is spectacular in a dark room! When operating properly, in low humidity, your generator can consistently produce 1-2" sparks every second and 4-5" sparks every 3-5 seconds. Sparks of up to 8-12" can be produced under ideal conditions. If the air is dry enough, and you let your generator run for a few minutes without discharging the dome, you can get "lightning" from the dome to the base, a full 12". Experiment producing sparks with other objects. Try the flat of your hand or finger tips. You will discover that flat or round objects produce larger and more distinct sparks than thin or more pointed objects.

RAISING HAIR

To raise your hair (or someone else's!) you will need a wooden chair or plastic step stool (it must be non-metal) that is sturdy enough to stand on and that will insulate you from the ground. If you don't insulate



yourself, your hair won't be raised and you will receive an electrical shock instead. To raise your own hair, you will need someone to plug in the generator for you. While standing on the plastic stool with the generator unplugged, place one hand on top of the dome with your other hand at your side. Have your helper plug in the generator. Make sure you do not touch anything else while it is running. Depending on the humidity in the room and in your generator, it might take two to five minutes before your hair begins to stand on end. Being in contact with the running generator causes the positive charges built up in the storage dome to be transferred to your body. Once those charges are on your body, they will try to get as far away from each other as possible (like charges repel) causing the hair on your head to stand on end. You can try this experiment with different people who have different hair length or hair fineness. Or try it with people standing on different insulating objects. Which conditions produce the best results? Form a hypothesis or guess as to why particular conditions produce better results and then design an experiment to test your hypothesis.

FLOATING OBJECTS

Because of the amount of positive charge that accumulates on the outside of the dome, some objects in this experiment may be attracted to the dome at first. Once some of its positive charge is transferred to the objects, they are then forced away from the dome because both surfaces have the same charge, which causes them to move as far away from each other as possible. Place a small disposable aluminum pie or tart pan on top of the storage dome before plugging in the generator. When you plug it in, the pan should acquire the same charge as the dome, which will cause it to be repelled away from the dome! Try a stack of two or more pie pans and watch them lift off one at a time. You may have better success using a looped piece of tape or some sticky tack to attach the bottom pan to the top of the dome. You can also try this experiment by making pans from aluminum foil shaped around the bottom of a bowl. Make sure the top edges of the aluminum foil bowls are smooth as possible because all sharp edges or points will dissipate charge from the dome of your generator.

DEFLECTING A FLAME

Your Van de Graaff generator can create an electrical wind that is powerful enough to deflect the flame of a candle and turn a toy windmill or propeller. To create a wind, attach a long, thin metal rod or needle (a darning needle or dissection pin will work well) to the side of the generator dome, near its middle, with the sharp end pointing out. Use modeling clay or a piece of tape, making sure that the metal touches the dome. Plug in your generator, light a candle, and hold it in front of the point. The flame should lean away from the generator. To see how far the effect of the wind extends, slowly move the candle away from the generator until the flame is no longer deflected.

VI. INSTRUCTIONS & APPLICATIONS

INSTRUCTIONS:

1. Operate this generator only under adult supervision. This generator is not a toy!
2. Plug the generator into a standard grounded (3-prong) 110 volt outlet.
3. Do not operate the generator in a wet or damp location. Do not operate outdoors.
4. Check for loose or defective wires before operating the generator. Replace if necessary.
5. Unplug the generator before performing adjustments or maintenance. Never remove the base cover plate unless the generator is unplugged. A dangerous electrical shock hazard exists whenever the base cover plate is removed.
6. The electrical shock you receive from normal contact with the generator is not harmful, although it can be uncomfortable, startling, and occasionally even painful. The static shock you get from this generator is similar to, although much stronger than, the one you might get from touching a metal door knob after walking over carpet on a dry day.
7. You can get a small static shock when you unplug the electrical cord. To prevent this, touch the grounded discharge wand to the dome several times until all static electricity is dissipated. Then unplug the cord.
8. Even after your generator has been unplugged, the charge that has built up on it can still shock you. You can avoid getting shocked by touching the discharge wand to the dome before approaching it with your hand. Any charge that is left on the dome will be transferred to the wand instead of to your hand.
9. The switch on the base of the generator is not an On/Off power switch for the unit, but rather a switch for a 25-watt drying lamp in the base used for drying the unit when the humidity is high. Keep the wand in contact with the dome while switching

APPLICATIONS:

They are used where a very high voltage at very low current is needed. For example, to accelerate electrons or ions to high speed, a form of particle accellerator. Accelerating electrons to sterilize food and process materials, accelerating protons for nuclear physics experiments, producing energetic X-ray beams in nuclear medicine, physics education, and entertainment. One of Van de Graaff's accelerators used two charged domes of sufficient size that each of the domes had laboratories inside - one to provide the source of the accelerated beam, and the other to analyze the actual experiment. The power for the equipment inside the domes came from generators that ran off the belt, and several sessions came to a rather gruesome end when a pigeon would try to fly between the two domes - causing them to discharge (The accelerator was set up in an airplane hangar).

VII. CONCLUSION

The Van de Graaff generator in its simplest form is seen as a didactical instrument, because of its solidity and simple construction. This generator became an ideal demonstration apparatus of electrostatic influence machine. Van de Graaff high voltage electrostatic generators are used in public schools and universities for teaching basic principles of high voltage electrostatics charge and laws of electrostatics. The Van de Graaff generator is extremely useful because it produces electric fields which are strong enough to be measured, manipulated, felt directly and played with. Men have always been fascinated by lightning and big sparks, therefore this machine was always the ideal and much appreciated display in important exhibitions, science museums and science centers. Table top Van de Graaff generators develop over 200,000 Volts and floor models offer up to 1,000,000 Volts of high voltage lightning electrical discharges.

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