Principle, Model, And Maintenance Of van De Graff Generator

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Abstract. The van de Graff generator is an electrostatic generator invented by Robert in 20th century and useful in accelerating charges. The generator plays a really important role in the scientific research by its unique characteristics, for example, to output a high voltage with a simple structure and a wide application and educational value. The main applications of the generator can be classified as two purposes, which are accelerating charge and to show as a popular educational tool for demonstrating principles of electrostatics and high voltage phenomena. This essay will analyze the basic principle, illustrate the model, also state the maintenance and the way to clean the generator. This simple generator not only makes a huge contribution to the physics in accelerating charges in nuclear physics experiments but is also used as an educational tool to show the electrostatic and help students to understand the movement of charges. It fosters a deeper understanding of physics principles and sparks the imagination and curious on the science.

Keywords: van de Graff generator; high voltage, accelerate charges; AC motor.

1. Introduction

The first development of the generator can be tracked back to about 1920s. Robert J. Van de Graaff start working on his generator concept while he graduated from MIT in the late 1920s. In 1933, with only few feet tall machine, he generated million volts [1]. During the 1930s, the work of generator was recognized as a potential method to create a very high voltage by using the electromagnetic charge [2]. Van de Graaff created his first prototype is in about 1929. And this prototype only consists system of belts and pulleys which is used to accumulate and transfer electric charges to a metal ball hanged upon the belt. The design was relatively simple but showed a great potential to generating high voltages. So that in following several years, he struggled at improving the generators, solving problems such as how to generate a stable voltage, how to make it a better yield etc. Finally, by 1931, he had constructed a larger version capable of producing voltages in the range of several hundred thousand volts.

In addition to being suitable for demonstrations, this machine can also be used for studying the working principle of the model if belt electrostatic generators and to test the parameters of the belt or other materials in this structure [3]. The generator has a variety of applications in a wide range of areas. In addition to particle research and the experiments, the generator can also be used in radiation therapy by producing high-energy particle beams, used in X-ray production by producing accelerated electrons to shoot the target metal. At the same time, the generator can also be found in industrial areas, though the two seem unrelated. The accelerated particle beams do a great job in achieving high toughness and create a special hard surface. Besides, although no use in space exploration yet, the generator shows a great potential to be utilized in space propulsion for the interstellar travel.

The rest of this paper is organized as follows. In Section 2, it introduces the principle and model of the van de Graff generator. In Section 3, it introduces the maintenance and the repair method of generator in real life. The last Section 4 is devoted to the conclusion.

2. Principle and Model of van de Graff Generator

2.1. Principle Behind Generator

The generator uses many theories of electrostatics. This paper will illustrate some important theories, for instance, tip discharge principle, friction transfer, self-excitation.

The first part is the friction transfer. This principle is the main source of electrons in the motor. In general, the transfer of electric charge occurs when two different materials are rubbed together [4]. And the object lost electrons carry positive charge, and the object gain electrons carry negative charge. When the conveyer and the roller have friction, the roller will carry negative charge and the conveyer will carry positive charge. The roller is made of relatively neutral cotton, bottom roller is made of Teflon that are easier to attract electrons. When the generator started to work, the electron in the cotton will transfer to the roller and made it negatively charged. At the same time, the belt will be positively charged.

The second part is tip charge principle. This principle is used by the collecting comb and conveyer(belt). The collecting comb shapes like a brush, and brush the conveyer. According to the principle of tip discharge, tip discharge must occur when the charge on the conveyor belt passes through the collector comb [4]. It can be seen from this chart that the comb A and comb B both contact with the belt. Brush A is positively charged and the charge will fly away from the brush A, then carried to the brush B. B is negatively charged so it attracts the positive charge. Consequently, the charge will be quickly transferred to the outer surface.

The third part is same charge repel each other. The charges accumulated in the roller will repel the same negative charge in the comb. And metals are good conductors of electricity, so that the negative charge will flow away and only positive charge exist on the top on collector comb. Consequently, the electric field is created between the positively comb and the negatively roller (this phenomenon is called charge self-excitation). Because of the action of the field, the negative charge in the air that between them will transfer to the comb. And the positive charge will transfer to the roller, however, the belt resists the charge. As a result, the charge will be carried to the upper roller by the belt.

The upper roller is made by aluminum that are easy to lose electrons. When the positively charged belt have a friction with it, electrons transferred to the belt and make the roller carry positive charge. Then the roller attracts electrons to the tip of the comb to form another electric field. like the one between the bottom roller and comb, but with opposite charge in each object. So that the positive charge will be attracted to the comb. The comb is connected to the metal ball, so that the charge will distribute on the surface.

The final part is the metal ball and Faraday cage. Van de Graaf proposed that the metal cavity round ball at the top of the motor could be regarded as a Faraday cage, and when the high-density electrons on the rubber strip surface reached the metal dome through the discharge of the upper comb tip, they would automatically transfer to the outer surface of the dome [5]. The Faraday cage mainly use the principle of electrostatic shielding. It is the that a conductor shell will protect the interior, so that its interior is not affected by external electric fields. The invention of Faraday's case is when Faraday once risked being electrocuted and did a famous experiment - Faraday locked himself inside a metal cage, and when there was a powerful electrostatic discharge outside, nothing happened.

2.2. The Model of van de Graff Generator

This section will talk about the specification of the components that can be seen in the Generator, and the function that they have. The model of van de Graff generator is shown in Fig. 1.

The first is the AC motor. A 220V motor should be used in this experiment, and the motor is used to control the rollers to make the belt rotate.

The second is the belt. As this essay mentioned before, the belt is made of cotton (or other materials that is insulated and neutral, for example, nylon). So that the positive charge will not stay at the belt all the time, instead, the charge will be transferred to the comb.

The third is the rollers. Two rollers are needed inside the generator. The generator mainly uses PVC pipes, also the upper roller remained stable and the lower roller is responsible to rotate the belt towards the upper roller [6]. The upper roller is made of aluminum that can easily loose electrons. The roller at bottom is made of Teflon.

The fourth is the metal ball. The big metal ball is at the top of the whole construction, it is used to store the electrons. The upper comb is connected to it and the comb can transferred the positive

electrons to the metal ball and distributed around the ball. Once if you touch the metal ball, the charge will be transferred to people's body and let their hair stand because the opposite charge will repel each other.

The last is the comb. There are two combs inside the generator, first one is the one next to the lower roller, this comb is connected to the metal and then it can transfer the negative charge away. And then in the comb only positive charge exist. So electric field formed easily. The second comb is upon the upper roller. As the second electric field formed between upper comb and roller. The positive electron will be conducted away through the metal that is connected to the big metal ball.

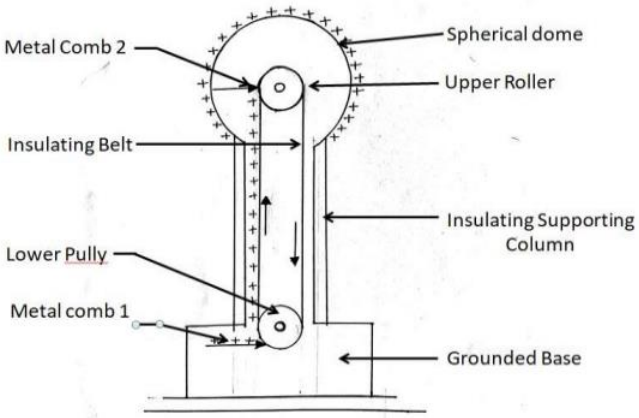

Fig. 1 the model of van de Graff generator [6].

3. Problems and Maintenance of the Generators

3.1. The Problem in Real Life

The charges on the globe lead to an electrostatic voltage which depends on the environment, such as humidity level, pulley materials, belt speed and globe size. In real life [7], when people operate or assemble a generator, various problems could be happened. This essay will show the cause of the problems and examine the reasons behind the problems.

The first problem is the generator with little output. This problem is the most common one in the real life, and this may cause from various reasons. First one is that the comb is in the wrong position. If the comb is too far from the belt, the electric field will not be established quickly. And the belt cannot carry sufficient charge. So that the metal ball cannot have sufficient charge. If the comb is too close to the belt, there will also be a problem, The sharp tip of the comb may cause damage to the belt, so that the belt cannot work as usual [8]. Another one is the wet and unclean of the generator, this is the reason of the insulation performance deteriorates. If the insulation brackets, two rollers, the belt, the surface of the metal ball is stained by water, fibers, or dusts, etc. many small tips will emerge. As a result, the generated charge will discharge directly into the air, rather than transfer to the right place. To solve this problem, a great way is to clean it regularly. Another solution is to put a light bulb inside the generator to dehumidification and drying.

The second problem is the belt deviates from the center line of the upper and lower rollers [9]. If the belt is not at the right position, the belt may slip off during operation, so no charge will be carried up to the big ball. At the same time, the belt will rub against the inner wall of the support, and the belt may hurt from the rub. To solve this problem, the operator can adjust the nuts at both ends of the upper roller, in order to fix the belt to the mid line of the upper and lower rollers.

3.2. Maintenance and Repair Methods

The generator needs to be repaired especially after a long period of unused. At no matter the science museum or other educational places, a correct way to repair it is essential.

There are some ways to clean the generator. The first is the reagent used. The cleaning agent usually be sodium dodecyl sulfate. Degreasing agent is trichloroethylene or methanol. Rinsing agent usually just distilled water, sometimes deionized water is also accepted. To drying and wiping as usual lint remover is used [10]. The other is the clean of the stand column in the center. The surface of the column may be stained by the fingerprint, the dusts, or the water. So that the light bulb that is mentioned before is useful to maintain the column dry. To clean the fingerprint and dusts, methyl alcohol is needed. Finally, it is the maintenance if the big metal ball. The surface off the metal ball should be smooth, without any sharp tips on it. So that the surface should not have any chisel grain, burr, pits on it. In order to avoid the tip charge principle occurred on the surface.

4. Conclusion

In conclusion, the generator behaves as a great project in science area nowadays. It is a design that can be used in a large area. At the same time, it makes a vast contribution on nuclear experiments and behave as an essential exhibition goods in sciences museums all over the world. With its simplicity and effective design, the device attracted vast scientists and achieve a huge success. Not only used in scientific region, it plays a crucial role in other areas like medicine, industry, and education. Specifically, as an educational tool, the device serves as a captivating instrument to engaging students and public in the fascinating science. It can demonstrate complex principle, such as electrostatics, high voltage phenomena in an easy and experienced way. The generator holds promising prospects for various fields due to the unique capabilities and versatility. The proposed design is a step forward towards a feasible instrument that can be adopted on a wide scale for the educational and the research purposes. The ability to produce high-energy particle beams also makes it a valuable tool for the material modifications and medical imaging and theory. It will stand as a captivating educational tool as usual and explore more functions in the future.

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