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Operating Principle of Van De Graaff Generator, Collectorless Generators and the Multipliers of Constant Stress

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I. Introduction

Van de Graaff generator (Fig. 1) long time it was the basic source of high voltages and widely it was used in the static accelerators. It and, until now, successfully is used in different laboratories in the entire world.

The first generator was developed by American physicist by Robert by Van de Graaff in 1929 the year and made it possible to obtain a potential difference to 80 the kilovolts . In 1931, 1933 they built the more powerful generators, which made it possible to reach stress in 1 million and 7 millions of volts. But, without looking the almost centenary history of this generator, the principle of its operation is not known up to now.

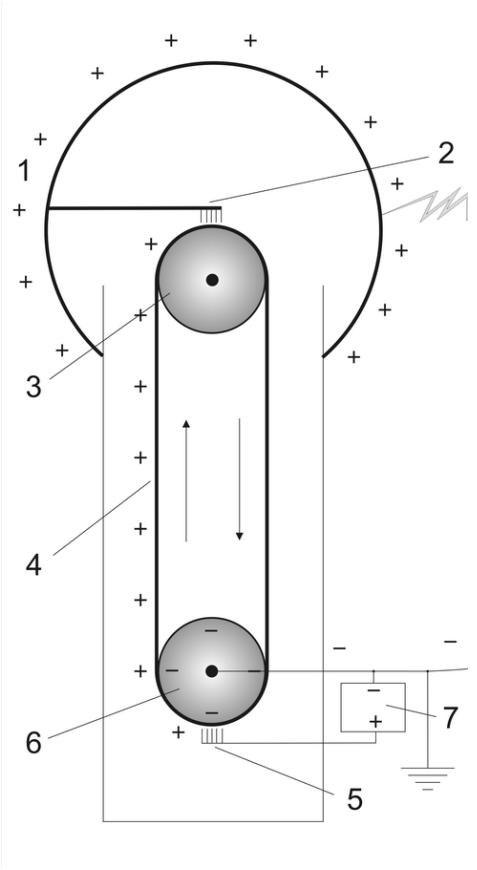

Fig. 1: Van de Graaff generator

Van de Graaff generator consists of dielectric (silk or rubber) tape 4, which it moves with the aid of the revolving rollers 3 and 6, moreover upper roller dielectric, and lower metallic and is connected with the earth . The upper part of the tape is located in the metallic hemisphere [1]. Two electrodes 2 and 5 in the form brushes are located at small distance from the tape and serve for the electrization of tape and removal from it of charges. The brush 5 serves for the ionization of air, high voltage on which will be given from the source 7. Resultant positive ions under the action of Coulomb force move to the grounded roller 6 and they settle on the tape. The moving tape transfers charge inside the sphere 1, where it it is removed by brush 2, under the action of Coulomb force charges they are pushed out to the surface of sphere and the field inside the sphere it is created only by booster charge on the

tape. Thus, on the external surface of sphere is accumulated electric charge. The possibility of obtaining the high voltage is limited by the corona discharge, appearing with the ionization of air around the sphere.

Contemporary Van de Graaff generators instead of the tapes use the chains, which consist of the alternating metallic and plastic it is sectional, which are called the pelletrons.

Unfortunately, the given oscillator circuit is only technical diagram, but the physical principle of its action, until now, is not explained. It is not understandable, what reasons cause an increase in the potential of the charges, located on the tape, with its motion from bottom to top. Generator will unclearly also function, if the moving tape was arranged the horizontally earth's surface. Not clearly also, how can be changed the polarity of generator. But since neither the physical nor mathematical model of generator is thus far developed, its improvement can be carried out only by the trial-and-error method. With this is connected the circumstance that his construction practically did not change from the times of the invention of Van de Graaff generator.

II. Mathematical Model of Van De Graaff Generator

If there is a capacitor, whose capacity C, and this capacitor it is charged to a potential difference U_0, that the energy, accumulated in it, is determined by the relationship

$$W_C = \frac{1}{2} C U_0^2 \tag{2.1}$$

Charge Q - accumulated in the capacity, is equal

$$Q_{C,U_0} = CU_0 \tag{2.2}$$

From relationship (2.1) it is evident that if the charge, accumulated in the capacity, remains constant, then stress on it can be changed by changing the capacity. In this case is fulfilled the relationship

$$Q_{C,U} = CU = C_0 U_0 = const,$$

where C, U - instantaneous values, and C_0, U_0 - initial values of these parameters.

This relationship presents the law of parametric self-induction [2-5].

The stress on the capacity and the energy, accumulated in it, will be in this case determined by the relationships:

$$U = \frac{C_0 U_0}{C} = K U_0 \tag{2.3}$$

and the energy, accumulated in the capacitor, will be equal

$$W_C = \frac{1}{2} \frac{(C_0 U_0)^2}{C} = K \frac{C_0 U_0^2}{2}. \tag{2.4}$$

Coefficient

$$K = \frac{C_0}{C} \tag{2.5}$$

let us name the transformation ratio of constant stress. It is easy this coefficient by the passing track of changing the relation of capacities.

The incremental stress, which can ensure this transformation, is determined from the relationship.

$$\Delta U_C = \left(\frac{C_0}{C} - 1 \right) U_0. \tag{2.6}$$

As follows from the relationships (2.3) and (2.4) with the decrease of capacitance of capacitor on it increases not only stress, but also the energy, stored up in the Ger. This energy is selected in the mechanical source, which ensures a change in the capacity. Therefore the transformer in question can be considered, and as the converter of mechanical energy into the electrical.

An increase in the energy, accumulated in the capacitor, with a change in its capacity is determined from the relationship

$$\Delta W_C = \frac{1}{2} (C_0 U_0)^2 \left(\frac{1}{C} - \frac{1}{C_0} \right). \tag{2.7}$$

Relationships (2.3-2.7) determine physics of the work of Van de Graaff generator. The moving metallic pelletrons or the sections of tape have relative to the earth a capacity, which during the motion of these sections relative to the earth changes according to the specific law. In the base of generator these sections should be loaded to the assigned potential of the specific sign. If the capacity of these sections will change relative to the earth, then will change the potential of the charges, located on them. In the upper part of the generator these sections betray charges with the high potential to sphere, charging it to the high voltage.

For calculating the generator it is necessary to know the initial potential of pelletrons and the law of variation in their capacity with respect to the earth during the motion of tape. Should be also known the distance of their displacement from the lower part of the generator, where they are charged, to its upper part, where they return their charge to sphere. Therefore in this case the main mathematical problem of calculating the generator is the presence of the dependence of the

capacity of pelletrons from the distance to the earth. With the vertical position of generator this there will be one dependence, with the horizontal position - another. If tape moves in parallel to the earth, then this dependence will be absent, and generator work will not be. The precise calculation of the capacity of pelletrons relative to the earth to carry out difficultly, but a good approximation is assumption about the fact that the pelletrons present the conducting spheres, whose diameter is equal to their size. In this case it is necessary to calculate the capacity of the sphere of the intended size relative to the flat conducting surface, which is the earth. This dependence is known and is determined by formula [6]

$$C = 4\pi\varepsilon a \sum_{n=1}^{\infty} \frac{\sinh\left[\ln\left(D+\sqrt{D^2-1}\right)\right]}{\sinh\left[n\ln\left(D+\sqrt{D^2-1}\right)\right]} =$$

$$= 4\pi\varepsilon a\left(1+\frac{1}{2D}+\frac{1}{4D^2}+\frac{1}{8D^3}+\frac{1}{32D^5}+\ .....\right), \quad (2.8)$$

where $D=\frac{d}{2a}$, a - a radius of sphere, d - distance from the lower part of the generator to its upper part.

But during calculations should be considered also the capacity between the pelletrons, which it is easy to measure. In this case the capacity of pelletron with the number n with respect to the first pelletron can be calculated as $n-1$ the series-connected capacitors. In this case the total capacitance between the first pelletron and the pelletron with the number n will be determined by the relationship

$$\frac{1}{C_{\Sigma}}=\frac{1}{C_{1-2}}+\frac{1}{C_{2-3}}+.....+\frac{1}{C_{(n-1)-n}}.$$

The first term in the decomposition (2.8) represents the capacity of the secluded sphere and does not depend from the distance to the earth. Us they will interest only that capacity, which depends on distance.

In the case, when d it is considerably more than a in the relationship (2.8) it suffices to take only second term of expansion. In this case the dependence of the capacity of pelletron on the distance to be determined by the relationship

$$C=4\pi\varepsilon\frac{a^2}{d} \quad (2.9)$$

In the lower position of pelletron its capacity relative to the earth comprises

$$C_0=4\pi\varepsilon\frac{a^2}{d_0}, \quad (2.10)$$

where d_0 the distance of pelletron to the earth in the lower position.

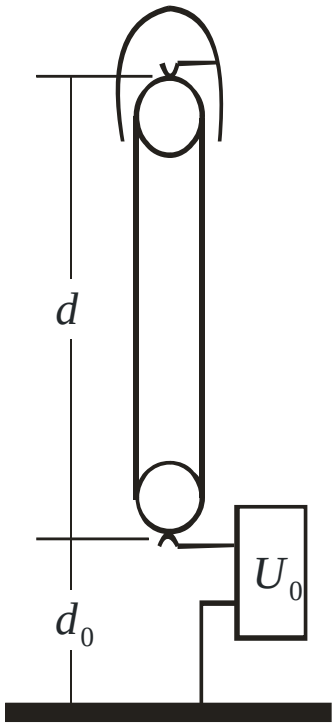

Fig. 2: Oscillator circuit

The transformation ratio of potential can be found from the relationship (2.5)

$$K=\frac{d}{d_0}.$$

Thus, are acquired all necessary data for calculating the generator. The practical oscillator circuit, in which are taken into account the principles examined, is represented in Fig. 2.

In contrast to the construction, given in Fig. 1, both upper and lower roller they are made from dielectric, and lower and upper brushes slide on peletronam. Each peletron, moving around the lower roller, by means of the brush is charged from the voltage source U_0. On the polarity of this source depends the polarity of the stress, manufactured by generator.

In order to increase transformation ratio, one should decrease d_0. With this purpose lower roller can be made composite. Its internal part should be carried out from the metal and grounded, and outside dressed collar from rubber or cylinder from the dielectric. In this case the thickness of collar or cylinder will be the size

d_0. It is possible to enter and differently. Roller to make completely from the metal and to ground, and on the rubber tape of peletrony to apply the way of metallization. Then the thickness d_0 of belt will serve as size.

Earlier us lacked the possibility to calculate stress and power of Van de Graaff generator, now this possibility is located. For this it follows to use relationships (2.3) and (2.7).

Let us give concrete example with the following parameters of the elements of the generator: rubber tape d_0 has a thickness 1 cm and a width 10 cm, which corresponds to a radius a of equivalent sphere 0.05 m. On this tape there are metallized square sections (pelletrons), which alternate with the same not metallized sections. The speed of belt 50 m/s, the distance between the lower and upper brushes d are 5 m, the voltage of the voltage source U_0 is equal 10 kV.

The stress, generated by generator, will comprise with the parameters indicated.

$$U=\frac{d}{d_0}U_0=5 \ \ MV .$$

With the speed of belt 50 m/s the charge to sphere in second will return 250 pelletrons. Each peletron will return energy in accordance with the relationship (2.4). After using relationships (2.9) (2.10) we obtain the generatable power

$$P=500\pi\varepsilon\frac{a^2d}{d_0^2}U_0^2$$

Calculation according to this formula taking into account the given parameters gives power 174 W. This power considerably less than that power, which is necessary for the mechanical motion of tape.

Using relationships (2.1) and (2.4) it is possible to calculate the electrical efficiency of the generator, which is equal to the ratio of the manufactured energy to the energy, expended by the voltage source. In this case efficiency it will be equal

$$EFF = \frac{d^2}{d_0^2} .$$

With the parameters efficiency indicated it composes the value of 2.5x10 ^{4}. This high efficiency means that practically entire mechanical energy (if we do not consider energy consumption for the drive of the motion of tape) it is expended on the production of electrical energy. By this high efficiency possesses none of the existing generators. Let us give the alternative oscillator circuit of van de Graff generator which it is represented in Fig. 3.

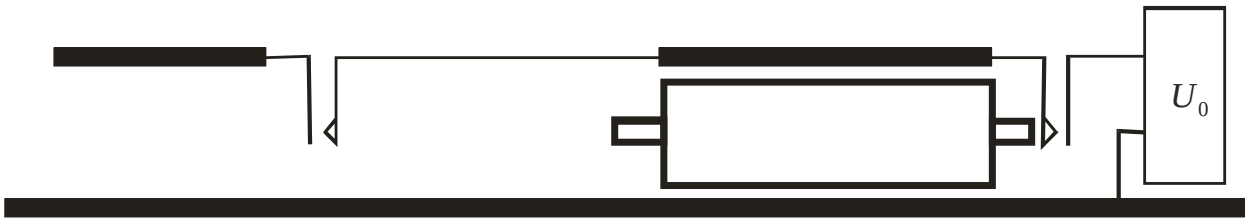

Fig. 3: Alternative oscillator circuit of van de Graff

In the diagram thick lines designated the facings of two parallel-plate capacitors. Solid line designated the lower facing, which is general for both capacitors. Between the facings of left capacitor is located the metallic plate, at ends of which are protrusions, with the aid of which can be locked and be opened contact pairs. When plate is located in the extreme by right position, it locks the contact pair, which connects the voltage source with the upper plate of right capacitor, charging it to the potential U_0. In this position of plate the capacitance of right capacitor is maximum. When plate begins to be moved to the left, right contact pair is opened, disconnecting capacitor from the voltage source. During further motion of plate the capacitance of right capacitor begins to decrease according to the linear law and potential on it grows. In the end left situation, when plate exceeds the limits of right of capacitor, and potential on it reaches maximum value, occurs closing left contact pair and part from the left capacitor passes charge into the right capacitor, and their potentials are equalized. Further cycle is repeated with the return of plate to the end right position. Thus, the transformation of potential in this case occurs according to the already examined above diagram.

III. Collectorless Generators and the Multipliers of Constant Stress

Collectorless constant-potential generators are not thus far created. Be absent also the transformers of constant stress.

The schematic of the transformer of constant stress, realizing the principle examined, is represented in Fig. 4.

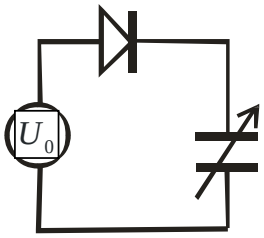

Fig. 4: Schematic of the transformer of constant stress

In this diagram to the variable capacitor by means of the diode the dc power supply is connected U_0 The incremental stress, which can ensure this transformer, is determined from the relationship (2.6).

It should be noted that this transformer can work only in the regime of an increase in the stress, since. with the attempt to obtain the decrease of voltage across capacitor this cannot be made for that reason, that the diode ensures the straight connection of the voltage source to the capacitor and therefore voltage across capacitor decrease cannot. Properties of the transformer of constant stress can be used for creating the dc power supply, whose diagram is given in Fig. 5.

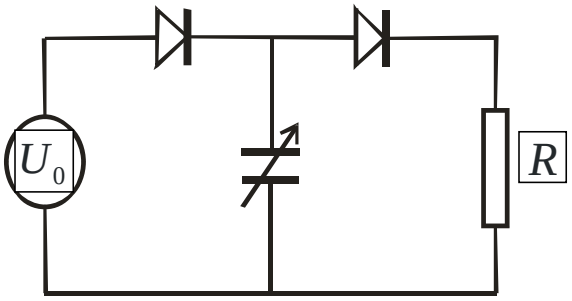

Fig. 5: Diagram of dc power supply

In this diagram is present still one diode and load resistance R.

In the initial state the capacitance of capacitor is equal C_0, and stress on it equally U_0. At this time through the load resistance the current flows

$$I_0 = \frac{U_0}{R}.$$

In this case the energy, obtained by capacitor from the voltage source, is determined by the relationship (2.1)

As soon as capacitance of capacitor will begin to decrease, secondary stress will appear on it. Secondary stress through the right diode enters the resistances R.

In the following cycle proceeds an increase in the capacitance of capacitor from the values C to the values C_0. But stress on it cannot be less than U_0, therefore the voltage source begins to charge the being increased capacity. And up to the moment, when capacitance value reaches value C_0, stress on it will be equal U_0. During this cycle the left voltage source will repeatedly consume the energy, determined by the relationship, (2.1). In this case complete cycle to be completed and the system returns to the initial state.

The operating principle of the generator examined is such to the operating principle of the valve water pump, whose schematic is represented in Fig. 6 .

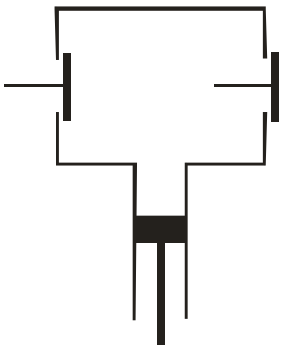

Fig. 3: Schematic of the valve water pump

With the displacement of piston downward left admission valve is opened, and water is sucked in into the cavity of pump. With the displacement of piston upward the water through the right release valve is ejected outside.

The role of valves in the schematic of the described generator diodes play, while the role of cylinder with the being moved piston performs variable capacitor.

Hence it follows that the basic problem of the creation of the proposed generator is the development of the capacitor, whose capacity changes with mechanical method. In this case the capacitor must have the great significances of initial and final capacity, also, with the large relation of these values.

IV. Conclusion

The physical principle of the work of Van de Graaff generator, until now, was not finally described, but there is only a technical oscillator circuit. There are no calculated relationships, which give the possibility to calculate this generator. In the article physical oscillator circuit is represented and it is shown that the principle of its operation is based on the use of a law of parametric self-induction. Are obtained also the calculated relationships, which make it possible to calculate the parameters of generator. The calculation, carried out employing the proposed procedure, shows that the generator in question possesses the very high electrical efficiency, which is not accessible in the existing generators. Is examined the operating principle of the multiplier of constant stress, and also the schematic of collectorless constant-potential generator.

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