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A study of space charge measurement

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A B S T R A C T

At present, there is no appropriate measurement techniques for space charge. In this paper, a U-shaped cavity device is developed as the space charge measurement device, which can be applied to transmission lines. Its design principle and calculation techniques of design parameter are also introduced. To test the space charge measurement accuracy of the U-shaped cavity device, a space charge generator is developed specifically for this experiment. The test results are excellent and show that the U-shaped cavity device can meet the design requirements. This technique is suitable for space charge measurement under transmission line normally charged work condition.

Introduction

Under the thunderstorm weather condition, the coronas of transmission lines themselves and those caused by thundercloud electric field, will produce a large amount of space charge, which may affect the choice of lightning discharge development path [1] and cause lightning disturbance such as transmission lines shielding failure [2]. It is necessary to carry out actual measurement and analysis on this kind of space charge to research this phenomenon; further to study its impact features and impact degree on development of lightning discharge paths [3].

Presently, the measurement techniques of space charge, generally, include induction method, the pulse electro-acoustic method, pressure wave propagation, etc. [4]. But these methods are not suitable for transmission line field measurement.

In this paper, a U-shaped cavity device is designed and developed as the space charge measurement device, which can be applied to measure transmission line space charge. Its design principle and calculation techniques of design parameter are also introduced. To calibrate the space charge measurement accuracy of the U-shaped cavity device, the authors design a space charge generator, analyze the generator's construction requirements, and test its effects.

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Design principle

U-shaped cavity design principle

When a conductor is introduced into an electrostatic field, the charges in the conductor will redistribute to reach electrostatic equilibrium, namely the electrostatic induction. The influence of conductor on electric field can be regarded as the influence of induction charge on it. Inside the conductor, the electric field produced by the induction charge offsets the original electric field, thus interior field intensity of conductor is zero everywhere. Therefore, a U-shaped cavity conductor is designed and space charge will enter the cavity when it is put near power lines. If the volume of U-shaped cavity device is small enough, its effect on the space electric field and space charge distribution can be negligible. Charges within U-shaped cavity are the charges existing in space, its charge density is equal to the space charge density, and this is the value we need to measure in this paper. Therefore, a micro electric field detection device is designed; it is placed into the U-shaped conductor to measure and display values for the charge electric field.

The designed U-shaped cavity conductor device is shown as Fig. 1. Assume that ρ is the charge density, d is the slit width, S is the lateral area, x is the distance from the point to be solved to the U-shaped cavity side.

According to the Poisson equation, in the static electric field with dielectric constant ε,

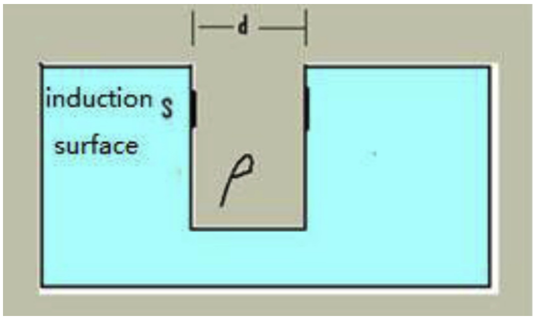

Fig. 1. U-shaped cavity conductor.

$$\frac{d^2u}{dx^2} = -\frac{\rho}{\xi} \tag{1}$$

Solving equation, we can obtain,

$$u = -\frac{\rho x^2}{2\xi} + c_1 \cdot x + c_2 \tag{2}$$

Plug the boundary conditions, for $x = 0$, potential $u = u_x$, then $c_2 = u_x$. For $x = d$, we can get $c_1 = \rho d/2\xi$ from $u = u_x$. Thus, the electric field intensity is:

$$E = \frac{du}{dx} = \frac{\rho}{\xi}\left(d/2 - x\right) \tag{3}$$

when $x = 0$,

$$E_0 = \frac{\rho}{\xi} * \frac{d}{2}.$$

when $x = d$,

$$E_\mathrm{d} = -\frac{\rho}{\xi} * \frac{d}{2}.$$

According to the above calculation, induced electric field of lateral area S is the electric field induced by space charge, and has no relationship with the conductor potential and outer electric field. It can be used to characterize the space charge density.

When $x = 0$, $E_0 = \rho d/2\xi$, it shows the space charge density in U-shaped slit is:

$$\rho = \frac{\xi \cdot E}{d/2} \tag{4}$$

In order to measure electric field intensity of the charge, a hole is made at the side of the cavity, and a miniature cylinder with sensors is embedded in the hole. The cylinder is driven to rotate at constant speed by a micro motor, as shown in Fig. 2. The width of conductor is 8 cm, the depth is 7 cm, the height is 6 cm. The width of slit of U-shaped cavity $d = 3$ cm, and the radius of the miniature cylinder is 0.5 cm, the height of the miniature cylinder is 2 cm.

Micro motor, battery, chips, and interface is installed in the U-shaped cavity conductor. Set the rotation frequency and opening angle, then the cylinder area which exposes in the electric field will vary periodically, the quantity of power line and induced charge received by the sensor will also vary periodically, resulting in a constant and measurable current.

From Gauss theorem, the induction charge on slit lateral surface S is:

$$q = D \cdot S = E \cdot \xi \cdot S \tag{5}$$

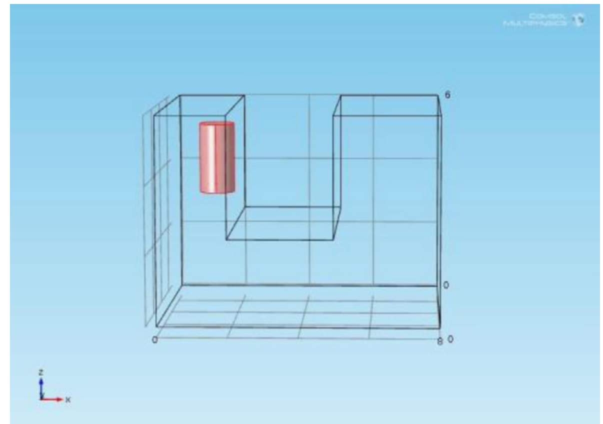

Fig. 2. Interior of U-shaped cavity conductor.

Because electrostatic field E is constant, only S varies periodically, the measured current is:

$$i = \frac{dq}{dt} = E \cdot \xi \cdot \frac{dS}{dt} \tag{6}$$

Combine (4) and (6), the space charge density is:

$$\rho = \frac{2i}{\frac{dS}{dt} \cdot d} \tag{7}$$

Space charge generator design principle

To calibrate the measuring effectiveness of U-shaped cavity charge measurement device, a kind of space charge generator is designed and developed. The generator is composed of two units, one is the corona discharge unit to produce space charge, the other is the space charge homogeneous flow cavity unit, to make space charge distribute evenly and keep a certain density which can provide to U-shaped cavity charge measurement device for calibration.

Corona discharge unit is mainly composed of “needle-plate” electrode and DC high voltage power generator. When a certain DC high voltage is imposed on the “needle-plate” electrode to cause corona discharge, corona charges are produced. The “needle” is a 4 cm-long electrode with the diameter of 0.48 cm, its tip has a diameter of 0.16 cm. The “plate” is a 5 cm × 5 cm square, which is placed 5 cm away from the “needle” and connected to the ground.

Space charge homogeneous flow cavity unit is mainly composed of homogeneous flow pipe and axial flow fan, as shown in Fig. 3. This unit docks with the corona discharge unit, axial flow fan makes corona charge to produce homogeneous flow in pipe, and keep a certain charge density. The anemometer (as shown in Fig. 5) is used to measure the flow rate in the pipe, which can be regarded as flow rate of the space charge. In Fig. 3, filter at the pipe outlet is used to collect and measure space charge. The front filter is used to filter out the space charge of outer space and reduce the influence of outer space residual charge. Homogeneous flow pipes are DN75 and DN110 insulation plastic pipes. Space charge is produced in the pipe which has 75 mm inner diameter. In order to make the space charge easy to spread, we connect the DN75 and DN110 pipes in different angle (see Fig. 4 and 6).

When we calibrate the U-shaped cavity device, it is placed in homogeneous flow pipe (as shown in Fig. 3 and Fig. 4) to measure. Its measurement results are compared with the measurement results of filter at pipe outlet, to determine the space charge measurement effectiveness and accuracy of U-shaped cavity device.