N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 4, Number 424 (2017), 208 – 218

UDC 537.523.3:541.13

Sh. A. Bahtaev, G. V. Bochkareva, G. D. Musapirova

Almaty university of power engineering and telecommunications, Kazakhstan.
E-mail: bgw@mail.ru mgulz1@yandex.ru

NON-CONTACT MEASUREMENT METERS OF MICRO-SIZES ON CORONARY DISCHARGE

Abstract. The basis for non-contact cores micrometers on corona discharge is the results of studies of the high-frequency (HF) conductivity of the plasma of the corona discharge case, the method for determining the radius of curvature of the surface of the corona electrode, methods and devices for monitoring and measuring the diameter of micro wires. The investigations were carried out when a large constant voltage and a small HF alternating voltage are applied simultaneously to the discharge gap, which is carried out by supplying an additional high voltage between the electrodes with an amplitude lower than the value of the high-voltage DC voltage, while in the plasma of the corona discharge case the mode of the resonant oscillatory process is established.

Keywords: corona discharge, radius of curvature, HF conductivity, microelectrodes, crown cover, electronic component.

Introduction. The presence of a measuring probe in the ionization region of the corona discharge greatly violates the distribution of the field density and space charges. In this connection, a method for HF diagnostics of a corona discharge plasma was developed, when a low-amplitude HF alternating voltage is applied to the discharge gap. Probing with HF alternating voltage with a small amplitude makes it possible to determine the dependence of the HF conductivity on the parameters of the discharge gap and electrical characteristics of the discharge [1].

In the device, a fully formed corona discharge, i. developed corona, is subjected to an additional alternating voltage with a frequency in the range from 200 Hz to 1.5 MHz with an amplitude of 10 to 100 V. By supplying an alternating voltage with adjustable frequency and with a small amplitude to the corona-discharge gap and measuring the high-frequency (HF) conductivity of this gap, we, as it were, perform HF probing of the developed corona, similar to the method of microwave plasma diagnostics. In this case, the most sensitive to the effect of the HF-field is the corona layer (cover) of the discharge, where, in fact, all the basic ionization processes in the corona discharge occur. Therefore, it is natural to assume that the electron density (n_e) and their collision frequency with neutral conductors (v_m) in the corona cover can be determined from the values of the HF conductivity of the discharge gap by passing a small microwave field used as a probing signal.

The HF-conductivity of the corona-discharge gap is determined by the ratio of the value of the high-frequency current of the corona to the value of the applied alternating voltage. In view of the fact that the probing HF-field has a small amplitude (10÷100 V) in comparison with the main constant voltage (3÷4 kV) supporting the corona discharge, the measured conductivity is called the dynamic differential HF-conductivity (q_d) as opposed to the static, determined from the current-voltage characteristic of the corona. When measuring q_d of the developed corona in a wide range of frequencies (from 200 Hz to 1.5 MHz), a number of anomalies were found in the dependences of q_d on the probing voltage frequency, frequency location of which also depends on the magnitude of the corona current, on the atmospheric air pressure and on the dimensions of the corona and external electrodes. All measurements were carried out for a positive corona on a micro wire in a coaxial cylinder.

To exclude the effect of the geometric capacity of the discharge chamber, it is also necessary to measure the differential HF-conductivity of the chamber (q_e) in the absence of the corona discharge. To do this, we determine the bias current through a given gap at a value of the probe field voltage equal to q_d. Knowing the total current of the corona gap and the current of its geometrical capacity, it is possible to determine the current called the "compensated" current, which makes it possible to calculate the differential HF-conductivity of the corona itself (q_d-q_e).

From the experimental data it follows that the total q_d (f) in the frequency range up to 200 kHz has a plateau (minimum), the location of which depends mainly on the diameter of the outer cylinder. With increasing frequency, the q_d (f) curve slowly increases, reaching a maximum and at a certain frequency, depending on the diameter of the corona wire and the value of the corona discharge current, crosses the conductivity straight line of the geometric capacity of the discharge chamber ($q_d = q_e$), decreasing to a minimum, and then again increases [2].

Figure 1 shows the functional diagram of the device for diagnosing the plasma of a corona discharge case. The proposed device comprises two identical chambers 1 and 2 with identical in shape and size electrodes 3 and 4, a high-voltage power supply 5 and a high-frequency voltage generator 6. The signal outputs from the two current converters 7, which are the resistors, are connected to the inputs of the balance circuit of the difference voltages 8, while the output of the balanced circuit 8 is applied to one of the inputs of the microprocessor 9. The signals from the two arms (points "a" and "b") of the chambers 1 and 2 are fed to the other inputs of the microprocessor via the separation capacitors C_1. High voltage is supplied to the main corona discharge chamber 1 through the ballast resistance $R_б$, and high-frequency voltage is applied to both chambers 1 and 2 through the separation capacitors C_2. The second ballast resistance $R_б$, connected to the point "b" of the additional chamber 2, serves to create the symmetry of the two measuring arms of the device, which also leads to mutual compensation of high frequency pickups on them.

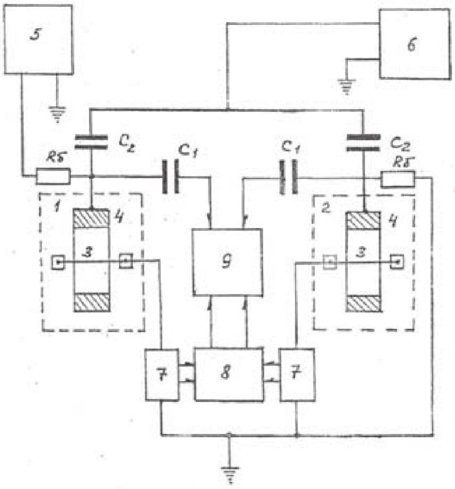

Figure 1 – Functional diagram of the device for diagnosing the plasma of the corona discharge case

When a sufficiently high voltage of negative polarity is applied to the outer cylinder of the main chamber, a corona discharge occurs between it and the corona electrode in the form of a micro wire, a stable shape of the positive unipolar corona shell is formed. When high-frequency voltage is applied to both chambers, the corona cover in the main chamber is probed, while in the additional chamber a capacitive current flows. High-frequency current components, passing through the chambers, are registered by current converters, then they enter the inputs of the balance circuit, where their differences are determined. These differences, only in the cases of q_{max}, $q_0(q_d = q_e)$, q_{min}, are measured by a microprocessor and simultaneously the corresponding resonant frequencies f_{max}, f_0, f_{min} are determined. When the experimental values of the characteristic points q_d and f on the q_d (f) curve are known, the microprocessor calculates the values n_e and v_m according to the given program, corresponding to the corona discharge case plasma.

Method for determining the thickness of the corona discharge case [3]. In this case, HF-diagnostics of corona plasma is also used, only with the difference that resonant oscillatory processes are created in the plasma of the corona discharge case by adjusting the frequency of the high-frequency voltage and then calculating the thickness of the corona discharge case by the calculation method.

When constructing the frequency dependence of the HF-conductivity of the corona, it was established from the arithmetic difference between the total current and the displacement current (capacitive) that the values of q_d may be greater or less than or equal to the value of the HF-conductivity of the discharge gap in the absence of a constant corona current (q_e).

For us, of greatest interest is the region when $q_d = q_e$, which is primarily the electronic component of the current in the corona discharge case. In this situation, as it were, a plasma resonance occurs in the corona case, i. e. the resistance of the corona case to the alternating voltage becomes minimal (voltage resonance) and the value of q_d is compared with q_e. It is established that the frequency f_0, at which $q_d - q_e = 0$, is very sensitive to changes in the thickness of the corona electrode and the corona discharge current. This means that f_0 will primarily depend on the velocity of the electron mean free path in the corona layer of the discharge gap.

Based on the obtained experimental data and theoretical calculations for the positive corona in the cylindrical system of electrodes, the calculated formula for the thickness of the corona layer (case) was derived:

$$L_e = \sqrt{\frac{0{,}7K_eU_0}{f_0 \ln\frac{R}{r_0}}}, \qquad (1)$$

where r_0 and R – radii of the corona and outer electrodes, cm; K_e electron mobility in the corona case, $cm^2/(B{\cdot}c)$; f_0 – resonance frequency at $q_d = q_e$, Hz; U_0 – alternating current voltage, V.

Thus, if the value of the corona discharge current is constant and for known values of R, r_0, U_0, K_e and f_0, the derived calculation formula makes it possible to determine the thickness of the corona case for a given electrode configuration. In other sizes and shapes of the electrode system, a calculation formula is also derived for determining L_e, starting from the distribution of the electric field and the drift zone of electrons in the corona layer, taking into account the location of the corona case in the area with a field density of 31 kV/cm (minimum breakdown voltage between the electrodes at a distance 1 cm).

To determine the thickness of the corona case, discharge chambers in the form of a cylinder with a diameter of 2 to 36 mm were used, and a microcircuit from tungsten with a diameter of 5 to 50 microns (μm) served as the central corona electrode. From the ГС-100И type of generator, an alternating sinusoidal voltage is applied to the chamber with an adjustable frequency from 200 Hz to 1.6 MHz. High voltage to the chamber is supplied from a high-voltage source of the BC-23 type. Parameters of the output AC voltage are measured at a load of 1 kOhm using the ДЭСО-2 oscilloscope, the B3-2A tube voltmeter and the frequency meter 43-22. The current of the corona was set beforehand on the microampere No. 1244 of class 0.2, which was then switched off in order to eliminate the influence of parasitic capacitances and pickups on the accuracy of measuring the main signal. The amplitude of the variable high-frequency voltage was chosen in the range from 2 to 100 V, depending on the steepness of the characteristics of the positive corona and the geometric dimensions of the discharge gap.

The value of f_0 ($q_d = q_e$) for a given configuration of the electrodes and with the constancy of the corona discharge characteristics (constancy of the discharge current and atmospheric conditions) is as follows: firstly, the dependence of the HF-conductivity of the discharge gap (q_e - capacitive) on the frequency of the alternating voltage in the absence of corona discharge is determined. Then the dependences of the HF-conductivity are constructed in the presence of the corona discharge (q_d) and by coincidence $q_d = q_e$ the value of f_0 is found, which is the calculated value for determining the thickness of the corona discharge case.

The calculated values of the thickness of the corona case are given in Table 1.

The experimental values of f_0 were determined for the corona discharge in the cylindrical electrode system when R=0.2 cm, U_0=10 V, I=20 μA, and for K_e=540 $cm^2/(V \cdot s)$ its mean value in the corona case under normal conditions of atmospheric air in Almaty (p=690 mm Hg, T=20 °C). The table shows the values of f_0 obtained for different r_0 and the calculated values for the thickness of the corona case L_e, and for comparison, the values of L_e calculated from the empirical formula $1.56\, r_0^{0.56}$ are presented.

Table 1 – Calculated values of the thickness of the corona discharge

r_0, cm	5·10-4	15·10-4	30·10-4	50·10-4
f_0, Hz	1450·103	1250·103	810·103	300·103
L_e, cm	20.63·10-3	24.15·10-3	30.1·10-3	56.13·10-3
1.56 $r_0^{0.56}$, cm	11.1·10-3	22.82·10-3	28.02·10-3	52.4·10-3

The data of the table show that the resonance of the corona case plasma occurs at different frequencies, depending on the value of r_0, which determines primarily the thickness of the corona layer (case) of the corona discharge. As was to be expected, the L_e values obtained by the proposed method slightly exceed the known L_e data for the same series of radii r_0.

Thus, there is a solution for the task to develop a method for determining the thickness of the corona discharge case, which provides high measurement accuracy due to fixation of the resonant frequency, when the influence of the high-frequency alternating voltage on the measurement results is excluded.

Method for determining the radius of curvature of the surface of the corona electrode [4]. The development of the method for determining the radius of curvature of the surface of the corona electrode is also based on the results of studies of the high-frequency (HF) conductivity of the plasma of the corona discharge case, when a large constant voltage and a small HF alternating voltage are applied simultaneously to the discharge gap.

Before proceeding to the consideration of the method for determining the radius of curvature of a corona surface of arbitrary shape, to establish the correctness of its application for solving this problem, it is necessary to check it for electrodes with a simple geometric shape, for example, coaxial cylinders.

For comparing the measured values of the thickness (L_e) of the corona case according to this method, the value of the thickness of the corona layer, determined by the Peak formula, can serve as the first approximation. In normal atmospheric conditions (δ=1), it shows that when the corona discharge is ignited, the electric field strength at the distance $\Delta=0{,}308\sqrt{r_0}$ (cm) from the corona electrode remains constant for any r0 and is equal to 31 kV/cm. Neglecting the influence of the space charge in the corona layer (E_0r_0=Er), we really get

$$\Delta=\frac{E_0r_0}{E}-r_0=\frac{E\left(1+\frac{0.308}{\sqrt{r_0}}\right)r_0}{E}-r_0=0.3\sqrt{r_0}, \tag{2}$$

which indicates that the thickness of the layer is independent of the discharge current. Apparently, the formula (2) is valid only in the case when E_0r_0=Er.

At comparable times of the electrons range and the half-period of the probing voltage, the decrease of q_d to negative values is already observed. To calculate the time range in the first approximation, a distance can be achieved as $0{,}3\sqrt{r_0}$, but when applied externally. Therefore, it is more correct to determine the shift of the apparent boundary, starting from the values of the half-periods of the alternating voltage E~.

The distribution of the field density of an alternating voltage in a cylindrical system is described by the formula

$$E_{\sim}=\frac{U_{\approx}}{(r_0+L_e)\ln\dfrac{R}{r_0}}, \tag{3}$$

where L_e– thickness of the corona layer.

For the range time of the electrons of the distance L_e it is valid

$$t=\frac{L_e(r_0+L_e)\ln\dfrac{R}{r_0}}{k_eU_{\approx}}, \tag{4}$$

taking t=T/2 and indexing the frequency f_0 *at* $q_d=q_e$ we determine the dependence of L_e from f_0 with the help of the formulas (3) and (4)

$$\frac{1}{2f_0}=\frac{L_e(r_0+L_e)\ln\dfrac{R}{r_0}}{k_eU_0\sqrt{2}}, \tag{5}$$

where U$_0$– the active value of the alternating voltage, which is equal to ~10, ~30V.

The solution of the equation is in the form of

$$L_e=-\frac{r_0}{2}\pm\sqrt{\left(\frac{r_0}{2}\right)^2+\frac{k_eU_0\sqrt{2}}{2f_0\ln\dfrac{R}{r}}}, \tag{6}$$

Substituting the value K_e=540cm2/V·s and negleting $\left(\dfrac{r_0}{2}\right)^2$, we get the final formula

$$L_e=-\frac{r_0}{2}\pm 19{,}7\sqrt{\frac{U_0}{f_0\ln\dfrac{R}{r_0}}}, \tag{7}$$

where L$_e$, R, r$_0$ – in cm; U – in V; f$_0$– in Hz.

Thus, if the value of the corona discharge current is constant and for known values of R, r$_0$, U$_0$, K$_e$, and f$_0$, the derived calculated formula allows to determine the thickness of the corona case for a given electrode configuration. With other dimensions and shapes of the electrode system, the calculation formula is also derived for determining Le, starting from the distribution of the electric field and the drift zone of electrons in the area with a field density of 31 kV/cm (minimum breakdown voltage between the electrodes at the distance of 1 cm).

The experimental values of f0 were determined for the corona discharge in the cylindrical electrode system when $R=0.2$ *cm*, $U_0=10$ *V*, $I=20$ *μA*, and for $K_e=540$ *cm2/(V·s)* its mean value in the corona case under normal conditions of atmospheric air in Almaty (ρ=690 mm Hg, T=20^{0}C).

The expression (7) allows to make qualitative estimates of the value L_e with the distance $0{,}3\sqrt{r_0}$. the calculations show, that the value L_e is closed to $0.3\sqrt{r_0}$, at frequencies f_0, though it is $L_e > 0.3\sqrt{r_0}$, with a decrease in the diameter of the corona wire. For example, L_e=0.029 cm for the values R=0.2 cm, r_0=0.005 cm, f_0=1070 kHz, U_0=10 V, and the distance $0.3\sqrt{r_0}$ is equal to 0.021 cm with decreasing radius r_0=0.001 cm, L_e=0.022 cm, and $0.3\sqrt{r_0}$ =0.0095 cm.

Table 2 shows the values of f_0 obtained for various r_0 and the calculated thickness values of the corona case L$_e$ by the formulas (7) and $0.3\sqrt{r_0}$.

Table 2 – Calculated values L_e for various r_0

r_0, cm	5·10-4	15·10-4	30·10-4	50·10-4
f_0, Hz	1450·10-3	1250·10-3	810·10-3	300·10-3
L_e, cm	20.63·10-3	24.15·10-3	30.1·10-3	56.13·10-3
$0{,}3\sqrt{r_0}$, cm	6.71·10-3	11.62·10-3	16.43·10-3	21.21·10-3

The data obtained for L_e show that the resonance of the corona case plasma occurs at different frequencies, depending on the values of r_0, which determine, first of all, the thickness of the corona layer (case) of the corona discharge. As expected, the L_e value obtained by the developed method far exceeds the calculated data for the same range of radii r0 by the formula $0.3\sqrt{r_0}$. As mentioned above, this is due to the appearance of the buildup of electrons by a high-frequency field, which leads to an intensification of the ionization processes in the corona case.

When determining the radius of curvature of the surface of the corona electrode of arbitrary shape, a constant high and variable high-frequency voltage is applied to the second electrode in the form of a flat disk (D~2 cm), closely located (4-5 mm) to the corona electrode (Figure 2).

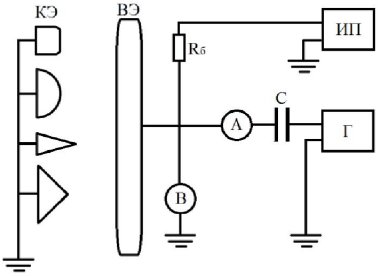

Figure 2 – Scheme for determining the radius of curvature of the surface of the corona electrode: КЭ – corona electrodes of various shapes; ВЭ – external electrodes; $R_б$ – ballast resistance; A – AC microarammeter; B – AC millivoltmeter; C – blocking capacitor; ИП – source of power; Г – high-voltage generator

A variable sinusoidal voltage with an adjustable frequency from 200 Hz to 1.6 MHz is applied to the discharge gap from the ГС-100И generator and a high-voltage is supplied from the high-voltage source of the BC-23 type. The parameters of the high-frequency voltage are varied with a microammeter and an AC voltmeter. The amplitude of the alternating high-frequency voltage was chosen in the range from 2 to 100 V, depending on the steepness of the characteristic of the positive corona and the geometric dimensions of the discharge gap.

The corona discharge arises at the top of the surface and, with a further increase in voltage, propagates through the rest of the surface.

In order to determine the initial strength of the corona discharge, in the case of electrodes of arbitrary shape, a connection is normally used between the change in the strength of the electrostatic field in the immediate vicinity of the electrode surface and the radii of curvature of this surface

$$-\frac{dE}{E}=\left(\frac{1}{R_1}+\frac{1}{R_2}\right)dx \tag{8}$$

where R_1 and R_2 – the main radii of curvature of the surface at the given point, i.e. minimum and maximum radii of curvature; x is measured from the surface of the electrode in the direction of the normal. As a result of integration and substituting the obtained expression for the field strength in conditions of discharge independence and subsequent integration, we obtain an equation for determining the initial intensity E_0.

For determining the initial tension corresponding to the given point of the corona electrode of arbitrary shape, the equation for cylindrical wires can be used, if the equivalent wire radius is calculated by the formula

$$r_{0'rd}=\frac{R_1}{1+\frac{R_1}{R_2}}\cdot\left(1+0,2\sqrt{\frac{R_1}{R_3}}\right) \tag{9}$$

The simplest way is to calculate it when the electrode is a ratation surface, for example, if the needle is approximated by a hyperboloid of rotation. In this case, the maximum radius of curvature (R_2) is equal to the radius of curvature of the curve, with the rotation of which electrode is obtained, and the minimum (R_1) is equal to the length of the normal to this curve from the axis of rotation to the point under consideration.

The radius of curvature of the top of the electrodes is precisely determined at the initial stage of the corona discharge. Indeed, for the top of the electrode of arbitrary shape we can admit $R_1 << R_2$, then with a certain error according to the formula (6.11), the resonant frequency f0 for the electrode of arbitrary shape is determined at the beginning, with the condition $q_d=q_e$, and then at this frequency the calibration curve is determined by the radius of curvature of the corona surface of the electrode of arbitrary shape.

The value of f_0 ($q_d=q_e$) for the given configuration of the electrodes and with the constancy of the corona discharge characteristics (constancy of the discharge current and atmospheric conditions) is as follows: firstly we determine the dependence of the HF-conductivity of the discharge gap (q_e - capacitive) on the frequency of the alternating voltage in the absence of corona discharge. Then dependences of the HF-conductivity in the presence of the corona discharge (q_d) are constructed and, by the coincidence $q_d=q_e$, the value of f_0 is found, which serves for determining by the calibration curve, which corresponds to the radius of curvature of the surface of the electrode of arbitrary shape.

To construct the calibration curve (Figure 3) of dependence of the equivalent radius of micro wires from f_0, discharge chambers were used in the form of a cylinder with a diameter of 2 to 36 mm, and microfibers made of tungsten with a diameter of 5 to 50 microns (μm) served as the central corona electrode.

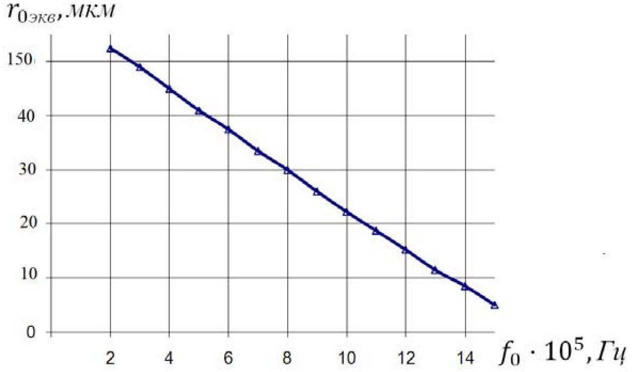

Figure 3 – Dependencies of the equivalent radius from f_0

The experimental values of f0 were determined for the corona discharge in the cylindrical electrode system when R=0.2 cm, U_0=10 V, I=20 μA. It should be noted that in the case of determining the radius of curvature of the surface of stationary parts of high-frequency equipment, the load resistance of 1 kOhm was located in a high-voltage circuit.

Methods and devices for measuring the diameter of microwires (MW). Thin and ultra-thin wire (5-100 microns) of various metals and alloys are widely used in the vacuum and electronics industries. The hogeneity of the parameters and the reliability of the operation of electric and radio tubes depend to a large extent on the quality of the tungsten wire, electrical characteristics of which, with a constant composition of the metal, are determined mainly by the geometric dimensions of its cross section. Therefore, the development of new methods and devices for the precise control of the MW size in production is of great practical importance [1].

Method for monitoring the MW diameter [5]. The main distinguishing feature of the new proposed method is that a negative corona pulse mode is used to control the MW diameter, which takes place when corona wire is cored to a diameter of up to 100 microns, whereby a stabilized negative-corona current is provided to increase the noise immunity of the measurements and the amplitude of the carrier pulses is measured.

The device implementing the proposed method comprises an annular electrode surrounding the controlled MW, a high voltage power supply source with an adjustable stabilized output current, a load resistor, a separation capacitor for removing impulse signals and a pulse voltmeter. When a sufficiently high voltage of positive polarity is applied to the annular electrode, conditions are created for the appearance of a pulsed regime of the negative corona, and ionization and excitation processes of atoms and molecules of the gas proceed in the vicinity of the corona laser, which in turn lead to the formation of numerous electron avalanches. It is established that for the pulsed regime of the negative corona, the amplitude of the pulses is directly proportional to the run length of the electron avalanches in the corona layer, the thickness of which is determined by the Peak formula and is equal to $\Delta = 0{,}3\sqrt{r_0}$, where r_0 is the MW radius. Hence, by measuring the amplitude of the current pulses with the developed corona (10-50μA), the radius (r_0) of the corona MW is determined, at this, the amplitudes of such pulses that have the largest density (carrier frequency) in the frequency spectrum of the corona current pulses are measured. The

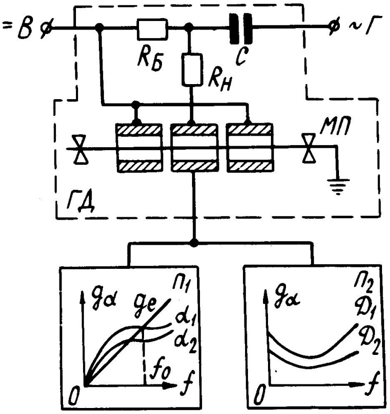

Figure 4 – CW based on the frequency dependence of the differential conductivity of the developed corona

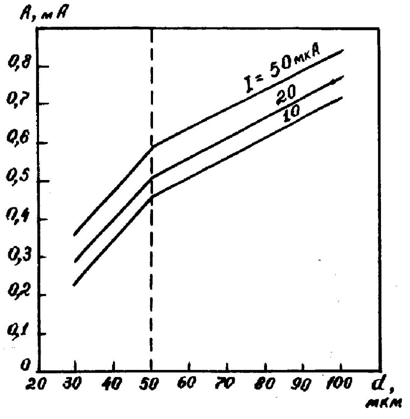

Figure 5 – Dependences of the amplitude of current pulses on the MW diameter

output signal is removed from the load resistor and fed through the separation capacitor to the input of the pulse voltmeter. During the measurement, the high voltage power supply operates in the stabilized current mode with its value set at the source output: 10, 20, 50μA.

Figure 5 shows the dependence of the amplitude of the carrier-frequency current pulses (A) on the diameter (*d*) of the corona MW for different values of the current of the negative corona. Herewith, the inner diameter of the outer annular electrode was 1 cm with a working length of 3 cm, the load resistance was 1.2 kOhm, the separation capacitance was 1 mkF. The pulse lengths varied depending on the MW diameter and lie in the range from 30 to 100 microseconds.

Experimental measurements have shown that a change in atmospheric air pressure within ± 20 *kPa* and wire vibration within ± 2.5 mm do not significantly affect the accuracy of measuring the MW diameter, which according to this method, as in all known CWs, amounts to approximately 0.5-1% of measured diameter. The existence of a fracture on calibration lines and its location is determined by the ratio *lnD/d* (D is the diameter of the outer annular electrode), which is included in the formula of the current-voltage characteristic of the corona discharge. Therefore, if necessary, to change the measurement range and the shift of the fracture point on the calibration curves in one direction or another, the question is solved by selecting the value *D*.

Device for measuring the diameter of micro wires. The main drawback of the known device [5] is related to the complexity of performing the object measurement: to find the resonant frequency, first of all, the capacitive conductance of the discharge gap is measured, and then, in the presence of a corona discharge, the high-frequency conductivity of this gap, after this, when these conductivities are equaled along a graded curve of equivalent radii, the radius of curvature of the surface of the corona electrode is determined. As follows from here, the impact on the accuracy of measuring the state of the environment will be significant.

The objective of this device is simplification and automation of the measurement process to ensure continuous monitoring of the diameter of the moving micro wire during its manufacture.

The technical result is continuity of control at high accuracy of measuring the diameter of the micro wire, which is provided by eliminating the influence of the state of the environment on the corona discharge zone.

At this device, the determination of the radius of curvature of the corona surface is ensured by feeding an additional high-frequency DC voltage between the electrodes and adjusting its frequency, creating a resonant oscillation process in the corona discharge plasma, then, at equality of the values of the high-frequency conductances of the discharge gap with the corona discharge and without it, it is possible to determine the radius of curvature of the surface of the corona electrode along the gradient curve of the equivalent radii obtained in the values of resonant frequencies (f_0).

In this case, two chambers in the form of cylinders of the same size are used, and if a high-frequency low-amplitude voltage is applied to both chambers, then a high voltage is applied omly to one of the chambers at the same time. Thus, the values of high-frequency conductivities are measured simultaneously and the difference is immediately determined using a balance circuit.

In addition, in the device, the frequency control unit, under the influence of the resulting difference in high frequency conductivities, regulates the frequency of the generator and finds an automatically resonant frequency when this difference tends to zero.

Figure 6 shows the functional scheme of the device. The device contains two parallel chambers PK and CK, which consist of measuring 1 and security 2 electrodes, measured wire 3, dies or holders 4 of micro wires, separation capacitances C_1-C_4, ballast R_1 and load resistors R_2-R_5, diodes D_1, D_2, power supply unit (БП), generator (Г), frequency counter (Ч) and frequency control unit (БРЧ).

Thin and ultra-thin wires (5-100 microns) from various metals and alloys are widely used in the electrovacuum and electronics industries. The uniformity of the parameters and the reliability of the operation of electro-radio devices depend to a large extent on the quality of the tungsten wire, the electrical characteristics of which, with a constant composition of the metal, are determined mainly by the geometric dimensions of its cross section. Therefore, continuous measurement of the diameter of the micro wire in the process of its manufacture is of wide practical importance. Micro wires are produced in the process of their hot (tungsten, molybdenum) or cold (nichrome) drawing through diamond dies. Most wire diameter meters do not provide the necessary measurement accuracy due to the effect of possible wire misalignment from the main axis and the resulting vibration when it moves. In view of the fact that in the proposed device the occurrence of resonant frequencies is directly related to processes in the corona layer or in the corona case, the influence of these factors on the accuracy of the measurement is minimal. In addition, the use of two measuring chambers and a balanced measuring circuit further reduce the influence of these factors.

The high voltage of the set value and the negative polarity from the БП is fed through the ballast resistance R_1 to the discharge chamber PK, where the corona discharge occurs, and simultaneously an alternating sinusoidal voltage with an adjustable frequency from 200 Hz to 1.6 MHz is fed to both chambers. Variable signals from the discharge and signal (CK) chambers pass through R_4C_3 and R_5C_4 - the chains are rectified by diodes D_1, D_2 and their difference is fed to the БРЧ. The frequency control unit of generator, depending on the polarity and the value of the potential difference on the capacitors C_5, C_6, regulates the

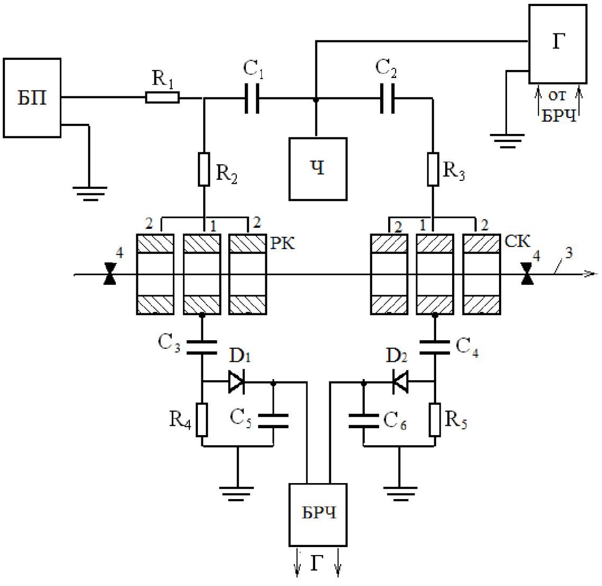

Figure 6 – Functional diagram of the device

frequency of the generator in one direction or the other. When the potential difference becomes zero, the БРЧ finishes the adjustment and at this point the oscillator frequency is fixed by the frequency meter, which is the resonant frequency (f_0) of the discharge chamber.

The high-voltage is supplied from the BC-23 type high-frequency source, and the ГС -100И type generator is used as a high-frequency generator. Frequency meter Ч3-22 is taken to measure voltage. The amplitude of the alternating high-frequency voltage was chosen in the range from 2 to 100 V, depending on the steepness of the characteristic of the positive corona and the geometric dimensions of the discharge gap.

To construct the calibration curve (Figure 3) of dependence of the diameter d of the micro wires from f_0, discharge chambers in the form of cylinders with the diameter of 2 to 36 mm were used, and the central corona electrode was microfibers made of tungsten with the diameter of 5 to 50 microns (μm).

The experimental values of f0 were determined for the corona discharge in the cylindrical electrode system when R=0.2 cm, U_0=10 V, I=20 μA. It should be noted that load resistances of 1 kOhm are located in the high voltage circuit.

REFERENCES

[1] Bakhtaev Sh.A., Bokanova AA, Bochkareva GV, Sydykova G.K. Physics and technology of corona discharge devices. Almaty, AUCP, 2007, 278 p.

[2] Bakhtaev Sh.A., Sydykova GK, Toigozhinova A.Zh., Kodzhabergenova A.K. Corona discharge on microelectrodes. Қызылдорда, Ақмешіт Баспа үйі, 2017, 212 p.

[3] Predpatent of the Republic of Kazakhstan №14033. A method for determining the thickness of a crown discharge case // Bakhtaev Sh.A., Bokanova AA, Ermagambetov SB, Uteuov M.Kh., Eleukulov EO, Toigozhinova A.Zh., Bull.No.2 15.06.2004.

[4] Innovative Patent of the Republic of Kazakhstan, No. 24408. Method for determining the radius of curvature of the corona electrode // Bakhtaev Sh.A., Bochkareva GV, Musapirova GD, Nusupbekov NA, Bull. №8, August 15, 2011.

[5] Patent of the Republic of Kazakhstan # 5070. A method for controlling the diameter of a micro wire // Bakhtaev Sh.A., Bochkareva GV, Bokova GI. Bull. №10, 1998.

[6] Innovative Patent of the Republic of Kazakhstan, No. 96543. A device for measuring the diameter of microwires // Bakhtaev Sh.A., Bochkareva GI, Musapirova GD, Avkhadieva FR, Abdreshova SB Bull. №2, 01/30/2017.

[7] Ming-Wei Li; Zheng Hu; Xi-Zhang Wang; Quing Wu; Yi Chen. Synthesis of carbon nanowires using dc pulsed corona discharge plasma reaction // Journal of Materials Science, 2004, Vol. 39, Issue 1, p. 283–284.

[8] Salvermoser, M.; Murnick, D.E. Efficient, stable, corona discharge 172 nm xenon excimer light source // Journal of Applied Physics, 2003, Vol. 94, Issue 6, p. 3722.

[9] Wang, F., Liu, J.B., Sinibaldi, J., Brophy, C., Kuthi, A., Jiang, C., Ronney, P.D., Gundersen, M.A. Transient Plasma Ignition of Quiescent and Flowing Fuel Mixtures // IEEE Transactions on Plasma Science, 2005, Vol. 33, pp. 844–849.

[10] Liu, J.B., Wang, F., Li, G., Kuthi, A., Gutmark, E.J., Ronney, P.D., Gundersen, M.A. Transient plasma ignition // IEEE Transactions on Plasma Science, 2005, Vol.33, p. 326-327.

[11] Mainelis G.,Welleke, K., Adhikari, A., Reponen, T., and Grinshpun, S.A. Design and Collection Efficiency of a New Electrostatic Precipitator for Bioaerosol Collection. Aerosol Science and Technology, 2002, 36, p. 1073-1085.

[12] Ashmarin GV Lelevkin VM, Tokarev AV Study the possibility of creating electrostatic dis- charge at small intervals. Report on the anniversary conference KRSU 2003.

[13] Yamada, Kimio . An empirical formula for negative corona discharge current in point-grid electrode geometry // Journal of Applied Physics. 2004. Vol. 96. Issue 5. P. 2472-2475.

[14] Pingao Shi, Dezhen Wang. Numerical simulation of pulsed corona discharge with dust particles at atmospheric pressure // Physics of Plasmas. 2005. Vol. 12. Issue 4.

[15] Chen J. Direct current corona-enhanced chemical reaction // P.h.d. dissertation, University of Minnesota, 2002.

[16] Yehia, A., Mizuno, A., and Takashima, K. On the Characteristics of the Corona Discharge in a Wire-Duct Reactor // J. Phys. D: Appl. Phys. 2000. Vol. 33. P. 2807-2814.

[17] Ashmarin GV, Lelevkin VM, Niyazaliev IA, Tokarev AV, Yudanov VA value of the electric wind for heat exchange in technological devices based on corona discharge // Herald KRSU. 2006. Vol. 6, N 5. P. 147.

Ш. А. Бахтаев, Г. В. Бочкарева, Г. Д. Мусапирова

Алматы энергетика және байланыс университеті, Қазақстан

ТӘЖДЕУШІ РАЗРЯДТАҒЫ МИКРОӨЛШЕМДЕРДІ ЖАНАСПАЙ ӨЛШЕУІШТЕР

Аннотация. Тәждеуші разрядтағы микроөлшемдерді жанаспай өлшеуіштер негізінде тәжделуші разряд қабы плазмасының жоғарғы жиілікті (ЖЖ) өткізгіштігін, тәжделуші электрод бетінің қисықтық радиусын анықтау әдісі, микросымның диаметрін өлшеу құрылғысы және тәсілдерін зерттеулер жатыр.

Зерттеулер разрядтық қашықтыққа бір уақытта улкен тұрақты және аз жоғарғы жиілікті (ЖЖ) айнымалы кернеу бергенде, электродтар арасында қосымша амплитудасы жоғарғы вольтты тұрақты кернеу шамасынан аз мәндіжоғарғы вольтты кернеу беру арқылы іске асады, және оның жиілігін өзгерте отырып тәждік разрядтың плазма қабында резонанстық тербелмелі режим қалыптастырады.

Түйін сөздер: тәждік разряд, қисықтық радиусы, ЖЖ-өткізгіштік, микроэлектродтар, тәж қабы, электрондық құрамы.

Ш. А. Бахтаев, Г. В. Бочкарева, Г. Д. Мусапирова

Алматинский университет энергетики и связи, Казахстан

БЕСКОНТАКТНЫЕ ИЗМЕРИТЕЛИ МИКРОРАЗМЕРОВ НА КОРОННОМ РАЗРЯДЕ

Аннотация. В основу бесконтактных измерителей микроразмеров на коронном разряде положены результаты исследований высокочастотной (ВЧ) проводимости плазмы чехла коронного разряда, способ определения радиуса кривизны поверхности коронирующего электрода, способы и устройства для контроля и измерения диаметра микропроволок. Исследования проводились, когда на разрядный промежуток подаются одновременно большое постоянное напряжение и малое ВЧ переменное напряжение, которое осуществляется путем подачи между электродами дополнительного высоковольтного напряжения с амплитудой, меньшей величины высоковольтного постоянного напряжения, при этом в плазме чехла коронного разряда устанавливается режим резонансного колебательного процесса.

Ключевые слова: коронный разряд, радиус кривизны, ВЧ-проводимость, микроэлектроды, чехол короны, электронная составляющая.

Сведения об авторах:
Бахтаев Ш.А. – д.т.н., профессор кафедры ЭиР АУЭС,
Бочкарева Г.В. – к.т.н., доцент кафедры ЭиР АУЭС, bgw@mail.ru,
Мусапирова Г.Д. – к.т.н., доцент кафедры ММиПО АУЭС, mgulz1@yandex.ru