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# ELECTRICAL MACROPARAMETERS OF HIGH FREQUENCY BIPOLAR DISCHARGES IN AIR UNDER REDUCED PRESSURE*

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Measurmeent of electrical macroparameters has been one of the ways of high frequency discharges diagnostics. For the interpretation of results and appropriate choice of a discharge equivalent diagram appears decisive. Experimentally established electrode voltage drops may lead to specification of an equivalent diagram and then to localization of capacity susceptance into the electrode layer region.

## ЭЛЕКТРИЧЕСКИЕ МАКРОПАРАМЕТРЫ ВЫСОКОЧАСТОТНЫХ БИПОЛЯРНЫХ РАЗРЯДОВ В ВОЗДУХЕ ПРИ ПРИВЕДЕННОМ ДАВЛЕНИИ

Измерение электрических макропараметров являлось одной из целей диагностики высокочастотных разрядов. Для интерпретации результатов выбор соответствующей эквивалентной диаграммы разряда имеет решающее значение. Экспериментально установленное электродное падение напряжения может привести к уточнению выбора эквивалентной диаграммы и к локализации емкостной проводимости в области электрода.

## I. INTRODUCTION

Measurement of electrical macroparameters has been one of the ways of high frequency discharges diagnostics. For the interpretation of results an appropriate choice of a discharge equivalent diagram appears decisive. Experimentaly established electrode voltage drops may lead to specification of an eqivalent diagram and then to localization of capacity susceptance into the electrode layer region.

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## II. THEORETICAL ANALYSIS

### High frequency discharges electrode voltage drop

A theoretical analysis of high frequency (further abbreviated hf) discharges electrode voltage drop determination is in [1]. From the analysis it follows that for the thermal energy, which the electrode obtains after time-transformation per 1 sec, we may write

$$Q_e = Q_{Ke} + Q_{Ae} = \left[\frac{1}{2}(U_{Ke} + U_{Ae})I_v + pU_sI_v\right] \cos\varphi\,, \qquad (1)$$

where $Q_{Ke}$ is the thermal energy obtained by the electrode when it is a cathode; $Q_{Ae}$ is the thermal energy obtained by the electrode when it is an anode; $\frac{1}{2}(U_{Ke} + U_{Ae})$ is the average value of the sum of the anode and cathode voltage drops, whose separate components, with respect to thermal inertia of the electrode layer, cannot be differentiated. Let us denote this by $U_e$ and identify as electrode voltage drop; $U_s$ is the discharge voltage on the discharge channel beyond the electrode region; $I_v$ is the discharge current; $\cos\varphi$ is the phase shift between the current and voltage; $p$ is the constant $0 \le p \le 0.5$ expressing the relative value of the discharge column thermal energy, which the electrodes obtain. From the experiment it follows that $p \doteq 0$.

After modification

$$Q_e = [U_eI_v + pU_sI_v] \cos\varphi \qquad (2)$$

$$Q_e = \bar{U}_eI_v \cos\varphi \qquad (p \doteq 0)\,, \qquad (3)$$

where $\bar{U}_e$ is the approximate electrode voltage drop value (determined in voltage effective values).

Respecting the fact that the discharge current $I_v$, the discharge voltage $U_v$ and the phase shift $\cos\varphi$ do change on varying the excitation discharge power output (the character of the discharge changes as well) it is useful to determine $\bar{U}_e$ by the relation

$$\bar{U}_e = dQ_e/dI_r\,, \qquad (4)$$

where $I_r = I_v \cos\varphi$ represents the resistance component of the discharge current $I_v$.

### High frequency discharges electrical macroparameters

The principal condition of the electrode voltage drops determination is the knowledge of the electric macroparameters which themselves are representatives of one way of hf discharge diagnostics. As a matter of fact, the electric macroparameters are always derived on the basis of an available equivalent discharge diagram.



In the case of bipolar hf discharge we generally start with a parallel combination of resistence and capacity (Fig. 1a). Using the values measured for the discharge

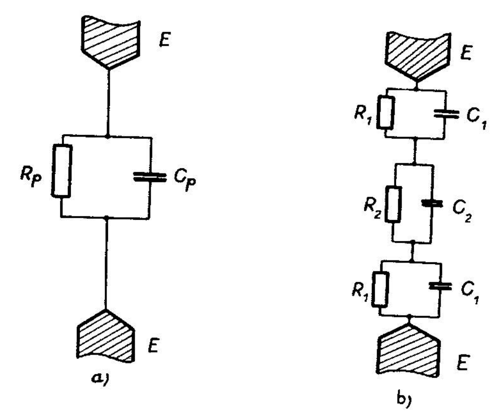



Fig. 1. Equivalent circuit diagram of bipolar hf discharges a) complete discharge ($R_p$, $C_p$); b) distribution of discharge in the region of the electrode layer ($R_1$, $C_1$) and the channel of discharge ($R_2$, $C_2$).

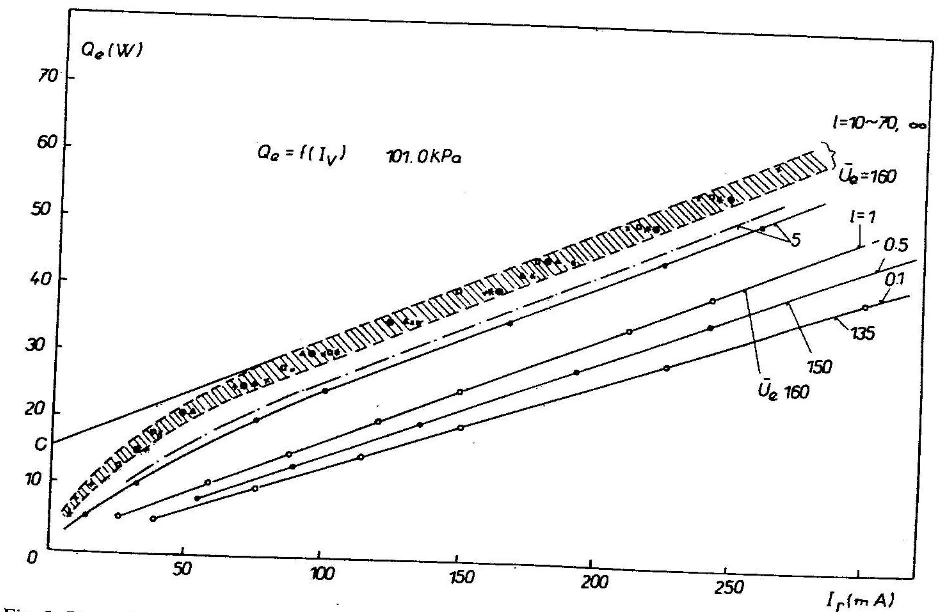



Fig. 2. Dependence of the thermal energy absorption $Q_e$ by the electrodes on the resistance component of the discharge current $I_r$. $l$ — distance of electrodes mm; pressure — 100 kPa; $\bar{U}_e$ — electrode voltage drop $V_{ef}$.

excitation power output $N_v$, the discharge voltage $U_v$ and the discharge current $I_v$, among which the following general relation is valid

$$N_v = U_v I_v \cos\varphi \,, \tag{5}$$

we may determine the discharge admittance,

$$\bar{Y}_v = \frac{1}{R_p} + j\omega C_p = G_p + j\omega C_p \tag{6}$$

$$Y_v = \sqrt{(G_p)^2 + (\omega C_p)^2} = I_v / U_v \,,$$

the discharge conductance

$$G_p = Y_v \cos\varphi \tag{7}$$

or the capacity susceptance

$$\omega C_p = \sqrt{Y_v^2 - G_p^2} = Y_v \sin\gamma \,, \tag{8}$$

the discharge capacity

$$C_p = \frac{Y_v \sin\gamma}{\omega} \tag{9}$$

and the resistance component of the discharge current

$$I_r = I_v \cos\varphi \,. \tag{10}$$

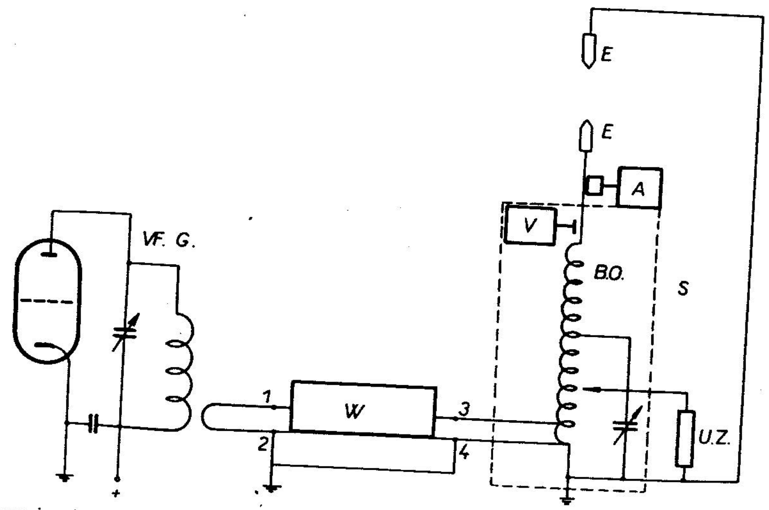



Fig. 3. Measuring instruments in the generator circuit. 2 — hf wattmeter VF. G. generator; A — hf A-meter, B. O. Excitation circuit; V — hf V-meter.



Measurements of electrode voltage drops $\bar{U}_e$ for unipolar and bipolar discharges according to relation (4) have shown (Fig. 2) that $\bar{U}_e = (150 \sim 160)$ $V_{ef}$ and for the region of the above discussed drop there may be considered the distance 0.05 ~ 0.1 mm from the electrode surface, which in fact means the region of the electrode layer [1]. For hf discharges the voltage drop mentioned produces the capacity at each electrode, which corresponds with the electrode layer region.

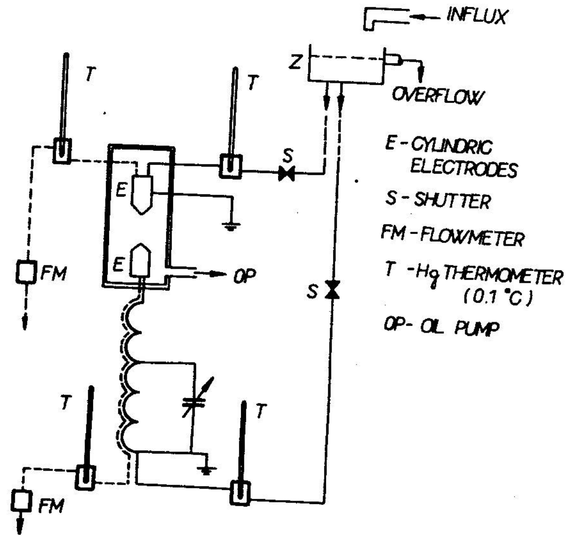


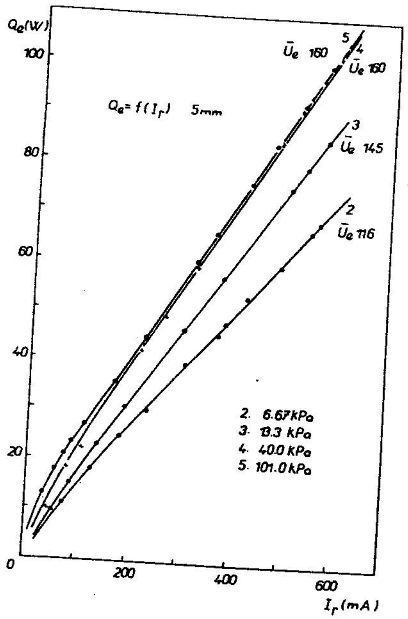

Fig. 4. Cooling system of electrodes.

Under thes assumption it is more convenient to substitute in calculations of electrical macroparameters the hf bipolar discharge by a series combination of parallel circuits according to Fig. 1b. For symmetrical discharges (hf arc) the region of the electrode layer is represented by a parallel combination of $C_1$ and $R_1$ whereas the region of the channel discharge is represented by the $C_2$ and $R_2$ combination.

The general relation for the discharge admittance absolute value (6) may be rewritten in the form

$$Y_v = \sqrt{\frac{1 + \omega^2 (C_1^2 R_1^2 + C_2^2 R_2^2 + \omega^4 C_1^2 C_2 R_1^2 R_2^2}{(2R_1 + R_2)^2 + \omega^2 R_1^2 R_2^2 (2C_2 + C_1)^2}} \,. \tag{11}$$

For short bipolar discharges up to 10 mm, where we can put $C_2$, $R_2 = 0$ relation (11) may then be transformed into



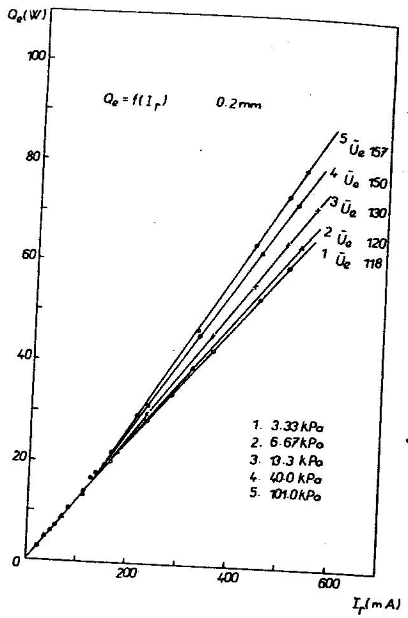
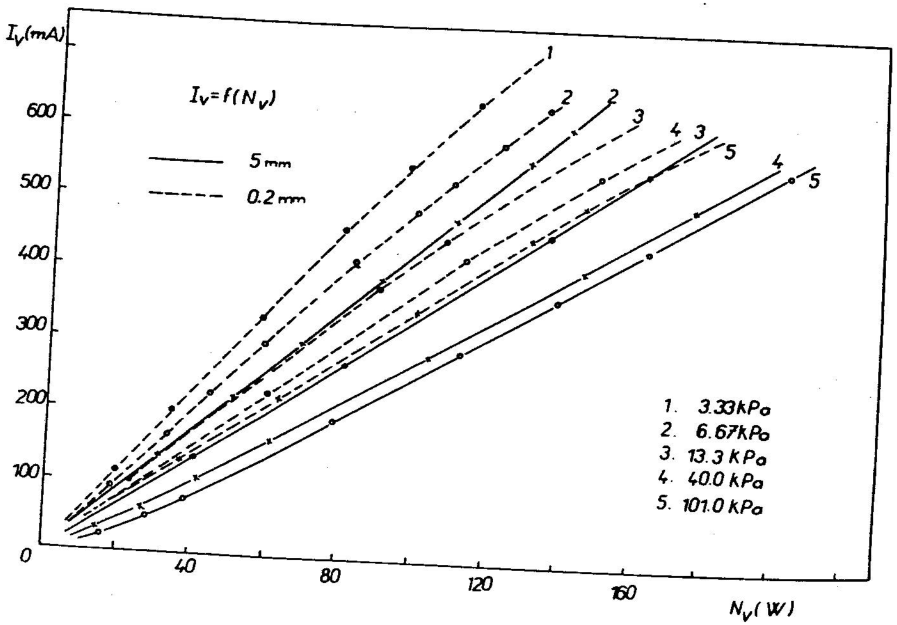




Fig. 5, 6. Dependence of the thermal energy absorption $Q_e$ by the electrodes on the current $I_r$ in the air at a lower presure. Distance of the electrodes 5 mm (Fig. 5) and 0.2 mm (Fig. 6).






$$Y_v = \sqrt{\left(\frac{1}{2R_1}\right)^2 + \left(\frac{\omega C_1}{2}\right)^2} = \frac{I_v}{U_v}, \qquad (12)$$

where $1/R_1 = G_p(1/R_1)$ represents the conductance and $C_1$ the capacity susceptance within the region of the electrode voltage drops $\bar{U}_e$, it means, within the region of the electrode layer.

Using Eqs. (7), (8), (9) the separate components of admittance and capacity $C_1$ of the hf discharges electrode layer may fairly be determined.

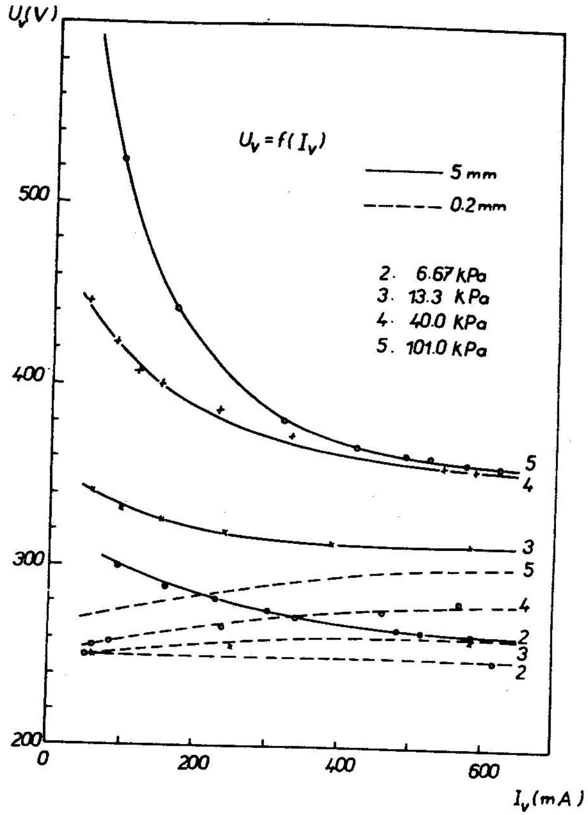



Fig. 8. Dependence of the discharge voltage $U_v$ on the current $I_v$, $U_v = f(I_v)$.

Fig. 7. Dependence of the discharge current $I_v$ on the power $N_v$, $I_v = f(N_v)$. Distance of the electrodes 5 and 0.2 mm.

## III. EXPERIMENTAL ARRANGEMENT AND RESULTS OF MEASUREMENT

The experimental arrangement for the discharge generation is shown in Figs. 3 and 4. In Fig. 3 the general connections of the hf wattmeter W, the hf ampermeeter A and the hf voltameter V and the hf generator circuit [3], [4], [5] are given for illustration. Then in Fig. 4, there is demonstrated the cooling system for the determination of the thermal energy absorbed by the electrodes [6]. Discharges are generated with the aid of hf generators having a piezoelectric stabilization of frequency of 27.12 MHz [3]. Air serves as gaseous medium at pressures 3.3~100 kPa, that means 25~760 mm Hg. The discharge length is varied within the interval of 5~0.2 mm. Results of measurements of electrode voltage drops for bipolar discharges in air at various pressures and for two extreme distances of electrodes (5 and 0.2 mm) are presented in Figs. 5, 6.

Based on relations (6—12) the individual discharge current and power output characteristics are determined, as shown in Figs. 7—10.

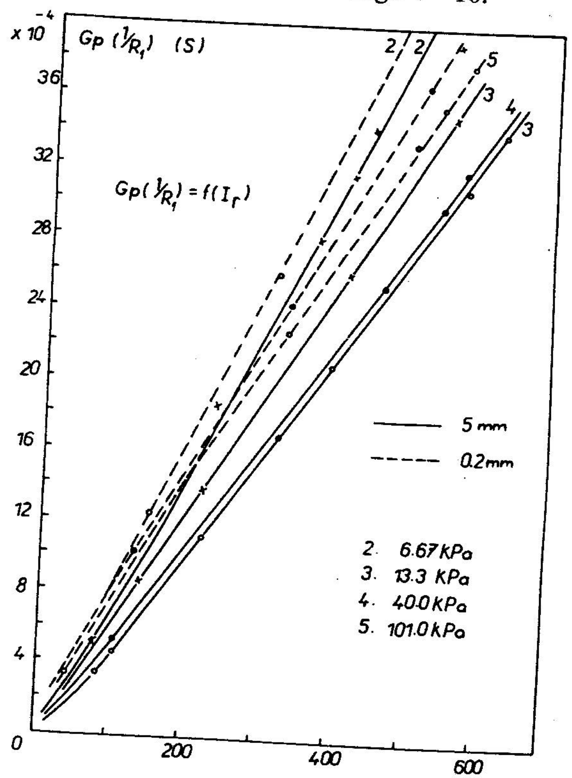



Fig. 9. Dependence of the conductance $G_p(1/R_1)$ of the electrode layer on the resistance component of the discharge current $I_r$, $G_p(1/R_1)=f(I_r)$.



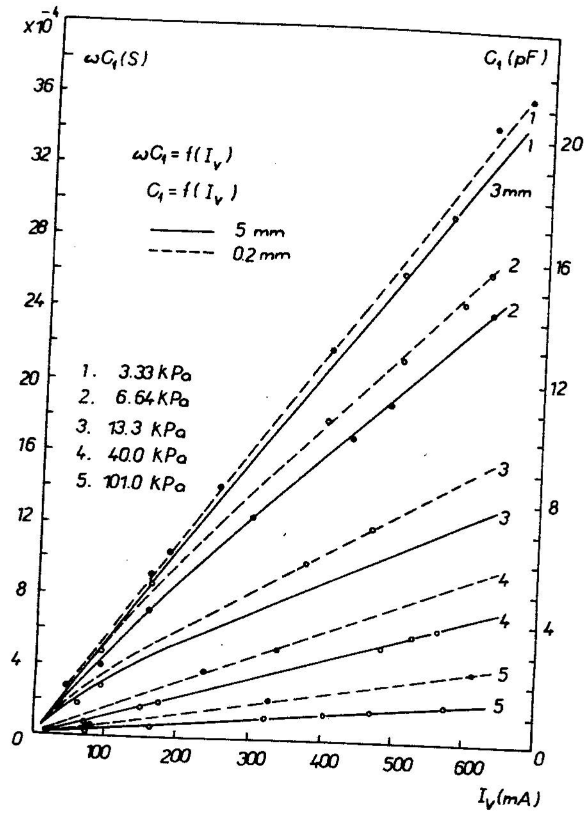



Fig. 10. Dependence of the capacity susceptance $\omega C_1$ and the capacity $C_1$ of the electrode layer on the discharge current $I_v\omega C_1$. $C_1=f(I_v)$.

## IV. CONCLUSION

From the theoretical analysis and experimental results two essential conclusions may be drawn:

1) By measurements of the electrode voltage drops it has been established that for hf discharges generated in air within the region of pressures 3.33~100 kPa the following approximate value of the electrode voltage drop holds $\bar{U}_e = 120 \sim 160\ V_{ef}$ (dependent on pressure), Figs. 2, 5, 6.

2) The discharge capacitance component is determined by the electrode voltage drop region, i. e. by the electrode layer region. It is directly proportional to the power output of the generated discharge and thus, to the discharge current $I_v$. It is pressure dependent; at pressures ranging from 3.33 to 100 kPa and a generation power output of up to 220 W it reaches values from 0.1~25 pF, Fig. 10.

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