FIELD EMISSION METHOD OF PRESSURE DYNAMICS REGISTRATION IN VACUUM INTERRUPTERS

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ABSTRACT

A new method of pressure dynamics registration in vacuum circuit breakers (VCBs) is described. It is based on dependence of field emission parameters on the pressure in VCB. It was noticed that position of current-voltage characteristic in the Fawler-Nordheim (F-N) coordinates depends on the pressure in vacuum chamber. Having made some assumptions we could register pressure dynamics by registering the change of current-voltage characteristic's intercept calculated at constant slope. This value was named as the $\tilde{A}$*-parameter. On measuring dependence of the* $\tilde{A}$*-parameter on time during a comparatively short period, one can forecast the alteration of the pressure in vacuum interrupter for a long time period.*

1. INTRODUCTION

Measurement of pressure in VCB has always been a great problem for manufacturers of vacuum switchgear. The factory made VCB can't keep its internal pressure all the time, yet its shelf life is more than 10 or 20 years and customers want to be sure that pressure in vacuum chamber won't increase considerably during this period. Thus one needs a technique that could enable to detect a residual pressure alteration in VCB.

Now the best method to measure the internal pressure of the vacuum tubes is the magnetron [1,2]. Recently Zhao Zjyu et al. suggested new method based on the magnetron but without detaching vacuum tube from interrupter [3].

In this paper we diverted ourselves from universally acknowledged magnetron method and paid attention to field emission investigations. It was found that some field emission parameters depended on the pressure inside vacuum chamber. Having made some assumptions we introduced parameter that was linearly connected with pressure in chamber. This parameter could be measured during long time period. Thus it is possible to estimate pressure change in vacuum chamber during its shelf life.

2. EXPERIMENTAL SETUP

Fig. 1 shows the experimental circuit. A pair of fixed electrode (anode) and movable electrode (cathode) made of Cu-Cr compound was set in vacuum chamber. The diameter of the electrodes was 55 mm. Distance between them was adjusted by means of micrometric screw. The residual pressure in chamber was controlled by changing of pumping speed and measured by gauge. It was altered from 5×10^{-6} to 3×10^{-4} torr. DC power supply having maximum voltage 30 kV was used.

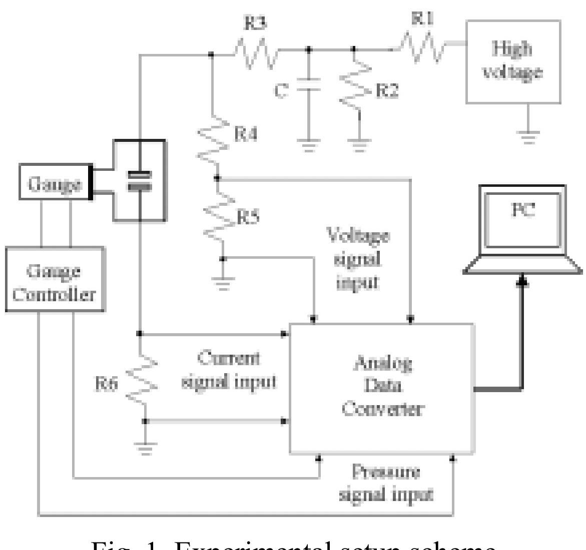


Fig. 1. Experimental setup scheme

Resistors R1, R2 and capacitor C form the high-pass filter. The current in circuit was limited to 1mA by resistor R3. Resistors R4, R5 and R6 were used to measure voltage between electrodes and cathode current respectively. Voltage, current and pressure signals were converted by ADC and worked out by PC.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In general F-N theory [4] defines dependence of field emission current density on applied electric field intensity. Our first assumption consisted in uniform distribution of emission sites on the surface of cathode. Thus we could consider the simplest form of F-N equation as dependence of field emission current on voltage between contacts

$$I = A_0 U^2 \exp\left(-\frac{B}{U}\right), \quad (1)$$

where A_0 and B are the semi-empirical constants dependent on distance between electrodes, cathode work function, number of emission sites and their form.

It was noticed during field emission tests that position of current-voltage curves (CVC) in the F-N coordinates ($1/U$, $\ln(I/U^2)$) depends on the pressure in vacuum chamber, the slope of each characteristic being almost constant (Fig. 2).

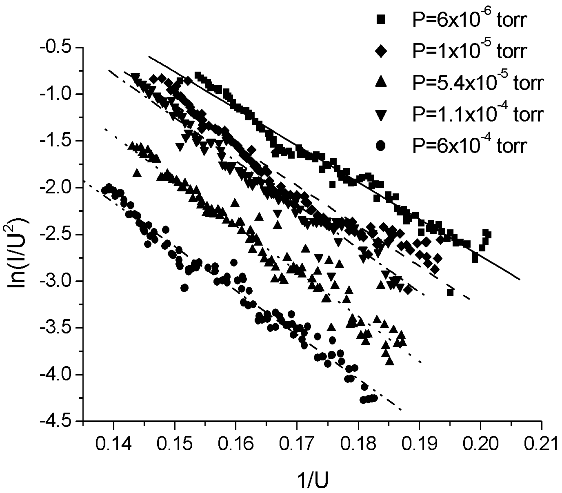


Fig. 2. Current voltage curves shift in the Fawler-Nordheim coordinates at different residual pressures

This phenomenon can be explained from the position of adsorption-desorption processes on the cathode surface, because these processes can change effective emission area. The value of effective emission area affects semi-empirical constant A_0 mentioned above and doesn't affect constant B.

To describe this phenomenon numerically the following algorithm of data processing was used. In the F-N coordinates CVC of field emission cathode should be linear:

$$\ln\left(\frac{I}{U^2}\right) = A - \frac{B}{U}. \quad (2)$$

Coefficient $A=\ln A_0$ is a CVC's intercept and depends on the cathode work function, the number of emission sites and their form. Coefficient B is a CVC's slope and depends on the cathode work function and the form of emission sites (see for example [4]). Intercept A and slope B were defined for each CVC by the least squares approximation.

Alteration of slope B for forty CVCs in the F-N coordinates at different residual pressures from 5×10^{-6} to 3×10^{-4} torr is shown on Fig. 3.

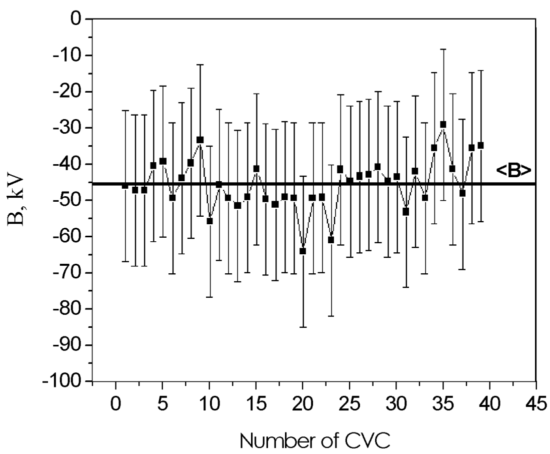


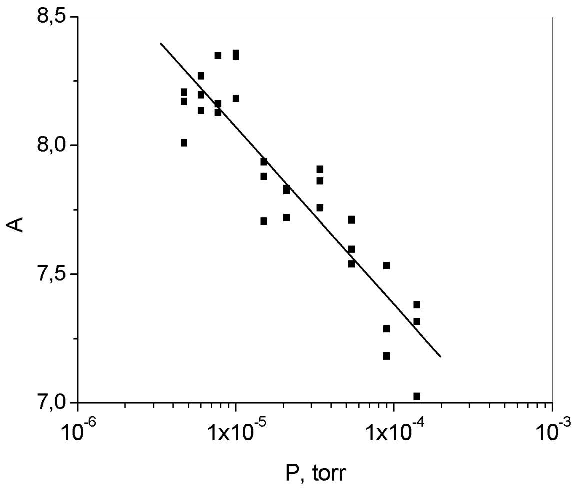
Fig. 3. Values of CVC's slope B at different residual pressures in vacuum chamber.

Simultaneous analysis of intercept A and slop B is difficult enough because error in determination of one of these coefficients influences on the precision of determination of the other one. Therefore average value $\langle B\rangle$ for a quantity of CVC's slopes was found. Our second assumption consisted in approximation of each CVC in the F-N coordinates by the least squares method at constant slope $\langle B\rangle$. In that way we calculated new value of CVC's intercept and called it $\tilde{A}$-parameter.

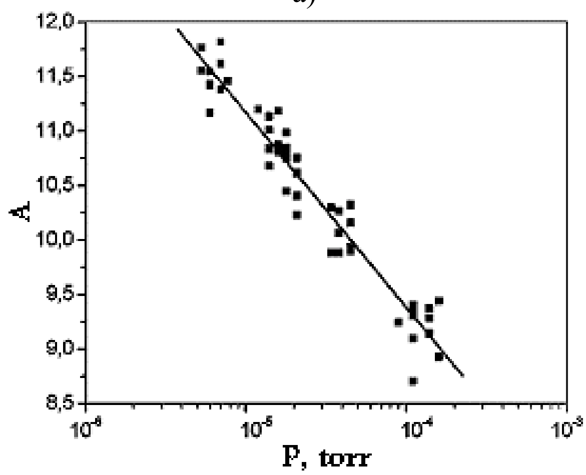
Fig. 4 demonstrates how $\tilde{A}$-parameter depends on the residual pressure in vacuum chamber at two different distances between electrodes. It is easy to see from Fig. 4 that these data can be fitted by two lines described by equations (3) for distance d=0.5 mm and (4) for d=0.25 mm:

$$\tilde{A} = - 0.7 \cdot \lg(P) + 8.8, \qquad (3)$$

$$\tilde{A} = - 1.8 \cdot \lg(P) + 13. \qquad (4)$$



a)

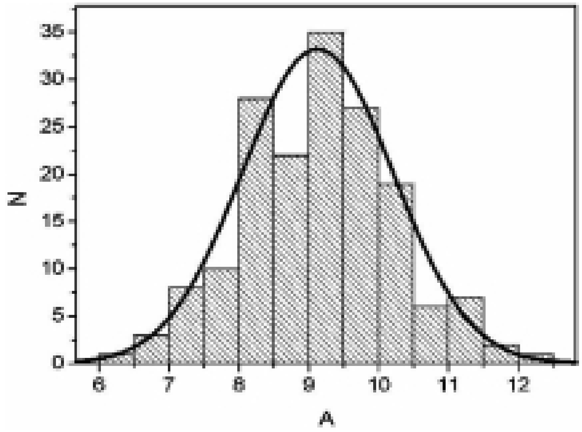


b)

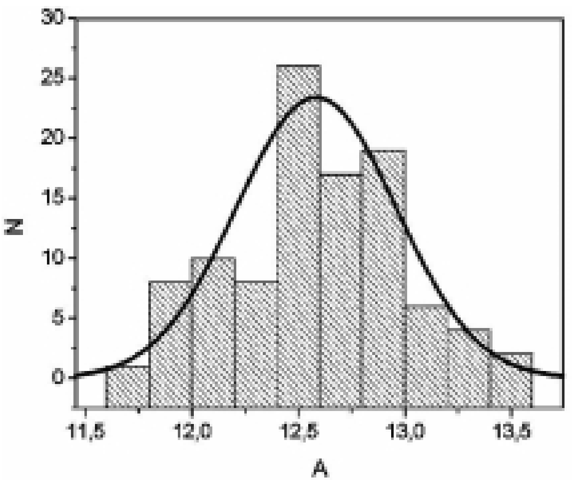
Fig. 4. Dependence of $\tilde{A}$-parameter on the residual pressure in vacuum chamber: a) — d=0.5 mm, b) — d=0.25 mm
Straight lines are described by equations (3) and (4) respectively

From Fig. 4 one can see that $\tilde{A}$-parameter has some dispersion even at constant residual pressure, so it is interesting to investigate it's distribution.

Fig. 5a represents experimental frequency function of the $\tilde{A}$-parameter at constant conditions in vacuum chamber: d = 0.5 mm and $P = 4.7\times10^{-6}$ torr. Fig. 5b demonstrates experimental frequency function of the $\tilde{A}$-parameter measured in industrial VCB at d = 0.25 mm. Residual pressure in VCB was assumed to be about 10^{-7} — 10^{-6} torr.



a)



b)

Fig. 5. Distribution of the $\tilde{A}$-parameter:
a) — in vacuum chamber at distance between electrodes d = 0.5 mm and residual pressure $P = 4.7\times10^{-6}$ torr (σ_A=0.17);
b) — in industrial VCB at d = 0.25 mm (σ_A=0.38). On both plots full line represents Gaussian frequency function for comparison

Fig. 5 reveals that distribution of the $\tilde{A}$-parameter in both cases is similar to Gaussian frequency function with standard deviations σ_A equal to 0.17 and 0.38 for vacuum chamber at d = 0.5 mm and industrial VCB at d = 0.25 mm respectively.

Using data received one can estimate the residual pressure change in VCB during its shelf life. Suppose that gas leakage rate during forecast period remains constant. In this case the following equation can be written:

$$\lg P_2/P_1 = k\Delta t\,, \quad (5)$$

where Δt is the time of the experiment, P_1 and P_2 are residual pressures at the beginning and at the end of the experiment respectively, k is a factor, depending on leakage rate. On the other hand dependences (3) and (4) were received experimentally. We wrote them in the form of equation:

$$\Delta\tilde{A} = \gamma \lg P_2/P_1\,, \quad (6)$$

From equations (5) and (6) one can derive:

$$\Delta\tilde{A} = \gamma k \Delta t\,. \quad (7)$$

Thus the change of the $\tilde{A}$-parameter during time period Δt linearly depends on this period.

From experimental data received during experimental period Δt and described by equation (7) we can derive factor k. Then using equation (5) residual pressure change during forecast time period T can be found (Fig. 6). It should be noticed that experimental period Δt must be sufficiently large because of significant dispersion of the $\tilde{A}$-parameter.

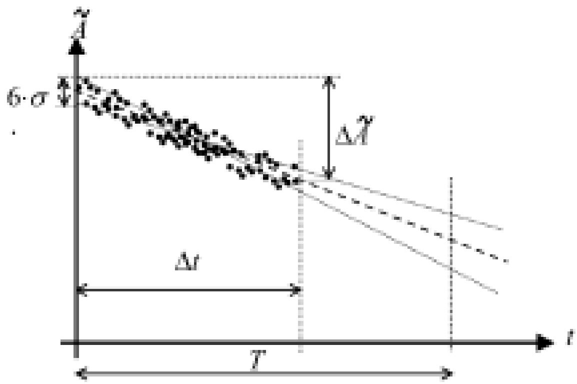


Fig. 6. Forecast scheme, describing how to use experimental data in order to estimate the $\tilde{A}$-parameter change during period T

Here some examples: using this method we can forecast the increase of residual pressure in VCB by two orders of magnitude during one year of shelf life with the error less than 7%; by three orders of magnitude during five years with the error less than 20%; by four orders of magnitude during ten years with the error less than 30%.

4. CONCLUSIONS

During field emission tests of Cu-Cr electrodes it was noticed that position of CVC in the F-N coordinates depends on the residual pressure in vacuum chamber. To describe CVC shift $\tilde{A}$-parameter was introduced. It was shown by the experiment that $\tilde{A}$-parameter linearly depended on the logarithm of residual pressure in vacuum chamber. This dependence allows us to estimate the change of residual pressure in VCB during its shelf life.

5. ACKNOWLEDGMENTS

This work was supported by the industrial group “Tavrida Electric Ltd”.

6. REFERENCES

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