Modeling of a Discharge Pulse in a Circuit With Two Discharge Gaps

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Abstract **–Many technological processes refer to formation of high voltage pulses in liquid medium. The high electrical conductivity of this medium imposes usage of switches in the high voltage circuit – most often controlled dischargers. The paper is dedicated to modelling of the electrical processes in a high voltage circuit with two discharge gaps and defining of the formed discharge pulse parameters. The analytically obtained results are compared to experimental ones from a prototype.**

Keywords **– high voltage circuit, discharge gap, pulsed discharge in liquid medium.**

I. Introduction

The application of different technologies for treatment of liquid medium suggests forming of discharge pulses with certain parameters – energy, duration, amplitude of the current, etc. Often, when the electrical conductivity of the liquid medium is high it is necessary to be used high voltage switching element [2,3,4,5].

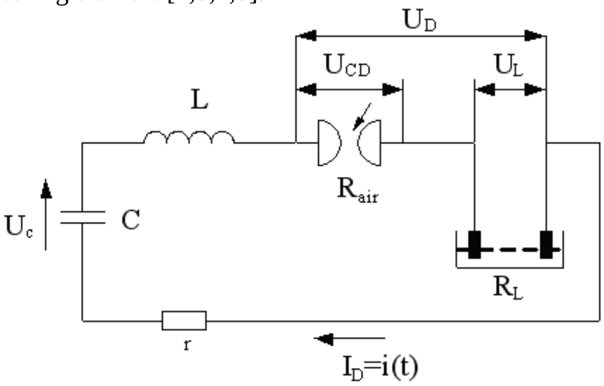

Fig.1 Discharge circuit with two discharge gaps

A similar discharge circuit is shown on Fig.1, where:

C – work capacitor battery (accumulating capacitive element), charged to voltage U_C;

L – inductivity of the capacitor battery and the connecting conductors;

CD – controlled discharger with resistance R_{IN};

R_L – resistance of the load (liquid medium);

r - resistance of the terminals of the capacitor battery and the connecting conductors;

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R_{air} – resistance of the air gap in the trigatron.

The circuit on Fig.1 is non-linear because both of the discharge gaps are nonlinear:

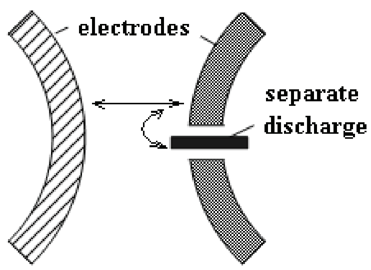
- for controlled discharger are valid:
  $U_{CD}=U_{CD}(t)$
  $I_{CD}=I_{CD}(t)$
  $U_{CD}=U_{CD}(I_{CD})$

- for the load (liquid medium) are valid:
  $U_L=U_L(t)$
  $I_L=I_L(t)$
  $U_L=U_L(I_L)$

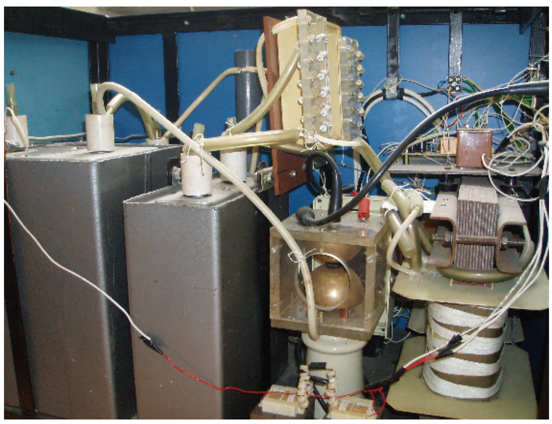
II. Analyses

The purpose of the current work is modeling of a discharge circuit with two discharge gaps and analytical and experimental study of the formed discharge pulse in the liquid medium.

If the controlled discharger is a trigatron – Fig.2, i.e. discharge in air is realized, the processes description according to fig.3 is as follows:



a)



b)

Fig. 2. a) Trigatron and b) experimental prototype

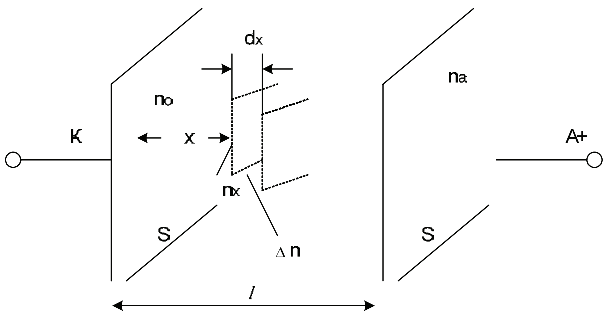


Fig. 3

If we suggest that near the cathode at the expense of external factors appeared n_o- free electrons. We accept that at a distance x from the cathode due to the avalanche process the electrons reach concentration $n_x>n_o$. Then, the increasing of the electrons dn for a distance dx is valid Eq.1:

$$dn = (\alpha - \zeta) n_x dx \tag{1}$$

- α - α - shock ionization coefficient
- ζ - coefficient, considering the reduction of electrons due to the recombination and their acceptance by the atoms, which become negative ions.

After integrating Eq.1:

$$n = n_0 e^{(\alpha-\zeta)x} \tag{2}$$

For $x=l$ the number of additional electrons formed by the avalanche process and hit the anode is n - Eq.3:

$$n = n_0 \left[e^{(\alpha-\zeta)l} - 1 \right] \tag{3}$$

If γ_{ph} is photo-ionization coefficient, then the number of new generated electrons n'_0 is:

$$n'_0 = \gamma_{ph} n_0 \left[e^{(\alpha-\zeta)l} - 1 \right] \tag{4}$$

In that case for the electrons near to the cathode is valid Eq.5:

$$n_1 = \frac{n_0}{1 - \gamma_{ph}\left[e^{(\alpha-\zeta)l} - 1 \right]} \tag{5}$$

And for the electrons near the anode (n_{an}) is valid Eq.6:

$$n_{an} = \frac{n_0 e^{(\alpha-\zeta)l}}{1 - \gamma_{ph}\left[e^{(\alpha-\zeta)l} - 1 \right]} \tag{6}$$

Then, the amplification of the gas discharge medium $k = \frac{n_{an}}{n_0}$ can be presented with Eq.7:

$$k = \frac{e^{(\alpha-\zeta)l}}{1 - \gamma_{ph}\left[e^{(\alpha-\zeta)l} - 1 \right]} \tag{7}$$

For creation of independent discharge is necessary k→∞ i.e. Eq.7 for an independent discharge becomes Eq.8:

$$(\alpha - \zeta) l = \ln\left(1 + \frac{1}{\gamma_{ph}} \right) \tag{8}$$

If we suggest for the α - shock ionization coefficient Eq.9:

$$\alpha = P_g A e^{-\frac{A U_i P_g l}{U}} \tag{9}$$

where:

- A – constant characterizing the gas
- P_g – pressure of the gas
- U_i – ionization voltage
- U - voltage applied between the electrodes, which create the field

From Eq.8 and Eq.9 can be defined the minimum between the electrodes, which guarantees inducing of independent discharge- Eq.10:

$$U = \frac{A U_i P_g l}{\ln P_g A l - \ln\left[\zeta l + \ln\left(1 + \frac{1}{\gamma_{ph}} \right) \right]} \tag{10}$$

The specific electrical conductivity γ is an integral characteristic of the discharge and generally can be defined from Eq.11:

$$\gamma = \frac{n_e e^2 \lambda_{av}}{2 m_e \upsilon_h} \tag{11}$$

where:

- n_e – concentration of the electrons
- e - charge of the electrons
- λ_{av}- free running average length of the electrons $\lambda_{av} = \frac{1}{\pi n_a r^2}$

(n_a – concentration of the atoms; r – radius of the gas atoms)

- m_e - electron weight
- υ_h - heat velocity of the electrons for gases $\upsilon_h = \sqrt{3kT_e m_e^{-1}}$ (k - Boltzmann constant; T_e – temperature of the electron gas)

After transforming Eq.11 becomes Eq.12:

$$\gamma = \frac{n_e}{n_a T_e^{0,5}} \cdot \frac{e^2}{2\pi\sqrt{3}k^{0,5} m_e^{0,5} r^2} \qquad (12)$$

For a discharge channel with length l_{ch} and radius r_{ch} the discharge voltage U_{CD} as a function of the discharge current I_{CD} – $U_{CD} = f_1(I_{CD})$ – Eq.13 can be received after transforming Eq.12:

$$U_{CD} = I_{CD} \frac{n_a T_e^{0,5}}{n_e} \cdot \frac{2\sqrt{3}k^{0,5} m_e^{0,5} r^2 l_{ch}}{r_{ch}^2 e^2} \qquad (13)$$

$$\frac{dU_{CD}}{dI_{CD}} = U_{CD} \left(\frac{1}{I_{CD}} + \frac{1}{n_a} \cdot \frac{dn_a}{dI_{CD}} + \frac{0,5}{T_e} \cdot \frac{dT_e}{dI_{CD}} - \frac{1}{n_e} \cdot \frac{dn_e}{dI_{CD}} \right) \qquad (14)$$

Eq.14 assumes a principle possibility for descending $\left(\frac{dU_{CD}}{dI_{CD}} < 0 \right)$ or ascending character $\left(\frac{dU_{CD}}{dI_{CD}} > 0 \right)$ of the volt-ampere characteristic or the presence of such sections on it. Most often, at the high current values of I_{CD} forms a ascending section, which can be presented by Eq.15:

$$U_{CD} = \sqrt{\lambda_1 I_{CD}} \qquad (15)$$

where λ_1 is a proportion coefficient - λ_1, Ω^2.A.

We accept that the liquid medium is technically clean i.e. there are dissolved impurities (gases and others) in it. A triggering pulse is applied to the trigatron and electrical discharge occurs. The resistance of the trigatron rapidly decreases and the voltage of the charged work capacitor C is fed to the electrode system, which leads to [1]:

- ionization of the gas in the dissolved gas inclusions. They can originate from local overheating under the influence of applied voltage due to the presence of impurities in the technically clean liquid medium.
- shifting of free charges in the ionized gas inclusions and concentration in the border regions under the influence of external electrical field. The ionized gas inclusions are turned into electrical dipoles.
- at the expense of Coulomb forces – chaining together of the created electrical dipoles and creating a channel with high electrical conductivity.

Therefore, according to above stated the VAC of the liquid medium can also be described by Eq.16:

$$U_L = \sqrt{\lambda_2 I_L} \qquad (16)$$

On Fig.4 are shown the dependencies $U_{CD}=U_{CD}(t)$, $I_{CD}=I_{CD}(t)$, $U_D=U_D(t)$ and $I_D=I_D(t)$. U* can be defined from Eq.10 [1].

We assume that in the discharge circuit is met the condition for aperiodic discharge - $r + R_{air} + R_L > 2\sqrt{LC^{-1}}$

For the discharge circuit on Fig.1 is valid Eq.17:

$$u_C(t) + L\frac{di(t)}{dt} + \sqrt{\lambda_1 i(t)} + \sqrt{\lambda_2 i(t)} + r.i(t) = 0 \qquad (17)$$

Eq.17 can be also presented as Eq.18:

$$\frac{1}{C}\int i(t)dt + L\frac{di(t)}{dt} + \sqrt{\lambda_1 i(t)} + \sqrt{\lambda_2 i(t)} + r.i(t) = 0 \qquad (18)$$

After differentiating and transforming is received Eq.19:

$$\frac{d^2 i(t)}{dt^2} + \left[\frac{\sqrt{\lambda_1} + \sqrt{\lambda_2}}{2L\sqrt{i(t)}} + \frac{r}{L} \right] \frac{di(t)}{dt} + \frac{1}{LC} i(t) = 0 \qquad (19)$$

Eq.19 is a nonlinear parametrical equation. It represents a model of the discharge circuit, considering the presence of two discharge gaps. Up to the present moment, the performed check shows that Eq.19 doesn't have analytical solution.

The numerical solution of Eq.19 is done on the basis of the direct method of Euler, using MATLAB. The results are shown on Fig.5 for U_C=10 kV, C=1 μF, L=0,1 μH, r =0,5 Ω.

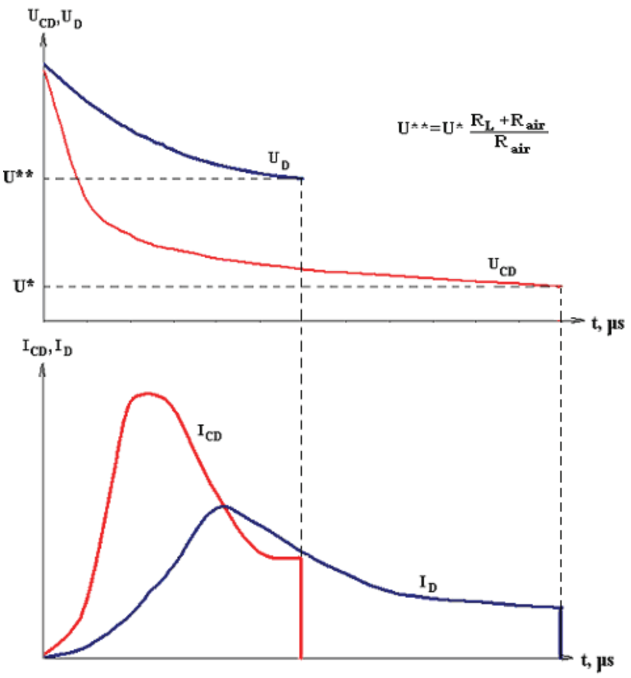


Fig.4

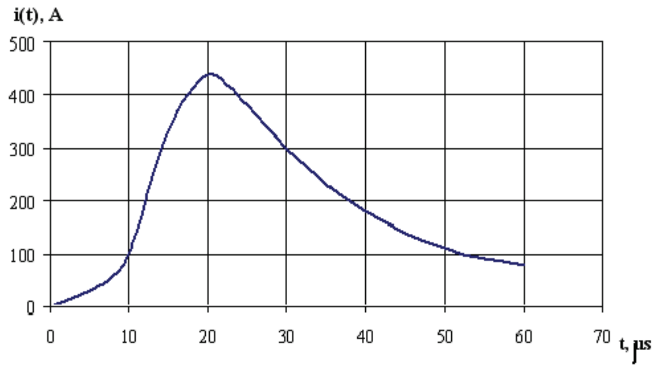


Fig.5

Experimental analyses in a discharge circuit with the configuration from Fig.1 and the above mentioned parameters show that:

- U* (Fig.4) is 700V and it is changing by ±15% as a function of the frequency of the discharge pulses. The experiments are conducted for single discharge pulses and a series with repetition frequency up to 5Hz.
- U** (Fig4) is about 2,2 kV and should be considered when defining the pulse energy.
- The experimental curve $i(t)=f_2(t)$ is above the analytically received one with approximately 27%. When commenting the accuracy, it should be mentioned that the parasitic inductivities and resistances of the capacitor battery for the calculations are taken from the catalogue data. And the accepted presentation of VAC describes well the region of the high currents.

III. Conclusion

A nonlinear model of a discharge circuit with two discharge gaps is suggested. The numerical solution of the nonlinear parametrical differential equation can be used for defining the parameters of the discharge pulse and their conformity with the requirements for certain technological application.

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