Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 6, Part 2

COMPARATIVE EXPERIMENTAL STUDY OF THE INFLUNECE OF DIFFERENT CONTROLLABLE HIGH-VOLTAGE SWITCHES OVER THE FORMATION OF DISCHARGE PULSE IN LIQUID MEDIUM

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Abstract

Various technological applications are adapted to the usage of a discharge in liquid medium. When talking about formation of a high-voltage discharge pulse, the discharge circuit follows to include two discharge mediums, one of which functions as a controllable high-voltage switch. Both of the discharge mediums influence on the parameters of the formed high-voltage discharge pulse.

The present work is dedicated to experimental study of a high-voltage discharge pulse formation in liquid medium with the usage of a trigatron (controllable air discharger) and a thyratron as controllable switches. The obtained results could be used in development of different devices for certain technological applications.

Key words: *high-voltage discharge, discharge in liquid medium, controllable high-voltage switch, trigatron, thyratron*

1. INTRODUCTION

Formation of a high voltage pulse discharge in liquid medium can be decomposed into two circuits:

- System for capacitive energy accumulation;
- High voltage discharge circuit, which forms the pulse discharge in liquid medium;

The discharge circuit should include a controllable high voltage switch. Most often are used two types of such switches:

- **Trigatron** – a three-electrode controllable discharger – fig.1, which suggests development of a discharge in air in uniform electric field. It is created between sphere-sphere electrodes after formation of a discharge between the control electrode 1 and electrode 2 – fig.1 and saturation of the inter-electrode space with current carriers.
- **Pulse thyratron** – an example variant of a power pulse thyratron is shown on fig.2. The discharge happens in hydrogen medium at low pressure, by which are accomplished both high electrical strength and high speed of the ionization and deionization processes i.e. possibility for generation of steep pulses. The possibility for hydrogen absorption from the walls of the metal-ceramic lamps is compensated by an internal hydrogen generator. The thyratron is a three-electrode gas-filled lamp where the discharge occurs between the anode (A) and the cathode (C). The cathode is heated and ribbed for achieving large emission area. Beginning of the discharge is controlled by the grid (G), which is situated at a distance of few milimeters from A, by feeding a positive pulse with respect to the cathode.

The thyratron is kept in off state if G has zero potential compared to the cathode. In the conducted experiment is used thyratron a ТГИ1-1000/25.

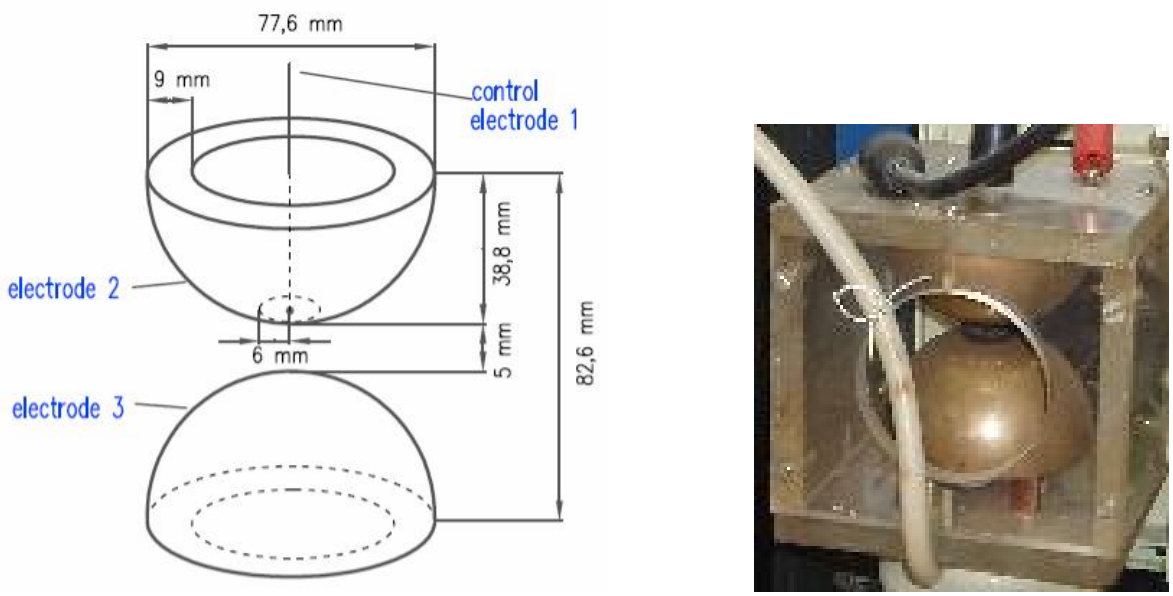


Fig.1 Trigatron

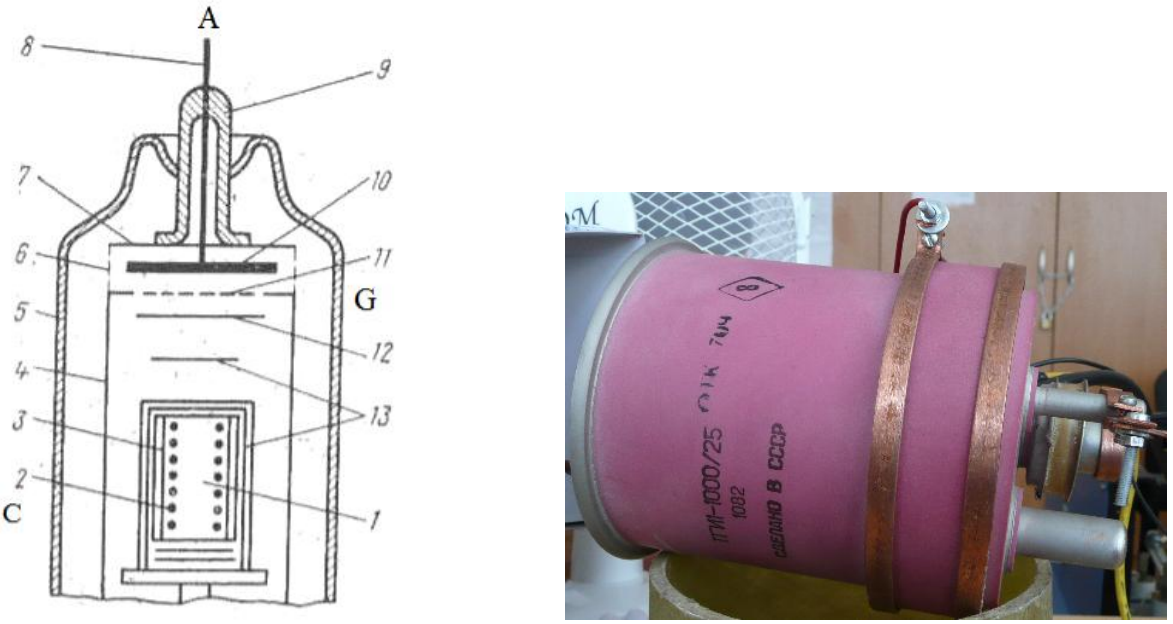


Fig.2 Thyratron ТГИ1-1000/25.

In fig.3 is shown the control pulse, which is applied to G. It can be seen that the steepness of the leading edge is in the order of 1500V/μs.

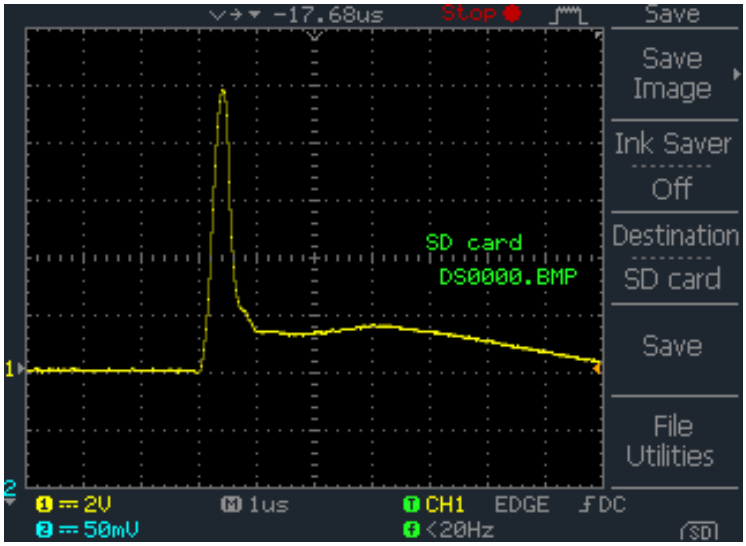


Fig..3 Control pulse, applied to the grid G of the thyratron

In fig.4 and fig.5 are presented the circuit diagrams for the experimental study respectively with a trigatron and a thyratron. High-voltage discharge pulse in the liquid medium occurs after charging the capacitor battery (CB) C by supplying a control pulse to the thyristors T_1 and T_2.

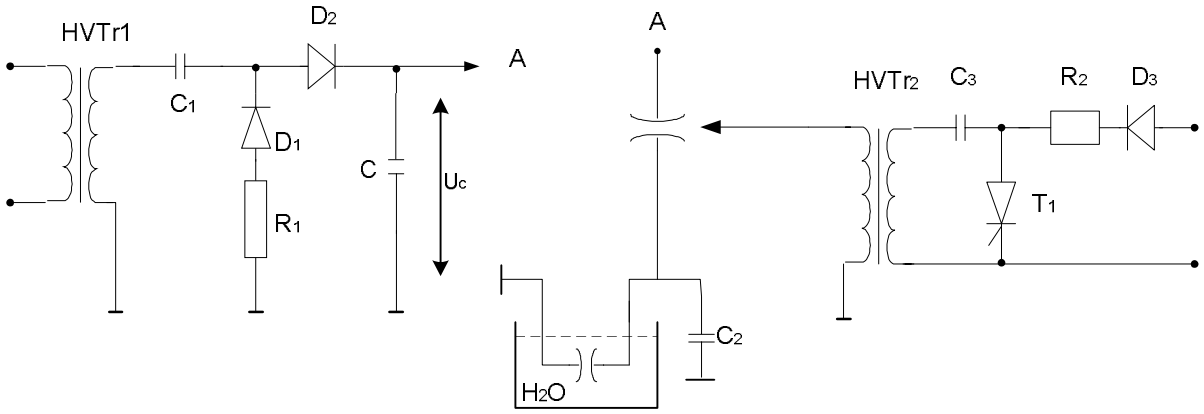


Fig.4 Circuit diagram for realization of a pulse discharge in water with the usage of trigatron as a high-voltage switch

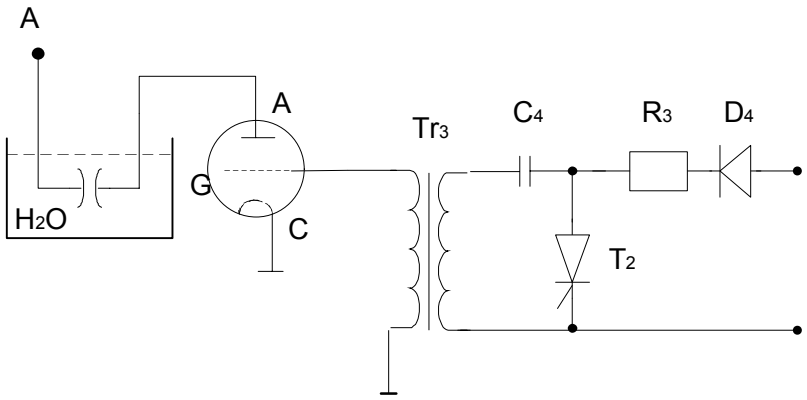


Fig.5 Circuit diagram for realization of a pulse discharge in water with the usage of thyratron as a high-voltage switch

The purpose of the current work is to conduct an experimental study for the two controllable dischargers (CD) – fig.4 and fig.5 with respect to the following parameters:

- Discharge current – i=i(t);
- The voltage to which CB– C remains charged– fig.5,after breaking up of the gas-discharge channel in CD (suspending of the discharge process) - u_c^*;
- energy given in the gas-discharge interspace – W;
- resistance R=R(t) of the high-voltage circuit,

at parameters capacitance of CB and voltage to which it is charged before formation of the discharge pulse U_c.

ANALYSIS

The character of the discharge pulse with a CD – trigatron is shown on fig.6. The discharge appearance is connected with supplying high-voltage high-frequency pulses between the control electrode 1 and electrode 2 – fig.1. These pulses are formed by the discharge of C_3 through the primary winding of the high-voltage transformer $HVTr_2$ after turning on of the thyristor T_1 – fig.5.

The change of the discharge current i=i(t), immediately after applying a high-voltage high-frequency pulse in the first few microseconds can be followed in details on fig.7.

After these high-voltage high-frequency pulses follows some time for increasing of the current carriers concentration – approximately 160 μs. This time depends on the geometry of the trigatron and the parameters of the packet with high-voltage high-frequency pulses and is almost uninfluential of the capacitance C=0,5÷2μF of CB, and the voltage to which it is charged $–U_C$= 9,5÷11,5kV.

The reason for the above effects is that there exist two spatially decomposed gas-discharge channels in two different discharge circuits. The first channel is between the control electrode 1 and electrode 2 – fig.1 and the second one is between electrodes 2 and 3.

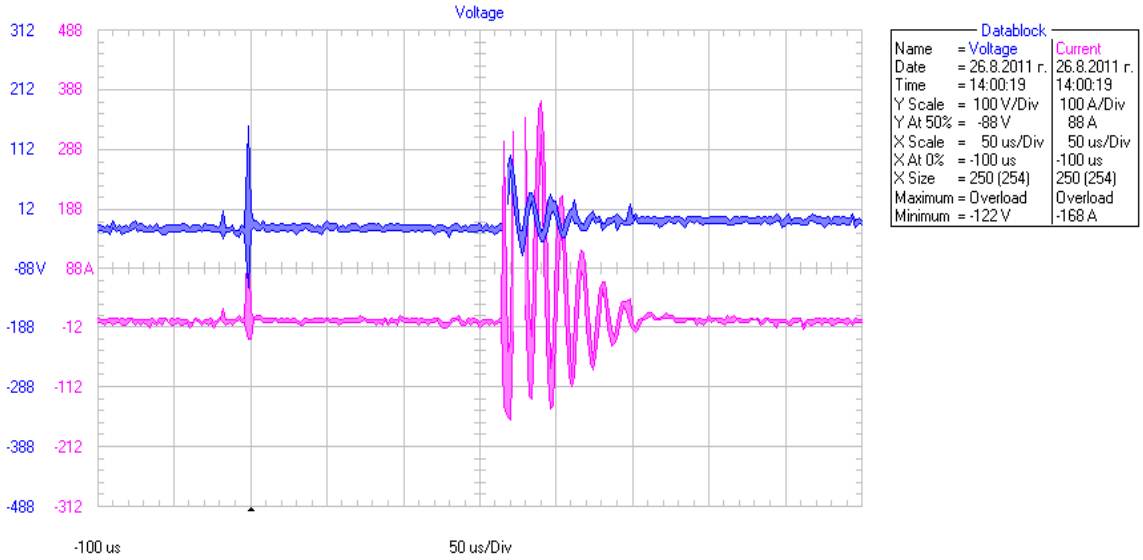


Fig.6 Time diagram of the discharge process at parameters C=0,5μF, U_C=11,5kV

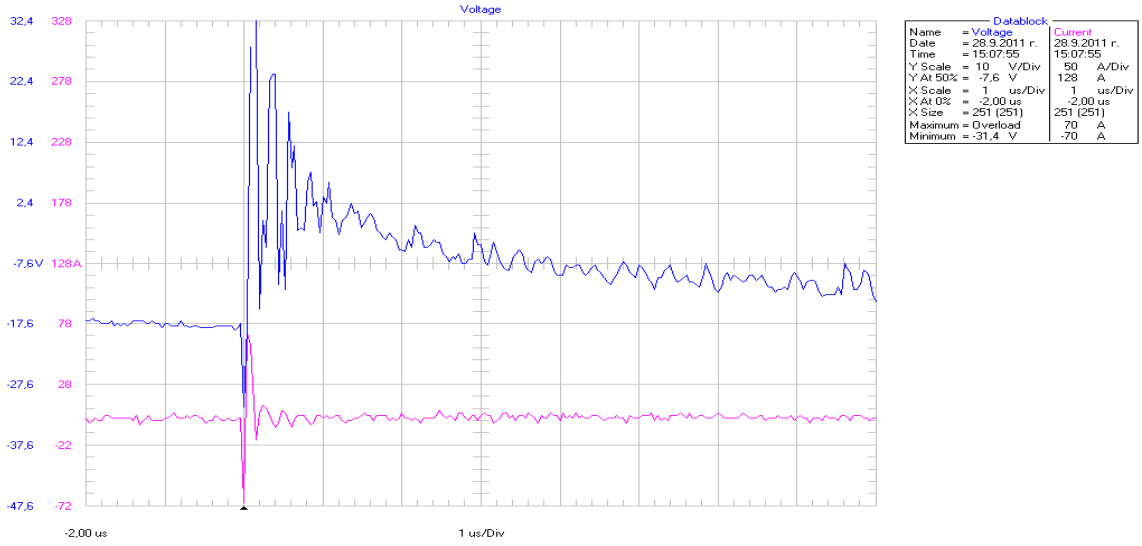


Fig.7 Time diagram of the discharge current

Development of a periodically attenuating pulse discharge starts after the necessary concentration of current carriers is reached.

The character of the discharge process with a CD - thyratron is shown on fig.8 and fig.9. The dependency i=i(t) in fig.8 presents a periodically attenuating process, and i=i(t) – fig.9 is aperiodic process, which develops at smaller accumulated energy in CB – C – fig.5.

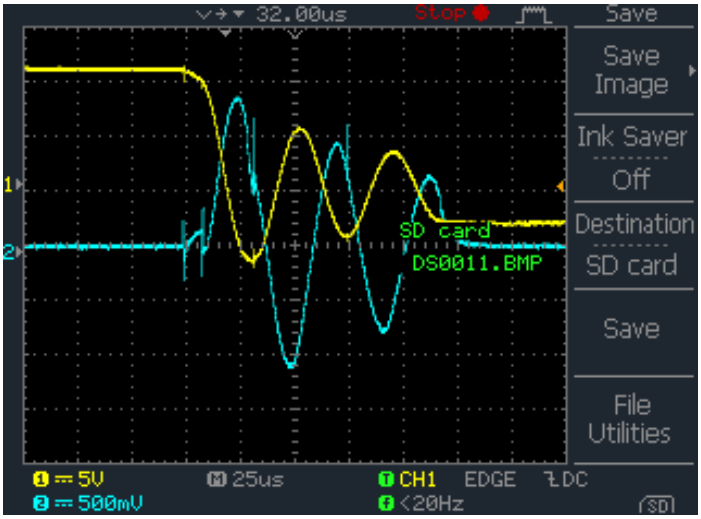


Fig.8 Discharge current and voltage at parameters U_C =11kV, C=1,5μF

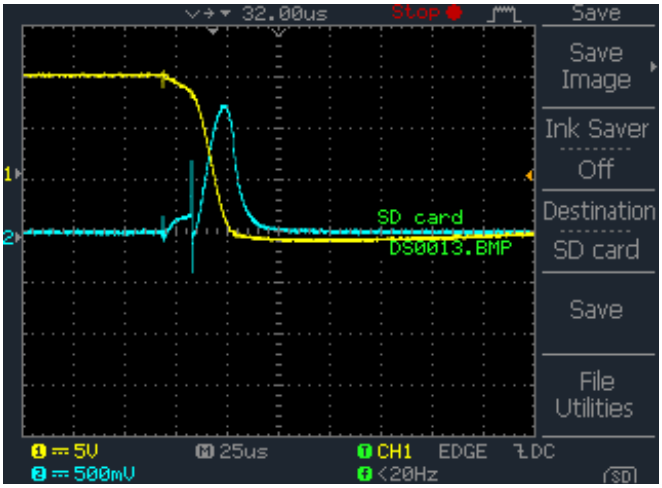
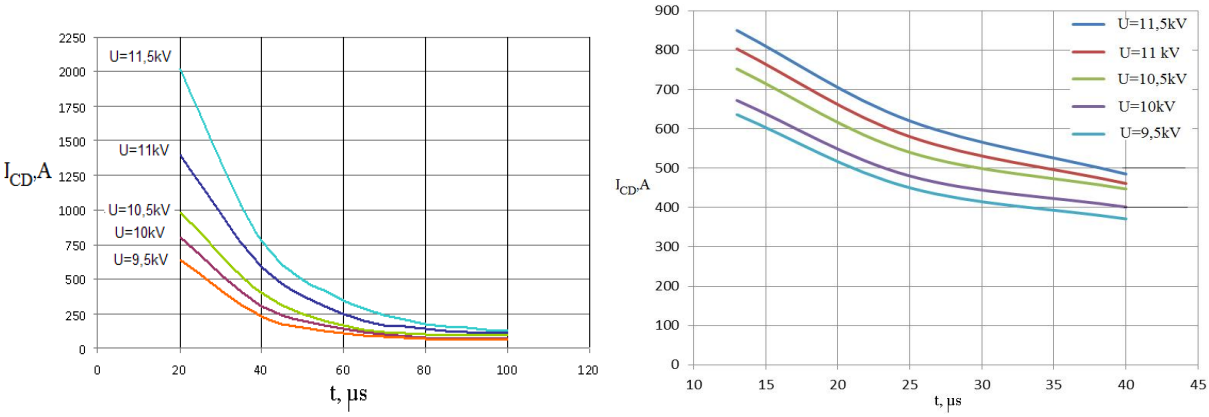


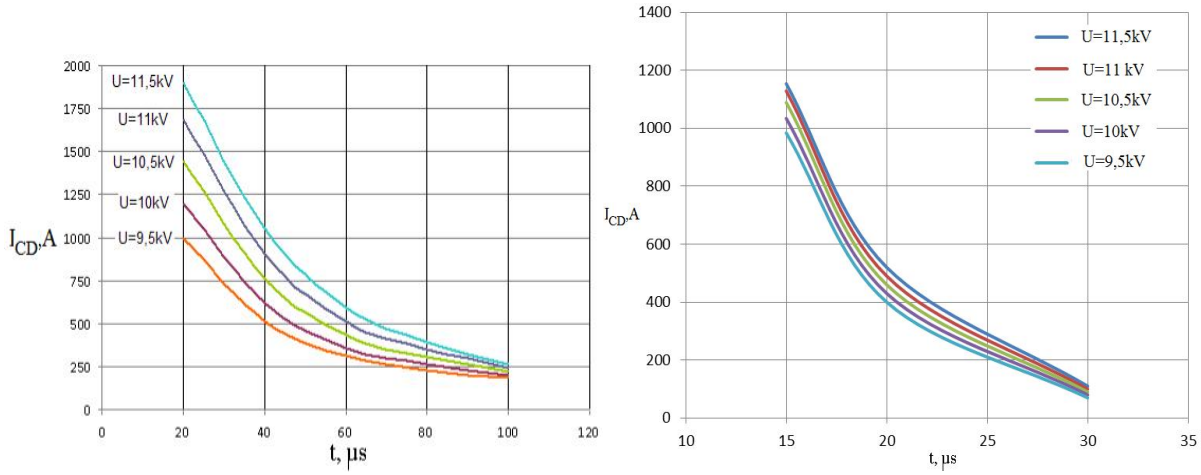
Fig.9 Discharge current and voltage at parameters U_C =10kV, C=1,5μF

The change of the wrap curve formed by the oscillation amplitudes of the current in the high-voltage circuit can be traced in fig.10 to 13, where the graphics with index "a" refer to a CD-trigatron and those with index "b" – to a CD-thyratron.



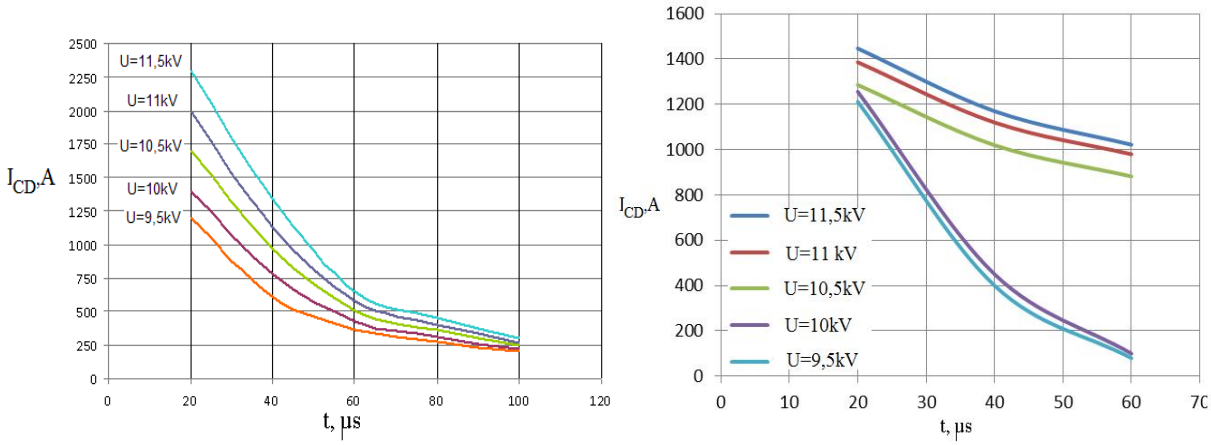
a) trigatron b) thyratron

Fig.10 Wrap curves of the current oscillation amplitudes at capacitance of CB - C=0.5 μF



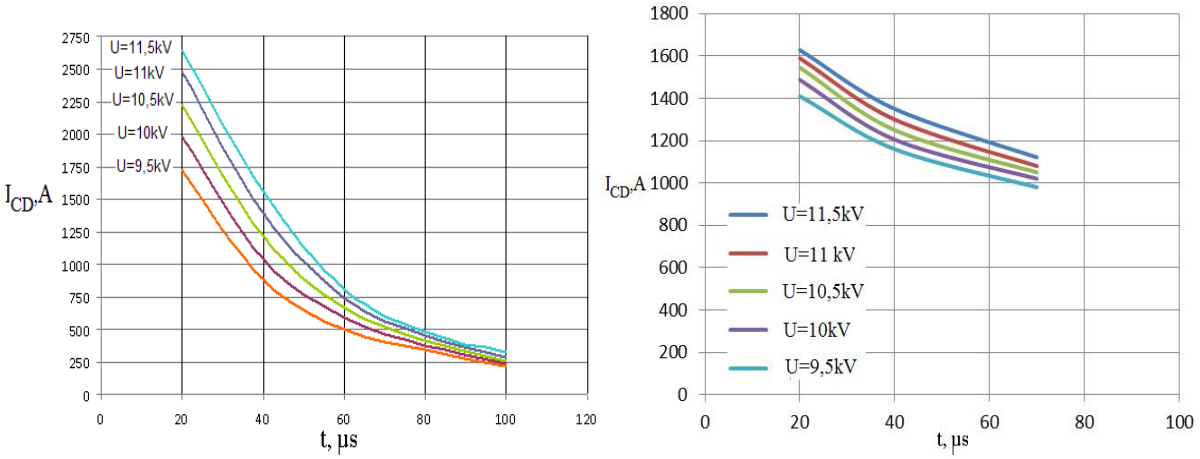
a) trigatron b) thyratron

Fig.11 Wrap curves of the current oscillation amplitudes at capacitance of CB - C=1 μF



a a) trigatron b) thyratron

Fig.12 Wrap curves of the current oscillation amplitudes at capacitance of CB - C=1.5 μF



a) trigatron b) thyratron

Fig.13 Wrap curves of the current oscillation amplitudes at capacitance of CB - C=2 μF

The circuit including the charged capacitor battery (CB) - C (fig.5), the connecting conductors and the CD can be examined as a RLC circuit where:

- R=R(t) – non-linear resistance of the gas-discharge interspace in the CD;
- L – inductance of the connecting conductors and parasitic inductances of the connected in parallel and /or series capacitors of the CB;
- C – capacitance of the CB.

The change of the discharge current can be defined by equation 1 [5]:

$$\frac{d^2i}{dt^2} + 2\delta\frac{di}{dt} + \omega_0^2 t = 0\,, \qquad (1)$$

where:

- $\delta = \frac{R}{2L}$ - coefficient of attenuation
- $\omega_0^2 = T^{-2} = \frac{1}{LC}$ - circuit resonance frequency

When $\delta<\omega_0$, the change of the current has a periodically attenuating character – fig.14. The condition $\delta<\omega_0$ can be also presented as $R<2\rho$, where $\rho = \sqrt{\frac{L}{C}}$ is the characteristic resistance. For low-resistance gas-discharge circuits is uppermost valid the above condition.

Fig.14 specifies the change of the discharge current in time.

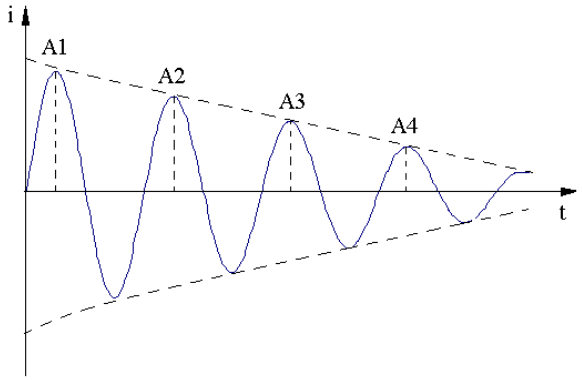


Fig.14 Time diagram of the discharge current

When R=const is valid equation 2:

$$\frac{A_1}{A_2} = \frac{A_2}{A_3} = e^{\delta T} = \Delta = const\,, \qquad (2)$$

where:

Δ – decrement of attenuation.

The formed gas-discharge channel in CD is a non-linear, unstationary dynamic load with randomly changing geometry in space.

The examined CD has three electrodes with two independent discharge circuits and two different in space gas – discharge channels which develop consecutively in time. One of them ensures the beginning of the discharge on the basis of a packet with high-voltage high-frequency pulses, and the other one forms a high-voltage pulse discharge based on the accumulated energy in the capacitor battery. [1,4]

The shown curves in fig.10,11,12 and 13 give a possibility also to define R=R(t).

It is accepted that the curve R=R(t) is discretized for time intervals equal to the period of the attenuating periodic oscillation i.e. in the range of one period R=const. Consequently, the task for defining R=R(t) turns into determination of R=R(T_i), where i=1..n.

If in equation 2 is accepted that $\frac{A_1}{A_2} = \Delta_1; \frac{A_2}{A_3} = \Delta_2 .. \frac{A_i}{A_{i+1}} = \Delta_i$ - fig.2, than for R_{Ti} is valid equation 3:

$$R_{Ti} = 2\rho\left(\ln A_i - \ln A_{i+1}\right) \quad , \qquad (3)$$

where $\rho = \sqrt{\frac{L}{C}}$.

As far as L includes the inductance of the connecting conductors and the parasitic inductances of the capacitors in CB, than its defining could be done by measuring the period of the attenuating periodic oscillations T, according to equation 4:

$$L = \frac{T^2}{4\pi^2 C} \qquad (4)$$

In fig.15÷18 is presented the change of R_{Ti} for the first four periods at parameters C and U_C.

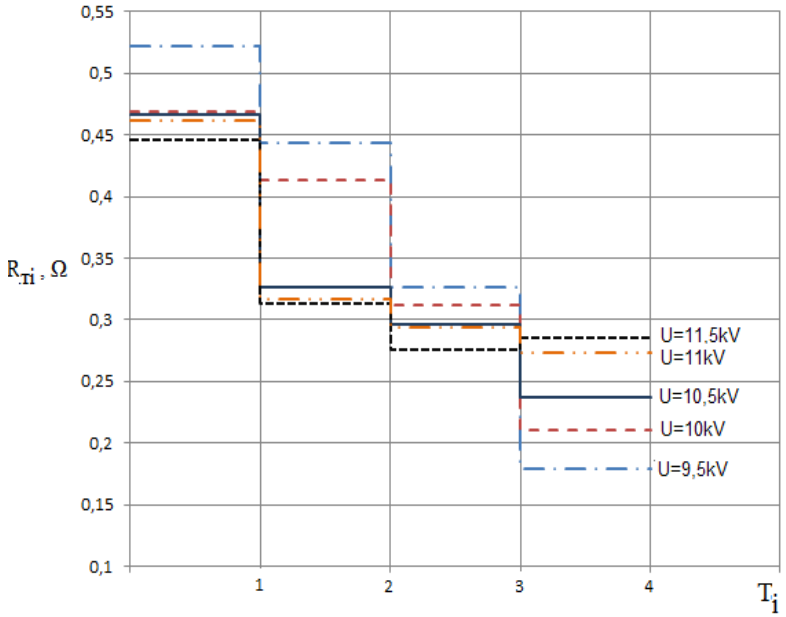


Fig.15 Dependency R=R(T_i) at a parameter C=0,5μF for a trigatron

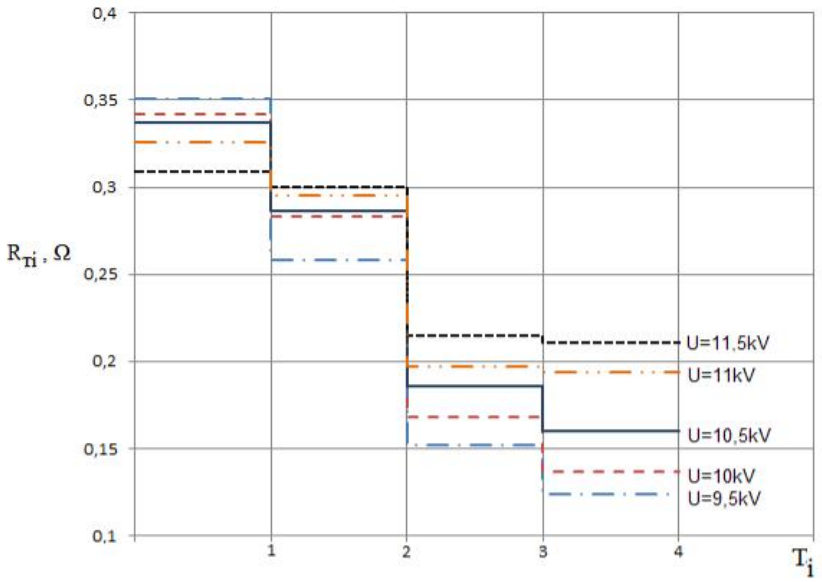


Fig.16 Dependency R=R(T_i) at a parameter C=1μF for a trigatron

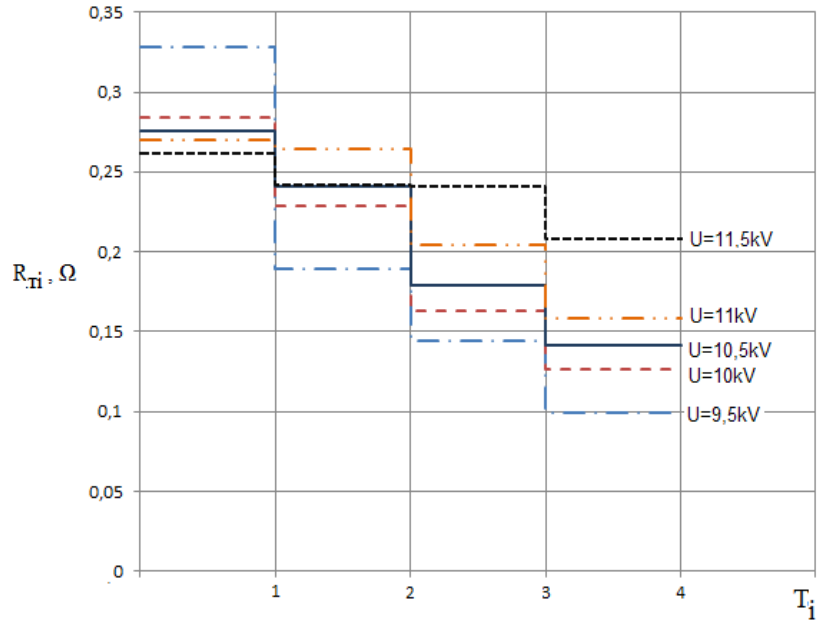


Fig.17 Dependency R=R(T_i) at a parameter C=1,5μF for a trigatron

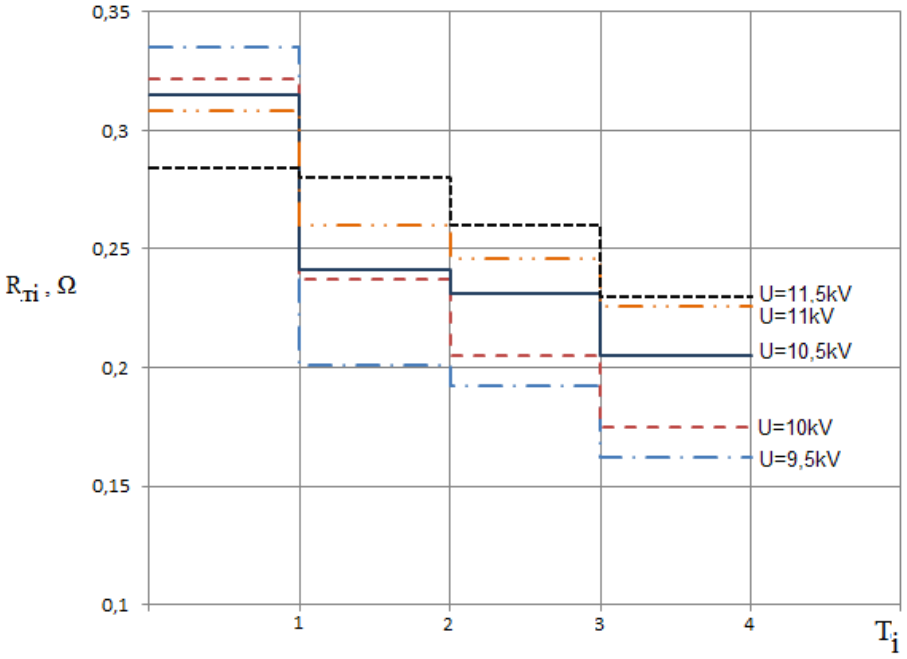


Fig.18 Dependency R=R(T_i) at a parameter C=2μF for a trigatron

The above curves refer to a CD – trigatron.

Fig.19 and fig.20 display the dependency R=R(T_i) with a controlled discharger - thyratron.

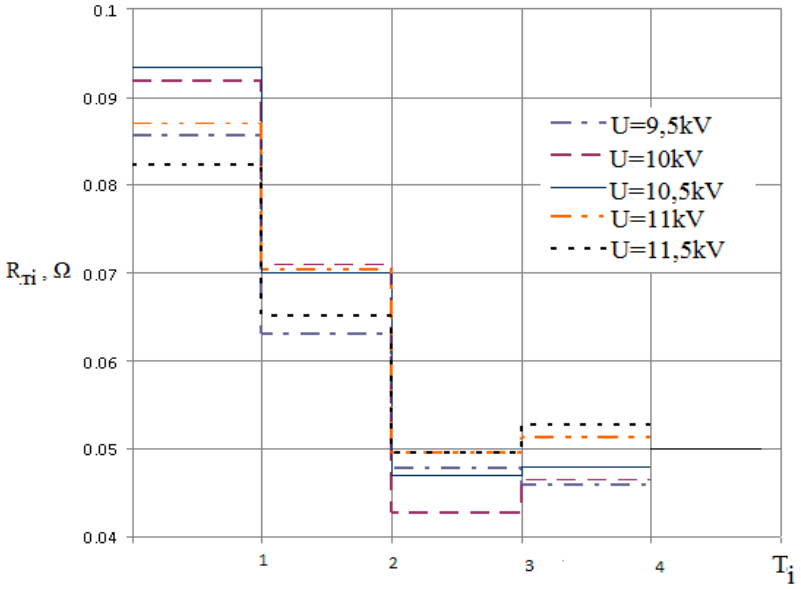


Fig.19 Dependency R=R(T_i) at a parameter C=2μF for a thyratron

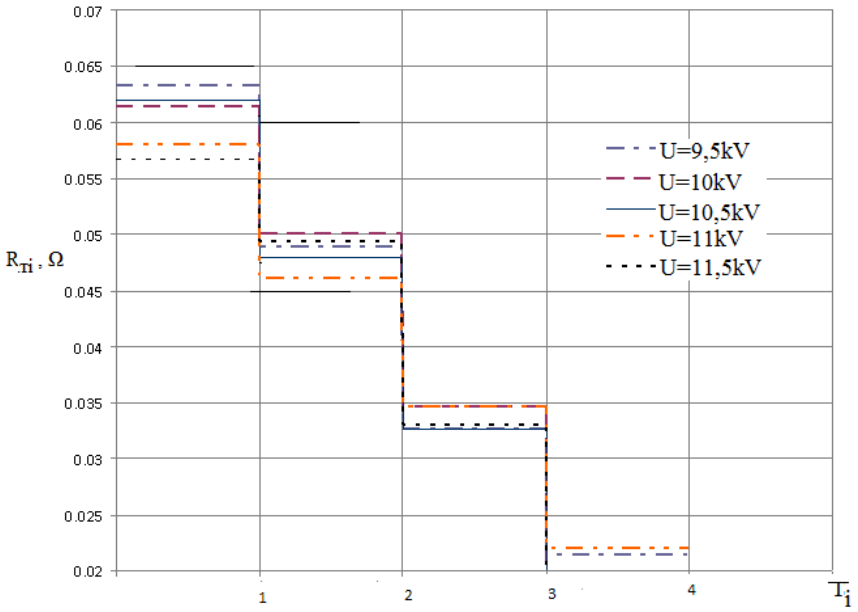


Fig.20 Dependency R=R(T_i) at a parameter C=3μF for a thyratron

The voltage - $U_C^* = U_C^*(U_C)$, to which the CB remains charged after discontinuation of the discharge at a parameter C, is shown in fig.21a (for trigatron) and fig.21b (for thyratron).

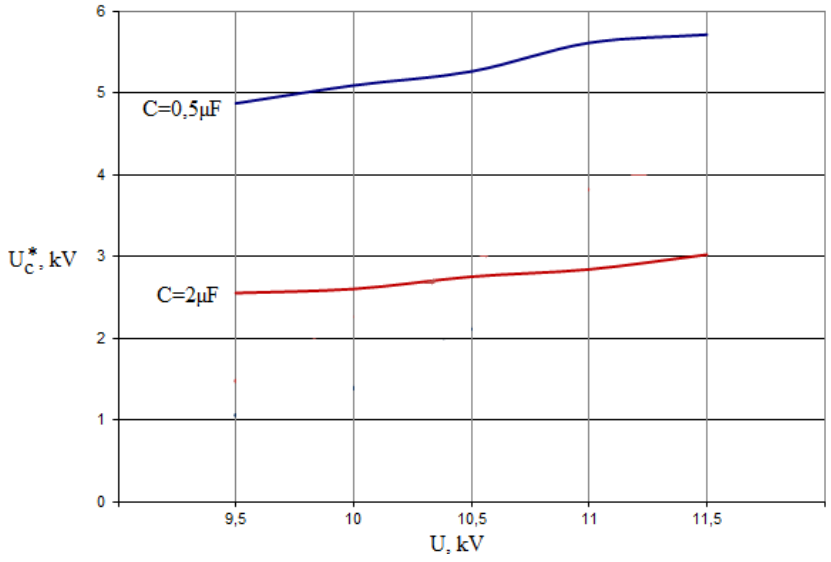


Fig.21a Dependency $U_C^* = U_C^*(U_C)$ with the usage of a trigatron

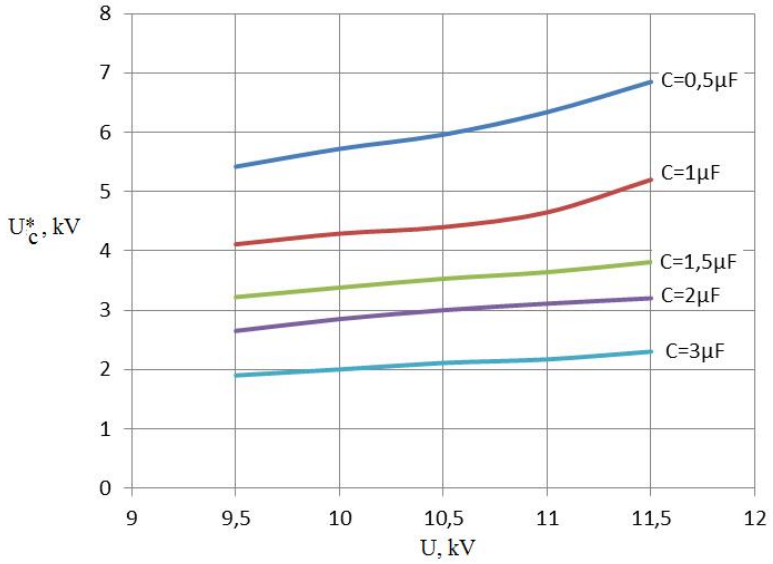


Fig.21b. Dependency $U_C^* = U_C^*(U_C)$ with the usage of a thyratron

The change of U_C^* depends on the parameters of the processes in the discharge interspaces as well as from the capacitance of CB – C – fig.5 and the voltage U_c, to which the last is charged.

The change of $U_C^* = U_C^*(U_C)$ influences over the discharge pulse energy W. In fig.22 is shown the change of $W=W(U_c)$ at a parameter capacitance of the CB.

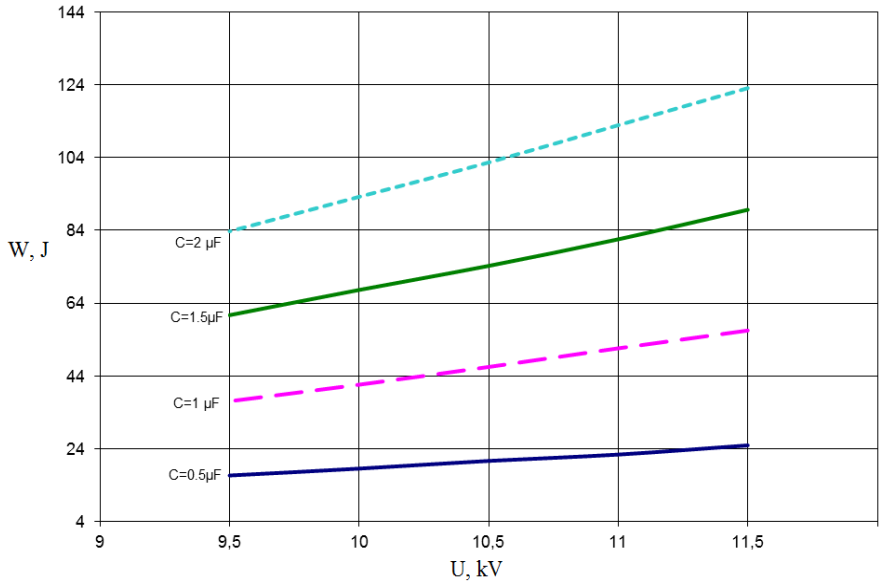


Fig.22a. Dependency of the energy from the voltage to which the capacitor battery CB is charged $W=W(U_c)$ with the usage of a trigatron

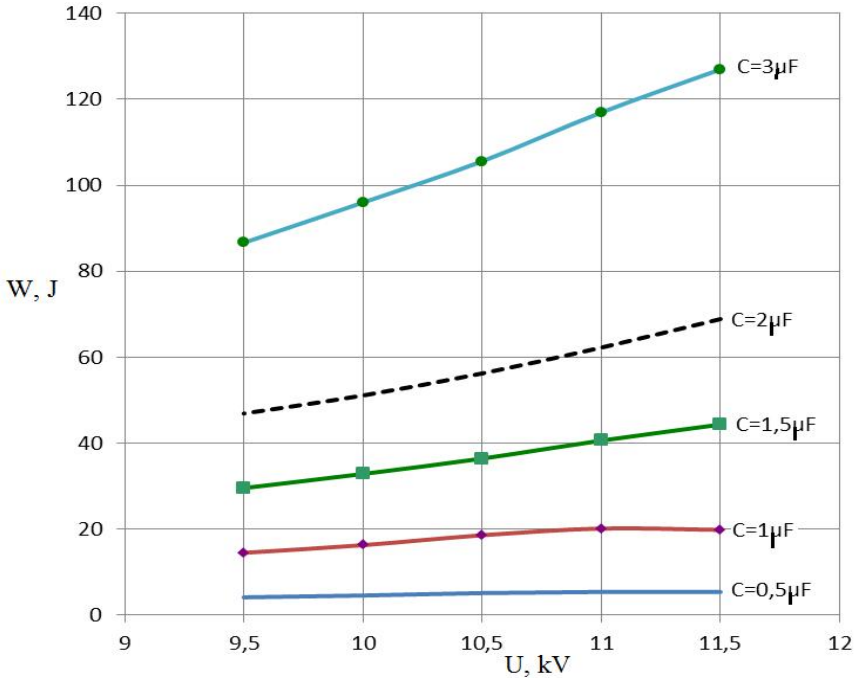


Fig.22b. Dependency of the energy from the voltage to which the capacitor battery CB is charged $W=W(U_c)$ with the usage of a thyratron

CONCLUSIONS

In this research are studied experimentally the commutational capabilities of:

- ✓ a three-electrode, controllable air discharger- trigatron, which works at atmospheric pressure, with two separated discharge circuits and two spatially different gas-discharge channels. They are connected with the development of the discharge and formation of a high-voltage discharge pulse;
- ✓ a thyratron ТГИ1-1000/25.

The experiment is conducted with two discharge circuits, each with two connected in series discharge interspaces:

- ✓ a trigatron and a discharge in water;
- ✓ a thyratron and a discharger in water,

at parameters – capacity and voltage to which is charged the capacitor battery in the discharge circuit.

The results of the comparative analysis are:

- ❖ The energy of the formed high-voltage discharge pulse in both cases is approximately the same and changes in the range of 14÷124 J.
- ❖ When using a controllable discharger – trigatron, the discharge pulse is periodically attenuating with frequency 36÷71kHz and duration of about 100μs. When using a thyratron

and with higher energy stored in the capacitor battery, the high-voltage discharge pulse also is periodically attenuating, but with a lower frequency of 10÷20kHz and a changing duration in more wide range of 50÷100μs. When the stored energy in the capacitor battery is lower than the formed discharge is aperiodic with a duration of about 30μs.

- The maximum discharge current for a controllable discharger - trigatron changes in the range of 0,6÷2,8kA at a capacitance of the capacitor battery C=0,5÷2μF and voltage, to which it is charged U_C = 9,5÷11,5kV.
- For a thyratron, the maximum values of the discharge current are 30÷35% lower, but change (decrease) significantly less in the range of the discharge pulse.
- The voltage over the capacitor battery, immediately after the discharge has stopped, at both controllable dischargers is approximately the same (U_C^* = 2÷6,5kV) and depends on the capacitance of the battery and the voltage, to which the last has been charged.

The obtained results could be further used for designing of start-control apparatuses for formation of high-voltage discharge pulses in liquid medium, which could be used in different technological applications.

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