VOLTAGE PULSE FORMATION FOR ENERGIZING THE MAGNETRON GUN WITH A SECONDARY-EMISSION CATHODE

I.A. Chertishchev, N.G. Reshetnyak, V.P. Romas'ko, V.V. Zakutin
National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
E-mail: ch.igor@kipt.kharkov.ua

Various techniques have been investigated for forming a high-voltage pulse to energize magnetron guns with secondary-emission cathodes. To generate a powerful beam, it was necessary that the storage element in the modulator should have a low wave impedance. A capacitor and a low-impedance forming line were used as a storage element. The flat part of the pulse was formed by means of different correction circuits. The influence of correction circuit elements on the pulse form has been investigated. Consideration has been given to the circuits of spike control by means of the driving generator, and also, by including the correction circuits in the discharge circuit. Spike formation through the use of pulse-transformer parasitic parameters was also considered. The undertaken studies have demonstrated the possibility of creating a modulator for energizing the accelerator with electron energy up to 150 keV.

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INTRODUCTION

The research into electron beams of different configuration and intensity is connected with the beam use in high-voltage pulse microwave electronics, accelerator engineering for modification of material surfaces, etc. To generate electron beams, various types of electron emission are used. In the last few years, studies have been made at the NSC KIPT on cold-cathode electron sources operating in the mode of secondary emission in crossed electric and magnetic fields. The special feature of the magnetron gun use lies in creating the voltage pulse with a spike in its initial part for initiation of secondary-emission electron multiplication, and in the flat part – for electron beam generation. At the beginning of the voltage pulse, there is no beam, and the modulator operates in the no-load mode. The beam current duration is determined by the length of the flat part of the pulse. With the secondary-emission magnetron gun as the base, an accelerator has been created, which is used for material modification [1]. The accelerator provides the beam with particle energy of ~ 100 keV, the beam current ~ 110 A and the target energy density ~ 20 J/cm^2. The paper describes the results of experiments on formation of ~ 10 μs voltage pulse for energizing a powerful magnetron gun of the accelerator of energy up to 150 keV. Comparison is made between various voltage pulse-forming circuits; their merits and demerits are considered.

EXPERIMENTAL SETUP

Experiments on powerful electron beam formation and generation were carried out at the electron accelerator at a cathode voltage up to 150 kV. The schematic of the setup is shown in Fig. 1. The secondary-emission system was energized by means of a pulse generator 1. In the circuit under consideration, a full storage capacitor C1 discharge through the correction circuit L2R2 to the pulse transformer PT was used. The joint discharge of both the storage capacitor and the capacitor C2 provided the voltage pulse with a spike, which was supplied to the gun cathode 6. The voltage pulse spike amplitude ranged between 30 and 200 kV, the spike fall time was ~ 0.6 μs, the amplitude of the flat part of the pulse was between 10 and 150 kV, the pulse length was 10 to 50 μs, and the pulse-repetition rate was 3 to 5 Hz.

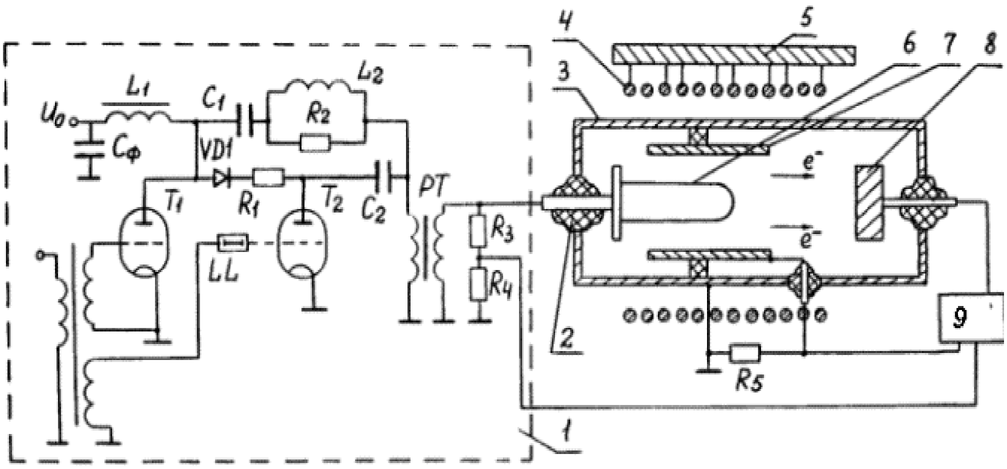


Fig. 1. Experimental setup schematic: 1 – pulse generator; 2 – insulator; 3 – vacuum chamber; 4 – solenoid; 5 – solenoid power supply; 6 – cathode; 7 – anode; 8 – Faraday cup; 9 – computer measuring system

The electron source (6 – cathode, 7 – anode) is arranged in the vacuum volume 3, the pressure in which is ~ 10^{-6} Torr. The magnetic field for electron beam generation and transport is created by the solenoid 4 consisting of 4 sections, which were energized by dc sources. The amplitude and longitudinal distribution of the magnetic field could be regulated by varying the current value in the solenoid sections.

The measured data on the voltage pulse, beam current on the Faraday cup and the parameters stability were processed by means of the computer measurement system 9. The obtained data were displayed on the computer screen. The measurement error was within 1…2%. A digital data-storage oscilloscope Tektronix TDS-2014 was also used in the studies. The cross-sectional size of the beam and the radial beam current distribution were determined from beam prints on the targets.

EXPERIMENTAL RESULTS

In the experiments on high-voltage pulse formation we have measured the amplitude, duration and nonuniformity of the voltage pulse peak on the gun cathode; the electron beam current; the thyratron current as a function of resistance and inductance of the correction circuit, and also, as a function of capacitance and wave impedance of the storage element.

To increase the modulator efficiency, it was necessary to have a low-resistance storage element [3]. A capacitor with a total capacitance of 1.5 μF was used as a storage unit. To decrease the gun voltage at no-load conditions, it was necessary that the internal resistance of the forming element should be considerably lower than the load resistance referred to the primary winding of the pulse transformer.

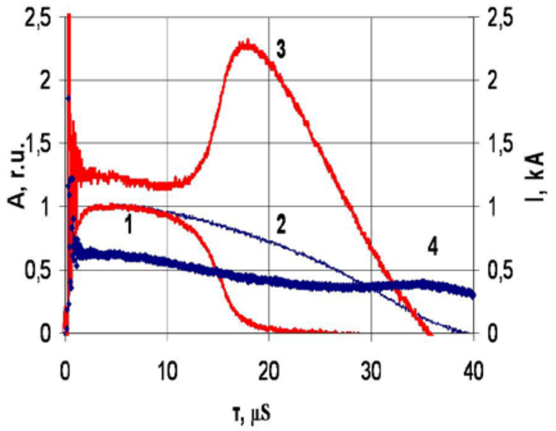


Fig. 2. Voltage pulses normalized to the amplitude for: 1 – 100 kV; 2 – 50 kV and thyratron current pulses for 3 – 100 kV; 4 – 50 kV

Fig. 2 shows normalized voltage pulses and thyratron current pulses at output voltages of 50 kV and 100 kV. With an increasing voltage, the pulse transformer core will quicker attain the saturation mode. In this case, the commutation switch current will increase due to decrease in the magnetizing inductance. It can be seen from Fig. 2 that the voltage pulses coincide up to the time point 10 μs. After this time, for voltage of 100 kV, the pulse transformer enters the saturation mode, and the voltage pulse duration decreases. This means that the calculation and choice of the correction circuit should be made for definite pulse duration (for voltage of 100 kV – up to duration of 10 μs), and then, due to pulse transformer core saturation the pulse droop will be formed. The pulse peak can be formed at low voltages, when the modulator is operated in the soft mode. Fig. 3 shows pulses of voltage, electron beam current and equivalent beam resistance. The nonuniformity of the voltage pulse flat part was within ±2.5% over the pulse length of ~ 8.5 μs. At the initial part of the voltage pulse there is no beam, and the modulator operates under no-load conditions. Upon onset of beam generation, the beam resistance quickly (for a few tens of nanoseconds) reaches a certain value, and then, as seen from Fig. 3, remains unchanged with time. This allows one to make calculation and choice of the correction circuit at a constant load resistance.

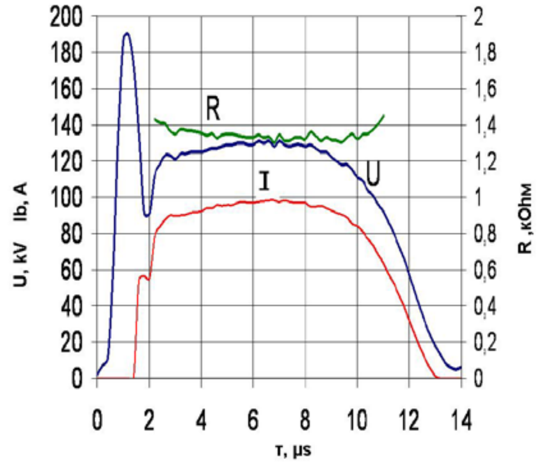


Fig. 3. Voltage (U), beam current (I) and equivalent beam resistance (R) pulses

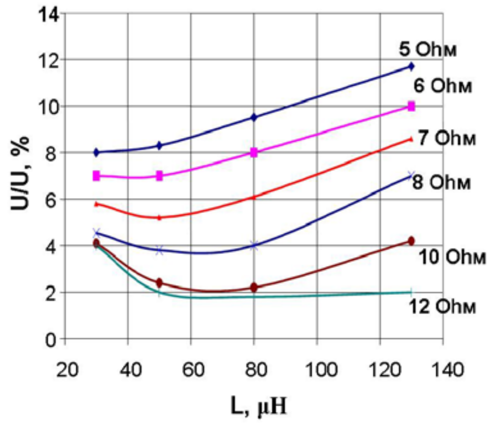


Fig. 4. Calculated nonuniformity of the voltage pulse peak as a function of resistance R(5…12 Ω) and correction circuit inductance L within 10 μs duration

Fig. 4 shows the calculated nonuniformity of the voltage pulse peak versus resistance and inductance of the corrective circuit within the 10 μs pulse duration for beam resistance of 500 Ω (gun cathode voltage being 50 kV, beam current 100 A) at storage capacitance o f 1.5 μF. It is obvious from the figure that for the nonuniformity of the pulse peak to be no more than ± 2.5% it is necessary that the correction circuit resistance should be 8 Ω and higher.

Fig. 5 shows the nonuniformity of the voltage pulse peak calculated versus capacitance at different equivalent beam resistance values. It can be seen from the figure that nonuniformities of the pulse peak of no more than ± 2.5% can be attained at a storage capacitance of no less than 1.25 μF. With a decrease in the beam resistance the pulse peak nonuniformity increases, and its correction becomes more difficult. So, to decrease the storage element value, it is necessary to use a low-impedance forming line. Experiments were made with the forming line having the wave impedance of ~ 6 Ω.

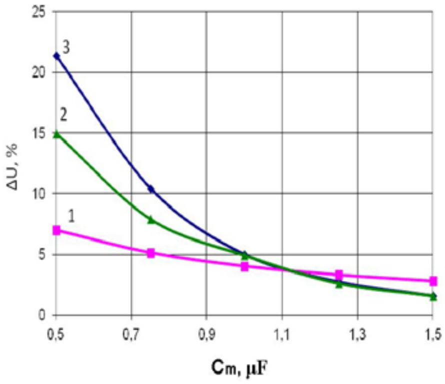


Fig. 5. Calculated nonuniformity of the voltage pulse peak versus storage capacitance at equivalent beam resistance referred to the primary circuit.
1 – R = ∞; 2 – R = 40 Ω; 3 – R = 20 Ω

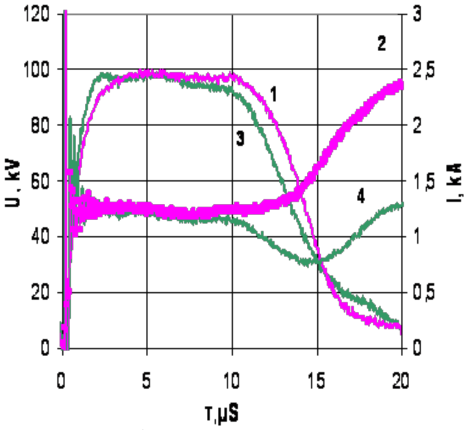


Fig. 6. Pulses of the modulator output voltage (1) and thyratron current (2) at forming unit capacitance of 1.5 µF; and the same (3), (4) at forming unit capacitance of 1 µF

Fig. 6 shows the voltage and thyratron current pulses for two forming unit capacitance values: 1.5 µF and 1 µF. It can be seen from the figure that for the pulse length of 10 µs, with 1 µF capacitance the pulse peak nonuniformity increases by ~ 2%, and the peak value of the thyratron current is ~ 1.35 kA, whereas at forming line capacitance of 1.5 µF the peak current is 2.4 kA. Thus, with the use of a lower capacitance value it appears possible to facilitate essentially the mode of modulator operation.

Fig. 7 shows the pulse peaks for capacitance values of 1.5 (curve 1, without correction) and 1 µF (curves 2 and 3, without and with correction, respectively). It is evident from the figure that the voltage pulse peak duration at the nonuniformity level ±1% for the capacitance C=1.5 µF will make 8.5 µs, and for C = 1 µF it will be 8 µs. So, using a low-impedance forming line with the total capacitance 1 µF as a forming unit, it is possible to attain through correction the same nonuniformity of the pulse peak as that in the line having the total capacitance 1.5 µF for the pulse flat part duration ~ 8.5 µs. However, it should be noted that the pulse correction will be possible only for limited pulse duration of up to 9…10 µs. For the pulse-modulator output voltage of 100 kV, it will be sufficient, because the pulse transformer saturation would not allow the generation of longer pulses.

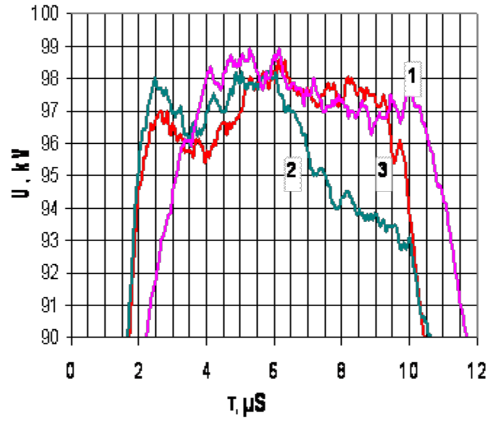


Fig. 7. Voltage pulse peaks at forming lines having the total capacitance of 1.5 µF (1) and 1 µF (2 and 3)

For different missions, it is necessary that the voltage overshoot could be controlled. Consideration has been given to some possibilities of the overshoot adjustment:

- the use of the driving generator;
- oscillations at the pulse peak due to pulse transformer parasitic parameters;
- various correction circuits.

In case of the driving generator, a priming capacitor of a relatively low capacitance (10 to 20 nF) (see C2 in Fig. 1) is brought into the modulator circuit. With thyratron action (see T2 in Fig. 1) the priming capacitor discharges together with the main capacitor through the primary winding of the pulse transformer (PT) into the load resistor (R3). The priming capacitor is charged through the charging diode (see VD in Fig. 1), and its voltage will be equal to a two-fold power supply voltage, and the main capacitor voltage value will depend on the chosen point of the charging curve.

Fig. 8 shows the spike-to-flat part ratio of the voltage pulse versus the repetition rate of the modulator. It can be seen from the figure that by varying the repetition rate of the modulator we change the operating point on the charging curve and by this means we control the voltage pulse spike. The advantage of spike formation with the driving generator lies in the ease and wide range of controlling, which can be realized by varying both the repetition rate of the modulator and the delay time of the driving pulse. The disadvantage of the method is the necessity of using additional circuit elements (thyratron, high-voltage elements, etc.).

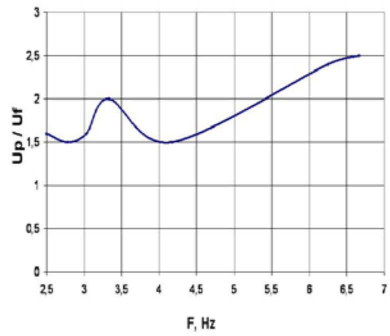


Fig. 8. Spike-to-flat part ratio of the voltage pulse U_p/U_{fl} versus the repetition rate of the pulse modulator (F)

The voltage pulse spike can also be formed by using parasitic parameters of the pulse transformer such as stray inductance and dynamic capacitance.

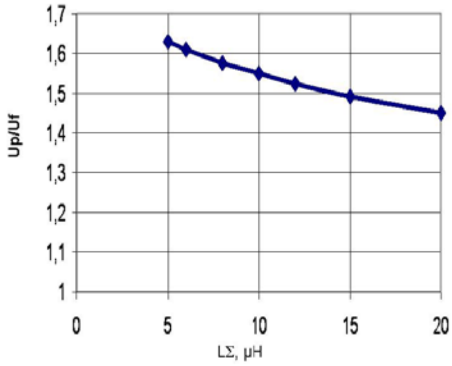
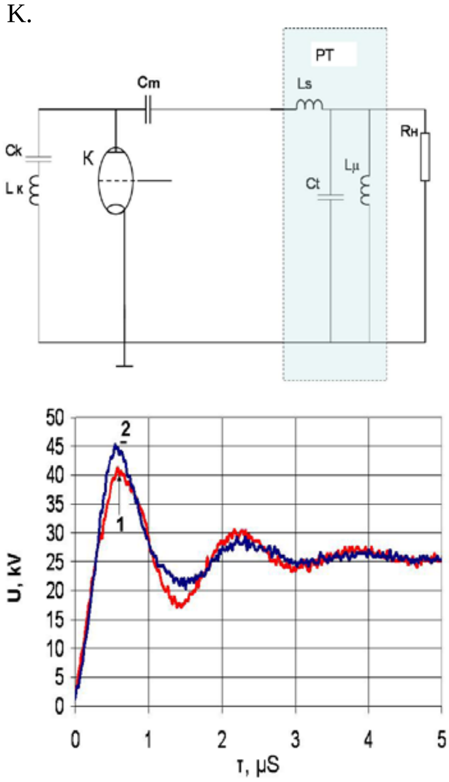


Fig. 9. Spike amplitude-to-flat part ratio versus the sum of PT stray inductance and external inductance

Fig. 9 shows the ratio of the spike amplitude to the flat part of the voltage pulse versus the sum of PT stray inductance and external inductance. It can be seen from the figure that by decreasing the inductance from 20 down to 5 μH the spike amplitude can be increased by 20%; however, a further reduction in the inductance is impossible. The disadvantage of spike formation by using parasitic parameters is a narrow regulation band.

Consideration was also given to controlling the spike by means of various correction circuits.

Fig. 10,a shows the diagram for correction circuit connection to increase the voltage spike amplitude. The correction circuit includes the inductor Lk and the capacitor Ck connected in parallel to the commutation switch K.



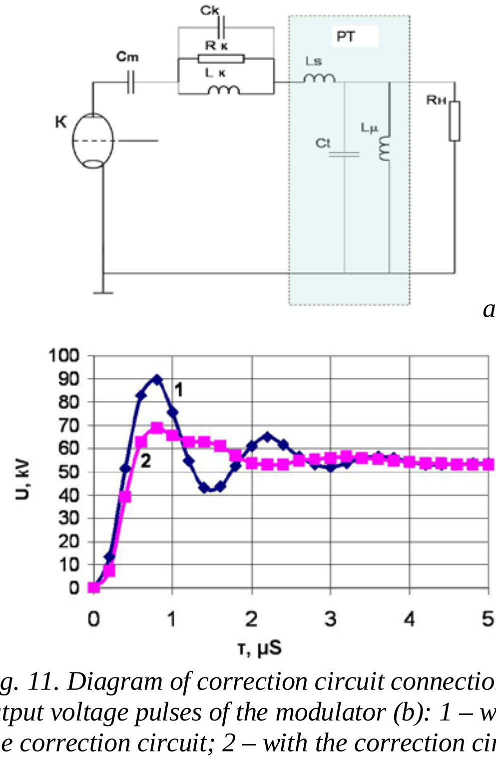
a

b

Fig. 10. Diagram of correction circuit connection (a). Output voltage pulses of the modulator (b): 1 – without the correction circuit; 2 – with the correction circuit

Upon commutator reaction, the correction capacitor Ck discharges simultaneously with the storage capacitor Cн through the pulse transformer PT into the load resistor Rн. Fig. 10,b shows modulator output voltage pulses obtained with and without use of the correction. The correction inductance was 6 μH, and the correcting capacitance was 0.01 μF. The 25% increase in the voltage spike amplitude (see Fig. 10,b, curve 2) is due to the energy stored in the correction circuit during charging.

Fig. 11,a shows the diagram for correction circuit connection (inductor Lk, capacitor Ck and resistor Rk) to reduce the spike amplitude. The inductor Lk and the Capacitor Ck constitute a parasitic oscillating circuit meant for the pulse transformer eigenfrequency. The resistor Rk serves to reduce the tuned-circuit Q-factor. The correction inductance made up 6μH, the balanced capacitance was 0.01 μF, and the resistance was 27 Ω. With thyratron K switching, the storage capacitor Cн discharges through the correction circuit and the pulse transformer into the load resistor Rн. Fig. 11,b shows the voltage pulses at the modulator output with and without using the correction circuit. The reduction in the voltage spike amplitude (see Fig. 11, curve 2) is due to the introduction of additional wave impedance into the circuit for a rather short time (~ 1.2 μs). It is demonstrated that if using the correction circuits, the voltage spike amplitude can be varied by factors of 1.8 to 1.2 with respect to the flat part of the pulse.



a

b

Fig. 11. Diagram of correction circuit connection (a). Output voltage pulses of the modulator (b): 1 – without the correction circuit; 2 – with the correction circuit. The spike is reduced by 25%

CONCLUSIONS

The undertaken studies have demonstrated the possibility of forming a high-voltage pulse for energizing a powerful magnetron gun with electron energy of up to 150 keV. Circuitry for formation of voltage pulse spikes and flat parts has been considered. Advantages and disadvantages of each of the design circuits have been discussed.

REFERENCES

1. A.N. Dovbnya, V.V. Zakutin, N.G. Reshetnyak, et al. Pulse modulator for energizing a powerful magnetron gun with a secondary-emission cathode // *VANT. Ser. "Yaderno-fizicheskie issledovaniya"*. 2008, №5, p. 57-59 (in Russian).
2. N.I. Aizatskyi, V.N. Boriskin, V.A. Gurin, et al. A multichannel system for investigating generation of pulsed secondary-emission electron beams // *VANT. Ser. "Yaderno-fizicheskie issledovaniya"*. 2004, №1, p. 118-119 (in Russian).

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ФОРМИРОВАНИЕ ИМПУЛЬСА НАПРЯЖЕНИЯ ДЛЯ ПИТАНИЯ МАГНЕТРОННОЙ ПУШКИ С ВТОРИЧНО-ЭМИССИОННЫМ КАТОДОМ

И.А. Чертищев, Н.Г. Решетняк, В.П. Ромасько, В.В. Закутин

Исследованы различные возможности формирования высоковольтного импульса напряжения для питания магнетронных пушек с вторично-эмиссионными катодами. Для получения мощного пучка необходимо, чтобы накопительный элемент в модуляторе имел малое волновое сопротивление. В качестве накопительного элемента использовались конденсатор и низкоомная формирующая линия. Плоскую часть импульса формировали при помощи различных корректирующих цепочек. Рассмотрено влияние элементов корректирующих цепочек на форму импульса. Рассмотрены схемы регулировки выброса при помощи затравочного генератора и при включении цепей коррекции в разрядный контур, а также формирование выброса за счет паразитных параметров импульсного трансформатора. Проведенные исследования показали возможность создания модулятора для питания ускорителя с энергией электронов до 150 кэВ.

ФОРМУВАННЯ ІМПУЛЬСУ НАПРУГИ ДЛЯ ЖИВЛЕННЯ МАГНЕТРОННОЇ ГАРМАТИ З ВТОРИННО-ЕМІСІЙНИМ КАТОДОМ

І.О. Чертіщев, М.Г. Решетняк, В.П. Ромасько, В.В. Закутін

Досліджені різні можливості формування високовольтного імпульсу напруги для живлення магнетронних гармат з вторинно-емісійними катодами. Для здобуття потужного пучка необхідно, щоб накопичувальний елемент у модуляторі мав малий хвильовий опір. В якості накопичувального елемента використовувалися конденсатор або низькоомна формуюча лінія. Плоску частину імпульсу формували за допомогою різних корегуючих ланцюгів. Розглянуто вплив елементів корегуючих ланцюгів на форму імпульсу. Розглянуто схеми регулювання викиду напруги за допомогою затравочного генератора та при включенні ланцюгів корекції у розрядний контур, а також за рахунок паразитних параметрів імпульсного трансформатора. Проведені дослідження показали можливість створення модулятора для живлення прискорювачів з енергією електронів до 150 кеВ.