

HIGH-VOLTAGE NANOSECOND PULSE GENERATOR FOR MAGNETRON GUN TRIGGERING

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A small-sized nanosecond generator was developed to trigger a magnetron gun. A voltage pulse of amplitude up to 20 kV is applied to anode for gun triggering. Rise and fall fronts of high-voltage pulse are 20 and 70 ns consequently. Thyatron TGI1-500/16 with a low-inductive storage capacitance was used as a switch. The capacitance is discharged to the cable transformer (input wave impedance 25 Ohm, transformation ratio $n = 2$) operating at a load of 500 Ohm (the capacitance of the magnetron gun anode to ground is 40 pF). Using this resistance transformer on RF cables makes it possible to change rapidly the polarity of the trigger pulse.

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INTRODUCTION

NSC KIPT researches the processes of intense electron beams forming in electron sources with secondary-emission cathodes in crossed fields. The electric field required for beam generation in a gun is created by a voltage pulse of a special form with a spike at a flat part from two pulse generators; this voltage pulse is fed to the gun cathode [1, 2].

The sharpness of the voltage pulse fall was 20...70 kV/ μ s at pulse-fall time of 0.3...0.6 μ s. Pulse spike amplitude 1.3...1.7 times exceeded the amplitude of the flat part of the voltage pulse. The disadvantages of this method are the longtime fall of the voltage pulse spike and electric breakdown occurrence at high spike amplitude, which considerably reduces the electrical strength of the anode-cathode gap of the magnetron gun.

In this paper a method of voltage pulse forming by summing electric fields of two pulses in the interelectrode gap of the magnetron gun is proposed: a microsecond flat-topped pulse applied to the cathode and a nanosecond pulse with a sharp fall applied to the anode of the gun.

For this purpose, a nanosecond pulse generator was developed to trigger a secondary emission process in the magnetron gun. This will increase the electrical strength of the anode-cathode gap and increase the fall sharpness of the voltage pulse spike.

THE METHOD OF CREATING A NANOSECOND PULSE GENERATOR

A generator was developed and manufactured to initiate a secondary emission multiplication process on the magnetron gun cathode by a nanosecond voltage pulse applied to its anode. A simplified diagram of the high-voltage nanosecond generator is shown in Fig. 1.

In Fig. 1: C_s – storage capacitance; R_c – charge resistance; T – filament transformer; r_i – current sensor; S – switch (thyatron TGI1-500/16); PIT – pulse isolating transformer; TU – trigger unit; C – filter capacities; RT – resistance transformer.

Voltage pulse of positive polarity can be obtained by activating the load in the cathode circuit of the switch (thyatron S). In this case the windings of the filament transformer T (see Fig. 1) and the pulse transformer (PIT) should be isolated from the primary windings and keep the pulse voltage of the specified amplitude.

Besides, the cathode capacitance to ground increases. All this leads to circuit complication and weight-size parameters increase and the cathode total capacitance to ground can negate the generation of a nanosecond voltage pulse of given amplitude.

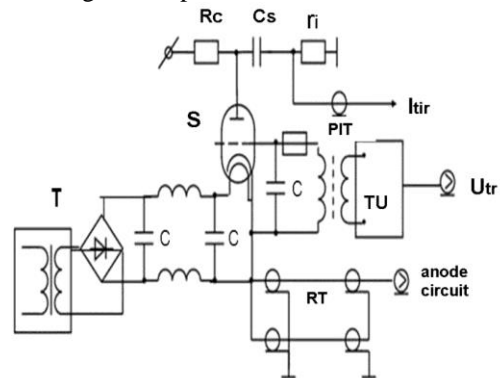


Fig. 1. A simplified diagram of the high-voltage nanosecond generator of positive polarity with multiplication of output voltage by resistance transformer on radio-frequency cables with wave impedance

Therefore, in order to simplify the circuit and reduce considerably the dimensions of the pulse generator for obtaining the output voltage of positive polarity a simple inversion on RF cables is used (Fig. 2). The storage capacitance C_s is discharged through the thyatron S (TGI1-500/16) onto the braid of the radio-frequency cable.

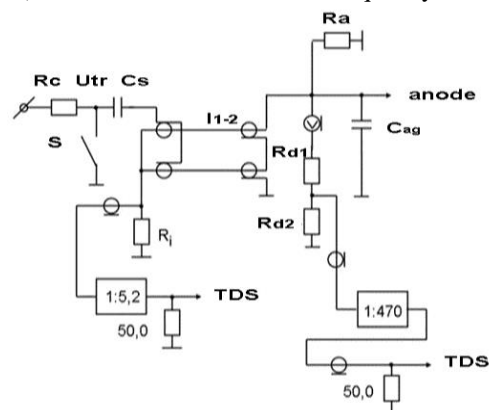


Fig. 2. Block diagram of the generator with storage capacitance, anode load and transmission path

In Fig. 2: S – switch (thyatron TGI1-500/16); C_s – storage capacitance; R_c – charge resistance; R_i – discharge current sensor of the thyatron; $I_{1,2}$ – transmission path (RF cable RC – 50-3); R_{d1} , R_{d2} – voltage di-

vider; R_a – anode load; C_{ag} – magnetron gun anode capacitance to ground.

The amplitude and wave form of the output voltage of the pulse generator depend on:

- the value of the storage capacitance C_s ;
- the transformer ratio of the resistance transformer on RF cables;
- the value of the anode load resistance;
- the value of the anode capacitance to ground;
- the parameters of the thyatron grid circuit TGI1-500/16 (C_3 , R_1);
- the length of the cables of the transmission path;
- additional induction.

Functional diagram of the nanosecond pulse generator is presented in Fig. 3. Where T1 – power transformer; VD1 – VD4 – diode bridge; C1, C2, C5, C6 – filter capacitance; TU – the thyatron trigerring unit; S – thyatron TGI1 – 500/16; R1 – limit resistance of grid current; R2, R3 – grid voltage divider; R6 – charge resistance; R4, R5 – charge resistance divider; C3 – grid filter capacitance; C4 – charge capacitance.

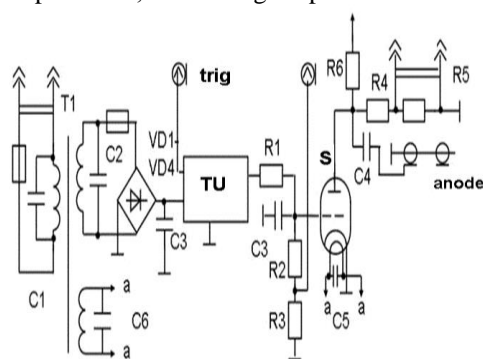


Fig. 3. Generator of nanosecond pulses of positive polarity. Electrical schematic diagram

Dividers R4 and R5 are used for measurement of the charge voltage, dividers R2 and R3 – for measurement of the voltage on the thyatron grid, which is used to trigger TDS oscilloscope. Pulse generator dimensions are 300×220×300 mm.

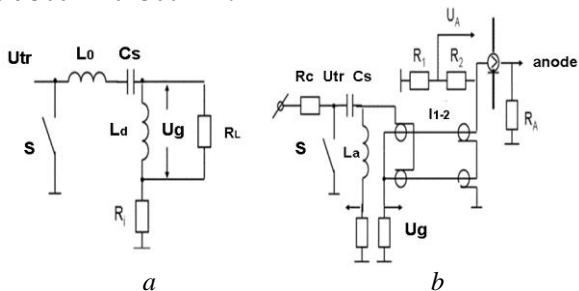


Fig. 4. Simplified equivalent circuit of the storage capacitance discharge C_s with an artificial oscillating loop (a), simplified equivalent circuit of the generator (b)

Simplified equivalent circuit of the storage capacitance discharge C_s with an artificial oscillating loop and a simplified equivalent circuit of the generator are presented in Fig. 4, where L_d – discharge loop inductance; R_1 – current sensor for determining the maximum discharge current through the thyatron (switch S); L_a – additional loop inductance; R_1 – load resistance, L_d – discharge loop inductance; C_s – storage resistance; R_u – arm of the input voltage divider; $I_{1,2}$ – transmission path (RF cable RC – 50-3); S – switch; R_i – switch current

sensor; R_1 – load resistance, R_A – anode load; R_1 , R_2 , – anode voltage divider.

Since RF cables with a wave impedance of 50 Ohm are used, the load resistance value will vary from 17 to 100 Ohm depending on the number of cables and the way they are connected.

Fig. 4,b shows a simplified equivalent circuit of the generator in which the load is the resistance transformer on RF cables with a multiplication factor of $k = 2$, an output resistance of 100 Ohm and an input resistance of 25 Ohm.

Low resistance R (0.5 Ohm) and input resistance of the transformer represent the voltage divider at the transformer input with a division factor of 50.

The current of the storage capacitance discharge is

$$I_{tir} = U_c / \rho_k + r_1,$$

where ρ_k – wave impedance of the discharge loop; U_c – charge voltage; r_1 – load resistance.

Dependencies of the output voltage on the storage capacitance value are presented in Fig. 5,a,b.

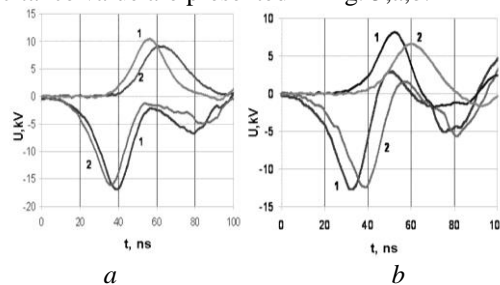


Fig. 5. Dependencies of input (negative) and output (positive) voltages on the value of the storage capacitance: 1,2 – without and with anode load $U_3 = 16$ kV. The cable length is 5 m. The transformation ratio is 2. a – capacitance is 620 pF; b – capacitance is 300 pF

As can be seen from the oscillogram (see Fig. 5,a) the voltage pulse is 9 kV at maximum charging voltage of 16 kV and storage capacitance of 620 pF. The voltage will be about 7 kV at storage capacitance of 300 pF; it is a small value for investigation of the magnetron gun trigger on the anode.

Further the increase of the generator output voltage is possible by reducing the internal resistance of the generator, that is, by increasing the value of the storage capacitance up to several thousand picofarads (Fig. 6, where $C_s = 3.6$ nF). The dependences of the output voltage across the magnetron gun anode on transmission path parameters are presented in Figs. 6, 7.

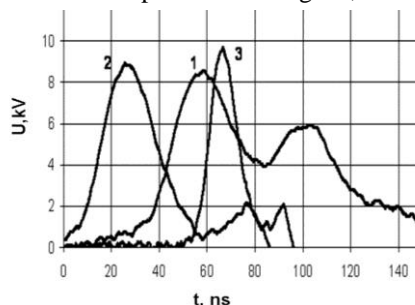


Fig. 6. The dependence of the output voltage across the magnetron gun anode on transmission path parameters: 1 – $\rho_k=50$ Ohm; 2 – $\rho_k=25$ Ohm; 3 – transformation ratio $n-2$. Four RF cables are mixed at input

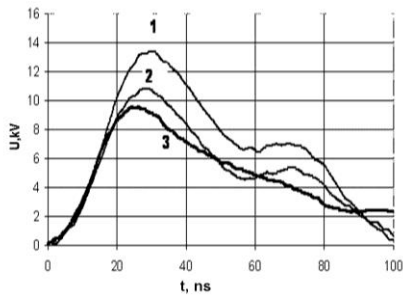


Fig. 7. The dependence of the anode output voltage on transmission path parameters. Charge voltage is 10 kV:
 1 – $\rho_k=25$ Ohm; 2 – $n=2$ (resistance transformer);
 3 – $\rho_k=50$ Ohm

As can be seen from oscillograms (see Figs. 6, 7), using the resistance transformer allows increasing the output voltage. In this case, increasing the resistance in the anode circuit leads to output voltage increase.

The dependence of voltage across the anode of the magnetron gun on the load resistance in the anode circuit is presented in Fig. 8.

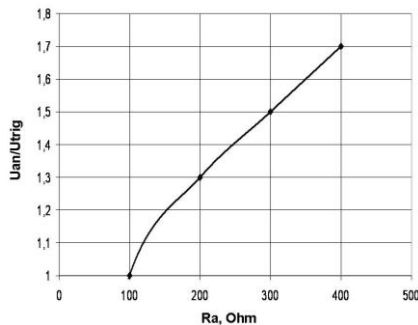


Fig. 8. The dependence of voltage across the magnetron gun anode on the load resistance in the anode circuit of the magnetron gun

The dependence of the generator output voltage on the load voltage is presented in Fig. 9.

It follows from Fig. 9 that the amplitude of the output voltage pulse increases 1.4 times with increasing the load resistance by a factor of 2 at a charge voltage of 10 kV.

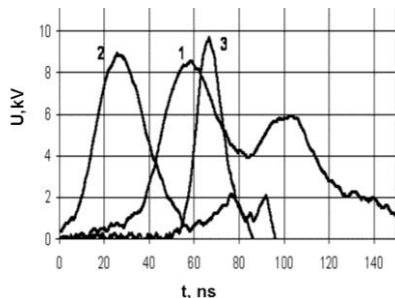


Fig. 9. The dependence of the generator output voltage on the load voltage: $R1 = 170$ Ohm; $R2 = 240$ Ohm;
 $R3 = 360$ Ohm

Thus, using a cable phase shifter within nanosecond range we have obtained:

- a considerable reduction in the generator mass-dimension parameters;
- decrease of the generator production time;
- increase of the operation reliability;
- use of protection elements in the generator power supply (0...16 kV) ensures safety of work at high voltage;

- possibility of rapid changing the voltage polarity across the magnetron gun anode;
- increase of the voltage across the magnetron gun anode at considerably lower charge voltage of the storage capacitance (using a resistance transformer on RF cables).

In this case, the optimum total resistance of the anode circuit (together with voltage dividers) is 500 Ohm. Voltage pulse of 17 kV was obtained on the anode at a charge voltage of 10 kV.

Thus, the possibility of adjusting both the rate of fall (rise) of the nanosecond pulse and its form was provided. It was achieved by changing the value of the storage capacitance, as well as the parameters of the transmission path.

MEASUREMENT OF VOLTAGE NANOSECOND PULSES

Fig. 10 shows a circuit for measurement of voltage nanosecond pulses. Voltage pulses from the generator of trigger pulses (GTP) of negative polarity are fed to the anode of magnetron gun A, into the circuit of which a load resistance of 216 Ohm is applied which is a voltage divider with division factor of 12 and further division by 10.

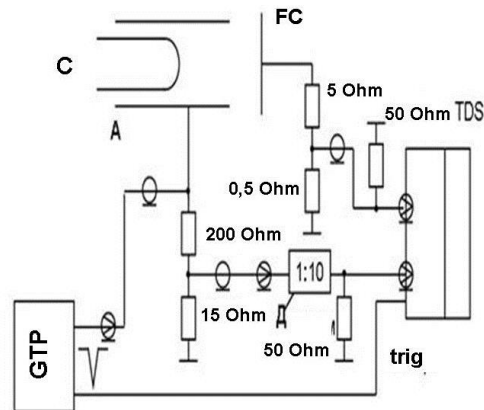


Fig. 10. Circuit for measurement of voltage nanosecond pulses

FC (Faraday Cup) load is a resistance of 5.5 Ohm with a voltage division factor of 11. Triggering the oscilloscope TDS-2012 is carried out by a voltage pulse of the thyatron grid.

Fig. 11, a, b show voltage pulses across the anode of a magnetron gun of positive and negative polarities, at which experiments were carried out to trigger secondary emission in the magnetron gun.

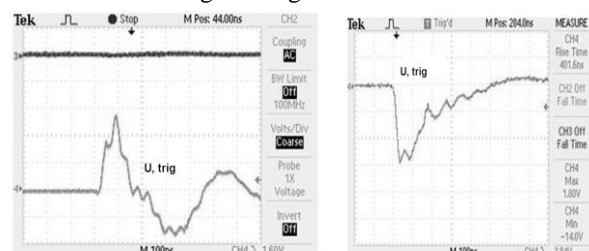


Fig. 11. Voltage pulses across the magnetron gun anode; a – positive polarity; b – negative polarity, vertical scale of 5 kV/div

CONCLUSIONS

The presented circuit design for generating a controlled high-voltage nanosecond pulse made it possible not only to generate pulses of both polarities, but also to increase substantially the generator output voltage exceeding the charge voltage of the storage capacitance. At the same time, there are some circuit designs of the transmission path.

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ВИСОКОВОЛЬТНИЙ НАНОСЕКУНДНИЙ ІМПУЛЬСНИЙ ГЕНЕРАТОР ДЛЯ ЗАПУСКА МАГНЕТРОННОЙ ПУШКИ

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Разработан малогабаритный наносекундный генератор для запуска магнетронной пушки. Импульс напряжения амплитудой до 20 кВ для запуска пушки подаётся на её анод. Фронты нарастания и спада высоковольтного импульса составляют 20 и 70 нс. В качестве коммутатора использован тиратрон ТГИ1-500/16 с малоиндуктивной накопительной ёмкостью. Разряд ёмкости осуществляется на кабельный трансформатор (входное волновое сопротивление 25 Ом, коэффициент трансформации $n=2$), работающий на нагрузку 500 Ом (ёмкость анода магнетронной пушки на землю 40 пФ). Использование данного трансформатора сопротивлений на радиочастотных кабелях даёт возможность оперативно изменять полярность запускающего импульса.

ВИСОКОВОЛЬТНИЙ НАНОСЕКУНДНИЙ ІМПУЛЬСНИЙ ГЕНЕРАТОР ДЛЯ ЗАПУСКУ МАГНЕТРОННОЇ ГАРМАТИ

М.Г. Решетняк, В.П. Ромасько, І.О. Чертищев

Розроблено малогабаритний наносекундний генератор для запуску магнетронної гармати. Імпульс напруги амплітудою до 20 кВ для запуску гармати подається на її анод. Фронти наростання і спаду високовольтного імпульсу становлять 20 і 70 нс. В якості комутатора використано тиратрон ТГІ1-500/16 з малоіндуктивною накопичувальною ємністю. Розряд ємності здійснюється на кабельний трансформатор (вхідний хвильовий опір 25 Ом, коефіцієнт трансформації $n = 2$), що працює на навантаження 500 Ом (ємність анода магнетронної гармати на землю 40 пФ). Використання даного трансформатора опорів на радіочастотних кабелях дає можливість оперативно змінювати полярність запускаючого імпульсу.