https://doi.org/10.46813/2024-151-073

MODERNIZATION AND ADJUSTMENT OF THE MICROWAVE POWER CONTROL SYSTEM OF THE "ALMAZ-2M" ACCELERATOR

D.Yu. Zaleskyi, V.I. Pristupa, V.S. Us, G.V. Sotnikov
NSC "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine
E-mail: zalesky@kipt.kharkov.ua

The microwave power source of the "Almaz-2M" accelerator is controlled by supplying a microwave modulated pulse from the "Rubin" master microwave generator to the KIU-12M klystron. The "Rubin" frequency must be adjusted to the resonant frequency of the accelerator, which may change under the influence of external conditions and aging of the materials of the accelerator elements, so it is necessary to adjust the "Rubin" frequency. At the same time, the "Rubin" frequency meter –"wave meter" also needs calibration. This paper describes a method for calibrating a "wave meter" with an accuracy of 1.5 MHz. For experiments on wakefield acceleration of an electron beam using a profiled sequence of bunches, it is important to synchronize all elements of the accelerator - the gun, the master oscillator, the klystron. For this purpose, a standard accelerator launch system was carried out. This made it possible to obtain trigger pulses with a rise time of about 200 ns. Also, based on modern microcircuits, a new trigger system with a leading edge of less than 100 ns has been developed.

PACS: 84.30.−r, 84.30.Jc, 84.30.Sk, 84.30.Ng

INTRODUCTION

The "Almaz-2M" electron accelerator [1, 2] has been in operation for quite a long time, since the 60s of the last century, and therefore requires constant maintenance in working order, and needs modernization to perform new experiments. This modernization is carrying out constantly and also as new scientific tasks arise.

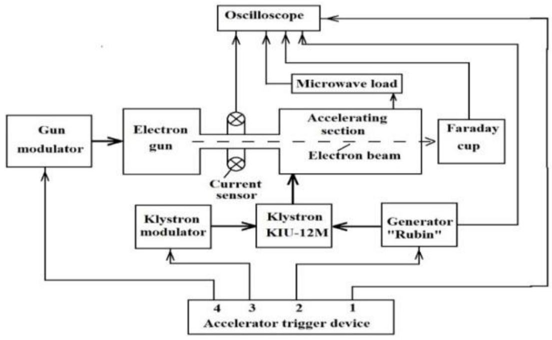
Currently, such an actual task is to conduct research on wake acceleration in various dielectric structures [3–7]. The important parameter in wakefield accelerator is the transformer ratio. In a structure with collinear motion of bunches, where the drive and accelerated bunch move along the same path, the transformer ratio, defined as the ratio of the maximum increase in the energy of the electrons of the accelerated beam to the maximum energy loss of the particles of the leading beam [8, 9], cannot exceed 2. To increase it, it was proposed to use charge profiling inside a single bunch [10], profiling a sequence of bunches (ramped bunch train) [11–14], or using multi-zone multi-channel dielectric structures [15-18]. In order to obtain profiling a sequence of bunches, precise synchronization of separated units of the "Almaz-2M" accelerator is necessary.

Synchronization of separated units of the "Almaz-2M" accelerator in time is provided by the accelerator launch devices, and in frequency by the master generator "Rubin".

In Fig. 1 The control diagram of the "Almaz-2M" accelerator is presented.

The accelerator is controlled as follows. Short trigger pulses are sent to the circuits responsible for generating microwave power – the "Rubin" generator and the klystron modulator.

In this case, the frequency of generation of the klystron microwave power supplied to the accelerating section of the accelerator is set by the "Rubin" magnetron, and the duration of the pulse from the klystron is obtained by superposing the pulses generated by the klystron modulator and the "Rubin". This duration is equal to the duration of the microwave pulse envelope of the signal from the microwave load detector.



a

b

Fig. 1. Accelerator control circuit (a) with output oscillograms (b). The yellow beam is a pulse from the "Rubin" generator detector. The violet beam is a pulse at the klystron cathode. The blue beam is a pulse from the Faraday cup. The Green – impulse from the current sensor at the output of the electron gun

The launch time of the electron gun is set by the pulse of the launcher channel 4, and the pulse duration of the output beam of electrons from the gun is determined by the parameters of the forming line of the gun modulator.

As a result, the pulse envelope from the Faraday cup is obtained by superimposing a microwave electromagnetic field pulse in the accelerating section and a current pulse measured at the gun output.

Thus, by adjusting the delay time of channels 2-3-4 of the launcher relative to each other, it is possible to adjust the required duration of the electron beam at the output of the accelerating section (on the Faraday cup). Channel 1 is used to synchronize the oscilloscope sweep.

1. SETTING UP THE "RUBIN" GENERATOR

As mentioned above, the frequency of the microwave power source is set by the "Rubin" generator. As can be seen from the graph in Fig. 2, this frequency significantly affects the efficiency of the accelerator, determined by the output current.

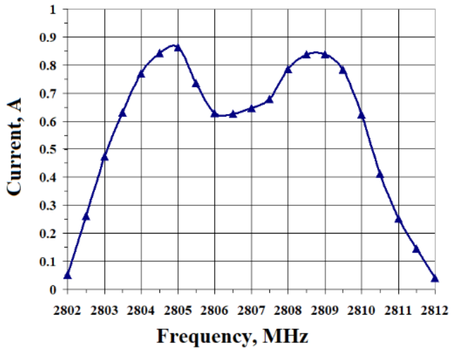


Fig. 2. Dependence of accelerator output current on frequency

From Fig. 2 shows that a change in frequency of just 1…2 MHz relative to the Rubin operating frequency of 2805 MHz can reduce the current by 15…27%, respectively.

1.1. ADJUSTING THE FREQUENCY OF THE "RUBIN" GENERATOR

Frequency adjustment is carried out by changing the operating frequency of magnetron 1 of the "Rubin" generator (Fig. 3). The tuning to a given frequency is controlled by a wave meter. The wave meter scale has divisions that must be calibrated to determine the actual frequency when tuning the magnetron.

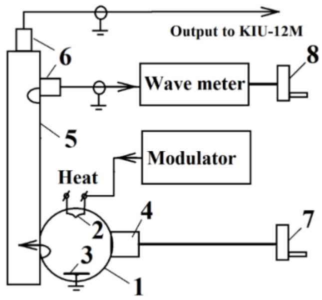


Fig. 3. Schematic of the Rubin generator, where: 1 – MI-30 microwave magnetron; 2 – anode; 3 – cathode; 4 – frequency setting mechanism; 5 – waveguide; 6 – coaxial waveguide junction; 7 – frequency adjustment arm; 8 – wave meter adjustment arm

To carry out calibration, the wave meter input cable was disconnected from the coaxial-waveguide junction and connected to the G4-80 measuring microwave generator. The G4-80 frequency in the range of interest to us was previously calibrated with a Ch2-9A frequency meter with an accuracy of 1.5 MHz. The output from the detector diode of the resonator was disconnected from the input of the wave meter amplifier and then was connected to the oscilloscope.

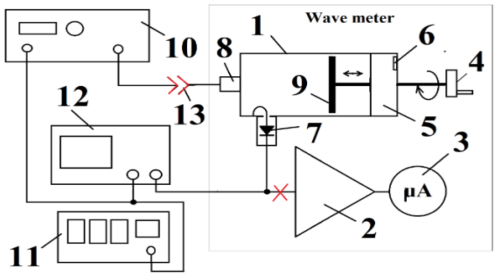


Fig. 4. Scheme of wave meter calibration, where 1 – resonator; 2 – wave meter amplifier; 3 – resonance indicator; 4 – wave meter tuning arm; 5 – tuning mechanism; 6 – measuring scale; 7 – detector diode; 8 – microwave element of the communication line; 9 – resonator tuning plunger; 10 – microwave generator G4-80; 11 – pulse generator G5-54; 12 – oscilloscope; 13 – coaxial connector

The measurements were carried out both in the G4-80 continuous generation mode and in the pulsed generation mode, while a pulse of the required duration was supplied to the G4-80 from a G5-54 rectangular pulse generator. In Fig. 5 the oscillogram is shown at the moment of resonance of the wave meter resonator in the pulse generation mode.

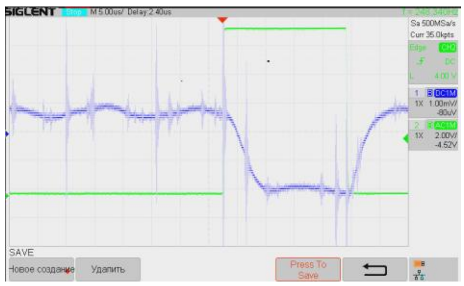


Fig. 5. Oscillograms of a pulse from a wave meter in resonant mode, where blue beam – signal from the G5-54 pulse generator, green beam – signal from detector diode 7 (Fig. 4)

As a result of the calibration of the "Rubin" wave meter, the dependence shown in Fig. 6 was obtained.

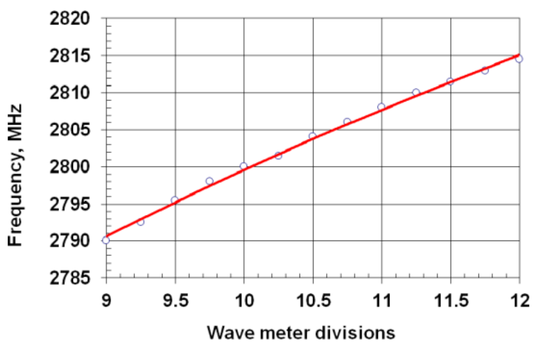


Fig. 6. Wave meter calibration curve

As stated above (see Fig. 1), the accelerator is controlled by the launch device.

2. LAUNCH DEVICES FOR THE "ALMAZ-2M" ACCELERATOR

2.1. DESCRIPTION OF THE OPERATION OF THE "ALMAZ-2M" ACCELERATOR LAUNCH DEVICE

In the normal mode of operation of the "Almaz-2M" accelerator, the trigger device provides the following sequence of trigger pulses for the accelerator circuits, as shown in the oscillograms in Fig. 1,b. In this case, the pulse from the microwave load coinsides with the flat top of the signal corresponding to the current pulse from the output of the electron gun. In this case, a homogeneous sequence of electron bunches is formed, where all bunches have an equal charge.

However, in the mode of forming a charge-profile pulse sequenc, it is necessary that the pulse corresponding to the microwave signal falls on the inclined part of the current pulse from the gun output. This operation regime is shown in Fig. 7. Besides, it is necessary that the front of the triggering pulse be sufficiently short. Therefore, it is problematic to use in new experiments a standard accelerator trigger device, which we used previously, since the front of its trigger pulses is about 0.5 μs. Therefore, we modernized the standard launch device.

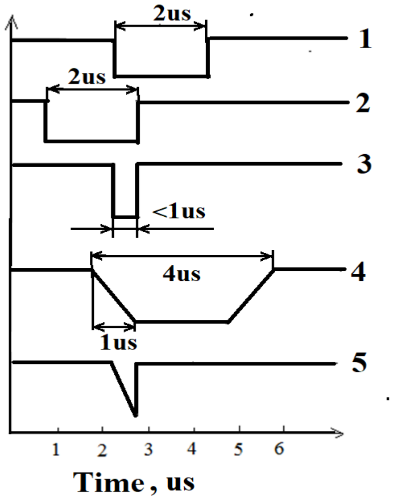


Fig. 7. Diagrams of the time characteristics of the launch of the main components of the accelerator, where 1 is a pulse from the detector of the "Rubin" generator; 2 – pulse at the klystron cathode; 3 – pulse from the microwave load detector; 4 – pulse from the current sensor at the output of the electron gun; 5 – pulse from the Faraday cup

2.2. DESCRIPTION OF THE CIRCUIT OF A STANDARD ACCELERATOR LAUNCH DEVICE

As can be seen from Fig. 1, the accelerator launch device has four outputs. Each output of the device generates a pulse, time-shifted relative to the reference pulse (see channel 1 in Fig. 1) or the master pulse. This is determined by the block diagram of the device, which consists of a master oscillator and three identical circuits independent of each other, which generate pulses with a time delay relative to the trigger pulse from the generator.

The time delay diagram of a standard trigger device is shown in Fig. 8.

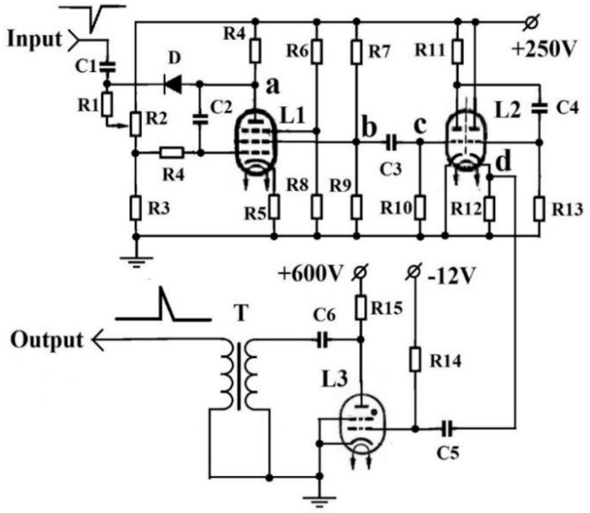


Fig. 8. Pulse generation circuit with delay

Fig. 9 illustrates the operation of the circuit using voltage diagrams at points a, b, c, d indicated in Fig. 8.

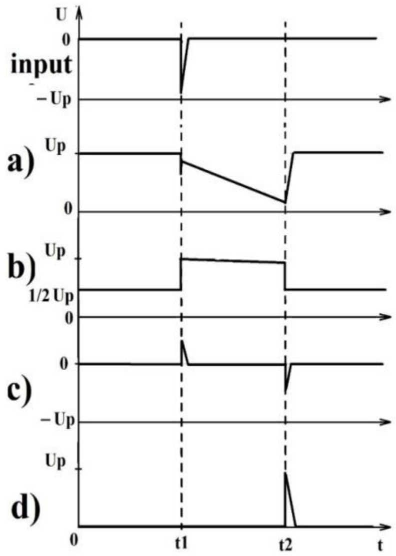


Fig. 9. Diagrams of voltage changes over time in a pulse generation circuit with a delay

As can be seen in Fig. 8, the formation of the delay time is carried out by an element on an electron tube pentode L1 type 6zh2p. The circuit uses a ramp voltage generator [19] of the Fantastron type [20]. It is known that this circuit has good characteristics in terms of linearity and stability of time delays.

The timing circuit works as follows. When a trigger pulse arrives at its input (top graph), the lamp L1 opens and capacitor C2 begins to discharge until the voltage on the upper grid of the lamp is equal to the voltage on the voltage divider formed by R6 and R8. After this, L1 closes and the voltage at point "a" quickly increases to the supply voltage Up = 250 V. In this case, on the second grid from the top (point "b") a rectangular pulse is formed with an amplitude Up and with a leading edge at starting moment t1 and falling edge at moment t2, which corresponds to stopping discharge C2.

At point "c" the signal is short voltage spikes, positive at the leading edge of the pulse at point "b" and negative at its falling edge.

From the differentiating circuit C3, R10, the signal is supplied to a double triode L2 of the 6n2p type.

As can be seen from the diagram in Fig. 8. the first half of L2 acts as an inverting amplifier and a positive input pulse limiter, and the second half is a cathode follower.

As a result, a short pulse with an amplitude close to Up is formed at the output L2 (point "d") at time t2. This pulse is supplied to the igniting input of the thyratron L3. As a result of the operation of the thyratron, the primary winding of the pulse transformer "T" receives a voltage pulse with an amplitude equal to the supply voltage L3–600 V. Since the transformer has the same number of turns in the primary and secondary windings, short pulses with amplitude of about 600 V with a given delay.

2.3. MODERNIZATION OF THE STANDARD ACCELERATOR LAUNCH DEVICE

To determine the possibility of improving the characteristics of the standard accelerator launcher circuit, preliminary measurements were carried out. They showed that the reason of instability could be the poor quality of old paper capacitors installed in the device. This is primarily capacitor C2, type MBGO, since it is the most important timing element of the phantastron circuit. The capacitance of this capacitor must be constant and should not change under the influence of external factors, such as temperature. In other words, it must have a TCC (temperature coefficient of capacitance) close to zero.

In addition to the capacitor C2, all other capacitors in the circuit are also important to reduce pulse fronts. They must also be of high quality and designed to work in high-frequency and pulse circuits, have low inductance, low discharge resistance and low self-discharge.

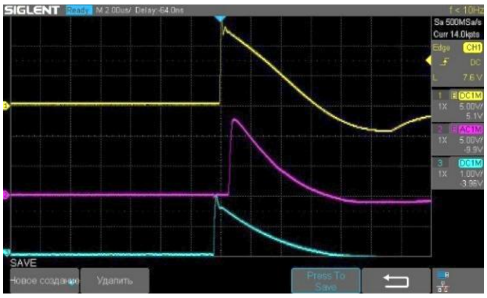
To replace these capacitors, polypropylene film capacitors of the MPP type (SVV-21) were selected that meet the above requirements [21].

In addition, it was replaced with a new high-quality potentiometer R2, which made it possible to more accurately adjust the delay time.

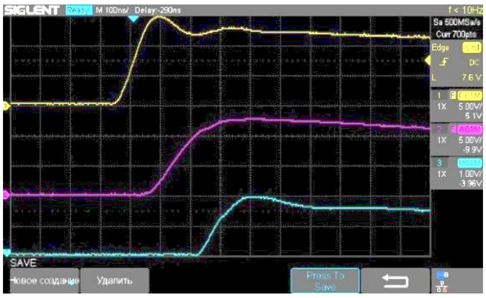
The test results of the modernized accelerator launch device are presented in Fig. 10.

As can be seen from Fig. 10. The replacement of circuit elements described above gave results in reducing the fronts of triggering pulses from 500 to at least 200 ns (magenta beam), and the other two channels even to 120 and 150 ns. The time delay adjustment has also been improved and allows you to set the delay from zero to maximum with an accuracy of no worse than 200 ns.

However, some difference in the duration of the leading edges of the output pulses of different channels remains unclear. This is likely due to the influence of other delay channel circuit elements such as vacuum tubes and pulse transformers. But their replacement is problematic since these electronic components are no longer produced by industry. Therefore, further modernization of this launch device is not advisable.



a



b

Fig. 10. Oscillograms of pulses at the output of the trigger device, where is an oscillogram with a sweep of 2 μs (a), an oscillogram with a sweep of 100 ns (b). The delay time between pulses is about 200 ns, the pulse amplitude is 600 V

2.4. NEW ACCELERATOR LAUNCH DEVICE

As mentioned above, despite the fact that it was possible to significantly improve the technical characteristics of the standard accelerator launch device, its further modernization is not possible due to the lack of components used in it. Therefore, we developed and tested a new scheme for launching device of the accelerator [22].

This scheme has the following advantages compared to the standard accelerator launch scheme:

• It has more than twice the best timing characteristics: less than 100 ns on the pulse edge (instead of 200 ns).

• Due to very low energy consumption, it does not contain hot parts.

• Unlike a standard launcher, it has a printed circuit board and is therefore compact in size.

• Due to two previous advantages, it has greater reliability.

• Consists of modern accessible and inexpensive electronic components.

CONCLUSIONS

As a result of the work performed to modernize and configure the control system of the "Almaz-2M" accelerator, the following results were obtained.

• A method for calibrating the "wave meter" of the "Rubin" master oscillator with an accuracy of 1.5 MHz has been developed and implemented.

• The standard accelerator launch system has been modernized. This made it possible to obtain trigger pulses with a rise time of about 200 ns and with the same accuracy of setting the beginning of the pulses.

• Based on modern microcircuits and radio components, a new scheme for launching accelerator systems with a rise time of less than 100 ns has been developed.

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Article received 30.04.2024

МОДЕРНІЗАЦІЯ ТА НАЛАШТУВАННЯ СИСТЕМИ КЕРУВАННЯ НВЧ-ЖИВЛЕННЯМ ПРИСКОРЮВАЧА «АЛМАЗ-2М»

Д.Ю. Залеський, В.І. Приступа, В.С. Ус, Г.В. Сотніков

Керування джерелом НВЧ-енергії прискорювача «Алмаз-2М» здійснюється шляхом подачі НВЧ модульованого імпульсу від задаючого НВЧ-генератора «Рубін» на клістрон КВУ-12М. Частоту «Рубіна» необхідно налаштувати на резонансну частоту прискорювача, яка може змінюватись під впливом зовнішніх умов та старіння матеріалів елементів прискорювача. У той же час частотомір – «хвилемір» генератора «Рубін», також потребує калібрування. Зроблено опис методу калібрування «хвилеміра» з точністю до 1,5 МГц. Для експериментів з прискорення кільватерного електронного пучка з використанням профільованої послідовності згустків важлива синхронізація всіх елементів прискорювача – електронної гармати, задаючого генератора та клістрона. Для цього було модернізовано штатну систему запуску прискорювача. Це дозволило отримати імпульси запуску з часом зростання близько 200 нс. Також на основі сучасних мікросхем розроблено нову систему запуску з переднім фронтом менше 100 нс.