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Subnanosecond electron accelerator with gas-filled former

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Abstract. A subnanosecond electron accelerator prototype based on ARSA small-size accelerator with gas-filled former (nitrogen ~ 4 MPa) has been developed and studied. A former operation principle is charging a short storage line and its discharge to a stepped line with an accelerating tube, generating electrons. Electron beam current pulse length does not exceed 0.3 ns, current amplitude ~ 1.5 kA.

Keywords: accelerator, gas-filled former, voltage subnanosecond pulses.

1. Introduction

At present a technique for obtaining ultra-short electron beams is developed well enough, due to scientific studies [1–3]. These papers present a theoretical background for generating beams with minimal duration and examples of development of subnanosecond accelerators using oil-filled formers (voltage up to 1 MV) and gas-filled ones (voltage up to 300 kV) which are successfully applied in various areas of science and technology.

Employment of oil switches requires their periodical circulation and, consequently, a larger delay (several minutes) between pulses. Accelerators based on gas switches allow both a significant reduction of pulse interval, and operation in any position. In these accelerators electron energy is not high, that is why the task for obtaining subnanosecond electron beams with energy up to 1 MeV with gas-filled formers is acute.

RFNC-VNIIEF has developed a subnanosecond electron accelerator prototype based on ARSA [4] small-size accelerator with a gas-filled former. The accelerator is meant for generating subnanosecond electron pulses of accelerated electrons with energy up to 800 keV and half-height duration 0.3 ns.

2. Subnanosecond accelerator design

An external view of the subnanosecond electron accelerator is given in Fig. 1. It consists of charger *1* and high-voltage unit *2* of ARSA accelerator with mounted subnanosecond pulse former *3* with an accelerating tube. Rack *4* serves to ensure the accelerator stability.

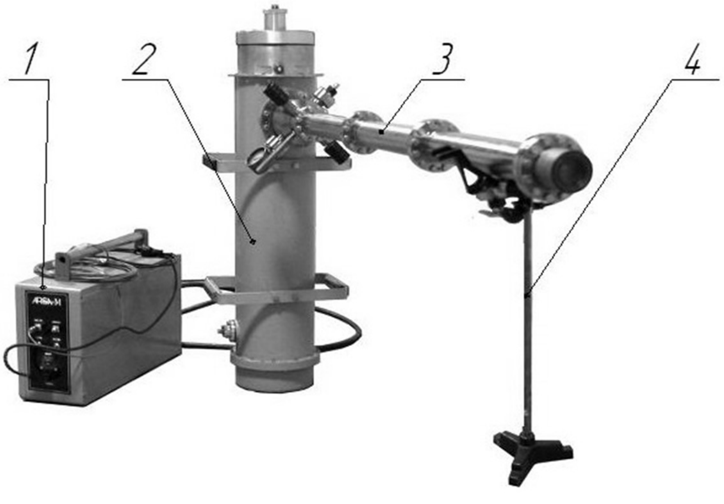


Fig. 1. Subnanosecond electron accelerator: *1* – charger; *2* – ARSA accelerator high-voltage unit; *3* – subnanosecond pulse former; *4* – rack.

ARSA accelerator high-voltage unit is used as a source for high-voltage subnanosecond pulses. Nanosecond pulses are converted into high-voltage subnanosecond pulses with the aid of former 3, resulting into electron beams generation. The former design is given in Fig. 2.

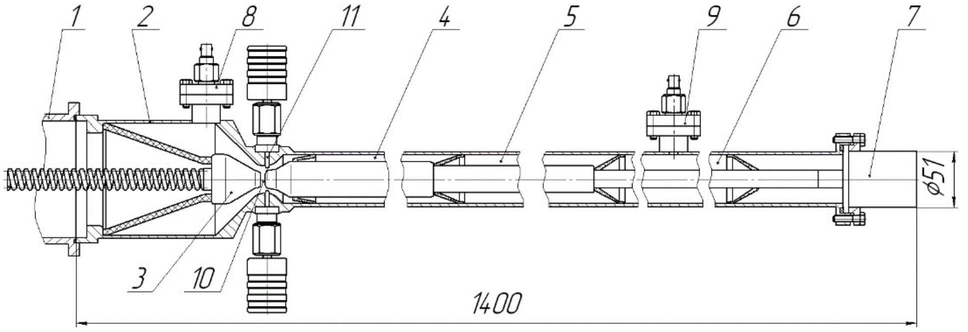


Fig. 2. Design of subnanosecond pulse former: *1* – ARSA accelerator output branch pipe; *2* – biconical line unit; *3* – short stor age line; *4*, *5*, *6* – stepped line; *7* – accelerating tube; *8*, *9* – voltage dividers (nano- and subnanosecond); *10* – spark gap; *11* – chopping gap.

The former is installed on ARSA accelerator output branch pipe *1* and contains a unit of biconical lines *2* with a short storage line *3*, and a stepped line subdivided into sections *4*–*6* with wave resistances 18 Ohm, 36 Ohm and 60 Ohm. The transmission line is connected to accelerating tube *7*. To register charge voltage of short storage line *3*, capacitive divider *8* with nanosecond resolution is mounted on unit body *2*. Voltage pulses on the accelerating tube are registered with the aid of subnanosecond capacitive divider *9*, installed at a distance of 300 mm from the tube cathode. After the former is assembled, it is filled by nitrogen up to pressure 4 MPa (40 atm.).

The former's operation principle is the following. Following ARSA cascade generator operation, the short storage line *3* is pulse charged. After the line is charged up to maximum voltage (about 800 kV), spark gap *10* between short storage line and transmission line breaks down, and the short storage line discharges to the first transmission line section *4* matching it. Due to a small length of short line *3* in the transmission line, a subnanosecond voltage pulse is formed. Its amplitude is twice lower than the short storage line charge amplitude, due to an equation for wave resistances of transmission line section *4* and line *3*. A subnanosecond voltage pulse is supplied through a stepped line to the accelerating tube, resulting in electron radiation generation. Increase of wave resistances of stepped line sections and tube mismatched operation mode (whose resistance is several times higher than the last transmission line section resistance) leads to increase of the tube voltage amplitude practically up to the short storage line charge amplitude value. Chopping gap *11* is adjusted in such a way as to break down at the maximum subnanosecond pulse voltage, closing on itself the energy excesses of ARSA accelerator cascade generator and shortening the subnanosecond pulse tail.

For the gas-filled former the metalceramic accelerating tube SNIT-1000, capacitive voltage dividers with nano- and subnanosecond resolution have been specially developed and manufactured. All the mentioned units are meant for operation in the compressed gas atmosphere. The accelerating tube is made with distributed wave parameters and is a part of the transmission line with the same wave resistance, what allows elimination of subnanosecond pulse distortion.

The accelerating tube is one of the most important former units. At present the industry produces only one type of a sealed-off vacuum tube IMA3-150E, suited for short electron pulse formation. Its basic drawback is low mechanical glass insulator strength, what does not permit to locate the tube in the compressed gas media, which is an insulating medium in the gas-filled former. That is why a metalceramic sealed-off vacuum tube SNIT-1000 (see Fig. 3) has been developed and manufactured for the subnanosecond accelerator prototype in cooperation with an enterprise

L.C. «Pulse Technology», Ryazan. Application of ceramic insulator VK94-1 allows operation in compressed gas media.


(a) (b)

Fig. 3. SNIT-1000 accelerating tube: (a) – side view; (b) – back view.

The accelerating tube is a part of the transmission line with the same wave resistance, what allows elimination of subnanosecond pulse distortions.

3. Calculation of output subnanosecond accelerator characteristics

The subnanosecond accelerator output parameters was calculated by two computer programs: a circuit analysis program and a three-dimensional simulation package for physical processes.

A circuit analysis program operates with equivalent device circuit elements. Its advantage is a capability for simulating the switching spark gaps operation and the process for subnanosecond pulse shaping. The former short charge line time was calculated by the given program, it was ~ 5 ns. A change calculation for the voltage pulse, while it’s passing through the former, demonstrated that for the selected structure the voltage pulse amplitude on the accelerating tube was close to the amplitude of the short storage line charge voltage.

Non-uniformity effects in the structural former element shape (grooves in conductors, insulators etc.) are analyzed in the package of three-dimensional physical process simulation when passing through the former of Gauss pulse with half-height duration 0.2 ns. Calculations have shown that the highest passing pulse amplitude losses (17%) and the pulse length broadening (by 0.05 ns) occur in the spark gap area between the short storage line and the transmission line. Biconical lines application allows about a three-fold losses reduction. The losses on base insulators, as well as on slots and grooves meant for fixing insulators do not exceed 1%, thus they may be neglected.

4. Experimental studies of subnanosecond accelerator characteristics

In the given paper to measure a megavolt voltage pulse on ARSA accelerator high-voltage unit output, supplied onto the subnanosecond former, there was used a double-stepped resistive divider, whose first step was filled by blue vitriol solution until resistance 1.2 kOhm [5] was reached. A conductive layer of the first step is performed in the form of a tube, what practically eliminates the skin effect at frequencies ~1 GHz and minimizes self-inductance and interelectrode capacitance. Due to the liquid column homogeneity over the length, not only resistive, and capacitance, and inductance division occurs, that is why at the second step input the voltage grows during picoseconds, and the entire divider resolution time is determined by the second step and is ~1 ns. To additionally attenuate signal, there were used dividers SDNR5. The total signal attenuation was a factor of ~ 10^5 times. The voltage pulse oscillogram at the subnanosecond former input, registered by oscilloscope TDS 3032 (pass band 300 MHz) is given in Fig.4. The voltage pulse amplitude was $U \approx 800$ kV, the first peak duration was $\tau_{0.5} \approx 3.5$ ns.

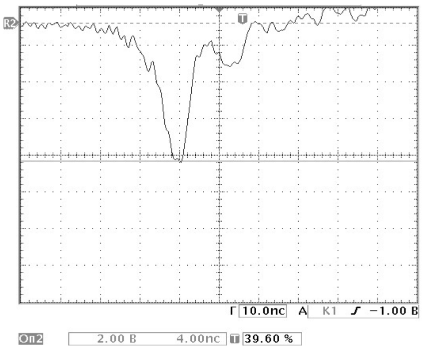


Fig. 4. Voltage pulse oscillogram on the subnanosecond former input (scan – 4 ns per cell).

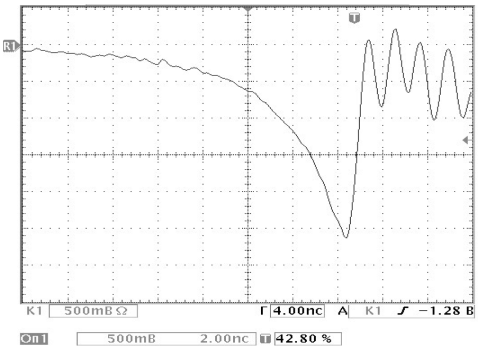


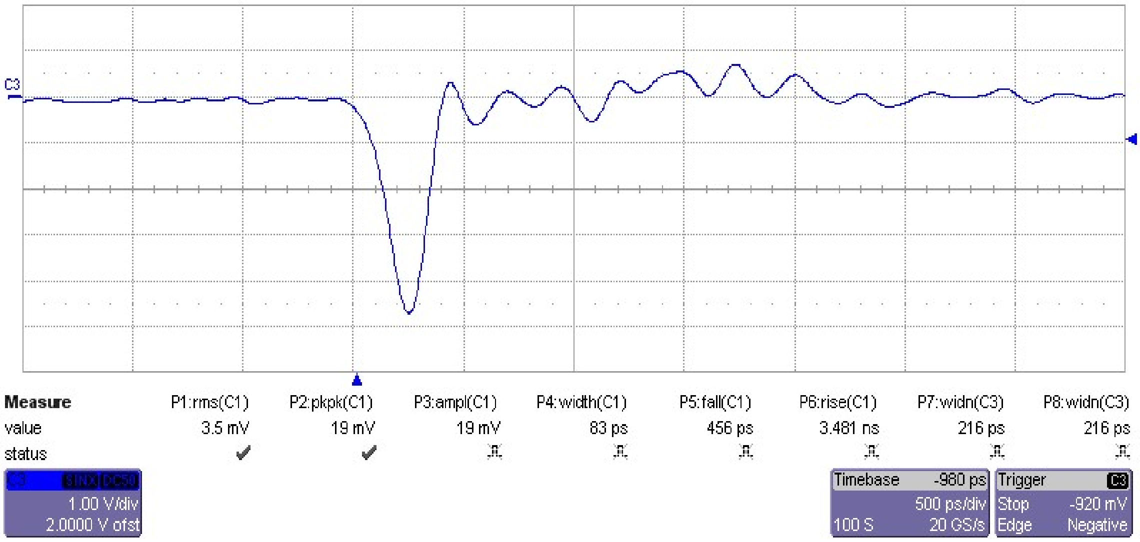
Fig. 5. Charge voltage pulse oscillogram for short storage line (scan – 2 ns per cell).

The charge pulse voltage of the short storage line was registered by a nanosecond capacitive divider (Fig. 5).

The pulse rise time was 6 ns. When reaching the spark gap breakdown voltage, breakdown occurs (an abrupt drop on the voltage oscillogram), connecting the short storage and the forming line.

To measure the form and amplitude of SNIT-1000 accelerating tube electron radiation pulse, there was used a low-inductance current shunt based on a high-frequency metal-dielectric resistor C-2-10-0.5 with resistance 1 Ohm built in connector SR-75-155FV.

Temporal shunt gauge was fulfilled with the aid of the subnanosecond electron beam ($\tau_{0.5}$ ~ 0.15 ns) of SPIN-2 accelerator [6]. The shunt was placed at a distance 10 mm from IMA3-150E electron tube output window. A signal was transmitted from the shunt along the cable RK50-4-21 of length 5 m with double shielding was supplied to oscilloscope LeCroy Wavemaster-8500A with a pass band 5 GHz. In order to diminish the signal amplitude, attenuators SDNR 14-02 were used. A typical oscillogram of SPIN-2 accelerator electron beam current, registered by a shunt, is given in Fig.6. The measured current pulse length was $\tau_{0.5}$ ~ 0.2 ns. Basing on these measurements one can evaluate the shunt resolution time $\tau_{0.5}$ ~ 0.15 ns.



Measure	P1:rms(C1)	P2:pkpk(C1)	P3:ampl(C1)	P4:width(C1)	P5:fall(C1)	P6:rise(C1)	P7:widn(C3)	P8:widn(C3)
value	3.5 mV	19 mV	19 mV	83 ps	456 ps	3.481 ns	216 ps	216 ps
status	✓	✓						

C3 SINX DC50
1.00 V/div
2.0000 V ofst

Timebase -980 ps
500 ps/div
100 S 20 GS/s

Trigger C3
Stop -920 mV
Edge Negative

Fig. 6. SPIN-2 accelerator electron beam current oscillogram, (scan – 0.5 ns per cell).

Fig.7 shows an oscillogram for subnanosecond accelerator electron beam current (SNIT-1000 tube), registered by the shunt. Oscillograms was recorded on Le Croy oscilloscope (pass band 1.5 GHz). The registered current pulse duration was $\tau_{0.5} \approx 0.4$ ns. Taking into account oscilloscope and shunt resolution times, the electron beam current duration did not exceed $\tau_{0.5} \approx 0.3$ ns. The electron beam current amplitude was ~1 kA.

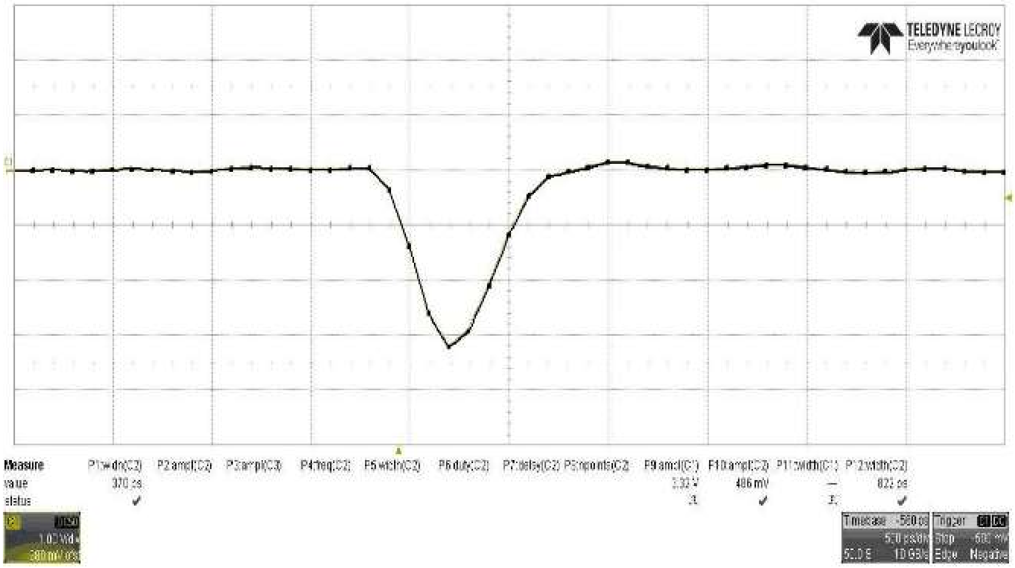
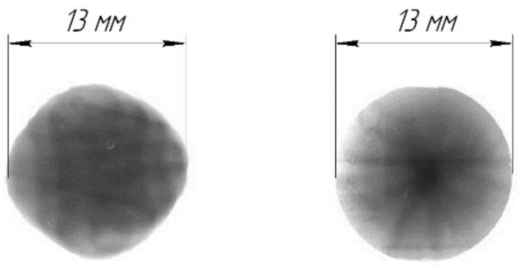


Fig. 7. Electron beam current oscillogram for subnanosecond accelerator with SNIT-1000 tube, (scan – 0.5 ns per cell).

The accelerating tube electron beam structure was registered with the aid of TsVID-01-1 radiation monitoring film. Fig. 8a presents SNIT-1000 tube sign of electron beam. For comparison (Fig. 8b) IMA3-150E tube sign, used in SPIN-2 accelerator is presented.



(a) (b)

Fig. 8. Tube electron beam signs: (a) – SNIT-1000; (b) – IMA3-150E.

SNIT-1000 tube electron beam possesses a more uniform distribution, a central focusing section is absent in it, as it takes place in the tube IMA3-150E. Electron beam uniformity on the window increases the tube life and a capability for operation at high currents.

Maximal electron energy was estimated by the method, described in paper [7], and was ~ 800 keV.

5. Conclusions

RFNC-VNIIEF has developed, manufactured and studied the subnanosecond electron accelerator prototype based on ARSA small-size accelerator with the gas-filled former.

The metalceramic accelerating tube, capacitive voltage dividers with nano- and subnanosecond resolution has been developed and manufactured for the former.

The electron beam current pulse has been registered. With regard to time resolution of oscilloscope and shunt the current pulse width does not exceed 0.3 ns. The electron beam current amplitude is ~ 1.5 kA, maximal electron energy ~ 800 keV.

The subnanosecond accelerator will be used for determining the time resolution of nanosecond detectors of electron and bremsstrahlung radiation pulses, certification and control over performance of measuring channels, as well as studies of electric-physical characteristics (life time, carrier mobility) wide-band gap insulators and promising semiconductor heterogeneous structures.

6. References

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