UPGRADING OF THE HIGH-CURRENT ACCELERATOR "TONUS"

A.I. Ryabchikov, A.V. Petrov, V.B. Karpov, N.M. Polkovnikova, V.G. Tolmacheva, and Yu.P. Usov
Nuclear Physics Institute at Tomsk Polytechnic University, Lenina Str. 2a, Tomsk, 634050, Russia,
Phone: 7-3822-417962, Fax: 7-3822-423934,E-mail: usov@npi.tpu.ru

In the paper presented, the new technical development of the high-current electron accelerator "Tonus-NT" (Tomsk nanosecond accelerator – new technologies) is described. It has been developed taking into account the experience of 30-years exploitation of the previous analogue – the accelerator "Tonus".
The scheme of the accelerator includes the high-voltage transformer with resonant contours (Tesla transformer) charging the double forming line filled with the transformer oil and the high-voltage diode. The gas-filled trigatron spark gap with up to 10 atm operating pressure is used for the double forming line switching. The main accelerator parameters are as follows: accelerating voltage range 0.4-1.7 MeV, line impedance 36.6 Ω, pulse duration 60 ns, pulse repetition rate up to 10 pps.
PACS numbers: 29.17.+w

1 INTRODUCTION

Extension of the area of physical investigations using relativistic electron beams and their applications to high-power microwave and X-ray generation, plasma chemistry, *etc*. make more and more strict requirements to parameters of high-current accelerators. For practical applications, it becomes important to provide a repetitive mode of operation of high peak power accelerators with significant energy consumption that requires high reliability of their main units. An adequate solution to this problem is the accelerator scheme based on forming lines with distributed parameters where Tesla transformer is employed as a high-voltage generator [1-3]. With a Tesla transformer, charging units are highly efficient, simple, handy for exploitation, and rather reliable. Comparing to Marx generators [4, 5], pulsed transformers allow avoidance of a large number of spark gaps (which repetition rate and life-time are limited) and using commercially available switching elements in the primary circuit. These advantages of Tesla transformers were duly recognized in the development of repetitively-pulsed high-current electron accelerators [3].

Using this scheme, we have designed and constructed the accelerator with the coaxial double forming line (DFL) on the basis of the installation "Tonus" [6]. Taking into account a multipurpose function of the accelerator, we have provided the wide range of operating voltages (0.4-1.7 MV) and increasing the forming line impedance from that of the analogue up to the values corresponding or close to maximum power at ~60 ns output pulse duration and 10 Hz pulse repetition frequency.

Increasing the forming line impedance has allowed, on the one hand, easier operation mode of the main switch, and on the other hand, significant increasing the electric strength of the forming lines at the given dimensions of the accelerator body. The latter circumstance has also allowed us to provide a possibility of increasing the charging voltage up to 1.5-1.7 MV for operation in the single-shot mode or at low (up to 0.3 Hz) rep-rate frequency. Because of the same reasons, the transformer with ~0.6 interwinding coupling coefficient was chosen, so that the spark gap actuated at the second half-wave of charging voltage corresponding to the most efficient energy transfer.

The accelerator was manufactured and launched into operation in the end of 2000 with the following parameters: up to 1 MV accelerating voltage, up to 25 kA beam current, ~60 ns pulse width (FWHM), and 0.1 Hz rep-rate frequency for up to 10 shots in a bunch. It is supposed that the designed parameters (or close) will be achieved by the end of 2001 following the schedule of stage-by-stage launching.

2 ACCELERATOR ELECTRIC CIRCUIT

The electrical schematic diagram of the accelerator is shown in Fig. 1.

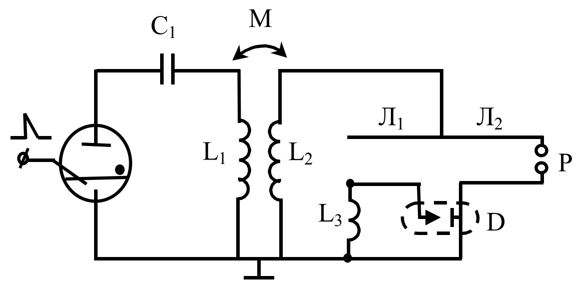

Fig. 1. Accelerator electrical schematic.

Charging of the DFL, consisting of two lines L_1 and L_2, is effected from the Tesla transformer through the charging inductance $L_3 \approx 21$ μH. Three capacitors IK-3-50 connected in parallel serve as a primary energy storage $C_1 \approx 8.14$ μF. The capacitance of the secondary contour $C_2 \approx 2.4$ nF is the sum of the DFL capacitance and own capacitance of the transformer. The interwinding coupling coefficient is $k \approx 0.66$. The primary contour own frequency is $f_1 \approx 22$ kHz. The contours mismatch coefficient $\alpha = L_1C_1/L_2C_2 \approx 1.34$. The DFL charging time is of ~25 μs, the coefficient of voltage transformation is of ~52. As the primary contour switch, the IRT-6 mercury spark gap is employed at charging voltages of up to 20 kV. For operation at a higher charging voltage, installing the IRT-4 ignitron is provided. The DFL commutation is effected by the trigatron gas spark gap triggered at the maximum of charging voltage from the auxiliary unit of 100 kV. The loading of the DFL is the electron diode D.

3 ACCELERATOR DESIGN

The schematic of the accelerator is presented in Fig. 2. The coaxial DFL, spark gap, high voltage insulator, and diagnostics are placed within the pipe of 1200 mm diameter filled with the transformer oil. The middle (high-voltage at charging) and inner DFL electrodes are made of stainless steel and have tubular rings at their edges and places of suspension on insulators. The rings increase the rigidity and reduce the voltage gradient in the oil. The middle electrode is hanged, at one end, on the high-voltage input of the polyethylene lead-in base insulator and at the other end, on the caprolon insulator fixed to the accelerator body in the special shell. The inner electrode is hanged at these places on two caprolon insulators. The suspension on insulators is made in such a way that the electric field is "forced out" by the screening rings from places of electrode-insulator contact in order to minimize the probability of the breakdown along the solid dielectric surface. The inner electrode is connected to the accelerator body through the charging inductance L_3 from the side of the electron gun high-voltage insulator. The wave impedances of the outer and inner lines are 17.2 and 19.4 Ω, respectively.

The pulsed transformer, along with the base insulator, is placed within the separate tank of 1200 mm diameter filled with the transformer oil as well. The primary winding of the transformer has 4 turns made of the copper ribbon of 0.2 mm thickness, which are placed on the inner surface of the conical shell. The high-voltage winding contains 263 turns winded as a single layer on the cylindrical shell of 480 mm diameter with the step of 2 mm. The full length of winding is 650 mm; it is made of MGTFwire of 0.35 mm^2 cross-section area. The secondary winding has the protective capacitive screen transparent for ac magnetic flux, which reduces the level of overvoltage between turns. The transformer high-voltage output has longitudinal slits for elimination of the short-circuited turn effect. The primary and secondary windings are fixed at the insulating base. The storing capacitors are located outside the tank and primary winding by the low-inductance strip line.

The controllable high-voltage spark gap comprises two plexiglass cylinders separated by the gradient ring providing uniform voltage distribution. The operating voltage is controlled by variation of the gap between the electrodes (up to 50 mm), filling gas pressure (up to 10 atm), and kind of filling gas (N_2 or SF_6 and N_2 mixture). Instability of the spark gap breakdown voltage does not exceed 5%.

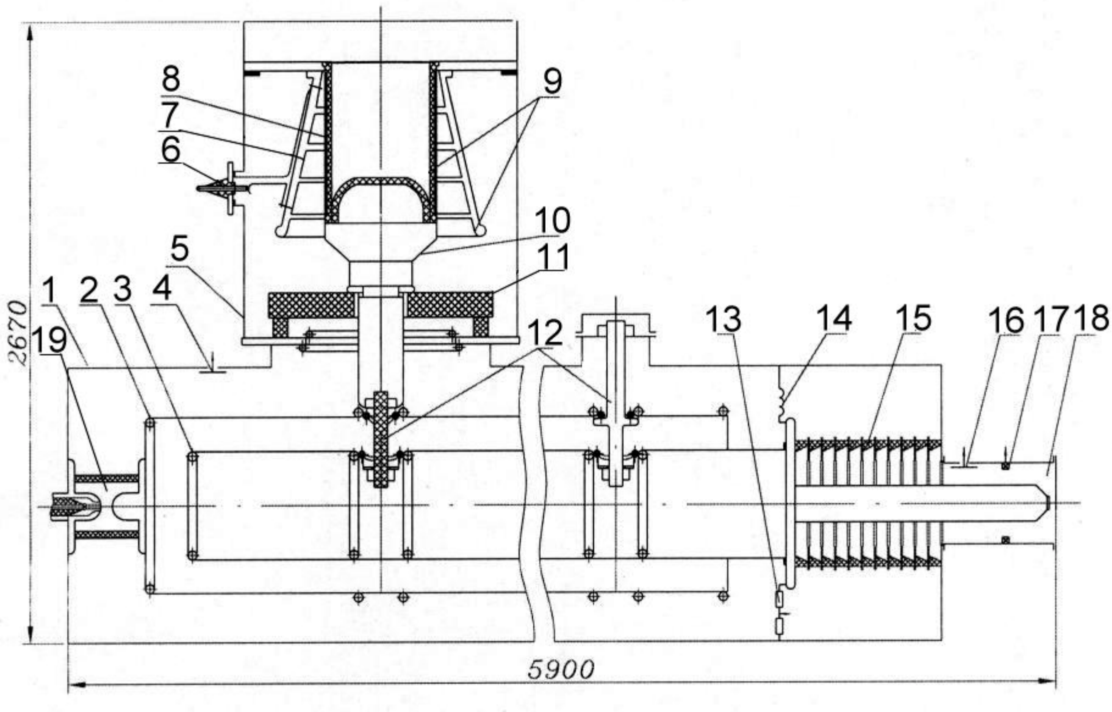

Fig. 2. The schematic of the accelerator: 1 – body, 2 – middle electrode, 3 – inner electrode, 4, 16 - capacitive voltage dividers (VDs), 5 – body of Tesla transformer (TT), 6 – output of TT primary winding, 7 – TT primary winding, 8 – TT secondary winding, 9 – insulating shells, 10 – high-voltage input, 11 – base insulator, 12 – suspension insulators, 13 – active VD, 14 – charging inductance, 15 – electron gun high-voltage insulator, 17 - Rogovsky coil, 18 – electron diode, 19 – controllable high-voltage spark gap.

The accelerator has the sectioned high-voltage insulator separating the vacuum volume of the electron gun from the volume filled with the transformer oil. The insulator consists of 11 plexiglass rings, between which the duralumin gradient rings are installed. The outer diameter of rings is 540 mm, the height is ~50 mm. The inner surface of rings makes the angle of 45° with the gun axis. The sectioned insulator is placed between the metal flanged tightened by 12 plexiglass rods. At the high-voltage flange of the insulator, the cathode holder made as a cylindrical tube is fixed. At its end, the arrangement for fixing cathodes of different diameters and smooth variation of the anode-cathode gap is located.

The anode of the electron diode is Ti foil of ~50 μm thickness leaning on the plain grid for electron beam extraction from the vacuum volume. To obtain bremsstrahlung X-ray radiation, the target of a material with a large atomic number is installed replacing that release window.

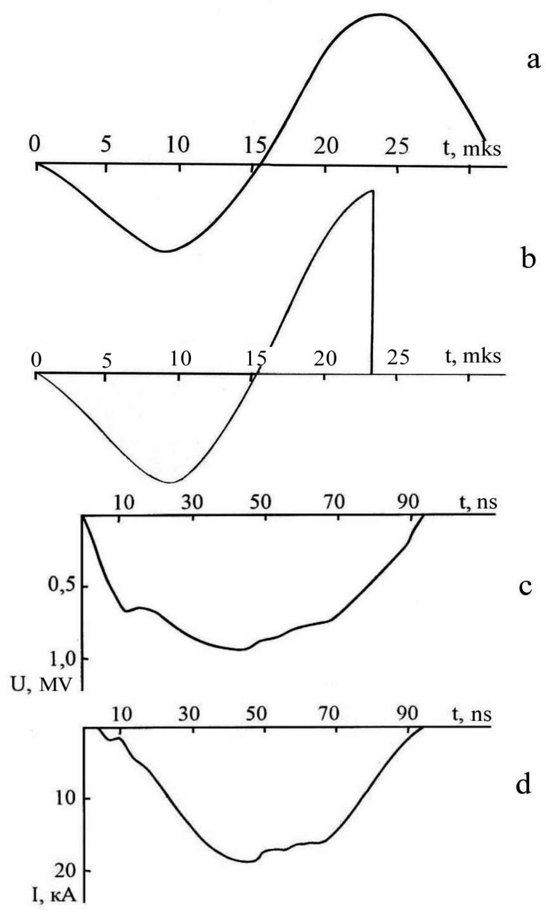

Fig. 3. Typical oscilloscope traces of: a) DFL voltage at spark gap switched off; b) DFL voltage at spark gap breakdown; c) diode accelerating voltage; d) diode current.

In Fig. 3, the typical oscilloscope traces are presented for charging voltage, accelerating voltage, and diode current. The capacitive divider located in the line region registered the waveform of charging voltage. For measurements of the accelerating voltage, the two-stage liquid (KCl water solution) active divider and placed within the vacuum volume capacitive divider were used. Their indications were corrected taking into account inductive voltage drop at the cathode holder. The amplitude of the diode current was measured by the Rogovsky coil.

The efficiency of Tesla transformer determined from measurements of DFL charging voltage amplitude is of ~83%.

The authors are grateful to the Institute colleagues I.F.Isakov, A.I.Pushkaryov, and V.V.Pryakhin for their help in accelerator manufacturing.

REFERENCES

1. S.B.Vasserman, Preprint 77-110, Institute of Nuclear Physics of Siberian Branch of USSR Academy of Sciences, Novosibirsk, 1977, 43 p.
2. V.M.Lagunov, A.G.Ponomarenko, and L.P.Fominsky // *ZhTF*. 1972, v. 42, # 9, p. 1947.
3. S.P.Bugayev, A.S.El'chaninov, F.Ya.Zagulov, B.M.Koval'chuk, G.A.Mesyats, and Yu.F.Potalitsyn. In *High-power nanosecond pulsed sources of accelerated electrons.* Novosibirsk, 1974, p. 113.
4. G.A.Mesyats. *Generation of high power nanosecond pulses.* Moscow: Sovetskoye radio, 1974.
5. A.N.Didenko, V.P.Grigoryev, and Yu.P.Usov. *High power electron beams and their application.* Moscow: Atomizdat, 1977.
6. I.Z.Gleizer, A.N.Didenko, Yu.P.Usov et al. // *Atomnaya energiya*, 1974, v. 34, # 5, p. 378.