500 keV, 200 A MICROSECOND ELECTRON ACCELERATOR WITH A REPETITION RATE OF 10 Hz

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Abstract

The described experimental stand was designed to study high-power pulse gyrotrons and gyroklystrons. The stand is based on a pulse-periodic microsecond electron accelerator with a repetition rate of up to 10 Hz, which generates a helical electron beam (HEB) with electron energy up to 500 keV and current of 200 A.

INTRODUCTION

For some years, the team of the Institute of Applied Physics (RAS) has been designing a high-power pulse gyroklystrons operating in the long-wave region of the millimeter-wave range. To study the gyroklystron, we have created an experimental stand based on a microsecond electron accelerator which has a clock frequency of 10 Hz and generates a helical electron beam (HEB) with electron energy of up to 500 keV and current of 200 A. The overall view of the accelerator is shown in Fig. 1.

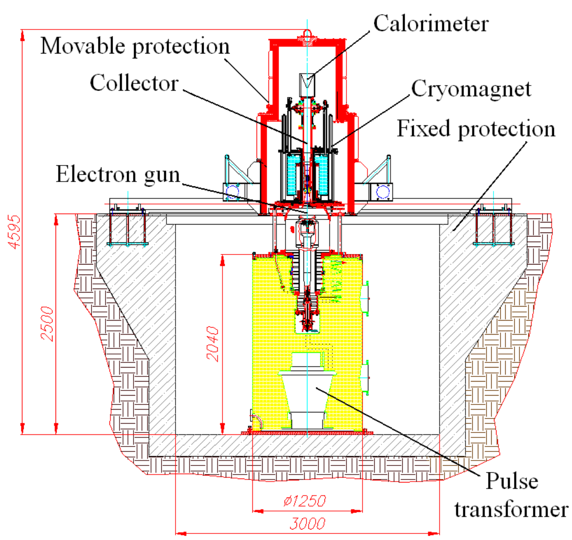

Fig. 1. Overall view of the accelerator

The accelerator was created in the framework of the Scientific and Technical Program “Development of Unique Research Tools and Equipment for RAS Institutions”. In what follows, we describe the components and features of the accelerator and its potential for solving the problems of high-power microwave electronics.

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ELECTRON GUN

The configuration of gun electrodes is shown Fig. 2. The average radius of the emitter is 50 mm, and that of the formed beam, 9 mm. The selected angle (50°), at which the emitter generatrix is inclined to the symmetry axis, is sufficiently large, to ensure the fast escape of electrons from the emitter and, as a result, to reduce the influence of the Coulomb field of the beam on the value of the velocity spread. This formation regime allows one to maintain the acceptable quality and stability of the beam as the current grows up to 0.5–0.7 of the Langmuir current values. The maximum voltage at the cathode is equal to 500 kV, the current, to 200 A, and the calculated pitch factor is approximately ~1.3, when the velocity spread is about 10%.

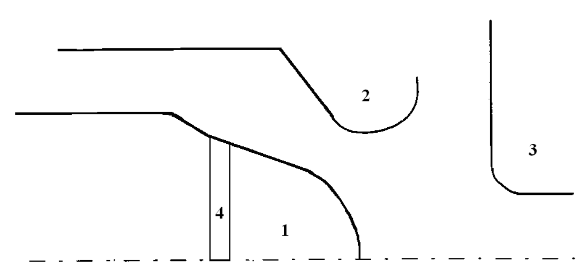

Fig. 2. Configuration of the gun electrodes: 1 – cathode, 2 – intermediate anode, 3 – anode, 4 – emitter

The electrodes of the gun are fixed on two sealed sectioned ceramic insulators, 250 and 300 mm in diameter. We used a low-temperature (operating temperature, 1050°C) impregnated cathode made of barium aluminate in Scientific and Production Association “Toriy” (Moscow).

HIGH-VOLTAGE PULSE GENERATOR

The source of high-voltage pulses comprises a pulse-periodic generator of high-voltage pulses (modulator) and a high-voltage pulse transformer.

The pulse-periodic high-voltage pulse generator (modulator) which feeds the primary contour of the pulse transformer is manufactured at IAP RAS and has the following design parameters:

- amplitude of voltage pulses, 7–23 kV,
- current amplitude, up to 5 kA,
- flat-top duration, 1 μs,
- flat-top instability, ±1%,
- pulse repetition rate, up to 10 Hz.

Fig. 3. Photo of the upper part of the stand. Visible components: cryomagnet, calorimeter, part of the biologic protection.

High-voltage pulse transformer was manufactured by Stangenes Ind. and is similar to the transformers of the SLAC accelerator center (USA). The transformer having a voltage transformation coefficient of 1:23 shares the common oil tank with the accelerating tube of the electron gun. A capacitor measurement voltage divider, a Rogowski coil, and filtering capacitors are fixed on the transformer platform. The transformer is biased by a stabilized power source of type 6671 made by AGILENT.

The cathode heater is fed by a stabilized power unit of the XKW 40-75 type made by XANTREX via the secondary coiling of the pulse transformer.

CRYOMAGNET

The cryomagnet is a superconducting solenoid placed in a cryostat with a vertical "warm" bore (Fig. 3).

The superconducting solenoid is a wound superconducting wire made of the NT-50 alloy (50% Nb/50%Ti). Since the gyroklystron is heated by an external heater to ensure good vacuum, a removable water jacket is included in the design to protect the cryomagnet against the radiation. The parameters of the cryomagnet are given in Table 1.

Table 1. Parameters of the cryomagnet

Operating magnetic field	Up to 2.4 T
The length of the homogenous-field section at the (–1%) level	180 mm
Operating current of the solenoid	Up to 25 A
Diameter of the working bore	132 mm
Internal diameter of the water jacket	121 mm
Operating volume of the liquid helium	24 l
LHe evaporation rate	5 l/day
Major diameter of the cryostat (without the nozzles of the water jacket)	650 mm
Overall height of the cryostat	600 mm
Weight of the cryomagnet	250 kg

The cryomagnet is fed by a stabilized type-6551 source made by AGILENT.

The solenoid correcting the magnetic field at the cathode is fed by a stabilized source of the XKW 40-75 type made by XANTREX and ensured the variation of the magnetic field at the cathode to ±15% of the nominal value.

VACUUM SYSTEM

The vacuum pumping system consists of two vacuum pumps: the high-vacuum cryosorption pump Coolstar 3500 and pump AVAP-100 comprised by a forepump and a nitrogen sorption pump. AVAP-100 produces a vacuum of 10^{-5} mm Hg (with a cold cathode), and Coolstar 3500, $4{\cdot}10^{-7}$ mm Hg in the operating regime.

ACCELERATOR TESTS

In the process of testing the accelerator, a HEB having an electron energy of 450 keV and a current of 200 A was formed. During the experiments, the high-voltage pulse source was connected either to the transformer coil, or to the forming line. The characteristic oscillograms of the voltage and current pulses are shown in Fig. 4 and Fig. 5.

The first experiments with an accelerator employed a relativistic gyrotron. At a wavelength of 1 cm, we obtained a power of 10 MW in the $TE_{5.3}$ mode with an efficiency of 25%. The pulse duration and repetition rate were 0.8 μs and 5 Hz, respectively (Fig. 5). The average power of a sequence of multimegawatt pulses was measured by a modified MK3-71 standard power meter (special operating and ballast heads with a 200 mm were developed). The envelope of the microwave pulse was recorded by means of a standard semiconducting detector.

The spectrum was measured by the heterodyne method. The measured signal and the reference signal of the heterodyne were sent to the signal mixer, the signal of the difference frequency was recorded by a Tektronix TDS-3052 oscilloscope, and then processed by means of a standard computer program.

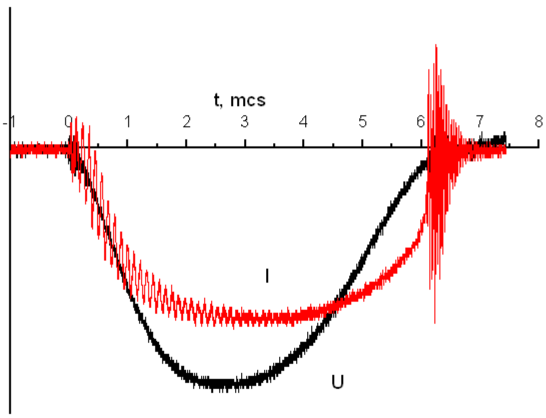

Fig. 4. Characteristic oscillograms of the current from the shunt and the voltage from the capacitor divider, which were obtained for one of the variants of the forming scheme

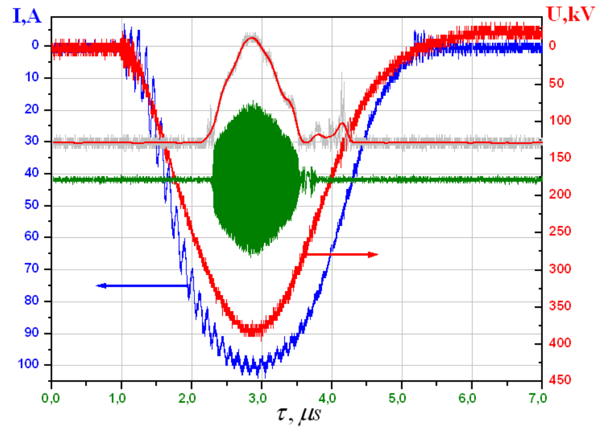

Fig. 5. Oscillograms of the current, voltage, and power envelope of the output microwave radiation, and of the corresponding signal from the mixer (green line). Signal parameters are $U = 395$ kV, $I = 100$ A, $P_{out} = 10$ MW, and efficiency = 25%.