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Section A

A compact far infrared free electron laser

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Abstract

The Korean Atomic Energy Research Institute and the Budker INP developed a design and manufactured the main parts of a free electron laser with emission power of one watt in the infrared region of 25 to 30 microns including 10-cm microtron. After the commissioning of microtron, beamline and undulator electron beams were transmitted through the undulator and by using a special code microtron electron beam, performance parameters were measured and computed.

An 8 MeV microtron that was developed as injector of relativistic electrons into a compact electron synchrotron with an energy of 200 to 600 MeV was chosen as a source of electrons for the Free Electron Laser (FEL). The design of the microtron had a number of advantages that permitted the simplification of its service, and prolongation of the service life of its main units [1].

A cylindric RF-cavity working in the first acceleration type [2], at a frequency of 2.8 GHz, was used in the microtron (Fig. 1). A cathode, 2.5 mm in diameter, was made of a hot-pressed brick LaB_6. The cathode was pressed into a cylindrical tantalum case. The heater was made of tantalum in the form of traverses. With an optimum depth of the cathode position and a coordinate of the cathode center, $X_0 = 1.7$ (in units of $\lambda/2\pi$), the capture coefficient was 7.9%.

With the power of the RF-generator being about 1.5 MWt and the coupling coefficient of the RF-cavity $\beta = 2.7$, the microtron provided macropulse current up to 35 mA, with an electron energy of 7.5–8 MeV [3]. A Russian production magnetron MI-456 served as the RF generator.

In operation, the microtron has demonstrated high reliability, stability of parameters, and the opportunity of improving them. This predetermined a modernization of the microtron for creating an infrared FEL on its base. As a result of the modernization, the pulse duration of the modulator was increased by a factor of two on account of enlarging the quantity of sections of the artificial line. Characteristic impedance changed along the artificial line according to the hyperbolic low. It allowed for compensation of the losses in the magnet core of a pulse transformer. The line was being tuned thoroughly for the purpose of minimizing modulation and slope of the pulse, being fed to the magnetron through the pulse transformer.

After the modernization, the modulator provides a magnetron current pulse with a duration of not less than 6.5 mcs at a level of 0.9, with a current amplitude up to 130 A and voltage on the magnetron up to 55 kV. In this case, the pulse slope of the magnetron current does not exceed 1% [4].

The next step of the modernization was an increase of the coupling coefficient of the RF-cavity to $\beta = 5.4$, with the Q_0-factor of 9200.

For the purpose of extending the service life, the design of the cathode has been improved [5]. A polycrystal cathode was replaced with a LaB_6 monocrystal. The replacement gave the possibility of increasing the emission by a factor of more than two, without increasing the operating temperature of the cathode. The LaB_6 crystal was pressed into a graphite case. That made it possible to limit the diffusion of boron into tantalum that earlier had led to mechanical destruction of the case of the cathode.

An accelerated electron beam is extracted from the last, 12th in number, orbit of the microtron. Measurements of the beam current in the last orbit, ahead of the extraction tube of the microtron, and in the beam line of the FEL show that not less than 80% of the accelerated beam is extracted from the microtron.

The main parameters of the microtron are shown in Table 1.

From the microtron, the accelerated electron beam is extracted into the beamline (Fig. 2) that is dedicated for

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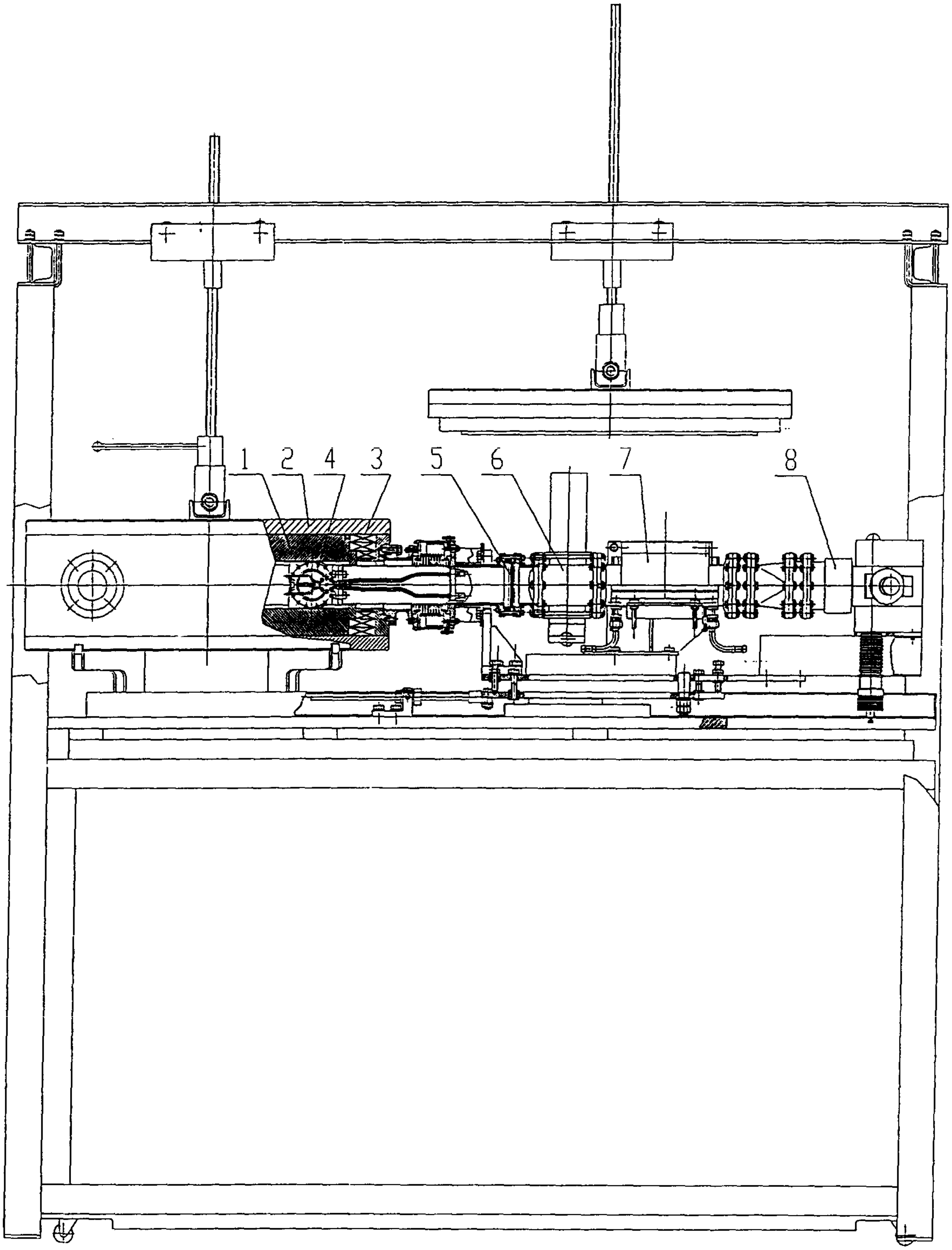

Fig. 1. 8 MeV microtron. 1, A magnet-vacuum system pole; 2, a yoke; 3, coil; 4, RF cavity; 5, ceramic vacuum insulation window; 6 irectional coupler; 7, a ferrite insulator; 8, a tuned magnetron.

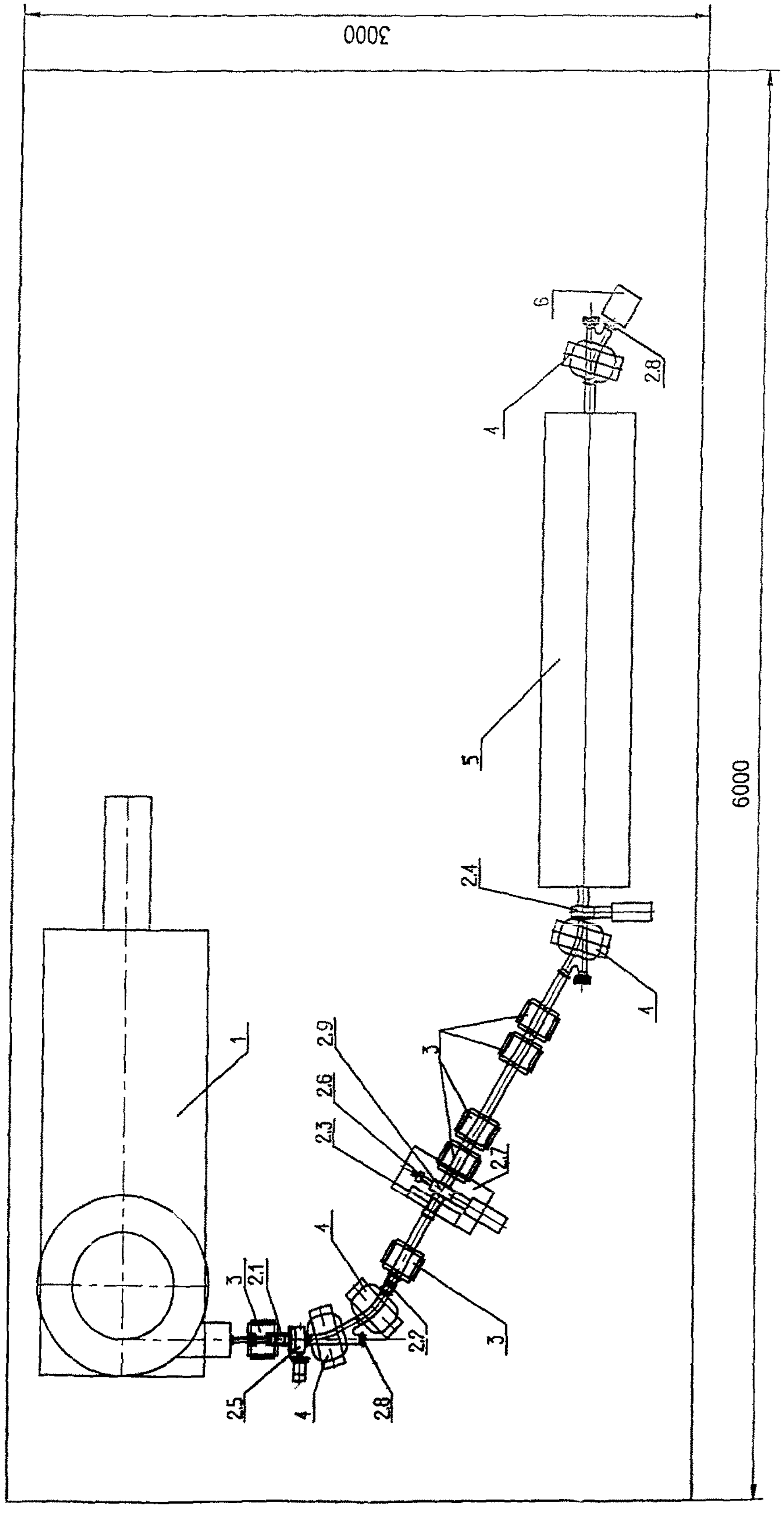

Fig. 2. Layout of the compact FIR FEL. 1, A microtron; 2.1, 2.2, bellows; 2.3, ceramic tube; 2.4, luminescent screen; 2.5, valve; 2.6, vacuum gate; 2.7, current transformer; 2.8, aluminium output window; 2.9, OTR probe; 3, quadrupole lenses; 4, bending magnets; 5, undulator; 6, dump.

Table 1
Microtron parameters

Electron energy	7.3–8 MeV
Electron energy spead	~16 KeV
Average macropulse current	70 mA
Pulse width	>5 mcs
Peak current	~1 A
Repetition rate	1–10 Hz

Table 2
Microtron electron beam parameters

Emittance ϵ_x	1.5 mm mrad
Betta, β_x	51.5 cm
Alfa, α_x	−2.29
Gamma, γ_x	0.12
Emittance ϵ_y	4.9 mm mpad
Betta, β_y	444.8 cm
Alfa, α_y	7.61
Gamma, γ_y	0.32
Energy spead, $\Delta E/E$	0.002

Table 3
Undulator parameters

Undulator period	1.25 cm
Number of period	160
Dap	0.5 cm
K parameter	0.4–0.6

transporting the beam to the undulator, and for matching beam parameters with the optimized parameters for FEL operation. The beamline consists of three 30° bending magnets and six quadrupole lenses.

For observation of the beam position in the beamline, a luminescent screen is mounted at the end of the first straight section of beamline. There is also one introductory probe with a luminescent screen in front of the entrance of the undulator and one introductory probe with an optical transition radiation screen. The optical transition radiation probe consists of two 5 mm tantalum plates with 0.5 mm slits, located at right angles to each other. The upper plate is covered with an aluminum film for watching the optical

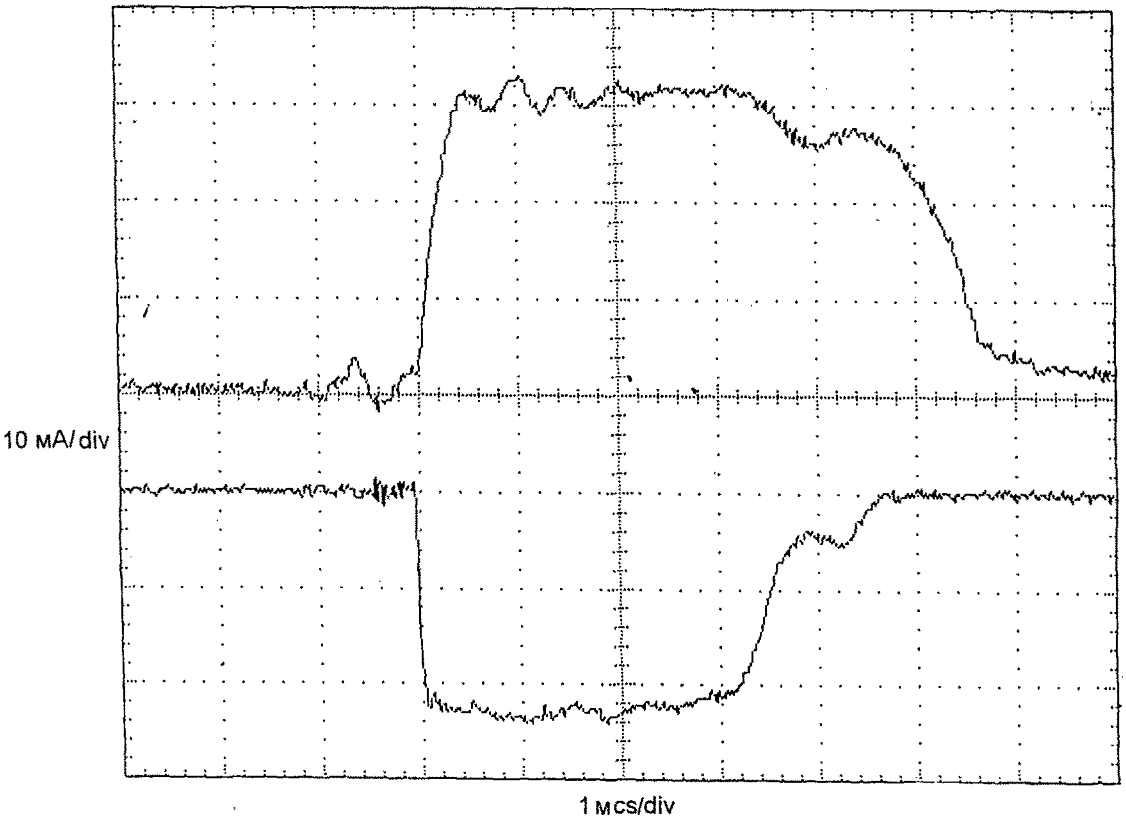

Fig. 3. Puls current oscillograms in beamline and after undulator.

transition radiation. The 0.5 × 0.5 mm slit is meant for scanning a profile of the electron beam by using a corrector and Faraday cup. The Faraday cup inside the microtron, a current transformer, and a Faraday cup functionally integrated with the dump after the fourth bending magnet, are used for measuring the macropulse current and the macropulse time structure of the electron beam.

It is very important for the FEL operation to choose in a proper way the optimum parameters of the electron beam at the undulator entrance by using beamline elements. For a proper choice of the operating conditions, it is necessary to know the parameters of the electron beam at the entrance of beamline. A method of measuring the beam dimensions due to dependence on the quadrupole lenses gradient was used for measuring of the microtron electron beam performance parameters. Dimensions of the electron beam were determined from the size of the light spot on the luminescent screen by using an objective and a CCD-line, controlled by a CAMAC-PC system. A special code was written for computation of the electron beam parameters from the measured dimensions of the light spot.

Performance parameters of the microtron electron beam are shown in Table 2.

The FEL undulator is an equipotential-bus undulator [6]. Its upper part consists of straight buses, that is from the top to the left and from the top to the right alternately clenched by poles. Between the poles are inserted the plates of permanent magnets. The lower part of the undulator is inversion symmetry to the upper one. Parameters of the undulator are shown in Table 3.

Up to now, the following has occured: magnetic measuring of the elements of the beamline and of the undulator have been carried out; the whole assembly and commissioning has been made; microtron electron beam performance parameters have been measured; the optimal parameters of beamline components for the FEL operation have been computed; the beam has been transmitted through the beamline (the upper graph) and through the undulator to the dump (the lower graph) (Fig. 3). The optical cavity is under design and production.

Nowadays, linear accelerators are preferably used as sources of electrons for infrared FELs. If compared with pulse microtrons, linear accelerators have advantages: higher peak current and longer pulses, and disadvantages: rather a large energy spread, far greater cost, and significantly more complicated operation conditions. The achieved performance of the given microtron, as well as the parameters of the electron beam, permit the employment in this FEL of a rather long undulator with a small period. This gives an opportunity of reaching a lasing due to rather a big gain and of counting on successful operation of the FEL with the given microtron.

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