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ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

N.G. Gavrilov, E.I. Gorniker, G.N. Kulipanov,
I.V. Kuptsov, G.Ya. Kurkin, A.D. Oreshkov,
V.M. Petrov, I.V. Pinaev, I.K. Sedlyarov,
A.N. Skrinsky, A.S. Sokolov,
V.G. Veshcherevich, N.A. Vinokurov,
and P.D. Vobly

PROJECT OF A RACE-TRACK MICROTRON-RECUPERATOR FOR FREE ELECTRON LASER

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Institute of Nuclear Physics
630090, Novosibirsk, USSR

ABSTRACT

The project for a race-track microtron – the beam source for a FEL is considered. The beam, utilized in a FEL, returns to a microtron where it decelerates and releases its energy to an RF system. The energy of electrons is 35 MeV and the mean current ranges from 0.1 A.

The works are being conducted at the Institute of Nuclear Physics (Novosibirsk) on the creation of a race-track continuous microtron-recuperator at 35 MeV electron energy, which is intended to be employed in a FEL. Utilized in the FEL, the beam will liberate its energy to the RF microtron system when, being decelerated, it passes along the same microtron orbits in inverse sequence. The layout of the microtron is depicted in Fig. 1. Its overall dimensions are limited by a room where the microtron is to be accommodated. The microtron comprises an injector *1*, two magnetic systems of a 180° separating bend *2*, a common straight section with RF cavities (the section is common to electrons of different energy), magnets for the injection *4* and extraction *5* systems and solenoidal magnetic lenses *6*, four separated straight sections with magnetic quadrupole lenses *7*, a FEL magnetic system *8* placed in the fourth straight section, and a beam dump *9*.

A 300 kV electron gun of the injector *1.1* generates 1-ns electron bunches at a repetition frequency of 45 MHz. Having passed through an RF cavity, which modulates the electron energy (velocity) and identical to all RF cavities of the device, the bunch is longitudinally compressed in a bunching straight section *1.2* down to 150 ps and then accelerated up to 2.1 MeV in two RF cavities *3* of the injector with the total 1.6 MV accelerating-voltage amplitude in the equilibrium phase $\varphi_0 = 29^{\circ}$. The electrons are injected into the common straight section of the microtron using a 180° magnetic mirror and two identical 65° bending rectangular magnets opposite in sign *4*. This magnetic system of 180° bend is achromatic, and its horizontal and vertical optical matrices are mutually coincide and look like the matrix of the empty straight section.

The working-voltage amplitude of RF cavities, in the common straight section of the microtron is 800 kv for one cavity and, hence 9.6 MV for 12 cavities, with the flight factor taken into account. These RF cavities are half the wavelength, λ = 165 cm, distant from each other, which corresponds to their resonance frequency f = 180 MHz.

A separated 180° bend *2* for the first three tracks of the microtron is completely similar to the magnetic injection system considered above, i. e. this is a 180° magnetic mirror with two 65° bending magnets on each track. Variation in the orbit length is going from the next microtron track is one wavelength of its RF system. The choice of this type of bend and its achromaticity are due to the necessity for the beam to pass through RF cavities of the common straight section, the necessity to reduce the horizontal beam size and to simplify the matching of β-function on three isolated straight sections where there are quadrupole lenses *7*.

The forth straight section is intended for the FEL magnetic system *8*. To lengthen it, a 180° achromatic bend on the fourth track comprises two 90° bends. The distance between 90° magnets are such that the length of the fourth track is different from the length of the third track by about 2.5λ of the wavelength of the microtron RF voltage. At the exit from the FEL magnetic system there are two RF cavities to compensate for the average losses in electron energy in the FEL. The RF cavities and a detector of horizontal beam displacement, installed behind a 90° bending magnet stabilizes the electron energy at the exit of the forth straight section.Entering again the common straight section from the fourth track, but now in the decelerating phase of RF voltage, the electrons release their energy to the RF system during the passage in the same direction through the same three microtron tracks. Emphasis should be made that in this case their sequence is inverse. After that the electrons are extracted using the magnets of the extraction system *5* (identical to the magnets of the injection system) and are directed to the beam dump *9*.

To provide the proper focusing of both the accelerated

and the decelerated electrons, the magnetic system (except for the fourth track) is mirror-symmetrical relative to the line going through the centre of the straight sections. Here the matched β-functions are of the same symmetry.

To minimize the length of the electron bunch (maximum peak electron current) in the FEL magnetic system, the longitudinal phase motion of the beam in the microtron was optimized by means of small variations in the values of the equilibrium electron energy on each track (and, correspondingly, the microtron geometry). The equilibrium phases of four passages through the RF system are φ_1 = = 21.9°, φ_2 = 34.6°, φ_3 = 47.6°, and φ_4 = 1.6°. Figure. 2 illustrates the longitudinal phase-energy diagram of the position of the electron bunch on four separated straight sections. The maximum relative spread of the electron energy on the fourth track is ± 0.5%. The diagram also shows that after the fourth passage through the RF system the quadratic abberation of the longitudinal focusing is absent.

The lengths of the straight sections of the microtron are such that with the injection of electron bunches, in each four periods of its RF voltage (i. e. at 45 MHz frequency), on the common track the accelerated and decelerated bunches are uniformly distributed in the longitudinal direction (i. e. with respect to the time of the passage through cavities) with an about 0.8 m interval. In this case, a mutual influence of the accelerated and decelerated beams at different electron energies is drastically decreases.

Calculations of the longitudinal and transverse beam dynamics show that the microtron-recuperator can operate in a steady mode at an average current higher than 0.1 A. Here the final bunching of electrons occurs only on the last track, thereby contributing to the obtaining of a high (about 100 A) peak current, small transverse emittances of the beam being conserved.

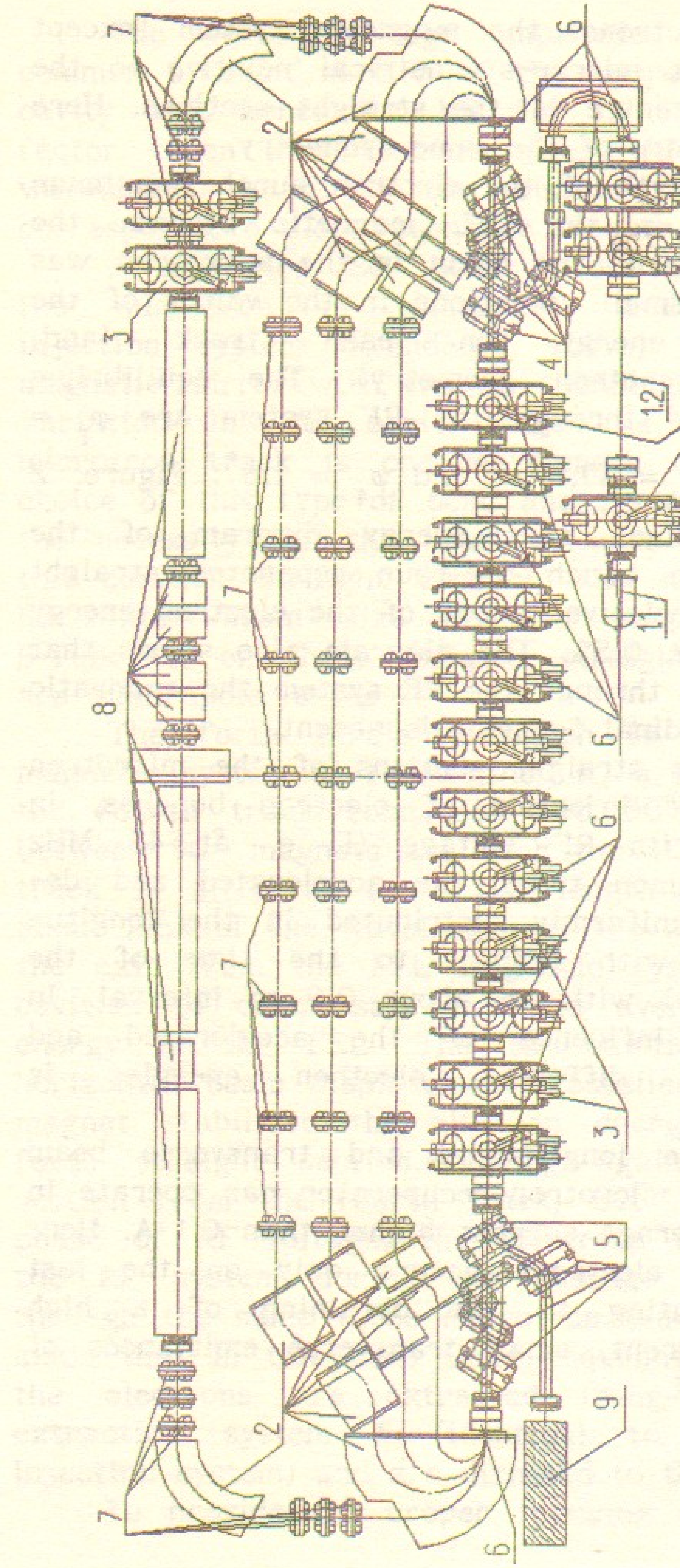

Fig. 1. The general layout of the race-track microtron-recuperator:
1 – injector; 1.1 – electron gun of the injector; 1.2 – bunching straight section; 3 – RF cavities; 4 – magnets of the injection system; 5 – magnets of the extraction system; 6 – solenoidal magnetic lenses; 7 – quadrupole magnetic lenses; 8 – magnetic system of the FEL; 9 – beam dump.

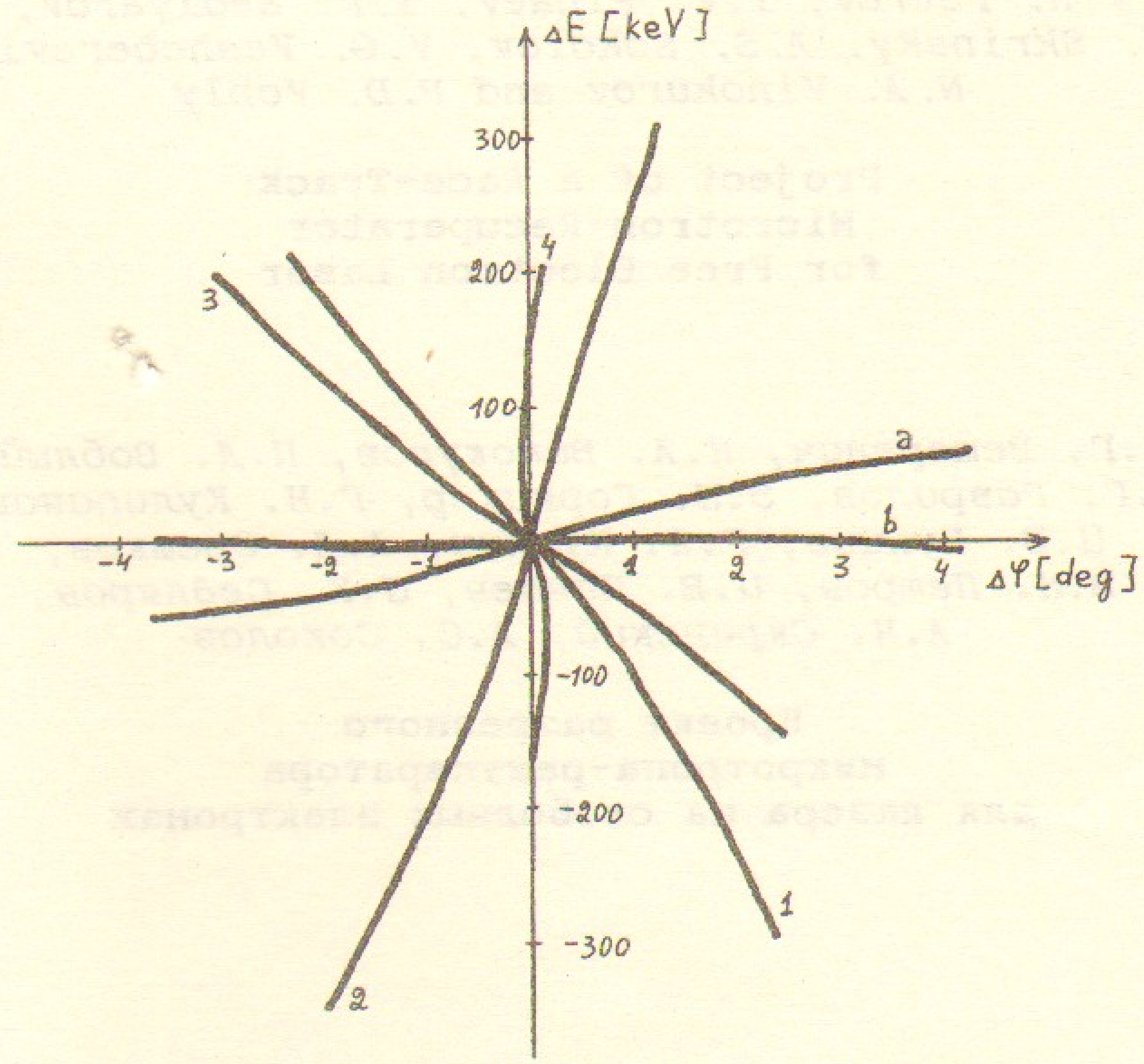

Fig. 2. The longitudinal phase-energy diagram of the electron bunch position:
a – after the bunching straight section; *b* – after the injection to the common straight section; *1, 2, 3, 4* – at the 1st, 2nd, 3rd and 4th straight sections, respectively.

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В.Г. Вещеревич, Н.А. Винокуров, П.Д. Воблый,
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И.В. Купцов, Г.Я. Куркин, А.Д. Орешков,
В.М. Петров, И.В. Пинаев, И.К. Седляров,
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