THE PROJECT OF HIGH POWER SUBMILLIMETR-WAVELENGTH FREE ELECTRON LASER

V.P.Bolotin, N.G. Gavrilov, D.A. Kairan, M.A. Kholopov, E.I. Kolobanov, V.V. Kubarev, G.N. Kulipanov, S.V. Miginsky, L.A. Mironenko, A.D. Oreshkov, M.V. Popik, T.V. Shaftan, M.A. Sheglov, O.A. Shevchenko, A.N. Skrinsky, N.A. Vinokurov,P.D. Vobly.
Budker Institute of Nuclear Physic Lavrentyv ave., 11, 630090 Novosibirsk, Russia

Abstract A 100-MeV 8-turns accelerator-recuperator intended to drive a high-power infrared FEL is under construction in Novosibirsk now. The first stage of the machine includes one-turn accelerator-recuperator that contains full RF-system.
Keywords accelerator-recuperator, free electron laser, magnetic system.

I. Introduction

The efficiency of the conversion of the beam power to the radiation power is rather small in an FEL, being typically not more than a few percent. For high power applications, therefore, it is necessary to recover the beam power after the FEL interaction. The main reason for the energy recovery, except of simple energy saving, is the dramatic reduction of the radiation hazard at the beam dump.

One of the possible methods of the beam energy recovery is to return the beam to the radiofrequency (RF) accelerating structure, which was used to accelerate it.[1, 2] If the length of path from the accelerator through the FEL to the accelerator is chosen properly, the deceleration of particles will occur instead of acceleration, and therefore the energy will return to the accelerating RF field (in other words, the beam will excite RF oscillations in the accelerating structure together with the RF generator). Such a mode of accelerator operation was demonstrated at the Stanford HEPL.[3] The first high power free electron laser using such accelerator recuperator was successfully commissioned recently.[4] An obvious development of such an approach is the use of multipass recirculator[5, 6] instead of simple linac. By increasing of the number of passes, cost and power consumption can be reduced. However, the threshold currents for instabilities also decrease, so the "optimal" number of passes exists.[7] The general scheme of such FEL is shown in Fig.1

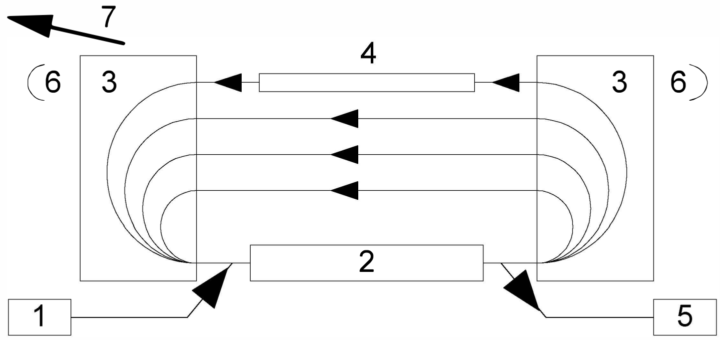

Figure 1. The scheme of the FEL with the accelerator-recuperator. 1-injector; 2-RF accelerating structure 3-180-degree bends; 4-FEL magnetic system; 5-beam dump; 6-mirrors; 7 output light beam.

The electron beam from the injector 1 enters the RF accelerating structure 2. After the first acceleration in the accelerating structure the beam passes through the magnetic system (bends 3 and focusing quadrupoles), which returns it to the accelerating structure for the second time. To have the acceleration of the beam at each pass though the accelerating structure it is enough to choose the orbit lengths to be integer of the RF wavelength (approximately). After several passes through the accelerating structure the beam reach the required energy and enters the FEL magnetic system 4, which is installed in the straight section of the last orbit. Here the small (about 1%) amount of the electron beam power is converted to the light. The exhaust beam returns to the accelerating structure. To provide a deceleration of the exhaust beam instead of an acceleration, the length of the last orbit is approximately half-integer of the RF wavelength. Due to the relatively small energy difference the decelerating beam follows almost the same orbits, as the accelerated one. Finally, the low-energy exhaust beam is absorbed in the beam dump 5. Some desirable features of an accelerator-recuperator are listed below.

1. The ejection (and, correspondingly, the injection) energy is to be less than 10 MeV, to avoid neutron generation in the beam dump.
2. The electron optical system has to provide proper focusing for the accelerating and the decelerating beams. It is not so trivial, as each orbit, except for the last one, is used to transport two beams (accelerating and decelerating) with the different initial conditions simultaneously, and there are many beams with very different energies inside the linac.
3. Energy acceptance is to be a few percents or larger to decelerate the spent electron beam. This can be achieved by employing magnetic system consisting of achromatic bends with low enough transverse dispersion function inside.
4. It is preferable to have a zero transverse dispersion function in the straight line sections to allow the optimization of the betatron phase advances at each orbit to increase the threshold current for the transverse beam breakup.
5. The frequency of the RF system tends to be low to decrease the longitudinal and transverse impedances and increase the longitudinal acceptance. Another advantage of low frequencies is the possibility of using the separated (uncoupled) RF resonators with individual tunes of fundamental and asymmetric modes.

To preserve low transverse emittance it is preferable to have a high peak current only at high energies. So the rotation in the longitudinal phase space by $\pi/2$, $3\pi/2$,... may be useful.

The high power infrared FEL for the Siberian center of photochemical research, which is under construction now, is the implementation of this approach.

II. First stage of the FEL.

A 100-MeV 8-turns accelerator-recuperator intended to drive a high-power infrared FEL is under construction in Novosibirsk now.[8] The first stage of the machine includes one turn accelerator-recuperator, that contains full-scale RF-system, but reduced number of turns (Fig. 2).

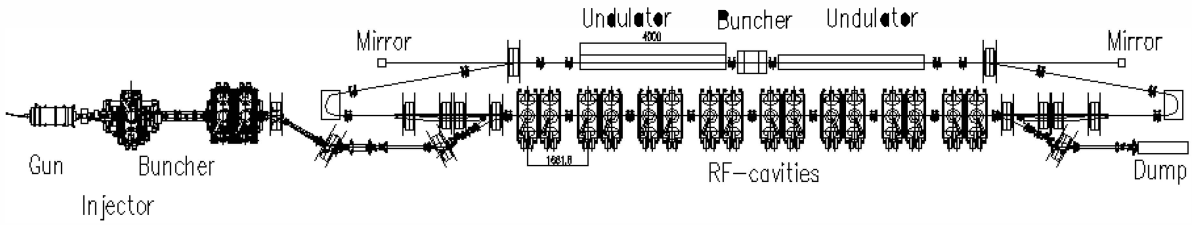

Figure 2 Scheme of the first stage of the high power free electron laser.

Main parameters of the accelerator-recuperator are listed in Table 1.

Table 1. Parameters of the accelerator-recuperator.

RF wavelength, m	1.66
Number of RF cavities	16
Amplitude of accelerating voltage at one cavity, MV	0.8
Injection energy, MeV	2
Final electron energy, MeV	14
Bunch repetition frequency, MHz	2 - 22.5
Average current, mA	4 - 50
Final electron energy dispersion, %	0.2
Final electron bunch length, ns	0.02 - 0.1
Final peak electron current, A	50 – 10

The FEL is installed on the single backward turn of the accelerator-recuperator. It consists of two undulators, a magnetic buncher, two mirrors of optical resonator, and an outcoupling system. Both undulators are identical. They are electromagnetic planar ones, of length 4 m, period is 120 mm, gap is 80 mm, and deflection parameter K is up to 1.2. One can use one or both undulators with or without the magnetic buncher. Both mirrors are identical, spherical, made of polished copper, and water cooled. The outcoupling system contains two or four adjustable planar 45 copper mirrors (scrapers). These mirrors scrape radiation inside the optical resonator and redirect small part of it to user. This scheme preserves the main mode of optical resonator well and reduces amplification of higher modes effectively. The buncher is simply a three-pole electromagnetic wiggler. It is necessary to optimize the relative phasing of undulators.

The expected radiation parameters are shown Table 2.

Table 2. Expected radiation parameters.

Wavelength, mm	0.1...0.2
Pulse length, ns	0.02...0.1
Peak power, MW	1...7
Average power, kW	0.6...7

III. Conclusion.

The reliable operation of the 2 MeV injector at average current 10 mA was achieved last year. The measured beam parameters are suitable for the beginning of the commissioning. The assembler of RF-system is in progress. The commissioning is scheduled next year.

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