THE RADIATION COMPLEX FOR FUNDAMENTAL RESEARCH

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Abstract

The facility for research in the field of laser physics and technology, accelerator physics, radio physics as well for laser radiation application is discussed. It will include high current racetrack microtron and several free electron lasers, driven by electron beams with different energies from microtron, far infrared laser, corresponding to the first stage of the project, being under putting into operation. Accelerator's and laser's parameters are presented as well as the main laser's features are discussed. First experiments are suggested in the frame of light application program.

1. INTRODUCTION

Free electron lasers (FEL) provide radiation with the properties not available for many other devices, that makes these light generators very attractive for numerous applications. On the other hand FELs are and for a long time will remain expensive and complicated facilities. First of all this concerns FEL's driver. That is why it is reasonable concentrate recourses, combining the investigations in the field of laser and accelerator physics with light application program for fundamental and applied research. The Lebedev Physical Institute radiation complex will include several FELs, driven by electron beams from different racetrack's orbits to cover wave range 10-160 μm. Our program consists of the following topics: 1) physics of racetrack including its investigation and further development as a free electron laser driver, high current instabilities first of all; 2) FEL's physics and technology including non linear processes and the development of new undulators and laser schemes; 3) radio physics, the investigation of light propagation in media in particular; 4) light application program; it is assumed that the main attention will be paid to the experiments, that use such FEL's features, as high light power, picosecond structure of radiation and its coherent nature, deep frequency tuning, The followed are some details of the facility under development as well as the research program planed.

2. HIGH CURRENT RACETRACK MICROTRON AS A FREE ELECTRON LASER DRIVER

Complexity and the high price of FELs are manly originate from these properties of their drivers. It is not simple to match the rather strict requirements to the accelerator with a low price and compactness. Among the large family of electron accelerators, the racetrack microtron, which occupies a position between linacs and classical microtrons, seems to be the most suitable to satisfy both requirements and provide at the same time a high intensity and a high quality electron beam. The effective accelerating structure as well as the opportunity of beam steering during acceleration makes it possible, like in linac, to provide a high power, high brightness electron beam. On the other hand, beam recirculation in a time independent magnetic field results in low energy spread as well as a compact machine. Being inherent to recirculators, high efficiency conversion of the rf power into beam energy makes it possible to recover rf power, thus resulting in an efficiency increase for the whole facility.

The Lebedev Physical Institute Racetrack Microtron is under operation since 1986 [1]. It consists of two 180° bending magnets with uniform magnetic field and non compensated fringe field and high current linac between them, disk loaded wave guide being used as the main accelerator structure. Beam injection is performed from electron gun of diode type installed aside of common part of orbits. High field rf cavity installed on the common axis is used for injected beam pre acceleration. The cavity and the main rf structure are powered through a power divider by one 20 MW klystron with a pulse duration of 9 μs. The accelerated beam is focused by quadrupole doublets, installed on return paths near bending magnets. Monitoring system consists of monitors of induction type as well as luminescent screens, also installed on each orbit. The main microtron parameters are collected in table 1.

Table 1
Some racetrack parameters

Orbit number	1	2	3	4	5
Beam energy (MeV)	6	12	18	24	30
Pulse current (A)	0.5	0.4	0.28	0.23	0.2
Pulse duration (μs)	6				
Energy spread (%)	1.5 -0.7				
Hor. emittance	7 π·mm·mrad				
Vert. emittance	3 π·mm·mrad				
Bunch phase length	20 - 36 degrees				
Max. klystron power	25 MW				
Rf wavelength	16.5 cm				
Repetition time	0.1 - 5 Hz				

The intensity have been reached so far at our racetrack is limited by the injection system (for the first orbits) as well as by beam current auto modulation for the far orbits. This interesting phenomena, predicted in [2], [3], was studied experimentally and theoretically [4]. The instability observed is not one of absolute nature and can be suppressed by accelerator tuning. It originates from the positive feed back arising in the system at some frequencies due to strong dependence of beam current at accelerator orbits on the voltage at accelerating structure and the phase of the injected beam, inherent to the machines of microtron type. Our program in the field of racetrack physics and technology is assumed to continue the exploration of the instability mentioned as well as to improve some accelerator parameters. First of all this concerns the injection system as well as the rf system. It is planed to increase rf pulse duration from 9 μs nowadays up to 12-15 μs in future to relax the achievement of saturation regime in FELs and to improve also the emittance of the injected beam and to increase its current as well.

3. FAR INFRARED FEL - FIRST PROJECT STAGE

We had started laser physics with far infra red FEL covering the 80-160 μm wavelength range. The objective is twofold. First, due to the division into several stages we can continue our activity in the field of experimental racetrack physics and pursue its improvement without disturbing the FEL program. Secondly, such a strategy allows us to start the application program at an early stage in the whole program.

The far infrared FEL, in the process of being put into operation now, has been realised using a conventional scheme. It is driven by an electron beam (6-8 MeV, 0.5 A) extracted directly from the racetrack's rf cavity. After having passed the rf cavity the beam traverses the vacuum chamber of the microtron's bending electromagnet (which is turned off) and is delivered to the laser (undulator plus open resonator) by an achromatic transport system. The latter includes quadrupole doublets, correcting coils and a three magnetic achromatic bending system. The last bending magnet provides beam injection on the laser axis. Focusing and beam diagnostic system precisely match the injected beam with the undulator acceptance. This assumes injection conditions which allow the formation of a stationary phase ellipse of the electron beam moving along the undulator. We use a luminescent screen for measurement of the beam profile and its displacement from the resonator axis at any point in the undulator. Together with an on line computer control this allows us to optimise the focusing system and to calculate the position and the strength of the correctors. Passive induction type correctors are being used for this purpose [5]. The main laser's parameters are presented in table 2.

Table 2
Far infrared FEL parameters

Wavelength range (μm)	80-160
Power of FEL radiation (in the pulse 6 μs)	60 kW
Macro pulse duration	6μs
Micro pulse duration	30 ps
The energy of the injected beam (MeV)	6 - 8
Gain per path (at the peak current 10 A)	20%
Energy spread of the injected beam (%)	1.5
Optical cavity length	165 cm
Mirror diameter	2.8 cm
Minimum diameter of laser mode	5 mm

Two copper mirrors, installed in the vacuum chamber, form nearly confocal open resonator with a length of 1.65 m. Each mirror can be adjusted under vacuum conditions by using special equipment for electromechanical tuning. Together with the resonator length measurements system and a computer control these provide cavity length stabilisation or automatic correlation with other laser and accelerator parameters. The resonator length control system is realised on the basis of the analysis of interference pattern of the radiation of He-Ne laser injected into the cavity. Relatively short length, metallic mirrors with the apertures for the extraction and the injection of radiation and the use of the same mirrors for generation and control system are the features of the resonator.

The energy spectrum of the electron beam will be measured by a magnet spectrometer with a resolution of 0.1-0.2%. Beam and accelerator parameters will be measured during single accelerator pulse. An on line computer system will be used for automatic measurements.

The outlook of the racetrack microtron and far infrared FEL is presented in fig. 1.

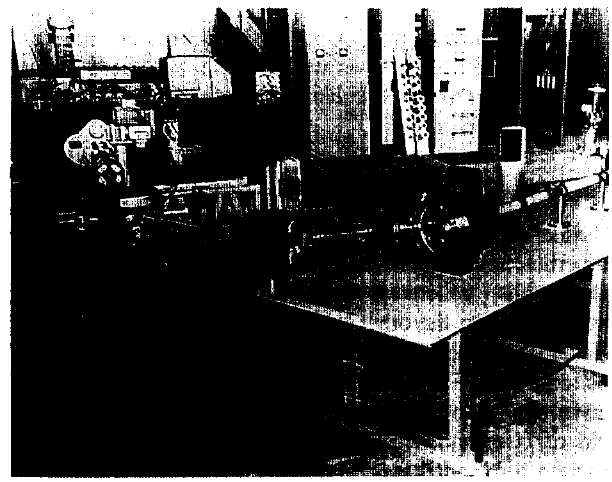

Fig.1. The outlook of the Lebedev Physical Institute radiation complex

4. HELICAL UNDULATOR.

As a component of a far infrared free electron laser the undulator has to satisfy a number of requirements to provide laser saturation during the accelerator pulse of 6 μs. Since the light power growth in the FEL's resonator is proportional to $\exp(G/L)$, where G and L are the gain per path and the resonator's length respectively, the relation G/L has to be maximised in order to minimise the transition time. A helical undulator with a steep magnetic decrease at the ends [6] had been chosen (non adiabatic entrance and exit) for effective use of the space between the mirrors. The spiral trajectories inside the undulator are matched with the linear trajectories outside the undulator by adjusting the magnetic field over approximately one undulator period. The undulator's double-start winding has a period of 32 mm and consists of 35 turns of copper wire with a diameter of 2.5 mm. The coils is placed in slots to provide mechanical stiffness. The winding ends are connected by a stainless steel ring at the undulator entrance. A similar ring is used at the undulator exit for connection to the power supply through a coaxial feeder. A capacitor bank, discharged through a water -cooled ignitron, is used as the undulator power supply. A rise time of 120 μs has been chosen in order to maintain a flatness of 10^{-3} for the working part of the current pulse through the undulator. The maximum magnetic field of 0.35 T on the undulator axis is achieved at a current of 40 kA through the undulator winding with a maximum repetition rate of 0.05 Hz.

The measurement of field distribution along the undulator had allowed to locate field distortion and to correct for them. We used a passive corrector of the induction type: a piece of metal with circulating current in it. The current is induced by the in time varying magnetic field of the undulator. The most suitable corrector has a cylindrical form which is bounded by strait lines in the azimuth direction and by a spiral line in the longitudinal direction. We used a corrector with an azimuth extent of 180°; the longitudinal size was equal to one half of the undulator period. The necessary correction was adjusted at a measurement stand by appropriate displacement of the corrector along the axis (correction strength) and around the axis (correction direction).

The undulator parameters are listed in table 3.

Table 3
Helical undulator parameters for far infrared FEL

Period of winding	3.2 cm
Number of turns	35
Aperture	2.7cm
Maximum current through winding	45 kA
Repetition rate at maximum current	0.05 Hz
Undulator parameter	0 - 1.4

5. LIGHT APPLICATION PROGRAM

FELs successfully complement classical lasers allowing to penetrate in the spectrum wave ranges not available for these devices before [7]. Synchronised with rf generator rf structure of FEL's radiation presents with new attractive possibilities, multi probe methods being among them. In the simplest case the sample under investigation is explored by laser radiation and rf field simultaneously. In general a sample is exposed to the radiation of two synchronised lasers with different wavelength. Two colour FEL on the basis of the racetrack microtron had been proposed at Lebedev Physical Institute [8] that might be used for such purposes. Our program assumes organising the researcher work station in the radiation free zone. FEL's radiation will be transferred to researcher's work station to be located in synchrotron hole from the laser, located in experimental hole near the racetrack. Such a strategy will provide also good shielding from intensive electromagnetic and acoustic interference of operating racetrack and pulsed helical undulator.

We plan to start FEL application program with experiments on rf absorption by high T_c sample which is placed in the rf cavity and exposed to far infrared laser radiation. These experiments are able to give direct evidence in an energy gap in the electron spectrum in the superconducting state. The temporal structure of the FEL radiation also allows us to study the non equilibrium states of high T_c materials.

The investigation of the methods of detecting of the radiation is included in our program as well. We have studied the possibilities of an optic-to-acoustic converter, traditionally used for detecting continuos flows, for the detecting of single radiation pulses with a duration of several microseconds. It has been found that transition time of the electrical signal at the converter output as well as its form did not depend on the pulse duration; the signal amplitude was proportional to the incident energy $u \propto P_{rad}T$, where P_{rad} and T are the incident power and the pulse duration respectively. The method is suitable for the detection of single pulses down to 2×10^{-11} J, and even less.

The method described above has been used for detecting spontaneous radiation of our undulator driven by an electron beam that was accelerated in the racetrack 's linac (7 MeV, 0.5 A). A copper tube with a diameter of 5 mm was used to guide the radiation to the converter. The latter was wrapped by light materials and placed in lead box in order to decrease ionising radiation as well as acoustic interference from the undulator. An appropriate geometry has been used to isolate the useful signals from other undesired acoustic signal. This can been achieved by varying the arrival times of the different signals at the detector.

6. CONCLUSION

The work has been started at the Lebedev Physical Institute on putting far infrared FEL into operation. Electron beam from racetrack's linac has been delivered to the undulator. The beam transport system as well as the whole facility proved to be reliable and flexible enough in order to make necessary tuning and adjustments. The precise matching of the injected electron beam with the undulator as well as the detecting of stimulated radiation are the next steps of the program uder development.

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8. REFERENCES

[1] K.A.Belovintsev, A.I.Karev and V.G.Kurakin, "The Lebedev Physical Institute Race-Track Microtron", Nuclear Instruments and Methods, A261, pp. 36-38, 1987.
[2] E.L.Kosarev, "Transition Processes and the Current Limitation in Microtron", Zh. Tekh. Fiz. vol. 43, pp. 2239-2247, 1972, in Russian.
[3] K.A.Belovintsev, A.I.Karev and V.G.Kurakin, "Computer Simulation of a Racetrack Microtron", Trudi FIAN, vol. 135, pp.146-167, 1963, in Russian.
[4] V.G.Kurakin, "High current racetrack microtron as a free electron laser driver", Nuclear Instruments and Methods, A341, pp.407-411, 1994.
[5] A.I.Bukin, E.B.Gaskevich, V.G.Kurakin and O.V.Savushkin, "The experimental study of helical undulator", Trudi FIAN, vol. 214, pp. 155-163, 1993, in Russian.
[6] E.B.Gaskevich, Trudi FIAN, vol. 214, pp. 164-171, 1993, in Russian
[7] W.Grill, Nuclear Instruments and Methods, B68, p. 61, 1992.
[8] E.B.Gaskevich, A.I.Karev, V.G.Kurakin, "Two colour FEL complex based on a high current racetrack microtron", Nuclear Instruments and Methods, A341, ABS47-ABS48, 1994