FREE ELECTRON LASERS BASED ON LINAC-800

V.S. Alexandrov, N.I. Balalykin, V.V. Kobets, I.N. Meshkov, V.F. Minashkin, I.A. Seleznev, A.P. Sergeev, G.D. Shirkov, G.I. Sidorov, E.M. Syresin, N.A. Tokareva, S.I. Tiutiunnikov
Joint Institute for Nuclear Research, Dubna, Moscow region, 141980, Russia
E-mail: shirkov@jinr.ru

The project "FELs and LINAC-800" is being under development at JINR. It is based on an accelerator facility presented to JINR by NIKHEF, Amsterdam. Analysis has shown that it is possible to build in Dubna a universal light source with unique characteristics consisting of a complex of Free Electron Lasers (FEL) covering continuously the wavelength range from far-infrared (150 μm) down to ultraviolet (150 nm). Besides, LINAC-800 could be used for different applications and as an injector for the next generation synchrotron radiation source.

PACS: 29.17.+w; 29.20.-c; 41.60.Ap; 41.60.Cr

INTRODUCTION

The submitted project is based on 800-MeV linear electron accelerator which is a component of the accelerator facility donated to JINR by the Institute for Nuclear and High Energy Physics (NIKHEF, Amsterdam) [1, 2].

The NIKHEF linear accelerator, so called MEA (Medium Energy Accelerator), was designed by Haimson Research Corporation (USA) and it is analogous to well-known "Two-mile Stanford Linear Accelerator" SLAC in USA. In the ninetieth MEA injector was substantially modified with the assistance of Budker Institute of Nuclear Physics, Novosibirsk. As a result of that it was changed into the accelerator of polarized electrons with the extremely improved parameters.

Over the last ten years synchrotron radiation (SR) became one of the most important tools for investigations in a wide variety of fields of science like physics, radiation chemistry and photochemistry, molecular biology, science of materials, medical diagnostics and others. This essential progress was stimulated by the development of new, increasingly bright SR sources installed at electron storage rings. Since eighties a number of research laboratories have performed the development of free electron lasers. Considerable advances in this direction allow realization of large-scale projects such as MARS (BINP, Novosibirsk), X-Ray FEL (DESY, Germany), FEL Jefferson Lab. (USA).

The progress in development of linear accelerators and high-precision undulators opens up wide opportunities for creation of Free Electron Lasers (FEL) [3].

FEL generates tunable coherent high-power radiation in a wide range of wavelength from 1 millimeter to ultra-violet and X-ray radiation. It can have a quality of optical properties of conventional lasers such as high spatial coherence and beam divergence close to diffraction limit. FEL differs from conventional lasers in using a relativistic beam of electrons as its active medium as opposed to atoms or molecules in excited states. Hence the term "free electron laser" occurs.

The FEL devices have several advantages. A resonance condition that involves the energy of the electron beam E and the periodicity of the magnetic system of the undulator determines the radiation wavelength:

$$\lambda \approx \frac{d}{2\gamma^2}\cdot K(B), \qquad \gamma = \frac{E}{mc^2}. \qquad (1)$$

Here d is a period of the magnetic field, $m = 511\text{keV}/c^2$ is the electron mass, $K(B)$ is a coefficient depending on the strength of the magnetic field.

It is possible to tune the wavelength easily and rapidly over a wide range by variation of either the beam energy or the strength of the magnetic field. The electrons of a beam moving in a vacuum serve as an "active medium" in FEL, so the typical problems of conventional lasers such as working material damage or thermal lens formation are avoided. Therefore, FELs can generate the radiation of a high peak and average power.

To form the basis of FEL complex the accelerator LINAC-800 will be constructed as a modified version of MEA accelerator [1, 2]. The accelerator design provides beam extraction at intermediate energy between 15 and 150 MeV and at full energy of 800 MeV as well. One can use the extracted beam of the intermediate energy range to generate FEL radiation in the infrared and ultraviolet regions. The beam of the maximum energy up to 900 MeV will enable to create FEL covering the wavelength range of vacuum ultraviolet and soft X-ray. A significant fraction of the spectrum will be covered by several FEls providing high intensity of the output radiation.

Technical inspection of the accelerator equipment transferred from Amsterdam to Dubna has shown that it has a significant operating resource and can be used for many years in the future at an appropriate upgrade of auxiliary equipment (mainly this concerns klystrons and control electronics). Referring to SLAC experience one could say that such linacs can keep operating for several tens of years.

The detailed analysis of the problem of creation of LINAC-800 based FEL (in view of recourses of the existent system and recent progress in accelerator technology) has revealed that it will be quite possible to built in Dubna a light source with the unique characteristics, including the following component devices:

– a complex of FELs covering the wavelength range from far-infrared (150 μm) down to UV (150 nm) and far-infrared coherent radiation source providing the high-power radiation (up to 100 MW of the peak power and up to 50 W on average) in the wavelength range between 150 μm and 1 mm;

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2006. № 3.
Series: Nuclear Physics Investigations (47), p.148-150.

– a VUV/soft X-ray free electron laser with minimal wavelength down to 5 nm (SASE FEL – Self Amplified Spontaneous Emission Free Electron Laser).

– After complete commissioning of the FEL facility we will have a unique light source covering continuously the wavelength range from 1 mm down to 5 nm. The prime advantage is: a significant fraction of the spectrum (from 1 mm down to 5 nm) will be covered by FELs providing the output radiation of extremely high brilliance.

IMPLEMENTATION PHASES OF FEL PROJECT

The project is to be performed in three phases.

PHASE 1

LINAC-800. As it was specified above for the construction of this part of FEL complex the equipment of MEA-800 will be used [1, 2]. At the first stage any improvement of the available equipment is practically not planned. In future modernization of separate functional units and creation of new systems will be required to adapt the accelerator for corresponding conditions of FEL radiation. Creation of 15…150 MeV beam extraction area will be carried out and the following capabilities will be provided:

- mounting of the devices to compress the longitudinal size of electron bunches;
- installation of additional focusing elements and beam adjusters to improve the parameter control of the accelerated beam;
- development of the electron beam monitoring system providing parameter measurement of the electron bunches with small emittance and longitudinal size;
- additional setup of two injectors – a high frequency subharmonic buncher and a high-frequency gun with photocathode.

PHASE 2

INFRARED FEL (WAVE LENGTH OF 1… 300 μm). Development of the output device for the electrons with the energy of 15…50 MeV is required to fulfill this phase of the project. Installation of the high frequency subharmonic buncher to upgrade LINAC-800 injector must also be performed [2, 4]. This FEL device is constructed according to design of a generator with quasioptical resonator. To create the free electron laser we assume to use after slight redesign the undulator and units of the optical resonator developed and delivered to JINR in 1999 by Samara Automatic System Research-and-Production Association.

ULTRA VIOLET FEL (WAVE LENGTH OF 200…400 nm). The output device for the electrons with the energy of 100…150 MeV needs to be constructed to fulfill this phase of the project. The same design of the generator with optical resonator will be used. It is necessary to develop and create an undulator, an optical resonator and control systems of electron beam and radiation.

PHASE 3

VUV/SOFT X-RAY FEL (WAVE LENGTH OF 5…100 nm) [1, 2]. Two versions of this FEL in the range VUF – soft X-ray are being considered:

1.SASE scheme – Self Amplification of Spontaneous Emission.

At this scheme an electron bunch with energy of 200…800 MeV, passing through the undulator, endures an influence of own incoherent ("spontaneous") radiation. It results in the bunch density modulation along its length and, accordingly, an amplification of the radiation level at the resonance wave length appears [see (1)].

To create such a laser it is necessary to accelerate electrons in the linac, up to energy of 200…800 MeV, to construct an undulator (with high precision of mechanical and magnetic parameters) and to work out a new injector that will contain:

- a high-frequency gun with photocathode,
- a laser system of electron emission initiation,
- compressors of an electron bunch longitudinal size.

2.Circular FEL-generator.

At this scheme an electron bunch, accelerated up to energy of 200…800 MeV, as in the first version, passes through the system of bending and focusing magnets, which are analogous to the synchrotron focusing system (Fig.1), and returns into the linac passing through its high-frequency sections in a decelerating phase [5, 6]. Having lost more than 90% of their energy, the electrons enter beam dump. Such schemes of the linac-recuperator have been already put into practice in several laboratories in the World (BINP, Novosibirsk; Jefferson Nat. Accelerator Lab., USA and others).

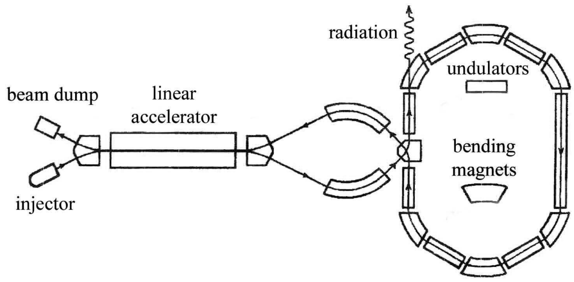

Fig. 1. The scheme of a circular FEL-generator together with an accelerator [6]

The magnetic system of the circular FEL consists of undulator sections, separated by isochronous bending sections. The first and the last sections are situated in one line. The bending magnet is placed between them to provide injection and extraction of the electron beam. When the isochronous bend is passed, the laser radiation is lost, but the beam density modulation is partially kept. Due to this fact and at a big length of undulator sections in this system the amplification of the signal occurs as in a conventional single-pass FEL. Generated from the last undulator, an electromagnetic wave comes into the first undulator, where it interacts with a new coming electron bunch that leads to the periodic electron energy modulation in the new bunch with a period equal to the wave length. Such a feed-back becomes a positive one under definite conditions and the generation develops at the beam current exceeding the threshold.

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2006. № 3.
Series: Nuclear Physics Investigations (47), p.148-150.

REALIZATION OF THE PHASE 1

- JINR Technical Project "LINAC-800 and free electron lasers" has been developed;
- The Detailed Contract Design "Linear accelerator LINAC-800, chapter "Technological Approaches" has been developed and approved by Russia State Specialized Design Institute (GSPI);
- Conceptual design of the unique injector providing formation and acceleration of short bunches into LINAC-800 has been developed in cooperation with Research-and-Production Association "ISTOK" (Fryazino) [2]. An agreement for production of the injector has been worked out;
- Preparation of specialized building of 270 m length to mount LINAC-800 equipment is in progress: the hatch between accelerator and modulator halls has been reconstructed to install the large-sized elements of the accelerator; the floor of the modulator hall has been renovated; external water-water and water-oil coolers are being under reconstruction and placing; geodetic works in the accelerator hall have been accomplished; support platforms for accelerating section of three stations has been installed; all of the accelerating sections have been delivered.

Summary of radiation properties from coherent radiation sources in Phase 2

Parameter	FIR	G1	G2	G3	G4
Radiation wavelength [µm]	150…1000	20…150	5…30	1…6	0.15…1.2
Peak output power [MW]	10…100	1…5	1…5	3…15	10…20
Micropulse energy [µJ]	500	50…200	25…100	25…100	50…100
Micropulse duration (FWHM) [ps]	5…10	10…30	10	10	3…5
Spectrum bandwidth (FWHM) [%]		0.2…0.4	0.6	0.6	0.6
Micropulse repetition rate [MHz]			19.8/39.7/59.5		
Macropulse duration [µs]			5…10		
Repetition rate [Hz]			1…100		
Average output power (max.) [W]	10…50		0.2…1		

Realization of two initial stages of the project will not require a significant modification of JINR infrastructure. All the accelerator equipment and a user room facility can be mounted inside the existing building. Actually the only initial milestones of the project will result in a user facility unique in the world. At present none of the functioning devices provides such a wide spectrum of coherent radiation. The parameters of coherent source radiation are listed in Table. The table notations are as follows. Symbols "G1-G4" concern to FEL-oscillators, "FIR" is used for a Far Infra Red coherent radiation source.

Successful commissioning of the Coherent Radiation Facility will allow performing a wide range of scientific experiments in various areas of physics, chemistry, biology, medicine, etc.

REFERENCES

1. *Dubna Electron Synchrotron (DELSY). Phase I: Free Electron Laser. Conceptual Design Report.* Edited by G. Arzumanian, I. Meshkov, V. Mikhailin et al. Dubna, JINR, 2001, 197p.
2. V.V. Kobets, N.I. Balalykin, I.N. Meshkov et al. *Linear Accelerator LINAC-800 of the DELSY project*. Proc. of LINAC 2004, Lübeck, Germany. 2004, p.105.
3. E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov. *The Physics of Free Electron Lasers* (Springer-Verlag), Berlin, 2000.
4. T. Tomimasu, Y. Morii, E. Oshita et al. // *Nucl. Instr. and Methods.* 1998, A407, p.370.
5. D.A. Kayran, V.N. Korchuganov, G.N. Kulipanov et al. *MARS - A Project of the Diffraction Limited Fourth Generation X-Ray Source*. Proc. of APAC 1998, Tsukuba, Japan. 1998, p.704.
6. A.N. Matveenko, O.A. Shevchenko, N.A. Vinokurov. *Isochronous Bend for High Gain Ring FEL*. Proc. of the 2004 FEL Conference, Triest, Italy. 2004, p.629.

ЛАЗЕРЫ НА СВОБОДНЫХ ЭЛЕКТРОНАХ НА ОСНОВЕ ЛИНАК-800

В.С. Александров, Н.И. Балалыкин, В.В. Кобец, И.Н. Мешков, В.Ф. Минашкин, И.А. Селезнев, А.П. Сергеев, Г.Д. Ширков, Г.И. Сидоров, Е.М. Сыресин, Н.А. Токарева, С.И. Тютюнников

Проект ЛСЭ и ЛИНАК-800 реализуется в ОИЯИ. Он основан на ускорительном оборудовании, предоставленном ОИЯИ NIKHEF (Амстердам). Анализ показывает, что в Дубне станет возможным сооружение универсального источника с уникальными характеристиками, состоящего из комплекса лазеров на свободных электронах (ЛСЭ), покрывающих непрерывно длины волн от дальнего инфракрасного излучения (150 мкм) до ультрафиолета (150 нм).

ЛАЗЕРИ НА ВІЛЬНИХ ЕЛЕКТРОНАХ НА ОСНОВІ ЛІНАК-800

В.С. Александров, Н.І. Балаликін, В.В. Кобець, І.Н. Мешков, В.Ф. Мінашкін, І.А. Селезньов, А.П. Сергієв, Г.Д. Ширков, Г.І. Сидоров, Є.М. Сиресін, Н.А. Токарева, С.І. Тютюнников

Проект ЛСЕ і ЛІНАК-800 реалізується в ОІЯД. Він заснований на прискорювальному устаткуванні, що було дано ОІЯД NIKHEF (Амстердам). Аналіз показує, що в Дубні стане можливим спорудження

універсального джерела з унікальними характеристиками, що складається з комплексу лазерів на вільних електронах (ЛВЕ), що перекривають безперервно довжини хвиль від далекого інфрачервоного випромінювання (150 мкм) до ультрафіолету (150 нм).