

# THE PROJECT OF A HIGH-POWER FEL DRIVEN BY AN SC ERL AT KAERI

*S.V. Miginsky, A.V. Bondarenko, B.C. Lee<sup>1</sup>, S.H. Park<sup>1</sup>, Y.U. Jeong<sup>1</sup>, Y.H. Han<sup>1</sup>, S.C. Kim<sup>1</sup>  
Budker INP, Novosibirsk, Russia*

*<sup>1</sup>Korea Atomic Energy Research Institute, Daejeon, Korea  
E-mail: S.V.Miginsky@inp.nsk.su*

The project of a high-power FEL at Korea Atomic Energy Research Institute and its recent status are described. The FEL is driven by a superconducting energy recovery linac. The first-stage machine will operate in the far IR region and its CW power is expected to be a few kW. Possible upgrade of the machine is also considered. The upgraded machine will operate in the near IR region and its expected power is a few tens kW.

PACS: 41.60.Cr

## 1. INTRODUCTION

The project of a free electron laser (FEL) driven by an accelerator-recuperator (AR) was started at KAERI in 1998. It is ever considered as a high-power CW source of IR-FIR radiation. The first step was the commissioning of an electron injector very analogous to the one of the Novosibirsk FEL [0] in collaboration with BINP. Since then, the project has been revised several times. Now a superconducting (SC) energy recovery linac (ERL) is considered as the driver of the FEL.

## 2. INJECTOR

The source of electrons is a 300 kV DC electron gun with a gridded thermionic cathode manipulated with a controlled pulser. Electron bunches from the gun gain the correlated energy spread in a bunching 176-MHz normal-conducting RF cavity, are compressed due to klystron-like bunching in a 2.5 m drift space, and gain higher energy in a pair of analogous accelerating cavities. The latter also compensate the residual correlated energy spread. Basic parameters of the gun are:

- electron energy (kinetic).....300 keV;
- average current:.....12 mA;
- charge of bunch.....2 nC;
- repetition rate.....0...11 MHz;

- pulse duration.....1.1 ns;
- normalized emittance..... $20\pi$  mm·mrad;
- operation mode.....CW.

The injection energy (full) is 2 MeV.

## 3. RF SYSTEM

The RF accelerating structure consists of two 352.2 MHz superconducting cavities embedded into one cryostat [0], [0]. These cavities were previously used in LEP, CERN. Each cavity has four  $\pi$ -type cells. The cavities are fed by two 50 kW tetrode generator modules. Maximum energy gain obtained for one cavity is 12 MeV [0].

The normal-conducting cavities of the injector are very similar to the ones at BINP [0]. They were modified a little to decrease their resonant frequency from initial 181 to 176.1 = 352.2/2 MHz. The accelerating cavities of the injector are fed by two 100 kW tetrode generator modules.

## 4. BEAMLINES

An injection beamline (Fig. 1) is intended to conduct a 2 MeV electron beam from the injector to the SC cavities and control its parameters so that to avoid any losses inside the cavities. The injection shift was provided for future upgrade to ERL.

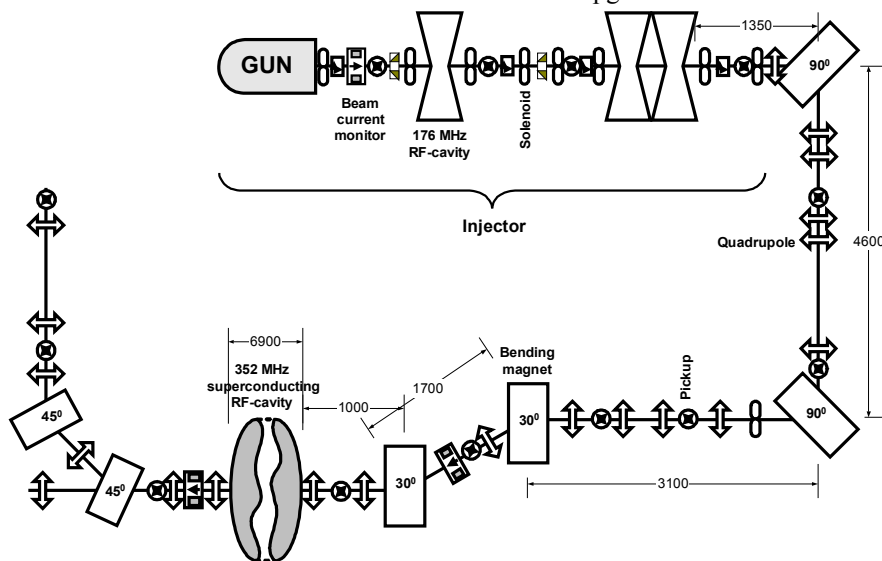


Fig. 1. Current status of the SC linac at KAERI

The extraction beamline conducts an accelerated 10 MeV electron beam to a scanning device to extract it to the atmosphere. Beam losses in the beamline are vanishingly small.

The future ERL will be connected to the existing machine without any modification. It consists of two 180° bents and two straight sections (Fig. 2): one is for the FEL, another for Compton backscattering. One can choose the regime controlling the lenses. The dispersion

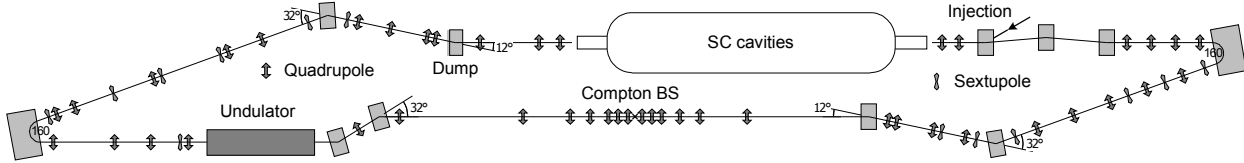


Fig. 2. Future energy recovery linac at KAERI

The beamline can be adjusted for the beam energy 10...22 MeV. As the electron-transit time depends on the energy, the phase of the second (deceleration) pass differs for different energies. It means that the extraction energy and the energy spread are varied. At 10 and 22 MeV the extraction energy will be 2.1 and 2.8 MeV, and the energy spread 1.85...2.38 and 1.7...3.9 MeV, respectively. It is without the energy spread added by the FEL. To absorb such a wide-spectrum beam, the dump is combined with the first dipole magnet in the left bent. The acceptance of the dump is 0.27...3.1 and 0.6...7 MeV for 10 and 22 MeV regimes, respectively. So, the FEL may add  $\pm 0.7$  and  $\pm 1.1$  MeV energy spread, respectively.

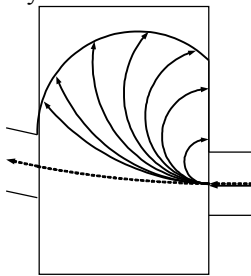


Fig. 3. Dump

The beamline was optimized for aberrations to minimize emittance growth. An appropriate number of sextupoles is added to suppress chromatic aberrations. Due to that, from the cavity to the active section and from the latter to the cavity  $\partial \eta / \partial p = 0$  and  $\partial \eta' / \partial p = 0$ , while  $\partial \alpha_{xy} / \partial p$  and  $\partial \beta_{xy} / \partial p$  are in compromise with the strengths of the sextupoles, as both parameters degrade the emittance. The emittance growth is  $\sqrt{\Delta \varepsilon^2} / \varepsilon \leq 0.5$  due to the aberration in sextupoles, the same due to  $\partial \alpha_{xy} / \partial p$  and  $\partial \beta_{xy} / \partial p$ , and  $\sqrt{\Delta \varepsilon^2} / \varepsilon \leq 0.2$  in quadrupoles. Thus, the total relative emittance degradation through the whole machine is  $\approx 1.5$ . The sensitivity to the lenses gradients is moderate, so the permissible relative PS instability is  $8 \cdot 10^{-3}$ .

### 5. FEL

The conventional scheme of the FEL is considered. It will consist of a 2 m helical in-vacuum undulator made of permanent magnets. Its period will be 35 mm, maximum  $K = 1.6$  at the gap of 15.5 mm. One mirror of

function  $\eta$  is zero together with its derivative in one of these sections, so one bent is achromatic, while the other is almost achromatic. Both bents are almost isochronous, so that the total ERL is perfectly isochronous to avoid any problems with longitudinal beam instability. The ERL has enough degrees of freedom to control both betatron phase independently to suppress regenerative transverse beam instability.

the optical cavity is blind and made of copper, another one, the outcoupler, is semi-transparent and made of CVD diamond [0]. The expected average power is a few kW, the tuning range 35...70  $\mu\text{m}$ .

### 6. ATTAINED RESULTS

Recently, stable current of 6 mA at the energy of 10 MeV was obtained. At the higher current an instability connected with the SC cavities occurs. It appears as exponential rise of the beam losses at the extraction beamline of the characteristic time  $\sim 1$  s. Every time a quench occurs in the cryostat.

The injector is capable to emit higher average current. Its limitation is giant current pulses occurred at an average current  $> 8$  mA. After the cleaning procedure its maximum stable current exceeds 12 mA.

7.6 and 7.8 MeV maximum energy gains were obtained for the SC cavities. The limiting factor in our case was not mechanical vibrations of the cavities as in [0], but the reactive power in the feeders. After the upgrade to feeders one can expect to achieve 12 MeV.

### 7. POSSIBLE UPGRADE

The most desirable upgrade is an addition of one more pair of SC cavities. In this case the maximum beam energy of the ERL will exceed 40 MeV. It will enable to make an FEL in the near-IR region. Of course, a new beamline is to be designed in this case. The main difference is that  $\pi/2$  rotation in the longitudinal phase space will be done, so the appropriate longitudinal dispersion will be in the bents. It is necessary as the peak current is extremely critical for a shorter-wavelength FEL, while the bunch duration does not limit the linewidth. In this case higher harmonic linearization of the accelerating voltage is extremely useful to minimize the longitudinal emittance.

The FEL power is proportional to the average electron current, so any improvement of the injector is highly helpful. Boost of the injection energy and the current is also considered.

As the average power of the upgraded FEL can reach several tens kW, its alternative schemes, like regenerative amplifier [0] or electron outcoupling [0] should be considered thoroughly. In other case its power will be limited by the optical resonator mirrors.

## 8. CONCLUSION

The SC linac at KAERI operates successfully and stably now. The design of the beamline for the ERL satisfies all the requirements for successful operation together with an FEL. These facts together give a good future prospect for constructing and commissioning the whole machine in the nearest future.

## REFERENCES

0. V.P. Bolotin, N.A. Vinokurov, D.A. Kayran et al. Status of the Novosibirsk terahertz FEL // *Nucl. Instr. and Methods*. 2005, v.A543, №1, p.81-84.
0. P. Bernard, D. Bloess, G. Cavallari et al. *Superconducting RF cavities for LEP*. Proc. of European Part. Acc. Conf., Rome. 1988, v.2, p.958-960.
0. D.Boussard, G.Cavallari, H.P.Kinderman et al. *Further results from the test of a 352 MHz superconducting cavity in the CERN SPS*. CERN/EF/RF 88-3. 1988.
0. A.V. Bondarenko, S.V. Miginsky. Simulation and minimization of thermal deformation of mirrors in a resonator of free electron laser // *Nucl. Instr. and Methods*. 2005, v.A543, №1, p. 110-113.
0. D.C. Nguyen, C.M. Fortgang, J.C. Goldstein et al. Synchronously injected amplifiers, a novel approach to high-average-power FE // *Nucl. Instr. and Methods*. 1997, v.A393, №1-3, p.252-256.
0. G.N. Kulipanov, A.S. Sokolov, N.A. Vinokurov. Coherent undulator radiation of an electron beam microbunched for the FEL power outcoupling // *Nucl. Instr. and Methods*. 1996, v.A375, №1-3, p.576-579.

## ПРОЕКТ МОЩНОГО ЛСЭ В КАЕРИ НА БАЗЕ СВЕРХПРОВОДЯЩЕГО ЛИНАКА-РЕКУПЕРАТОРА

*С.В. Мигинский, А.В. Бондаренко, Б.Ч. Ли, С.Х. Пак, Я.У. Джонг, Я.Х. Хан, С.Ч. Ким*

Описан проект мощного ЛСЭ в Корейском институте атомной энергии, а также текущее состояние дел. В ЛСЭ будет использован сверхпроводящий линак-рекуператор. Машина первой очереди будет работать в дальнем ИК-диапазоне, ее ожидаемая средняя мощность несколько киловатт. Рассматривается возможная модернизация машины. Модернизированная машина будет генерировать десятки киловатт средней мощности в ближнем ИК-диапазоне.

## ПРОЕКТ ПОТУЖНОГО ЛВЕ В КАЕРИ НА БАЗИ НАДПРОВОДНОГО ЛИНАКА-РЕКУПЕРАТОРА

*С.В. Мигинський, А.В. Бондаренко, Б.Ч. Лі, С.Х. Пак, Я.У. Джонг, Я.Х. Хан, С.Ч. Кім*

Описано проект потужного ЛВЕ в Корейському інституті атомної енергії, а також поточний стан справ. У ЛВЕ буде використаний надпровідний лінак-рекуператор. Машина першої черги буде працювати в далекому ІЧ-діапазоні, її очікувана середня потужність – кілька кіловат. Розглядається можлива модернізація машини. Модернізована машина буде генерувати десятки кіловатів середньої потужності в ближньому ІЧ-діапазоні.