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High Power Infrared Free Electron Laser Driven by a Energy Recovery Superconducting Accelerator

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Abstract

A high average power infrared free electron laser driven by a 40MeV energy recovery superconducting accelerator is being developed at the Korea Atomic Energy Research Institute. The free electron laser is composed of a 2-MeV injector, two superconducting acceleration cavities, a recirculation beamline, and an undulator. Each accelerator module contains two 352-MHz 4-cell superconducting cavities and can generate an acceleration gain of 20 MeV. The 2-MeV injector has been completed, and generates stably an average current of 10 mA. One of the 20 MeV superconducting accelerator modules has been installed, cooled down to 4.5K, and RF-tested. An average power of 1 kW at the wavelengths of 3~20 μm is expected.

1. Introduction

There are several potential applications of tunable high average power free electron lasers (FELs) in nuclear industry. For example, it is possible to separate stable isotopes such as silicon (Si^{29}), carbon(C^{11}), oxygen(O^{18}), etc., by using selective multi-photon dissociation of molecules. Tunable ultraviolet FELs are useful in separating long-lifetime elements from nuclear spent fuels using selective photochemical reactions. In these applications, few tens of kilowatts in average power of radiation at a reasonably low cost is needed. One of the best

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ways of generating high average power FEL radiation at low cost is using superconducting accelerator with energy recovery as a driver of FELs.

After successful development of a millimeter-wave FEL driven by a 0.4-MeV electrostatic accelerator [1], and an infrared FEL driven by a 8-MeV microtron accelerator [2], and being encouraged by the pioneering demonstration of energy recovery FELs by the Jefferson Laboratory [3], and JAERI [4], the Korea Atomic Energy Research Institute (KAERI) started a project for the development of a high power infrared FEL driven by a 40-MeV superconducting accelerator with energy recovery. This paper describes design concept of the FEL and the results of the first stage of the project.

2. Energy Recovery Superconducting Linac

2.1 Schematic Layout of the FEL

The KAERI infrared FEL is composed of a 300-keV electron gun, a 2-MeV pre-accelerator, two 20-MeV 352-MHz superconducting acceleration cavities, an undulator unit, and a energy recovery beamline. Schematic layout of the FEL is shown in Figure 1, and design parameters of the FEL are listed in Table 1.

2.2 2-MeV Injector

The 2-MeV injector [5] is composed of a 300-keV electron gun, one RF bunching cavity, and two normal-conducting RF acceleration cavities. The kinetic energy of the electron beam is 1.5 MeV nominally, and 2 MeV at maximum. The duration of a pulse is 350 ps and its repetition rate is variable from 11 kHz to 22

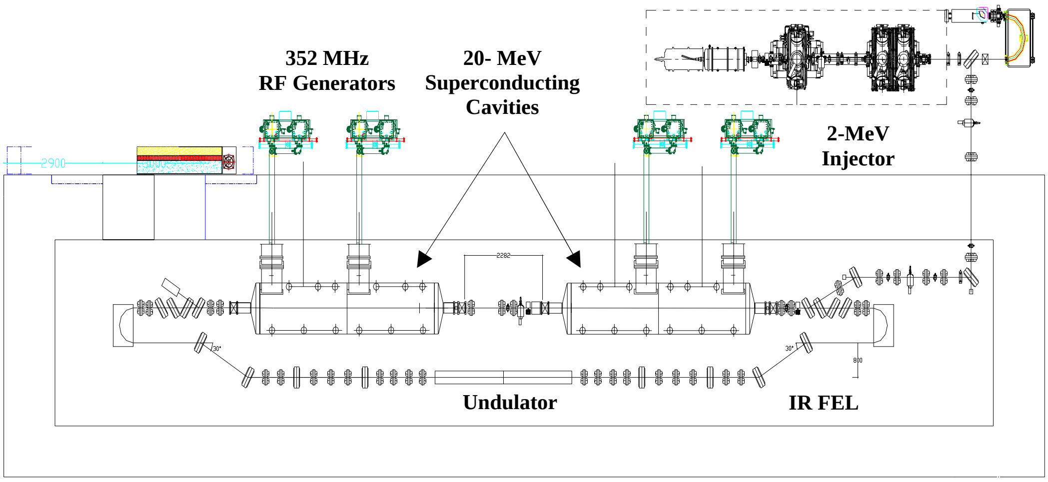

Figure 1. Schematic layout of the KAERI infrared FEL driven by a supercond ucting energy-recovery linac.

MHz. The peak current is 6 A, and the average current at the maximum repetition rate is 45 mA. The resonant frequency of the RF cavities is 176 MHz, which is a half of the resonance frequency (352 MHz) of the main superconducting accelerator.

Table 1 Parameters of the KAERI infrared FEL

Accelerator	Energy	20-40 MeV
	Average current	10 mA
	RF frequency	352 MHz
Undulator	Period	35 mm
	Magnetic field	1.7-3 kG
	Gap	20 mm
FEL	Wavelength	3-20 μm
	Pulse width	~50 ps
	Average power	1-10 kW

2.3 Superconducting Cavities

Each main accelerator module from CERN contains two 352-MHz 4-cell superconducting cavities and can generate an acceleration gain of 20 MeV. The superconducting cavities are made of OFHC copper with thin Nb coating. Each cavity is equipped with a power coupler, which can deliver 150 kW CW, and four higher order mode (HOM) couplers. The resonant frequency of the cavity can be tuned by controlling the cavity length, which in turn, is adjusted by changing the lengths of the nickel bars attached to the cavities. Table 2 shows the parameters of the superconducting acceleration cavities, and Fig.2 shows the schematic of the cavity.

Numerical and analytical analysis[6] shows that the wakefields generated by the bunched electrons passing through the superconducting cavities affect the beam trajectory negligibly at an average current of 50 mA. The HOM powers excited by the repetitive electrons will be about 140 W and 1.1 kW for the TE_{111} and the TM_{110} modes, respectively.

One superconducting cavity module has been installed successfully, and cooled down to 4.5 K. An 352-MHz RF generator for the superconducting cavity with average power of 100 kW has been installed and tested successfully. Figure 3 shows the photograph of the superconducting cavity.

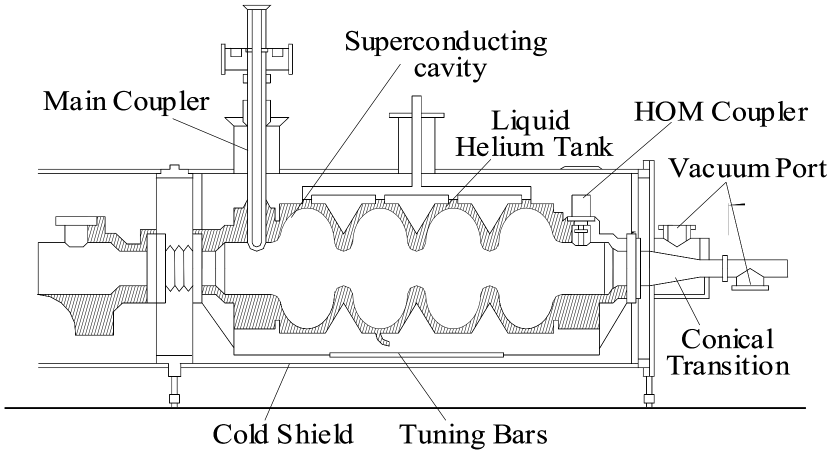

Figure 2. Schematic of the 352-MHz superconducting acceleration cavity.

Table 2 Parameters of the superconducting cavities

Resonant frequency	352 MHz
Cavity material	Nb-coated copper
Number of cell	4-cell 1 cavity
Q_0	3.4×10^9 @ 6 MV/m
R/Q	500
Tuning range	50 kHz
Active length	1.7 m

2.4 Energy Recovery Beamline

Since the injection energy is rather low, there is a limitation in the pulse duration of the injected electron beam caused by the induced energy spread in the cavity. The maximum duration (if no "linearizer"[7]) is

$$\Delta t \approx \frac{1}{\omega}\sqrt{\frac{2\Delta E}{E}} \approx \pm 100 \text{ ps in our case.}$$

Figure 3. Photograph of the 352-MHz superconducting acceleration cavity.

The energy recovery beamline is still under design. We must compromise between wide-tunability of the electron beam energy (which results in wide-tunability of the FEL radiation) and high average power. One of the candidates is achromatic bend scheme as shown in Fig. 4. In this case, in contrast to the simplest ones, as in the first stage of BINP FEL[8], the dispersion can be controlled, and θ-function is less for the given dispersion (up to twice). The total beamline length spread can be compensated by the dispersion. Estimation shows that the permissible track length spread is ~10 mm, While tuning electron energy within 20~40 MeV the appropriate length varies within ±6 mm, that is less than the permissible track length spread. Estimation of the effects of energy spread and injection pulse duration on the track length error show that by reducing the injection pulse duration from 100 ps to 50 ps will not only enhance FEL power but also enhance the flexibility in the design of beamline. Table 3 shows a result of the calculation of beam trajectory in the achromatic bend.

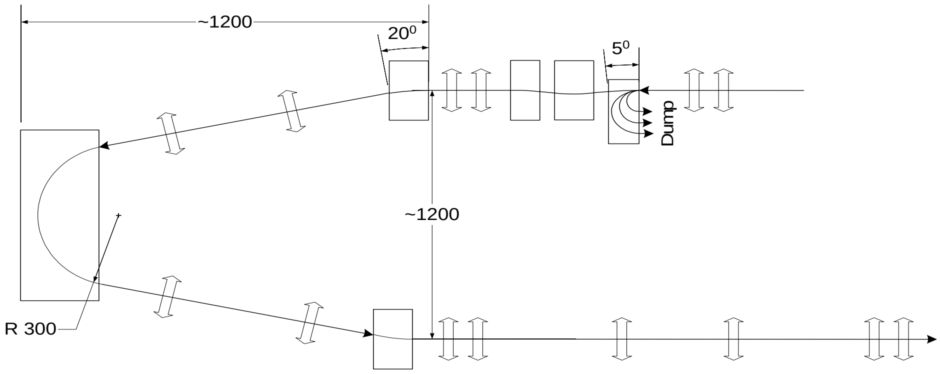

Figure 4. Achromatic bend for energy recovery beamline.

Table 3. Results of beam trajectory in the achromatic bends.

	β_x, m	α_x	β_y, m	α_y
Left bent:				
Entrance	3~12	±1	3~12	±1
Exit	0.3~3	0	0.3~3	0
Right bent				
Entrance	0.3~3	0	0.3~3	0
Exit	3~12	±1	3~12	±1

3. Undulator

An upgraded version of the high-precision electromagnetic undulator assisted by permanent magnets [9] will be used in the high power infrared FEL. This type of undulator is very compact in its structure, cost-effective, and generates high magnetic field with very high precision. The field strength changes depending on the electric current through main coil. Fig. 5 shows a schematic of the undulator.

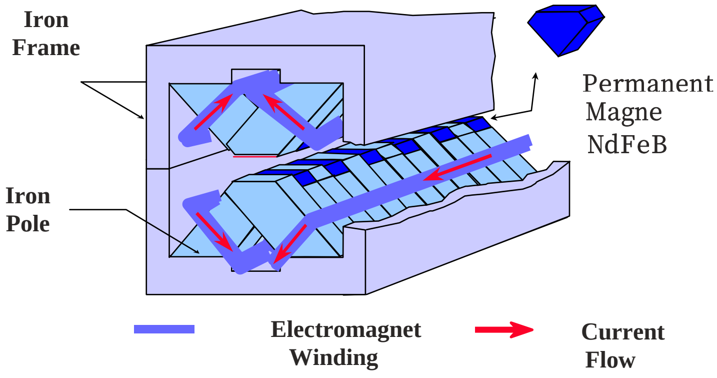

Figure 5. Schematic of the electromagnet undulator.

4. Smmary

A high average power infrared free electron laser driven by a 40MeV energy recovery superconducting accelerator is being developed at KAERI. The 2-MeV injector has been completed, and generates stably an average current of 10 mA. The 2-MeV electron beam has been transported successfully to the entrance of the superconducting cavity. One of the superconducting cavities from CERN has been installed and cooled down to its operating temperature, 4.5K. Two 50-kW 352-MHz RF generators have been installed and tested successfully. Low-power RF test of the cavity has been finished, and high-power RF test will be performed soon, which will be follower by acceleration of electron beam up to 20 MeV.

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