PRESENT STATUS OF A MICROWAVE FEL EXPERIMENT AT KEK

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Abstract

The status of R/D work on a high-power microwave free-electron laser (FEL) is presented. Experimental setup for an X-band FEL is described, and, in particular, experimental results of kilo- ampere electron beam transport in the ion-focused regime (IFR) are reported.

Introduction

The energy of an accelerator for the high energy physics continues to rise rapidly. Probably, an electron-positron collider of next generation will attain its maximum energy in the TeV region. Such an extremely high energy accelerator may be a linear collider to avoid a huge energy loss caused by the synchrotron radiation.

To realize a linear collider in the TeV region with a practical physical dimension and with a reasonable cost, one must adopt a higher accelerating gradient, 300 MV/m[1] for instance, and the development of a new high-power rf source for this purpose is required.

A free electron laser (FEL) driven by an induction linac is one of the most promising candidates for such a new rf source, and a two beam accelerator (TBA) scheme employing the FEL as a power source was proposed by Sessler[2]. In this scheme, a long- distance transport of a driving electron beam may be a serious problem. To overcome a strong beam breakup (BBU) and resistive wall instabilities, the ion-focused regime (IFR) may be a solution for the problems[3].

Based on the TBA/FEL concept, R/D work of a single stage FEL has been started at KEK aiming for an FEL operation of 300 MW at 9.4 GHz driven by an electron beam of a few kA. In order to investigate basic features of the microwave FEL performance in the IFR, we have employed ion channel guiding even in the single- stage FEL test stand.

FEL test stand

Fig.1 shows the test facility for an X-band FEL. It consists of an 800 keV induction linac energized with two magnetic pulse compressors, a wiggler magnet and a transport line. In the following, we describe them briefly.

Magnetic pulse compressor

As a pulsed power supply for the induction linac, two magnetic pulse compressors were developed, each of which has an output power of 3.2 GW[1]. Its equivalent electric circuit is shown in Fig.2. It consists of capacitors (C_0, C_1, ESC), saturable inductors (MS1, MS2), a pulse forming line (PFL) and transformers. An initial pulse of 1.6 μsec and 25 kV obtained by the discharge of capacitors is stepped up to $\sim$240 kV by a transformer and compressed by the combination of saturable inductors and capacitors. The resulting signal is a 200 kV pulse with 80 nsec duration.

Induction linac

A driving electron beam is generated by an induction linac which consists of four induction modules stacked, each of them is energized with a 200 kV pulse from the magnetic pulse compressor, and high voltage of 800 kV in total is superimposed on a gap between a cathode and an anode.

The cathode is a velvet of 50 mm diameter, and electrons are emitted from the velvet surface by the field emission. The anode is a stainless steel mesh of 64 % transmission efficiency. Three or four kA electron beam can come out from the anode.

Wiggler magnet

The wiggler magnet has 12 periods of a 16 cm wavelength, and the magnetic field is produced by 48 air-core solenoids. Maximum field is about 1.3 kG and each period is excited with independent power supply for tapering the magnetic field to optimize an output rf power. A quadrupole magnet coil for the horizontal focusing is embedded in the wiggler magnet frame. The wiggler is located just after the transport line, as shown in Fig.1.

In addition to them, there are some parts associated with rf injection or monitoring, such as magnetron or an rf pickup crystal etc. Details of them will be presented in another paper of this proceedings[4].

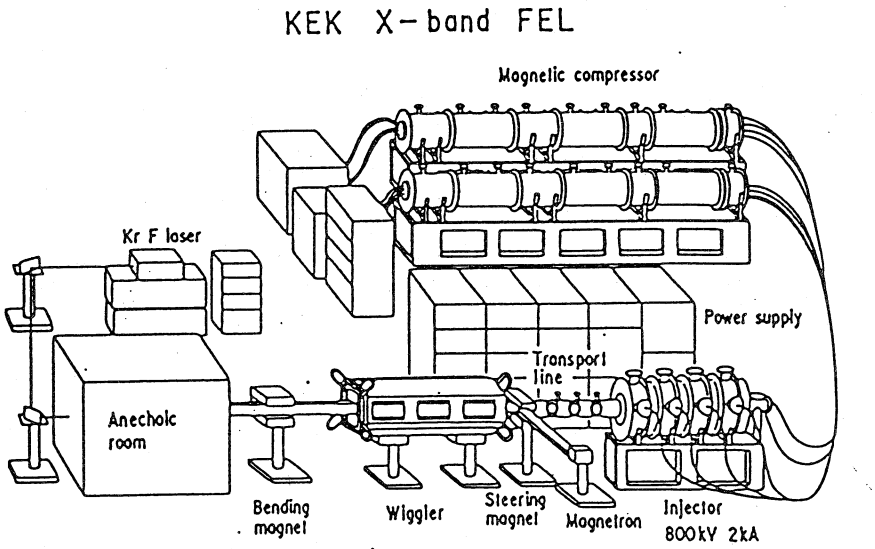

Fig.1 Test facility for an X-band FEL at KEK.

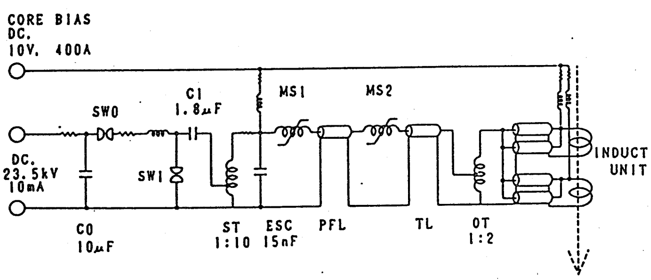

Fig.2 An equivalent circuit of MPC.

Beam quality

Measurement of a beam emittance which is essential for the FEL operation have been done[5]. Emittance is measured by employing a pepper-pot mask which has 64 holes of 1 mm diameter, aligned in an 8x8 array, each hole separated by 5 mm. An electron beam from the injector hits the mask and survived beamlets impinge onto a target located 50 mm downstream from the mask. The target is a plate of a plastic scintillator and, in front of it, an aluminum attenuator of 700 μm thick is placed to reduce low energy components. The scintillation light is reflected by a mirror and observed by a CCD camera.

Analyzing the recorded picture, we have obtained a normalized emittance ϵ_n of 0.41 cm.rad. for a beam current Ib of 840 A. Then, the beam brightness defined by $B_n = Ib/(\pi\epsilon_n)^2$ was 5.0 kA/(cm.rad.)^2.

Meanwhile, energy spectrum of the electron beam is also investigated. At just downstream of the injector, an attenuator made of aluminum foil and a current pickup (Rogowski coil) are placed. A transmitted current is read with the current pickup as a function of the attenuator thickness between 0 and 1.2 mm.

A preliminary analysis for the attenuation curve shows somewhat wide spread in the energy spectrum of $\Delta E/E \simeq$10-20%. To reduce the energy spread, we are planning to install an energy selector which consists of three dipole magnets and a scraper. It will bring an improvement of the spectrum.

Beam transport in the IFR

It may be instructive to briefly describe the beam transport mechanism in the IFR before presenting the IFR experiment.

A special gas is introduced into the transport line. In our case, diethylanilin (DEA) is selected because of its large photo- ionization cross-section for an uv-laser. The gas pressure is kept roughly constant by the ion gauge and controllable valve. Typical pressure is 5x10^{-4} torr. In advance of firing an electron beam, a high-intensity KrF laser (wavelength 248 nm) passes through the chamber and ionizes gas molecules resulting a plasma channel. Thereafter, an electron beam of a few kA is injected into the plasma channel. Plasma electrons are repelled by the space-charge forces of the head of injected electron beam, and only positively charged and massive ions remain; thus, an ion channel is formed. The remaining part of the electron beam is focused by the space-charge force of the positive ions. Consequently, the stable propagation of electron beam can be expected. Fig.3 shows the experimental setup for the beam transport in the FEL. The length of the line is 2.2 m and 6 current pickups are installed along the beam line.

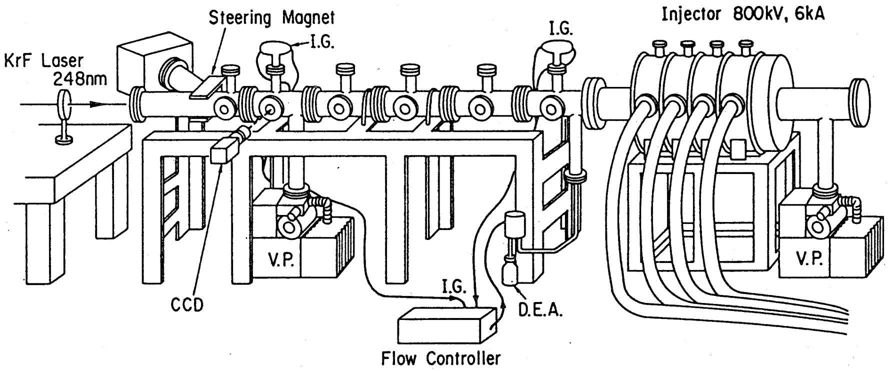

Fig.3 Experimental setup for the beam transport in the IFR.

DEA gas is introduced from the upstream of the chamber and vacuum pump is connected to the downstream. The KrF laser with the pulse energy of about 100 mJ and 20 nsec width was introduced from the downstream end about 100 nsec before the electron beam injection. After that, the electron beam of about 2 kA was injected to the plasma channel from the 800 kV diode. The experiment was done for the following four cases according to the state of the laser and gas.

	laser off	laser on
no gas	X	X
gas	X	1.32kA

Table
X means no current observed at the most downstream.

As seen in the table, only when DEA gas was introduced and the laser beam was fired, an electron beam was transported to the end of the beam line without serious beam loss. Thus, the feasibility of the IFR has been demonstrated successfully.

Summary

The construction of the microwave FEL test stand at KEK has been completed. An electron beam of 2-3 kA has been transported over 2.2 m in the IFR without any external focusing magnetic field. Experiments of FEL amplification at 9.4GHz are going on.

Hereafter, in the near future, the energy of the electron beam will be increased up to 2-3 MeV to improve the beam quality. Though the repetition rate of the present magnetic pulse compressor is low, it must be 1kHz as an rf source for the linear collider. So, we are developing a solid-state prepulser to increase the repetition up to 100 Hz. Accompanying with the improvement of the repetition rate of the magnetic pulse compressor, the field emission cathode will be replaced with a thermal cathode.

References

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