Preliminary Experimental Results from an X-band Free Electron Laser

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ABSTRACT

An X-band free-electron laser (FEL) is going to be operated at KEK . The output power is designed to be 300 MW for an electron beam of 1 kA and 1 MeV. An FEL experiment in the ion focusing regime (IFR) has been performed. This paper describes preliminary experimental results on RF amplification.

INTRODUCTION

A microwave FEL is a possible candidate for high power RF source of a linear collider as proposed by A.M.Sessler in a two-beam accelerator(TBA)(1). An FEL is more efficient than klystrons in the higher frequency range than 2.8 GHz. In fact, a collaboration between LBL and LLNL had demonstrated a successful FEL experiment of 1.0 GW at 34.6 GHz with the efficiency of 34 % (2). Therefore, a 500 GeV x 2 linear collider employing a multistage FEL has been designed (3).

A high power FEL requires a high current beam and so the beam control and steering is important, particularly for the long transport as a driving beam in the TBA. Such a high current beam can be transported using solenoids or ion channel. In 1984, beam transport experiment using a uv-laser-ionized channel succeeded in guiding and focusing a 7 kA relativistic electron beam at LLNL(4). Also the ion channel can damp beam break-up(BBU) by Landau damping. In fact, BBU at the Advanced Test Accelerator (ATA) at LLNL has been suppressed using ion focusing regime (IFR) (5). Although a high power laser is required, IFR is simpler and more reliable than solenoid focusing system for a multi-kilo ampere beam.

The possibility of ion-focusing in FEL operation has been investigated theoretically to design a multistage FEL of the TBA(6). In an FEL in the IFR, electrons are performed wiggle motions and betatron oscillations by a resorting force in the ion channel. However, the FEL operation is assured on the condition that the betatron wavelength due to ion channel is sufficiently large compared to the wiggler wavelength. Ion channel can be expected to transport a high current beam through induction cells, free spaces and wigglers which have strong vertical focusing.

An FEL has been designed and constructed since 1986, at KEK. In order to study the performance of the FEL and the high power beam guiding , an FEL experiment in the IFR has been performed.

DESIGN OF AN FEL

We have designed to obtain 300 MW output power for a beam of 1MeV and 1kA by using 1D-FEL simulation code. Design parameters are listed in Table 1 (7). Fig.1 shows numerical predictions of the dependence of output RF power on the current. Tolerances with respect to the beam quality, particularly, emittance and energy spread of a driving beam, are also examined and required $\varepsilon < 1$ cm•rad and $d\gamma/\gamma < 10\%$, for the desired performance.

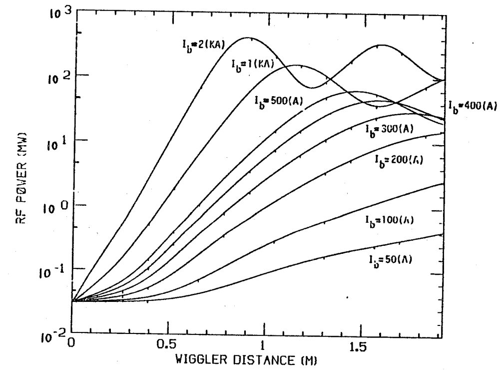

Fig.1 The output dependence on the current.

Table 1

Injection energy	1MeV
Beam current	1kA
Wiggler length	1.92 m
period	16 cm
peak field	1.23KG
RF frequency	9.4 GHz
Input power	30 kW
Waveguide size	5.5 X11. cm^2

FEL TEST STAND

A test stand of the X-band FEL has been constructing in KEK since 1986. The layout of FEL RF system is shown in Fig.2

Beam source and RF source

A beam is provided by an induction accelerator which is driven by two magnetic compressors. The injector produces a 100nS wide, 750KeV and 2kA beam, using a field emission cathode. The details of the injector are described in ref.8. The beam emittance is about 0.5 cm rad for the size of 40 mmΦ. An emittance selector is placed to match the emittance of injected beam to the wiggler acceptance.

An input RF is supplied by the pulsed magnetron 2J55 (New Japan Radio Co. Ltd.) . The tube generates 9388 MHz, 50kW microwave signal with 2.5μs duration in synchronism with the electron beam source. The power supply is a hard- tube type modulator with 12kV and 12A. The signal is transmitted into the oversized waveguide (WRJ-2) in the wiggler through a ferrite isolator, a directional coupler, taper, an RF window and an H-corner. The taper not only connects the X-band waveguide to the oversized waveguide but also converts TE10 mode into TE01 mode.

Wiggler section

The wiggler is a plane-polarized type with wiggler period of 12. Each period is energized by its own pulsed power supply; therefore, the field strength can be easily varied by changing the charging voltage of a capacitor in the power supply , and the tapering is easily provided. The peak current and rise time are 650A and 5ms, respectively. The slow rise time diminishes the field disturbance due to eddy current on the surface of the waveguide. The wiggler field is 2 kG at 650A. The field distribution along the horizontal direction is quadratic and its peak field falls down to 90 % at the edge of effective area . However, this field reduction is completely compensated by eddy current on the copper plates which is introduced at the both sides of the waveguide (9). An air core Q magnet is placed outside of the wiggler to provide horizontal focusing.

A beam passing through a hole in the H-corner is coupled with the TE01 mode in the wiggler and the input RF signal is amplified in the oversized waveguide. This waveguide is made of stainless steel to provide good penetration of the pulsed wiggler field.

RF monitor system

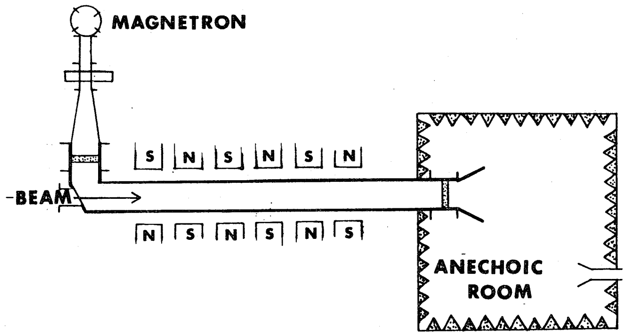

Fig.2 The layout of FEL RF system.

The 2.5m long waveguide terminates at a RF window followed by a rectangular horn antenna in a large anechoic room (2.5x2x2mm^3). The window is made of quartz, and is transparent to both 9.4GHz microwave and KrF (248nm) laser beam for the IFR beam guiding. The inner wall of the anechoic room is covered with microwave absorbers (trade-mark:RANTEC). The amplified microwave is radiated through the rectangular horn. A receiving horn picks up a part of output signal with about 40 dB of attenuation. The signal is further attenuated by the directional coupler and precision variable attenuator to the milli-watt level where the crystal detectors can operate.

Circuits for measuring the power, gain, frequency spectrum, phase and mode have been designed and assembled. The power level is determined by means

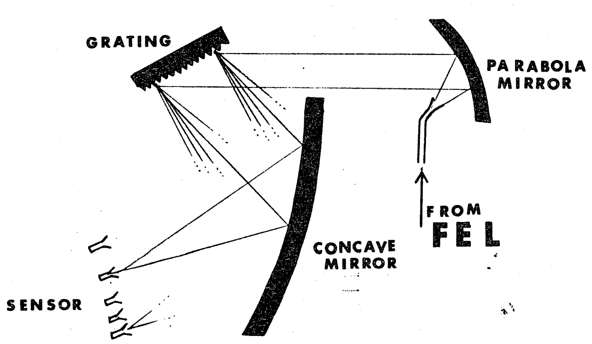

Fig.3(a) The RF spectrometer.

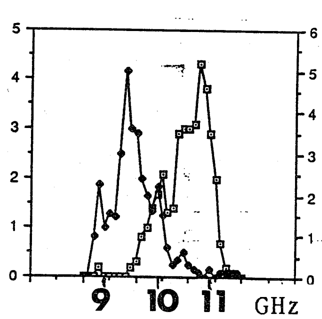

Fig.3(b)

Frequency resolution of the RF spectrometer.

of a calibrated crystal detector . The frequency spectrum is analyzed with a grating spectrometer which is similar to that proposed by N.Ohigashi et al.(10). The spectrometer, as shown schematically in Fig.3(a) , consists of an entrance horn, a parabola mirror, a grating, a spherical mirror and an array of crystal detectors. The spectrometer is designed to measure over the frequency range between 8 GHz and 12 GHz. Each detector is calibrated by a Gunn-oscillator. The frequency resolution is about 1GHz as shown in Fig.3(b). Several channel detectors can be monitored simultaneously, and also time output in each channel for a single shot can be monitored. Supperradiant and sideband growth will be investigated by this spectrometer.

RF extraction

An RF extraction section has been designed, not shown in Fig.2. At the end of the FEL, all of the RF power must be extracted and transported to accelerator structures. The proposed circuit for the extraction consists of an H-tee, a waveguide , an E-tee with a short plunger. All RF wave at the E-tee can be reflected back by tuning the position of the short-plunger. All energy of RF wave will be transmitted through H-tee port to the exit by tuning the length between the E-tee and the H-tee.

PREMININARY FEL EXPERIMENT

FEL experiments started this summer. First of all, beam transport experiment was prepared. A KrF laser(Lambda Physik EMG150MSC) was tuned to produce a plasma channel. The laser was introduced into the beam line from downstream. The working gas was Diethlaniline and vacuum pressure was about 10^{-4}mmHg. After the drastic success of short distance transport (11), we have tried beam transport in the waveguide.

Exciting the wiggler magnet, we could pass an electron beam of several hundred ampere through the long waveguide to the end of wiggler by tuning a steering magnet located in front of the wiggler, although an outer portion of beam hit a 30mmϕ aperture in the H-corner waveguide. The beam current was monitored by a Rogowsky coil and an integrator.

Both the RF signal from the magnetron and the electron beam from the 750 keV diode have been introduced to the waveguide, and the RF output waveform from a crystal diode in the anechonic room was examined by tuning the wiggler field and Q field. A sharp peak was observed, and the width of the peak equalled to the beam width. The peak amplitude was about 10 times larger than the background amplitude. In order to check the validity of these results , we turned off the wiggler so that the peak disappeared. Further we damped the electron beam into the waveguide wall by means of a magnetic kicker, namely, by exciting a particular wiggler. The signal also disappeared. The amplified signal seems to be due to the FEL action.

We could not obtain more gain than the above in the preliminary experiment. The spread of the beam energy seems to be larger than the design value. Plasma interaction with the RF in the waveguide which may prevent RF propagation has to investigated. A work is being continued to search for improved operating condition such as beam energy spread and RF matching. An energy selector will be introduced to eliminate the low energy component in the beam.

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