Particle Accelerators, 1990, Vol. 31, pp. 83–88
Reprints available directly from the publisher
Photocopying permitted by license only

THE MICROWAVE FREE ELECTRON LASER TEST STAND at KEK

**J.Kishiro, K.Ebihara, S.Hiramatsu, Y.Kimura, M.Kumada,
H.Kurino*, Y.Mizumachi, T.Monaka, T.Ozaki and K.Takayama**

**National laboratory for High Energy Physics
1-1 Oho, Tsukuba, Ibaraki, 305, Japan
* Tohoku University, Physics Department, Sendai, 980, Japan**

Abstract A free electron laser (FEL) is the most promising device for an extremely high power microwave source in a future high energy accelerator. A test stand of a single stage FEL designed to generates 300MW microwave at 9.4GHz has been constructed at KEK to investigate the feasibility of the FEL.

INTRODUCTION.

There are several plans of future high energy accelerators in the world.

The 500GeVx2 electron linear collider, for instance, may have a length of more than 30km and have to be driven by about several tens of thousand klystrons if we take conventional technologies. This number of klystrons and the size of the accelerators are not convenient for future accelerator realization. Also, reduction of the primary electric power has to be considered by making the efficiency of each device as high as possible.

The two beam accelerator (TBA) employing the free electron laser (FEL) as a high power microwave source[1] is the most promising scheme to overcome these difficulties. The accelerating gradient of about 300MV/m promises well to reduce the accelerator size down to 4km[2] and the high efficiency of the FEL also enables us to reduce the primary electric power. In order to investigate the feasibility of the FEL, we developed a single stage FEL test stand which is designed to generate the 300MW coherent radiation at 9.4GHz by employing a high power beam from an induction accelerator[9]. The stand consists of two magnetic pulse compressors, a high current electron beam generator and a solenoid wiggler magnet. The details and the performance of each device are described in this article.

OVERVIEW OF THE TEST STAND.

To drive the FEL, we designed an electron generator. An electron beam of 4kA is expected from a field emission cathode, on which a 100ns pulsed electric potential of 800kV is imposed by the combination of four induction units. The pulse power of 6.4GW required for the electron generation is supplied by two magnetic pulse compressors. A magnetic pulse compressor consists of a step up transformer, two saturable inductors and two water filled capacitors, by which 1μs pulse power of 23kV is increased up to 200kV and compressed down to 100ns. Behind the anode of the electron generator, an emittance selector is placed to carve out a good part of the emittance. Without the focusing magnetic field a beam of about 2kA can be transported by using the technique of ion channel guiding, which shows excellent performance in transporting high current beam without conspicuous emittance growth[3]. Going through two small steering magnets, which are used to match the beam emittance and the wiggler acceptance, the beam is injected into the wiggler magnet together with the 50kW microwave generated by a magnetron. A wiggler magnet consists of twelve pairs of air core solenoid magnets and has a total length of 2m. A quadrupole magnet is combined into the wiggler to assist the focusing force to the beam. An anechoic room is placed behind the wiggler magnet to damp the radiation field and to attenuate the field to a level acceptable by the crystal detector. A KrF optical UV laser is introduced into the beam line from the opposite side of the line to make the plasma channel.

MAGNETIC PULSE COMPRESSOR.

Among many methods to generate a high power pulse signal, the magnetic pulse compressor is the most reliable device because it consists of only the passive components such as saturable inductors and capacitors[4]. The pulse power of 6.4GW required for the electron generation should have an amplitude and the width of 200kV and 100ns, respectively. In order to maintain the energy spread of the beam less than 2% the flatness of the pulse should be less than 3% for a duration of at least 60ns.

A cut-away view and the electrical circuit diagram of the pulse compressor are shown in Fig. 1 and 2, respectively. The DC. high voltage of 23kV stored in a capacitor C_0 is transferred into another capacitor C_1 by using a triggerable air gap switch SW_0. The other gap switch SW_1 discharges C_1 within a time duration of 1μs which is determined by the combination of the capacitance of C_1 and the leakage and stray inductance of the step-up transformer. Then the energy is resonantly transferred into an energy storage capacitor (ESC) by increasing the voltage by the 1:10 step-up transformer. The energy is successively transferred from the ESC to a pulse forming line (PFL) and from the PFL to an output terminal. The compression factor of each stage is 2/5 and 1/4, respectively.

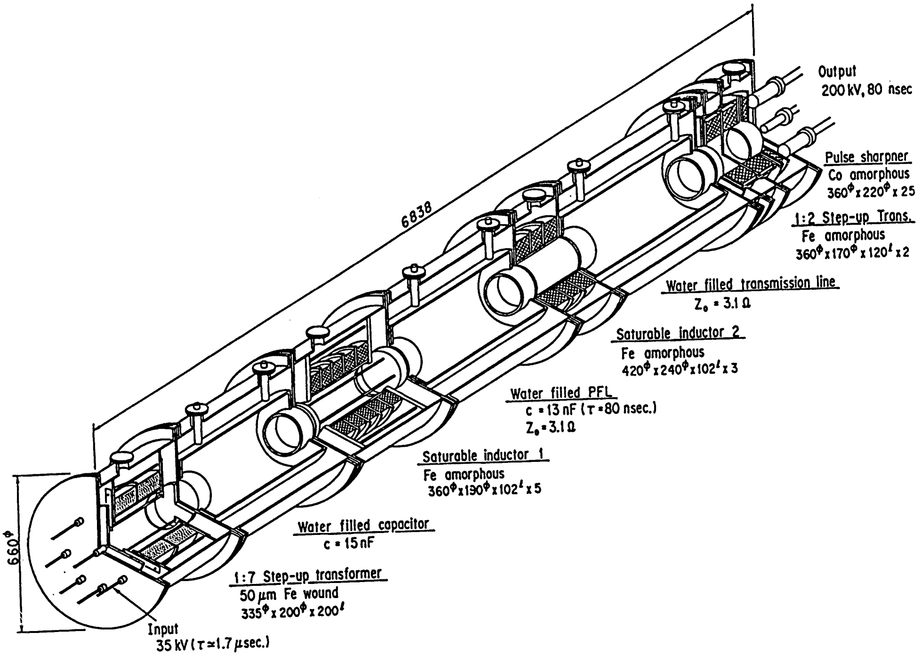

Fig. 1. Cut-away view of the magnetic compressor.

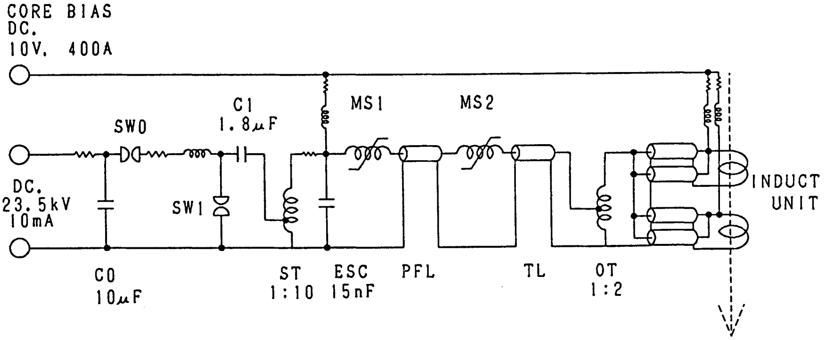

Fig. 2. Equivalent circuit diagram of the magnetic compressor.

The saturable inductor material is a Fe amorphous core and five and three cores are stacked in MS1 and MS2, respectively, to maintain volt-second product design value. The output impedance of this compressor is 12.5Ω so that two pairs of two high voltage 50Ω solid coaxial cables can be connected between the compressor and two units of the induction accelerator.

Fig. 3 shows the voltage waveform of each stage and the output signal on a dummy load, respectively.

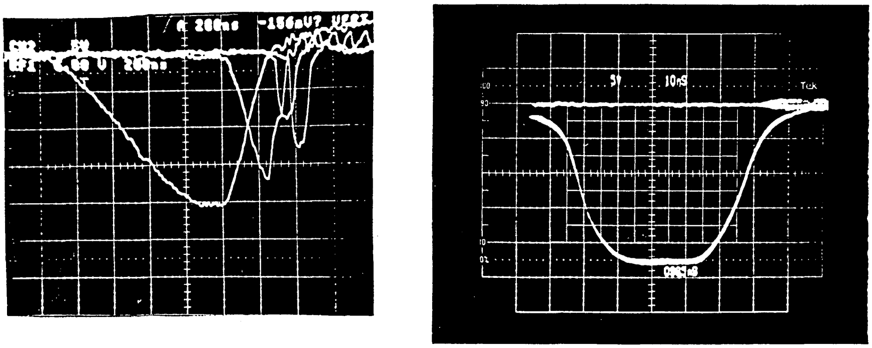

Fig. 3. Voltage waveform on each stage (a) and on a dummy load (b).

The volt-second products of each stage have been finely adjusted by rewinding the amorphous core. Fig. 3(a) shows the saturation of each inductor and the flatness of the output signal is also quit good (Fig. 3(b)).

ELECTRON GENERATOR.

Fig. 4 shows the cut-away view of the electron generator.

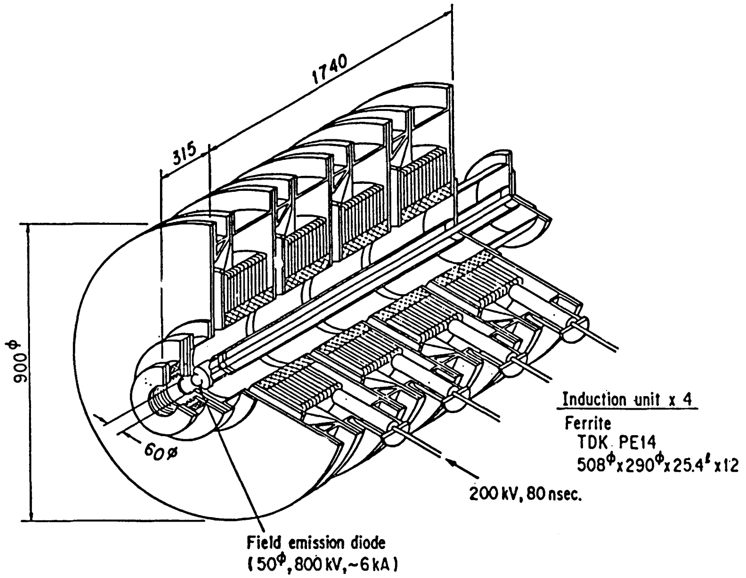

Fig. 4. Cut-away view of the electron generator

Four induction accelerator units are stacked into one to get 800kV high voltage on the cathode. A stainless steel rod of 76.3mmϕ is installed in the stack and on top of which a 50mmϕ velvet cathode is mounted. About 50mm downstream, a small mesh is placed as an anode.

The size of the cathode and the spacing between the cathode and anode were determined by considering the space charge limiting current based on the Child-Langmuir equation[5]. Also the program code EGUN[6] was used to examine the correlation between the diode size and the beam emittance. The design value of the diode current is 8kA, a part of which, about 4kA, can penetrate the anode hole as the beam and the other part goes into the anode electrode itself.

Each induction unit consists of twelve ferrite cores, TDK PE14, and a solenoid magnet. The solenoid magnet is wound inside of the troidal ferrite core to avoid the difficulties caused from the cathode rod field emission. It can be used as a beam guiding magnet when we use the unit as a post-accelerator.

The beam spot is observed by a scintillator plate placed behind the anode (Fig. 5). The deformation of the beam spot might come from the bad surface condition of the cathode, and the field emission cathode makes it somehow difficult to generate an uniform beam. Before the constant beam current is acheived, the diode impedance is so varied dynamically that it is rather difficult to get impedance matching between the pulse compressor and the beam generator. Also the energy of the beam spread over such a wide range that the efficiency of the FEL operation may be reduced. By considering these difficulties, we plan to replace the field emission cathode by a thermal emission cathode by next year. However, at present, we adjust the impedance of the induction unit by using a ballast load and make the energy spread as small as possible by adjusting the operational timing between the two pulse compressors.

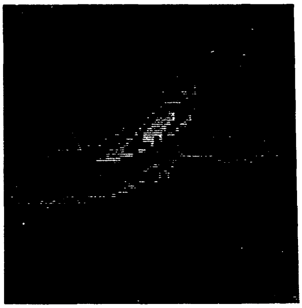

Fig. 5. Beam spot

WIGGLER MAGNET.

A 2m air core solenoid wiggler magnet was constructed to make a FEL . The magnet consists of twelve pairs of solenoid magnets providing a planar wiggler field to the beam. The parameters of the wiggler magnet and those related to the FEL operation are optimized by using a computer simulation code which is coded not only based on the theory proposed by D.Prosnitz[7] but also including the effects of both the betatron oscillation of the beam in the wiggler and the longitudinal space charge force[8].

The saturation length of the wiggler is about 1.2m and the power of the coherent radiation at this point is about 110MW. However, if we take a tapered wiggler field beyond this saturation point, the output power obtainable can be increased up to 300MW (Fig. 6).

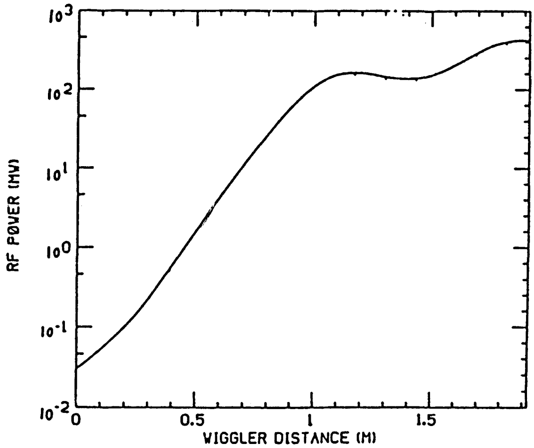

Fig. 6. RF gain curve of the wiggler.

The tolerance of the beam quality in the wiggler such as emittance and the energy spread are examined by this computer code, 1 cm.rad and 10%, respectively. In addition to the instruments described above, there are many monitor pickups in the stand, several copper sulfate high voltage dividers which have nice frequency response to measure short pulses, Rogowsky type current pickups, a scintillator plate to observe the beam size and the emittance[3] and also several RF crystal detectors. The light emitted from the scintillator is monitored by the charge coupled device (CCD) TV camera. We put both a high speed shutter and an image intensifier in front of the camera which enables us to observe the time structure of the beam.

SUMMARY.

The whole system described above has been completed this June. The operation and the experiment started just one month ago. During this one month we successfully carried out the ion channel guiding experiment over the length of 5m[3]. Coherent radiation at 9.4GHz is expected by this autumn.

REFERENCES.

1 A.M. Sessler, AIP Conf. Proceedings, No.91(1982)154
2 S.Hiramatsu *et al.*, Proceedings of this Conf.
3 H.Kurino *et al.*, Proceedings of this Conf.
4 D.L.Birx *et al.*, UCID-18831(1980)
5 I.Langmuir, Phys. Rev. 3(1931)238
6 W.B.Herrmannsfeldt, SLAC-226(1979)
7 D.Prosnitz *et al.*, Phys.Rev., 24(1981)1436
8 K.Takayama, KEK internal report
9 S.Hiramatsu *et al.*, Proc. of the 10th Int. Free Electron Laser Conf, Israel, 1988 to be published in Nucl. Instrm. and Methods