Design and Operation of Inductive Acceleration Modules for FEL with Controlled Voltage Ramp

S.Kawasaki[a], H.Ishizuka[b], A.Tokuchi[c], Y.Yamashita[d], S.Nakajima[e], K.Sakamoto, H.Maeda and M.Shiho

Japan Atomic Energy Research Institute, Naka Laboratory

Nakamachi, Ibaraki 311-01 JAPAN

Abstract

A new pulse compression system is fabricated for grading up the induction accelerator LAX-1, which is currently used for Raman FEL research at JAERI[1]. It is designed so that the capacitance of PFL can be varied partly, and the output voltage ramp be controlled within ± 20 %. The system consists of a series of PFLs and magnetic switches for pulse compression from 2 μ s and 30 kV to 130 ns and 250 kV. The final output is supplied with to 2 × 4 units of accelerating cavity. The design, circuit parameters, mechanism of varying the PFL parameters and the results compared with those of the numerical simulation are presented. Relation to the beam dynamics and FEL performance is also considered.

I. INTRODUCTION

The instantaneous energy spread and emittance of the electron beam are well recognized to give great influence to FEL performance. The evolution (and/or fluctuation) of the beam energy and intensity in time, can as well be the cause of the degradation of the resulted radiation on an average, through the beam dynamics and the slippage[2][3]. We have studied a Raman FEL in the microwve frequency range at JAERI, using an intense electron beam of 1 MeV and 2 kA generated with an induction linac. The plasma cathode used there has an intrinsic time-dependent impedance and the electron beam rather differs from being constant in both energy and intensity although the driving voltage was shaped nearly rectangular of 150 ns in duration. Stable transport of the beam in the wiggler field over the whole duration was not obtained and an effective FEL amplification of the input microwave was realized only in a narrower span (~40 ns)[4] (Fig.1). In the design of upgrading of LAX-1 in view of its application of the resulted FEL radiation to control the plasma parameter in a medium-sized Tokamak JFT-2M, the driving acceleration pulse is required to be tailored for the beam to produce an intense microwave of 30-120 GHz over the full beam duration (130 ns), by means of a variable PFL compression scheme.

a) Saitama Univ., Fac. of Sci., Urawa 338 JAPAN.

b) Fukuoka Inst. of Tech., Fukuoka 811-02 JAPAN.

c) Nichicon Co. Ltd., Kusaru, Shiga 525 JAPAN.

d) Hitachi Metal Ltd., Magnetic and Electric Materials Res. Lab., Kumagaya, Saitama 360 JAPAN.

e) Hitach Ltd., Kokubu Works, Hitachi, Ibaraki 316 JAPAN.

II. PFL AND MAGNETIC SWITCH

Fig. 2 shows a schematic of the circuit of the magnetic compression device, including PFLs and magnetic switches. The operation of the circuit depends mainly on the magnetic characteristics of the core material, and on the arrangement of the successive stages. We had investigated various plans with many kinds of core materials and PFLs, and finally chose the components as shown in the figure. The circuit consists of a pulse step-up transformer PS, an intermediate capacitor ISC, and a series of 11 PFLs between magnetic swithes MS. Thin foils of amorphous metal "Finemet" and "AC10" available from Hitachi Metals and TDK, are used for the cores. The capacitance and characteristic impedance in the PFLs can be varied in a large range in three sections of the PFLs, to control the final waveform; the rising and falling times and the voltage ramp of the flat part. In these sections the circuit forms a folded planar PFL, where the central and outer electrodes are immersed in pure water with dielectric material inserted between them. The position of the dielectric layer can be moved mechanically in vertical direction to change the capacitance of the PFL within ± 50 %. Two of the PFLs (PFL2 and PFL11) are for getting the leading and falling edges of the pulse shorter than 20 ns and the group of PFL3-9 is for the ramp control. The pulse form is thus subject to fine control when it should be ajusted to the time-dependent impedance change of the electron beam diode. The pulsed waveform of the voltage and current in each stage were numerically simulated with the same computer code as used for the design of LAX-1. The results of the simulation are shown in Fig. 3, for the cases of the pulse with a flat top and a positive/negative voltage ramp, assuming the load of pure resistance.

0-7803-1203-1/93$03.00 © 1993 IEEE

III. EXPERIMENTAL RESULTS

The device is composed of 2 systems identical with one described in the previous section. The either of their outputs is divided into 4 channels to feed independently to 4 accelerating cavities a pulse of 250 kV respectively. We will have thus an inductive accelration of 1 MV/system, or 2 MV in all. The device was tested with a dummy load of pure resistance of 50 ohms/each channel. The circuit voltage(V) at several nodal points were measured as well as the flowing currents(I) between them, and from them the values of power transported(P) through the successive stages of the circuit are calculated. Energy losses(E) in the stages are to compare with the values expected from the core characteristics. Some of the results are shown in the Fig. 4a)-d). Fig. 4a) is the input voltage to and the current through MS1. Fig. 4b) is for those measured at the entrance of the PFLs, and Fig 4c) for the voltage at the load when the impedances of PFLs are fine-ajusted to get a flat top within $\pm$ 1.7% over 120 ns. Changing the impedances of the PFLs we obtain the pulses as shown in the Fig. 4d): typical examples of the output for the cases of a flat top, positive and negative ramp, which should be compared with the Fig. 3. The coincidence of the measurements and the simulation is fairly good. The input energy from the primary capacitor is 1390 J and the power consumed at the load 860 J approximately. The transmission efficiency is then 62 %. The accelerating cavities are under construction at present and the first operation of the electron beam is expected before the end of the fiscal year 1993.

IV. DISCUSSION AND CONCLUSION

It was successfully demonstrated that the output pulse of the pulse modulator for generating an intense relativistic electron beam for Raman FEL research could be controlled in the shape with a variable voltage ramp by adjusting the impedances of the PFLs inserted btween the magnetic switches. The modulator will be matched to the impedance evolutiom of the electron beam diode and get the beam of constant particle energy. The planar PFLs the capacitance of which is changeable with a relatively simple mechanism work well and show a moderate power loss. At the Raman FEL experiment the transmission of the beam through and the satbilty in the wiggler are affected quite seriously by the partid energy with collective effects related to the intense self-field. It is necessary to keep the energy constant within a few % over the pulse length at least in our geometry of the experiment[5]. The beam with time-dependent energy may also produce the radiation with a large spectral width on an average. If we use a cavity to confine the FEL radiation to enhance the gain, the fluctuation of the beam energy will affect the spectral characteristics through the slippage and the competition between the possible modes[3]. We will be able to investigte these issues experimentally in detail with the new driver, while so far the effect was discussed mostly for a low gain continuous beam FEL.

IV. REFERENCES

[1] M. Shiho, K. Sakamoto, S. Maebara, A. Watanabe, Y. Kishimoto, S. Kawasaki, T. Nagashima, and H. Maeda, "JAERI millimeter FEL experiment by using focusing wiggler", *Nucl. Instr. Meth.* **A 304** 141 (1991).

[2] C.M.Tang, B.Hafizi, E. Esarey, A. Ting, W. Marable, and P. Sprangle, "Key issues affecting the performance of free electron lasers", *AIP Conf. Proc.* No. **249** 1020 (1992).

[3] T. M. Antosen, Jr. and B. Levush, "Spectral characteristics of a free electron laser with time-dependent beam energy", *Phys. Fluids* **B 2** 2791 (1990).

[4] K. Sakamoto, T. Kobayashi, S. Kawasaki, Y. Kishimoto, S.Musyoki, A. Watanabe, M. Takahashi, H. Ishizuka, M. Sato, and M. Shiho, "Millimeter wave amplification in a Free Electron Laser with a focusing wiggler", submitted to *Journal of Appl. Phys.*

[5] K.Sakamoto, T. Kobayashi, Y. Kishimoto, S. Kawasaki, S.Musyoki, A. Watanabe, M. Takahashi, H. Ishizuka, and M. Shiho, "Beam divergence with harmonic gyroresonance in focusing wiggler and axial field", *Phys. Rev. Lett.* **70** 441 (1993).

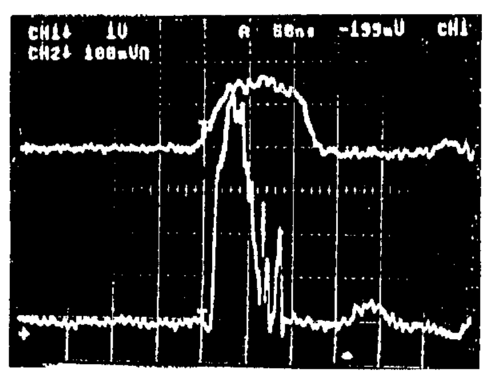

Figure 1. Accelerating Pulse of LAX-1 and Amplified RF
upper:output 500 kV/div. time scale:50ns/div.
lower:amplified FEL of 35 GHz.

Figure 2. Schematic of the Device and Equivalent Circuit of PFLs.

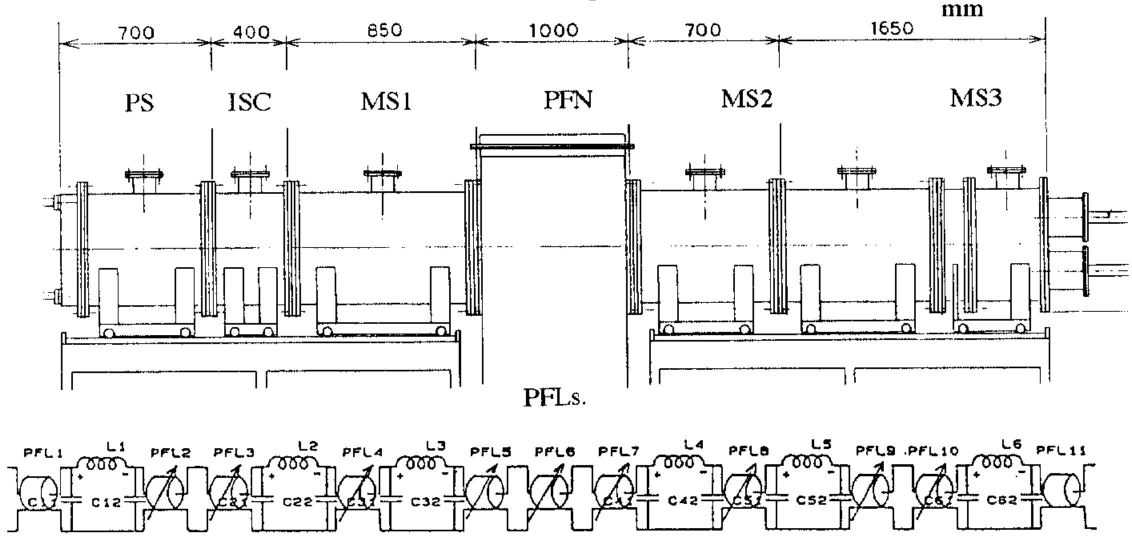

Figure 3. Simulation of the Output Waveforms.
case 2: flat impedances for PFL2-10.
case 3: PFL impedances decreasing from 2 to 10.
case 4: PFL impedances increasing from 2 to 10.

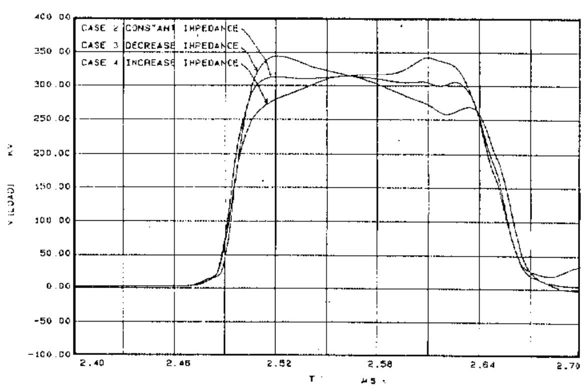

Figure 4. Voltages and Currents in the Compression Circuit.
4a) Input to MS1.
4b) Input to PFLs.
4c) Load voltage with a flat top.
4d) Outputs with various ramp.
100 kV/div.