An Induction Linac and Pulse Power System at KEK

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Abstract

A R&D program on a free electron laser(FEL) in the microwave regime is currently in progress at KEK, intending to investigate the feasibility of an FEL as a promising GW order high power microwave source for the two beam accelerator(TBA) scheme[1][2] in a future high energy linear collider. The first prototype of the KEK FEL was an induction linac driven X-band(9.4GHz) FEL energized by a 800keV, 1kA electron beam[3]. The rf power amplification exceeded 30MW[4], however, theoretical work indicated that the 800keV operation was in the Raman regime and the FEL gain was limited by a strong space charge effect. To cure problems arising from the space charge effect, a new generation of the KEK FEL has been completed, in which the driving electron beam energy was upgraded to 1.6MeV and about 700A beam current was successfully transported through a wiggler magnet.

In parallel to the FEL investigation, several types of high current induction linacs and a pulse power system were also developed. The pulse power system consists of two gate-turn-off thyristor(GTO) switch modules, two magnetic pulse compressors and a dc high voltage source. A 1.6kV dc high voltage is resonantly discharged by the GTO switches and its pulse duration is compressed to 200kV, 100ns pulse power by a combination of two step-up transformers and three saturable inductors. The induction linacs are of two types. One is loaded by a ferrite magnetic cores (TDK PE14) and the other is loaded by amorphous cores (Metglass 2605S). The details of the induction linacs and pulse power system design and a performance will be reported in this article.

I. INDUCTION LINAC

To get the 1.6MeV high current electron beam, eight induction units were installed, four of which have been used in the previous 800keV operation. These were formed by 12 ferrite cores of 50.8cm outer dia., 29cm inner dia. and 2.54cm thickness. The other four units are newly designed for improving the vacuum seal and consist of 5 amorphous cores, Metglass 2605s, of 49.3cm outer dia., 31.5cm inner dia. and 4.4cm thickness. The previous version of the unit has only an acrylic resin to insulate the oil filled and vacuum region. This resulted in rather poor vacuum because of the evaporation of the acrylic compound. An additional ceramic insulator has been installed in the vacuum region in the new design and less than 10^{-7} *Torr* is possible throughout the whole beam region. Figure 1 shows the inner structure of the new induction unit.

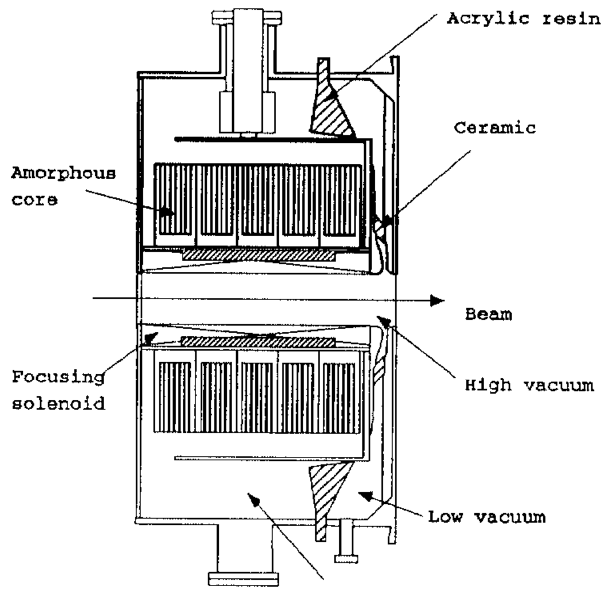

Figure 1. New induction unit.

The use of amorphous core is motivated by the lower magnetic coercive force than the ferrite core: this provides lower magnetic reset current and results in lower heat dissipation in the unit. Moreover the higher saturation magnetic field, B_S, of the amorphous material is suitable to reduce the unit size. The heat dissipation of the pulse operation in the unit volume depends on the material; however, the concern is not in the unit volume but in the whole volume. The high saturation material, like amorphous, in general, has high loss but requires small volume to realize the same volt-time product. Thus the total dissipation is almost independent of the ferromagnetic material.

The other consideration for choice of the material is the magnetization current, I_M, which is required to be as small as possible, because it detracts from the beam current, *i.e.* beam current I_b is $I_b=I_{ps}-I_M$, where I_{ps} is the current from a power supply. The size of I_M can be measured by examining the unit impedance without the beam loading, *i.e.* $R_M=V_{IDU}/I_M$. Too good electrical conductivity of the amorphous core will lower the impedance. The table I shows the measured induction unit impedance of both the ferrite and amorphous core loaded.

Table I Impedance of the induction unit.

cell number	1 2 3 4	5 6 7 8
$R_M(\Omega)$	118 94 105 79	91 86 81 100
magnetic core	Ferrite(TDK PE14)	Metglass(2605S)

The fabricated units almost meet the design goal of $R_M \geq 100\Omega$, required to insure the impedance matching between the induction unit and the power feeder (50Ω coaxial cable) from the power supply, for a 2kA beam. The new design has not been optimized the core size, and took the other structures, like cooling channel etc. Then the whole unit size became almost the same as the previous version in spite of the advantage of high B_S of the amorphous core. In the third design it is foreseen an optimization work.

II. PULSE POWER SYSTEM

The pulse power system was designed to energize the two units of induction linac. The system consists of a high voltage source, two modules of solid state switches and two magnetic pulse compressors(MPC).

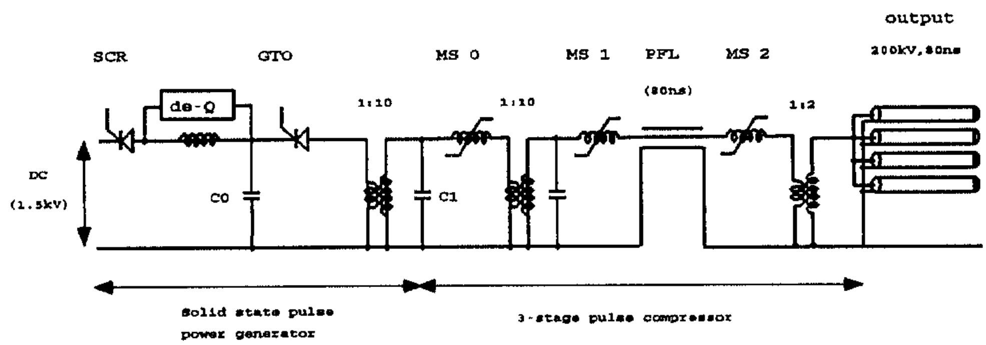

Figure 2. MPC circuit diagram.

A. Magnetic pulse compressor

Among the several types of pulse power system, MPC is the most preferable system because it consists of only passive components, thus making possible huge power switching. The KEK MPC is three stage saturable inductor switch, compressing a power pulse from 7μs to 80ns. A schematic drawing is shown in Figure 2. The characteristics of the MPCs are:

Output voltage	*200kV*
Output current	*16kA*
Output impedance	*12.5Ω*
Output pulse duration	*80ns(FWHM)*
Input voltage	*2.6kV*
Input pulse duration	*7μs(half-sinusoidal)*

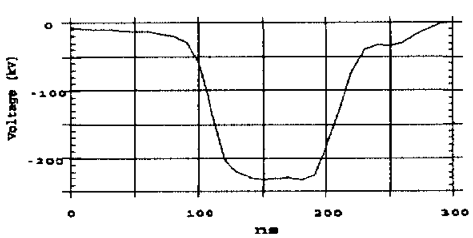

Figure 3. MPC output wave form.

The output power from the dc high voltage source(1.6kV) is resonantly charged into the capacitor C_0(2.7kV). Two 1:10 step-up transformers increase the voltage up to 250kV and three stages of amorphous inductor switches compress the power pulse down to 80ns. The output pulse is formed by a pulse forming line(PFL), which has a length corresponding to 80ns and an impedance of 3.1Ω, and at the final end of the MPC a 1:2 step-up transformer is installed for recovering the charging voltage to the PFL. Figure 3 shows a typical output wave form on a resistive matched dummy load.

B. Power station

The dc power source is the conventional type of rectifier from 420V primary AC power to 1.6kV DC power. The high voltage pre-pulser is formed by ten GTO switches, each of which has a capability of switching the high voltage power of 3kV, with current ramp rate of up to 6kA/μs.The charged DC 1.6kV power in a capacitor is resonantly charged into the capacitor C_0 and discharged into C_1 by the GTOs through a 1:10 transformer and successively compressed in duration by the MPC.

The charging voltage of the capacitor C_0 is continuously examined and automatically cuts off the power line between the power supply and C_0 by exciting a de-Q circuit. The stabilization of the MPC output voltage by the de-Q circuit was established within 1% and the advantage of the solid state switches was confirmed in the timing jitter of the output pulse, observed to be less than ±2ns.

III. 1.6MeV X-band FEL test stand

The re-assembling of the 800keV stand to the new 1.6MeV FEL test stand has been completed. Figure 4 shows the whole view of the 1.6MeV X-band FEL test stand. Two sets of the four induction units generate 1.6MV on a 40mm dia. field emission metal cathode. A carbon cloth is attached on the cathode surface, which has a good electric conductivity and makes the beam quality stable. A mesh-less type anode is placed at 89mm down-stream of the cathode. This diode is operated in the sense of "laser-based foilless diode"[5], because laser-induced ion channel guiding is used as a means of high current beam transport. Thus the diode is surrounded by dense ions; however, the electrode is designed neglecting this effect by using the EGUN code. A stable 1.2kA beam current is generated from the cathode and about 800A beam is constantly transported into the wiggler magnet. The beam is transported by employing ion channel guiding alone, without any external focusing magnets.

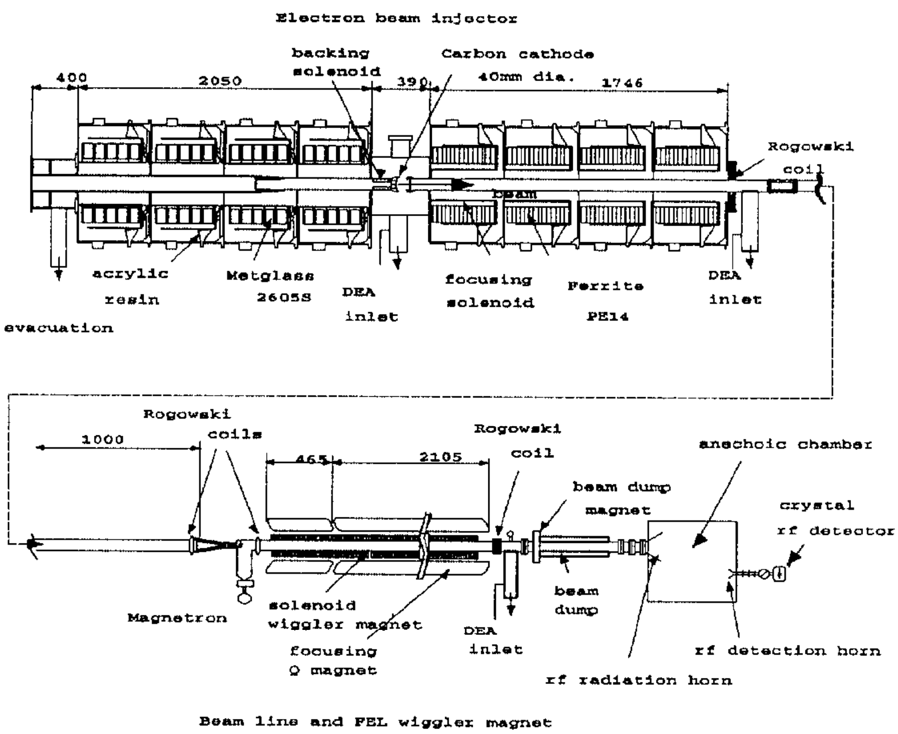

Figure 4. 1.6MeV KEK X-band FEL test stand.

The wiggler magnet is the planar type magnet, which consists of 12 small solenoid coils and an additional 4 similar coils. The 9.4GHz rf is injected from a magnetron into the over-sized waveguide and amplified rf is ejected into an anechoic room where power and mode contamination etc are measured.

IV. Preliminary FEL experiment at 1.6MeV

Figure 5 shows preliminary results for beam transmission in the wiggler section.

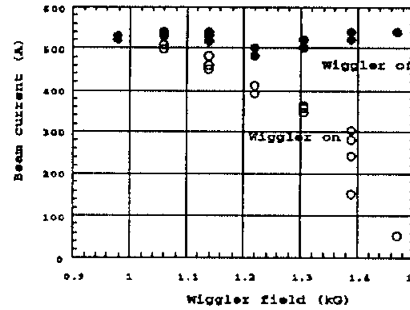

Figure 5. Preliminary result for beam transmission in the wiggler section.

With no wiggler excitation, the beam is completely guided by ion channel focusing. However, we have considerable beam loss for wiggler field higher than 1.2kG. Since maximum FEL gain at 1.6MeV is expected at a wiggler field of 1.4~1.5kG, improvement of the beam transmission at higher field is essential and is under way.

In preliminary operation, rf amplification by the FEL was observed as shown in Figure 6 and maximum power of 16MW was obtained. Due to the beam loss in Fig.5, amplified rf power degrades toward the high wiggler field side. Meanwhile, a 1-D FEL theory "benchmarked" at 1.6MeV predicts a saturated power in excess of 50MW, for 0.5kA beam.

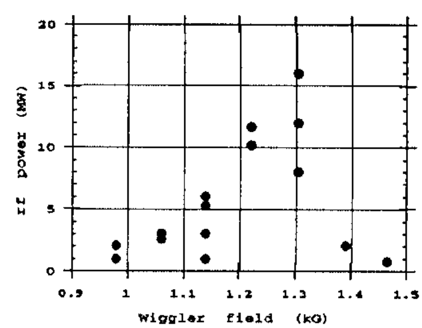

Figure 6. Amplified rf power in preliminary studies.

V. REFERENCES

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