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The RF System for FELI Linac

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FELI (Free Electron Laser Research Institute, Inc.) is constructing a Free Electron Laser facility covering from 20 μm (infra red region) to 0.35 μm (ultra violet region), using an S–band linac.

The linac consists of a thermoionic 0.5ns–pulse triggered gun, a 714–MHz SHB (subharmonic buncher), a 2856–MHz standing wave type buncher, and seven ETL (Electro–technical Laboratory) type accelerating sections[1].

An RF system of the linac for FELs is required of long pulse duration and high stability. Two S–band klystrons (TOSHIBA E3729) are operated in three pulse operation modes (pulse width and peak RF power): 24 μs–24MW, 12.5 μs–34MW, 0.5 μs–70MW. Each klystron modulator has a PFN consisting of 4 parallel networks of 24 capacitors and 24 variable inductors, and it has a line switch of an optical thyristor stack. An S–band klystron and its modulator were combined to test their performance at the works of NISSIN ELECTRIC Co. in December 1993. These equipments were installed at FELI in January 1994. The design and experimental results of the RF system are summarized in this paper.

Keywords: FEL, RF, Klystron, modulator, long pulse

1. Introduction

The electron beam of linacs for high quality FELs should satisfy the following requirements:

(1) Long pulse duration,
(2) High peak current,
(3) Low energy spread,
(4) Low emmitance,
(5) Period of micro pulse should be highly stabilized.

So the RF system of linacs for FELs is required of long pulse duration and high stabilities in both RF power and RF phase.

It needs enough macro pulse length to saturate the FEL power because of low gain at ultraviolet region. Therefore, the RF pulse durations are 24 μs for visible or ultra violet region, 12.5 μs for infra red region, and 0.5 μs for injection mode to a storage ring with an FEL resonator.

The relation of beam energy stability $\Delta T/T$ and RF power stability $\Delta P/P$ is

$$2\Delta T/T = \Delta P/P$$

Then the relation of RF power stability $\Delta P/P$ and cathode voltage stability $\Delta V/V$ of a klystron is

$$\Delta P/P = (5/2)\Delta V/V$$

So the stability of beam energy is determined by the stability of klystron cathode voltage.

$$\Delta T/T = (5/4)\Delta V/V$$

To stabilize the beam energy within 0.1%, the stability of klystron modulator voltage should be better than 0.08%.

2. The layout of RF system

The layout of our RF system is shown in Fig. 1. A main signal generator oscillates 22.3125MHz, and the frequency is multiplied to 178.5MHz, 714MHz and 2856MHz. A grid pulser for the thermoionic gun(EIMAC Y646B model) uses 178.5MHz at 5.6ns micropulse repetition or 22.3125MHz at 44.8ns one. The micropulse width from the gun is 0.5ns, which corresponds to 75° for 714MHz since the pulse length of 120-keV beam emitted from the gun is 8.7cm. So the SHB uses a 714MHz RF. An RF amplifier for the SHB contains a klystron 1AV88R (TOSHIBA) and a modulator. The klystron is widely used for the UHF TV broadcasting and its peak power is 15kW. The modulator uses MOS- FET modules.

The first main klystron(E3729) supplies RF power to a buncher and three accelerating sections, and the second main klystron supplies RF power to four accelerating sections.

An S-band driver amplifier has a klystron TH2436 (THOMSON). Its peak power is 3kW at 24-μs pulse operation and the RF power is delivered to three klystrons. Two of them are klystrons E3729 and one is a klystron for an RF Gun. The driver amplifier uses a commercially available MOS-FET modules (BEHLKE)[2].

The wave guides are pressurized by SF_6 gas of 2kg/cm^2, and their temperature is controlled by the water at 40°C to stabilize the RF phase.

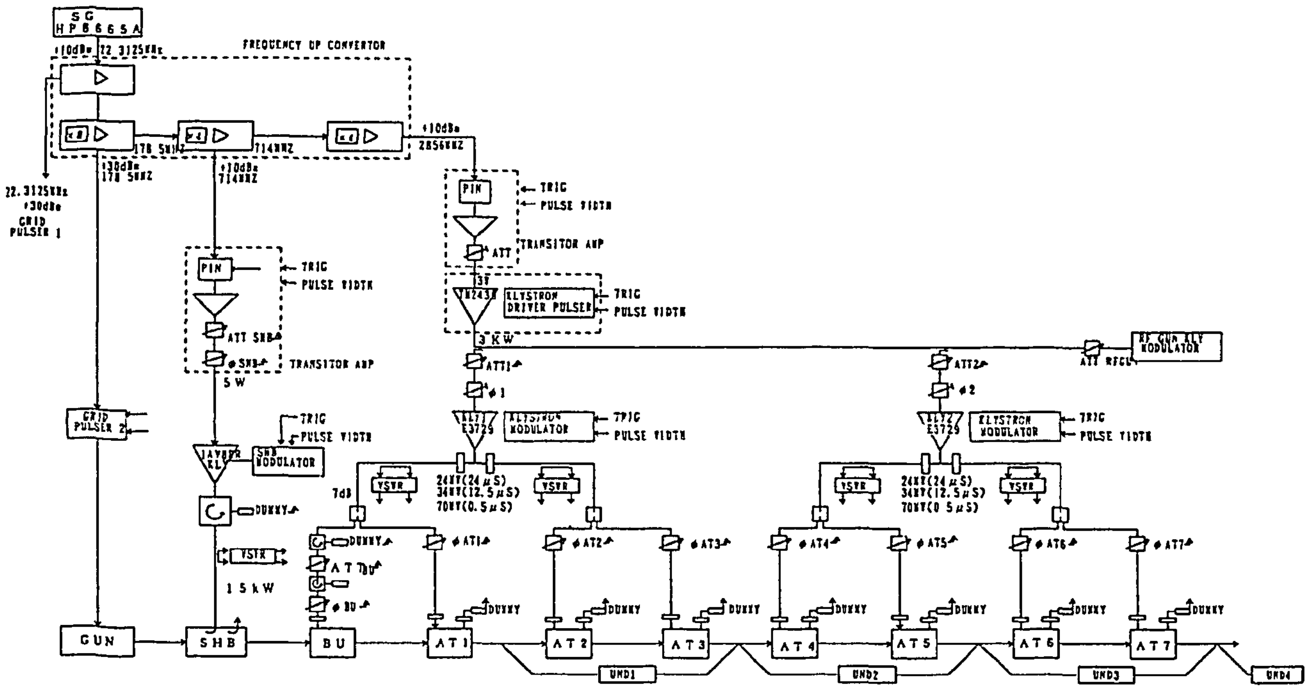

Fig. 1 The layout of RF system for FELI linac

3. S–band klystron

As the klystron of our linac for FELs should be available for long pulse operation, we chose the klystron E3729 (TOSHIBA) which was modified from the type of E3712 (4 μs -80MW, 50pps). At long pulse operation (24μs–24MW, 10pps) there was no problem for the cathode and collector of E3712 in the thermal point. So E3729 uses same body of E3712, but the tuning of cavity is changed so as to improve the efficiency at long pulse and low peak power operation. However, the efficiency achieved at short pulse and high peak power operation is sacrificed a little.

4. Klystron Modulator

In order to satisfy the requirement of 24μs pulse duration and 0.08% output voltage stability, our klystron modulator has following measures. The block diagram of klystron modulator is shown in Fig. 2 and its properties are shown in Table 1.

The PFN (pulse forming network) consists of 24 sections 4 parallels in 24μs operation, 15 sections 4 parallels in 12.5μs operation, and 24 capacitors in parallel without extra inductor in 0.5μs operation. Each section contains an inductor (11.4μH) and a capacitor (37nF). Energy inductor is equipped with a motor-drive plunger tuner to vary the inductance.

A charging power supply consists of not IVR and Dc-Q circuit but an inverter and converter for achieving high stability. It can deliver 3A at 50kV with an output voltage stability within ±0.01% using input AC voltage stabilized within ±1% by a motor generator.

The line switch consists of not thyratron but 30 optical thyristors of type SLG1500GX22 (TOSHIBA) in series. A saturable inductor is placed in series in order to protect the each thyristor from overvoltage due to unbalance of voltage sharing caused by the lag of each thyristor's turn-on time.

If we choose a thyratron as a line switch, a variation in voltage drop across the thyratron is 10~25V. If the output voltage of PFN is 20kV, this variation due to the thyratron means an uncertainty of 0.1%. The stability of final output voltage should be within 0.08%, so the thyratron is not acceptable[3]. For this reason, we choose optical thyristors. Though the pulse rise time of our modulator is comparatively small (about 2 μs), the operation specification of the optical thyristor's stack (50kV, 7000A) is severe. Therefore, the life time test of thyristor was done before we chose optical thyristors.

Table 1 Characteristic properties of klystron modulator

Mode	*1*	*2*	*3*
Flat top duration (μs)	*24*	*12.5*	*0.5*
Output voltage (kV)	*285*	*305*	*385*
Output current (A)	*280*	*306*	*440*
Output stability (%)	*0.08*	*0.08*	*1.5*
Repetition frequency (Hz)	*10*	*10*	*10*

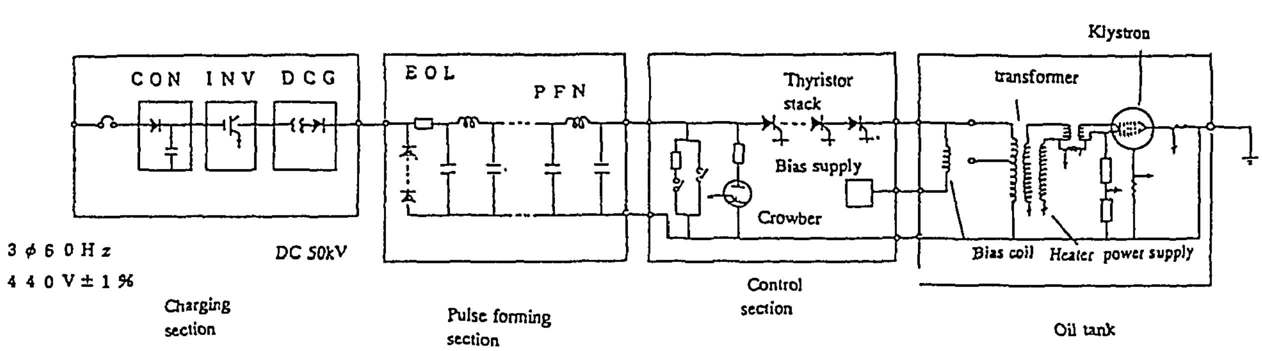

Fig. 2 The block diagram of S-band klystron modulator

5. RF test results

The klystron E3729, the modulator, the driver amplifier and two RF dummy loads for E3729 were combined to test their performance. The klystron had been conditioned on the short pulse operation (4 μs-70MW) at the Nasu works of Toshiba Co. We need conditioning of the klystron for the long pulse operation. Then we studied the optimum focusing magnetic field to operate it stably and efficiently. The reason is the instability in the late part of the output RF wave form was found in the long pulse operation at a focusing magnetic field even if it is stable in the short pulse operation.

Table 2 shows the achieved maximum output powers at these modes. these were calculated from the temperature rise of RF dummys' water.

Table 2 Achieved maximum output power of E3729

Mode	*1*	*2*	*3*
Pulse width(μs)	*24*	*12.5*	*0.5*
Output power(MW)	*25*	*36*	*71*
Focus field(tap NO)	*4*	*4*	*5*
Magnet current(A)	*16.5*	*17.0*	*18.0*

Focusing field is stronger in the case of the tap NO.5 than that of the tap NO.4, and becomes stronger in both cases at more current. There happened some instabilities at the foucsing field of the tap NO.4 when input RF power is over saturated. So we use focusing field of the tap NO.5 at normal operation. The klystron needs more conditioning in the mode 1 for an RF output power over 20MW.

The output characteristics of the klystron are shown Fig. 3, and the characteristics between drive powers and output powers are shown in Fig. 4

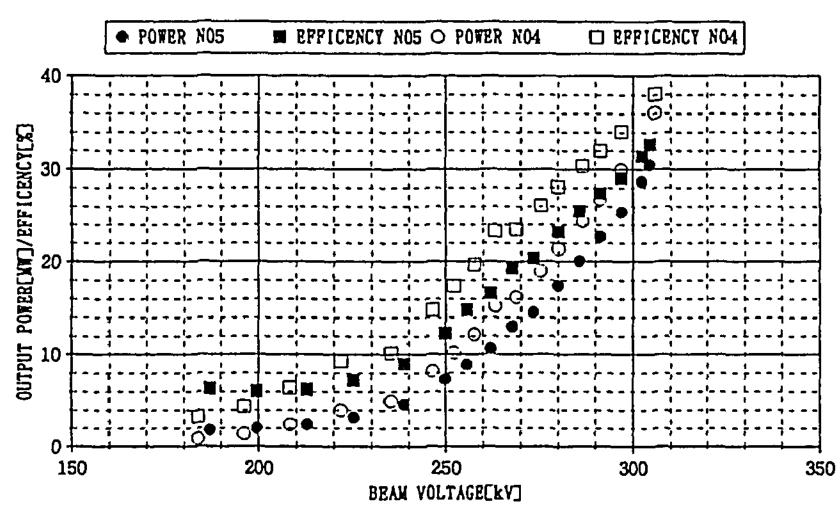

Fig. 3 Output characteristics in mode 2

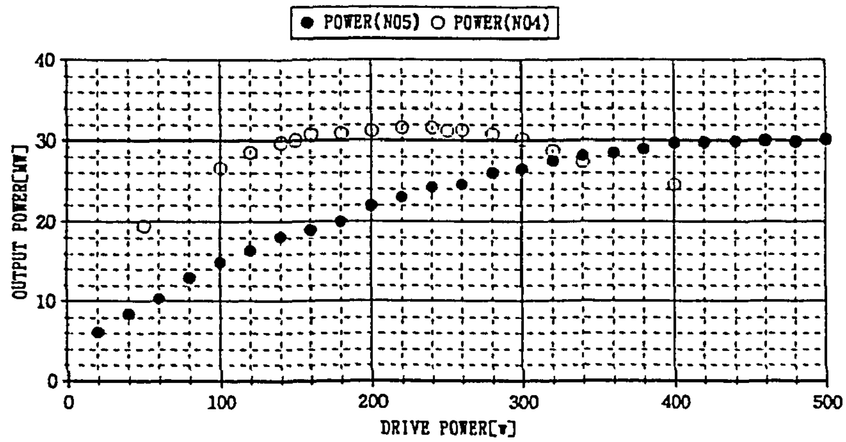

Fig. 4 Characteristics between drive power and output power

The pulse shape of the klystron cathode voltage is shown in Fig. 5.1, and the magnified wave form shown in Fig. 5.2 well demonstrates the flatness to be 0.1%p-p. However, we will try more pricise adjustment of PFN parameters to achieve the planned flatness of 0.08%p-p. The output RF wave form at the directional coupler is shown in Fig. 6. Though the magnified RF wave form is not shown, the flatness of 0.2%p-p was achieved.

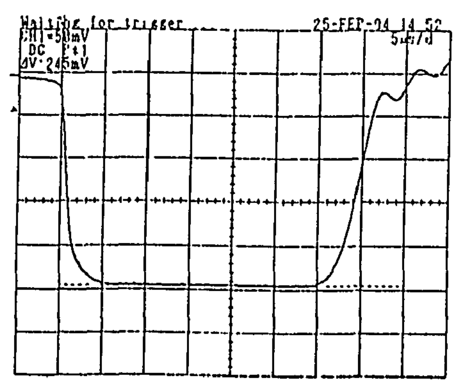

Fig. 5.1 The pulse shape of klystron cathode voltage in mode 1

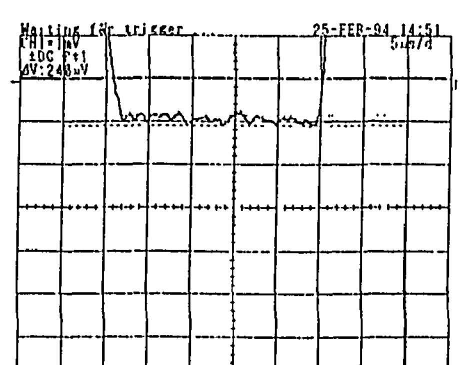

Fig. 5.2 Magnified wave form of cathode voltage. (flatness 0.1%)

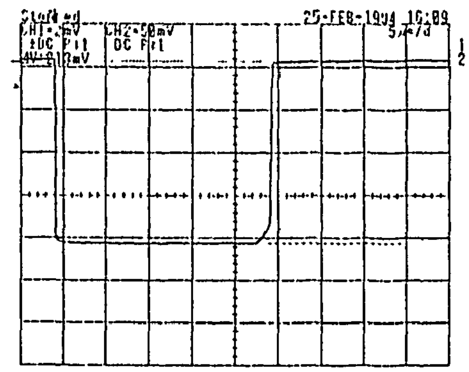

Fig. 6 Output RF wave form in mode 1

6. Conclusion

The RF system for FELI linac was constructed and the pulse shape and flatness of klystron cathode voltages were tested in each operation mode. The RF output and operation efficiency of the klystron were also measured with a calorimetric method, and our designed parameters of 24 μs–24MW, 12.5 μs–34MW, 0.5 μs–70MW were achieved. The wave form flatness of klystron cathode voltages was 0.1%. Furthermore, we will try to adjust the PFN parameters to achieve better flatness.

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