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Development of Long Pulse, High-Flatness Pulse Modulator for an S-band Klystron

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Abstract

Two infrared free electron lasers (FELs) of the FELI are operating using an S-band 80-MeV linac with a thermionic gun and a 165-MeV linac and UV-FEL facility are in the commissioning stage. Since an RF system for linac-based FELs is required of long pulse duration and high quality, improved pulse klystrons (Toshiba E3729) have been operated in 24-MW, 24-μs pulse mode for the FELI linac. Our klystron modulator developed by the FELI and NISSIN Electric Corp. has an inverter-converter charging system. The line switch is consisted of 30 light triggered thyristors (Toshiba SL1500GX22). A saturable reactor is used in series to protect 30 thyristors from overvoltage caused by a delay of thyristor's turn-on time. The flatness of modulator pulses is 0.08%$_{P-P}$ at 24-MW, 24-μs pulse operation. The 24-μs stable RF pulses can increase a conversion efficiency from electron beam power to FEL power for IR- and UV-FELs.

1. Introduction

The FELI is now operating two IR-FELs using an 80-MeV linac with a thermionic gun and is testing a 165-MeV linac and an UV-FEL facility. It is essentially necessary for linac-based FELs using pulsed rf sources to get a stable and long rf pulse from a klystron. A stable and long rf pulse sources enables to yield a stable and saturated FEL pulse source. The FELIX group has succeeded in keeping a pulsed rf source stable to accelerate a 22.5-MeV, 10-μs beam with an energy spread of 0.5% [1]. For this purpose, we have developed a 24-MW, 24-μs pulse modulator for an S-band klystron (Toshiba E3729) at three operation modes shown in Table 1. Mode 1 and Mode 2 are for FEL generation and Mode 3 is for injection to a storage ring.

2. Klystron Modulator

Figure 1 shows the circuit diagram of the klystron modulator. This modulator is consisted of the charging

Table 1 Parameters of Klystron Modulator

Mode	Mode 1	Mode 2	Mode 3
Output voltage(kV)	285	304	390
Output current(A)	280	305	477
Pulse width(μs)	24	12.5	0.5
Flat-top (P-P) (%)	0.08	0.08	1.5
Stability (%)	0.08	0.08	1.5
Repetition(pps)	10	10	10
Rise time(μs)	2	2	2
Fall time(μs)	3	3	3.5

*Rise and fall time is measured from 10-90% of the output pulse.

section using the converter-inverter, the pulse forming network(PFN) section, the main switch section using light triggered thyristors, and the mounting tank for the klystron to supply high voltage by a pulse transformer. The output voltage is measured at the secondary side of the pulse transformer by a capacitive divider. Details of these sections are as follows.

(1) Charging Section

We use a converter-inverter charging circuit instead of IVR~De-Qing one, because De-Qing one has the following problems.

i) A charging voltage of the PFN involves about 0.2% fluctuation due to an input voltage.

ii) Pulse repetition rate is low (10pps). Therefore, the scale of charging section becomes bigger due to a large time of constant at resonant charging.

Therefore, our inverter is consisted of 5 cascades at 15kHz and we have acheived a high stability within $\pm 1 \times 10^{-4}$ of charging voltage.

(2) Pulse Forming Section

The output pulse width of the PFN are 24μs, 12.5 μs and 0.5μs at mode 1, 2 and 3, respectively. Each reactor of the PFN is adjustable by means of a remote control system using a motor driving plunger. The minimum adjustable amout of the PFN reactor is 0.005% and the maximum adjustable span is 45%.

Converter Inverter DCG EOL PFN Earthing Saturable Pulse Klystron
Clipper (Pulse forming Network) Switch Reactor Transformer

Light triggered
thyristor

Crowbar
Switch

Charging section Pulse forming section Main switch section Klystron mounting tank
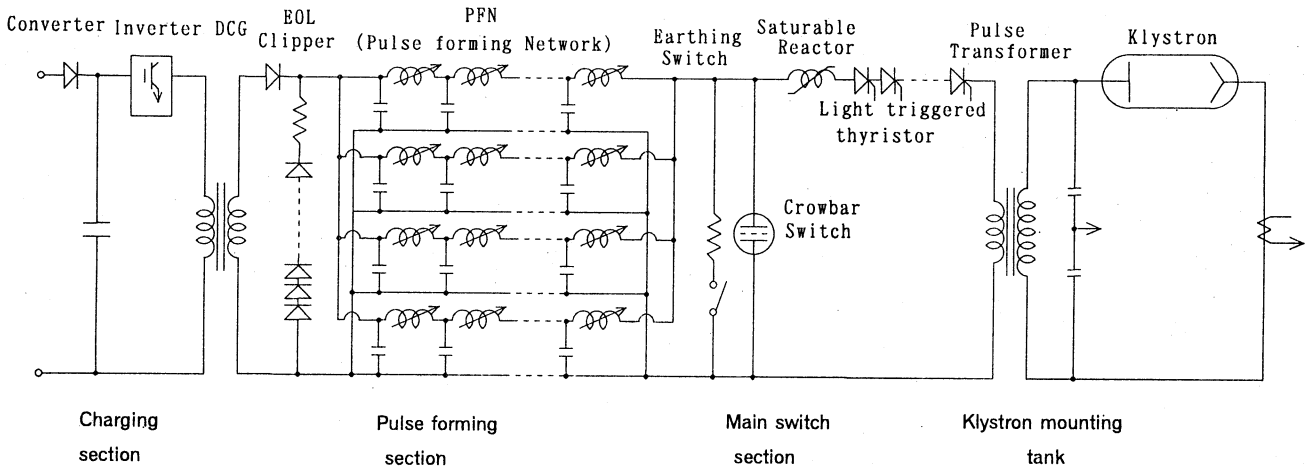
Fig. 1 Circuit diagram of klystron modulator

Therefore, the adjustment of output waveform has been easily performed, and a 0.08% flat-top of output pulse waveform has been achieved. If the klystron has break down during a high voltage is applied, the PFN capacitors suffer from large reverse voltage. To reduce this damage, an EOL (End of line) clipper circuit is set and the reliability of the modulator is improved.

(3) Main Switch Section

We have used the light triggered thyristor(Toshiba SL1500GX22, 30series) stack as the main switch for keeping the output voltage stable. Generally speaking, a thyratron is suitable for switching of high voltage and large current. But in this case, the thyratron is not suitable because a change of its resistance become large during the conduction time, if the pressure in the tube changes. Therefore, we decided not to use the thyratron in order to achieve the 0.08% stability.

However, in order to use the light triggered thyristors, we had to solve the following problems.

i) The value of dI/dt is more ten times ($\sim$3000A/μs) than the thyristor's specification.

ii) It is necessary to trigger 30 thyristors simultaneously as a switch.

Before adopting the light triggered thyristor, we have tested dI/dt of the same device. The results was that the thyristor was breaked down at about 1700A/μs. The damage occured at the only part of near the center gate. The reason is that the light triggered thyristor could not have the conduction space by the high dI/dt.

Therefore, we have set a saturable reactor in series with the light triggered thyristors to secure the conduction space before large and high dI/dt main current follows and to keep a counter-measure to a delay of each thyristor's turn on. The use of the saturable reactor enables us its running under a hard

condition of dI/dt $\sim$3000A/μs. On the other hand, the use of the light triggered thyristors makes it is easy to insultate the gate drive circuit and to withstand to a high reverse voltage.

3. Performance

(1) Light Triggered Thyristors

Figure 2 shows the time response of the resistance of light triggered thyristors at the mode 1. After the main current reached the peak, the resistance is about 0.6–0.3Ω/30devices, that is, 20mΩ–10mΩ/1 device. The resistance at the whole conduction is about 0.5 mΩ(at 4kA). Therefore, the conduction space of this thyristor is about 1/40–1/20 of the whole conduction at the mode 1. Though we have already tried 4 x 10^7 shots under this condition, there are no any troubles at all.
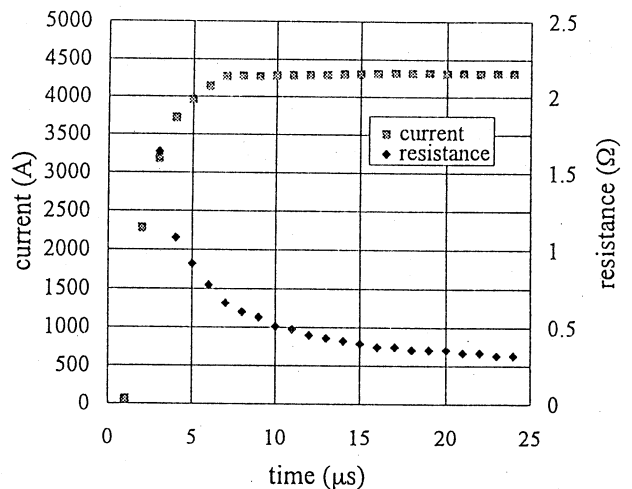
Fig. 2 Time dependence of the resisitance of light triggered thyristor

It is easily understood from Fig. 2 that the resistance of the light triggered thyristor decreases in micro–second order, so we can adjust the waveform so as to cancel this effect.

(2) Klystron Modulator and Klystron

Table 2 shows the characteristics of the output at three modes and Figs. 3 and 4 show the waveforms of the output voltage at the mode 1.

Table 2   Performance of Klystron Modulator and Klystron E3729

Mode	Mode 1	Mode 2	Mode 3
Output voltage(kV)	285	304	390
Output current(A)	280	305	477
Pulse width(μs)	23.2	12.0	0.5
Flat–top (P–P) (%)	0.08	0.08	0.3
Stability (%)	0.07	0.06	0.15
Repetition(pps)	10	10	10
Rise time(μs)	2.0	2.5	2.0
Fall time(μs)	4.5	6.5	6.4
RF output(MW) from E3729	24	34	70

*Rise and fall time is measured from 10–90% of the output pulse.

The rise time of the output is about 2-3μs. This shows that the light triggered thyristors can withstand for the rise of 2-3μs because of the effect of saturable reactor. Fig. 4 shows the flatness of the modulator pulse is kept within 0.08%P-P at 24-MW, 24-μs pulse operation

(3) Modulator Pulse and 24-μs rf Pulse

Figure 5 shows the waveforms of the modulator current pulse and 24-μs rf pulse. Tiny ripples seen on the waveforms are due to white noise of the sampling oscilloscope (TDS460–Tecktronics).

4. Conclusions

We have succeeded in the development of the long pusle (24μs), and high–flatness (0.08%) klystron modulator using the light triggered thyristor as a main switch and the remote controll systems for variable reactors of the PFN. This modulator have contributed needless to say much to the FEl oscillations[2].

References

[1] D. A. Jaroszynski, et al., Nucl. Instr. Meth., A331, (1993) 52

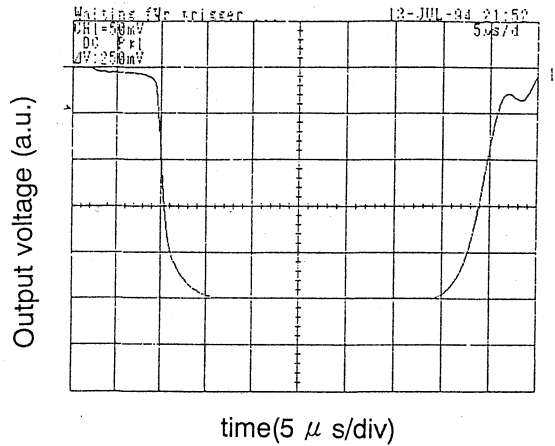[2] T. Tomimasu, et al., Proc. PAC'95 (DALLAS, May 1-5, 1995) FAA30
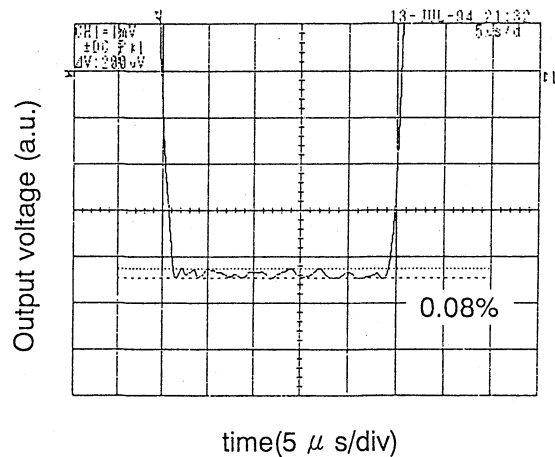
Fig. 3   Waveform of output voltage at the Mode 1

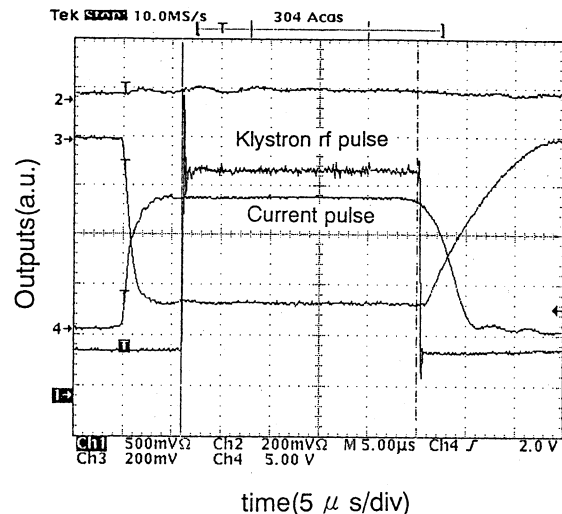Fig. 4   Expanded view of top part of the waveform shown in Fig. 3

Fig. 5   Modulator pulse and 24-μs rf pulse