PULSE MODULATOR FOR 85 MW KLYSTRON IN ATF LINAC

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Abstract

Three compact pulse modulators have been designed and constructed to drive 85 MW klystrons (TOSHIBA E3712) for 1.54 GeV ATF linac. They are conventional line type modulators consisting of two parallel pulse forming networks (PFNs) with 14 sections. The PFNs are charged in a command resonant charging mode by a 25 kV common dc power supply. The charging voltage of the PFNs is controlled with an accuracy of ±0.1% by a new type of loss-free de-Qing system connected in parallel to a charging transformer. This de-Qing system can save approximately 5 % of wall plug power. A compact self-healing type of capacitor with a long lifetime has been developed to obtain compact PFN. The design, specifications and results of performance tests of the modulators are described in this paper.

Introduction

Accelerator Test Facility (ATF) is now under construction to develop the major accelerator components of Japan Linear Collider (JLC).[1] The ATF consists of a 1.54 GeV S-band linear accelerator and a 1.54 GeV damping ring. The ATF linac is a high gradient accelerator and its regular accelerator unit consists of an 85 MW klystron with a two-iris SLED, a 200 MW pulse modulator and two 3m-long accelerating structures. This unit allows to achieve a maximum gradient of 52 MV/m.[2] The R&D of the 200 MW pulse modulator has been carried out since 1987 and is still continuing. The major goals of the modulator are reasonably compact size, low cost, high efficiency and high reliability. New three 200 MW line-type modulators have been constructed.

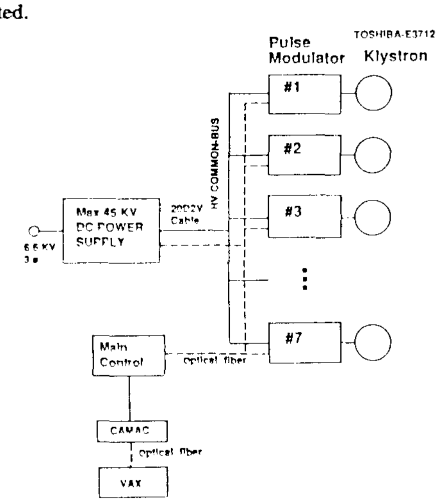

Figure 1. Pulse modulator system with HV common-bus.

Pulse modulator system with HV common-bus[3]

The ATF linac consists of 11 pulse modulators. Seven pulse modulators of them are a modulator system with High-Voltage common-bus as shown in Figure 1. This system consists of 7 pulse modulators and one 25 kV dc power supply capable of driving 7 modulators. This system makes it possible to reduce both the cost for the dc power supply, and the size for the pulse modulator. Four pulse modulators have already been installed and used to operate four E3712 klystrons. New three compact pulse modulators have been connected to this system.

E3712 klystron

TOSHIBA E3712 klystron is an S-band high power klystron tube developed for JLC.[4] The klystron can produce a peak output power of 100 MW at an rf pulse width of 1μs in a short pulse operating mode, and a peak output power of 85 MW at an rf pulse width of 4.5μs in a long pulse operating mode. The klystron is operated by the long pulse operating mode for a pulse compression technique with a two-iris SLED. Table 1 shows the specifications of E3712 klystron.

TABLE 1
Specifications of E3712 klystron

Peak rf power	85 MW
RF pulse width	4.5 μs
Beam voltage	397 kV
Beam current	485 A
Efficiency	44 %
Gain	55 dB
Pulse repetition rate	50 pps
Frequency	2856 MHz

New pulse modulator

The pulse modulator consists of a command resonant charging unit with a loss-free de-Qing circuit, a discharge unit with PFNs and a thyratron, and a pulse transformer as shown in Figure 2. Table 2 shows the specifications of the pulse modulator. As shown in Figure 3, components in the modulator cabinet have been arranged in consideration of compact size and easy maintenance. The cabinet separates into two parts. The command resonant charging unit is installed on the left side and the discharge unit on the right side. The size of the cabinet is 2.5m wide x 1.5m deep x 2.2m high. The details are described in the following subsections.

TABLE 2
Specifications of the pulse modulator

Peak power output	193 MW
Average power output	79 kW
Transformer ratio	1:16
Output pulse voltage	24.8 kV
Output pulse current	7776 A
Output impedance(PFN)	3.0 Ω
Flat top width	4.5 μs
Rise time	0.8 μs
Pulse width	7.5 μs
Flatness	±0.5%
Repetition rate	50 pps

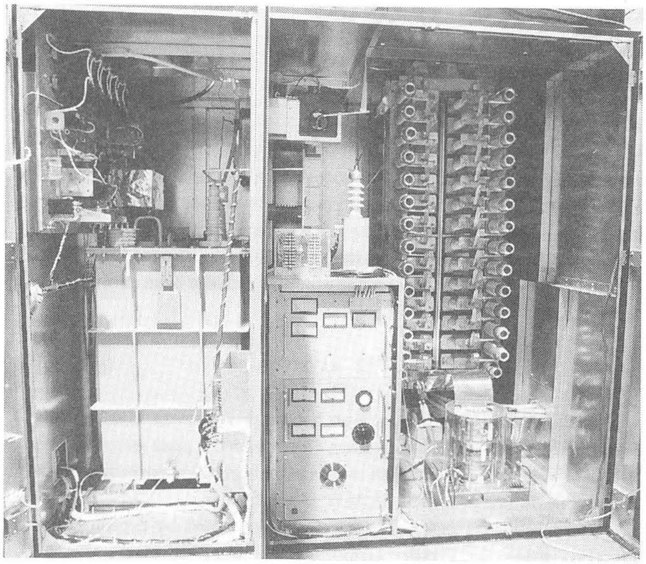

Figure 3. Front view of the pulse modulator.

Command resonant charging system

The command resonant charging system consists of a charging transformer with a 1:12 secondary winding for de-Qing, a command charging SCR switch and a de-spiking circuit. This system is used to ensure that a thyratron switch tube has enough time to recover, and to stop the next charging cycle in the event of a thyratron or klystron fault after charging PFNs. The charging time was chosen to be 10 ms which is half of the repetition period. Therefore, the primary inductance of the charging transformer is 8.5 H. The thyratron is triggered after 15 ms from command charging trigger, so that a recovery time of 5 ms is available for the thyratron.

In order to achieve high efficiency and a high degree of regulation in the command resonant charging system, a new type of loss-free de-Qing system has been developed.[5] It consists of the secondary of the charging transformer, a de-Qing SCR switch, an energy storage capacitor and an auxiliary dc power supply. The PFNs are charged by the dc power supply which consists of high-voltage main and low-voltage auxiliary dc power supplies in series. At the moment of de-Qing, the energy stored in the charging transformer is absorbed into the energy storage capacitor and returned to the auxiliary dc power supply.

In order to make a compact charging unit, the charging transformer, command charging SCR switch, de-spiking circuit and ground switch are housed in the same oil tank.

Pulse forming network

The pulse forming network is made up of two parallel PFNs. Each PFN consists of 14 sections with fixed capacitors and tunable inductors. A nominal characteristic impedance of the PFN is 6 Ω. The full charging voltage of the PFN is 50 kV. Approximately 5% positive mismatch was designed at full voltage. Two types of capacitor were used as PFN capacitors. One is Marcon No-healing (NH) type of capacitor, the other is Nichicon Self-healing (SH) type of capacitor. Each capacitor is bushing style, metal box and 45nF, and was designed for an operational lifetime of 88,000 hours at 50 pps. The end of line clipper (EOLC) circuit is made up of a series combination of diodes and 5 Ω ceramic resistors.

Thyratron

ITT F-331 or EEV CX1536A thyratron has been used as the switch tube which discharges the PFNs. Forced air cooling is used for the thyratron.

Tail clipper circuit

The backswing voltage on the klystron tube is produced by the pulse transformer. In particular, when the conducting time of the thyratron is shorter, a higher peak voltage of backswing occurs and gives damage for a klystron tube. In order to protect the klystron tube, the clipper circuit was added at the primary of the pulse transformer.

PFN capacitor R&D

A SH type of capacitor has been developed to reduce the size of PFN capacitor, and to improve its electrical performance. The case volume V of capacitor is given by an equation

$$V = \frac{2W}{\varepsilon \cdot \eta \cdot E^2} ,$$

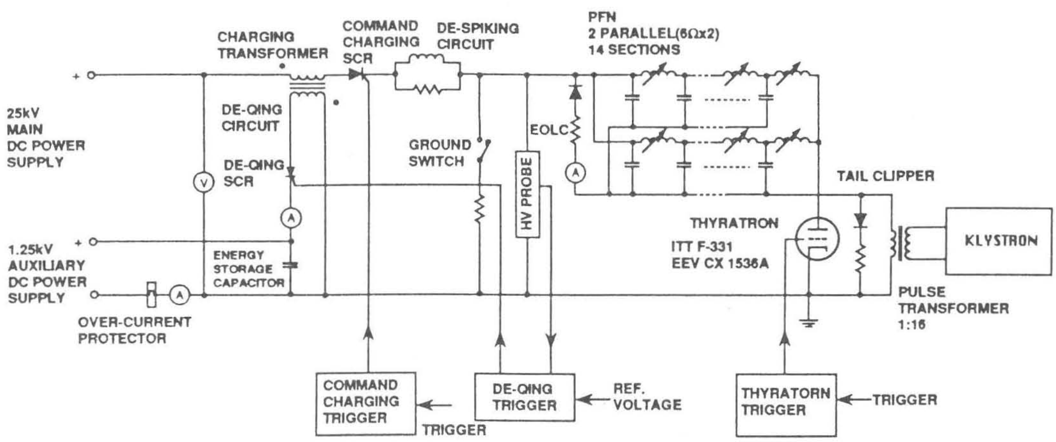

Figure 2. Simplified circuit diagram of the pulse modulator.

where W is stored energy, ε is dielectric constant, η is the ratio of dielectric volume to case volume, and E is field strength. Therefore, the case volume of capacitor is inversely proportional to square field strength. In other words, the most effective parameter for reducing the size of capacitor is to increase the field strength of the dielectric. A maximum electric field of conventional NH type of capacitor is ~60V/μm for a lifetime of 88,000 hours at 50 pps. The metallized film capacitor with unique clearing or self healing properties makes it possible to increase the field strength of the dielectric. In our case, polyethylene terephtalate and polypropylene films were used as the dielectric material, and the latter film was coated with thin Zn-electrodes (300Å in thickness) which form a series of microscopic capacitors. The maximum electric field was estimated by an accelerated life test to be ~120 V/μm for a lifetime of 88,000 hours at 50 pps. As a result, the case size of SH type capacitor (Capacitance: 0.045 μF, Rating voltage: 55 kVDC, Test voltage: 60 kVDC) is 240 mm wide x 90 mm deep x 162 mm high. Its energy density (W/V) is 19.4 kJ/m^3 which is more than twice the conventional NH type of capacitor.

Performance Tests

A preliminary test of the pulse modulator connected to a water dummy load[6] was started and some data have been obtained.

Command Resonant Charging Waveforms

Figure 4 shows an example of the PFN charging voltage and current waveforms. In this case, the modulator was operated at a repetition rate of 50pps and a de-Qing of 3.2%.

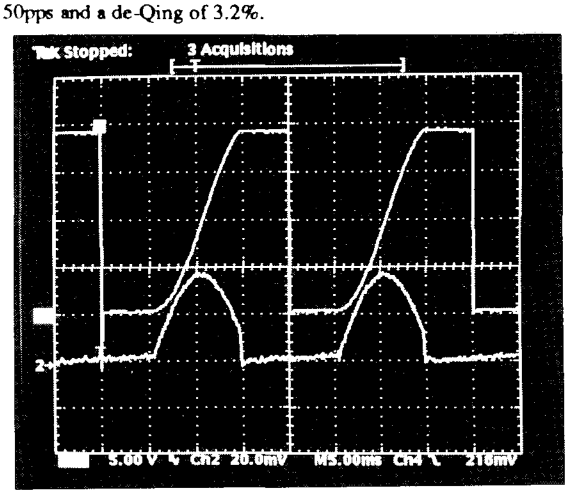

Figure 4. Charging waveforms of PFN.
Horizontal: 5ms/div
Upper trace: Charging voltage (10kV/div)
Lower trace: Charging current (4A/div)

Output Pulse Waveforms

After adjusting the PFN inductors, the output voltage and current waveforms were measured by an Iwatsu's high-voltage probe (model HV-P60) and a Pearson's current transformer (model 301X), respectively. An example of output waveforms was shown in Figure 5. In this case, the modulator was operated at a repetition rate of 50pps and a PFN charging voltage of 51.8kV. Pulses with a peak voltage of 24.0kV, a peak current of 8.5kA, a width of 7.8μs(FWHM), a flat-top width of 4.5μs within ±0.25% and a rise time of 0.35μs(10-90%) were successfully generated.

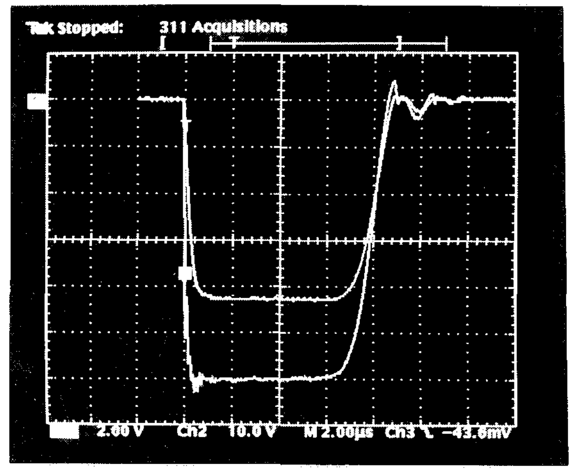

Figure 5. Output pulse waveforms at the dummy load(2.8 Ω).
Horizontal: 2μs/div
Upper trace: Output current (2kA/div)
Lower trace: Output voltage (4kV/div)

Conclusions

Compact pulse modulators using an SCR command resonant charging system with a loss-free de-Qing circuit have been developed for the ATF. New SH type of capacitor enables us to realize compact PFN. In the test operation of the modulator using a dummy load, 7.8μs wide (FWHM) pulses with a peak voltage of 24.0kV, a peak current of 8.5 kA, and a rise time of 0.35μs(10-90%) were successfully generated.

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