DEVELOPMENT OF 700 PPS HIGH-DUTY-CYCLE LINE-TYPE PULSE MODULATOR

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Abstract

High-duty-cycle line-type pulse modulator has been developed to drive 5.5 MW S-band klystron at 700 pps maximum repetition-rate and 14 μsec flat-top pulse-width. To keep enough recovery time to thyratron-tube, the command charging scheme was adopted. To do this, a charging SCR-bank has been developed, which is capable of handling peak charging current of 50 A. The system achieved world wide highest average output-power of 205 kW.

Two modulators have been installed in a new high-duty-cycle electron linear accelerator, which has been started its business operation in March 1996 as an electron-beam-sterilization facility.

Introduction

The electron beam sterilization facility needs very high-duty-cycle beam of energy around 10 MeV. For this purpose, a high-duty-cycle electron linear accelerator was designed, which requested to develop a new modulator to drive S-band klystron at 5.5 MW peak rf-output power, 14 μsec flat-top pulse-length and 700 pps repetition rate. The overall specifications related to the modulator are listed in Table 1.

To develop high-duty-cycle modulator, how to design the switching circuits is critical. In this paper, choice of switching device, understanding its proper usage and design of damage protection circuit will be described.

System Description

Figure 1 shows the system diagram of the modulator and Fig. 2 shows outlook of installed modulator in the electron beam sterilization facility. The system is basically a conventional line-type modulator, except its unique design on charging block using SCRs. Design details are described below.

Table 1
Overall specifications of the modulator

Klystron beam voltage [kV]	140
Klystron beam current [A]	108
Electron Injector Gun	
voltage [kV]	150
current [A]	0.7
Modulator peak output power [MW]	15.1
Pulse width [μs] for flat top	14
–3 dB	19.2
Pulse stability and flatness [%]	±0.7
Pulse rise time [μs]	2.5
Pulse repetition rate [pps]	60–700
Maximum average output power [kW]	205

Fig. 2 The modulator installed in the electron beam sterilization facility.

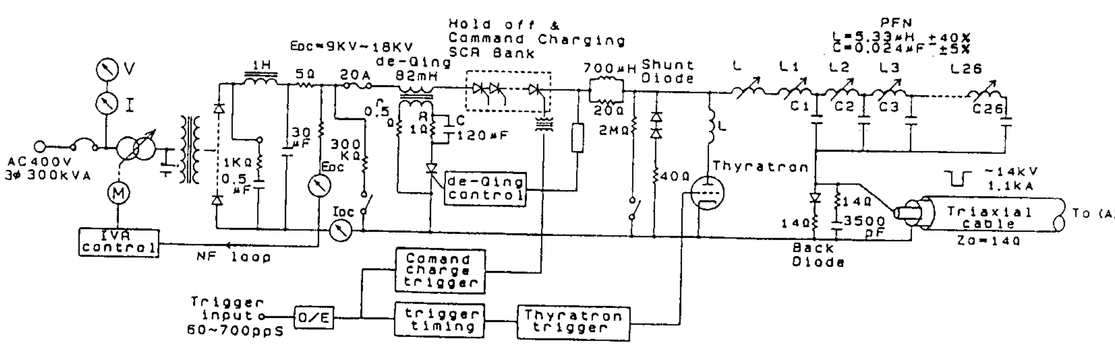

Fig. 1. Block diagram of the modulator.

Table 2
Thyratron switching parameters

	Operation	Rated max. CX-1720MN
Peak anode forward	33	50
voltage [kV]	108	5000
Peak anode current [A]	0	25
Average anode current [A]	14.4	25
Recovery time [μsec]	–	

Command Charging System

When we use a thyratron-tube at very high repetition-rate, it is very important to keep enough recovery time before starting the successive charging process after the PFN discharge, otherwise the thyratron will start to continuously discharge. The conventional 'swing-charge method' can not be applied, since the time-constant of the swing becomes shorter in high-repetition modulator, thus the thyratron voltage can reach to a few hundred volt within the recovery time of 25 μsec, resulting in continuos discharge.

To solve this problem, we adopted a command charging system, which operates in a time-sequence as shown in Fig. 3. Switching the thyratron and discharging PFN capacitors, the next charging process is started by triggering the charging SCR by command after waiting-time, during this period the thyratron can be recovered perfectly. At the maximum repetition rate, the waiting time becomes minimum of 510 μsec, which is much longer than the required recovery-time to the thyratron. By varying the length of the waiting-time, repetition rate can be changed for wide range of 60 to 700 pps.

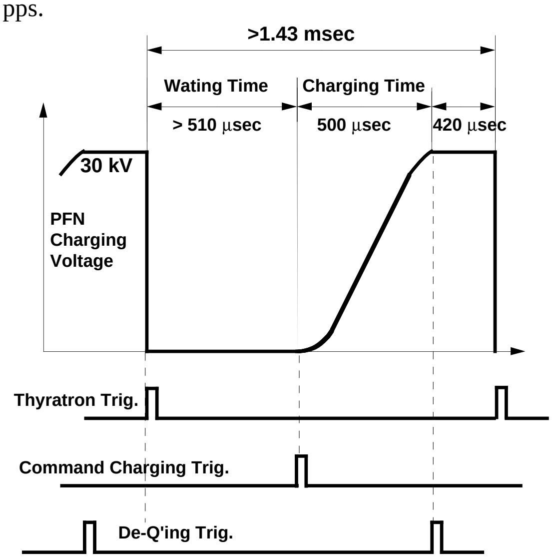

Fig. 3 Timing chart.

Design of Command Charging Block

The operating parameter of the command-charging-SCR-bank is listed in Table 3.

Table 3
Parameter of charging system

PFN charging voltage [kV]	33
Charging peak current [A]	50
rms current [A]	30
average current [A]	16

Choice of SCR

We chose Toshiba SH400EX29C for switching SCR, since it has one of the highest rated voltage among high speed switching SCRs except expensive optical-switching SCRs. To ensure reliable operation, we designed the operating voltage much lower the maximum rated voltage. We use total number of 30 SCRs in series, thus the sum of the maximum rated voltage becomes 75 kV, which is 2.5 times higher than the operating voltage.

Trigger Circuit

Figure 4 shows the trigger circuit of one SCR-module, each module consists of six SCRs in a series. We use five SCR-modules in a series connection. Triggering signal is distributed via isolation pulse transformer into the six SCRs.

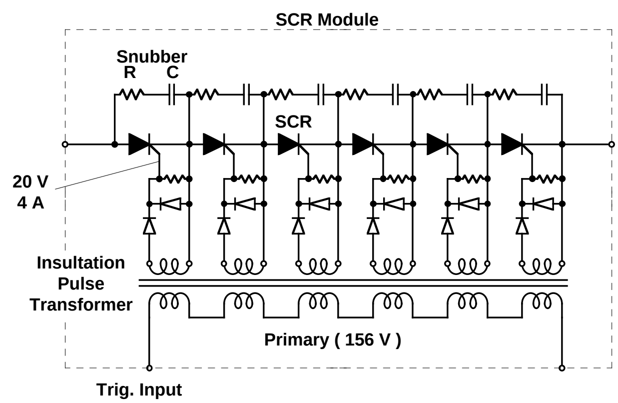

Fig. 4 Trigger circuit for SCR module.

Protection Circuit for SCR

In order to protect the SCRs from excessive over-voltage due to different turn-on time between SCRs, series RC snubber circuits were connected in parallel to the SCRs as seen in Fig. 4, which compensates the voltage differences between SCRs. The RC parameters were optimized by computer simulations as not to generate over reaction voltage associated with PFN discharge [1].

Low Noise Design

In order to eliminate unwanted EM-noise radiation, it is very important to make low-impedance return-circuit to transfer the very high rush-current of wide frequency components associated with PFN discharge. In our design, a sheet copper of 365 mm width and 0.1 mm thickness was used to form a ground circuit, which runs through the charging circuit, the PFN, the thyratron, end-terminal of the tri-coaxial cable, the pulse-transformer tank and the klystron. In high power operation, we do not see a noise ripple nor a jitter at any monitor signal on an oscilloscope.

High Power Test

We tested high power performances of the completed modulator connecting to an S-band klystron. Figure 5 shows the voltage waveforms at the klystron cathode at the design voltage of 142 kV, and the generated rf output power from the klystron at the designed output power of 5.5 MW and repetition of 700 pps. Ripple in the flat top was 1.6 kVpp (±0.6%) which is within the requested value. Figure 6 shows current trances in de-Q'ing circuit, they show designed waveform without any excessive rush currents. Figure 7 shows the charging patterns in PFN circuit and de-Q'ing trigger. Every waveforms showed expected design performances.

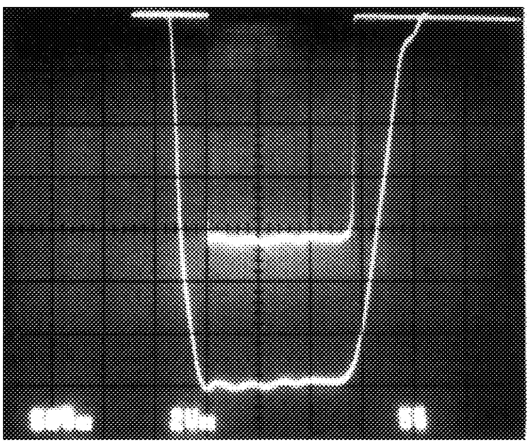

Fig. 5 Channel 1 (top): Rf output power, 5.5 MW peak. Channel 2 (bottom): Klystron beam voltage, 140 kV peak.
Ch. 1= 50 mV/div, Ch. 2= 20 kV/div, Time Base = 5 μs/div.

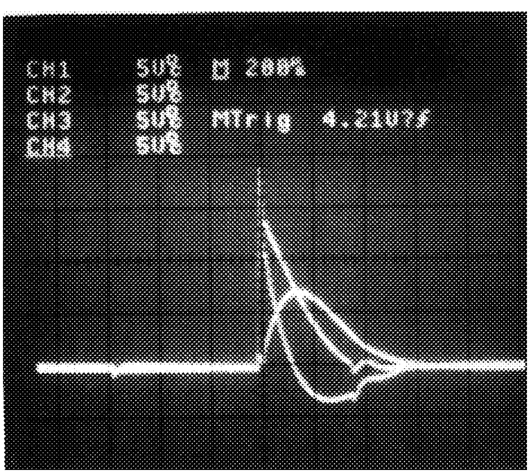

Fig. 6 Waveforms in de-Q'ing circuit.
Channel 1 (top): de-Q'ing current on resistor, 300 A peak.
Channel 2 (middle): total de-Q'ing current, 800 A peak.
Channel 3(bottom): de-Q'ing current on capacitor, 800A peak.
Ch. 1, Ch. 2, Ch. 3 = 200A/div, Time Base = 200 μs/div.

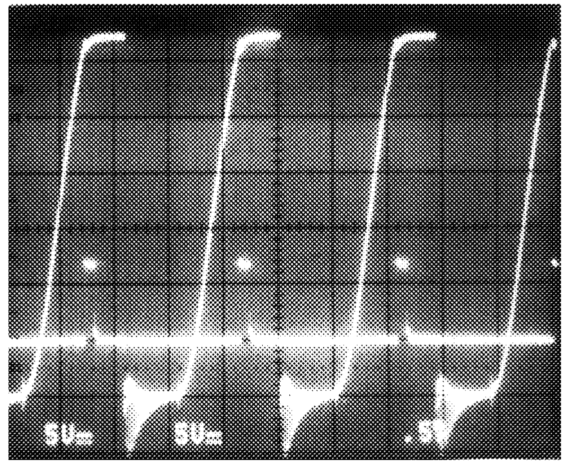

Fig. 7 Charging cycle on PFN capacitor.
Channel 1 (up): PFN charging voltage, 33 kV peak.
Channel 2 (down): de-Q'ing trigger.
Ch. 1= 5 kV/div, Ch. 2= 5 kV/div, Time Base = 500 μs/div.

Conclusions

We have succeeded in developing a high-duty-cycle line-type modulator, which can handle the world-wide highest average output power of 205 kW at 700 pps repetition rate. Two modulators have been installed in the S-band electron linacs, which has been constructed for a dedicated use of 'electron beam sterilization' and started its business operation at March 1996.

Acknowledgment

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References

[1] Details of the optimization work will be published in separated paper soon.