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KLYSTRON MODULATORS WITH HV COMMON-BUS FOR THE JLC

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Abstract

The Klystron Modulators with HV common-bus for the JLC (Japan Linear Collider) have been designed and constructed. The system consists of two modulators with a 10 or 18 section pulse forming network and a 45 kV DC power supply capable of driving 8 modulators. The modulators are operated for SLAC-5045 or TOSHIBA-E3712 klystrons at a maximum pulse repetition rate of 50 pulses/sec and the following two modes; 1) 67 MW in a pulse duration of 7.0 µs with a flat top of 4.5 µs and 2) 100 MW in a pulse duration of 3.5 µs with a flat top of 1.0 µs. The design, specifications and results of performance tests of the system are described in this paper.

Introduction

A TeV electron-positron linear Collider JLC (Japan Linear Collider) has been proposed in KEK[1]. It requires the S-band linacs as 1.54 GeV damping ring injectors[2], 4 GeV electron and positron pre-accelerators for the bunch length compression and 10-30 GeV electron linac for a positron production. The rf system of these linacs requires several hundred klystrons with a peak power of 100 MW at a frequency of 2856 MHz. Therefore, also a large number of klystron modulators are necessary. It is crucial to develop klystron modulators with a small size by a low-cost. A modulator system of that a large power supply provides dc to many modulators with HV common-bus is one of the suitable methods to reduce a cost and size. In order to study this type of modulator system, we have designed and constructed the system which consists of two modulators with a pulse forming network (PFN) and a high voltage dc power supply which can provide dc to 8 modulators, in the Accelerator Test Facility (ATF)[1] for the JLC.

Design and modulator specifications

SLAC-5045[3] and TOSHIBA-E3712[4] klystrons are used as the S-band RF sources of ATF. SLAC-5045 klystrons used at SLC are operated at 67 MW peak power in 4.5 µs flat topped pulse duration. The peak power can be increased up to 100 MW peak power if the pulse duration is decreased to 1 µs. TOSHIBA-E3712 klystrons can produce the peak power of 100 MW at 1 µs. Table 1 shows the specifications of E3712 klystron.

Table 1. Specifications of E3712 klystron

Operation mode	Long Pulse	Short pulse
Peak RF power	80 MW	100 MW
RF pulse width	4.0 µs	1.0 µs
Beam voltage	375 kV	450 kV
Beam current	460 A	604 A
Peak beam power	173 MW	272 MW
Efficiency	46 %	39 %
Perveance	2.0 $\mu AV^{-3/2}$	2.0 $\mu AV^{-3/2}$
Average beam power	56 kW	48 kW
Repetition rates	50 pps	50 pps
Drive RF power	300 W	375 W
Gain	54.3 dB	54.3 dB
Frequency	2856 MHz	2856 MHz

These klystrons are operated at the following two modes; (1) 67 MW in a pulse duration of 7.0 µs with a flat top of 4.5 µs (long pulse mode for a RF pulse compression), (2) 100 MW in a pulse duration of 3.5 µs with a flat top of 1.0 µs (short pulse mode). The klystron modulators with HV common-bus consist of two modulators with a 18 section pulse forming network (PFN) and a 45 kV DC power supply capable of driving 8 modulators as shown in Fig. 1. Two klystron modulators are provided with power by means of 20D cables from a dc power supply. These modulators connected with HV common-bus receive the same voltage. Each modulator is of a line-type with a 18 section PFN. Regulation of the output pulse voltage is performed by the de-Qing circuit which controls the charging voltage of the PFN. Its output pulse voltage is stepped up to 15 times by a pulse transformer. The power supply and klystron modulators are remotely controlled from the main control room. The details are described in the following sections. Specifications of the modulator are listed in Table 2.

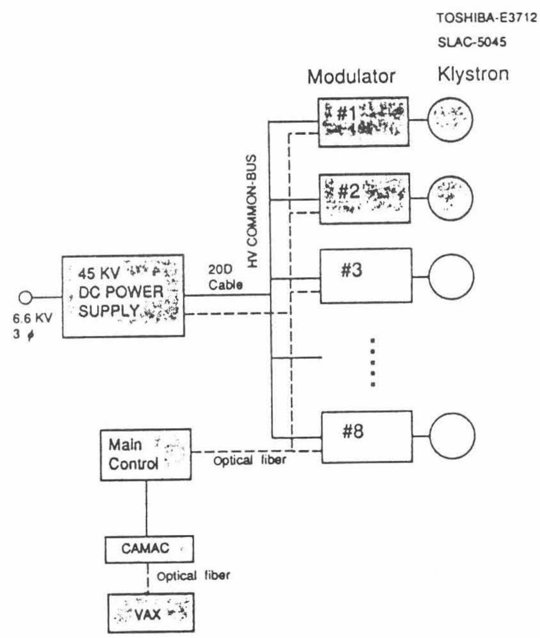

Fig. 1. Klystron modulators with HV common-bus
Modulators #3~#8 will be constructed in near future.

Table 2. Specifications of the modulator

Operation mode	Long Pulse (80MW)	Short Pulse (100 MW)
Peak power output	174 MW	272 MW
Average power output	60 kW	44 kW
Transformer ratio	1:15	1:15
Output pulse voltage	25.0 kV	29 kV
Output pulse current	6930 A	8625 A
Output impedance	3.6 Ω	3.4 Ω
Pulse flat top	4.5 µs	1.0 µs
Rise time	0.8 µs	0.8 µs
Pulse height deviation from flatness	1.0%(p-p)	1.0%(p-p)
Pulse amplitude drift		
Short term	<0.5 %	<0.5 %
Long term	<1.0 %	<1.0 %
Repetition rates	50 pps	50 pps

45 kV dc power supply

A simplified diagram of the dc power supply is shown in Fig. 2.

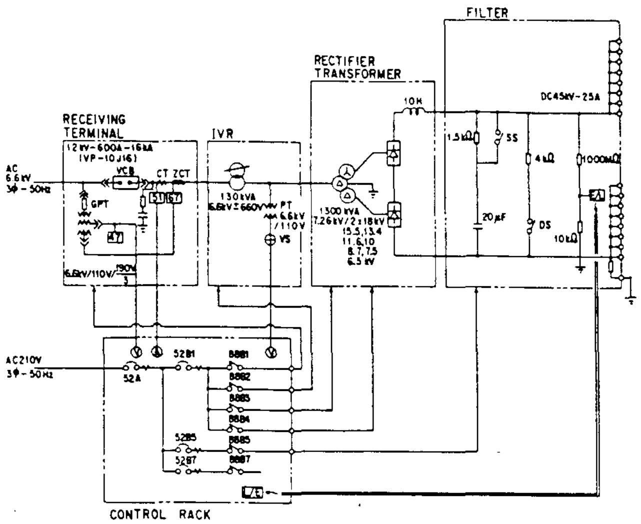

Fig. 2. A simplified diagram of the dc power supply

The line input is 6.6 kV ac, three-phase and 50 Hz and fed to receiving terminal board. A vacuum circuit breaker (VCB) is equipped to disconnect from the line for maintenance purpose as well as interlocks of over current and voltage of the common-bus. The VCB disconnects the line within one cycle of ac voltage (20 msec) when the interlock is worked. An induction voltage regulator (IVR) is used to regulate the ac line voltage in a range of ± 10%. The output voltage of the IVR is controlled with an accuracy of ± 1% by a feedback loop to the ac input line. The stepped-up ac is rectified to dc in 12-phase full wave scheme. The voltage level can be changed by selecting a primary tap of the rectifier transformer. The LC filter decreases the voltage ripple and determines the voltage drop due to the pulse load. A capacitance of 20 µF make this drop 7.5 % for the operation of two modulators. In order to reduce rush current in charging the capacitance, a limiter of 1.5 kΩ resister is prepared, which is by-passed after suitable charging time. A discharging-switch which is closed when the high voltage is off is installed as well as above mentioned limiter-switch in the filter cabinet. The specifications of the dc power supply are listed in table 3. The rectifier transformer, rectifier and choke are housed in the same oil tank.

Table 3. Specifications of 45 kV dc power supply

Rectification method	12 phase full-wave rectifier
Regulating range of IVR	± 10%
Maximum output voltage	45 kV
Maximum output current	25 A
Choice of rated output voltage	16,19,22,25,29,34,39,45 kV

Klystron modulator

The klystron modulator is composed of a charging unit with a de-Qing circuit and a discharging unit with the PFN, a trigger circuit, thyratron and an inverse-clipping shunt circuit as shown in Fig. 3. Each modulator connects with HV common-bus and receives the HV from the dc power supply through to 20D cables. The PFN capacitors are resonantly charged through a charging transformer. The inductance of the charging transformer was determined by the resonant charging frequency and total capacitance of the PFN (0.9 µF). The repetition rates is 50 pps and charging time is chosen to be 10 msec (half of the maximum repetition time). A de-Qing circuit in secondary of the charging transformer regulates the voltage applied to the PFN. A step down ratio of 25:1 was chosen to employ a silicon-controlled rectifier (SCR) switch. A simple series connection of the resistor and SCR switch was adopted. In this system, the common voltage is supplied to the modulators. The klystrons should be operated at different voltage to obtain the same rf power from each klystron since the perveance is slightly differnt. The regulation of the de-Qing circuit is chosen to be 15 % to realize the flexibility of adjustment of the klystron voltage.

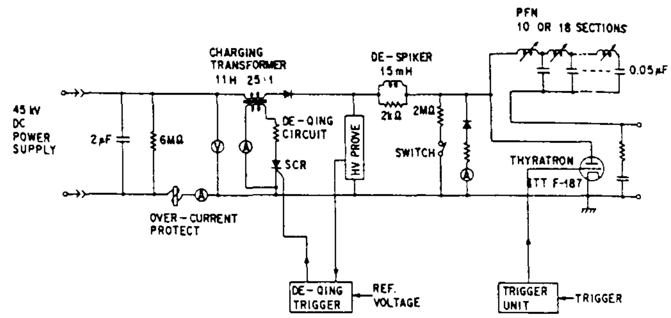

Fig. 3. A simplified diagram of the modulator

The PFN consists of 18 sections with fixed capacitors and tunable inductors. The capacitors are specified to be 0.05 µF and 70 kV operating voltage. The capacitors are composed by condenser paper, polypropylene film and aromatic hydrocarbon. As the inductance of each PFN coil is small, it is necessary to minimize the residual inductance of the capacitor. A special low inductance capacitor[5] was developed for the PFN. The residual inductance of each section is less than 100 nH. The tunable inductors are mounted on the capacitor's high voltage bushing stub. Fine adjustment is made by varying the insertion depth of an aluminum cylinder in the coil. The inductor consists of 7.5 turns of copper rectangular wire (2 mm X 45 mm) wound on the epoxy bobbin (97 mm diameter) of variable length with an aluminum insertion cylinder (89 mm diameter, 520 mm length). The inductance of this PFN coil is variable in a range from 0.4 to 1.4 µH, corresponding to a range of the characteristic impedance of the PFN between 2.8 Ω and 5.3 Ω.

Control and monitor system

The distance between the dc power supply and klystron modulators is about 100 m and each control equipment is distributed in a wide range. In order to operate this modulator system, the intensive control and monitoring system is indispensable. The modulator control system is schematically shown in Fig. 4.

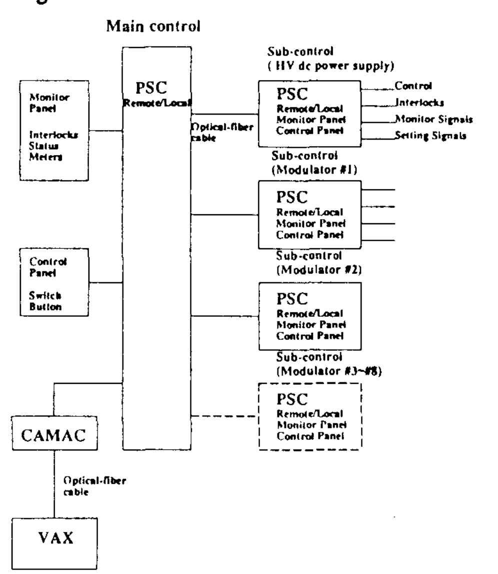

Fig. 4. Block diagram of the modulator control system.

It consists of a main control and sub-control equipments. The main control equipment remotely controls the dc power supply and all of eight modulators. It is necessary to operate the modulator system as a unit for a maintenance and test operation, and make it easy. The sub-control equipment manually controls each modulator in the local mode. It is located near the modulator and has the control panel which contains all the necessary controls, meters, and interlock displays to operate the modulator. The remote control and data collection are performed by a programmable sequence controller (PSC), which have a CPU, digital input/output, ADC, DAC and so on and act with reliability. The PSCs of the sub-control are connected to main control with optical-fiber cables. The PSC of the main control is also connected to the ATF control system consisting of CAMAC and two microVAXs which are connected to the KEK network.

Performances

Prior to the practical use of the modulator for klystrons, it is tested by feeding the output power to a dummy load (4Ω) using 32 ceramic resistors[7]. After adjusting the PFN inductances, the output pulse waveform is shown in Fig. 5, which is picked up by a current transformer in the dummy load. Its expanded trace of the pulse top is also shown in Fig. 6. The pulse top is flat within ± 0.5 %.

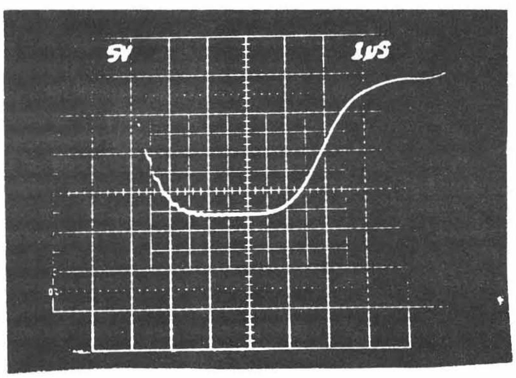

Fig. 5. Output pulse current (peak ~ 7200 A) at dummy load (1 μs/div)

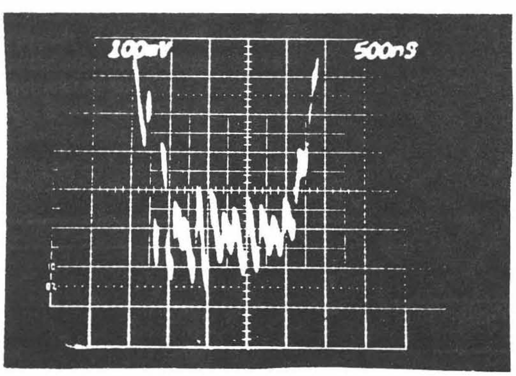

Fig. 6. Expanded pulse top trace of the output pulse current at the dummy load (500 ns/div).

For the high-gradient study[8,9] of S-band disk-loaded structures, this modulator system is used to operate SLAC-5045 and TOSHIBA-E3712 in short pulse mode to obtain a peak power of 200 MW, using a -3 db directional coupler. The output pulse waveforms of E3712 klystron in the operating are shown in Fig. 7.

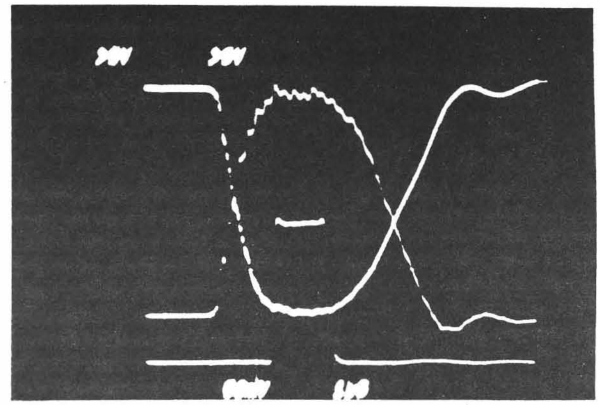

Fig. 7. Output waveform of E3712 klystron at 100 MW
H: 1 μs/div
Upper trace: Beam voltage (444 kV)
Middle trace: Beam current (535 A)
Lower trace: Output power (100MW)

Summary

In order to study the modulator system of a large dc power supply feeding many modulators, we have designed the modulator system consisting of a HV dc power supply and eight modulators. The HV dc power supply and two modulators have been constructed and used to operate SLAC-5045 and TOSHIBA-E3712 klystrons successfully to obtain 100 MW for each klystron.

References

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