DEVELOPMENT OF AN X-BAND KLYSTRON MODULATOR FOR JAPAN LINEAR COLLIDER

M. Akemoto, S. Yoshimoto, T. Shidara, S. Takeda and J. Urakawa
KEK, National Laboratory for High Energy Physics
Oho 1-1, Tsukuba, Ibaraki 305, Japan

Abstract

An X-band Klystron Modulator has been designed and constructed to drive two kinds of prototype X-band pulsed klystrons: (1) 30 MW klystron (XB-50K) requiring a 450 kV beam voltage with a 0.5 μs flat top and (2) 120 MW klystron (XB-72K) requiring a 550 kV beam voltage with a 0.5 μs flat top. The modulator generates 2.0 μs pulses with 37 kV voltage and 7300 A peak current for the operation of the XB-72K. It is a conventional line-type modulator with a 6 section pulse forming network (PFN) which is resonantly charged and discharged by the single thyratron switch at up to 200 pps. In order to reduce the size of the modulator, the special low inductance capacitors using films coated with thin Al-electrodes of 300 Å thickness have been developed for the PFN. Its output pulse voltage is stepped up to 15 times by a pulse transformer.

Introduction

In order to realize an electron-positron linear collider JLC (Japan Linear Collider) in TeV energy range, there are many technical problems to be solved by the R&D works. Among them, a high-power rf source is one of the most important issues. Since the designed accelerating gradient of the JLC is 100 MV/m, 100 MW-class X-band klystron and its modulator are necessary. As a first step of the development program, a design and fabrication of 30 MW and 120 MW klystrons are under progress [1]. In order to operate above two kinds of prototype klystrons, we have designed and constructed a line-type modulator using a pulse forming network (PFN) and a pulse transformer in the Accelerator Test Facility (ATF) [2]. The design, specifications and results of performance tests of the modulator are described in this paper.

Design and modulator specifications

Table 1 shows the specifications of two prototype X-band klystrons. The modulators for these klystrons are required to generate the maximum high-voltage of 550 kV and a pulse flat top of 400 ns. The pulse width is particularly short, so that its rise and fall times must be as short as possible to obtain a high efficiency.

The line-type modulator was chosen because of its high efficiency, relatively low cost and high reliability that had been proved at SLAC so far. The level of the main high-voltage in the modulator was mainly limited by the ratings of the available switch tubes. The thyratron ITT F-169 (maximum rating: 100 kV) was chosen. In order to obtain a short rise time, it is necessary to keep the turns ratio of the pulse transformer as low as possible because of its leakage inductance and stray capacitance, which is 1:15 in the present case. As a consequence, the modulator is required to generate high voltage pulses with 37 kV in peak. This peak voltage demands about 72 kV maximum on the PFN which gives a sufficient margin to 100 kV thyratron. The size of the modulator can be made small by employing following parts and method; (1) a thyristor unit for regulating ac line voltage, (2) a water cooling for the charging unit and an inverse-clipping shunt circuit, and (3) PFN capacitors using films coated with thin Al-electrodes. The cabinets of the dc power supply and the klystron modulator are separated, considering that other large dc power supply with common-bus will be used to drive many modulators in future [3]. Specifications of the modulator are listed in Table 2. The details are described in the following sections.

Table 1
Specifications of X-band klystron

Klystron	XB-50K	XB-72K
Peak power output	30 MW	120 MW
RF pulse width	400 ns	400 ns
Operating frequency	11.424 GHz	11.424 GHz
Peak beam voltage	450 kV	550 kV
Peak beam current	172 A	490 A
Peak beam power	77 MW	270 MW
Klystron impedance	2616 Ω	1122 Ω
Power gain	59 dB	53-56 dB
Efficiency	41 %	45 %
Microperveance	0.57	1.2

Table 2
Specifications of the modulator

Operation mode	XB-50K	XB-72K
Peak power output	77 MW	269 MW
Average power output	39 kW	97 kW
Output pulse voltage	30 kV	37 kV
Output pulse current	2581 A	7342 A
Output impedance.	11.6 Ω	5.0 Ω
Pulse flat top	0.5 μs	0.5 μs
Rise time	< 0.5 μs	< 0.5 μs
Pulse height deviation from flatness	1.0 % (p-p)	1.0 % (p-p)
Pulse repetition rate	200 pps	200 pps
Transformer ratio	1:15	1:15

High voltage dc power supply

A simplified diagram of the dc power supply is shown in Fig. 1.

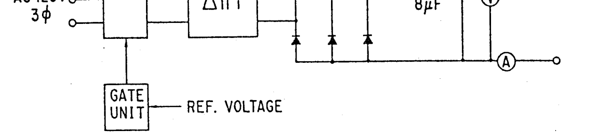

Fig. 1. A simplified diagram of the dc power supply.

The voltage of line input is 420 V ac with three-phase and 50 Hz. A thyristor unit is used to regulate the ac line voltage in a range of 0 ~ 98 %. This unit is also used to disconnect the line from the modulator within a few ms when the over-current or over-voltage of the dc power supply and klystron modulator occurs. The output voltage of the thyristor unit is controlled with an accuracy of ± 0.5% by the feedback control of the output voltage of dc power supply. The stepped-up ac is rectified to dc in 3-phase full wave scheme. The LC filter decreases the voltage ripple and determines the voltage drop due to the pulse load. The capacitances of 8 μF make this drop 2.0 % for the operation of XB-72K klystron. The specifications of the dc power supply are listed in Table 3. The rectifier transformer, the rectifier and the choke are housed in the same oil tank. The size of the dc power supply cabinet is 2.5 m wide x 2.0 m deep x 2.5 m height.

Table 3
Specifications of the dc power supply

dc output voltage	48 kV
dc average output current	3.1 A
Ripple at full load	< 1.0%

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, a thyratron and an inverse-clipping shunt circuit as shown in Fig. 2.

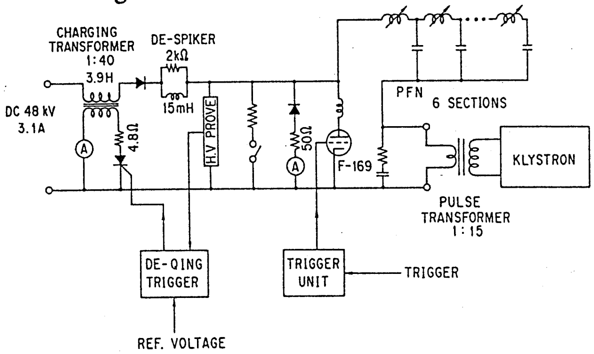

Fig. 2. A simplified diagram of the modulator.

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. The repetition rate is 200 pps and charging time has been chosen to be 2.5 ms which corresponds to the half of the maximum repetition time. The de-Qing circuit in the secondary of the charging transformer regulates the voltage applied to the PFN. A step down ratio of 40:1 was chosen to employ a silicon-controlled rectifier (SCR) switch. A simple series connection of the resistors and the SCR switches was adopted. The regulation of the de-Qing circuit was chosen to be 5 %. Since the modulator is operated with a high repetition rate of 200 pps, the coolings of the following components such as a charging choke transformer, de-Qing resistors, the resistors of an inverse-clipping shunt circuit and resistors of a matching element inserted in the output circuit are especially required. We adopted the water cooling system to reduce the size of the modulator.

The number of PFN sections was six, which was optimized by a computer simulation code. Since two klystrons, XB-50K and XB-72K, are driven by this modulator according to the experiment, two types of PFN unit consisting of six sections with fixed capacitors and tunable inductors are fabricated, which can be exchanged easily. The specifications of the PFN unit are listed in Table 4.

Table 4
Specifications of the PFN unit

PFN unit	XB-50K unit	XB-72K unit
Output impedance	12.8 Ω	5.5 Ω
Operating voltage	70 kV	90 kV
Pulse width	2.5 μs	1.8 μs
Number of sections	6	6
Total capacitor	98 nF	164 nF
Total inductance	16.2 μH	4.98 μH

It is necessary to minimize the residual inductance of the capacitor because the inductance of the PFN must be small, especially for the case of XB-72K. For this purpose, a special capacitor was developed. The details will be described in the following section. Tunable inductors are mounted on the high voltage bushing stub of the capacitor. Fine adjustment is made by varying the insertion depth of an aluminum cylinder in the coil. The size of the modulator cabinet is 2.55 m wide x 1.8 m deep x 2.5 m height.

PFN capacitor

A PFN capacitor is one of the most important parts in the line-type modulator. Especially, a compact capacitor with a long lifetime should be developed as the charging voltage of the PFN and repetition rate become higher. The elements of the high-voltage capacitor usually consist of sheets of condenser papers and films as a dielectric material, and aluminium foils as an electrode. In order to obtain a higher energy density and long lifetime of the capacitor, we adopt the new type element as shown in Fig. 3 [4]. It is composed of two polypropylene films coated with thin Al-electrodes (300 Å) which form a series of microscopic capacitor. Therefore, it makes possible to achieve a higher energy density and to fabricate the capacitor of self healing type. A unit capacitor for XB-50K and XB-72K consists of 23 and 17 elements in series, respectively. At each section of the PFN, two parallel oil-immersed capacitors in a same metal box are used to reduce their residual inductances. As the results, the residual inductance of each section was less than about 135 nH and the volume of the capacitor became about 60 % of the usual capacitor.

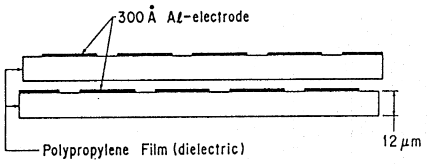

Fig. 3. Structure of the PFN capacitor element.

Performance tests

Prior to the practical use of the modulator for the klystron, the characteristics of the output pulse were measured for each operation mode. We used ceramic resistors as a dummy load. After adjusting the PFN inductances carefully, the waveforms of the output pulse were monitored by a current transformer and a capacitive divider. Figure 4 shows the current of the output pulse for XB-50K provided on conditions that output voltage of the dc power supply is 33.8 kV, the charging voltage of the PFN is 64.0 kV, the output pulse voltage is 30.3 kV, the repetition rate is 5 pps and the dummy load is 12.2 Ω. The output pulse had a rise time (10-90%) of 530 ns, 1.43 μs flat top with ± 0.5 % and 3.0 μs width.

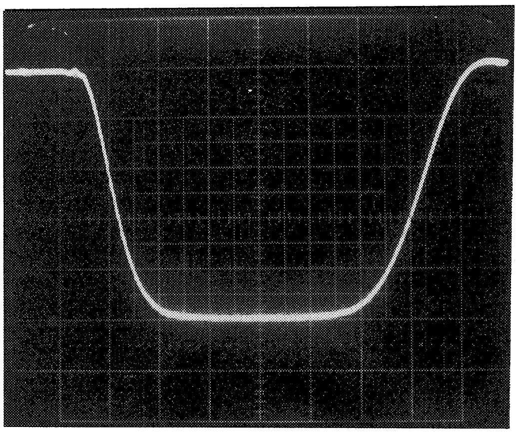

Fig. 4. Output pulse current (peak ~ 2480 A) at the dummy load (H: 500 A/div., V: 500 ns/div.).

Figure 5 shows the current of the output pulse for XB-72K provided on conditions that output voltage of the dc power supply is 46.0 kV, the charging voltage of the PFN is 83.2 kV, the output pulse voltage is 37.0 kV, the repetition rate is 5 pps and the dummy load is 4.9 Ω. The output pulse had a rise time (10-90%) of 340 ns, 1.01 μs flat top with ± 0.5 % and 2.24 μs width.

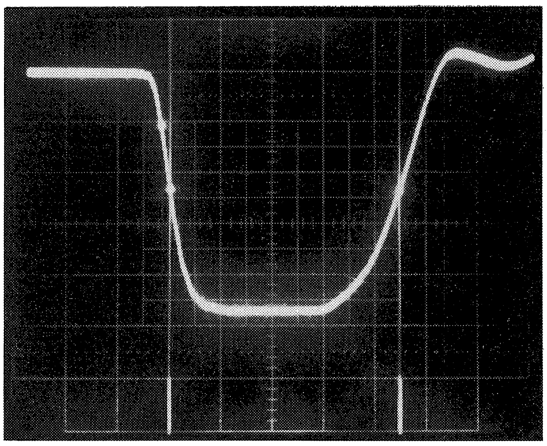

Fig. 5. Output pulse current (peak ~ 7550 A) at the dummy load (H: 1600 A/div., V: 500 ns/div.).

The full power test of the modulator has been started using a water resistor as a dummy load [5]. The main problem at the initial stage of the experiment was a failure of the new type of the capacitor in the PFN, which were found after the operation of ~ 4 x 10^4 shots at the 5 pps rate in two capacitors. The detailed analysis of the failure is under way.

Summary

In order to operate a 30 MW or 120 MW prototype X-band klystron, we have designed and constructed a line-type modulator using a PFN and a pulse transformer. In the test operation of the modulator using a dummy load, 3.0 μs wide pulses with 30 kV voltage and 2480 A current for XB-50K mode, 2.2 μs wide pulses with 37 kV voltage and 7550 A current for XB-75K mode were successfully generated.

Acknowledgements

We wish to express our thanks to Professors Y. Kimura and K. Takata for their encouragements. We also thank to Messrs. A. Tokuchi and H. Yoshimoto of Nichicon Co. for the fabrication of the klystron modulator.

References

1. H. Mizuno et al., "X-band klystron for Japan Linear Collider," Proc. of the 1990 Linear Accelerator Conference, Albuquerque, 168-170(1990).

2. S. Takeda, "Present Status of R&D for JLC project," Proc. of this symposium.

3. M. Akemoto et al.,"Klystron modulators with HV common-bus for the JLC," Proc. of the 1990 Linear Accelerator Conference, Albuquerque, 171-173(1990).

4. M. Hasebe (Nichicon Co.), private communication.

5. M. Akemoto et al., "100 kW Dummy Load using Water for a Klystron Modulator," Proc. of this symposium.