# X-BAND KLYSTRON MODULATOR FOR THE ACCELERATOR TEST FACILITY

Mitsuo Akemoto, Tetsuo Shidara, Seishi Takeda and Junji 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 a thyratron switch at up to 200 pps. In order to reduce the size of the modulator, a special low inductance capacitors using a film coated thin Al-electrodes of 300 Å thickness has been developed for the PFN. Its output pulse voltage is stepped up to 15 times by a pulse transformer. The design, specifications and results of performance tests of the modulator are described in this paper.

## I. INTRODUCTION

A TeV electron-positron linear collider JLC (Japan Linear Collider) has several technical problems to be solved. A high-power rf source is one of the most important issues. In order to realize 100 MV/m accelerating gradient, the developments of X-band 100 MW-class klystron and its modulator are required. At the same time, more than 4,000 klystrons are necessary for JLC. Therefore, it is crucial to develop klystron modulators considering in the following items: (1) small size, (2) low cost, (3) high reliability, (4) mass production and (5) high efficiency.

As a first step of the development of 100 MW class klystron at X-band, a 30 MW klystron named XB-50K was designed and fabricated [1]. 11 MW RF power of 70 ns pulse width was achieved at the repetition rates of 2 pps but an RF window ceramic was fatally damaged. RF power test using new RF window will be carried out in May 1991. Also a 120 MW klystron named XB-72K has been designed and will be fabricated in July 1991. 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] for the JLC. The development of an X-band modulator using magnetic-pulse-compression techniques was simultaneously started to produce pulses that were 200 ns wide, 600 kV, 1200 A peak current and a short rise time of ~90 ns [3].

## II. DESIGN AND MODULATOR SPECIFICATIONS

Table 1 shows the specifications of the prototype X-band klystrons. The modulators for these klystrons are required to generate a high-voltage of 550 kV and a short RF pulse width of 400 ns, so that its rise time has to be as short as possible considering the power efficiency.

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 |

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 (rating: 100 kV) was chosen. In order to obtain a shorter rise time, it was necessary to keep the turns ratio of the pulse transformer as low as possible. In the present case, a pulse transformer with a turns ratio of 1 : 15 was used to step up to the voltage necessary for the klystron. As a consequence, the modulator is required to generate 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. For a small size of the modulator, a thyristor unit for regulating ac line voltage, a water cooling for the charging unit and an inverse-clipping shunt circuit, and a PFN capacitors using a film coated thin Al-electrodes were employed. The cabinets of the dc power supply and klystron modulator was separately used, considering that other large dc power supply with common-bus will be used to many modulators in future [4]. Specifications of the modulator are listed in Table 2. The details are described in the following sections.

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 |

## III. HIGH VOLTAGE DC POWER SUPPLY

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

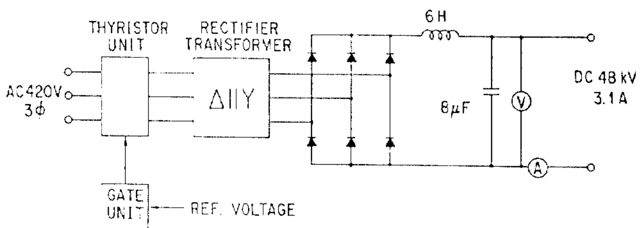


Fig. 1. A simplified diagram of the dc power supply

The line input is 420 V ac, 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 within a few ms, when the interlock of over-current or over-voltage of the dc power supply and klystron modulator is worked. The output voltage of the thyristor unit is controlled with an accuracy of ± 0.5% by a feedback loop to 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. A capacitance of 6 μF makes 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, rectifier and choke are housed in the same oil tank.

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% |

## IV. 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.

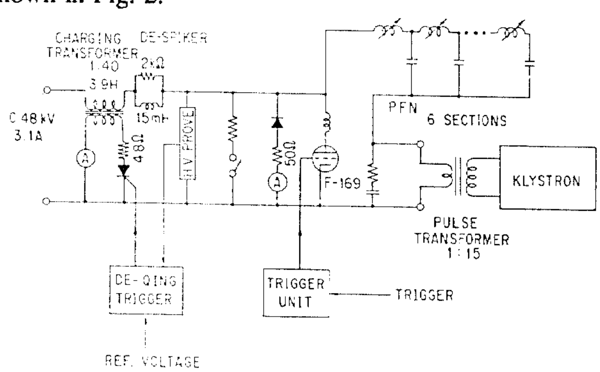


Fig. 2. A simplified diagram of the modulator

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 is chosen to be 2.5 ms (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 resistor and the SCR switch was adopted. The regulation of the de-Qing circuit is chosen to be 5 %.

For the operation of two kinds of klystron, two kinds of the PFN unit consisting of 6 sections with fixed capacitors and tunable inductors are used in order to exchange the PFN unit 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 | 11.6 Ω | 5.0 Ω |
| Operating voltage | 70 kV | 90 kV |
| Pulse width | 2.5 μs | 1.8 μs |
| Number of sections | 6 | 6 |
| Residual inductance | 150 nH | 150 nH |
| Total capacitor | 98 nF | 164 nF |
| Total inductance | 4.98 μH | 16.2 μH |

Since the inductance of the PFN coil, especially for XB-72K, is small, it is necessary to minimize the residual inductance of the capacitor. The residual inductance of each section has to be less than 150 nH. For this purpose, a special capacitor was developed. The details will be described in the following section. 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.

## V. PFN CAPACITOR

A PFN capacitor is one of the most important parts in the line-type modulator. Especially, a small size of the capacitor 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 a condenser paper and film as a dielectric material, and aluminium foil as an electrode. In order to obtain a higher energy density and low inductance of the capacitor, we adopt the new type element as shown in Fig. 5 [5]. 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.

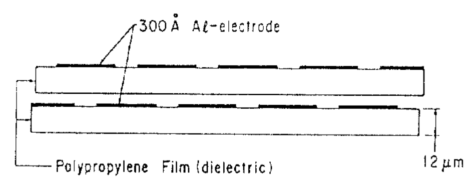


Fig. 3. Structure of the PFN capacitor

## VI. CONTROL AND MONITOR

The control system of the modulator is schematically shown in Fig. 4. This system makes it possible to control the dc power supply and the klystron modulator in local operation and/or remote operation mode.

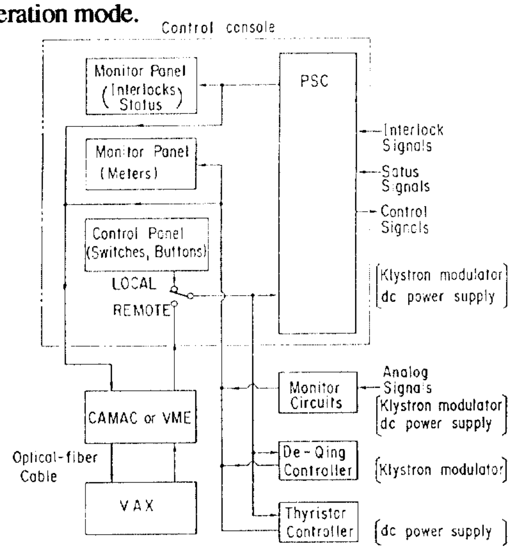


Fig. 4. Block diagram of the modulator control system.

In case of the local mode, the modulator can be manually controlled with the control console. 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 controls of the thyristor unit and de-Qing, and monitors of analog signals must be made with fast speed. They are therefore directly carried out by the hardware. A programmable sequence controller (PSC) is mainly used to control the on/off switches of devices and the display of the interlock status and on/off status and so on, since it acts with a high reliability but its working speed is slow. The remote control and data collection are performed by the PSC and hardware. They are connected to the ATF control system [6] consisting of CAMAC and a microVAX which are connected to the KEK network. The control system using VME will be also tested for the design of the future control system.

## VII. PERFORMANCE TESTS

Prior to the practical use of the modulator for klystrons, it was tested by feeding the output power to a dummy load in

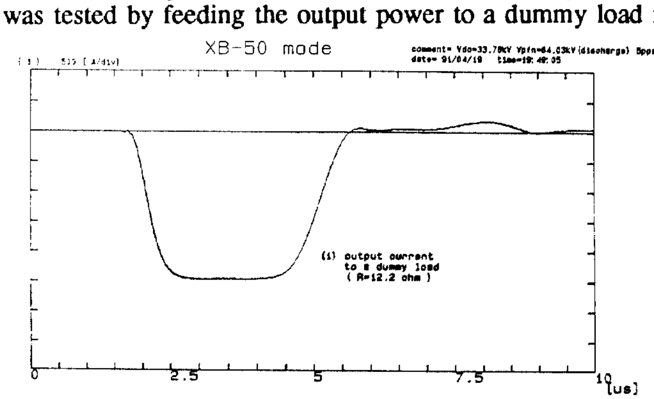


Fig. 5. Output pulse current (peak ~ 2480 A) at dummy load (H: 1 kA/div., V: 500 ns/div)

which a ceramic resistor is used. After adjusting the PFN inductances, waveforms of the output pulse for XB-50K and XB-75K were monitored by a current transformer and a capacitive divider. Figure 5 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 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 was a rise time(0-90%) of 530 ns, 1.43 μs flat top with ± 0.5 % and 3.0 μs width. Figure 6 shows the current of the output pulse for XB-72K provided on conditions that PFN is 5 sections, the output pulse voltage is 38 kV, the repetition rate is 5 pps and the dummy load is 5.2 Ω. The output pulse was a rise time(0-90%) of 380 ns, 0.6 μs flat top with ± 0.5 % and 1.9 μs width.

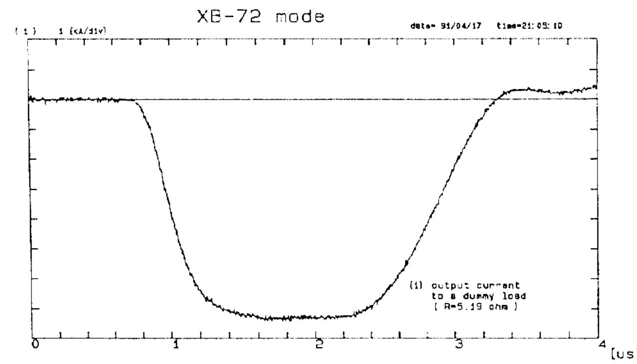


Fig.6. Output pulse current (peak ~ 7300 A) at dummy load (H: 1 kA/div., V: 200 ns/div)

## VIII. 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, 1.9 μs wide pulses with 38 kV voltage and 7300 A current for XB-75K mode were successfully generated.

## IX. ACKNOWLEDGEMENTS


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## X. REFERENCES


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