PULSED MODULATOR FOR C-BAND KLYSTRON

H. Baba, K. Sato and K. Shinohara, NIHON KOSHUHA Co., LTD, 1119 Nakayama, Yokohama, 226 Japan
H. Matsumoto and T. Shintake, KEK, 1-1 Oho, Tsukuba-shi, 305 Japan
J.-S. Oh, PAL POSTECH, Pohang, Kyungbuk, 790-600, Republic of Korea

Abstract

Hardware R&D on C-band (5712 MHz) RF-system for an electron/positron linear collider started in 1996 at KEK [1,2]. One of the most important R&D items is to develop a compact, reliable and low-cost modulator (pulsed klystron power-supply), called the “Smart Modulator”. As the first step toward the smart modulator, we have developed a prototype modulator. An inverter-type power supply was used to charge a high-voltage into the PFN capacitors, which eliminated the massive charging-transformer and also the de’Q-ing circuit from the traditional design. The developed modulator has a simple configuration and compact size. It shows excellent performances, and it is currently used for testing new C-band klystrons.

1 INTRODUCTION

An e^+e^- linear collider is a large-scale machine. In the main linac for two beams, more than 3500 klystrons and power supplies, and 7000 accelerating structures will be used to accelerate the beams up to the 500 GeV center-of-mass energy. Therefore, we have to develop an rf-system which satisfies the following demands:

(1) High reliability,
(2) Simplicity,
(3) Lower construction cost,
(4) Reasonable power efficiency and
(5) Operational ease.

The above list provides a guideline and boundary conditions to our design work. Among the system parameters, the choice of the drive rf frequency plays the most important role concerning the system performance as well as the hardware details. We proposed the C-band frequency as being the best choice to meet all demands listed above [1].

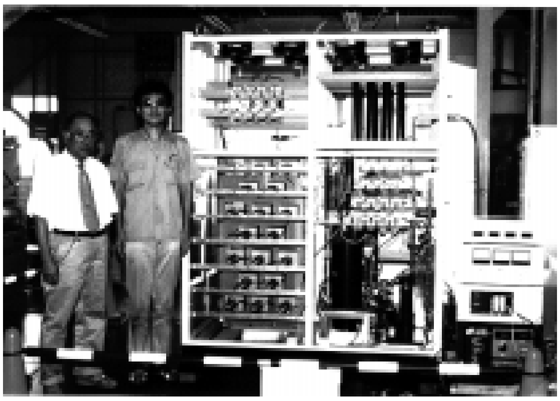


Figure 1: The C-band klystron modulator (prototype smart-modulator) developed by NIHON KOSHUHA Co. LTD.

The modulator (pulsed klystron power-supply) is one of the most expensive parts in the rf-system of electron accelerators. At the same time, it is sometimes the most unreliable and troublesome device, and occupies a large volume. Therefore, development of an improved modulator is essential for the linear collider project, and beneficial for various scientific and industrial applications.

2 SMART MODULATOR CONCEPT

In 1993, Prof. M. H. Cho (PAL, Pohang Accelerator Laboratory) and Prof. H. Matsumoto (KEK) proposed a concept of the “Smart Modulator”. It is an ideal modulator satisfying the demands listed in Sec. 1.

As the first step toward the smart modulator, we develop a first model (prototype modulator) as shown in Fig. 1. The key points are:

1. Direct HV charging using an inverter power supply.
2. No de’Q-ing circuit.
3. Much smaller size than the conventional modulators.
4. Use existing reliable circuit components.

We used components based on the established technologies only. For example, the PFN capacitor is a traditional paper-oil type. The R&D strategy in C-band is to improve the existing technology step-by-step. Thus if the capacitor is an essential problem for a mass-production, we will improve it in the future.

3 DESIGN DETAILES

3.1 Circuit Configuration

Figure 2 shows the circuit diagram of the developed C-band klystron modulator (prototype smart-modulator). It manly consists from three blocks: a HV power supply, a PFN and a switching thyratron, an interlock and miscellaneous power supplies. Since the inverter power supply has a voltage regulation capability, we do not need the de’Q-ing circuit, therefore the circuit diagram has a quite simple configuration. The design specification is listed in Table-1.

Table-1 : Design Specification of C-band Modulator.

Design Parameter		
PFN Charging Voltage (nominal)	46.8	kV
Output Voltage (nominal)	23.4	kV
Repetition Frequency (max.)	100	pps
Pulse Width (50%)	3.9	μsec
Rise Time (10 – 90%)	< 1.0	μsec
Fall Time (90 – 10%)	< 2.0	μsec
Pulse Flatness (for 2.5 msec)	< ± 0.5	%

3.2 Circuit Analysis

In R&D's, we were supported by two laboratories: CERN-PS and PAL-POSTECH. From the CERN-PS division, Dr. Peter D. Pearce joined our group in 1995 and created a basic design. He also provided much important information concerning circuit components.

From PAL (Pohang Accelerator Laboratory in KOREA), Dr. Jong-Seok Oh visited KEK for half a year in 1996. He carefully studied the efficiency issue concerning klystron modulators for linear colliders [3].

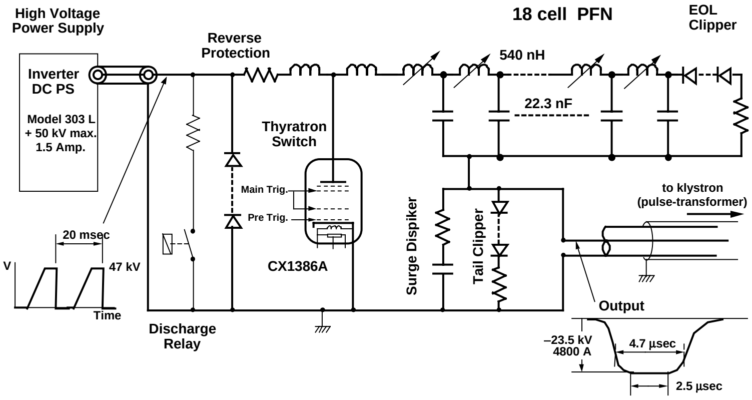


Figure 2 : Circuit diagram of the C-band klystron modulator.

3.3 The Inverter HV Power Supply

The inverter power-supply or the switching power-supply is widely used in the power electronics as well as the home electronics. Today's progress in power semiconductor devices, especially the IGBT (Insulated Gate Bipolar Transistor) technology made the power modules compact, less-weight and power efficient.

We use an inverter power supply: model 303L made by EMI Inc. USA (Fig.3). Although it is compact (483W x 311H x 560D), it is very powerful: the maximum charging rate is 37.5 kJ/sec. A large volume and massive traditional charging section was replaced by this compact module.

The benefits to use the inverter type power supply are

(1) Compact.
(2) Extremely low stored energy. In case of a high-voltage breakdown in the klystron or the thyratron, the dissipation energy in the output section of the inverter power supply is limited and does not cause fatal defects on the circuit components.
(3) Fully controlled output voltage. The de'Q-ing circuit is not necessary.
(4) Fully interlocked internally. It simplifies the interlock circuit in the modulator, and reduces the amount of works for assembling and wiring.

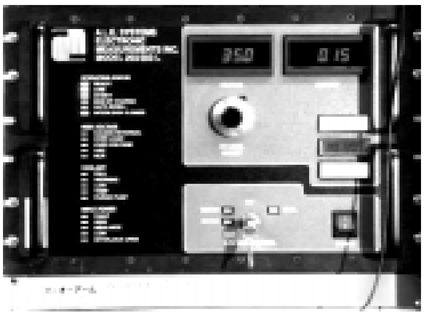


Figure 3 : The inverter (switching) power supply made by EMI Inc., size is 483 mm wide, 7 Unit high and 560 mm deep.

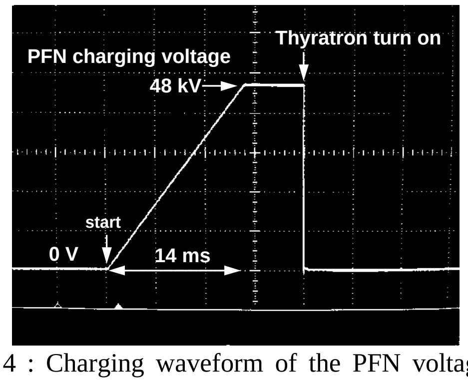


Figure 4 : Charging waveform of the PFN voltage. The external trigger starts the charging at 20 msec before the thyratron trigger (command charging).

Figure 4 shows the HV charging waveform on the PFN capacitor. Since the inverter-type power supply operates as a constant current-source, the voltages ramps linearly. When the voltage reaches to the target value, it is 48 kV in this case, the feedback control stops the switching. Since this model has no pulse-width-modulation capability, the voltage stability is defined by a quantized single-bucket charge in one switching cycle. The measured voltage step is 62 V, which corresponds to 0.1%, only. The details on the test results are reported in the separated papers by H. Matsumoto[5] and J. S. Oh [4].

An important key for safety operation is the optimum design of the reverse-protection circuit. We use a resistor in series and reverse protection diode in parallel at the output circuit. For details, refer the user's manual of the inverter power supply or contact to NIHON KOSHUHA Co. LTD[6].

3.4 Thyratron

The thyratron is a key device in high-power pulsed-power supplies. We use a two-gap thyratron: model CX1368A made by EEV Co., whose maximum rating is the peak forward anode voltage of 50 kV, the peak anode current of 10 kA, and average anode current of 10 A. The nominal operation parameters are 47 kV, 4.8 kA and 1.9 A, respectively.

The triggering scheme affects much on stability and lifetime of the thyratron tube. We apply the double-pulse scheme as shown in Fig. 5. The pre-pulse applied on the grid-1 produces pre-ionizing with 480 V pulse and the main-trigger of 700 V pulse applied on the grid-2 and grid-3 starts the main discharge. A negative DC-bias of −140 V is applied on grid-2, which suppress the spurious discharges. The double-pulse scheme maximizes the cathode utilization and therefore provides maximum life. To supply double-pulse, we use a standard trigger card : MA2458A made by EEV.

For stabile operations, it is also very important to keep the thyratron body at a constant temperature. This is

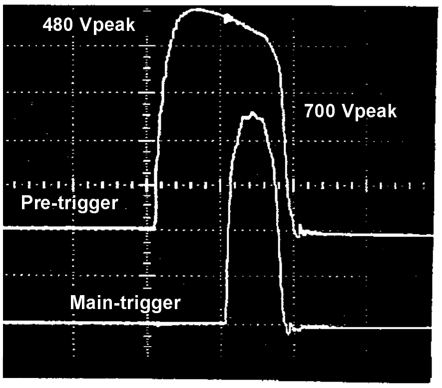


Figure 5 : Double-pulse thyratron trigger. The top waveform is the pre-ionizing pulse, and the bottom waveform is the main trigger to start discharge. Time scale is 1 μsec/div.

because the pressure of the deuterium-gas filled in tube is a function of the temperature on the reservoir and tube body. To cool the heater power of 600 W and the anode loss of 200 W at 100 pps operation, we use a factory made cooling module (air cooling fan with a chimney, EEV MA21161A).

3.5 Noise Less Design

In the linear collider, to accelerate the low emittance beams, many feedback-loops will be implemented. For example, the beam-trajectory feedback, the beam-to-rf phase feedback and the fast phase-modulation for the beam loading compensation. To make work those feedback loops, it is essential to eliminate any unwanted electromagnetic noise in the system.

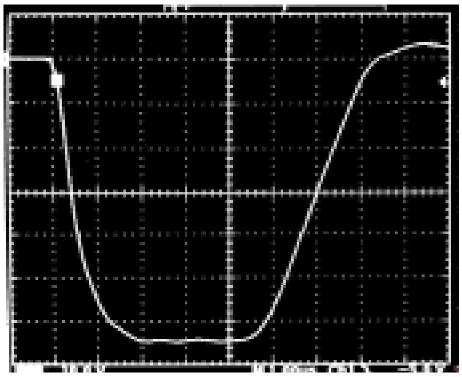
The wide-band impulse noise associates with the thyratron switching in the klystron modulator commonly dominates the EM-noise in electron accelerators. In our modulator, a low-impedance return-circuit is carefully arranged connecting the thyratron, the PFN, the output cable, the pulse transformer and finally the klystron. Thanks to this design, our modulator realized a very quiet EM condition. At a high-power test of the C-band klystron, we observe a clean rf-detector signal without substantial noise. Concerning the design details, contact to NIHON KOSUHA Co. Ltd. [6].

4 HIGH-POWER OPERATION

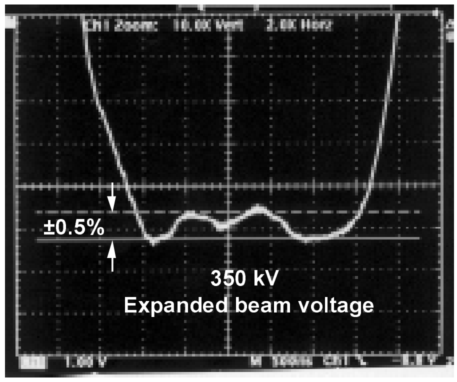
The completed modulator was firstly tested with a 5 Ω resistor as a matched load. Then the C-band klystron was connected through a 1:15 step-up transformer. Figure 6 shows the output waveform observed at the klystron gun. As seen in the magnified view, the flat-top of 2.5 μsec width and ± 0.5% flatness were obtained.

5 FUTURE R&D

The measured rise and fall times are 0.8 and 1.9 μsec, respectively. They are within the specification. However, according to the detailed analysis made by J. S. Oh [4], the measured pulse efficiency is 56.4%, only. This would not be a problem for a small scale machine such as in industrial applications. However for the linear collider project, we need to improve it at least 70% or even higher in order to limit the wall-plug power below 200 MW at 500 GeV c.m. energy case. We need further R&D's to improve the system efficiency.



(a) Output voltage on the electron-gun of the C-band klystron. (350 kV peak, 1 μsec/div)



(b) Expanded view (500 nsec/div).

Figure 6 : The output voltage into the C-band klystron.

ACKNOWLEDEMENT

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