HIGH POWER TEST OF THE COMPACT, OIL-FILLED MODULATOR FOR THE C-BAND KLYSTRON

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Abstract

We propose a new concept of pulsed modulator. The modulator supplies 114 MW peak power at 60 pps maximum repetition rate. The modulator is housed in a commercial stainless steel tank. The physical size is only 1.5 m wide, 1.0 m high and 1.0 m depth. All the high voltage components are immersed in insulating oil. Superior insulating performance of the oil enables the modulator to be compact and reliable in long-term operation. Since the stainless steel tank provides an ideal electric-shielding boundary like Faraday-cage, the modulator is very “quiet” and stable. The first model was constructed in March 2003. We obtained the expected performances; PFN charging voltage up to 45 kV, and -22 kV pulsed (4.5 μsec FWHM) output voltage at 60 pps repetition rate. It drives the 50 MW C-band (5712 MHz) klystron at -350 kV beam voltage through a 1:16 step-up transformer. The repeatability of pulsed voltage are better than 0.5% within 2.5 μsec flat-top.

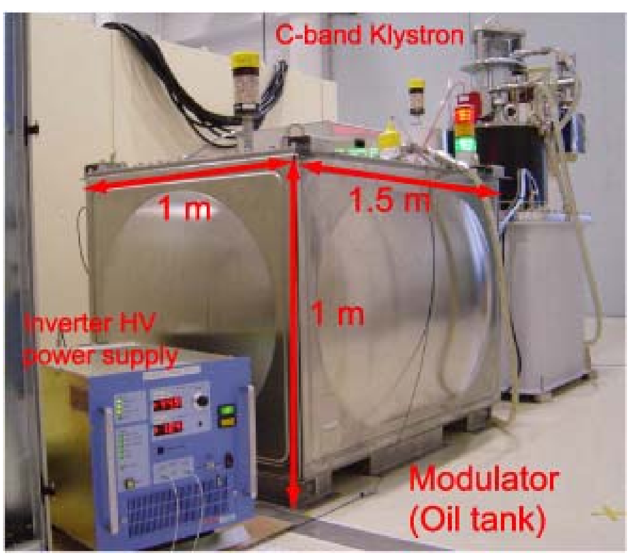

Figure 1: From left to right; the inverter-type high voltage power supply, the modulator, and the C-band klystron.

DESIGN CONCEPT

In X-ray FEL project at SPring-8, named SPring-8 Compact SASE Source (SCSS), FEL amplification is very sensitive to the electron energy in the undulator. Therefore, pulse-by-pulse stability of the acceleration is important in our main accelerator; 1 GeV (in future 6 GeV) C-band linac [1]. In order to obtain enough stability of the RF power and phase in the linac, voltage of the klystron cathode (V_k = -350 kV) should be stable within ± 0.5%.

In SCSS, “compactness” is one of the key point. Compact, low cost modulator is also useful for many compact accelerators for industrial and medical use, and future large accelerators, such as linear collider.

We has been constructed the new compact, stable modulator. High voltage components are immersed in insulating oil filled in a stainless steel tank. The oil-filled modulator has following advantages;

(1) Superior insulating performance of the oil enables the modulator to be compact.
(2) Free from the influence of environment, such as moisture or micro-dust contaminants.
(3) Since the stainless steel tank provides an ideal electric-shielding boundary like Faraday-cage, the modulator is very “quiet” and stable.
(4) “All-in-one” tank is movable, easily replaceable.
(5) All the inner components are attached on the hanger frame. In the case of the maintenance they are hanged out from the top panel of the tank, and we can easily maintain.

We designed this modulator not only for the C-band (5712 MHz) klystron, but also for our 500 kV pulsed electron gun [2]. In total 9 modulators of the same design will be used for the 1 GeV accelerator.

For details of the concept and history are described in our previous paper [3].

MODULATOR DESIGN

Structure

Figure 1 shows the photograph of our pulsed power system. We use a commercial stainless steel tank. The physical size is only 1.5 m wide, 1.0 m high and 1.0 m depth. The total weight is about 700 kg without oil (~ 1.4 m^2). Figure 2 shows the interior of the modulator. All the high voltage components, such as PFN circuit, a thyratron tube, reflection voltage clippers, and their monitors, are immersed in insulating oil.

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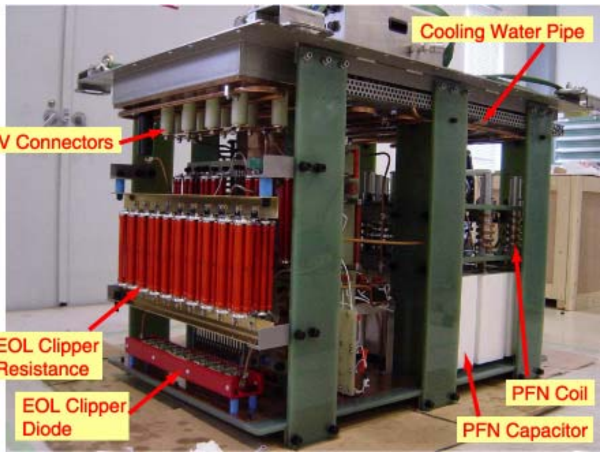

Figure 2: Inside of the modulator. All the inner components are attached on the frame, which is hanged from the top panel of the tank.

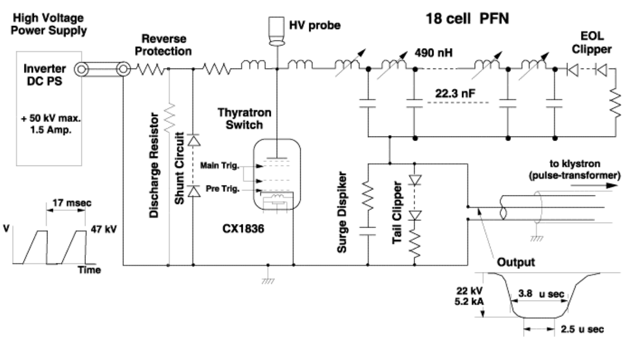

Figure 3: Circuit diagram of the modulator.

Table 1: Specification of the modulator and the klystron

Modulator <Nichicon Corporation>	
Maximum repetition	60 pps
Maximum charging voltage (V_{PFN})	50 kV
Average charging power	30 kW
Stored energy in PFN	475 J
Peak output power	114 MW
Pulse-by-pulse jitter of output voltage	< ±0.5 %
Timing jitter	<5 nsec
Pulse Transformer	
Step-up ratio	1:16
Pulse duration (at 70% of peak voltage)	3.8 μsec
Klystron <Toshiba Corporation, E3746A>	
Frequency	5712 MHz
Peak output RF power	50 MW
RF pulse width	2.5 μsec
Cathode voltage (V_k)	350 kV
Beam current (I_k)	317 A

Circuitry

Figure 3 shows the circuit diagram of the modulator. This circuit is almost same as SMART MODULATOR for C-band klystron in KEK [4]. Table 1 summarizes the specifications of our modulator and the C-band klystron.

In order to charge to PFN capacitor, we use an inverter-type high voltage power supply, which is newly produced by Toshiba Electro-wave Products Co. Ltd [3, 5]. The inverter power supply generates a maximum output voltage of 50 kV at average current of 1.5 A. Pulse-by-pulse jitter the output voltage is less than 0.1 %.

The line-type PFN consists of 18 series of paper-oil capacitors (22.3 nF) produced by Maxwell (General Atomics), and adjustable inductance coils. Since the inductance adjustment is performed using insulation rods from the safety window on the top panel, we can safely adjust PFN circuit during the operation. There is a high voltage probe (attenuation 1/2000), which monitors the PFN voltage.

For high voltage switch, a thyratron tube (E2V Ltd. CX1836) is used. This tube is deuterium-filled two-gap type. It is operated with twin pulse (pre-trigger and main trigger) scheme, which maximize the plasma density and therefore provides maximum life. The tube is installed in a chimney with an oil circulation screw, which stabilize temperature of the tube body.

For reverse voltage protection, there are three diode circuits; EOL clipper, tail clipper, and shunt circuit. Each of them has a current monitor. If excessive inverse current is observed, the interlock system immediately stops operation.

-22 V pulse generated by the modulator PFN is lead through 9 parallel coaxial cables of 41 Ω to a pulse transformer. The pulse transformer step-up the voltage to –350 kV, and supplies to the cathode of the klystron. In order to monitor the voltage of the cathode (V_k) and the current (I_k), a CVD (Capacitive Voltage Divider) and a current transformer is used. The divide ratio of CVD is about 1:7400, which is calibrated with +130 V square pulse generated by a pulse generator.

Modulator operation is controlled with a separated control box, which equips a touch panel.

OPERATION TEST

Operation progress

The first model of the modulator was constructed by Nichicon Corp. in March 2003. Operation test was performed with the C-band klystron with diode mode (without RF input).

First, at 10 pps repetition rate, we gradually raised the charging voltage (V_{PFN}). At V_{PFN} = 45 kV, we obtained nominal voltage of V_k = –350 kV. We performed the same process at 20 pps, 30 pps, 40 pps, 50 pps, and 60 pps.

Next, we adjusted the PFN inductance. After the adjustment, we obtained the expected performance; 2.5 μsec flat-top (flatness < ±0.5%) at V_k = -350 kV, I_k = 300 A, and 4.5 μs FWHM, with V_{PFN} = 45 kV. Figure 4 and 5 shows the waveform of the charging (V_{PFN} and the charging current) and the output pulse (V_k and I_k), respectively. These Vk and Ik are very stable. The stability of V_k waveform is within ±0.25 % of pulse-by-pulse. I_k waveform has oscillation or noise at the flat-top. The source of the oscillation is under investigation.

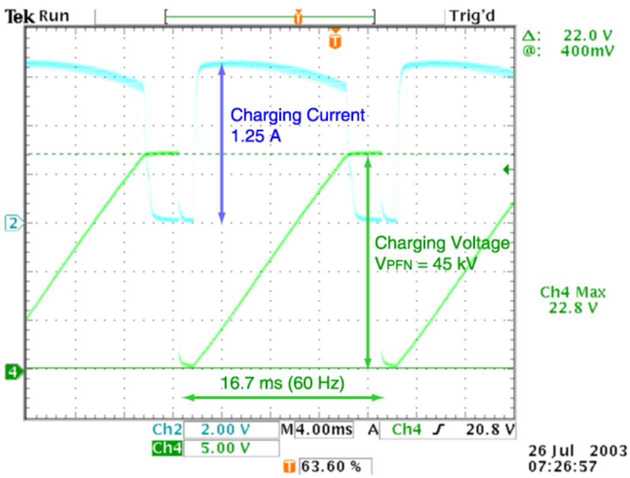

Figure 4: Waveform of the charging voltage (V_{PFN}) and the charging current.

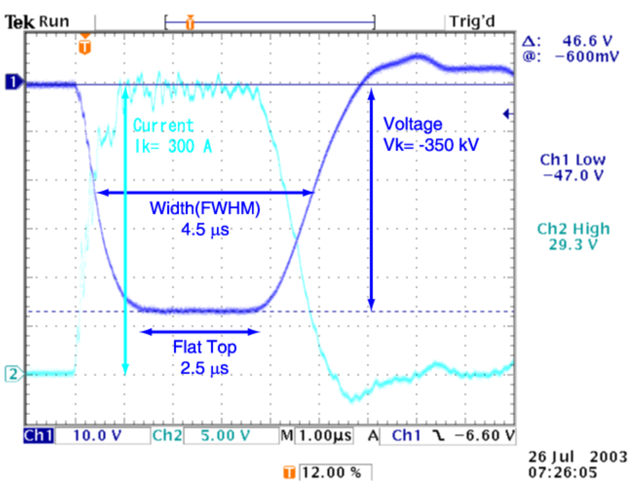

Figure 5: Waveform of the cathode voltage (V_k) and the current of the klystron.

Continuous operation test

We performed continuous operation test in July 2003. We operated the modulator with nominal condition; V_{PFN} = 45 kV, Vk = 350 kV, and Ik = 300 A at 60 pps repetition rate, for 6 days (140 hours, 3×10^7 pulses). The modulator worked well, except 5 times interlock suspension. One of the suspensions is due to the HV discharge at the klystron, two of them are due to the spurious triggering at the thyratron during the charging, and the others are due to the large reflection pulse detected at the shunt circuit. In each case, no damage appeared anywhere. Then we soon reset the interlock and we could start up again to normal operation. Figure 6 shows time variation of V_{PFN}, V_k, and I_k. At the beginning, Vk droped 1.5 %. After then V_k is constant within ±0.5 %. Ik is also constant within ±0.5 %.

During the operation test, temperature of the cooling water is kept to 25 or 28 degree, Room temperature is kept around 25 degree. Temperature of the modulator oil gradually rose from 25 degree up to 50 degree in about 24 hours.

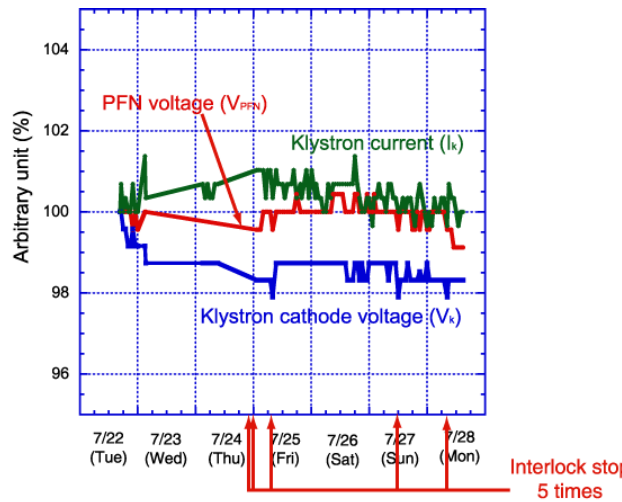

Figure 6: Time variation of the V_{PFN}, V_k, and I_k.

SUMMARY

The compact, oil-filled modulator was constructed and tested. We obtained the expected performance. Continuous operation test proves the stability and reliability of the modulator. One remaining problem is the oscillation of I_k waveform.

The modulator has been used for test of the electron gun [2] and the C-band klystron for half years. So far no serious trouble/damage have been observed.

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[5] K. Iida, et al., “Inverter-type High Voltage Power Supply for Capacitor Charging,” Proc. of Japan Linear Accelerator Meeting 2002, p252-254 (In Japanese).