COMPACT KLYSTRON MODULATOR FOR XFEL/SPRING-8

T. Shintake#, T. Inagaki, RIKEN/SPring-8, Hyogo, 679-5148, Japan
K. Shirasawa, C. Kondo and T. Sakurai, JASRI/SPring-8, Hyogo, 679-5198, Japan

Abstract

XFEL/SPring-8 employs 72 units of the pulse modulator power supplies in order to drive the pulse power klystrons and the electron gun[1,2]. We use single tank design in these pulse power supplies, i.e., all the PFN circuitry and high voltage pulse transformer are installed in a single metallic tank, and filled with insulation oil. This design provides good EM noise-shield performance, and superior operational stability against environmental temperature variation and humidity. The mass production and installation of the modulators are in progress. All accelerating structures and waveguide systems have been installed in the main accelerator. We start high power operation from October 2010 and perform debugging system and processing the accelerating structure at high accelerating gradient up to 40 MV/m maximum. The beam operation is scheduled in March 2011.

MOTIVATION

In the case of the X-ray FEL machine, the high bunch-length compression factor is required to produce a few kilo-ampere beam. As a result, the voltage and phase stability requirements on the accelerating voltage become very tight. In X-FEL/SPring-8 case, the stability requirement on klystron voltage at the most sensitive location is around 100 ppm peak-to-peak.

The quiet EM environment is essential to achieve highly stable power supply with fine voltage control. It is also important for various feedback loops, such as, beam energy and fine trajectory feedbacks.

Productivity, cost and maintainability are also important issue, since there will be 72 modulators.

In order to meet these requirements, we newly developed (1) inverter type precision high voltage capacitor charger, whose pulse-to-pulse voltage stability is better than 100 ppm peak-to-peak, and (2) compact single-tank klystron modulator.

Figure 1 shows installed modulator in the klystron gallery. To achieve very high accelerating gradient (~ 40 MV/m max), it is necessary to install many klystrons and modulators in small space, therefore the modulator has to be very compact.

In this paper, we report what we learned from our R&D work on the single tank compact modulator, and status of mass production and installation.

Fig. 1 Installed single-tank compact klystron modulators. In each 4 m section, we install C-band klystron modulators and control cabinets, which house the VME control, low-level rf system, inverter HV charger and vacuum controls.

shintake@spring8.or.jp

Table-1. Major parameter of klystron modulator.

RF Output from Klystron	50 MW
Pulse Repetition Frequency	60 pps
PFN Capacitor	29.3 nF x 16 section
PFN Impedance	4.4 Ω
PFN Charging Voltage	50 kV
Pulse Transformer	1 : 16
Klystron Gun	-350 kV, 320 A
Tank Dimension	W1.7m, D1m, H1.2m
Total Weight	4.5 ton

MODULATOR CIRCUIT

We employed the conventional line-type modulator circuit using thyratron switch tube. Its electrical parameters are summarized in Table-1.

In recent years, the solid state switch technology has been rapidly advancing due expanding market in the electro-motor car. However it is not yet enough to switch higher voltage; at least a few kV, with a very high speed such as dI/dt = ~5 kA/100 nsec, which is required in our modulator (rf pulse from the C-band klystron is only 2.5 usec width, thus the switching speed is big issue). Therefore, we did not employ the solid-state switches in our modulator at this moment.

We use E2V CX1836 thyratron (two gap metal ceramic, deuterium filled, barium aluminate impregnated cathode). Table-2 summarises thyratron tube parameter. We operate the tube at lower rating, and there is fairly large margin on the average current; it is about six times lower than its maximum rating. It is important to maintain stable H_2-gas pressure for a long term operation. To achieve best switching performance, we employ the twin-pulse trigger circuit (refer to CX1836 data sheet).

The PFN line consists of 16 film capacitors of 29.3 nF, and its characteristic impedance is 4.4 Ω. To reduce the number of components and simplify the circuitry, we eliminated the tuner from the series inductances in the PFN line. We performed computer modelling on PFN pulse response including pulse transformer and klystron capacitance. From the modelling, we determined optimum value of these inductances, i.e., number of winding and diameter of coils. In the mass production, we always obtained fairly identical pulse waveforms from each modulator; therefore no additional tuning was required.

FARADAY CAGE

Basic idea of single tank compact modulator is practical realization of Faraday cage. If an electric charge is enclosed in a boundary made by perfect conductor, all of the electric field lines from the charge are terminated with image charges induced on inner surface of the boundary. Therefore, we can not see the charge from outside. The Faraday cage becomes an ideal EM shield. To realize this concept in the klystron modulator, firstly we have to make a good metal box, then we carefully design noise filters on the penetrating cables through the boundary.

Table-2. Thyratron (CX1836) parameter and operation condition.

Parameter	Max Rating	Present Use
Anode Voltage	70 kV	50 kV
Anode Current	10 kA	5 kA
Average Current	10 A	~ 1.5 A
Operating Frequency	10 kHz	60 Hz

ENGINEERING DESIGN

(1) Tank was made by steel with nickel plated. This is based on "monocoque structure concept", which maximizes the space availability.

(2) As the oil seal, we use O-ring. All of the tanks were checked with He-leak tester.

(3) The EM noise leakage from thyratron switching was made very low. Typical noise voltage leaking on a pair line for the heater power is only 5 volt peak on 200 V AC-line voltage[3].

(4) By employing oil-immersed design, possible corona discharge at high voltage terminal was perfectly eliminated. In the conventional modulators, after long term operation, corona discharge and associated carbonized contamination on electrode frequently caused surface flashover on HV components.

(5) By introducing water cooling system with free oil convection, we eliminated air cooling fan. In the conventional modulators, air fan and its filters were troublesome components which required routinely maintenance.

(6) By using common hardware and control software in the all klystron power supplies at different frequency ranging from L-band, S-band, C-band and also in the electron gun, the machine productivity and maintainability have been improved.

CONCLUSIONS

Single tank compact modulator has been developed for XFEL/SPring-8. Mass production and installation will be completed in summer 2010, and high power operation of all system is scheduled from October 2010.

ACKNOWLEDGEMENT

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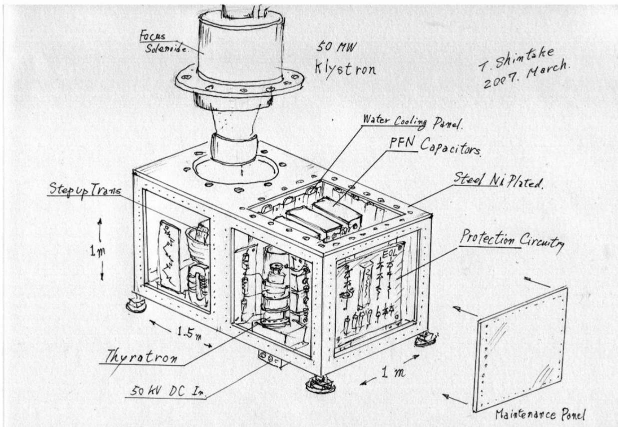
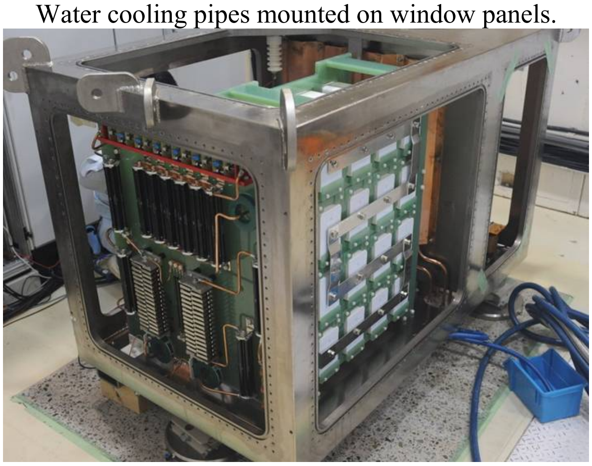


The conceptual design.

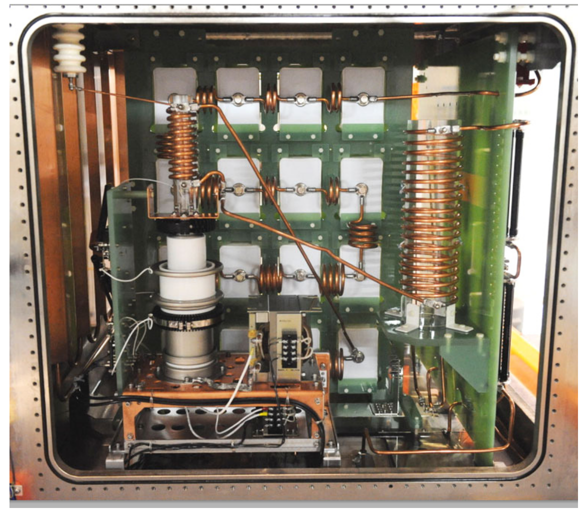
Water cooling pipes mounted on window panels.



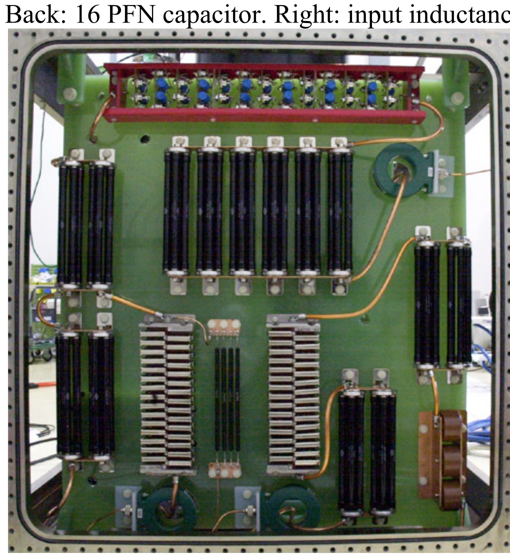
Installed components in the steel "monocoque" tank.

Pulse transformer using epoxy molded windings and low loss Super-E core.

Fig. 2 Developed modulator details.



Front: thyratron and its bias and heater transformer. Back: 16 PFN capacitor. Right: input inductance



EOL diode and resistor, tail and shunt circuits are mounted on epoxy board.

Heater power line, monitor signal output and 50 kV charging power go through connector box at the bottom of tank.

Fig. 3 Developed modulator details.