

DEVELOPMENT OF THE KLYSTRON MODULATOR USING A HIGH-VOLTAGE INVERTER POWER SUPPLY*

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Abstract

The existing klystron modulator in the Linac use a 60 Hz high voltage power supply and adopt traditional L-C resonant charging scheme with De-Qing circuit. The stability of the output high voltage is not satisfactory especially when the AC line voltage fluctuations. If an inverter power supply is used as a HV generator, it will just meet the demands A high frequency inverter switching makes the overall system size small. The command-charging feature can guarantee the high reliability of switching function. In order to increase the stability, operating reliability and comply with the PLC (programming logic controller) and touch screen control system of PLS, an upgrading works is now in progress. This paper will discuss some inverter power supply design considerations and show the test results.

INTRODUCTION

The existing modulators of PLS 150 MW test lab began operation form 1991. The main component of high voltage charging power consists of a motorized 3-phase variable phase control (SCR), a high voltage step-up transformer, a rectifier assembly and charging inductance as show in Figure 1. After more than ten years' operation, some components are no longer in good condition and circuit failure occurred often. The stability of the output high voltage is not satisfactory especially

when the AC line voltage fluctuations. The control of the modulators is based on manual method and therefore can not meet the requirement of new control system of PLS. Development of inverter power device was begun since 1996. In 2005, the modulator upgrade program using inverter power supply started. The upgrading includes two major parts. One is the replacing old HV powers with four 50 kV constant-current charging powers (Dong-A Hitec). The other is the addition of PLC in modulator as local machine controller. In the new control system, PLC achieves command control, status-monitor, safety interlock and real-time communication with the IOC.

SYSTEM DESCRIPTION

Klystron

The klystron currently used in the PAL linac is the Toshiba model E-3712, which was originally rated at 80 megawatts and 4 microseconds and 16 kilowatts average RF power. This tube is a pulsed cathode design with an oxide cathode. However, this new klystron station is designed to be easily adaptable to the other klystron tubes in the event it becomes necessary to change over. The nominal parameters of the klystron station are listed in Table 1.

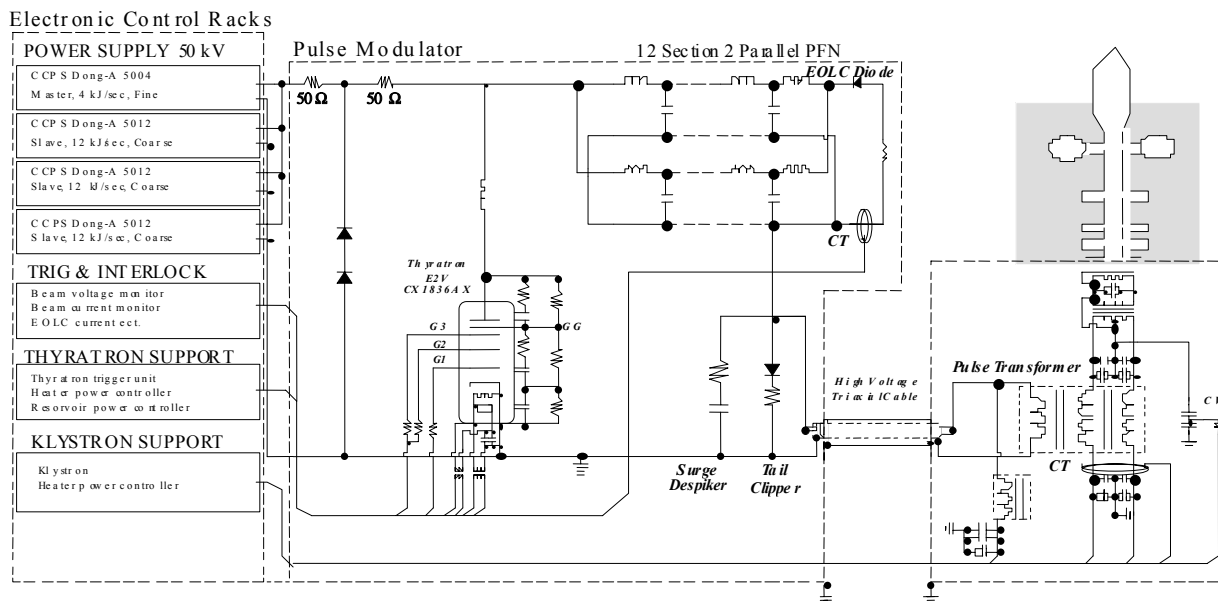


Figure 1: Simplified circuit diagram of line-type modulator for klystron station.

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Table 1: Specifications of the klystron

Parameter	Value
Frequency (MHz)	2856
Peak power (MW)	80
Efficiency (%)	44
Gain (dB)	53
Pulse Length (us)	4
Pulse rate (pps)	50
Beam voltage (kV)	391
Beam current (A)	474
Weight (kg)	380
Height (m)	1.9

Modulator

The existing modulator uses a traditional resonant charging scheme. The charging voltage regulation of the linac is done by a de-Q'ing circuit. PAL modulators have a simple de-Q'ing controller and test results show a stability of 0.2% (rms). The essential modulator performance specifications are listed in Table 2.

The goals for the system are upgrade compact size, remote operation via computer and good reliability. The quest for compact size influenced all of the design choices in the system. Two of the major results of this quest are the use of high power density switching power supplies and compact high voltage PFN capacitors [1]. The modulator is a thyatron-switched, line-type, transformer coupled design. It is similar to standard practice for high power pulsed cathode klystron modulators.

Table 2: Specifications of the modulator

Parameter	Value
Max. peak power (MW)	150
Max. average power (kW)	29.3
Step-up ratio	1 : 17
PFN voltage (kV)	48
PFN impedance (Ω)	3.73
Flat top width (us)	4.0
High voltage pulse length (us)	6.5
Pulse energy (J)	975.5
Pulse repetition rate (pps)	30

Charging System

Pulse forming network (PFN) is energized with capacitor charging switch-mode power supplies. Four SMART 5015 power supplies (Dong-A Hitech model) are used in parallel. This combination can charge the pulse forming network (PFN) to 50 kV at 57.8 kJ per second. The charging voltage is going linear up to the desired PFN level V_{DC} with charging time T_C as shown in Figure 2. After dwell time T_D , a main switch is triggered to discharge the PFN. The next charging cycle

of PFN starts with delay time T_I . This command charging provides safe operation for the thyatron recovery. The peak charging power P_O is given by E_O / T_C and the average charging power P_{AV} is given by E_O / T_P , where E_O is the PFN energy $C_O V_{DC}^2 / 2$ and T_P is the charging-discharging period [2].

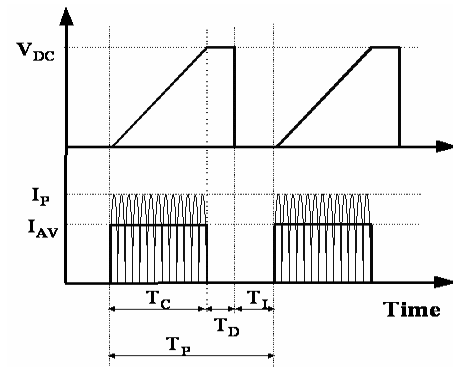


Figure 2: Charging voltage and current waveform of PFN.

The average current I_{AV} , the peak current I_P , and the resonant energy E_R are given by

$$I_{AV} = \frac{2}{\pi} I_P, \quad I_P = \frac{V_{DC}}{Z}, \quad E_R = \frac{1}{2} C_R (2V_{DC})^2$$

where V_{DC} is the source voltage driving the L-C circuit, Z is the resonant impedance, C_R is the capacitance of the resonant circuit. Then, the series resonant inverter can transfer maximum power P_O

$$P_O = \frac{1}{2} V_{DC} I_{AV} = \frac{1}{\pi} \frac{V_{DC}^2}{Z} = f_R E_R$$

where f_R is the resonant frequency. Therefore, a basic design parameter is C_R that is to be decided for the peak output power P_O with given parameters V_{DC} and f_R . If the switching frequency f_{SW} is smaller than the f_R , it is given by V_{DC} and f_{SW} . The supplies are based on a series-resonant, IGBT switched 50 kilohertz inverter. Careful attention was paid by the manufacture to thermal design of the inverter and transformer/rectifier to achieve 12 kW output power. The series resonant inverter power supply is developed for the capacitor charging application. The resonant frequency is 62.5 kHz with 4.4 μ F capacitor and total series inductance 1.5 μ H.

Pulse Forming Network

The PFN is made up of two parallel networks. Each of these is designed as a 12 sections, a type-E PFN with a nominal impedance of 3.73 ohms. The PFN is air insulated in a separate compartment of the modulator enclosure. Air insulation was chosen over oil or gas insulation in order to minimize and simplify maintenance time. The PFN inductors are simple solenoids wound of 11 turns from 0.4 inch diameter copper tubing on a 4 inch diameter, UHMW-PE, cylindrical support structure. A copper tuning slug is mounted on an axial, threaded rod for adjustment of the inductance. A slot in the end of

the tuning slug allows for insertion of a dielectric tuning wand to turn the slug and adjust the inductance during modulator operation. The tuning range of inductance is 2-4 μH [3]. Figure 3 shows PFN section (right side) of the modulator.

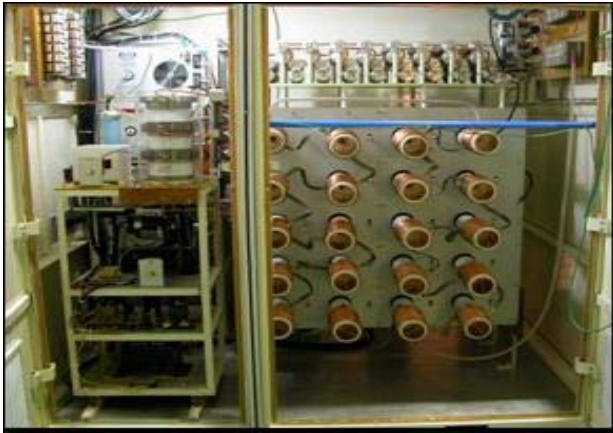


Figure 3: Photograph of PFN station and thyatron stand of modulator.

Thyatron

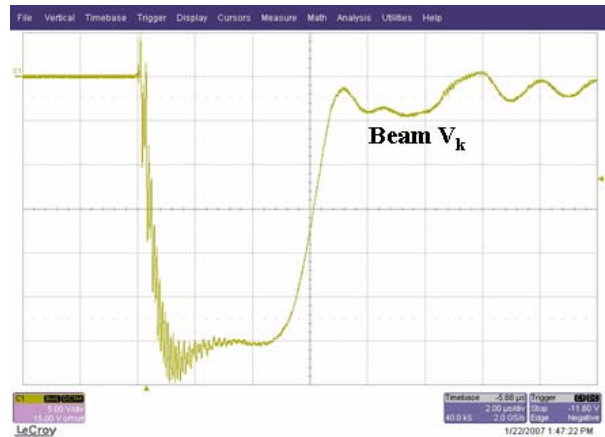
A thyatron switch was chosen because it is well proven in this type of modulator. The basic choices are the E2V CX1836AX and the Litton ITT F-303. The modulator was designed to accommodate any of these tubes, since all are available at PLS. However, the E2V CX-1836AX was chosen as the first choice because of its compact size and dispenser cathode. A thyatron support chassis supplies power to the cathode and reservoir heaters as well as grid bias and triggers. For the CX1836AX, both trigger grids are pulsed with solid state drivers manufactured by E2V (Model MA2709A). The second grid has an adjustable negative bias. An additional power supply is included to produce a keep-alive discharge for the F-303 in the event one of these tubes is installed.

Pulse Transformer

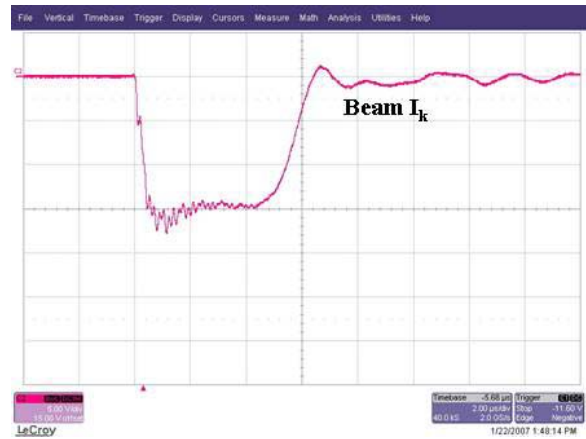
The pulse transformer is nominally rated at 400 kV output with 1 to 17 step-up ratio. It is designed to have less than 1% droops. Initial operation of the pulser indicated a substantial high frequency ringing on the leading edge of the pulse with an approximately 2 megahertz frequency. This was damped out with a resistor-capacitor snubber across the primary of the pulse transformer.

RESULTS AND SUMMARY

A compact klystron station has been designed to power the advanced PAL linac. Switching power supplies are used to achieve a compact size. Preliminary testing has achieved 310 kilovolt pulses with a klystron gun as the load. Figure 4 is showing modulator output voltage and current waveforms. Work is in progress to tune the pulse forming network for optimum fidelity.



(a)



(b)

Figure 4: Modulator output voltage wave forms. (a) Beam voltage 310 kV (50 kV/div), (b) Beam current 300 A (0.05 V/A, 100 A/div)

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