HIGH PERFORMANCE PULSE MODULATOR FOR 80MW S-BAND KLYSTRON IN SPring-8 LINAC

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Abstract

An 190MW compact pulse modulator is constructed to test spare 80MW S-band klystrons(E3712 TOSHIBA) and 2 different type thyratrons(F351 TRITON, CX1937A EEV), as well as to provide R&D tool for the development of high performance modulator. Typical specifications of the modulator are 190MW peak power, 390kV peak beam voltage, 60pps pulse repetition rate, 2.2μS flat-top pulse width with less than $\pm$ 0.15% of beam voltage. Compared with conventional modulator, new technologies were used in the several points such as a 40MHz inverter power supply, a command charging, a remotely controlled tunable slug of PFN coil to improve the stability of the output voltage, to prevent a thyratron prefire and to achieve an easy adjustment of pulse flatness.

1 INTRODUCTION

The S-band injector linac of SPring-8 is 140m long, and maximum electron energy is 1.15GeV. The main high power RF components of linac are composed of 13 units of E3712 S-band klystron tube and conventional pulse modulator. Table 1 shows the specifications of E3712 klystron.The conventional pulse modulator for 80MW klystron have been operated for 11,000hr in the past two years. It is a line type pulser because of its well-established technology and reliability. In order to make a pulse modulator more efficient, the high performance modulator was designed since last years,aiming at easy maintenance, compact size, low cost, high stability. A test modulator was constructed using three inverter type HV power supplies in paralled for the charging power supply. This paper presents the circuit design, specifications and the performance data.

2 MODULATOR SPECIFICATION

Table 2 shows the main specifications of test modulator. As the 80MW klystron tube requires about 400 kV on its cathode voltage and the thyratron anode voltage should be less than 50kV, a pulse transformer with turn ratio of 1:17 was selected.Therefore, the modulator generates pulses with the peak voltage of more than 23.5kV and the peak current of more than 8160A. In order to accelerate an electron beam with the pulse width of 1μsec, the flat-top of klystron beam voltage is required to be more than 2μsec. The long-term regulation and the pulse flatness of the klystron beam voltage is decided to be less than $\pm$ 0.15% to prevent RF phase modulation and microwave power fluctuation.

Table 1: Specifications of E3712 S-band Klystron

	typical	max.	
Peak RF output power		80	MW
Beam voltage	396		kV
Beam current	480		A
Efficiency	44		%
Gain	55		dB
Microperviance	1.96		
Pulse width (beam)		6.2	µS
Pulse width (RF)		5.0	µS
Drive power	300	500	W
Pulse repetition rate		60	pps
Frequency	2856		MHz

Table 2: Main specifications of the test modulator

Peak output power	190 MW
Average output power	78 kW
PFN charging voltage	50 kV
PFN impedance	2.85 Ω
Peak swiching current	8772 A
Pulse width (ESW)	5.5 µS
Pulse width (flat top)	> 2µS
Pulse flatness	±0.15%
Pulse risetime	<1.5µS
Pulse falltime	< 3.0 µS
Pulse repetition rate	60 pps
Pulse transformer turn ratio	1 : 17

3 MODULATOR CIRCUITS

Fig.1 shows simplified circuit diagram of the test modulator. The features of this modulator are :

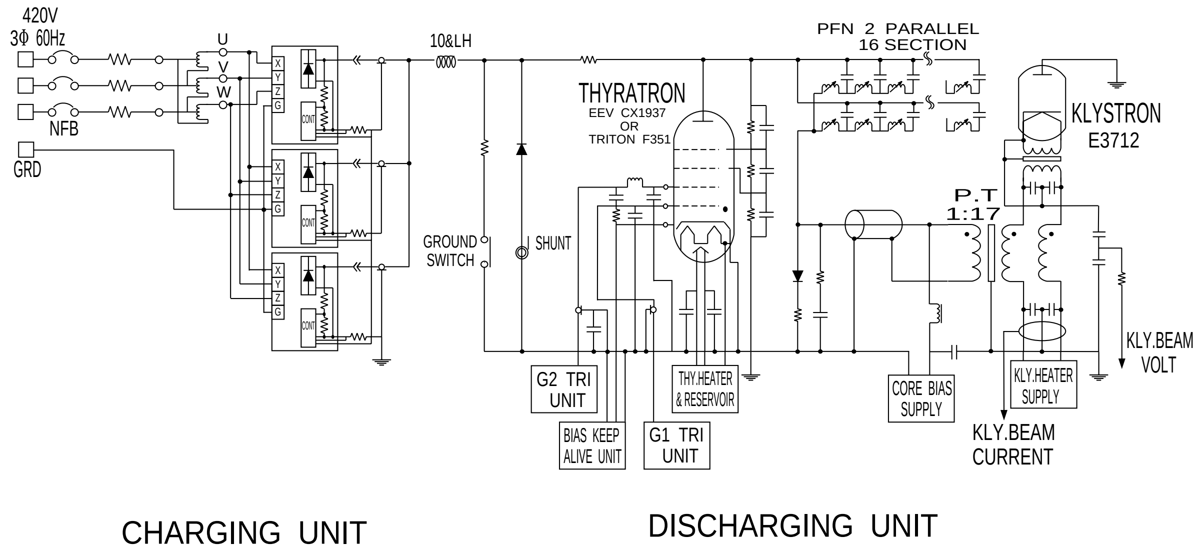


Figure 1: The simplified circuit diagram of the test modulator

Table 3: Specifications of major parts in the test modulator

Inverter power supply	Model 303S A.L.E SYSTEMS, INC. ! ! Output voltage 50kV current 1.5A Charge rate average 30kJ/s peak 37.5kJ/s Voltage regulation < 0.1% Efficiency 90%
Thyratron shunt	diode 45 (2.5kV,7.7A) in series R 8 (15 Ω,500W) in series,parallel
Tail clipper	diode 10 (5kV,4.5A) in series R 4 (10 Ω,500W) in series,parallel
Serge dispiker	C 0.0325μ F, 55kV DC R 6 (25Ω,500W) in series,parallel
PFN	2 parallel, 16section C total 32 (0.0325μF, 55kV) L total 32 (0.28μH, max.)
Thyratron	CX1937A EEV (75kV, 15,000A) F351 TRITON (55kV, 10,000A)
Triaxial cable	model# TRIAXIAL Isolation Design
Pulse transformer	1 : 17 ratio SI - 8164 Stangenes Industries, Inc.

1. Direct constant current charging by three inverter power supplies.
2. Without De-Qing circuit.
3. Command charging.
4. Improvement of maintenance due to reduction of several high voltage components,for example IVR,charging choke,hold-off diodes,etc.

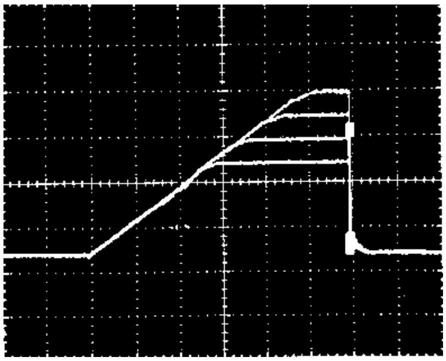
In addition to these points , we designed as follows :

1. Remote control for tunable slug of PFN coils.
2. Counter circuit to detect thyratron misfire.

The modulator cabinet size (involved power supplies rack) is 2700(W) × 2300(H) × 1500(D), this is 57% of the current cabinet volume of the SPring-8 modulator. Table 3 shows the specifications of major parts in test modulator.The inverter power supplies are state of the art switch mode power supply,designed primarily for use in pulsed power applications such as laser system and capacitor charging.The voltage reversal which is cause by mismatching a PFN characteristics impedance and klystron tube impedance forces a large surge current to flow through the output rectifiers in the inverter power supply. Therefore,the protection circuit with series terminating resistors and freewheeling diodes was carefully designed.

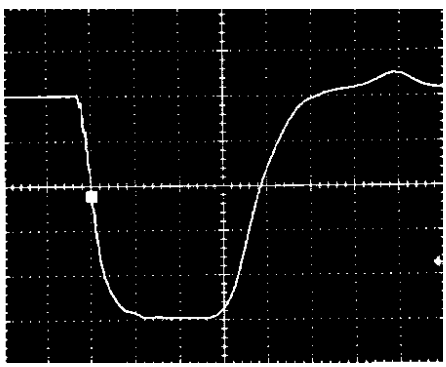
4 ACHIEVED PERFORMANCE

A preliminary test of new modulator was started in April and initial data have been obtained. Fig.2 shows the one cycle of charging voltage profile of PFN capacitors, as set a PFN voltage of 20∼35kV at 5kV step. The time added charge time to dwell time is fixed 15ms, and the charge time was varied linearly along with PFN charging voltage. In the case of change a pulse repetition rate, only the dead time is changed. Fig.3 shows the typical waveform of klystron beam voltage and its flat-top(Beam voltage and current are 396kV,480A). In this case, the test modulator was operated at repetition rate of 30pps and a PFN charging voltage of 51.1kV. After carefully adjusting tunable slug of PFN coils, the flat-top pulse width of klystron beam voltage was achieved the 2.2μs with ±0.15% which is designed values. The long-term(30hr)operational characteristics of klystron beam voltage was investigated in condition at repetition rate of 30pps, a PFN charging voltage of 40kV, two inverter power supplies. As a result, test modulator has achieved the output voltage fluctuation of less than $\pm0.15\%$.



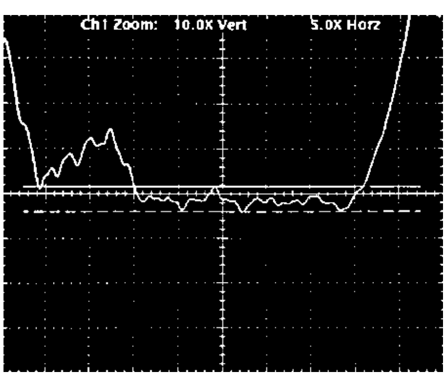
Vertical :10kV/div
Horizontal :2.5mS/div

Figure 2: Charging Voltage Waveform of PFN



Vertical :80kV/div
Horizontal :2μS/div

Figure 3: Klystron Beam voltage waveform



Vertical :2kV/div
Horizontal :400nS/div

Figure 4: Flat-top of klystron beam voltage

5 DISCUSSION

We have fabricated a test modulator and tested its performance. This modulator have not yet satisfied with full operation, which is to be used three inverter power supplies, a repetition rate of 60pps and a PFN voltage of 50kV. Speculated causes of the problem are as follows,

1. The deficiency of cooling water capacity supplied for inverter power supply

   The high voltage parts of inverter power supply is mounted in Freon liquid, and the cooling method which is condensed evaporated Freon by cooling water was adopted. In case of repetition rate of 60pps and a PFN voltage of 50kV, inverter power supply was stopped by internal temperature interlock after 40 minutes operation.Our cooling water system is able to supply at a rate of 8ℓ/min. and 32∼34℃ water through three inverter power supplies. Even thought these values are within the upper limit of required cooling water specifications, the cooling water deficiency may be a main reason to stop long-term operation.

2. The power factor of inverter power supply

   It is described that the power factor of inverter power supply is 0.9 in instruction manual. But in present, the power factor was measured to be about 0.67 in case of repetition rate of 40pps and a PFN charging voltage of 50kV. It is necessary to improve the power factor of inverter power supply by way of reconsidering both the choke coil inductance in smoothing circuits and the charging time of PFN.

6 CONCLUSION

High performance modulator for 80MW klystron was designed and fabricated,good performance which the flat-top width of klystron beam voltage with $\pm0.15\%$ flatness was 2.2μs and voltage regulation was less than $\pm0.15\%$ for long-term operation has achieved. To operate continuously the test modulator for full operation, the deficiency of cooling water capacity and the power factor of inverter power supply should be improved.

7 ACKNOWLEDGMENTS

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