Performance Characteristics of the Pulsed High Power Klystron Tube for PLS 2-GeV Linac*

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Abstract

PLS 2-GeV Linac employs the E-3712 klystron tubes manufactured by the TOSHIBA as one of the pulsed high power microwave sources. The rated power of the tube is 80-MW at 4 μs pulse width with 60Hz pulse repetition rate. As a part of the main linac we have completed the installation of two units of the E-3712 klystron tubes and the matching 200-MW modulators together with the accompanying waveguide networks and the accelerating columns. Since all the components are exposed as a virgin to high power microwave, careful power conditioning procedures are underway. The rest of linac components installation is also underway. We present the performance characteristics of the E-3712 klystron tube measured with the water load. The result of the initial power conditioning operation for the waveguide network and the accelerating structures installed as a part of the PLS 2-GeV linac is also presented.

I. INTRODUCTION

The PLS 2-GeV electron linac design [1] employs SLAC type S-band accelerating structures tuned at the frequency of 2856MHz, and the microwave output power requirement is more than 60 MW with the pulse width of minimum 4 μs. Following this design requirement the allowed high power klystron tubes available in the world are the SLAC-5045 and E-3712 klystron tubes manufactured by the Stanford Linear Accelerator Center in U.S. and the Toshiba company in Japan, respectively.

The type of the S-band pulsed klystron tubes under operation for the several large linear accelerators currently in operation or under construction world wide are shown in Table 1.

Table 1. Type of the pulsed high power S-band klystron tubes used in the large electron linacs.

e⁻-Linac	Energy	Klystron type	Power	No.
SLAC/USA	56	SLAC-5045	65 MW	247*
PF-KEK/Japan	3.0	Mitsubishi PV3030	30	40
ATF-KEK/Japan	1.54	Toshiba E-3712	85	9*
BEPC/China	1.4	HK-1	22	16*
ORSEY/France	1.85	----	24	15
ELETTRA/Italy	1.5	Thomson TH-2132	45	8*
PLS/Korea	2.0	Toshiba E-3712	80	10*
	(GeV)	& SLAC-5045	65	1

* System design includes energy compressors.
(Note: Data based on the private communication and the "Catalogue of High Energy Accelerators" by HEACC '89, Tsukuba, Japan. This table is not the complete list of the large linacs.)

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This paper presents the performance characteristics of the E-3712 klystron tube and the result of the initial power conditioning operation for the waveguide network and the accelerating structures installed as a part of the PLS 2-GeV Linac.

II. CHARACTERISTICS OF THE E-3712

The dimensional outline drawing of E-3712 klystron tube is shown in Fig. 1, and the operational parameters are listed in Table 2. The electron gun is made out of the dispenser cathode (9cm dia.) and the gun ceramic is tapered to have larger diameter at the anode side. The tube has five integral cavities, and the output cavity has two output waveguide coupling irises facing 180 degree apart each other, which allow more symmetrical distribution of the power flow to the output waveguides. The output waveguides are bent by E-band (go upward) and followed by H-corner (directing forward). Two output ceramic windows are placed such that the dominant electric field is in horizontal direction. The two output waveguides are combined to have a single waveguide by a power combiner. The single ceramic window is designed to withstand approximately 50MW at 4 μs pulse width, and has approximately 40A thick TiN coating to suppress multifactoring. The weight of the tube including solenoid is approximately 1,000kg (tube only: 300kg).

Table-2. E-3712 Klystron tube parameters

Description	Parameter	Description	Parameter
Frequency	2,856 MHz	Peak RF power	84 MW*
Pulse width	4 μsec	Avg. power	18 kW
Rep. Rate	60 Hz max.	Drive Power	500 W max.
Beam Voltage	400 kV	Gain	53 dB max.
Beam Current	500 A	Efficiency	42 %
μ-perveance	2.0	Focusing	electromag.

*100MW at short pulse (1 μs) operation.

III. 200MW MODULATOR FOR E-3712

Main design specification of the power modulator is listed in Table 3. The detailed design features are described in elsewhere [2,3]. Among those design parameters there are several key features that should be noted. To keep the maximum high voltage of the primary side below 50 kV, 1 to 17 turn ratio is chosen for the pulse transformer. The three phase primary voltage control (from 0 to 440 V, 120 kVA max.) is designed to use SCR phase control circuit with the active feedback control using the signal from the DC high voltage output. This SCR circuit replaces the bulky IVR or VVT that commonly used in most of the high power modulators in existing electron linacs.

The active feedback mechanism is providing less than ±0.5% fluctuation in the PFN charging voltage without too much difficulty in the presence of the somewhat high noise level coming from the firing of the thyratron tube. Typically PFN charging voltage stability is achieved using the De-Q'ing method, inspite of energy loss, in many accelerator applications.

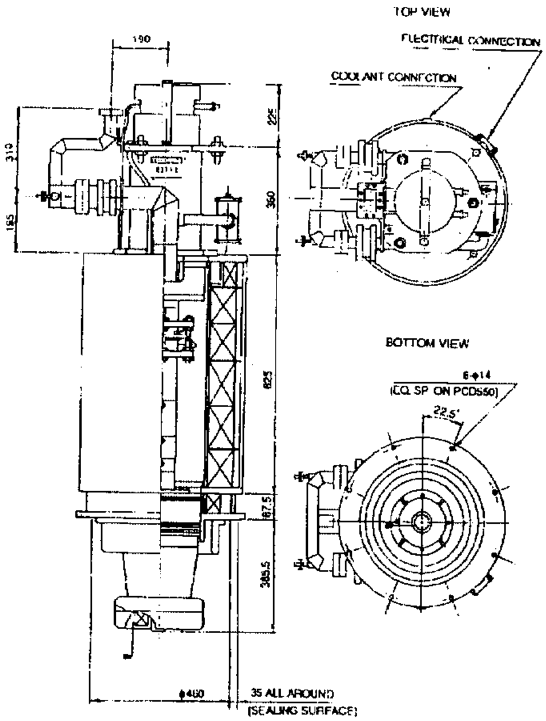


Fig.1 E-3712 Klystron tube dimensional outline

Table 3. Design specifications and the operational parameters of the 200MW modulator

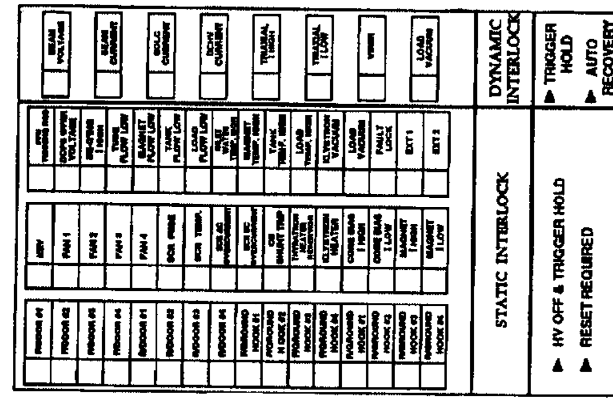
Peak power	80 MW	Peak beam voltage	400 kV
Avg. power	85 kW	Peak beam cur.	500 A
Pulse width(flat)	4.3 µs	Pulse rise time	<1.0 µs
ESW	~7 µs	Pulse fall time	<2.0 µs
PFN impedance	2.6 Ω	Pulse flatness	±0.5 %
Pulse trans turn R	1 : 17	Primary AC- voltage control	SCR phase (feedback)
Thyratron tube	ITT F-303		

IV. PROTECTION INTERLOCKS

The power modulator has number of interlocks to protect the klystron tube, modulator circuit, waveguides, and accelerating structures. The summarized list is shown in Table 4. Among those list many of the interlocks are intended for the protection of the maintenance crew of the modulator. During the system operation the most frequently activated interlocks are vacuum and VSWR. Table 5 is the summary of the vacuum and VSWR interlock action set levels and protection methods. The vacuum pressure set values are intended to protect severe multifactoring on the microwave ceramic windows.

It is observed that the general vacuum outgasing during the power conditioning operation tends to be very short bursting type, so it is very important to have very fast interlock action time (action before next trigger pulse) to prevent multiple exposure of microwave pulses.

Table 4. Interlock list for the protection of the klystron tube and the modulator (interlock indicator template).



We used internal interlock relays of TPG-300 (Balzers) cold cathode gauge, and the measured action time was approximately 60msec. We are testing an electronic type relay for making action time approximately 10msec not to make double firing during the 60Hz operation.

Table-5. Vacuum and VSWR interlock conditions

Vacuum	Actions
$P \geq 1.0\text{x}10^{-7}$ torr	Trigger hold off
$P < 5.0\text{x}10^{-8}$	Automatic recovery
$P \leq 5.0\text{x}10^{-7}$	Trigger off & high voltage off locked (manual reset required)*
VSWR	**Actions**
VSWR > 1.5	Trigger hold off
1st/2nd/3rd/4th Fault	1/2/4/8 sec trigger hold (auto reset)
Accumulated 8 faults	Trigger hold off locked (manual reset required)

* When high voltage shut down occurs soft restart computer controls the ramping rate of H.V. rise depending on the vacuum pressure (P is the vacuum pressure near the klystron windows).

V. KLYSTRON PERFORMANCE

The initial tube performance was measured using the microwave absorbing water-load. The water-load provides accurate rf output power by means of the calorimetric measurement. The magnitude and wave forms of the drive power, the forward, and reflected power are measured by the crystal detectors. Fig. 2 shows the rf output power characteristics measured by varying the beam voltage with the pulse width of 4 µsec. Fig. 3 shows the power transfer characteristics for the drive input power level. The output power saturation starts at about 300 W. Tube to tube variation of the beam voltage for the 80MW output power operation ranges from about 390 kV to about 405 kV.

For the beam voltage ripple less than ±0.5%, which is the performance requirement of the modulator, it is expected from the Fig. 3 that the output power fluctuation is approximately ±1.5% (equivalent to about ±1.2MW) of the 80MW. The phase variation due to the beam voltage variation is also measured using the double balance mixer, and the result shows approximately 1 degree/kV, which makes approximately ±2° fluctuation when the PFN is tuned at the best performance level. Typical wave forms of the beam voltage, drive power, and output rf power are shown in Fig. 4.

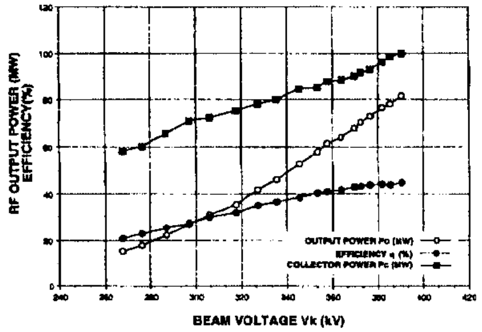


Fig. 2. Microwave output power characteristics of the E-3712 klystron (serial number of PLS-002).

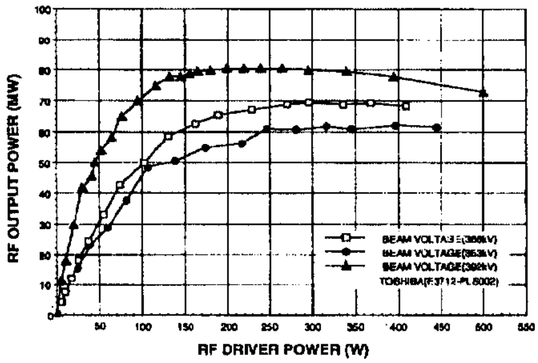


Fig 3. Microwave power transfer characteristics of the E-3712

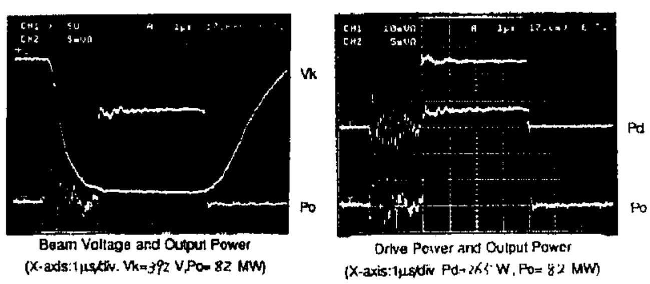


Fig 4. Wave form of the pulses; the klystron beam voltage (V_k), drive power(P_d), and the output power(P_o).

The vacuum behavior during the initial power conditioning operation (no electron beam and no SLED operation, i.e. detuned mode) for the one module of accelerating structures is shown in Fig. 5 (data taken near the input coupler of the 3rd accelerating structures). Total waveguide length for the one module is approximately 16m, and there are 4 sections of 3.07 m long accelerating structures. The schematic structure and vacuum system for one module are illustrated in Fig. 6. Typical residual gases measured near the accelerating structure were hydrogen, nitrogen, and molecules of water vapors.

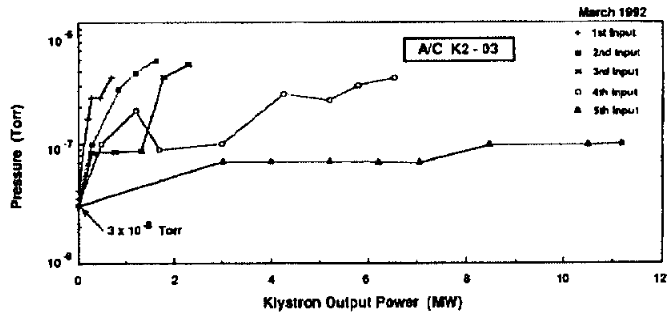


Fig. 5. Vacuum history of the accelerating structures during the power conditioning operation.

It was observed that the large amount of gas released by a burst tends to move upward near the microwave window before they are pumped away by the nearby ion pumps. The migration of burst gas seems responsible for making consecutive vacuum outgasing caused by the multifactoring near the high gas pressure region. Other interesting phenomena observed during the conditioning operation was that one can make audible sound detection (using such as sound noise detector or stethoscope) for the region of frequent multifactoring, especially inside the waveguide.

Due to the installation schedule conflict with the other utility the conditioning operation was performed up to near 50 MW. Overall observation gave series of lessons, especially the importance of vacuum measurement together with the VSWR and the reflected microwave power. It contains many informations about what is happening during the pulsed high power microwave is passing through the long waveguide networks including many vacuum flanges, and accelerating structures.

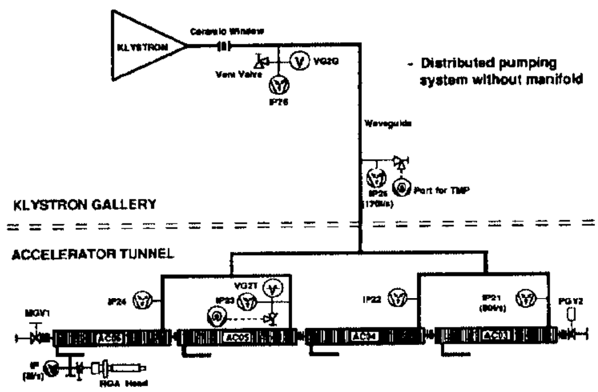


Fig. 6. Schematic diagram of the vacuum system and overall structure for the one linac module powered by a klystron.

VI. REFERENCES

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[2]. M.H. Cho, S.H. Nam, J.S. Oh, and W. Namkung, "Design of 200MW Pulse Modulator for PLS 2-GeV Electron Linac," *ibid.*, Vol.2, pp. 1591-1593 (1992).

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