KLYSTRON-MODULATOR SYSTEM PERFORMANCE FOR PLS 2-GEV ELECTRON LINAC

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Abstract

The 2 GeV electron linac at the Pohang Accelerator Laboratory(PAL) has been operated as a full energy injector for the Pohang Light Source(PLS) since December 1993. Total 12 units of high power klystron-modulator(K&M) systems are under continuous operation in the PLS linac. The peak power of the modulator and the klystron are 200 MW and 80 MW, respectively. The total accumulated high-voltage run-time of the oldest unit among the 12 K&M systems has reached nearly 50,000 hours as of May 2000 and the summation of all the units' high voltage run-time is approximately 541,000 hours. The overall system availability is well over 90%. In this paper, we review overall system performance of the high-power K&M system and the operational status of the klystrons and thyratrons, and overall system availability analysis for the period of 1994 to Dec. 1999.

1 INTRODUCTION

The Pohang Light Source is a third-generation synchrotron radiation facility. It is mainly consisted of a 2 GeV full energy electron injection linac and a 2.0 GeV storage ring (SR). The 2 GeV full energy electron beam from the linac is transported through a beam transfer line (BTL) to the storage ring. Total 12 units of high power klystron-modulator (K&M) systems are under continuous operation in the PLS linac. The peak powers of the modulator and the klystron are 200 MW and 80 MW, respectively. The klystron output frequency is 2856 MHz. Each klystron output is compressed with a SLED and supplied to four of three-meter long accelerating columns. The linac has been operated as a full energy injector for the PLS since December 1994. Annual operation hour of the K&M system is about 6,000 hours.

2 KLYSTRON AND MODULATOR

To satisfy PLS linac design requirements, E3712 S-band klystron tube is selected as a main microwave source. The tube is manufactured by toshiba in japan. Total twelve klystrons are currently under operation, and eleven out of twelve klystrons are E3712. At the linac preinjector, a SLAC 5045 (60 MW peak) klystron is used. The modulator that mates with the klystron tube is manufactured in Pohang Accelerator Laboratory.

2.1 Klystron

Operational parameters of the toshiba E3712 and SLAC 5045 klystron tube are listed in Table 1. The klystrons have two output ceramic windows to accommodate 80 MW and 60 MW peak power, respectively. The two outputs are combined after the window by a power combiner. The microwave power is compressed with a SLED to enhance accelerating field in the accelerating columns. Maximum accelerating field gradient of linac is 17 MV/m.

Table 1. Parameters of the E3712 and 5045 Klystron.

Description	**Toshiba E3712**	**SLAC 5045**
Frequency	2,856 MHz	2,856 MHz
Pulse-width	4 μs	3.5 μs
Repetition Rate	60 Hz Max.	180 Hz Max.
Beam Voltage	400 kV	350 kV
Beam Current	500 A	420 A
μ-perveance	2.0	2.0
RF Output Power	84 MW Peak	60 MW Peak
Drive Power	500 W Max	600 W Max
Gain	53 dB Max	49 dB Max
Efficiency	42 %	40 %
Focusing	Electromagnet	Electromagnet

2.2 Modulator

Table 2. Modulator Specification.

Description	*Parameter*
Peak Power	200 MW max.
Average Power	289 kW max
	48 kW normal
Repetition Rate (PRR)	180 Hz max.
	30 Hz normal
Peak Output Voltage	400 kV
ESW	7.5 μs
Flat-top Width (<±0.5%)	4.4 μs
Charging Time	5.76 ms

Specifications of the modulator are listed in Table 2. Maximum repetition rate of the modulator is 180 Hz as given in Table 1. However, the normal operating rate is 30 Hz. The injection rate of the electron beam to the PLS storage ring is 10 Hz. The modulator can be divided into four major sections: a charging section, a discharging section, a pulse transformer tank, and a klystron load. Three thyratron types have been tested and installed in the modulator: ITT F-303, EEV CX-1836A, and LITTON L-4888. All three types has similar electrical specification, and the ITT F-303 specification is given in Table 3. Forced air-cooling is used for the thyratron. Two triaxial cables in parallel are used to make electrical connections between the PFN and the pulse transformer. The pulse transformer has 1:17 turn ratio. Components in the pulse transformer tank are immersed in high voltage insulating mineral oil.

Table 3. 200 MW Thyratron (ITT F-303) Specification.

Description	ITT Spec.	PLS Spec.	
		30 Hz	180Hz
Peak Power (MW)	200	202	202
Ave. Power	200	45.5	273
Peak Anode V (kV), E_{py}	50	47	47
Peak Anode I (kA), i_b	15	8.6	8.6
Di_b/dt (kA/µs)	50	10.75	10.75
Ave. Anode I (ADC)	8 in Air	3.87	11.61
E_{py} x i_b x PRR (x 10^9)	300	24.3	72.8
E x di /dt x PRR (x 10^{15})	---	30	91

The klystron sits on the pulse tank top cover and is connected to the high voltage output of the pulse transformer. The klystron impedance seen at the primary of the pulse transformer is 2.8 Ω that matches with the PFN impedance. During fine-tuning of the PFN impedance, we intentionally produced about 5% positive mismatch to extend switch lifetime by reducing the thyratron anode dissipation [1, 2].

2.3 Operation Status

Table 4. Status of the Klystron (As of May 29, 2000)

MK No.	Klystron Model	HV Run(hr)	Heater Run(hr)	Installed Date
1	SLAC 5045 (S/N:511A)	45,805	51,138	93.07
2	E3712 (S/N:21011PLS)	50,051	35,238	95.08(18833)
3	E3712 (S/N:PLS002)	49,065	51,079	93.05
4	E3712 (S/N:74003PLS)	48,521	50,999	93.05
5	E3712 (S/N:89004PLS)	47,461	50,272	93.06
6	E3712 (S/N:14012PLS)	47,600	23,041	97.02(26772)
7	E3712 (S/N:65007PLS)	46,527	49,090	93.09
8	E3712 (S/N:82013PLS)	47,476	22,436	97.03(27290)
9	E3712 (S/N:41009PLS)	45,942	48,817	93.10
10	E3712 (S/N:98010PLS)	46,278	48,690	93.11
11	E3712 (S/N:77006PLS)	45,583	48,938	93.11
12	E3712 (S/N:93015PLS)	21,344	17,646	97.10

The current status of the klystron tube is given in Table 4. The klystron that has the longest operation is one in station number 3, and its high voltage run time reaches more than 50,000 hours as of May 2000. Since the installation of the linac in 1993, three klystrons had been failed and replaced. Table 5. shows the failure status of the klystrons.

Table 5. Failure Status of the klystron.

MK No.(Model #)	HV Run(hr)	Heater Run(hr)	Installed Date	Problems
2(S/N:21011PLS)	50,051	35,238	95.08(18833)	Mag. Coil short, Arc(13 kV)
6(S/N:14012PLS)	47,600	23,041	97.02(26772)	Kly. Arc (14 kV), Mag. Noise
8(S/N:82013PLS)	47,476	22,436	97.03(27290)	Heater internal short

Failure modes for the three failed klystrons have been all different kind as listed in Table 5. The klystron in the station 2 had an electrode damage due to a focusing electromagnet shortage. The klystron in the station 6 showed bad internal vacuum and caused frequent internal arcing. Heater shortage occurred in the station 8 klystron. The warranted lifetime of E3712 is 10,000 hours. However, the data listed in Table 4 clearly show that the real lifetime is much longer than the warranted lifetime.

Table 6. Status of the Thyratron (As of May 29, 2000)

MK No.	Thyratron Model	HV Run(hr)	Heater Run(hr)	Replaced Date
1	ITT F-303(S/N:136)	45,805	17,850	97.11
2	LITTON L-4888(S/N:100032)	50,051	40,796(15261)	96.10
3	ITT F-303(S/N:107)	49,065	3,343	99.12
4	ITT F-303(S/N:107)	48,521	51,363	93.06
5	EEV CX-1836A(S/N:1410)	47,461	9,218	99.03
6	LITTON L-4888(S/N:100045)	47,600	40,981	94.12
7	ITT F-303(S/N:137)	46,527	17,719	97.11
8	ITT F-303(S/N:112)	47,476	49,979	93.11
9	ITT F-303(S/N:105)	45,942	49,553	93.12
10	ITT F-303(S/N:114R)	46,278	36,212	95.06
11	ITT F-303(S/N:135)	45,583	20,790	97.06
12	ITT F-303(S/N:138)	21,344	12,037	98.09

In our maintenance plan, we are preparing spare klystrons expecting that the average lifetime will exceed over 45,000 hours. In an effort to extend the klystron lifetime, we have recently developed a new operation mode so called ‘cathode back-heating’. In this operation mode, the klystron heater current is reduced from about 4.9 A (~450 W) to 4.2 A (300 W). By reducing the klystron cathode temperature to 770°C, Ba evaporation rate reduces about 92.3 % compared to the case with 920°C temperature [4]. Current status of three types of thyratron placed in the modulator as listed in Table 6. The high voltage run-hour in Table 6 is the total accumulated hour, and it does not imply the installed thyratron run hour. A thyratron that has the longest run-hour is the one in station 4. It reaches more than 51,000 hours. The main causes of thyratron replacement can be summarized by three problems : high switching jitter, out of reservoir ranging control, and internal electrode or grid short. The fault analysis of the K&M system during the period of January to May of 2000 is shown in Fig. 1. In Table 7, the availability analysis of the system is listed since its installation.

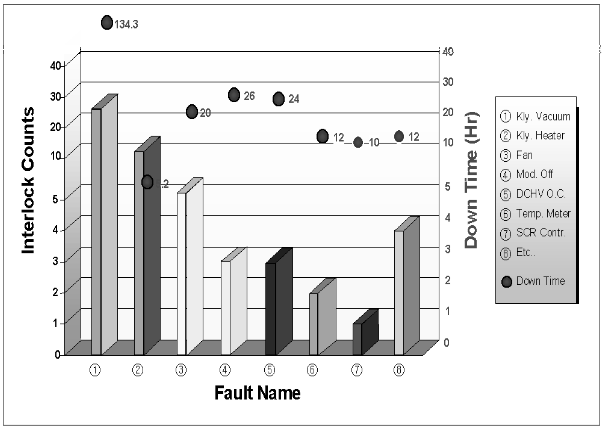

Figure 1. Fault analysis of the klystron and modulator system (Jan. 5, 2000 – May 29, 2000)

Table 7. Availability analysis of the klystron-modulator. (As of May 29, 2000)

As of May 29, 2000

Operation Period	'94	'95	'96	'97	'98	'99	'2000
Total No. of Modulators	11	11	11	11	12	12	12
Operation Time (hr)	4,752	7,152	6,432	7,128	6,816	6,264	2,904
Total Failure Counts	103	175	131	130	289	53	53
Total Down Time (hr)	563	1,075.8	413	529	468	178	243
System MTBF (hr)	28	41	49	55	24	118	55
MTTR (hr/failure)	5.46	6.15	3.15	4.07	1.62	3.35	4.59
Availability (%)	81	85	94	93	93	97	92

A(%) = 1 - FR x MTTR, FR : Failure Rate (No. of Faults / Run Time), MTTR (Mean Time to Repair)

From Fig. 1, the klystron vacuum has the highest fault count and the longest down time. The 7th klystron-modulator has been conditioned of the high voltage from March 23 to April 30 because of the serious vacuum fault in the klystron at March 23. The vacuum fault of the klystron often occurred during the condition of the high voltage. Thus the system availability is reduced for the modulator. The system availability in 2000 is 92 %. From the Table 6, we can see the availability decreases in 2000 compared to the previous years. At 1999, the system availability was about 98 %. The reduction has been caused by the increasing vacuum fault of the 7th klystron. We changed static interlock mode to dynamic fault of the SCR ac over current interlock mode. The over-current was caused by thyratron misfire due to misleading timing signals and electronic circuit malfunction due to electrical noises. We are trying to reduce the system failure count further. The fault count of modulator is shown in Fig. 3 during 1994 to 2000.

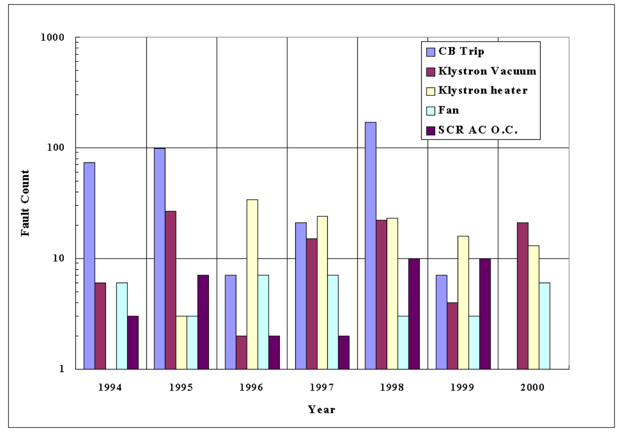

Figure 2. Fault count of modulator during 1994 to 2000.

3 SUMMARY

The K&M system is a key unit in linac facilities. PLS linac has 12 units of K&M system. The klystron is the S-band E3712 that is manufactured by Toshiba in Japan. It has about 80 MW peak power. The modulator is designed and constructed in PAL. The modulator has 200 MW peak power. The K&M system started its full operation in 1994. Among the twelve K&M units, one with the longest operation hour has accumulated over 50,000 hours operation time as of May 2000. Fault and availability analysis of the K&M system show that the system is running very stable and reliable, and the performance of the system has been continuously improved. To increase the klystron lifetime, a new operation mode, 'cathode back heating', was newly developed. And we improved interlock system which turned off the heater power supply of the klystron due to the vacuum fault of the klystron.

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