STATUS OF PLS 2-GEV ELECTRON LINAC PERFORMANCE

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Abstract

The 2 GeV electron linac at the Pohang accelerator laboratory (PAL) has been operated continuously as a full energy injector for the Pohang Light Source (PLS) since its completion on Dec. 7, 1994. There has been continuous effort to make the linac system more stable and reliable, such as the modifications of the klystron modulators, temperature stabilization of the main rf drive line, installation of one more klystron-modulator station with the addition of two sets of acceleration sections. The average high voltage operation time of the klystrons (E-3712, Toshiba) installed at the very beginning, 8 tubes are survived out of total 11 tubes, has been reached near 32,000 hours as of May 1998. Current overall system availability is well over 90%. In this paper, we report the major linac system upgrade for the nominal 2.5 GeV operation as well as the system performance and relevant machine statistics such as lifetime of klystrons and thyratrons, and overall system's availability, and others.

1 INTRODUCTION

PLS linac[1] has been injecting 2-GeV electron beams to PLS (Pohang Light Source) storage ring since September 1994. The linac klystron modulator system (K&M system[2]) has started its normal operation at the end of 1993, and the total accumulated high voltage run time of the oldest unit has reached beyond 37,000 hours. At the end of 1997 we have installed one more additional K&M module (total 12 modules with 44 accelerating structures), for the higher beam energy margin. The K&M system is normally operating in 70 to 80% of the rated peak power level to avoid the multipactoring phenomena occurring occasionally in random fashion in the waveguide networks and accelerating structures. The sum of all the high voltage run time of the K&M system is approximately 360,000 hours as of June 1998.

In this paper we have reviewed overall system performance statistics of the high power K&M system of the PLS linac for the period of September 1994 to June 1998. During this 4.5-year period the machine has been in operational mode for total 27,072 hours (counted only the scheduled run time).

2 K&M SYSTEM OVERVIEW

Key features of the K&M system design include 3-phase SCR controlled DCHV power supply, resonant charging of the PFN, resistive De-Q'ing, end-of-line clipping with thyrite disks, pulse transformer with 1:17 step-up turn ratio, and high power thyratron tube switching. The major operational parameters of the K&M system (PLS-200MW modulator) are listed in Table-1. The shot-to-shot beam voltage stability is controlled by the (1) the feedback of the DC high voltage to SCR primary input voltage control and (2) the resistive De-Q'ing. SCR DC feedback provides less than 0.5% fluctuation and additional De-Q'ing stabilizes the beam voltage better than 0.1% level. The details of the system design and performance characteristics are described elsewhere [2].

Table 1: K&M operation parameter summary.

Peak beam power	200MW*max.* (400kV @500A)
Beam vol. pulse width	ESW 7.5μs, 4.4μs flat-top
Pulse rep. rate	120pps *max.* (currently 30pps)
PFN impedance	2.64Ω (5% positive mismatch)
Voltage stabilization	SCR, DC feedback & 5% De-Q'ing
Pulse transformer	1:17(turn ratio), L_L:1.3μH, C_D:69nF
Thyratron switch	heating factor: 46.8x10^9VApps, 8.5kA peak anode current
Klystron tube	drive power:~300W, efficiency.:40%, gain:~53dB, peak power:80/65 MW (currently running at 50 to 65MW)

For the fault free stable operation of the system the thyratron tube is one of the most important active components which require continuous maintenance and adjustment. The thyratron tubes which meet the PLS-200MW K&M system specifications are listed in Table-2 together with their specifications, i.e. ITT/F-303, EEV/CX-1836A, and Litton/L-4888. We have all 3 types of tubes installed in our system, and the performance evaluations are underway. This effort is initiated to improve the system from the frequent occurring fault caused by the irregular recovery action of the thyratrons, which strongly depends upon the reservoir control.

There are three types of system's interlocks, namely dynamic, static, and personal protection interlocks. All the static fault activation is initiated by the relay logic circuit, and dynamic faults which require fast action response are activated using the electronic comparator circuit. When the system operation is interrupted by the static fault it can be recovered either by the automatic remote control computer or by the manual reset switch.

Table 2: Comparison of the thyratron tubes

ITEM	ITT F-303	Litton L-4888	EEV CX-1836A
Heater (Vac/A) *max*	6.6 / 80	6.7 / 90	6.6 / 90
Reservoir (Vac/A) *max*	6.0 / 20	5.5 / 40	6.6 / 7
Peak anode (kV/kA) *for*	50 / 15	50 / 10	50 / 10
Peak anode vol.(kV) *inv*	50	*n/c*	50
Avg. anode cur.(A) *max*	8	8	10
Min DC anode vol.(kV)	2	10	5
Heating factor ($x10^9$) *max*	300	400	*n/c*
dI/dt (kA/μs) *max*	50	16	10
Anode delay (μs) *max*	0.3	0.4	0.35
Trigger jitter (ns) *max*	2	10	10

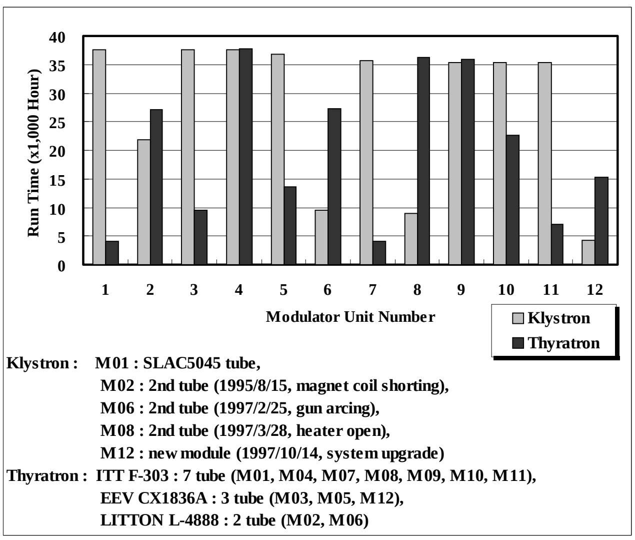

Figure 1: Run time statistics of all klystron and thyratron tubes (as of June 15, 1998).

3 SYSTEM AVAILABILITY STATISTICS

Since the completion of the PLS 2-GeV linac in December 1993 all the K&M systems have been operating continuously except scheduled short term and long term maintenance shut down. Fig-1 shows the accumulated run times of klystron and thyratron tubes as of June 15, 1998. As one can see in the figure rather shorter bars indicate that corresponding tubes have been replaced at least once or more. In fact we have replaced total 3 klystrons and 14 thyratrons during the total ~360,000-hr of operation time (run time sum of all 12 K&M modules). Table-3 & 4 show the calculated statistics of mean time to failure (MTTF) for the klystrons and thyratrons, respectively.

Machine availability analysis has been performed based on the data using the techniques described in detail in reference[4]. The results are summarized in Table-5. The MTBF (mean time between failure) is calculated by dividing the sum of the accumulated modulator run time with the total fault count ($MTBF = N*TO/FC$). The MTTR (mean time to repair) is equal to the total down time divided by total fault counts, $MTTR = TD/FC$.

During the early phase of the operation, from the late 1993 to early 1995, relatively low machine availability ($A = 1-MTTR*FC/TO$) has been obtained. This is due to the maintenance crew training as well as system debugging exercise. Most of time for the repair was spent for the extensive system diagnostics. The major changes that we implemented at the beginning of 1996 were the computer controlled automatic static fault reset and the modification of the circuit breaker (CB) trip interlock. They greatly contributed to the improved availability reaching over 90% as shown in the Table-5. Fig-2 shows the MTTF (mean time to failure) and the MTTR statistics of key component replacement works for the K&M system. For instance, the klystron replacement takes about 16 hours, and the thyratron tube replacement takes around 8 hours. Time estimation counted from the time of the fault to the time of complete recovery of the system.

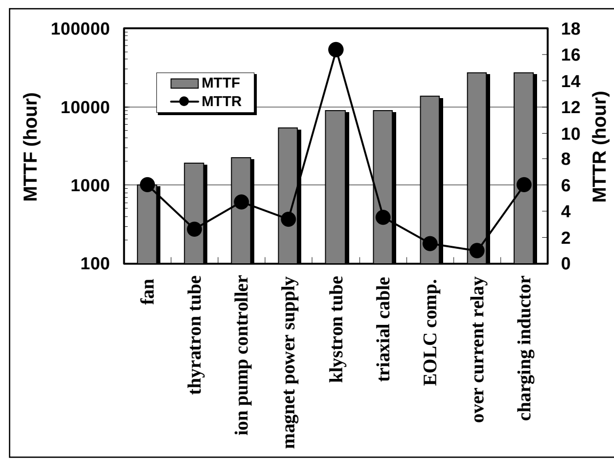

Figure 2: MTTF & MTTR for component replacement (data collection period: 94.9~98.6).

4 COMMENTS ON SYSTEM FAULTS

It has been observed that the most frequent system fault is the circuit breaker (CB) trip. This is mainly due to the problems in thyratron recovery characteristics which depend on the elaborate reservoir ranging (hydrogen gas pressure control in the tube). Thyratron tubes of F-303 and L-4888 require ranging adjustment (see Table-2), and according to our experience they are very sensitive to the effects which may cause internal gas pressure change. Once out of normal operating point self-fire, firing miss, or slow recovery (causes shorting of the PFN charging power supply) can occur. The CX-1836A thyratron tubes require not so delicate ranging according to the manufacturer's specifications.

Other occasional troubles were corona discharges that are found to occur when there are bad contacts in high voltage components. It has been found also that even a small corona discharge disturbs the ground potential, which are configured to have a single point ground connection inside the modulator, causing noise interference in digital displays as well as SCR phase controls.

5 SUMMARY

It has been approximately 5 years since the PLS 2-GeV linac has started its normal operation. We have analyzed the klystron modulator system's performance record for the period, which is the major source of the beam injection failure. It is observed that the average lifetime expectancy of the klystron is over 25,000-hr, and it is getting longer. Lifetime of the thyratron tube also appears to be reasonable except the occurrence of the infant failure, however the major improvement is necessary for the reservoir control which is the main source of the system trouble. The machine availability statistics of the K&M system for the beam operation mode is calculated to be over 90%. It appears to us that there are still lots of rooms for the improvement of the availability more than 95% with the smart design of the protection circuits and control schemes.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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Table 3: Klystron MTTF of the PLS linac.

Period	Per Period			Cumulative					
	Failed		MTTF (hrs)	Total no. of tubes	Failed		Living		MTTF (hrs)
	no. of tubes	Mean age (hrs)			no. of tubes	Mean age (hrs)	no. of tubes	Mean age (hrs)	
1994	0			11	0		11	9,990	
1995	1	18,833	89,671	12	1	18,833	11	16,430	199,558
1996	0			12	1	18,833	11	24,244	285,517
1997	2	27,031	24,960	15	3	24,298	12	21,879	111,812
1998	0			15	3	24,298	12	25,818	127,569
Jyear	Nfp	Tfp	T(MTTFp)	Nt	Nfc	Tfc	Nlc	Tlc	T(MTTFc)

Table 4: Thyratron MTTF of the PLS linac.

Period	Per Period			Cumulative					
	Failed		MTTF (hrs)	Total no. of tubes	Failed		Living		MTTF (hrs)
	no. of tubes	Mean age (hrs)			no. of tubes	Mean age (hrs)	no. of tubes	Mean age (hrs)	
1994	4	5,070	25,885	15	4	5,070	11	7,569	25,885
1995	3	8,828	26,416	18	7	6,680	11	12,366	26,112
1996	3	16,837	26,973	21	10	9,727	11	15,130	26,371
1997	4	23,820	20,712	26	14	13,754	12	12,833	24,754
1998	0			26	14	13,754	12	18,203	29,356
Jyear	Nfp	Tfp	T(MTTFp)	Nt	Nfc	Tfc	Nlc	Tlc	T(MTTFc)

*Note; T(MTTFp) = {(Nfc*Tfc+Nlc*Tlc) of jyear – (Nfc*Tfc+Nlc*Tlc) of j-1year}/Nfp
T(MTTFc) = {(Nfc*Tfc+Nlc*Tlc) of jyear}/Nfc

Table 5: K&M system availability of the PLS linac.

Operation period	1994	1995	1996	1997	1998	Total
Total no. of modulators	11	11	11	11	12	11.2
Operation time (hr)	2,298	7,152	6,432	7,128	3,432	27,072
Total failure counts	103	175	131	130	147	686
Total down time (hr)	563	1,076	413	529	232	2,813
Modulator MTTF (hr)	313	450	540	603	280	442
System MTTF (hr)	28	41	49	55	23	39
MTTR (hr/failure)	5	6	3	4	2	4
Availability (%)	81	85	94	93	93	90