KLYSTRON-MODULATOR SYSTEM AVAILABILITY OF PLS 2 GEV ELECTRON LINAC

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Abstract

PLS Linac has been injecting 2 GeV electron beams to the Pohang Light Source(PLS) storage ring since September 1994. PLS 2 GeV linac employs 11 sets of high power klystron-modulator(K&M) system for the main RF source for the beam acceleration. The klystron has rated output peak power of 80 MW at 4 microsec pulse width and at 60 pps. The matching modulator has 200 MW peak output power. The total accumulated high voltage run time of the oldest unit has reached beyond 23,000 hour and the sum of all the high voltage run time is approximately 230,000 hour as of May 1996. In this paper, we review overall system performance of the high-power K&M system. A special attention is paid on the analysis of all failures and troubles of the K&M system which affected the linac high power RF operations as well as beam injection operations for the period of 1994 to May 1996.

Introduction

The PLS 2 GeV linac employs 11 units of high power pulsed klystrons(80 MW) as the main RF sources. The matching modulators of 200 MW(400 kV, 500 A) can provide a flat-top pulse width of 4.4 sec with a maximum pulse repetition rate of 120 Hz at the full power level. For the good stability of electron beams, the pulse-to-pulse flat-top voltage variation of a modulator requires to be less than 0.5%. In order to achieve this goal, we stabilized high voltage charging power supplies well within requirement by a phase controlled SCR voltage regulator(both AC and DC feedbacks). The K&M system are normally operating in 70% to 80% of the rated peak power level to avoid the multipactoring phenomena occasionally occurring in a random fashion inside the waveguide networks and accelerating structures of the linac system. The sum of all high voltage run time for total 11 K&M systems installed in the PLS linac, is approximately 230,000 hours.
In this paper, we analyzed the overall system availability and the system fault statistics during the PLS commissioning operation. During this period the availability was ~90% for the case of 24 hr maintenance mode with 2-shift works and the availability drooped down to ~75% for the case of day-time only(44 hr per week) maintenance mode. The most frequent type of static fault which requires the attendance of a maintenance crew has been identified as main circuit breaker(CB) trips due to the abnormal behavior of thyratron switches. For the improvement of the system availability the SCR gate hold interlock and the slow start of the DC high voltage together with the automatic remote reset of the static faults using the computer control are adapted.

K&M System Performance

The key features of the K&M system design include the 3-phase SCR controlled AC-line power control, resonant charging of the PFN, resistive De-Qing, end-of-line clipper with thyrite disks, pulse transformer with 1:17 step-up turn ratio, and high power thyratron tube switching. The major operational parameters of the PLS-200-MW K&M system are listed in Table 1.

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 adjustments.

Table 1. Operational parameters of K&M systems.

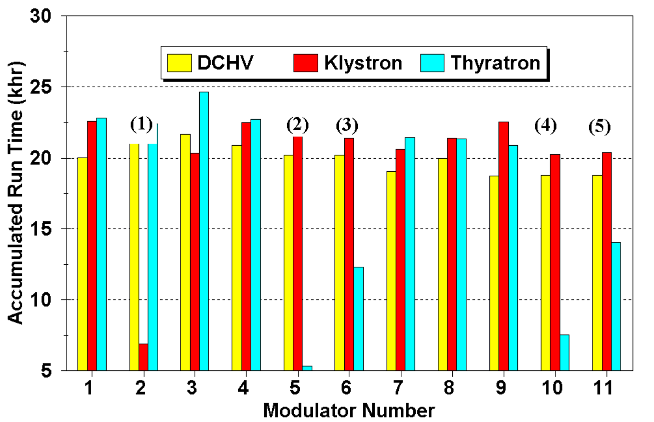
Peak beam power	~150 MW(200 MW max.)
Pulse width	ESW 7.5μs, 4.4μs flat-top
Pulse rep. rate	30 pps(120 pps *max.*)
PFN impedance	2.64Ω(5% positive mismatch)
Voltage stabilization	SCR, DC feedback & 5% De-Q'ing
Pulse transformer	1:17(turn ratio), L_{lk}:1.3μH,C_{st}:69nF
Thyratron switching loading	Heating factor: 46.8x10^9, 8.5 kA peak anode current
Klystron tube	Drive power:~300 W, gain:~53dB, peak power:80/65 MW (currently running at 50 to 65MW)

The thyratron tubes which meet the PLS-200-MW system specifications are listed in Table 2 together with their specifications. Three types of thyratron tubes, ITT/F-303, Litton/L-4888, and EEV/CX-1836A are installed in our system, and the performance evaluations are underway. This effort is initiated to improve the system from the frequent occurring faults(see Fig.3) caused by the irregular recovery action of the thyratrons, which strongly depends upon the reservoir control.

There are three types of system interlocks, namely dynamic, static, and personal protection interlocks. All the static fault activation is initiated by the relay logic circuit, and the dynamic faults which require a 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 remote control computer or manual reset. However, we have been performing all manual resets till July 1995 for the purpose of the experience accumulation, such as to find the type of troubles and system bugs which could provide ideas of the system improvement.

Table 2. Comparison of the thyratron tubes.

ITEM	ITT F-303	Litton L-4888	EEV CX-1836A
Heater(V_{ac}/A) *max*	6.6 / 80	6.7 / 90	6.6 / 90
Reservoir(V_{dc}/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



(1) Klystron replaced with Toshiba E-3712, (2) Thyratron replaced with L-4888
(3) Thyratron replaced with F-241, (4) Thyratron replaced with CX-1836A
(5) Thyratron replaced with L-4888

Fig. 1. Accumulated run times of the K&M systems.

The statistical analysis of the machine availability presented in this paper is applied to two different periods. One period is based on the operational method of the manual reset mode by the maintenance crew only for the period of September 1994 to May 1995. The other is based on automatic reset mode by the remote computer control for the period of May 1995 to May 1996. The major circuit change for the computer controlled reset mode is the CB trip interlock modification ; instead of CB trip activates SCR gate hold and the soft start of the DC high voltage.

System Availability Statistics

Since the completion of the PLS 2 GeV linac installation in December 1993, all the K&M systems have been in operation continuously except scheduled short-term shut downs. Fig.1 shows the total accumulated times of klystron and thyratron heater operation, and the high voltage run. Sum of the high voltage run time of each modulator has reached over 230,000 hour, and the experience accumulated so far provides the valuable information for the stable operation. Fig. 2 shows the monthly failure and down time statistics for the period of September 1994 to May 1995(manual reset) and the period of May 1995 to May 1996(auto reset).

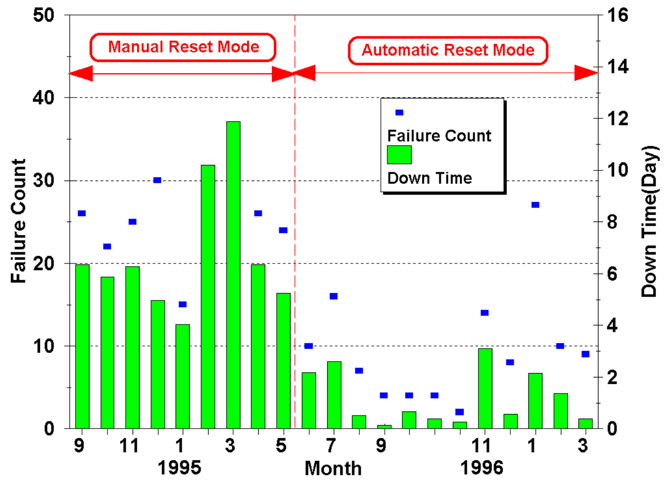


Fig. 2. Monthly failure and down time status of klystron-modulator system.

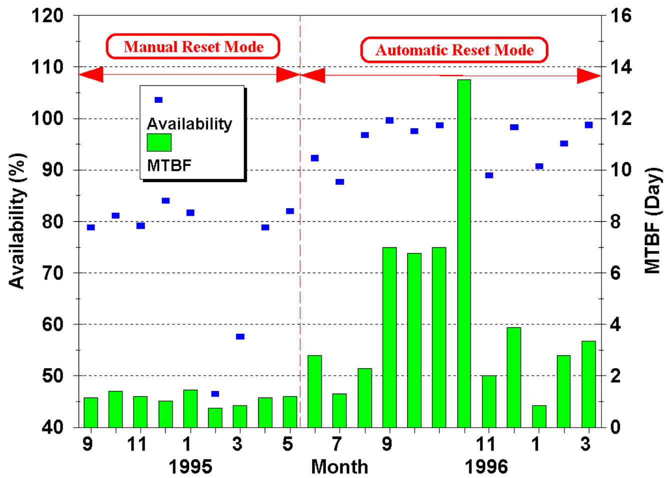


Fig. 3. Monthly availability and MTBF status of klystron-modulator.

Machine availability analysis has been performed based on the data using the techniques described in detail in reference[3]. Fig.3 is the monthly availability and MTBF (mean time between failure) statistics of klystron-modulator system. The table 3. is the summary of the average fault analysis data. The MTBF 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).

One can see in table 3, approximately 76% of the machine availability(A=1-MTTR*FC/TO) has been improved to approximately 96% by applying auto reset mode operation with the simple CB trip modification, which is also shown in

Fig 2 & 3. It indicates most of the system troubles are not so serious, and in many cases they are easily recoverable.

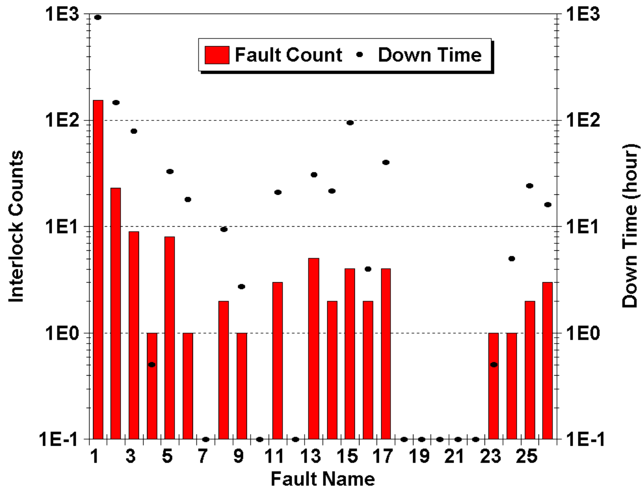


Fig. 4. Interlock status of klystron-modulator system for the period of September 1994 to May 1995.

Table 3. Fault analysis of klystron-modulator system for PLS.

Item	94.9-95.5	95.5-96.5
Number of modulators, N	11	11
Spare no. of modulators	0	0
Operation time(hr)[*1], TO	6000	7560
Total failure counts, FC	226	115
Total down time(hr)	1468	344
MTBF(hr)	26.5	65.7
MTTR(hr/failure count)	6.5	2.998
System availability, A	0.76	0.96

*1) Operation time for the statistical analysis.

Fig. 4 shows the total systems static fault count data collected during the period of September 1994 to May 1995. Fig. 5 is the total system static fault count data collected for the period of Jun 1995 to May 1996. From Fig. 4 & 5 one can see the significant decrease in CB trip count by the CB trip modification and the apparent relative increase in klystron troubles as the accumulated run time increases.

Summary

It is approximately 2 years since the PLS 2 GeV linac has started its operation. We have analyzed the klystron-modulator systems performance record for the period. It is observed that the reliability of klystron is well over our expectations compared with other components in the modulators. The life time of thyratron tubes appears to be reasonable except the occurrence of infant failures. However, the major improvement is necessary for the reservoir control which is the main source of system troubles. The machine availability statistics of the K&M system for the manual reset mode is calculated to be approximately 76%. It appears to us that there are still lots of rooms for the improvement toward the availability more than 96% with proper choices of the protection circuits and the automatic reset mode. During the period of Jun 1995 to May 1996 we have modified our OCR (over current relay) interlock not to interrupt main CB but SCR gate(with static fault action) as an attempt to reduce major source of static fault. During the period no system damage has been occurred, and we have activated remote reset control in the case of static fault. Just one year old statistics shows an excellent system's availability of approximately 96%.

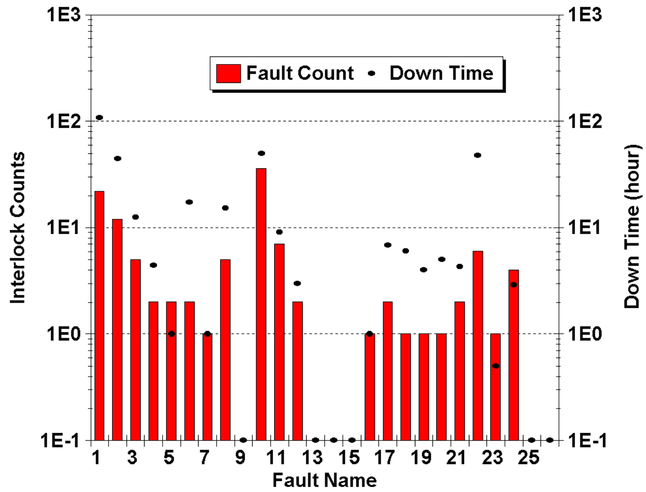


Fig. 5. Interlock status of klystron-modulator system for the period of Jun 1995 to May 1996. (1)CB trip, (2)klystron vacuum, (3)fan, (4)magnet flow low, (5)SCR ac over current, (6)magnet temp. high, (7)cooling temp., (8)thyratron heater, (9) triaxial cable, (10)klystron heater, (11)magnet current low, (12)EOLC, (13)core bias current low, (14)core bias current high, (15)key switch, (16)thyratron driver, (17)thyratron grid circuit, (18)replaced charging inductor, (19)replaced klystron, (20)replaced thyratron, (21)replaced MPS, (22)replaced ion pump controller, (23)PFN RC snubber, (24)De-Q'ing fault.

Acknowledgments

This work is partially supported by POSCO (Pohang Steel and Iron Co.) and Korea Ministry of Science and Technology.

References

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