AVAILABILITY ANALYSIS OF THE PLS LINAC VACUUM SYSTEM

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Abstract

The vacuum system of the PLS 2-GeV linac has been operating continuously for the last 4 years since its commissioning. It has been stabilized after the successful correction of initial phase troubles including the over-temperature and the communication failure of the ion pump controllers and the ceramic window leaks. And then, the down time is mainly caused by the replacement of a klystron and a microwave dummy load due to the long recovery time through the microwave conditioning. A stable operation is occasionally perturbed by a few hour multipacting breakdown. The present availability of the vacuum system is 99.8 % in 1997. This paper presents the overall availability analysis and describes major troubles of the PLS linac vacuum system.

1 INTRODUCTION

The PLS 2-GeV linac consists of a 100-MeV pre-injector and 10 regular modules[1]. Each regular module has four accelerating columns, a klystron, and an energy doubler. Four 60 *l*/s ion pumps in the accelerator tunnel and two 120 *l*/s ion pumps in the klystron gallery are used to evacuate each module. The pressure is monitored by the penning gauges and ion gauges, and the vacuum interlock is linked to the klystron and modulator system. The linac vacuum system is configured with a distributed pumping scheme which has several advantages such as the simplicity of the system layout, the good accessibility of assembly work, and the independent maintenance of each module. Since the completion of the PLS 2-GeV linac installation on December 10, 1993, the whole linac vacuum system has been operating continuously. For the flexibility and high reliability of the linac beam operation, one additional module with two accelerating columns was installed at the end of linac in January 1998.

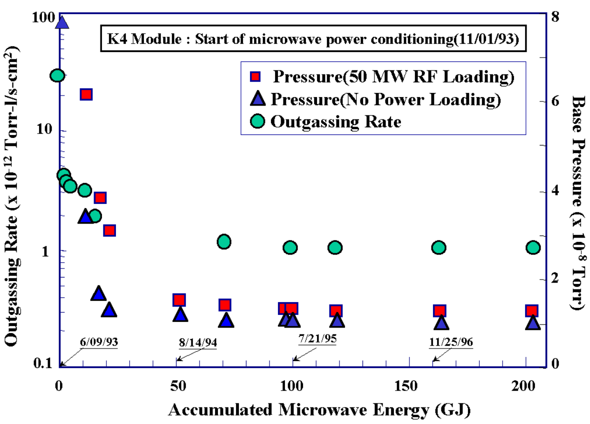

Figure 1. Tracking of the outgassing rate.

2 GENERAL PERFORMANCE

The vacuum system of the PLS linac gives the average pressure of about 1 x 10^{-8} Torr under the high power microwave loading of 54 MW peak with 4.1 µs pulse width and 10 Hz repetition rates. Figure 1 shows trends of the vacuum pressures and outgassing rate as a function of the accumulation of microwave energy. Both quantities fell very rapidly at the beginning of microwave conditioning. The initial outgassing rate of 3 x 10^{-11} Torr-*l*/sec-cm^2 decreased 4 x 10^{-12} Torr-*l*/sec-cm^2 after accumulated microwave energy level of 0.5 GJ. The outgassing rate leveled off at about 1 x 10^{-12} Torr-*l*/sec-cm^2 through the continuous microwave conditioning. And a base pressure of the vacuum system is not sensitive to the applied microwave power as shown in Figure 1. Occasionally the vacuum pressure rose up to the order of 10^{-7} Torr or even higher when microwave breakdown took place. The multipacting discharge, which occurs at certain levels of the microwave electric field, is one of serious problems we frequently face in the accelerating structure.

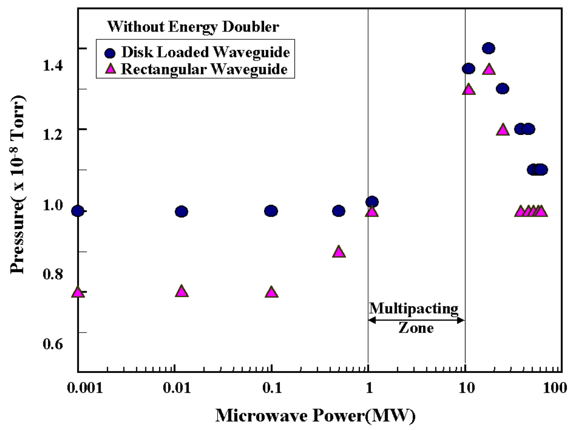

Figure 2. Pressure curves as a function of microwave Power (After conditioning up to 65MW).

Figure 2 shows the pressure variation as a function of microwave power level. The multipacting zone is clearly shown in this figure. The microwave frequency, *f* of 2856 MHz gives the *fd* values of 10 ~ 100 MHz-m in the PLS linac waveguide and accelerating columns, where *d* is the distance between accelerating electrodes corresponding to microwave field boundary. The most probable vacuum discharge can be generated with limited microwave power level of 1 ~ 10 MW or higher modes of 5/2 ~ 9/2 cycles in PLS linac[2, 3]. The short pulse process using 1.0 µs microwave pulse width is effective for the system to recover original working level with 4.1 µs long pulse.

3 MAJOR VACUUM FAILURES

Table 1 summarizes the replacements of main components related to the vacuum system through the whole period up to now. There are two different cases in the PLS linac vacuum system. The one is original component troubles associated with fabrication or installation errors. Accelerating columns and waveguide components were replaced thereby. These troubles were occurred only in the beginning of commissioning period. The other is long term degradation failures such as vacuum leak at the welding lips of the dummy loads or klystron troubles. A total of 12 pieces of high power dummy loads were replaced due to the vacuum leak by fatigue crack on the welding point.

Table 1. Replacements of main components.

Item	No. of Failure	Recovery Time(Hr.)
High Power Dummy Load	12	957
Klystron	4	384
Accelerating Column	2	683
W/G & Vac. Component	7	218
Total	24	2160

System recovery characteristics are analyzed in detail for the case of dummy load and klystron replacement. Figure 3 shows the pressure behavior and the recovery time for operating microwave power level after replacement of the dummy load. The cooling water leakage into the vacuum system was checked by closing the water valve of the dummy load. Sufficient power level for the beam acceleration was achieved after about 200 hours including the replacement work and microwave conditioning.

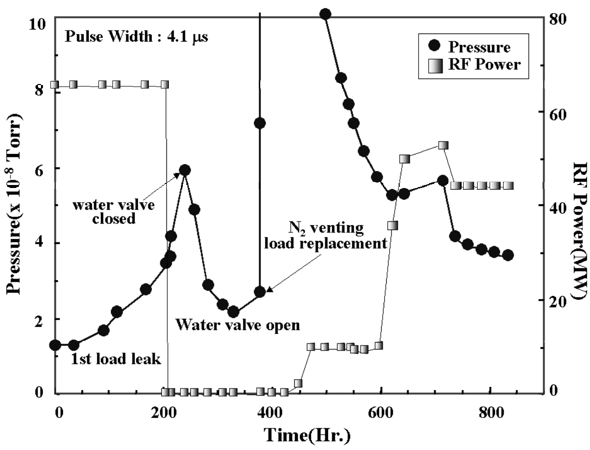

Figure 3. Pressure behavior after dummy load replacement.

It was expected that the degradation of the welding point might need continuous replacement of the dummy load. So dry-type SiC loads were purchased from Nihon Koshuha company in Japan, and six pieces were installed in January of 1998. This load is then free from water leakage[4].

System recovery profiles in the case of klystron replacement are shown in Figure 4. A klystron failure itself is not direct problem of the vacuum system, but the replacement of the klystron requires the venting of the whole module that results in long recovery time. Short pulse processing with 1.0 μs microwave pulse width takes long conditioning time to recover the original level. It usually takes about 100 hours to remove adsorbed gases or micro-dust particles on the inner surface of the vacuum system after N_2 venting.

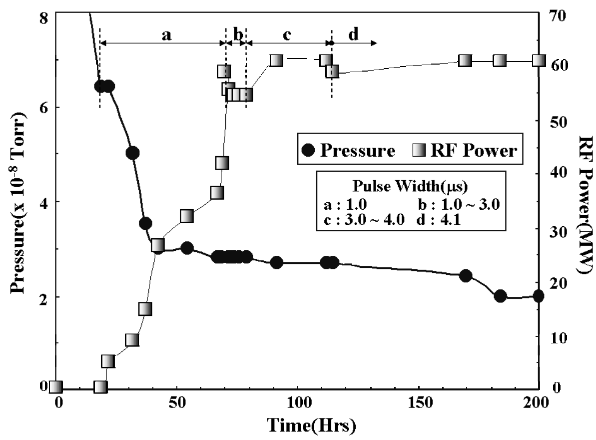

Figure 4. Pressure behavior after klystron replacement.

Table 2 summarizes the real leaks found in hardware components. A total of 39 air leaks were detected on the linac vacuum system. Most of the leaks were developed from the ceramic windows of the directional coupler located at the energy doubler. These leaks were caused by high electric field discharge because the energy doubler amplifies the microwave power level of 54 MW from klystron up to at least 200 MW. The micro-puncture of the e-gun resulted from high voltage discharge at the ceramic insulator. It was due to operator's mistake in applying the over voltage. The leak at the brazing point between the OFHC copper and OFHC copper of the waveguide occurred three times. All of the above real leaks were fixed by the vacuum sealant. The bolt loosening of the tuner flange of the energy doubler developed air leak as well.

Table 2. Summary of air leaks.

Item	No. of Event	Time
Ceramic window of E/D	33	18 hours
Ceramic window of D/C	1	2 days
Ceramic insulator of E-gun	1	1 month
Brazing point of W/G	3	4 hours
E/D tuner flange	1	1 month

E/D : Energy Doubler, D/C : Directional Coupler

4 AVAILABILITY ANALYSIS

Analysis of the machine availability is performed using the technique described in reference[5]. Table 1 lists the availability of the linac vacuum system during beam operations for the last three years from 1995 to 1997. The detailed analyses of the system troubles were carried out only for the normal beam operating period including the machine study. The replacement of dummy load or klystron was scheduled and carried out in the maintenance period except for a klystron replacement so that the down time for these troubles was not included in this analysis.

A total of 41 troubles with 140.8 hours down time in 1995 gave good system availability of 97.2%. Mean time between failure of 122.9 hours means that a fault occurred once every five days on the average in 1995. System upgrade or modification improved the performance quality of the vacuum system. Finally availability of 99.8% was achieved in 1997 with only 5 troubles.

Table 3. Availability analysis of linac vacuum system.

Year	1995	1996	1997
Operating Time(Hour)	5040	5232	4296
Fault Count	41	27	5
Down Time(Hour)	140.8	21.6	6.0
Mean Time between Failure(Hour)	122.9	193.8	859.2
Availability(%)	97.2	99.5	99.8

Figure 5 shows the fault counts of each trouble from 1995 to 1997. All failures can be grouped into categories related to ion pump controller, vacuum gauge controller, air leak due to high power microwave or high voltage breakdown, and vacuum venting due to hardware replacement.

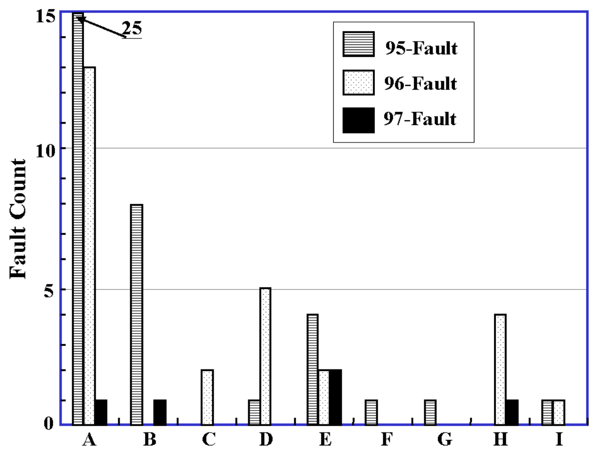

Figure 5. Annual fault statistics in linac vacuum.
(A: Ion pump controller problem, B: Gauge controller problem, C: BA-filament failure, D: Valve malfunction, E: Ceramic window leak, F: E-gun leak, G: Klystron replacement, H: Multipacting breakdown, I: Power trip)

There occurred many trips of ion pump controllers in 1995. They were caused by thermal heat loading due to dense installation of the ion pump controllers in a single rack. After correction of this trouble in 1996, it dramatically disappeared.

Figure 6 represents the down time distribution of each fault. Hardware component replacements of klystron are rare works but it takes a long time to recover to normal status. Malfunctions of the gate valve in 1996 occurred from the leakage of compressed air.

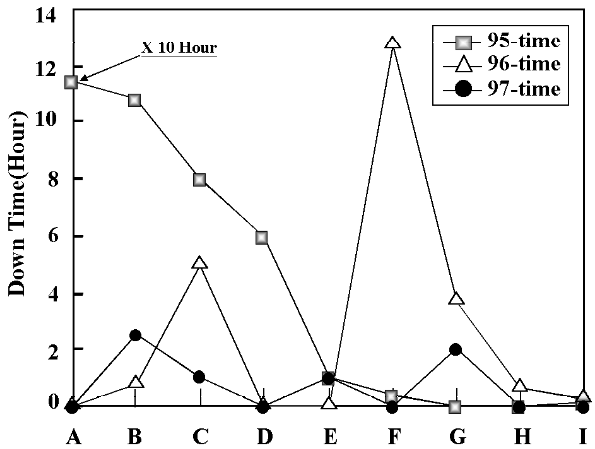

Figure 6. Annual down time statistics in linac vacuum
(A: Klystron replacement, B: Ceramic window leak, C: Ion pump controller problem, D: E-gun leak, E: Gauge controller problem, F: Valve malfunction, G: Multi-pacting breakdown, H: BA-filament failure, I: Power trip)

5 SUMMARY

The PLS linac vacuum system has been improved by uninterrupted operation. The outgassing rate was stabilized at about 1 x 10^{-12} Torr-*l*/s-cm^2 and dynamic pressure under normal operation is about 1 x 10^{-8} Torr. The dummy load requiring recovery time of about 200 hours will be gradually replaced by dry-type SiC load. The operational parameters and performance characteristics of the vacuum system are periodically checked and analyzed for better performance of the system. Availability of the PLS linac vacuum system achieved 99.8% in 1997.

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