RELIABILITY AND MAINTENANCE OF PLS LINAC MECHANICAL SYSTEMS*

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Abstract

The PLS 2-GeV electron linac has been used as a full energy injector since the completion of linac and BTL commissioning in 1994. Recently, overall system availability is well over 90%. As the operating hours increase, there exists observable failure information that affects the system reliability. Data from the follow-up test and periodic monitoring on the linac mechanical systems such as vacuum microwave components, water-cooling systems and alignment in structures are analysed. Presented here are system reliability and maintenance with particular emphasis on water-cooled microwave components. Also, we will discuss some of the principal modes of failure and the countermeasures encountered on it.

1 INTRODUCTION

PLS linac has been normally injecting 2-GeV electron beams to storage ring since the first start of beam injection for storage ring commissioning on September 1994[1]. After additional installation of one klystron-modulator system for higher energy margin in 1997[2], the linac is now consisted of twelve klystron and modulators, eleven SLAC-type pulse compressors on the ground floor and forty-four accelerating columns, six quadrupole triplets, and various mechanical devices in the tunnel, placed 6-m below the ground level. As the operating time increases, the follow-up test and replacement of the degraded mechanical devices are necessary for obtaining the required system availability and reliability. The averaged operating time of the water-cooling system is more than 7,500 hours per year with an operating availability of about 99.5% in 2001. And vacuum system has been performed with an availability of more than 99.8%. In linac tunnel, the re-alignment work of accelerating columns has been periodically conducted to adjust the deformation caused by environmental influences such as ground motion and thermal gradients, etc. In this paper we have reviewed the operating availability of PLS linac mechanical systems for time periods of normal operation since September 1994. The preventive maintenance and follow-up tests of failed components are discussed with particular emphasis on water-cooled microwave components.

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2 MECHANICAL SYSTEM OVERVIEW

The PLS linac has been operated with forty-four SLAC-type constant gradient accelerating columns and twelve klystron-modulator systems including preinjector module since one more K&M system installation in 1997. Typical one K&M module of one klystron-modulator system is feeding the microwave into 4 accelerating columns, supported by two 6.35-m extruded aluminium girders. The PLS linac mechanical systems are of convenience classified into high precision temperature-controlled microwave components, the evacuation systems, supporting structures and alignment devices, and water-cooling systems, as considered to properly sustain the system operation reliability and maintenance. The linac microwave components such as accelerating columns and S-band waveguide networks including SLED-type pulse compressors maintained in the average pressure of about 1×10^{-8} torr under high power rf loading of 54 MW with 4.1 μs pulse width and 10 Hz repetition rates, with the precise temperature-control of about 45±0.1 °C. The low conductivity water was also utilized for cooling of dissipated thermal load from the klystron collector and magnets. The precisely aligned accelerating columns were sustained with a positional error within 250 μm (rms), periodically checked and adjusted by He-Ne laser system.

3 OPERATIONAL RELIABILITY

Since the completion of the PLS 2-GeV linac in December 1993 and first 2-GeV beam achievement in 1994, all the linac mechanical systems have been continuously operating except scheduled short-term and long-term maintenance shut down. During the early phase of the operation, relatively low machine availability had been obtained due to the operation crew training as well as system debugging exercise through the commissioning.

3.1 Vacuum System

Each regular module has four 60 *l*/s ion pumps in the accelerator tunnel and two 120 *l*/s ion pumps in the klystron gallery 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, in which it has several advantages such as the simplicity of the system layout, the good accessibility of assembly work, and the independent maintenance of each module[3]. There are two different failure cases in the linac vacuum system.

The one is original component troubles associated with fabrication or installation errors, occurred only in the beginning of commissioning period. The other is the operated degradation failure such as vacuum leak at the welding lips of the output loads. A total of 39 air leaks were also detected on the linac vacuum system. Most of the leaks were developed from the ceramic windows of the directional coupler located at the SLED-type pulse compressor. These leaks were mainly caused by high electric field discharge because the pulse compressor 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 leaks of the waveguide occurred at the brazing area. All of the above real leaks were treated with the vacuum sealant.

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. The troubles are caused by dense installation of ion pump controller in a single rack-mounting panel. After the improvement of ion pump controller arrangement in 1998, the faults were little occurred. PLS linac vacuum system has been worked with a stabilized out-gassing rate at about 1×10^{-12} Torr-*l*/s-cm$_2$ and dynamic pressure about 1×10^{-8} Torr under normal operation. 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 about 99.8% in 2001.

3.2 Cooling Water System

PLS cooling water system consisted of two loops, in which they have the precise temperature control of about 45±0.1 °C for the microwave components such as accelerating columns, pulse compressors and waveguide networks, and normal cooling of klystron collectors and magnets. The deionised low conductivity water of more than 2 MΩ-cm was used for coolant to keep the accelerator components from being corrosive and conductive electromagnetic interference by the coolant. The PLS cooling water system was completed in middle of 1993 and commissioned at late of 1993. The cooling water system was installed module by module to maintain constant water flow and pressure balance at each module and easy operation and maintenance, resulting in twelve temperature control modules equivalent to the number of linac klystron-modulator modules.

The total operation time of linac cooling water system has reached about 69,000 hours and the availability has been maintained above 99.5%. Table 1 shows fault statistics and availability of cooling water system. The faults and failures of cooling water system occurred mainly at the precision temperature control system. The failures have been caused by the damages of DC power supply devices due to the limited design life time, degradation of electronic circuit boards, the leakage around the flow control valves.

Table 1: Cooling water system fault statistics and availability (recent 5 years)

Items	'97	'98	'99	'00	'01
Operation time (hr)	7598	6645	7441	7981	8145
Number of failure	5	32	24	12	14
Precision temp. control System	3	30	24	11	13
Normal cooling system	2	2	0	1	1
Total failure time (hr)	9	108	24	12	36
MTBF (hr)	844	61	310	665	225
Availability (%)	99.8	98.4	99.6	99.8	99.5

By improving temperature control system including software and the control valves, we ensured the operation performance of temperature control of the accelerating components within 45±0.1 °C under normal operation.

3.3 Water-cooled RF components

There are total twelve SLED-type pulse compressors to amplify the RF power from the klystron into accelerating columns. PLS SLED consists of two TE015 mode resonant cavities, 3dB power divider, and water cooling tubes for temperature control. The cavity temperature must be held constant to within 0.3 °C to maintain the difference between the driving frequency and the cavity resonant frequency less than 16 kHz[4]. The PLS temperature control system holds the temperature fluctuations to better than ±0.1 °C, by using independently dedicated temperature controller of SLED cavities. An example of the output power waveform of pulse compressor according to cavity temperature variation is shown in Fig. 1. Through the periodic tuning test, the system is identified so that the RF phase of the pulse compressors is sustained very stable by optimising temperature control variation of the structures.

As the operation time increases, the cooling tubes for supplying the temperature-controlled water appeared the water leaks at the dissimilar metal joints such as stainless steel manifold and OFHC copper tubes. It is estimated due to the corrosive products activated by a chemical reaction under air exposure condition[5]. Figure 2 shows an example of the water leaks in joint area for the SLED water supply. The more analysis of causes of corrosion will be performed in near future.

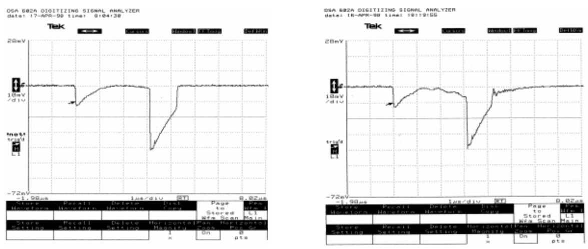

Figure 1: The RF waveform of pulse compressor output power; within temperature control of 45±0.1 °C (left) and beyond temperature control of 45±0.5 °C (right)[2]

Figure 2: Water leaks in tube joint of SLED system

RF output load has a function of absorption of residual travelling wave around the exit of accelerating column without refection. The direct water-cooled RF output loads produced by IHEP were initially installed in the accelerating columns. At commissioning stages, some RF loads appeared water leaks in welded joint due to the fabrication errors. Recently, new indirect RF output load using SiC ceramic developed by H. Matsumoto[6] was adopted to prevent the water leaks. SiC loads was successfully operated with up to 50-MW of RF power at a 1 μs pulse width and 50 Hz repetition rate in the 2856 MHz. The input VSWR obtained was less than 1:1.1 at the maximum RF power. In order to prevent the water leaks by micro-cracks on the welding point of the water-cooled output loads, the newly designed SiC loads were prepared and replaced. Six modules including preinjector in PLS linac have been replaced with SiC output loads. The fabricated SiC loads and water loads under vacuum processing are shown Fig. 3.

Figure 3: SiC loads and water-cooled RF loads under vacuum processing

4 SUMMARY

PLS 2-GeV linac has been operated for more than 8 years since the commissioning in 1994. The availability of linac mechanical systems including cooling water system, vacuum system and microwave components have been kept above 99%. The faults in the linac mechanical system components have been traced and diagnosed. On the faulty devices, the follow-up tests have been performed, and countermeasures for troubleshooting have been carried out. In addition, preventive maintenance has been done through the periodic short- and long time shutdown, in parallel with proper component replacement. With in-house development of water-cooled RF components, PLS linac mechanical systems have been secured more reliably.

5 ACKNOWLEDGMENTS

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