VACUUM WAVEGUIDE SYSTEM FOR SPRING-8 LINAC INJECTOR SECTION

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Abstract

In order to renew aged equipment and improve RF phase stability at the electron injector section of the SPring-8 linac, a pressurized SF_6 waveguide system was replaced with a vacuum waveguide system including newly developed S-band vacuum circulators and isolators in the 2013 fiscal year. As a result of the RF conditioning and the beam tuning, a satisfying beam performance was confirmed. A regular beam operation with this system has started in April 2014.

INTRODUCTION

The SPring-8 linac, a 1-GeV electron injector for SPring-8 and NewSUBARU, was constructed in 1996 and has been improved to upgrade its machine performance and reliability for a stable and a continuous beam injection [1]. Recently, some of its equipment requires renewal since their aging. For example, troubles with an aged motor-driven system in a waveguide phase shifter and attenuator had increased in recent years. These problems were significant at the waveguide system of the electron injector section. In this section, waveguides were filled with pressurized sulfur hexafluoride (SF_6) gas and the pressure was controlled to keep 112±1 kPa for RF phase stability [2]. However it became worse to more than 114 kPa in case of a rapid atmospheric depression during a typhoon passing, and caused a phase shift. Additionally, SF_6 gas filled in the waveguide system is one of global greenhouse gases whose global warming potential is 23,900 times larger than that of CO_2 and its usage must be reduced. Therefore, we decided to replace this system with a vacuum-type waveguide system. However, since no vacuum-type RF circulator was commercially available at that time, we started R&D in 2010.

In this paper, we describe the outline of this upgrade, R&D history of S-band (2856 MHz) vacuum circulators and isolators, the installation to the SPring-8 linac and the commissioning result.

WAVEGUIDE SYSTEM FOR INJECTOR SECTION OF SPRING-8 LINAC

The injector section of the SPring-8 linac consists of two pre-buncher cavities (PB1, PB2) and a buncher accelerator (B) where the electron beam is bunched and accelerated up to 9MeV. The resonant frequency of these cavities is S-band (2856 MHz) and provided RF peak powers are 7.5 KW for PB1 and PB2, and 7.5 MW for B, respectively. Fig. 1 shows a renewal configuration of the vacuum waveguide system for the electron injector section. An 80 MW klystron (Toshiba E3721), KLY-H0 provides RF power to the electron injector section, a klystron drive-line and a 3 m-long traveling-wave accelerator structure, ACC-H0. RF circulators are installed to absorb the reflected powers from the buncher accelerator structure and a reflection-type high power attenuator. In two pre-buncher lines, isolators, where reflected RF power is absorbed in a ferrite array, are installed between pre-buncher cavities and a phase shifter and attenuator (ϕA).

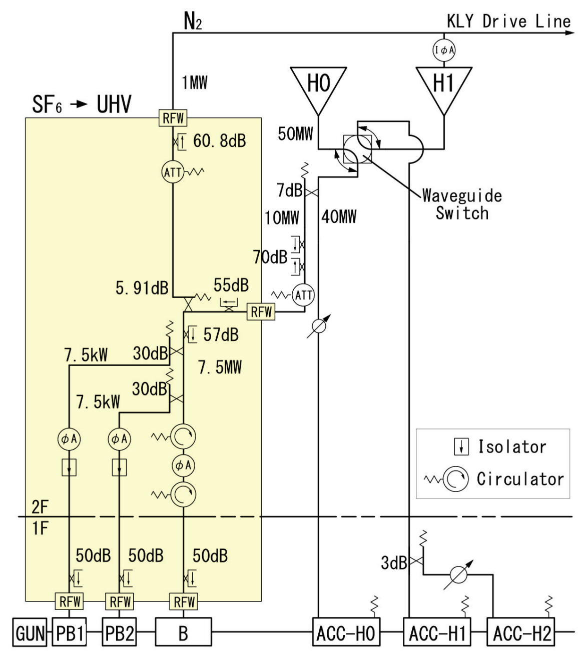

Figure 1: Layout of new vacuum waveguide system for electron injector section of SPring-8 linac.

VACUUM CIRCULATORS

There were two key points on the R&D of vacuum circulator and isolator. The one was a gas emission rate from ferrites and the other was a thermal contact between ferrites and waveguide wall or copper. It was found that the gas emission rate from ferrite was low enough to keep ultra high vacuum (UHV) with conventional sputter ion pumps [3].

We tried various methods for bonding ferrites and waveguide wall made of copper. The bonding method for the isolator was a soldering with a copper ring around the segmented ferrite pieces. For the isolators, we adopted a method with a Be-Cu ring surrounding a ferrite disk and

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the contact surfaces of ferrite and copper were precisely polished. Fig.2 shows the vacuum circulator and isolator installed to the waveguide system for the electron injector section.

After a pilot high power test of isolators, some voids were found in the solder area between the copper ring and copper plate. This was considered to be created by discharging or surface currents on the solder with a lower melting point such as 300 degrees Celsius, during the RF conditioning. To improve such a defect, the solder surface was covered by silver solder with higher melting point, melted by a pulsed YAG laser.

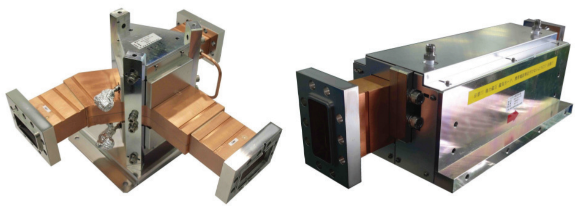

Figure 2: S-band vacuum circulator (left) and isolator (right) installed in the waveguide system.

LONG-RUN HIGH POWER TEST

To confirm the improvement for the bonding solder surface of the isolators, a long-run high power test was performed for about 40 days. Fig. 3 shows the setup for the high power test. Two circulators and two isolators were connected in series and kept in a pressure range of 10^{-6} Pa by using a sputtered ion pump (SIP) with a pumping speed of 100 L/s for N_2 and a non evaporable getters (NEG) pump with that of 400 L/s for H_2. SiC dummy loads were connected to the output ports of the circulator to absorb the reflected RF power.

The parameters of RF conditioning were a peak power of 10 MW, a pulse width of 2 μsec and a repetition rate of 10-20 pps, respectively. The total number of RF shots was 5×10^7, which corresponds to that of five months operation for the SPring-8 linac with a repetition rate of 4 pps.

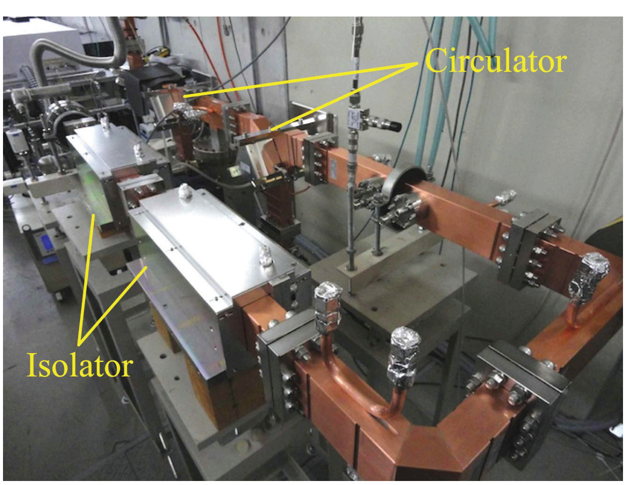

Figure 3: Setup of long-run high power test for vacuum circulator and isolators.

INSTALLATION AND COMMISSIONING

Installation

After the long-term stability of the circulators and isolators was confirmed, those components were installed in the waveguide system for the injector section of the SPring-8 linac during January-March maintenance period in the 2013 fiscal year. High power phase shifters and attenuators were installed in the klystron gallery (upper floor) considering an easy handling for troubles under the beam operation, although these were placed in the accelerator room (lower floor) for previous SF_6 system.

During the removal of old SF_6 components, some degradations of aged equipment were found. For example, there were many cracks on the control cables for high power phase shifter and attenuator caused by UV lights from fluorescent lamps. Fig. 4 shows a picture of the installed waveguide system including circulators and isolators at the klystron gallery of the SPring-8 linac building.

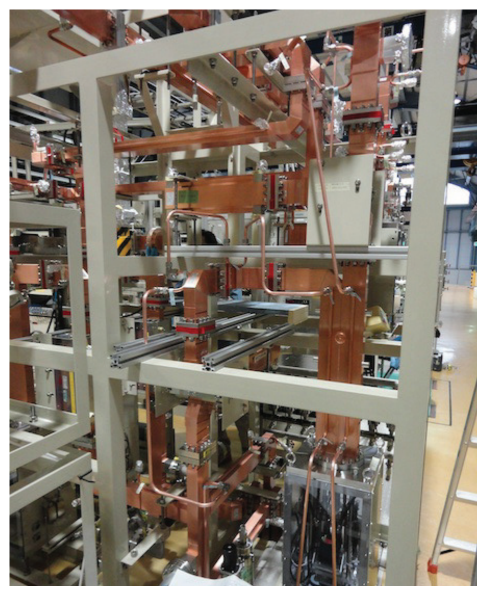

Figure 4: Vacuum waveguide system installed at klystron gallery (upper floor).

Vacuum System

The vacuum system of the waveguide section was separated from the RF cavities by RF windows to keep lower vacuum pressure in the cavities.

After the assembly of waveguides was completed, the waveguides were evacuated by turbo molecular pumps (TMP) to the pressure of less than 10^{-3} Pa. In order to accelerate outgassing from the ferrites in the circulators and the isolators, hot water with a temperature of 65 degrees Celsius was flowed in the cooling channel of those RF components for four days. The vacuum pressure history during the hot water baking is shown in Fig. 5.

Finally, the waveguides were kept in UHV by using SIP and NEG pumps. A penetration of water vapor through a fluoroelastomer O-ring near PB2 was observed. Surroundings of the component including the O-ring were

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temporary dehumidified by flowing dry nitrogen gas. We plan to replace this O-ring to a metal seal.

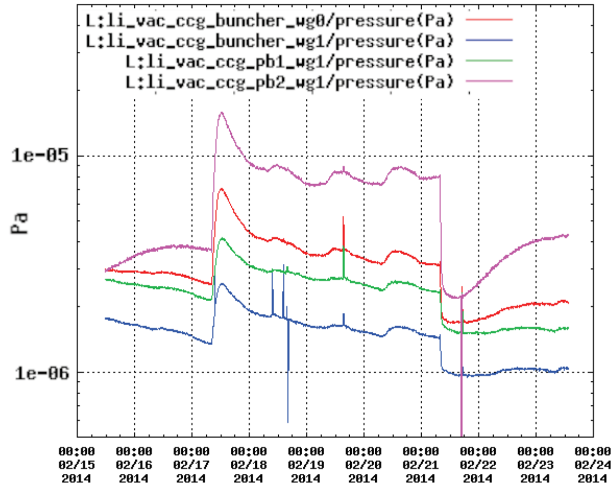

Figure 5: Vacuum pressure history during hot water baking of circulators and isolators.

RF Conditioning and Commissioning

After the vacuum pressure reached less than 10^{-5} Pa, RF conditioning with a pulse width of 2.7 μs and a repetition rate of 4 pps was performed for 40 hours in total and a stable transmission of RF power with a peak power of 7.5 MW at the buncher line was achieved. Fig. 6 shows the history of the vacuum pressure and the output power of the klystron during the RF conditioning. The base pressure at the PB2 became higher at last half phase of the conditioning. We expect that it is caused by a penetration of water vapor due to a rise up of the humidity in the atmosphere as mentioned in the former section.

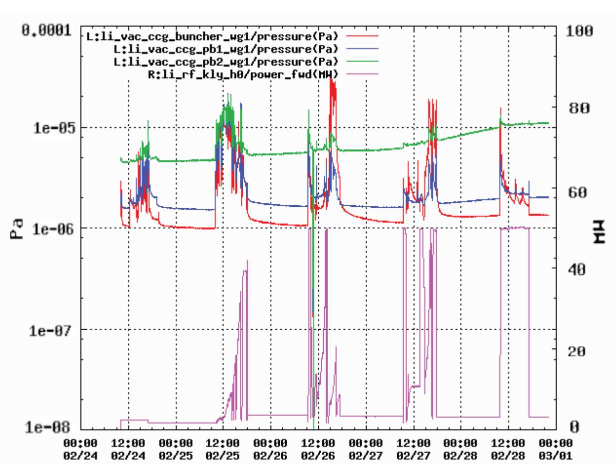

Figure 6: History of klystron output power and vacuum pressure during RF conditioning for newly installed waveguide components. (Red, blue, green lines: vacuum pressure, Magenta line: RF power)

After the RF conditioning, a beam tuning was performed. The attenuators and the phase shifters were optimized to get a maximum beam current. As a result, the same beam performance as that with the previous system was confirmed.

Figure 7 shows typical RF pulse shapes observed at directional coupler located between the buncher cavity and circulator. No effect of the reflected power is observed in the forward power shape since the isolation of the circulator was more than 20 dB in all power range.

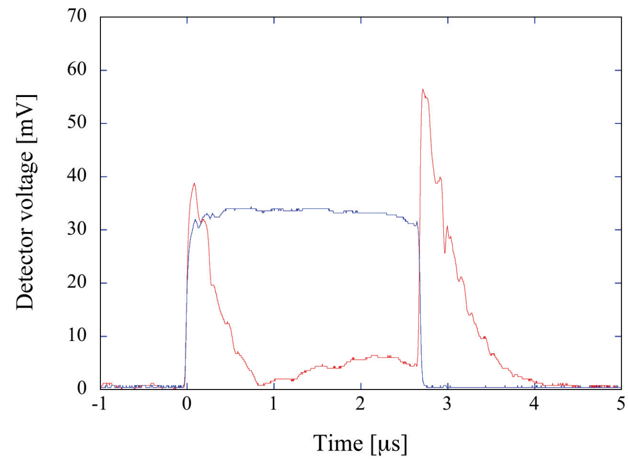

Figure 7: RF pulse shape observed at a directional coupler located between the buncher cavity and circulator. (Blue line: forward power, Red line: reflected power)

CONCLUSION

We had been developing the S-band vacuum circulator and the isolator since 2010. After several improvements were added, these components were installed at the electron injector waveguide system for the SPring-8 linac in the 2013 fiscal year. It was confirmed that beam performance was the same or more than that for the original SF_6 waveguide system and a regular beam operation of the SPring-8 linac restarted from April 2014. We continue measuring a long-term performance and stability of this system.

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