S-BAND VACUUM ISOLATOR AND CIRCULATOR FOR INJECTOR SYSTEM OF SPring-8 LINAC

T. Taniuchi#, S. Suzuki, H. Hanaki, JASRI/SPring-8, Hyogo 678-5198, Japan
A. Miura, S. Tsuruoka, K. Shinohara, Nihon Koshuha Co., Ltd., Yokohama 226-0011, Japan

Abstract

In the injector section of the SPring-8 linac, a waveguide system filled with pressurized sulfur hexafluoride (SF_6) gas has been used. It will be replaced with a vacuum waveguide system in order to update old equipment and improve phase stability. For this updating, we have developed a vacuum-type RF isolator and performed high power tests. The isolator has an isolation of 20 dB in a power range below 20 kW and works in a ultra high vacuum environment.

INTRODUCTION

Since its construction in 1996, the SPring-8 linac has been improved to upgrade its performance and reliability [1]. However, some of its equipment must be updated due to aging. For example, troubles with an aged motor-driven system in a waveguide phase shifter or attenuator have increased in recent years. Additionally, the sulfur hexafluoride (SF_6) gas that fills in this waveguide system [2] is a global greenhouse gas whose global warming potential is 23,900 times larger than that of CO_2 and its usage must be reduced. Therefore, we are planning to replace this system with a vacuum-type waveguide system.

In the waveguide system for the injector section, RF circulators are installed to absorb the reflected powers from standing-wave cavities such as pre-bunchers and a buncher. However, since no vacuum-type RF circulator was commercially available, we started R&D into such a device.

WAVEGUIDE SYSTEM FOR INJECTOR SECTION OF SPring-8 LINAC

Present Layout

As shown in Fig. 1, the electron injector section of the SPring-8 linac includes two pre-bunchers (PB1, PB2) and a buncher cavity (B). The RF frequency of these cavities is 2856 MHz. Their RF powers are provided through a 7 dB power divider installed at H0 klystron (Toshiba E3712, max. 80 MW). The maximum peak RF powers fed into each cavity are 12.4 kW for the pre-bunches and 6.2 MW for the buncher. The pulse width and the repetition rate are 2.5 μs and 5 pps. In this waveguide system, pressurized SF_6-type RF circulators absorb the RF power reflected from the standing-wave cavities. The SF_6 gas fills the waveguide section that is separated from the vacuum by RF windows. Its differential pressure is 112 kPa. Because the wall thickness of the waveguide for SF_6 is 4 mm in contrast with 5 mm for the vacuum waveguides, the waveguide deformation due to the variation of atmosphere pressure is larger, and causes RF phase variation. We stabilized the difference pressure of SF_6 gas to suppress this phase variation.

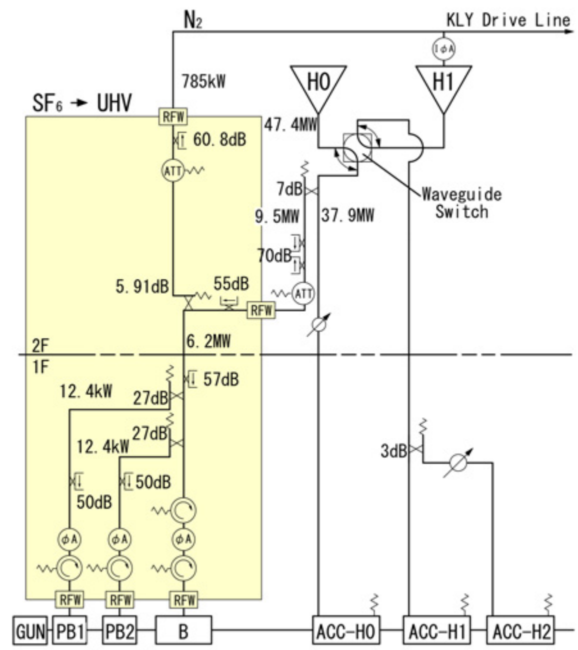

Figure 1: Waveguide system for injector section of SPring-8 linac.

Update Plan

We plan to replace the waveguide system for the injector section with vacuum-type waveguide components including an RF circulator that is under development. Since the peak power for the pre-bunchers is as small as 12.4 kW, we developed a vacuum-type isolator instead of a circulator. Because the backward power is absorbed in a ferrite piece in the isolator, an external dummy load is not necessary.

The RF configuration of the new waveguide system is almost the same as current one. But the phase-shifters and the attenuators including the motor-driven systems will be placed on the upper floor (2F) to ease its maintenance.

ISOLATOR FABRICATION

Outgas from Ferrite

The most critical issue for the R&D of vacuum isolators is outgassing from the ferrite pieces. A ferrite is a kind of sintered ceramics that has dense voids less than 10 μm on its surface (Fig. 2). We measured the outgassing rate from a garnet ferrite used in an SF_6-type isolator and found that it is about 34 times larger than that of stainless steel, after a baking process at 80ºC. Since the surface area of the ferrite is small enough, this is acceptable for an ultra high vacuum system. Residual gas was analyzed in a high power test described below.

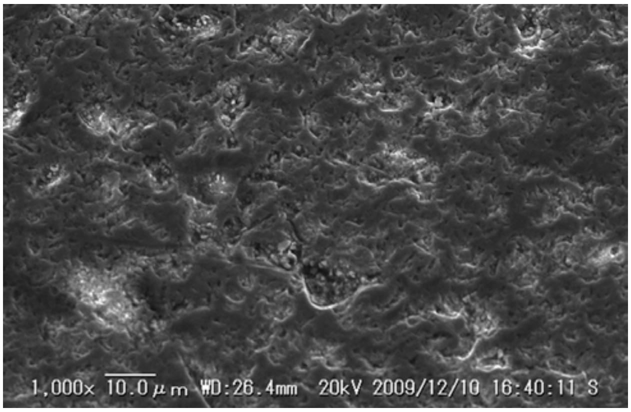

Figure 2: SEM image of a garnet-ferrite surface.

Bonding of Ferrite on Copper

The development of a bonding method of ferrite pieces on a copper surface was the most time consuming issue in this R&D. Because the difference in the coefficient of the thermal expansion between ferrite and copper is large, the usual brazing method with silver solder could not be applied. The successful bonding method was soldering with a copper ring around segmented ferrite pieces. It simultaneously satisfied mechanical strength and thermal conductivity. The thermal conductivity was 9.3 times larger than that of an electrically conducting adhesive (AMICON®). A ferrite located in an isolator is shown in Fig. 3.

Figure 3: Ferrite located in a prototype isolator.

HIGH POWER TEST

Experimental Setup

Figure 4 shows a prototype isolator and a setup for a high power test. The waveguide section including the isolator was evacuated by a sputter ion pump with a pumping speed of 45 L/s for N_2. The transmitted and reflected RF powers were measured using directional couplers located upstream/downstream of the isolator.

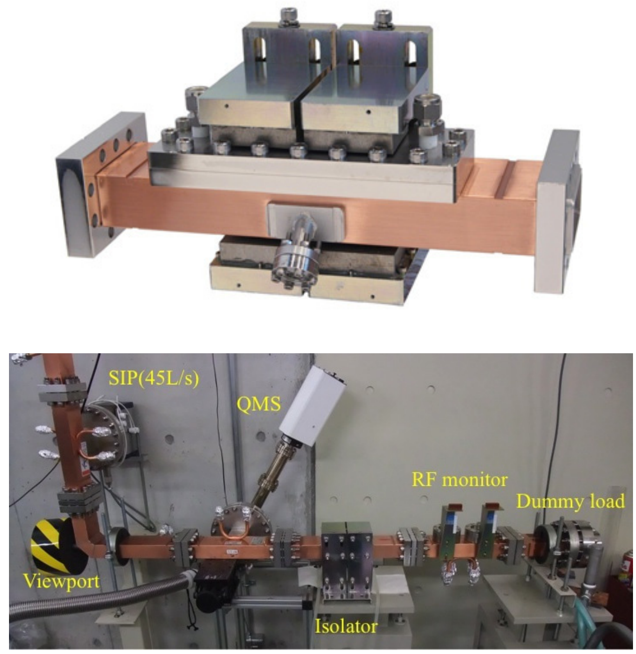

Figure 4: Prototype vacuum isolator (above: a viewport is located to observe ferrite surface) and setup for a high power test (below).

The temperature of the ferrite surface was measured through a BaF_2 window by a radiation thermometer. The outgas components were measured by a quadrupole mass spectrometer (QMS). A CCD camera was also installed at a viewport to observe the discharge lights.

RF Conditioning

An RF conditioning was performed with a pulse width of 2.5 μs and a repetition rate of 10 pps. An example of the RF conditioning in a normal (forward) direction is shown in Fig. 5.

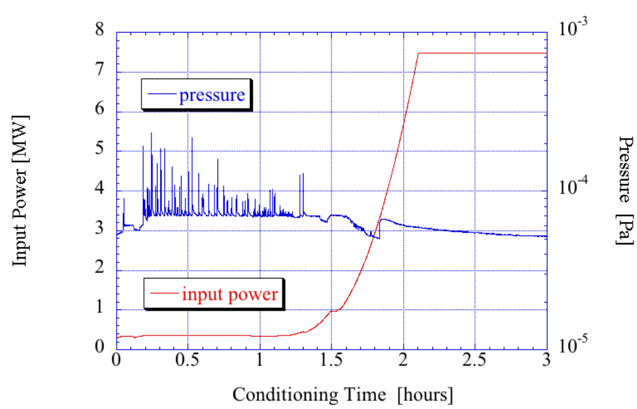

Figure 5: Input power and vacuum pressure history of RF conditioning of prototype isolator (normal direction).

Spike-like pressure risings were observed below 1 MW and they decreased around 4 MW. No discharge light was observed during the conditioning. Such a pressure rising history resembles ceramic RF windows or SiC dummy loads. Finally, the input power reached up to 45 MW.

RF Characteristics

The RF parameters were measured in a high power test. The insertion loss measured in a forward direction of the isolator maintained 0.3 dB to a maximum input power of 45 MW. This suggests that a circulator using this ferrite will work at this power level. Next, the direction of the RF input was reversed to measure the isolation. The isolation worsened as the input power was increased (Fig. 6). The isolation measured in a low power measurement was 16 dB and became 9 dB at an input power of 30 kW. The resonance frequency in a ferrite apparently varies as a function of the input power, and this frequency shift must be investigated.

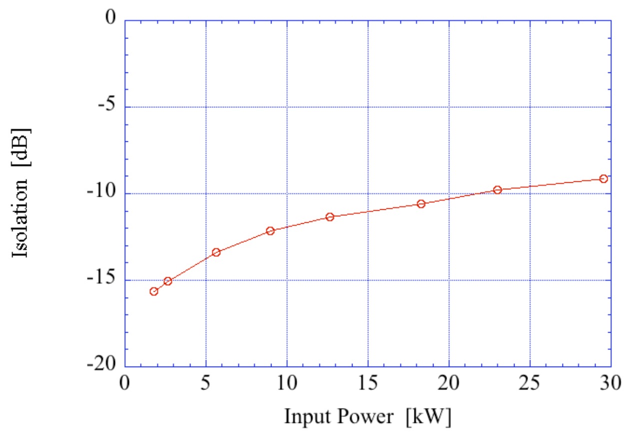

Figure 6: Isolation of prototype isolator as a function of input power.

To improve the isolation in a frequency region below 100 kW, the lengths of the ferrite pieces and the external magnets were expanded in a production version of the isolator. This improved the isolation to 32 dB in a low power measurement (Fig. 7).

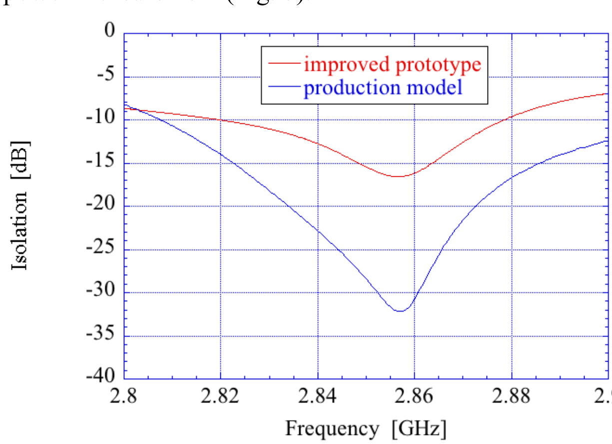

Figure 7: Improvement of isolation by expanding ferrite and external magnets.

Although a high power test for the production model is under going, the isolation of larger than 20 dB was confirmed in a power range below 20 kW.

Vacuum Characteristics

The pressure in the waveguide system without the isolator reached 3x10^{-6} Pa after 17 hours of pumping; it was 2x10^{-5}Pa with the isolator. This difference reflects the outgassing from the ferrite in the isolator. Based on a residual gas analysis by the QMS, H_2 and H_2O were dominant (Fig. 8).

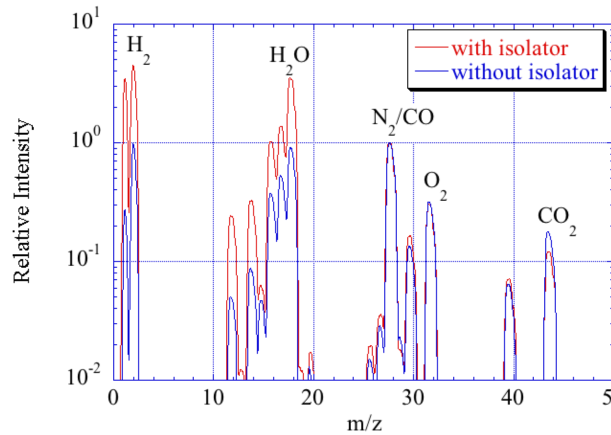

Figure 8: Residual gas spectrum with/without isolator (relative intensity was normalized for N_2/CO).

The water vapor was probably absorbed in the ferrite during the tuning in the factory for a week. Therefore, the isolator was baked out with hot water at 80ºC. The achieved pressure was improved to 1x10^{-5} Pa and was further improved to 3x10^{-6} Pa in a production model of the isolator.

SUMMARY

To upgrade the SF_6 waveguide system of the injector section of the SPring-8 linac, we developed a vacuum-type isolator. The RF and vacuum characteristics satisfied the required speculations. A vacuum-type circulator that works up to 10 MW, is also being developed and its high power test is scheduled this year. The SF_6 waveguide system for the injector section will be replaced with vacuum waveguides next year.

REFERENCES

[1] H. Hanaki et al., “Enhancements of Machine Reliability and Beam Quality in SPring-8 Linac for Top-Up Injection into Two Storage Rings”, PAC’05, Knoxville, May 2005, p. 3585 (2005); http://www.JACoW.org.

[2] S. Suzuki et al., “Initial Data of Linac Preinjector for SPring-8”, PAC’93, Washington D.C., May 1993, p. 602 (1993); http://www.JACoW.org.