

## RECENT IMPROVEMENTS IN SPRING-8 LINAC FOR EARLY RECOVERY FROM BEAM INTERRUPTION

S. Suzuki, T. Asaka, H. Dewa, T. Kobayashi, T. Magome, A. Mizuno,  
T. Taniuchi, H. Tomizawa, K. Yanagida and H. Hanaki  
Japan Synchrotron Radiation Research Institute (JASRI/SPRING-8)  
Kouto, Sayo-cho, Sayo-gun, Hyogo, 679-5198 Japan

### Abstract

The 1GeV SPRING-8 linac is an injector for the SPRING-8 synchrotron radiation storage ring with 8GeV booster synchrotron. In recent years, backup systems were installed to eliminate long-time interruption of the beam injections. The main gun system is usually operated, and the backup gun is always pre-heated and can inject electron beams into the buncher section at intervals of several minutes if the main gun fails. The first klystron, which feeds the RF powers to the buncher system and the downstream klystrons, can be relieved by the next klystron in about 20 minutes by switching the waveguide circuit. When one of the eleven working klystrons fails, one of the standby klystrons, which are kept on line as hot spares, is automatically activated to accelerate beams instead of the failed one to avoid beam interruption. The total downtime in FY 2011 was 0.11% in the top-up operation user time. The averaged fault frequency was 0.2 times per day.

### INTRODUCTION

The SPRING-8 accelerator complex is composed of a 1-GeV electron linac, an 8-GeV booster synchrotron, and an 8-GeV storage ring. The linac injects electron beams into the booster synchrotron and the 1.5-GeV storage NewSUBARU ring of the University of Hyogo.

In the early stage of SPRING-8 operation, the linac injected beams one or two times a day into each ring. In 2004, the top-up operation of the SR and the NewSUBARU ring (at 1 GeV) started to stabilize the stored currents and realized constant SR lights. At present, SR is being injected every 20 seconds to five minutes depending on the filling pattern, and the stored current stability is 0.03% at 99.5 mA. The NewSUBARU ring runs the injection every six or seven seconds with current stability of 0.01% at 250 mA.

To maintain such frequent injections to both rings without interruptions, injector linacs are strongly required to minimize device failures and the recovery time from such failures. We thus improved various components of linac and enhanced its stability and reliability. Important improvements achieved in recent years include the introduction of a twin gun system, a backup system for the first klystron, and the automatic exchange of a standby klystron. These improvements gradually reduced linac's downtime to 0.11% in FY 2011.

### IMPROVEMENT OF ELECTRON GUN SYSTEM

The SPRING-8 linac was equipped with only one electron gun system, i.e., a high-voltage inverter type pulse power supply, a pulse transformer, a high-voltage deck, and an electron gun. When any of these parts fail, the linac cannot inject beams into the booster synchrotron until the failure is fixed. In particular, the replacement of a cathode assembly requires at least three days to complete the mounting processes for a new cathode assembly and cathode evacuation and activation. Therefore, the construction of a backup system is an important issue for enhancing the reliability of the electron gun system and to reduce the downtime of the beam injection during gun failures. Thus we made the following improvements:

- 1) Composition of a twin electron gun system.
- 2) Development of a reliable high-voltage pulse power supply.

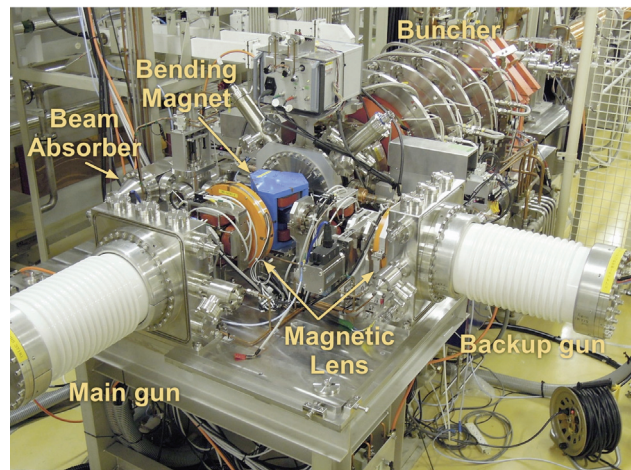


Figure 1 : Twin electron gun.

### Twin Electron Gun System

We considered two ideas to realize a twin gun system: duplicating the present electron gun or doubling the present injector part, including the gun and the buncher system, for example. We built a backup gun and its power supply and considered the following issues in our backup gun design.

- 1) The original performance of the main gun must be maintained after the backup gun's installation, but the backup gun's performance for the backup operation, the

beam current, for example, can be inferior to that of the main gun.

2) The backup gun's cathode has to be pre-heated during linac operation to immediately generate electron beams if a main gun failure occurs.

Figure 1 shows the twin electron gun system installed in the accelerator room. A 90° bending magnet was installed to orthogonally inject beams from the backup gun mounted on the main gun, which was relocated upstream to make space for the bending magnet. This bending magnet, which adopts a combined type and holds an  $n$  value of 0.5, focuses beams horizontally. We installed a magnetic lens for each gun to reduce the beam divergence caused by the space charge effects. A beam profile monitor and a coaxial type beam absorber to measure beam currents were also installed to diagnose the backup gun's beam. Beam simulation by Parmela from the backup electron gun is shown in Fig. 2.

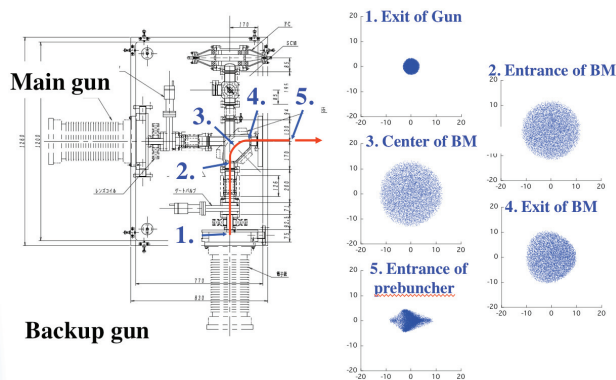


Figure 2 : Beam tracking simulation for backup gun.

The backup gun was tested and operated in September 2008. Since an additional high-voltage power supply system for the backup gun was constructed in 2008, we installed a remote change system to smoothly change the main and backup guns in FY 2010. The backup gun is always in a suspended state for emergencies. We check its injection to the synchrotron after every long-term maintenance.

### New High Voltage Pulse Power Supply

The previous pulse power supply often caused discharges at the high-voltage terminal of the inverter power supply. It was also difficult to maintain the pulse power supply because it was designed so many years ago. The new power supply was completed in 2005 and has been operated in a test stand for almost one year to confirm its performance and reliability. At the end of 2006, we replaced the previous power supply system with the new one.

The new system has the following features:

1) A pulse transformer with a step-up ratio of 1:30 decreases the primary voltage and solves the discharge problem. The inverter power supply now feeds a voltage

of only 12 kV to the PFN to generate a pulse voltage of 180 kV at the electron gun's terminal.

2) We installed a larger high-voltage deck to enhance the following: functionality, expandability, and serviceability.

The high-voltage pulse applied to the electron gun has a long rise/fall time of approximately 3  $\mu$ s because the large step-up ratio enlarges the stray capacitances of the secondary circuit. At first, we used a long pulse beam (1  $\mu$ s). However, the pulse's short flat top caused by the long rise/fall time does not limit operation since in practice we use short pulse beams with pulse widths less than 40 ns. The voltage stability of the inverter power supply is about 0.05% rms, which is sufficiently stable for the injector linac.

### BACKUP OF THE FIRST KLYSTRON

Linac is equipped with thirteen 80-MW pulse klystrons (Toshiba E3712) that feed 10-Hz RF power to the accelerating structures. Two of them are intermittently disabled by the trigger system in synchronization with 1-Hz beam trigger signals to avoid beam accelerations. That is, eleven of the klystrons are usually used to accelerate electron beams to 1 GeV, and the other two are kept as hot spares on line.

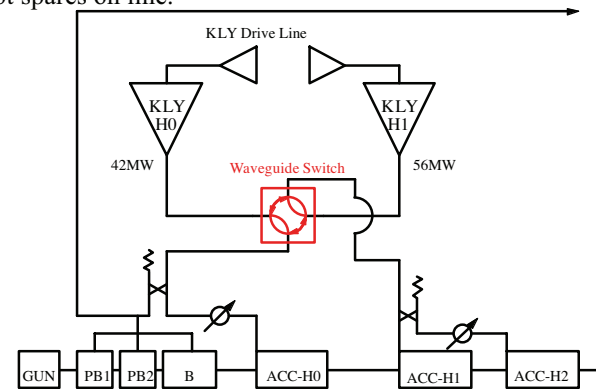


Figure 3 : Circuit using high power waveguide switch.

Except for the first and the Energy Compression System's (ECS) klystrons, when one of the eleven working klystrons fails and cannot be recovered within a few minutes, a standby klystron is activated to accelerate the beams instead of the failed one. But linac operation completely stops for a long time due to the serious failure of the first klystron because it feeds RF power to the linac's injector section and the long drive line for the other eleven klystrons. In 2004, we therefore constructed a backup system for the first klystron to feed RF power from the second klystron to the injector. The backup system is composed of waveguide circuits, a high-power waveguide switch, and its control system [1]. This system's circuit is shown in Fig. 3.

This backup system has worked very efficiently. In 2008, a serious failure of the first klystron occurred and it could not be recovered. We exchanged the first klystron

with the second one using this backup system and restarted linac in a few hours. The first was replaced with a new one and its RF conditioning was carefully performed without disturbing the linac operation because the second klystron had completely played the role of the first one for one month.

At that time, the exchanging time was long because a klystron drive system and part of the interlock signals had to be manually reconnected to the second klystron and its local controller. We upgraded this backup system to reduce the linac downtime to 10 minutes.

### AUTOMATIC KLYSTRON EXCHANGEING SYSTEM

Faults of the klystron modulators occur about once every three days and interrupt the top-up operation for a few minutes. When one of the normal 11 klystron systems fails (except for the first and ECS's klystrons), one of the standby klystrons can be activated to continue the beam acceleration, as mentioned above.

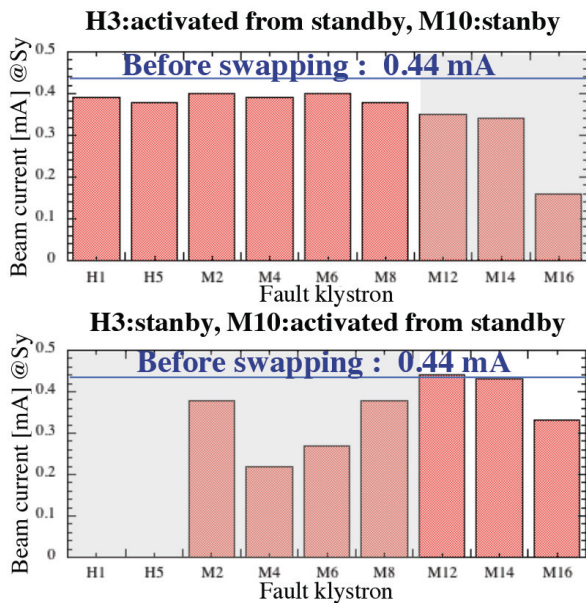


Figure 4 : The synchrotron current depending on a fault klystron.

The standby klystrons are H3(3rd) and M10(9th).

We introduced an automatic klystron exchanging system to shorten the linac downtime caused by the klystron failures. The system automatically controls the trigger system that defines the standby klystrons and can change them within one second. All the RF power of the 11 klystrons is adjusted at the same level to keep the same beam energy after the klystrons are exchanged.

When activating a standby klystron, since the currents of the Q magnets are not adjusted, they remain constant. Orbital variations may occur that reduce the current. We therefore examined the synchrotron currents that depend on every activating pattern (Fig. 4).

In this experiment, the 3rd and 9th klystrons were in standby mode. The current value before the experiment was 0.44 mA. Except for the first and ECS's, every working klystron was deactivated to simulate a klystron fault. If the third klystron were activated instead of the 2nd to 8th klystrons or the 9th klystron were activated instead of one of the 10th to 12th klystrons, the current reduction would probably be less than 20%.

### DISCUSSION

Figure 5 shows the operation statistics from 2005 to 2011. The fault rates gradually reduced as a result of improving the components.

Although in 2008 we recognized that long downtime was caused by the trouble of the gun bias circuit, introducing the twin gun and backup systems for failed klystrons considerably suppressed the interruption of the top-up operation caused by linac's failures. Although linac's downtime was 0.59% in FY 2005, it decreased to 0.11% in FY 2011.

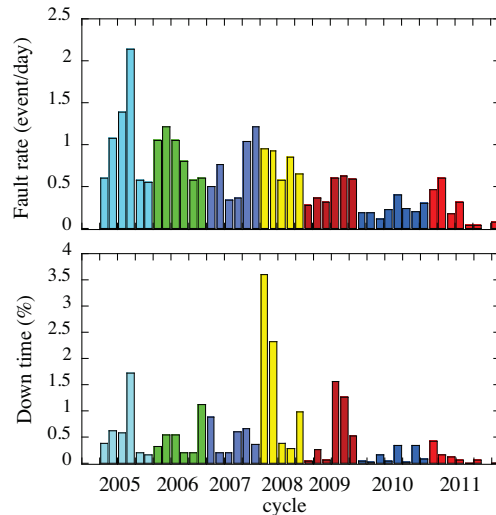


Figure 5 : The history of the fault in 2005 to 2011 fiscal year.

The twin gun system effectively reduced linac's downtimes that were caused by the failures of the cathode assembly and greatly improved reliability.

### REFERENCES

[1] T. Taniuchi, "HIGH POWER WAVEGUIDE SWITCHING SYSTEM FOR SPring-8 LINAC" EPAC'06, Edinburgh, Scotland, July 2006, TUPCH159, p. 1397 (2006); <http://www.JACoW.org>