TEST OPERATION OF THE PF LINAC RF SYSTEM UPGRADED FOR THE KEKB INJECTOR

H. Hanaki, S. Anami, A. Enomoto, H. Katagiri, S. Michizono, Y. Otake, Y. Saito
National Laboratory for High Energy Physics
Oho, Tsukuba, Ibaraki, 305 Japan

Abstract

The RF source of the PF 2.5-GeV linac has been reinforced by installing SLEDs and replacing the existing 30-MW klystrons with new 50-MW ones. Conditioning of the upgraded high-power units is proceeding and the discharge in the process has been analyzed. The averaged energy gain and energy multiplication factor of the upgraded units in operation is 163 MeV/unit and 1.93, respectively. A signal-analyzing system for diagnosing the RF source was developed and is now being examined.

1 INTRODUCTION

The B-physics project at KEK (KEKB) started in 1994, and construction will be completed in 1998. The PF electron linac, which will be an injector for the KEKB collider rings, will have its energy upgraded from 2.5 to 8 GeV by increasing both the RF power and the total accelerator length[1, 2].

The present klystron modulators have been upgraded[3] in order to increase the output power and to extend the high-voltage pulse width up to 4 µs on its flat top. The 30-MW Klystrons have been replaced by a new 50-MW type[4]. A SLED, which is an RF-pulse compressor, has been installed in every high-power RF source[5], except for two or three which require severe phase and amplitude control.

At present, eleven SLEDs have been installed as of this spring. The conditioning of seven of them has almost been completed, and they are actually being used for beam acceleration. The remaining four are being conditioned.

For a good understanding of the linac condition it is very important to quickly detect any problem or symptom concerning any problem regarding the RF system, such as a defect in the RF-wave form or variations in the vacuum of the wave guides. Therefore, an intelligent RF monitor system[6], which is now being examined, will be introduced in each two high-power RF amplifiers.

2 RF CONDITIONING

2.1 Procedure and History

Since the maximum RF power fed into an accelerator guide had been about 8 MW before the upgrade, multiplied microwaves greater than 70 MW cannot be fed in a short term. It is necessary to gradually increase the RF power so that gas molecules adsorbed on the surface of the RF components may not be released drastically and may not initiate a discharge.

If the vacuum in the waveguides or the accelerator guides exceeds an alarm level during the conditioning, a control system immediately cuts off the RF pulses so as not to cause any serious damage due to discharging.

When a SLED system is set up, the first conditioning of the high-power RF system is carried out according to the following steps:

1) The SLED cavities are detuned and RF pulses are fed into the accelerator guide while gradually increasing its power from 0 to 30 or 40 MW.
2) The SLED is turned on. The operating klystron output power is from 0 to 10 MW, mainly for conditioning the SLED cavities. It normally takes 4 or 5 days.
3) The klystron output power is from 10 to 40 MW or more, mainly for conditioning the accelerator guides. The period of this stage strongly depends on an accelerator guide, and is more than two weeks.

Although the above processes are presently carried out by manually operating a local controller with monitoring the vacuum, it will become automatic this summer.

Figure 1 represents the conditioning history of the number 4-7 unit as an example. In this case, the processes were completed in relatively short term.

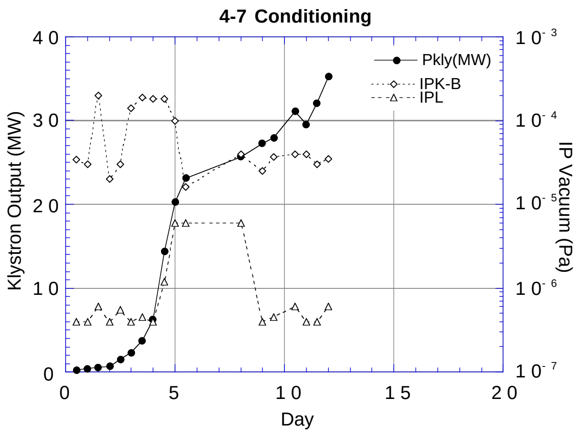

Figure 1: Conditioning history of the 4-7 unit. Plotted symbols of IPK-B and IPL represent the rough pressures in the waveguide and the accelerator guide, respectively.

2.2 RF-Pulse Reflection Caused by Discharge

The RF pulse reflected in the accelerator guide is observed with a long delay time (0 ~ 1 µs) on an oscilloscope, since the group velocity of the microwaves in the accelerator guide is very slow, and the filling time of the guide is about 0.5 μs in our case. That is, the delay time can give the discharge position in the accelerator guide.

Here, we focus on a multiplied part (width w = 0.6~1 μs) of a SLED RF pulse, and assume the following for the analysis. Suppose that an RF pulse, which travels in an accelerator guide, causes a discharge because of its high field strength at some position in the guide. Then a part of the travelling RF pulse, filling the accelerator guide from the upper stream to the discharge position, is reflected backward, and the other downstream part of it goes forward.

When a reflected RF pulse with a width of t_2 is observed, the pulse appears with a delay time of t_1, which is equal to the traveling time of the RF pulse to and from the discharge position (L). We can then find the following equations, which give the discharge timing (T) of an RF pulse and the normalized position (L) in an accelerator guide:

$$T = w - t_2$$

$$L = \frac{1}{g}\left[1 - \exp\left(\frac{t_1 - T}{2T_f}\ln(1-g)\right)\right]$$

where T_f is the filling time of the accelerator guide and g is defined as $1 - e^{-2\tau}$ (τ: attenuation parameter) for a constant -gradient structure. The positions of L =0 and 1 correspond to the input coupler and the output coupler, respectively.

In reality, the shapes of the reflected pulses were not as ideal as that assumed above, and it was not easy to determine the Ts and Ls. However, the analysis was performed according to the equations in order to understand the general characteristic of the discharge. Figure 2 and 3 are examples of the T and L distributions of the discharges which occurred in the 4-7 accelerator guide.

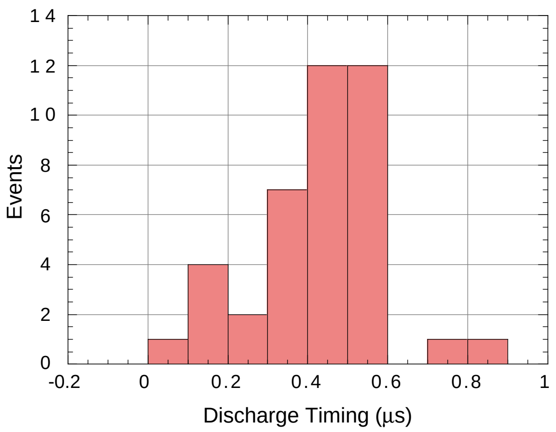

Figure 2: Discharge-timing distribution of RF pulses for the 4-7 accelerator guide.

Figure 2 explains that the growth of a discharge takes time, which is well-known. Figure 3 shows that discharges around the input or output couplers are remarkable. This result is consistent with the fact that the reflection from both couplers has been clearly observed. Note that the events around the input coupler may contain discharges in the waveguide.

.

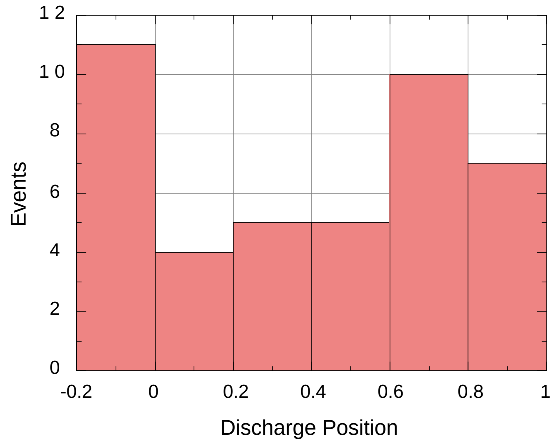

Figure 3: Discharge-position distribution of RF pulses for the 4-7 accelerator guide. The negative positions were caused by errors in reading t_1 or t_2 .

3 ACCELERATION TEST

Beam-acceleration tests were perfomed in order to obtain the energy gain of the acceleration units and the energy multiplication factors of the installed SLED. Figure 4 illustrates the distribution of the obtained values in case that the SLED cavity charging time was 3 μs. It shows that the energy gains are around a specified value of 160 MeV/unit, and the average is 163 MeV/unit (21.6 MeV/m). The multiplication factor is 1.93 on the average, which agrees with the computed value of 1.96. Note that the klystrons outputted different power levels to the SLEDs.

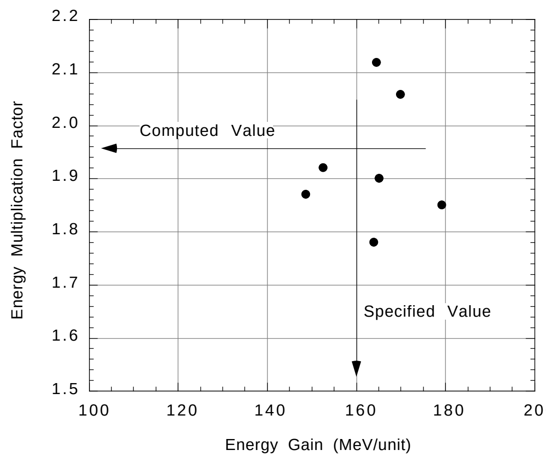

Figure 4: Distribution of the energy gains of the acceleration units with SLED operation and their energy multiplication factors.

The shape of the RF pulse ejected by the SLED does not have any flat part, and the pulse width must be as short as possible in order to obtain a high multiplication factor. This means that the stability of the energy gain strongly depends on the RF timing.

We experimentally and theoretically examined the energy loss caused by the timing shift, as shown in figure 5. Both results show rather good agreement.

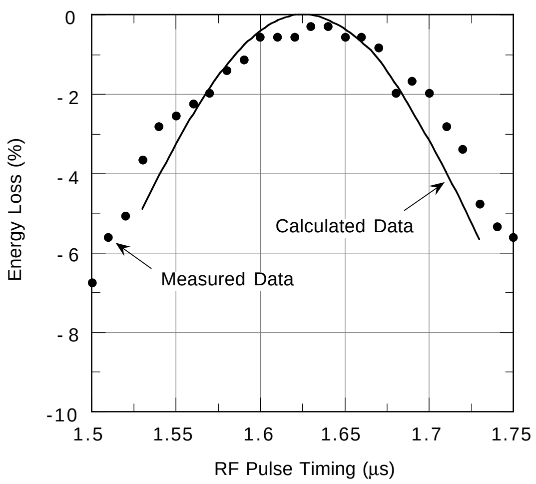

Figure 5: Energy loss as a function of the timing of the RF pulses. The SLED cavity charging time was 3.3 µs and the width of the multiplied pulse was 0.7 µs.

We fitted a quadratic function to the experimental results. According to the obtained function, to accomplish a beam energy jitter of less than 0.1 % requires that the timing jitters be less than 7 ns. The new trigger system will adopt RF synchronized timing circuits, so that the timing jitters will be basically much smaller. The delay time generated by the circuit, however, must be controlled with a time step of less than 5 ns.

4 RF MEASUREMENT SYSTEM

A signal-analyzing system will be newly installed, which will continuously take monitor signals from the modulator and SLED into its computer. The computer will analyze the data and diagnose any problem involving the RF source, when it occurs. This system will also provide automatic execution of the RF conditioning of the high-power RF units including the accelerator guides.

A prototype system based on a VXI system has been developed from 1995 (figure 6). This VXI system comprises a controller, a wave-form digitizer, an ADC and a digital I/O; also, along with the RF measurement equipment (a peak power meter, a phase detector, etc.), an RF monitor station for observing two high-power RF units has been developed. All of the monitor stations will be networked, and a few servers will manage the VXI controllers and databases. Measured and analyzed data or wave forms can be monitored on a remote X terminal anywhere. The wave form of a SLED RF pulse is displayed on it and refreshed more than 30 times per second.

As practical operation of all monitor stations, it can be expected that a poor reliability of the hard disks of each VXI system may spoil the reliability of the total monitor system, because the number of stations will be more than 30. Therefore, a complex system comprising a server and a couple of diskless VXI systems will be undergoing test operation this summer.

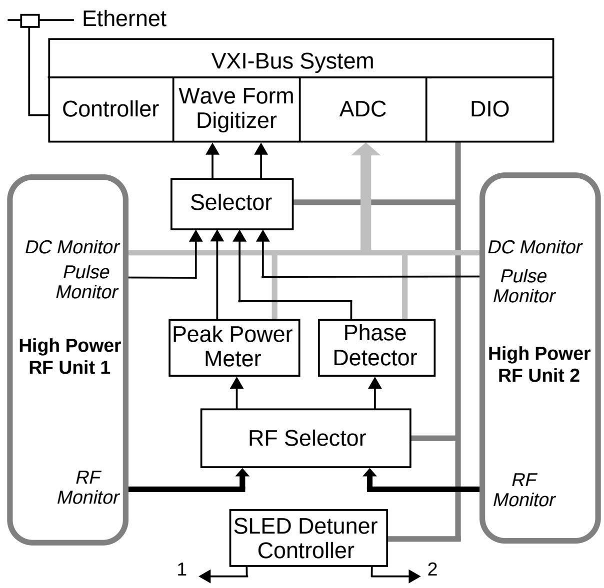

Figure 6: Block diagram of the prototype RF monitor station.

5 REFERENCES

[1] Design Report on PF Injector Linac Upgrade for KEKB (in Japanese), KEK Report 95-18, 1996.

[2] A. Enomoto, et al., "Reformation of the PF 2.5 GeV Linac to 8 GeV", Proceedings of the 1994 International Linac Conference (Tsukuba), p 184.

[3] H. Honma, et al., "Upgrade of the PF 2.5-GeV Linac Klystron Modulator for the KEK B-Factory Project", Proceedings of the 1994 International Linac Conference (Tsukuba), p 436.

[4] S. Fukuda, et al., "Development of the B-Factory Linac 50-MW pulsed klystron", Proceedings of the 1994 International Linac Conference (Tsukuba), p 427.

[5] H. Hanaki, et al., "Use of SLEDs for High-Gradient Acceleration", Proceedings of the 1994 International Linac Conference (Tsukuba), p 430.

[6] H. Katagiri, et al., "An RF Monitor System for KEKB Linac"(in Japanese), Proceedings of the 20th Linear Accelerator Meeting in Japan (Osaka, 1995), p 296.