# PERFORMANCE IMPROVEMENT OF THE SPring-8 LINAC

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*Abstract*

The beam stability of the SPring-8 linac has been improved by means of reinforcement of monitor systems, reduction of RF variations and beam energy compensation. A BPM system employing shared memories for fast data acquisition was completed. A quasi non-distractive profile monitor using OTR was installed in a chicane section to observe the beam energy and energy spread. A beam trigger pulse and a reference RF signal (2856 MHz) were synchronized to stabilize beam bunches. A beam energy compression system was installed to compensate the energy variation and reduce the energy spread due to beam loading. As a result, a minimum beam energy fluctuation of 0.01% (rms) was achieved and the reduced energy spread realized high-current injection into a synchrotron.

## 1 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 also into the 1.5-GeV storage ring NewSUBARU which was completed in the SPring-8 site in 1998 of the Himeji Institute of Technology.

The SPring-8 linac has been operational since August 1996, when beam commissioning began, and until the early summer of 2002 has not encountered any significant problems. The cumulative operation hours from the beginning of the user service operation till this summer has reached about 23,000 hours.

In 1997, an investigation into the instability of the linac's beam energy was started. As a result, we reduced variations in the RF power and phase by stabilizing the temperature drift of the atmosphere and cooling water and by readjusting the de-Qing efficiency of klystron modulators in order to reduce the PFN voltage fluctuation. Finally, a minimum energy fluctuation of 0.03% (rms) was achieved and the reappearance of the injection current was considerably improved[1].

Following the first refinement mentioned above, we planned a program of improvements to make the linac more stable and more reliable:

- Replace or improve unreliable RF devices such as the booster amplifier which drives a buncher system and thirteen of the 80-MW klystrons.
- Install sufficient beam or RF monitors to diagnose the linac's beam or RF system.
- Beam energy compensation by installing an energy compression system (ECS).

The program has been aggressively carried out and will be completed this year. Present performance of the linac with an operation of the ECS is given in Table 1.

Table 1: Beam parameters for SPring-8 linac (with ECS)

| | Synchrotron | | NewSUBARU |
|---|---|---|---|
| Pulse Width | 1 ns | 40 ns | 1 ns |
| Repetition | 1 pps | 1 pps | 1 pps |
| Current | 2 A | 350 mA | 200 mA |
| *dE/E* (p-p) | 0.62% | 1.4% | 0.4% |
| Energy Stability (rms) | 0.02% | – | 0.01% |
| $\varepsilon_n$ (90%, mm·mrad) | <240π | – | <200π |

## 2 IMPROVEMENT

### *2.1 Electron gun*

After long time operation of an electron gun, barium atoms evaporated from a heated cathode of the gun accumulate on a grid of the cathode assembly. This phenomenon causes electron emission from the grid when a high voltage is applied to the cathode. The grid emission current depends on the cathode high voltage only, therefore it cannot be independently controlled. This emission current is the background of an electron beam injection into the synchrotron, hence the purity of an electron bunch circulating in the storage ring can be spoiled because a part of the background electrons is injected from the synchrotron into RF buckets which have to be vacant.

In order to reduce the grid emission, a beam deflector, which kicks out only the background, has been developed and installed in the gun of the linac in December 2001[2]. This beam deflector is composed of a vacuum chamber with parallel-plate electrodes, which look like strip lines. 7-kV pulses are fed to both electrodes and each timing of them is adjusted so that the true 1-ns beam is not deflected, and so that most of the grid emission currents are kicked out of a straight beam orbit.

A test of the deflector has been carried out by deflecting a beam holding a 40-ns width. It was clearly observed that the deflector gated the 40-ns beam to transport only a 1-ns width beam to the prebuncher. The deflector will be employed in the linac operation from the autumn of 2002.

### *2.2 High-power RF source*

We had used a 7-MW klystron amplifier system, which was manufactured in the early stages of development of the linac, as the booster amplifier until the summer of 2001. This booster's modulator was not so reliable since its circuits did not have sufficient tolerance for severe noises generated by the modulator itself. On the contrary, modulators for the 80-MW klystrons are relatively quiet in terms of the noise and then reliable and stable. The first 80-MW klystron has fed an RF power of 40 or 50

MW only to the first regular accelerator column and leaves the sufficient margin of its output power. Therefore the RF output power branched to the buncher system and a drive line for the other 80-MW klystrons instead of the 7-MW booster.

Figure 1 illustrates a simplified diagram of the present linac's RF system. It shows that the head of the 80-MW klystrons now works as the RF reference. This improvement resulted in greater reliability of the reference power source. Furthermore, it resulted in good maintainability by excluding the unique 7-MW amplifier system which could not share spare components with the 80-MW klystrons' modulators.

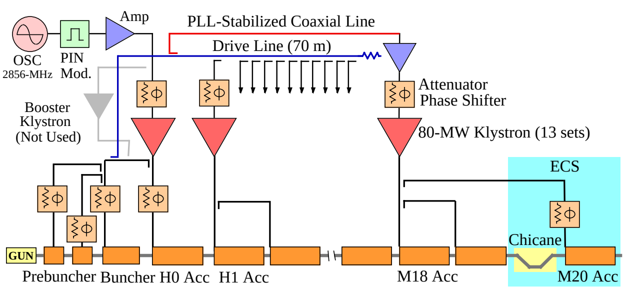


Figure 1: Diagram of improved RF.

## *2.3 RF Reference Generator*

The RF frequencies of the linac and the circular accelerators of the SPring-8 are 2856 MHz and 508.58 MHz, respectively. The electron gun is triggered by synchronizing with the RF reference of the circular accelerators. The frequency of 2856 MHz, however, is not an integral multiple of 508.58 MHz, therefore the linac's beam has not been able to synchronize with the linac's RF frequency. This fact caused beam energy instability for the 1-ns beam: The linac bunches the 1-ns beam and forms two or three bunches according to the beam trigger timing referred to the RF phase of the 2856-MHz RF. Consequently, the charge amount in each bunch was not stable and thus beam loading varied bunch-by-bunch. This random variation finally caused shot-by-shot fluctuation of the beam energy center.

In order to reduce the energy fluctuation, a new method was invented to realize complete synchronization of the beam trigger and the linac RF as expressed in Fig. 2[3]: A master oscillator generates a reference signal of 508.58 MHz. A beam trigger of 1 Hz is produced by counting the 508.58-MHz reference. Sinusoidal waves of 89.25 MHz with duration of 290 µs, whose frequency is 2856 MHz divided by 32, are programmed in an arbitrary waveform generator. The waveform data were automatically programmed by sampling ideal 89.25-MHz sinusoidal waves at the reference frequency of 508.58 MHz. The 1-Hz beam trigger starts the generator to oscillate by referring to the external 508.58-MHz clock, and thus a 89.25 MHz burst signal is created which synchronizes with the 508.58-MHz reference. This intermediate signal is filtered by a high-Q crystal filter with a bandwidth of 12 kHz to reduce phase noises. Finally, the filtered signal is multiplied by 32 to generate the 2856-MHz reference. Note that this RF reference signal is not CW but burst waves.

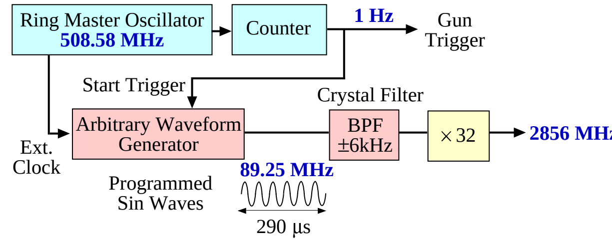


Figure 2: Block diagram of RF reference generator.

The electron gun can generate a 250-ps beam. The buncher compresses a part of the beam, then forms a single bunch. Figure 3 shows an example of beam current measurement in single bunch acceleration. The fluctuation of current observed when using the previous asynchronous system does not appear in the new synchronous system. This measurement clearly proves that the new 2856-MHz reference signal synchronizes with the beam trigger.

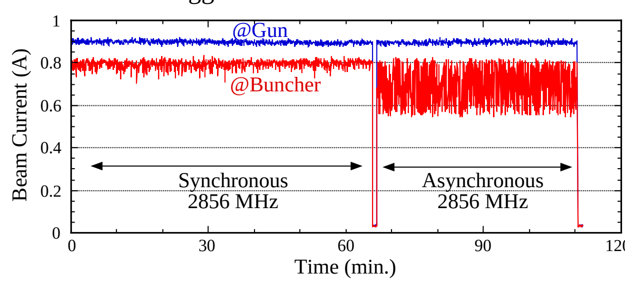


Figure 3: Stability of single-bunched beam.

## *2.4 ECS*

In the case of 1-ns beam injection into the New SUBARU storage ring, the beam energy spread, including the energy fluctuation over the long term, has to be less than ±0.3% since radiation caused by the beam loss is severely regulated at NewSUBARU. In order to narrow the beam energy spread caused by beam loading and consequently to extend the upper limit of the injection current, a conventional type energy compression system (ECS) was introduced [4].

The terminal beam energy is sensitive to the RF phase, which the beam bunches meet in an accelerator column of the ECS, since the phase value is around zero where the field gradient referring to a phase is the maximum. Hence the RF phase has to be strictly regulated to stabilize the energy of the beam compensated by the ECS. In order to reduce the phase fluctuation of the ECS's klystron, a phase-locked-loop technique was applied to an independent drive system for the klystron, as shown in Fig. 1.

It was observed that the ECS compressed the full energy spread of the 40-ns beam at high current of 350 mA, from 3.6% to 1.4% which is narrower than the energy acceptance of the booster synchrotron[5].

The ECS can also reduce the energy fluctuation according to the same principle. For example, the ECS suppressed the energy variation of 0.06% (rms) down to 0.01% (rms) for the 1-ns beam acceleration when the synchronous generator transmitted the reference RF [5]. Thus the ECS is quite useful to maintain the shot-by-shot and long-term beam energy stability.

### *2.5 Beam Position Monitor*

After R&D of a single-pass BPM, we decided to adopt an electrostatic strip line type BPM. The resonant frequency of 2856 MHz was chosen for the strip line, since the BPM had to detect three types of beams with the pulse widths of 1 ns, 40 ns and 1 µs. Twenty-eight sets of the BPM were installed in quadrupole magnets [6].

A signal processor for the BPM was required to have a wide dynamic range, since the 1-ns beam current ranges from 20 mA to 2 A. Therefore we employed a logarithmic detection method, which was originally capable of processing wide dynamic range signals [6]. A practical circuit comprises 2856-MHz bandpass filters, logarithmic detectors and ADC’s. The circuit has a dynamic range wider than 45 dB and a maximum position resolution of ten and a few µm (2σ).

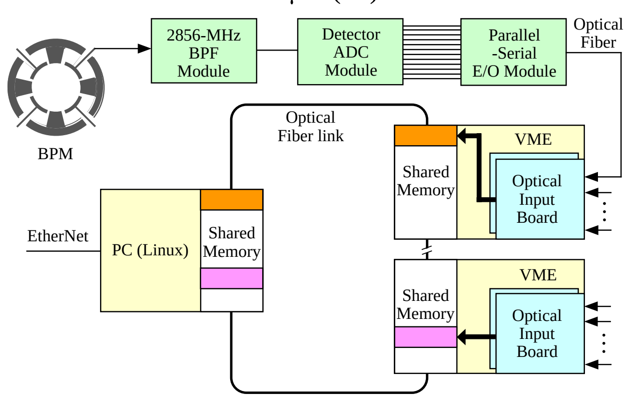


Figure 4: Block diagram of BPM data acquisition system.

A data acquisition system was required to process data of all the channels synchronizing with a beam pulse to represent a one-pass beam orbit of the linac. However, the system would be composed of several VME systems distributed along the linac. Therefore, a shared memory method was introduced for synchronized data acquisition, as shown in Fig. 4[7]. The 4-channel digitized data given by the signal processor are converted to optical serial data and transferred to a VME system in order to avoid electromagnetic interference. All the acquired data are stored in the shared memory and then read out and processed by a PC. The data acquisition system is almost completed except for data accumulation in a database. Operators of the linac can easily adjust steering magnets by watching displayed beam orbits. An automatic beam steering program has been made and it is now undergoing testing.

### *2.6 Beam Energy Monitor*

The beam energy, before being compensated by the ECS, is monitored by a thin screen inserted in the center of the chicane where the energy dispersion is 1 m. The screen is a 12.5-µm thick Kapton film coated with 0.4-µm aluminum. A CCD camera captures OTR (Optical Transition Radiation) lights radiated by beam irradiations on the screen. The captured beam images are analyzed to determine the beam energy and its spread. This analysis is executed automatically and the results are accumulated in the database. The beam emittance growth caused by the screen is negligible. Therefore the screen is inserted to monitor the energy during beam injection into the synchrotrons.

### *2.7 Control*

The linac control system was renewed to reinforce the function of the system and to complete the unified accelerator control including the SPring-8 circular accelerators [8].

All the VME-CPU's were replaced by new ones and a Solaris (UNIX) operating system replaced a previous OS9 system. Software architecture developed for the storage ring control was introduced, and inevitably, all the device managing programs were remade. The existing database system came to be available for the linac control.

As a result, the new architecture realized better productivity of control programs and the database system made troubleshooting much easier.

## 3 ACKNOWLEDGMENT

The synchronous RF reference generator was invented and developed by staffs of the storage-ring's RF group. The control group planned and managed the renewal of the linac control system. We are grateful to them for their very large contribution to the improvement of the linac.

## 4 REFERENCES


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