STATUS OF THE SPring-8 LINAC

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Abstract

The fluctuation of the beam current and energy had been investigated from '98 to '99. As a result, readjustment of klystron modulators and temperature stabilization were made so as for the RF system to obtain the phase and amplitude stability. Finally, the beam energy fluctuation of ±0.03% (1σ) was achieved and good reappearance of the injection current was obtained. A beam chicane and an accelerator column which compose an ECS were newly installed at the end of the linac in order to reduce the beam energy spread due to the beam loading.

A photocathode RF gun study succeeded to extract photoelectrons by irradiation of UV laser pulses. The electric-field gradient on a cathode reached 140 MV/m and the minimum emittance of 17π mm·mrad was obtained. A high-power solid-state switch has been developed in order to replace a thyratron for a klystron modulator.

1 INTRODUCTION

The SPring-8 1-Gev linac[1] has been operated from August 1996, when the beam commissioning began, till the summer of 2000 without any big problem. The cumulative operation hour from the beginning of the user service operation reaches about 13,000 hours.

Two new beam lines for experiments and for beam injection into the storage ring New SUBARU, called L3 and L4 respectively, were completed in 1998. The electron beam injection into the New SUBARU started in October 1998.

Stabilization of the linac's beam has been carried out from 1998. First the beam's stability was intensively examined and then the RF system was improved in order to reduce the RF power and phase variations[2]. As the next step, reduction of the beam energy spread was planned by introduction of an ECS (Energy Compression System). The ECS[3] was completed and will operate from this autumn.

A beam position monitor (BPM) is an indispensable device for the diagnosis of a beam passing through a linac. Development of a BPM system will be achieved this year [4] and the system will function from the autumn of 2001.

Studies of advanced technologies for electron linac have been continued in parallel with the improvement of the linac. The R&D of an RF gun has almost accomplished its original goal to compare experimental results and simulations. Development of a compact and reliable klystron modulator is also in progress.

2 OPERATION AND FAILURE

The parameters of the beams injected into the SPring-8 synchrotron or the NEW SUBARU are summarized in Table 1.

Table 1: Beam parameters for the SPring-8 linac

	Synchrotron		New SUBARU
Pulse Width	1 ns	40 ns	1 ns
Repetition	1 pps	1 pps	1 pps
Current	2A	80 mA	200 mA
dE/E (p-p)	0.6 %	0.8 %	0.4 %
ε_n (90%, mm·mrad)	<240π	<160π	<200π

The linac was in operation for about 5,000 hours in 1999. The failure rate, which corresponds to periods when no 1-GeV beam was available because of trouble etc., was 2.5 % of the total operation time.

The failure statistics for the year 1999 are given in Fig. 1. The event frequency of the vertical axis in the figure means the total failure count during one operation cycle. Most of the failure events are alarms from interlock circuits of devices equipped to the linac.

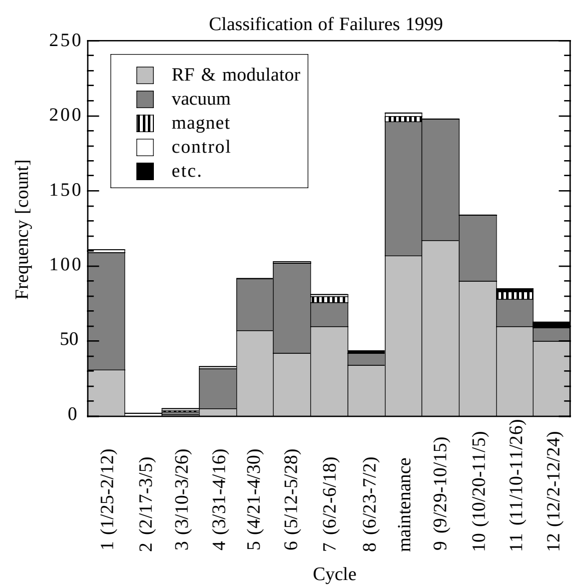

Figure 1: Linac failure statistics for 1999.

The majority of failures originate in the RF system of the linac and are mainly caused by deterioration or incorrect adjustment of the thyratrons as well as discharge in the klystrons. Such failures occurred frequently, especially at the startup of the linac after a long maintenance period.

Before the summer maintenance, the vacuum pressure at an injector section of the linac exceeded the alarm level frequently due to deterioration of the ion pumps mounted there. Therefore, six ion pumps were replaced at the summer maintenance. The noticeable vacuum failures after a long maintenance period were actually due to a rise in vacuum pressure in the accelerator guides or the waveguides during RF conditioning.

In February 1999, there was an accident when the electron gun was unable to emit a beam due to a control grid being short-circuited to a cathode of the gun. After replacement of the cathode assembly, the gun was operated without any trouble till the summer of 2000. However, we observed the cathode emission decreasing and the grid emission increasing as time elapsed.

We first excluded one 80-MW klystron (Toshiba E3712) which was suffering from vacuum deterioration. This klystron was originally unstable and had been kept as a spare. We replaced the klystron leaking water at M6 with this spare, however, it failed in a short time.

We continued measurement of the klystron's perveance, and no klystron showed any decrease in cathode emission current.

The SPring-8 linac adopted a thyratron F351 made by TRITON as a switching tube for a klystron modulator. In 1999, five of them were replaced because of failures. Their operational lives were around 22,000 hours. Four of them had the same trouble of short circuits in their reserver heaters. According to TRITON's investigation, the alumina coating on the heater had gradually evaporated during operations and finally the heater could not be isolated. The engineers reported that these phenomena were inevitable, that is, this was the life of an F351 tube.

A Thyratron CX1937A made by EEV, which has an automatic reserver system, is one of the alternatives. Therefore we replaced some of the malfunctioning F351's with CX1937A's. We will exchange the two models henceforth, then we will be able to compare their performance and operational lives.

3 IMPROVEMENTS

3.1 RF System

In 1998, we reduced the RF power and phase drifts by stabilizing the temperature drift of the atmosphere and cooling water. In addition, a readjustment was made to the de-Qing efficiency of the klystron modulator in order to reduce the PFN voltage fluctuation. As a result, beam energy stability was greatly improved and good reappearance of the injection current was obtained[2].

In 1999, an accurate evaluation of the beam energy variation was made by analyzing a beam spot image on a screen monitor mounted in the 1-GeV chicane section. As shown in Fig. 2, the energy fluctuation was ±0.018 % (rms) for a short term, and ±0.03 % (rms) for a long term (10 minutes).

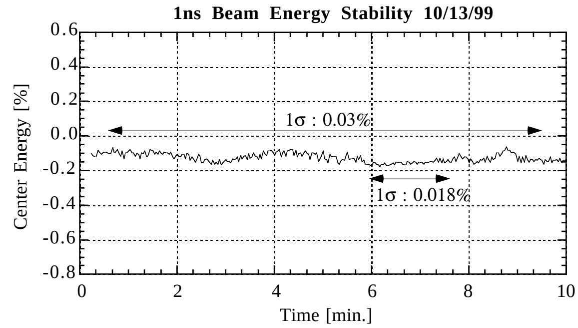

Figure 2: Energy variation of 1-ns beam.

In the case of 1-ns beam injection into the New SUBARU storage ring, beam injection loss has to be minimized since radiation caused by the beam loss is severely regulated at New SUBARU. Therefore, the beam energy spread, including the energy fluctuation in a long term, has to be less than ±0.3 %. As a result, the maximum beam current has been limited to 200 mA. In order to narrow the beam energy spread caused by beam loading and consequently to extend the upper limit of the injection current, introduction of an energy compression system (ECS) is determined.

A design for the ECS[3] is based on the conventional type developed at the Mainz 300-MeV linac. According to the calculated result, the beam energy spread or fluctuation will be kept within ±0.3 % (full width) even for a high current injection at 5 A as shown in Fig. 3.

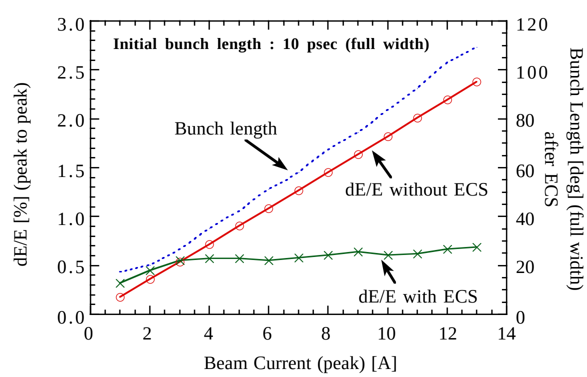

Figure 3: Beam energy spread and bunch length as a function of beam current.

The ECS is composed mainly of four chicane magnets and an accelerating structure. The chicane section was completed in January 1999 and has been used for a beam energy analyzer as mentioned above. The accelerating structure and RF components have just been installed in the summer of 2000.

3.2 Beam Monitor

We have been involved in the R&D of a single-pass BPM since 1995. After constructing a few kinds of pilot models, we decided to adopt an electrostatic strip line type. The resonant frequency of 2856 MHz was chosen for the strip line, since the BPM has to detect three types of beams with the pulse widths of 1ns, 40ns and 1μs.

The signal processing circuit for the BPM was requested to have a wide dynamic range, since the 1-ns beam current ranges from 20 mA to 2 A. Finally we concluded that the logarithmic detection method, which was originally capable of processing wide dynamic range signals, was the first choice for our case.

A prototype circuit[4] comprises 2856-MHz bandpass filters, logarithmic detectors and peak-hold circuits. The following ADC's take four output signals to convert them into x-y positions. The position resolution was estimated about 10 μm from the nominal noise level of the logarithmic detector. The circuit is now under examination. First results showed that the circuit had the dynamic range wider than 45 dB and the position resolution less than 10 μm (2σ).

We will begin operation of the BPM system from the autumn of 2001.

3.3 Beam Transport

In 1998, two new beam-transport lines were built: the L3 line to an experimental hole and the L4 line to the New SUBARU. Due to the great length of the L4 beam line (150 m), Twiss parameter matching of the transport line has to be made accurately in order to realize high injection efficiency.

First, transverse beam sizes are measured with three wire scanners and four screen monitors which are installed between the end of the final accelerator guide and the first bending magnet. Then Twiss parameters at the entrance of the 1-GeV chicane are calculated from the obtained seven beam sizes. These parameters give the optimum excitation currents of quadrupole magnets at the upstream side of the first bending magnet. In addition, beam emittance also results during this process. The measured emittance values are summarized in Table 1.

This matching process is carried out when the linac operation starts or when the operation parameters are changed, resulting in high injection efficiency greater than 90 %.

4 R&D

4.1 RF Gun

Work on a photocathode RF gun study started in 1996. A high-power RF test of the gun's RF cavity started in November 1998 and the first photoelectrons by the irradiation of UV laser pulses was observed in February 1999. High-power RF of up to 27 MW was fed into the cavity and the electric-field gradient on the cathode reached 140 MV/m. The maximum beam energy was 3.2 MeV and the charge per bunch was 2 nC. The minimum normalized beam emittance of 17π mm·mrad was obtained when the 10-ps pulsed laser was injected on the cathode plain holding the maximum electric fields of 90MV/m, and then 0.8 nC beam bunches were extracted[5].

A beam simulation code has also been developed as a comparison for the experimental results. The present code is a three-dimensional particle tracking code which treats all actions between each electron in order to solve the space charge effect. Figure 4 presents that the simulated results provided a good explanation for the experimental values of the emittance and their dependence on an initial phase of the RF power fed into the gun's cavity[5]. Therefore we consider that this code is useful for the design of our second phase.

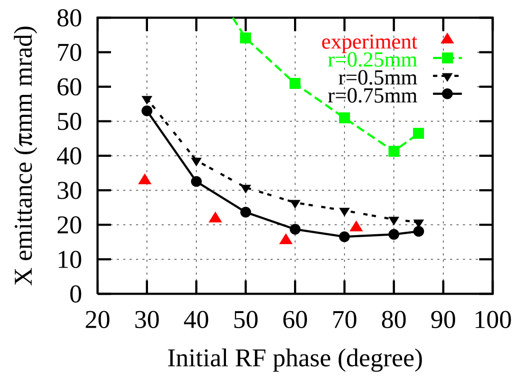

Figure 4: Beam emittance values as a function of initial RF phase.

4.2 Klystron Modulator

A thyratron, a kind of vacuum tube, is the bottleneck in the development of a reliable and compact modulator. Therefore we have developed a solid-state switching device which is able to replace the thyratron.

A pilot model, in which ten IEGT's (Injection Enhanced Gate Transistor) are stacked, was completed. An IEGT has a structure similar to an IGBT, which is widely used for high-power control, except that an IEGT has the advantage of smaller power loss. The pilot model is expected to have a practical specification of 32 kV / 4 kA and tests will begin from the autumn of 2000.

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