ENHANCEMENTS OF MACHINE RELIABILITY AND BEAM QUALITY IN SPring-8 LINAC FOR TOP-UP INJECTION INTO TWO STORAGE RINGS

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Abstract

The SPring-8 linac has been improved to realize stable top-up injection into the SPring-8 and the NewSUBARU storage rings. The beam energy instability of 0.02% rms in the long term was achieved by the following stabilizations: RF amplitude and phase stabilization, synchronization of beam timing and linac's 2856 MHz RF, and the installation of an energy compensation system (ECS). Beam feedback controls compensate for residual long-term variation of beam trajectory and energy. A beam deflector installed between a gun and a prebuncher reduces gun's dark currents, which spoil the purity of the stored beam in the storage ring.

INTRODUCTION

Synchrotron radiation (SR) lights of constant intensity, which can be realized by the top-up operation of a synchrotron radiation source, maximize the performance of the SR facility as well as ease user experiments [1].

SPring-8 and NewSUBARU storage rings have maintained the top-up operations since May 2004 and June 2003, respectively [1,2]. The parallel top-up operations of both rings started in September 2004. SPring-8 linac is now performing frequent beam injections into the two synchrotrons at short intervals to keep the stored current approximately constant. The present minimum injection interval is about 5 seconds for the parallel top-up operations and the constancy of the stored current is less than 0.1% for the SPring-8 storage ring, and less than 0.2% for the NewSUBARU.

The linac has been improved to realize ideal beam injection into the synchrotrons as follows:

- Enhancement of RF stability to stabilize beam energy and current [3,4].
- Introduction of beam feedback controls to minimize residual long-term beam instability.
- Enhancement of machine reliability so that top-up injection is not suspended [3,4].
- Reduction of dark currents to minimize satellite bunches around the main bunch stored in the ring [5].

At the end of the linac, we also installed a new bending magnet that can be momentarily excited to switch the beam direction at a short interval in order to perform parallel top-up injections into the two synchrotrons [4].

The first and second reinforcements in the above list accomplished minimum energy instability of 0.01% rms in the short term and 0.02% rms in the long term. The third one reduced the down time of the top-up injection; the most recent down time total caused by linac failures was only 72 minutes per 4260 of top-up operation, or about 0.2%.

The fourth issue of the dark current is important for providing a highly purified (i.e. no satellite) single bunch photon beam that enhances the X-ray detection sensitivity of user's measurement systems: The RF-KO system[6] of the booster synchrotron kicks out satellite bunches and achieved the very low impurity of the stored beam; the latest measured value of impurity is about 10^-9 after accumulating the satellites for one week, which is ten times the detection limit. The dark current reduction in the linac may reduce the intensity of the satellites to detection limit.

BEAM STABILITY

Improvements Before 2003

The linac holds thirteen 80-MW S-band klystrons that feed RF powers to accelerating structures, as illustrated in Fig. 1. The first klystron drives the remaining twelve klystrons via a 90 m long waveguide drive line.

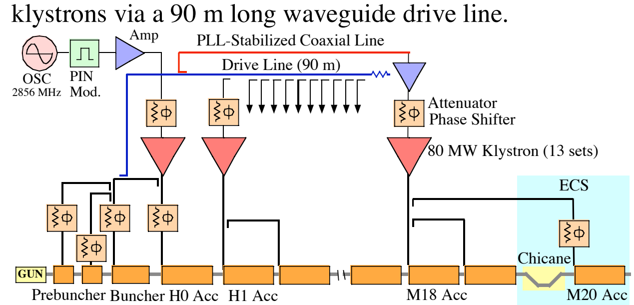

Figure 1: RF system of SPring-8 linac.

The beam stability of the linac was improved by reducing RF variations and providing beam energy compensation as follows [3].

The following three variations are the main sources causing fluctuation in high power RF: Variations in the klystron voltage cause variations in RF power and phases. The temperature drift of the klystron cooling water also results in RF phase variations in klystrons. Air temperature variations in the klystron gallery cause of the RF phase fluctuations in the waveguide drive line because its temperature was not stabilized. We therefore have improved the voltage regulation system for the klystron modulator and stabilized the temperatures of the gallery atmosphere and the cooling water. These improvements realized a greatly reduced energy fluctuation of 0.03% rms, even in the long term.

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We recently observed that temperature variations have increased and a nonnegligible phase fluctuation has reappeared. This problem is discussed in the next section.

A new synchronous oscillator synchronizes a 2856 MHz reference signal and a beam trigger pulse generated by counting two synchrotron's frequencies, 508.58 MHz or 500 MHz. Variations in the beam charge was reduced by this synchronizing technique; the stabilized beam loading consequently resulted in the beam energy fluctuation of 0.01% rms.

A beam energy compression system (ECS) was installed to compensate for accidental energy variation and reduce the energy spread due to beam loading. The reduced energy spread enabled high-current injection without increasing beam loss.

Room Temperature Issues

In 2002, we reduced the RF repetition rate from 60 to 10 Hz for electric power saving. As a result, we saw remarkable room temperature drifts in winter when the outdoor air temperature was low, because this power saving greatly reduced heat flow into the gallery air. An air conditioner system can only cool ventilated air and it also conducted the cold outdoor air into the gallery. When the outdoor temperature was below 5˚C, 5˚C cooled water was forced into heat exchangers to prevent freezing of the cooled waters. This incorrect measure greatly decreased the ventilated air temperature. The gallery temperature fell accordingly below a set value in winter as shown in Fig. 2.

To reduce phase drift in the waveguide, we took the following three measures: The 90 m long waveguide was covered with thermal insulation and 28˚C water was circulated in pipes inside the cover. Outdoor air intakes were closed to prevent excessive reduction of the ventilated air temperature. An air temperature sensor mounted at the air intake was relocated to measure the actual temperature of the air entering the heat exchanger. Gallery temperature variations have been consequently stabilized at ±1 ˚C as illustrated in Fig. 2.

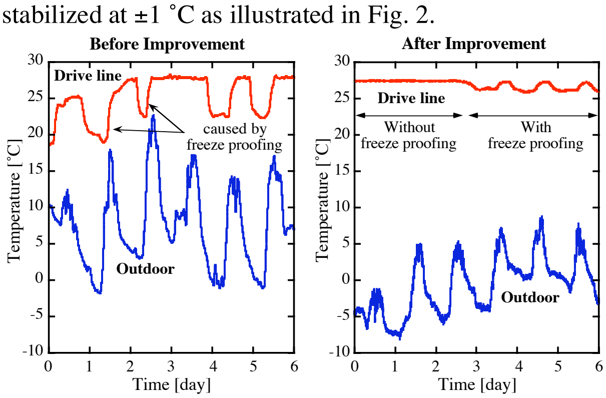

Figure 2: Room temperature variations before and after improvement.

Beam Feedback Controls

The above improvements have enhanced beam energy stability. We, however, have observed residual long-term variations of the beam positions that degraded the injection efficiency of the NewSUBARU.

To improve the long-term stability, we introduced the following feedback controls:

- Beam position stabilization at three beam transport lines
- Beam energy stabilization by adjusting ECS

Beam position controls are carried out at the following three parts in the linac: A drift space in the injector part, a drift space of a transport line to the NewSUBARU storage ring and a transport line between the ECS and a bending magnet downstream. These straight parts respectively contain two sets of steering magnet upstream and two sets of BPM downstream.

The control program adjusts the steering magnets and maintains beam position within the position window at reference BPMs. The position window was determined to be ±30 μm, which is nearly double the standard deviation of the measured values.

Beam energy is stabilized as follows: it is measured by BPMs installed at the dispersive sections of the beam transport line to the NewSUBARU or to the booster synchrotron. The program adjusts the RF phase of the ECS so that energy error remains within the energy window of ±0.03%. Figure 3 presents one example of the feedback control history; the beam energy fluctuation was 0.02% rms in the long term.

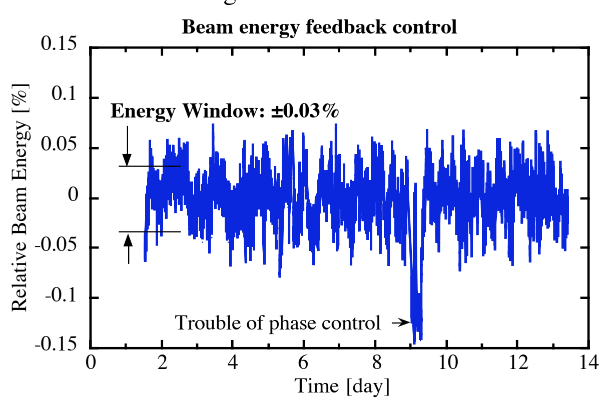

Figure 3: Beam energies stabilized by feedback controls.

LOW BACKGROUND BEAMS

The dark currents are generally composed of two components: the grid emission currents from a thermionic cathode assembly of a gun and the field emission currents generated in accelerating structures.

Grid emission currents are emitted by a cathode grid accumulating barium atoms evaporated from a heated cathode. Grid emission dominates the dark current if the cathode is not new. To reduce grid emission, a beam deflector was developed and installed between the gun and a prebuncher of the linac.

The deflector itself is composed of a rectangular chamber with two parallel-plate electrodes in it. Electron beams of 180 keV from the gun are horizontally deflected with an angle of 110-mrad when an electric field of 7 kV is applied between both the electrodes, then the beams are blocked by an iris plate placed 150-mm downstream. Two 7-kV pulses are fed to both electrodes whose timing 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 trajectory.

Figure 4 illustrates that the deflector has filtered out the faint charges around the main bunch that were observed when the deflector was not in operation.

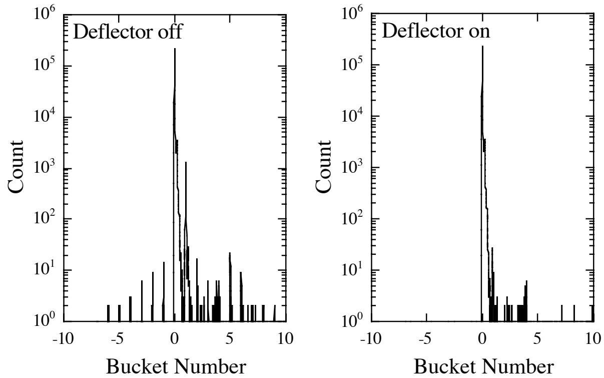

Figure 4: Satellite distributions of stored single bunch beam. RF powers for injector section were attenuated to be as low as possible to minimize the field emission for this measurement.

MACHINE RELIABILITY

Improvements in Klystron Modulators

Klystron modulators have been continuously improved to reduce their failure frequencies and to enhance their reliability. For example, VME control systems were reengineered to maximize availability of the linac operation considering reliability, usability, expandability and flexibility. An optically linked remote I/O system was newly developed to avoid noise interference caused by klystron modulators [7].

Klystron Modulator Diagnosis

It is indispensable to reduce the frequencies of the modulator's faults to prevent the degradation of the current stability in the top-up operation. Most faults are caused by prefires (spontaneous turn-on) of thyratrons. A prefire occurs when the thyratron's reservoir voltage is not adjusted at an optimum voltage.

To anticipate or prevent thyratron prefires, we diagnosed thyratrons referring the following values stored in a database: The reservoir heater voltages and prefire counts of thyratrons are automatically acquired in the database. Turn-on time jitters are measured by digital oscilloscopes installed in each modulator and acquired data are transferred to the database via an Ethernet.

Preparation of Standby Klystrons

Eleven of the klystrons have been used to accelerate electron beams up to 1 GeV and the other two have been kept for spares on line. The two spares were not powered in former years, hence it would take more than few hours for RF conditioning of the two klystrons and their accelerating structures when they had to work instead of a failed klystron. This RF conditioning, which might suspend the top-up operation, could be eliminated if the two klystrons had been powered and fed RF powers to the accelerating structures without accelerating beams.

The RF system works at 10 Hz, while the beam is ejected at 1 Hz. We thus introduced a trigger mask circuit that momentarily disables any working klystrons to prevent beam acceleration. Now all the klystrons are feeding RF powers to the accelerating structures and two are on standby and ready for beam acceleration.

Automatic Phasing

When a klystron on standby is switched to accelerate beams, phasing of this klystron may be indispensable before beam injection. An automatic phasing program scans the RF phase of a target klystron to find the optimum phase watching the beam energy monitored by a BPM in the chicane section. Phasing accuracy is about ±3 degrees. This automatic control eases linac operations and minimizes down time in top-up injection.

NEXT STEP

A serious failure of the first klystron, which feeds RF powers to the injector part and the drive line, absolutely suspends the beam acceleration for long time. A backup system for this klystron is now under development.

The three automatic control programs greatly enhanced beam stability and beam operation quality. Automatic adjustment of the linac optics has been investigated as the goal of automatic control.

We are now trying to reduce field emission currents in the first accelerating structure by applying solenoidal magnetic fields.

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