OPTICS CALCULATION AND EMITTANCE MEASUREMENT TOWARD AUTOMATIC BEAM TUNING OF LINAC

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Abstract

The SPring-8 1-GeV linac has thirteen sets of 80-MW klystron units. In usual operation, two sets of the klystron units are driven as standby units. If there is any trouble with an arbitrary klystron unit, the beam operation can be restarted immediately by using the standby unit. In that case, the optimization of beam optics has been carried out using beam screen monitors. More than one hour is spent for beam tuning in usual operation. In order to reduce the beam tuning time, we are developing an automatic beam optics tuning system. To understand the beam envelope, the particle tracking simulation of the linac was carried out with PARMELA and SAD. In a beam experiment, a beam waist was actually formed at the middle of the 12-m-long free space downstream of the 1-GeV magnetic chicane section as predicted by SAD. The emittance of the 1-GeV beam was estimated from the measured beam size and the calculated beta function.

INTRODUCTION

The top-up operation of the SPring-8 storage ring has achieved highly brilliant and extremely stable X-ray beams since May 2004 [1]. In order to keep the stored beam current constant in operation, beam losses are continuously compensated by injecting beams every several tens of seconds. Even when the beam is injected, all users' experiments with the synchrotron radiation are available. The stored beam current is stabilized less than 10^{-4} in four- or five-week periods for one operation cycle. To keep the variation of the stored beam current as small as possible, and to precisely preserve the beam-filling pattern in the storage ring, it is indispensable to stabilize the beam injector, which consists of a 1-GeV linac and an 8-GeV booster synchrotron.

The long-term variation of beam current and energy in the linac were reduced by improving stability of RF output power and phase of thirteen sets of klystron units, waveguides and so on [2]. To suppress the shot-by-shot beam current variation in the bunching section, an innovative timing system was introduced that synchronizes the gun trigger timing, the accelerating phase of the linac and the booster synchrotron with different RF frequencies [3]. Moreover, the active stabilization of beam energy in the linac was carried out with an energy feedback system by using an energy compression system (ECS) and a strip-line-type beam position monitor (BPM) [4]. Consequently, the beam energy fluctuation achieved 0.02% (rms) without any beam tuning in the long term.

In addition, to reduce the downtime of beam operation for the linac as much as possible, we have prepared backup equipment, including the twin thermionic gun system and two klystron units as standby units. If there is any trouble with an arbitrary klystron unit, the beam operation can be restarted immediately by switching it to the standby unit. However, it is required to optimize the beam optics by changing the energy gain in each accelerating structure in that case.

We are promoting the development of the automatic beam optics tuning system in order to obtain more precise matching of the beam optics at the beam delivery point for the booster synchrotron, and to reduce the beam tuning time.

DESIGN OF AUTOMATIC BEAM TUNING SYSTEM

This tuning system is performed with the following three procedures. In the first step, the twiss parameters are measured in a 60-MeV pre-injector. In the next step, the beam optics from the end of the 60-MeV pre-injector to the beam delivery point are calculated using a beam tracking code SAD [5], which has some functions for beam optics matching. Then, the measurement results of the twiss parameters in the 60-MeV pre-injector and the energy gain in each accelerating unit are used for the input data of SAD. Then the beam optics of the linac are optimized by SAD. The excitation current of triplets in the linac are given based on the calculation results from SAD. In the last step, the twiss parameters of the 1-GeV beam are confirmed with an emittance measurement system. A series of the above procedures is automatically performed by the accelerator control system.

CONFIGURATION OF 1-GEV LINAC

The 1-GeV linac consists of five sections as shown in Fig. 1: the 60-MeV pre-injector, the main accelerating section, the ECS, an optics matching section and two beam transport lines. The beam intensity from the 190-keV thermionic gun is controlled by varying the grid voltage of the gun cathode and also by physically defining the beam size using an iris that is placed downstream of the gun. The gun provides three beam time widths of 250 ps, 1ns and 40 ns. The bunch length forms 15 ps (FWHM) or less with two pre-bunchers (PB) and a main buncher (MB). To avoid beam loss, transverse growth of the beam

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size is constrained by two sets of magnetic lenses and seven sets of solenoid coils installed between the gun and bunching section. The bunched beam is accelerated up to 60-MeV by a 3-m long accelerating structure (H0). Then, the beam is accelerated up to 1-GeV in the main accelerating section, which consists of twenty-four sets of 3-m long accelerating structures. Triplets are placed in each accelerating unit as shown in Fig. 1. To suppress the energy spread, and to stabilize the beam energy, the ECS has been installed just downstream of the main accelerating section. The ECS consists of four bending magnets forming a chicane and a 3-m long accelerating structure. The matching section and the beam transport line are placed downstream of the ECS.

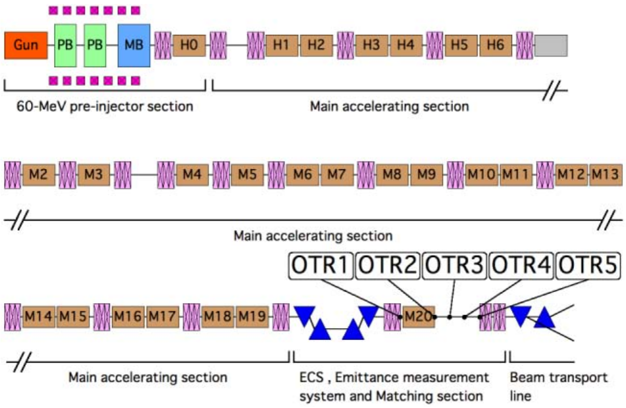

Fig. 1. Schematic view of the 1-GeV linac.

EMITTANCE MEASUREMENT SYSTEM

In order to obtain the twiss parameters for the 1-GeV beam downstream of the magnetic chicane section, the emittance measurement system was installed into the 12-m long free space section downstream of the linac. The system consists of 5 sets of optical transition radiation (OTR) beam screen monitors placed about 2.5 m apart as indicated by OTR1, OTR2, OTR3, OTR4 and OTR5 in Fig. 1. The OTR screen is made from 0.5-mm thick aluminium plate with a surface roughness of less than 1 μm. OTR is induced on the screen by the 1-GeV beam and its image is taken with a random shutter CCD camera. The camera is equipped with a 40 mm telecentric objective lens in order to obtain the beam size in the range of ±5 mm without distortion. The resolution of this monitor is less than 15 μm through image processing. Since the area of the field of view in the monitor is 9.6 x 7.2 mm, centering the beam position on the OTR screen in each monitor is carried out with the BPMs. The data of the beam size from the OTR beam monitors is stored in the data acquisition system. The OTR beam monitors can be remotely operated in the central control room. The series of operations mentioned above is automatically controlled with the GUI of a computer terminal. The whole measurement of emittance can be completed within 5 minutes.

BEAM OPTICS CALCULATION

In the particle tracking simulation, the linac was divided into two parts. The simulation of the 60-MeV pre-injector was carried out with PARMELA [6]. The initial condition for this simulation is summarized in Table 1. The twiss parameters at the gun were calculated by EGUN [7]. The parameters of bunchers and coils were optimized for 20000 particles from the gun so that the maximum transmission of 75% was obtained.

Figure 2 shows the particle distribution at the end of the 60-MeV pre-injector. Since the PBs and MB are operated at 2856 MHz, three bunches are formed in the bunching section for the 1 ns beam. The twiss parameters of the end of the 60-MeV pre-injector are shown in Table 2.

Table 1. Initial parameters for PARMELA.

Pulse width / Charge	1 ns / 1.5 nC
Energy	190 keV
Emittance x, y (rms)	20π mm mrad
Number of particles	20000

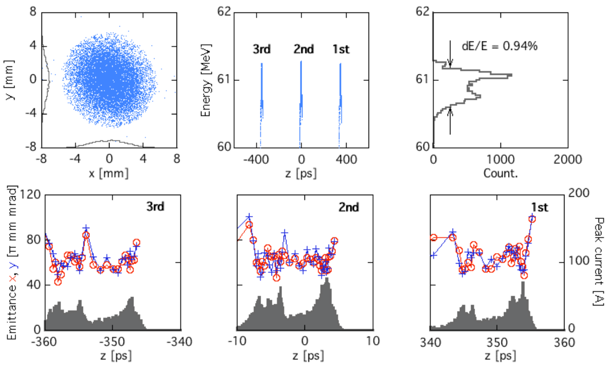

Fig. 2. Transverse particle distribution, the longitudinal phase space and normalized slice emittance for three bunches at the end of the 60-MeV pre-injector.

Table 2. Twiss parameters at the end of the 60-MeV pre-injector with PARMELA.

α_x	-0.044	α_y	-0.198
β_x	6.57 m	β_y	6.77 m
ε_x	60.0π mm mrad	ε_y	58.6π mm mrad

The beam optics from the end of the 60-MeV pre-injector to the beam delivery point was optimized with SAD. The initial condition such as the twiss parameters and the particle distribution are given by the simulation results with PARMELA. Figure 3 shows the calculation results of beam optics for the linac and beam transport line with SAD. In this calculation, the beta function was limited by the maximum excitation current of the power supplies for quadrupole magnets.

In addition, the particle tracking was carried out in order to obtain the particle distribution at the section of the emittance measurement system as indicated by 1-6 in Fig. 3. Each transverse particle distribution was simulated as shown in Fig. 4.

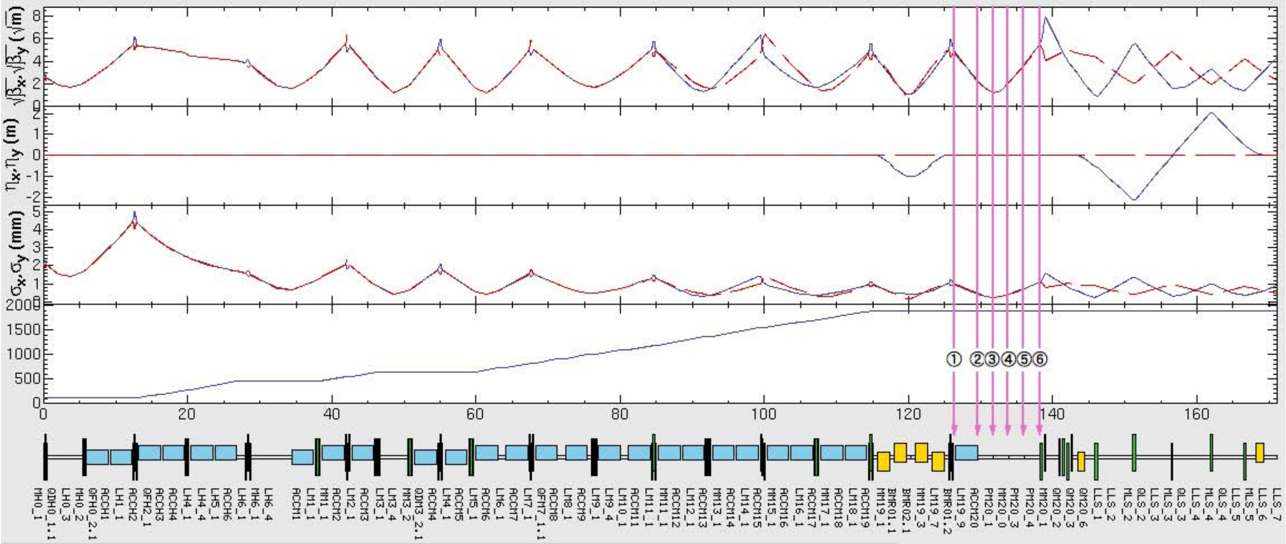

Fig. 3. Results of beta function β, energy dispersion η, beam size σ and energy γ calculated from the main accelerating section to the booster synchrotron.

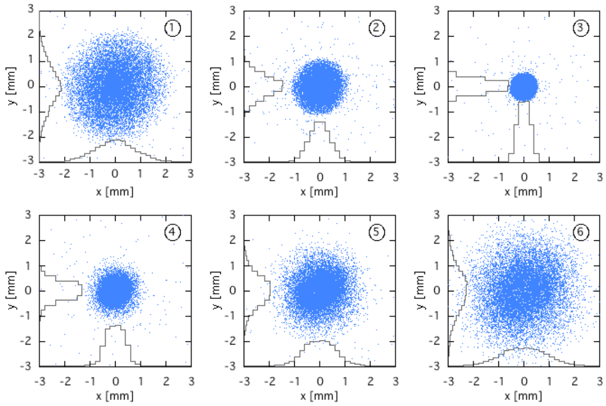

Fig. 4. Transverse particle distribution at 1-6 downstream of the magnetic chicane section as shown in Fig. 3.

TWISS PARAMETER MEASUREMENT

The emittance measurement was made using a 1-GeV beam of 1 ns (FWHM) width at a beam charge of 1 nC. Figure 5 (a) shows the measurement and the simulation results for beam size. The beam waist was actually formed at the middle of the 12-m long free space downstream of the magnetic chicane section as SAD predicted. The twiss parameters can be given by parabolic fitting for each beam size. In order to estimate the emittance at each OTR monitor, the emittance is obtained by using the measurement value of the beam size and the beta function from the calculation results. The normalized emittance of the 1-GeV beam is shown in Fig. 5 (b).

The normalized emittance is around 60π mm mrad at OTR1 and OTR2. This value corresponds to the simulation results. However, the emittance at OTR3, OTR4 and OTR5 is smaller as compared with the value at OTR1 or OTR2 as shown in Fig. 5 (b). The cause of the difference is still under investigation.

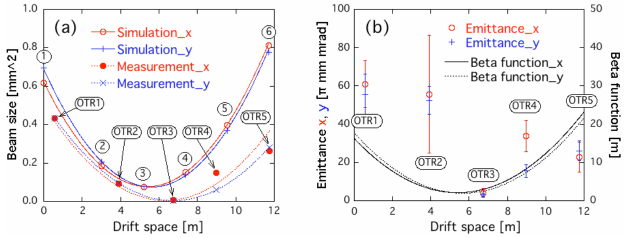

Fig. 5. Comparison of the simulation results with the measurement results for beam envelope (a) and emittance (b). The normalized emittance is obtained by using beam size (meas.) and beta function (calc.).

CONCLUSION

The first phase of the development of the automatic beam optics tuning system was completed. In the future, instead of the twiss parameters from PARMELA, we would use the twiss parameters obtained at the end of the 60-MeV pre-injector by the quadscan method. The beam optics of the linac are calculated by using SAD with the measured twiss parameters.

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