Beam Dynamics

Yoshikazu MIYAHARA
Ainosuke ANDO

The application programs for the operation of the whole system of the SPring-8 accelerator complex, especially of the storage ring related to beam dynamics, were deve-loped. The programs include the following items:
1) timing system of the whole accelerators for beam injection,
2) orbit corrections for beam injection into the storage ring,
3) orbit corrections with steering magnets in the storage ring,
4) chromaticity corrections with sextupole magnets,
5) tune analyses of the betatron and synchrotron oscillations,
6) first turn beam orbit corrections,
7) others.
The radiation loss of the beam energy by 0.11 % per turn was considered in the programs for several turns of revolution. The programs, operated on the GUI system, can be simulated by computers. It can be run on the real machine while taking the data from various monitors. The programs can also be used to set various parameters of accelerator equipment

The transverse and longitudinal beam impedance of the SPring-8 storage ring were obtained by computer simulation [1]. A simulation code of single bunch instability was also developed. It was found by the simulation that the single bunch transverse instability caused by the mode coupling between m=0 and 1 at a beam current of 3 mA/bunch can be suppressed by a slightly positive chromaticity. But the instability around 7 mA/bunch caused by the coupling between m=0 and 2 is too strong to store a higher beam current further. Longitudinally, the bunch length increases with the potential well distortion, but the energy spread of the beam bunch remains the same up to the maximum current of 7 mA. In addition, a simulation code of multi-bunch instability was developed. The simulation analyses revealed that the longitudinal and transverse coupled bunch instabilities are suppressed when a partial fill operation with 1/5 bunches filled is performed. Longitudinally, the partially filled bunched beam induces a modulation of RF voltages in the cavities to vary the synchrotron oscillation frequency of each bunch. This in turn decouples the bunch interaction. Transversely, a higher beam current per bunch caused by the partial fill operation, compared with full bunch operation (the same total current is assumed), induces a stronger head-tail damping within the bunch, which in turn suppresses the transverse coupled bunch instability. [2]

Recently a quasi-isochronous storage ring has attracted wide attention to generate coherent radiation with very short beam bunches. One example of such a ring is the New SUBARU of 1.5 GeV, which is under construction by the Himeji Institute of Technology at the SPring-8 facility site. The bunch length can be shortened by reducing the momentum compaction factor not only of the linear term but also of nonlinear terms on the momentum dependence. However, it was found that the bunch length has a lower limit because of the stochastic emission of the radiation. This effect on the path length fluctuation was investigated in detail. The orbit length variation all around the ring is proportional to the product of the momentum compaction factor and the momentum devi-ation. The compaction factor is proportional to the integral of the dispersion function around the ring. Suppose that the factor is zero, which implies that the dispersion function, alternately positive and negative, totally cancels to zero. An electron with a given momentum deviation has the same orbit length with others. This is true when the momentum is kept or decreases monotonically in one turn. But even if electrons lose the same amount of energy by photo-emission in one turn, their path lengths vary depending on the places where the emission takes place around the circumference. Usually this fluctuation of the path length hides behind the radiation excitation of the energy spread. In an quasi-isochronous ring, however, the fluctuation of the length dominates over the bunch stretch. An analytical expression of the equilibrium bunch length in linear optics was derived. The new formula provides an intrinsic lower limit of the equilibrium bunch length in an quasi-isochronous storage ring [3].

Based on the feasibility study on the laser Compton back-scattering for the high energy physics study, a bending magnets beamline BL33-B2 in the storage ring was assigned to the scattering experiment. A basic requirement for the vacuum chambers along the pathway of the injected laser beam and the produced gamma ray beam is the aperture which accepts the photon beam with a +/- 0.5 mrad divergence at the middle point of the interaction region in the direction of the electron beam. Another requirement is for the aperture for the electron pathway to tag the photons of energy 4 GeV at maximum and 1.5 GeV at minimum. These requirements were satisfied in the practical design of vacuum components.

A single pass FEL (SASE) system using the injector linac is under consideration. To realize the SASE, a very high quality of electron beam is required. In order to produce an electron beam with a small emittance and a high peak current, which are key issues of the SASE, a design study on a two-and half cell photo-cathode rf-gun was conducted. Main parameters of the gun injector such as cell length, field strength of solenoidal magnets, and acceleration gradient in the cavity were optimized with the aid of computer code Parmela. The optimum was found to be a 2.7 cell cavity. The geometry and coupling of the requested cavity was studied in detail with the code Mafia and Superfish. The beam iris of each cell was enlarged in order to widen the mode separation. In order to cancel the influence of the coupling iris upon the field symmetry, the so-called symmetrical double-sided input coupler was assembled to the second cell, and the critical matching was achieved in the Mafia-T3 simulation. With this cavity, the final normalized rms emittance reached the value of 0.81 mm-mrad at a charge of 1 nC in the Parmela simulation [4].

As a candidate of the fourth generation light source, an ultra small emittance ring for very brilliant X-ray generation was pursued. In recent storage rings, the gap and period of undulators have been reduced to 10 mm or less, so that X-rays with 0.1-0.2 nm long can be generated at a beam energy of 3 GeV. The SPring-8 storage ring was designed to operate at 8 GeV with an emittance of 6 nm-rad, which can be reduced, in principle, to 0.8 nm-rad at 3 GeV. This emittance, however, is still by one order larger than the emittance of the diffraction limit at the X-ray wavelength. It is known that the brilliance of the undulator radiation increases quadratically with the number of undulator periods, provided that the beam emittance is smaller than that of the diffraction limit. Thus, a new lattice has been investigated, which provides an emit-tance of 0.05 nm-rad at 3 GeV and is capable of being installed in the present tunnel of the storage ring. One of the serious problems is that the dynamic aperture is very small. Nevertheless, the present investigation pro-vides a starting point for a future machine [5].

References

[1] T. Nakamura, The 5th European Particle Accelerator Conference, Barcelona, Spain, June 1996.

[2] T. Nakamura, ibid

[3] Y. Shoji et al, Phys. Rev. E 54 (1996) R4556.

[4] Y. Huang and Y. Miyahara, Proceedings of AFEL97, Third Asian Symposium on Free Electron Lasers and Fifth Symposium on FEL Applications, Jan. 1997, Osaka, p133-140.

[5] Y. Miyahara, to be submitted to PAC-97.