Beam Dynamics

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1. Introduction

The beam dynamics group in SPring-8 has been in charge of lattice design and beam stability analysis in addition to the design work of application program and graphical interface of a computer system for beam control in the storage ring. In the following, we give an outline of some topics which have been done in 1995.

2. Investigation

2.1 Commissioning of the Storage Ring

The storage ring is to be commissioned in February 1997. To prepare for the commissioning, probable procedure of the commissioning has been investigated in regard to the beam injection, circulation and accumulation: 1) measurement of the energy of the electron beam injected in the storage ring, 2) steering magnet excitation for the first turn circulation of the injected beam, 3) estimation of the beam orbit displacement caused by the photon emission, 4) measurement of the betatron function with the use of steering magnets, 5) optimization of injection orbit, and so on. At the same time, application programs have been developed to perform these investigations. In principle, these programs are checked by tracking simulation on the parameters assumed for the storage ring. Accordingly, it is only necessary for the practical use of the programs to read the parameters measured and set up in the real machine.

2.2 Commissioning of Phase II Lattice

The storage ring composed of 48 DBA structures has 44 normal cells and 4 straight cells. The straight cells having no bending magnets are distributed equidistantly around the ring, which is named as Phase I lattice. It is planned that in a near future the quadrupole magnets in the straight cells are rearranged to produce four 30 m long straight sections, which is named as Phase II lattice. Because of the attractive feature of the long straight sections, earlier commissioning or direct commissioning of the Phase II lattice skipping the Phase I lattice was examined. However, it was found that the dynamic aperture of the Phase II lattice is extremely small in case of the direct commissioning because the closed orbit distortion can only be suppressed by the method similar to a beam transport line, thereof the COD is not homogeneously suppressed around the ring. On the other hand, it was found that a Transient lattice, which is realized by changing the quadrupole field strengths in the straight cells of the Phase I lattice to have the same phase advance of the betatron oscillations as that in the long straight sections of the Phase II lattice, has a sufficiently large dynamic aperture when the COD is corrected. Then the Phase II lattice via the Transient lattice, having a dynamic aperture about ±10 mm, can be easily realized.

2.3 Beam Instabilities and FEL

Beam instabilities of single bunch and coupled bunch, transverse and longitudinal in the storage ring were investigated by estimating coupling impedances and developing simulation codes. A new method to cure the transverse instability by introducing chromaticity modulation was developed; The modulation of sextupole field in the storage ring at the synchrotron frequency induces a frequency spread of the betatron oscillations and suppresses the instability by the Landau damping. A three dimensional simulation code for free electron laser was developed. Combining it with the estimation of the coupling impedance and the simulation codes of the instabilities, which includes the bunch lengthening, the FEL gain for a 30 m long insertion device in the storage ring was investigated assuming an operation of the storage ring at a beam energy of 3 GeV.

2.4 Laser Compton Back Scattering

A feasibility study has been made on constructing a facility of laser Compton back scattering in the storage ring to generate high energy gamma rays for nuclear study. It is possible to generate 10^7 polarized phtons per second with an energy up to 3 GeV whenArgon laser is used. The photons with an energy higher than 1 GeV can be tagged by an electron tagging system placed in the lower reach of the bending magnet dounstream of the interaction region. The ultimate energy reso-lution of the tagged photons, determined by the energy spread of the electron beam and by the accuracy of the scattered electron detector, is 1 %. It is considered so that this facility does not spoil the beam lifetime and injection efficiency. Inspection of the present vacuum chamber system including the beamline proved that the back scattering facility is much more easily constructed in an insertion device beamline than a bending magnet beamline. Modification of the vacuum chamber for the electron detection system was considered.

2.5 Low Energy Positron Beam

A low energy positron beam is a unique probe for the study of Fermi surfaces, defects, surfaces and interfaces of materials. So far the positron beam has been generated by the collision of high energy electron beam with a target or by the decay of activated nuclei. The third method is to use the synchrotron radiation with energies higher than 1 MeV. Such a high energy radiation can be provided by a high field superconducting wiggler installed in the SPring-8 storage ring. It is estimated that about 10^{10} slow positrons per second can be genera-ed by using a proper target-moderator system. Further studies are necessary for brightness enhancement. Main merits of using the radia-tion are lower heat load and lower contami-nation of the target compared with the conven-tional methods[1].

2.6 Modified Chasman-Green Lattice

In the third generation light sources, insertion devices are installed in dispersion free straight sections of Chasman-Green lattice to avoid the reduction of the brilliance of the radiation due to the energy spread of electron beam. In this case the brilliance is inversely proportional to the emittance of the beam. Meanwhile it has been noticed that the emittance can be decreased somewhat by introducing a small amount of dispersion in the straight sections. In order to compare the brilliance of the modified Chasman-Green lattice with that of the pure Chasman-Green lattice, the brilliance was defined as the brightness divided by the effective emittance, and the emittance was defined as the volume in the transverse phase space at the place of insertion devices. Then analytical formulae were derived, with which the effective emittance can be minimized. Numerical estimation on the SPring-8 storage ring indicates an increase of the brilliance by a factor of 2~3 by introducing dispersion in the straight sections [2].

2.7 Medium Beta Optics

It has been thought that the most preferable optics of the SPring-8 storage ring is of hybrid type, in which low beta and high beta sections appear alternately along the circumference of the ring. The reason is that wigglers and undulators had better be installed in the low and high beta sections, respectively. However, need of radiation users for wigglers is not high at present, so it was investigated to reduce the horizontal and vertical beta functions to 5~10 m in all straight sections (medium beta optics) to increase the brilliance. However, it was found impossible to do that without increasing the emittance. On the other hand it is possible to reduce the vertical beta function to 5~10 m in keeping the emittance if the horizontal beta function is allowed to be 20 m in all straight sections. (This modification is within the range of good field quality and power supplies of quadrupole magnets in the storage ring.) This optics increases the brilliance considerably because the vertical emittance can be reduced to 0.05 nmrad or less, which is close to the diffraction limit around the wavelength of 1 nm.

2.8 Low Momentum Compaction Factor

It is known that the bunch length of the electron beam in a storage ring is proportional to the square root of the momentum compaction factor. Then the bunch length can be decreased substantially by reducing the compaction factor, thereby opening up the possibility of generating an intense coherent radiation in the wavelength longer than the bunch length. But this concept is applied only to the linear dependence of the bunch length on the momentum spread of the electron beam. In order to develop a storage ring with a low momentum compaction factor, the dependence of the factor on higher order terms of momentum deviation of electron beam was analyzed and formulated into a computer code. This enables us to optimize the strengths of multipole magnets for minimizing the compaction factor. It is also possible to simulate the bunch length by combining the code with a six dimensional code.

2.9 Quasi-periodic Undulator

Ordinary undulators consist of a periodic array of magnets with alternating polarity. The radiation emitted in each magnet interferes with each other and produces enhanced emission at a fundamental frequency and its harmonics. The peaked radiation, further monochromatized by a single crystal using Bragg reflection condition, however, cannot avoid mixture of higher harmonics especially in hard X-ray region. Mixture of the harmonics degrades the quality of data in radiation experiments. Therefore all the harmonics other than interested are required to be eliminated. Recently a new concept of undulator was proposed, which comprises a quasi-periodic array of magnets (Quasi-Periodic Undulator) [3]. This undulator can generates only irrational harmonics, while crystal monochrometers pass only rational harmonics. Accordingly, there is no contamination of harmonics in the monochromatized radiation. Radiation spectrum of the undulator was analytically formulated, which enables us to find what kinds of parameters are important for designing an optimum structure of quasi-periodic array of magnets. We have derived equations which are convenient to estimate the frequency and intensity of spectral peaks for a given array of magnets [4].

2.10 Straight Sereies of Undulators

When constructing a very long undulator for the long straight section in the storage ring or for a single pass FEL in a linac, it is convenient to divide the undulator into many sections separated with some distance between the sections. Radiation spectrum generated by such a long undulator, investigated for an example of a 30 m long undulator divided into ten sections and operated at a beam energy of 8 GeV to generate X-rays, revealed that the intensity and width of the spectrum peaks can be the same as that of an undulator without separation if the phases of the wave packets generated in each section are matched.

2.11 Trapped Ion Stability

Stability of trapped ions in the nonlinear field of electron beam was investigated by tracking simulation in regard to homogeneous partial fill mode of beam operation. Ion stability was represented in a diagram, which is convenient to determine the stability of trapped ions for given parameters of electron beam. Characteristic feature of the diagram is that the boundary of the stability and instability has a periodic structure, which is caused by the parametric resonance of the low frequency components of the beam current distribution. The amplitude growth of the trapped ions in the unstable condition is very rapid, and it takes only about 0.1 ms for the ions to reach to the wall of vacuum chamber [5].

References

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