Asynchronized Energy Ramping at SRRC Storage Ring

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Abstract

The 1.3 GeV storage ring at SRRC will provide ultra-violet to soft x-ray radiation source to the potential users. The energy ramping of storage ring will push the critical photon energy to the edge of hard x-ray. There are several ways to ramp the electron energy, for example, increasing the extraction energy to 1.5 GeV from booster directly, ramping the magnets' power supplies with synchronized function generators, or asynchronized ramping of magnets at storage ring, etc. The tune drifting during the ramping procedure is expected and should be minimized such that the beam can survive through the ramping process. The betatron frequencies and ramping function of magnets were carefully monitored in order to avoid the betatron tunes cross the resonance line. A successful asynchronized ramping results will be presented in this paper.

I. INTRODUCTION

The storage ring at SRRC is providing an ultra-violet to soft x-ray radiation source to the synchrotron light users. The energy ramping of storage ring will push the critical photon energy to the edge of hard x-ray. A short wavelength will assure the capability of seeing and writing smaller feature. The brightness of the radiated photons will also be improved significantly, due to the increased beam energy, at the edge of the x-ray regime. The likely beneficial research areas include the general x-ray users, micromachining, microscopy, lithography and LIGA application, etc.

With a successful ramping program will also provide a powerful tool for the machine physicist to study the machine performance under different electron beam energy. There are key-signals, the betatron frequencies, which could indicate the characteristic of the ramping process. The betatron frequency is the major indicator for the following up situation for the quadrupoles and the dipoles. If the following up is not good enough, the wiggling of the betatron frequency will be very severe. If the betatron frequency hits the resonance line or stop-band, beam lost will occur.

Two sets of stripline type beam-position-monitor (BPM), which can pickup broad-band signal induced by the electron beam, have been installed at storage ring. The electrons pass through a pair of stripline type BPM will induce a voltage difference, if the beam is off the center of the beam position monitor. The successive analysis of the beam position at fixed BPM can give the information of the fraction of the betatron frequency and the bunch distribution of the electron beam.

The coordinate system was setup as shown in Fig. 1. Considering a single particle case, the description of motion of electron at the storage ring can be written as following [1],

$$\frac{d^2x}{ds^2} + K(s) = f(s)$$

where x(s) is the displacement in horizontal or vertical from the designed orbit. f(s) is the high-order perturbation terms. K(s) is the strength of quadrupoles and satisfies the periodicity relation

$$K(s+C) = K(s)$$

Here C is the circumference of the equilibrium orbit. A similar representation can be found for another transverse direction y.

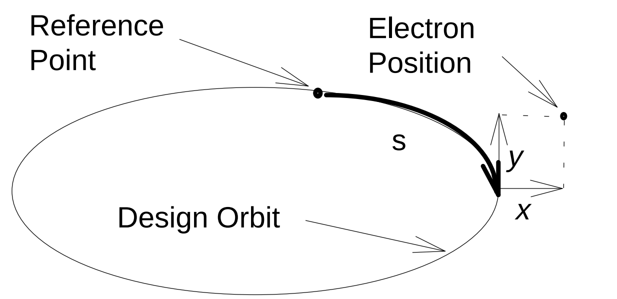

Figure 1. The coordinate system of the storage ring.

For a fixed position observation of the electron beam movement, the description can be rewritten as

$$x_j = a\sqrt{\beta_0}\cos(2\pi j\nu + \phi_0)$$

The $a\sqrt{\beta_0}$ is a constant and the successive passage number is represented by the index j. The initial phase is defined by ϕ_0 and ν is defined as betatron number. Hence the pickup signal by the BPM is a simple sinusoidal oscillation. The Fast Fourier Transform of the observed signal gave us the information of the characteristic of the beam behavior at the storage ring.

To observe the betatron tune we need to excited a coherent oscillation of the entire bunch. The transverse excitation force stimulates the oscillation will be damped by synchrotron radiation. The excitation electrode was fed by the spectrum analyzer which is set to measure the 200th harmonic of the revolution frequency. The setup of the tune measurement system was shown in Fig. 2.

We will utilize the available equipment and software programming tools to achieve energy ramping effect and keep the machine operated within safety margin. We will try to keep the working tune unchanged. The tune drifting during the ramping procedure should be minimized such that the beam can survive through the ramping process. A carefully monitored betatron frequency and ramping function of magnets setting could avoid the betatron tunes cross the resonance line that will induce beam loss during the acceleration.

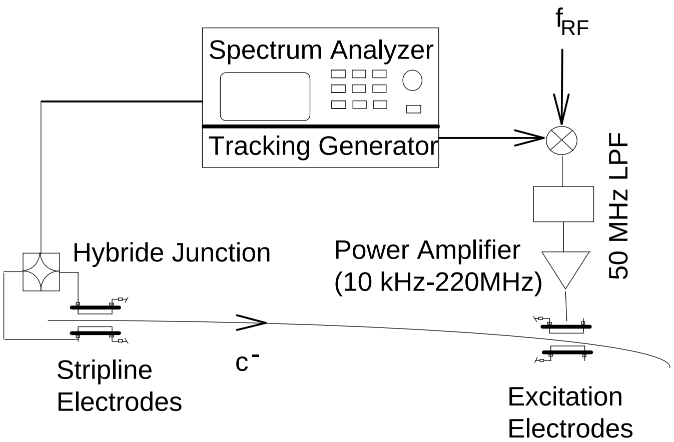

Figure 2. The betatron tune measurement system with transverse excitation.

The non-linearity of the magnet response forces us to use several linear segments to approach the non-linear curve. The non-linear effects are different in each type of magnet, so that the bending magnets, quadrupole magnets must each follow a different current ramp to control the accelerator tunes as function of energy. The concept of multi-knob ramping will be adapted at the first-phase experiment. This asynchronized ramping process is a very slow ramping process, which will take 10 ~ 20 minutes to complete the energy ramping.

II. THE EVALUATION OF BASIC PARAMETERS

Some of the basic parameters that related to the beam energy were listed as following [2,3,4,5]

$$P(kW) = 2.654 B(kG) E^3(GeV) I(A)$$

(radiation power loss per turn)

$$\varepsilon_c(KeV) = 0.06651 B(kG) E^2(GeV)$$

(critical photon energy)

$$N_{0.1}(\lambda_c) = 1.601 \times 10^{12} E(GeV)$$

photons / sec / mA / mrad / 10% BW

(photon flux at critical wavelength)

$$\varepsilon_{\min}(m - rad) = 7.37 \times 10^{-8} E^2(GeV) \varphi^3(rad)$$

(min. emittance for TBA lattice)

where B is the strength of bending magnet, E is the electron beam energy, I is the stored beam current and φ is the bending angle of dipole magnet. The betatron tune was decided by the particle simulation program MAD [6] based on the current setting of lattice.

Some of the major nominal parameters for the storage ring operated at nominal energy were calculated based on above formulations and listed in Table I [7]. The change of these parameters for the 1.5 GeV operating energy was shown in Table II.

Table I. The nominal parameters for the storage ring

Nominal energy	1.3 GeV
Natural beam emittance [3]	1.92 x 10-8 rad m
Radiation loss per turn (dipole)	72.28 keV
Critical photon energy	1.39 keV
photon flux (at critical energy)	2.08×10^{12} (photons/s/ mrad, 10% BW, mA)
betatron tune	7.18/4.13
bunch length (RF@800KeV)	7.4 mm

Table II. The machine parameters for the 1.5 GeV operation

Nominal energy	1.5 GeV
Natural beam emittance	2.56×10^{-8} rad m
Radiation loss per turn (dipole)	128.1 keV
Critical photon energy	2.14 keV
photon flux (at critical energy)	2.40 x 1012 (photons/s/ mrad, 10% BW, mA)
betatron tune	7.18/4.13
bunch length (RF@800KeV)	9.2 mm

III. THE PREPARATION AND SETUP OF EXPERIMENT

The preparation works for the ramping experiments include the program coding, temperature measurement of dipoles and quadrupoles, and sextupoles. The temperature measurements of dipoles and quadrupole were performed before the experiment of ramping process. The current of dipole and quadrupole magnets were driven to the maximum capacity of the power supplies. From experiments, we could find that the hottest point of the dipole magnet will not exceed 60°C and the hottest point of the quadrupoles will not exceed 40°C. The critical temperature of the magnets interlock system was set at 70°C. If any of the thermal sensors at magnets sensing the temperature exceeds the 70°C limit, the interlock system will interrupt the power supplies to protect the magnet from over heating. The temperature of the vacuum chamber will also protect by the interlock system. Several radiation survey meters also placed around the storage ring to monitor the radiation dosage constantly.

IV. RESULTS

The betatron frequencies were analyzed at spectrum analyzer from which we can find the working tune was set at (7.21, 4.08). We will change the working tune to a difference resonance point, the working tune is (7.11, 4.11), by increasing the first family of quadrupoles. The tune variation during the ramping process was observed around 72 kHz during the slow ramping process. Part of the reason of the tune variation was due to the asynchronized ramping process. A modified control program which will integrate the synchronization feature into the ramping process will cure part of the tune variation problem. The slow ramping is due to the waiting time for the setting process and waiting the power supplies to reach the setting current. A synchronized ramping program is under development. This will shorten the overall ramping time and minimize the tune variation.

The input data file was calculated based on the magnet fitting curve, the detail information could be find in reference [8], and try to keep the difference resonance point as our working tune. The ramping curve for the dipoles was shown in Fig. 3, which were taken from archived file. From the beam current curve, we find there is no significant beam lost during the ramping procedure except the beam lost due to the scattering effects.

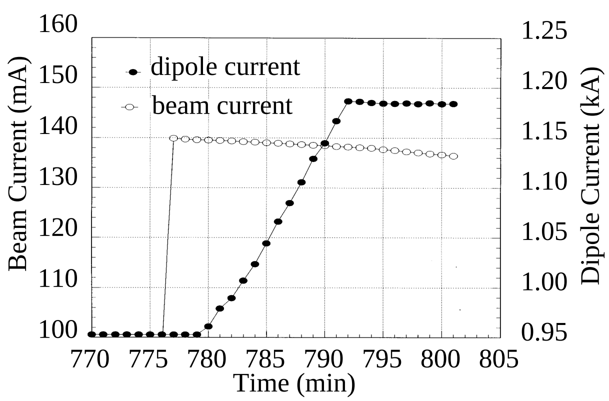

Figure 3. The beam current and the setting current of dipole magnets during the ramping procedure.

The correctors of the storage ring did not ramp with the dipole current setting, hence the closed-orbit-distortion increased at beam energy of 1.5 GeV. The beam dynamic application program was applied to correct the closed-orbit-distortion. The rms value in x-direction is less than .3 mm and in y-direction is less than .2 mm.

The averaged radiation dosage of the 1.5 GeV stored beam was measured around the experimental hall. Comparing with the case in 1.3 GeV, there is no significant increment of the averaged counting rate. The wall shielding is thick enough for the 1.5 GeV operation at the beam current less than 150 mA.

The reasons of the increasing of the gauge reading were 1) due to the change of closed-orbit and induce higher outgassing and 2) part of contribution coming from the increasing of the beam energy. Each of the two RF transmitters could deliver 60 kW power to the cavity. From the power loss estimation, these two transmitters could drive the 1.5 GeV electron beam at beam current as high as 300 mA, if beam instability and beam loading problem is not in our consideration.

V. CONCLUSION

The ramping process from 1.3 GeV to 1.5 GeV has been successfully tested at storage ring using asynchronized ramping method. The testing beam current is set at 140 mA. During the ramping process, there is no significant beam lost except the scattering lost. Some of the critical components have been checked and tested at the high energy operation. The beam line performance will be tested in the near future to verify the resolution and photon flux changing.

The operation of storage ring at 1.5 GeV is possible at SRRC. However, some of the components should be taken more careful examination. A further shorten of the ramping time to seconds is a goal for this ramping program. The necessary tool for this goal is to modify the control program of the power supplies and make the synchronized ramping possible. The slew rate should be able to set to have decimal point of percentage. The synchronized trigger signal should be ready at the time we try.

VI. ACKNOWLEDGMENT

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