ACCELERATOR PHYSICS ISSUES AT NSRRC

C.C. Kuo, H.J. Tsai, M.H. Wang, H.P. Chang, G.H. Luo, P.J. Chou, K.T. Hsu
National Synchrotron Radiation Research Center
101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu, Taiwan

Abstract

Over the past decade, NSRRC has served the synchrotron light users with its 1.5 GeV third generation storage ring. To provide stable hard x-ray for the x-ray community, two strong field superconduting wigglers have been installed and three more will be put in such a low energy ring. A superconduting rf cavity is to replace the normal conducting type and the beam current will be double too. Top-up injection study is under way. This paper presents the accelerator physics issues at NSRRC.

INTRODUCTION

It has been over one decade since the opening of the first synchrotron light source in Taiwan in 1993. Over the past years, the performance of the light source has been upgraded and significantly improved. For instance, the maximum operation energy of the booster injector and the storage ring have been increased from 1.3 GeV to 1.5 GeV; the orbit stability is controlled to within micron range; the beam instabilities are suppressed by various methods such that their effects are managed to acceptable levels; the available long straight sections have already occupied by all kinds of insertion devices and more superconducting wiggler magnets are planned to install in the short straight locations to enhance hard X-ray capability; the lattice emittance and its transverse coupling are optimized; the lattice working point and its nonlinear effects are fully investigated; the top-up injection project has been going on; a replacement of the normal conducting Doris-type cavities with a super-conducting CESR-type RF cavity will be carried out by the end of 2004; the stored beam current will be pushed to 400 mA and associated impedance issue has been studied. The following sections describe related accelerator physics issues as mentioned above.

LINEAR BEAM DYNAMCIS

The lattice structure of the 1.5 GeV storage ring is a 6-fold triple-bend achromat type. We calibrated the linear lattice function using an orbit response method and resulted in a finding that the distortion of linear optics mainly was due to the off-centered sextupoles. The betatron functions are also measured using quadrupole perturbation method. The results are in good agreement with the model calculated values too. We also studied the linear coupling sources and established a correction scheme with a set of independent skew quadrupoles along the ring. The coupling correction scheme we employed was capable of reducing batatron coupling width down to 0.0016 from the uncorrected value of 0.0119. The spurious vertical dispersion due to the energy coupling from the linear skew components in the horizontal dispersive regions can be also controlled simultaneously. It is also observed that the major contributions to the linear coupling are also due to the off-centered sextupoles in the vertical plane. These sextupoles were misaligned because of the lack of fiducially well defined marks of the magnet centers and, as a result, a well corrected orbit is far off centered in the sextupole magnets. An attempt to move the magnets to the beam center has been done using remotely movable girders in the vertical plane and it is proved that we can reduce the coupling strength by doing so. [1] Figure 1 shows the fitted linear optics in both horizontal and vertical planes in the presence of sextupole magnets and with w20 wiggler gap closed. Figure 2 shows the measured tune separation and coupling strength before and after coupling correction.

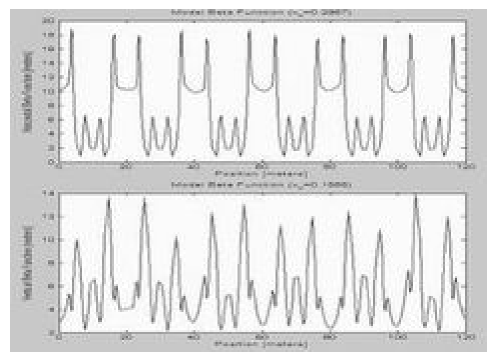

Figure 1: Fitted betatron functions with w20 gap closed. Measured betatron functions at quadrupoles are in good agreement with the model fitted values.

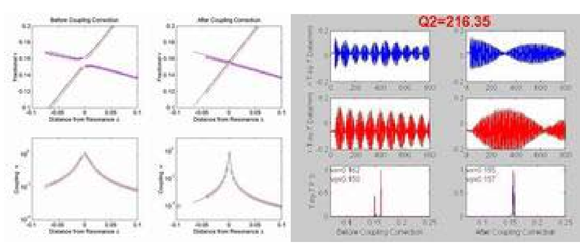

Figure 2: Measured and model fitted coupling width, coupling strength as a function of tune separation, betatron oscillations near coupling line before and after coupling corrections.

The linear effects in the presence of the insertion devices were investigated. Tune shifts due to insertion devices are listed in Table 1. Note that all insertion devices have been in use except three pieces of superconducting wigglers (IASW6), which will be located in three achromatic regions. It is shown that the vertical tune shifts are significant for most of IDs. Therefore, tune compensations are required. Beam current top-up injection operation mode enables to reduce thermal and electrical effects and provides more stable photon beam to the users. However, this operation mode needs to have some mechanisms to lock working point as well as beam orbit. Orbit feed-forward as well as feedback system are implemented. [2] A correction scheme to minimize EPU induced variation of coupling strength is under study.

The optics distortions due to these insertion devices were measured and we found it is in good agreement with the model predicted values. Minimization of the betatron beats is to reduce the nonlinear beam dynamics effects, but in the routine operations, for the sake of simplicity, we usually only compensate for the tune shifts. So far the limiting factors of the lifetime issues are not due to the optics perturbation with insertion devices.

In order to increase the photon flux in the hard x-ray region, a 3-GeV ring would be an optimal design. We have conducted preliminary design study on the 3-GeV ring that is fitted in the existing site. Moreover, a 2-GeV feasibility was explored recently to study the gain in the photon flux at higher photon energy. It was proposed to replace the second normal conducting bending magnet with a superconducting type. The bend angles of the original three 20 degree bending magnets are changed to 15, 30, and 15 degrees, respectively. However, we found that not only the beam dynamic issues need to be addressed, but a lot of costly hardware components need to be modified. The gain of the photon flux is not as attractive as one expected. Therefore, it seems that the optimal way to obtain high brightness, high energy photon beam in the existing ring is to install multipole high field (superconducting type) wigglers. Nonlinear beam dynamic issues due to these insertion devices are discussed below.

Table 1: Insertion devices in the NSRRC storage ring.

Insertion Device		SWLS	EPU5.6	U5	SW6	W20	U9	IASW6 (3 ea.)
Type		SC	Pure	Hyb.	SC	Hyb.	Hyb.	SC
Magnet Length (m)		0.835	3.9	3.9	1.404	3.0	4.5	0.85
Period Length (cm)		25	5.6	5	6	20	9	6
(Min.) Gap (mm)		55	18	18	18	22	18	18.5
Number of Periods		1.5	66	76	16	13	48	7.5
Maximum By (Bx) Field (Tesla)		6	0.67 (0.45)	0.64	3.2	1.8	1.25	3.5
Photon Energy (eV)	Min.	4000	80	60	5000	800	5	5000
	Max.	38000	1400	1500	14000	15000	100	14000
Defection Parameter Ky (Kx)		190.5	3.52 (2.37)	2.99	17.9	33	10.46	19.6
Vert. Tune Shift (Hor. Tune Shift)		0.0504 (-0.014)	0.011 (-0.012)	0.008	0.036	0.036	0.033	0.05

NONLINEAR BEAM DYANMICS

Nonlinear field is of importance for the design and operation of circular machines and nonlinear beam dynamics has been investigated.[4] We employed a turn-by-turn electron position monitoring system to measure the behavior of the perturbed particle in the NSRRC storage ring. The simulation results with the existence of the measured nonlinear field errors are compared with the extracted parameters from the experiments. The measured data such as resonance strengths, detuning parameters(mainly due to sextupole feed-down), as well as island tune, for the third-order and fourth-order as well as fifth-order resonance lines are reasonably reproduced using MAD simulation code, in which measured field errors are included.[3] Figure 3 gives the measured and simulated action-angle plot near the third-order resonance.

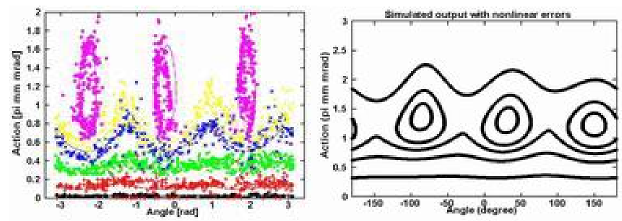

Figure 3: Measured (left) and simulated (right) action-angle plot near third-order resonance line in the horizontal plane.

There exist intrinsic nonlinear fields in the insertion devices. We need to manufacture insertion devices properly to minimize their nonlinear magnetic field errors and we also need to study the nonlinear effects due to their intrinsic nonlinear fields. Simulations using tracking codes can provide specifications in the field properties of each insertion device. Acceptable dynamical aperture is obtained from the simulations for the case all insertion devices and specified nonlinear field errors are inputted. It is found so far the existing insertion devices meet the specifications and no fatal effects were found in the machine operations.

Nonlinear beam dynamics in the longitudinal plane has been studied both theoretically and experimentally. Longitudinal beam dynamics behavior was investigated by applying both RF gap voltage amplitude and phase modulations. We studied these longitudinal beam dynamics with the Hamiltonian analysis method, particle tracking simulations, and measurement with a streak camera.

It was found that with the proper RF amplitude or phase modulation at about twice the synchrotron frequency the redistribution of the bunched beam into two or three beamlets are helpful to reduce the longitudinal instabilities and to increase beam current lifeime as well. Figure 4 gives the beam image recorded by a Hamamatsu streak camera with rf modulation on and off. [4]

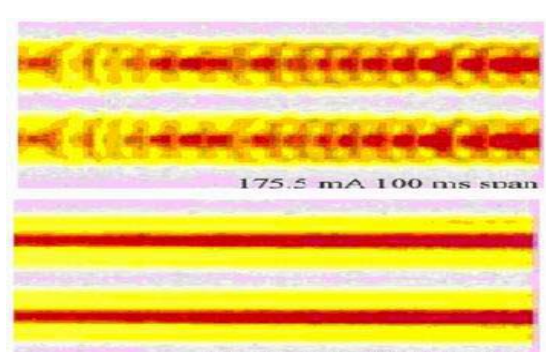

Figure 4: Longitudinal bunch motion measured by a dual scan streak camera without (upper) and with (lower) rf voltage modulation at twice synchrotron frequency.

IMPEDANCE AND INSTABILITIES

Broad band impedance of the storage ring has been estimated by simulations and by measurements. The estimated effective impedance Z/n was about 1 ohm couple years ago. However, we need to measure the impedance again because some smaller vacuum chambers have been installed since then. In order to ensure that doubling beam current, from 200 mA to 400 mA, there is no single-bunch instability, one need to study this instability threshold more carefully. Three additional smaller chambers for planned IDs are to be installed too and the change of the impedance needs to be calculated.

As mentioned above, the existing operating Doris-type RF cavities can generate multi-bunch instabilities, especially in the longitudinal plane. To suppress these instabilities, we have studied several methods, for example, by replacing the damping antenna with an adjustable plunger to control the strengths of the higher order modes, by precision control of the cavity body temperature, by modulating bunch beam in the longitudinal phase space, and by active bunch-by-bunch damping system, etc. Acceptable stable beam is in the routine operations.

However, if we want to increase stored beam current to 400 mA, we need to either add another rf system or replace it with a superconducting cavity. In 2000, we decided to use a CESR-type superconducting cavity module. The simulated rise time of any higher order modes at 400 mA is much longer than the synchrotron radiation damping time and it is hoped that without any detrimental cavity-like impedance in the vacuum chamber the active damping system is unnecessary. The system is now under high-power test and will be installed and commissioned by the end of 2004. [5]

We have observed fast ion instability, especially in the vertical plane, since the operation of the storage ring in 1993 and the way to suppress it is either to employ an active transverse damping system or to leave a longer empty bucket train to allow the drift of ions away from the beam center. The contaminated chamber in one of the insertion device causes some short lifetime problem because we need to operate it with short bunch train resulting in shorter Touschek lifetime, and also shorter gas lifetime due to higher vacuum condition. This chamber will be fixed later this year and hopefully longer lifetime will be obtained.

ORBIT AND TOP-UP INJECTION

Closed orbit correction and orbit stability is of paramount importance in the operations of the light source too. In the design and construction phases, the magnetic field errors (1 ppm to 100 ppm) and alignment errors (about 150 micrometers rms) were well controlled and as a result the measured closed orbit distortions due to these errors are within tolerable range (a few mm) and also in good agreement with the model simulated results. Closed orbit distortions could be corrected down to several tens micrometers with various correction techniques.

Beam orbit is also very sensitive to mechanical vibrations, electronic and electricity noises, air and water thermal fluctuations, etc. Orbit stability should be kept within a few micrometers. Cares have been taken to reduce these sources. A global feedback system then corrects the residual orbit errors down to micrometer level.

The orbit fluctuation could be more than 10 microns peak-to-peak if only the feed-forward field compensations are employed during ID field scan. However, with the help of a fast digital orbit feedback system, the orbit variation can be maintained within a few micrometers shown in Fig. 5. [2]

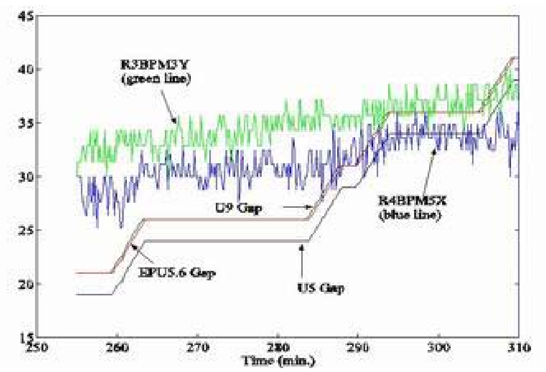

Figure 5: With look-up tables and global orbit feedback system, the orbit drift during ID field scan is within a few micrometers.

Top-up injection scheme is an attractive operation mode demonstrated by some synchrotron light facilities and it becomes a standard option in the modern light sources, under construction or in plan. We have proved that the top-up injection is executable with the field variations of insertion devices while keeping the orbit fixed using an orbit feedback system. The stable beam can be kept either in a fixed current bin mode or in the fixed time interval mode. Some users need to implement gating signal during injection and the fixed time interval mode is more attractive so far. We have run several shifts of top-up mode with potential users and promising results are obtained. [6]

CONCLUSION

Accelerator physics issues at NSRRC have been continuously studied in order to ensure the high performance of the light source. Major work will be focused on the superconduting devices and top-up injection mode in coming year.

REFERENCES

[1]. C.C. Kuo, et al, PAC 2003, pp 890-892.
[2]. H.P. Chang, et al, PAC 2003, pp1044-1046.
[3]. C.C. Kuo, et al, PAC 2001, pp 1767-1769.
[4]. M.H. Wang, et al, J. Appl. Phys. **92**, 555 (2002).
[5]. G.H. Luo, et al, EAPC 2000, pp 654-656.
[6]. G.H. Luo, et al, this proceedings.