SIMULATION STUDY OF TRANSVERSE SPECTRUM IN HIRFL-CSR

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Abstract

Particles in a storage ring oscillate in the longitudinal and transverse dimensions. Therefore, the signal that beam has generated can be analyzed in the frequency domain to extract many beam parameters, such as tune, momentum spread, emittance and their evolution with time and so on. In this paper, the transverse spectrum in HIRFL-CSR was simulated and analyzed under different conditions, including electron cooling, solenoid effect, the tune shift caused by power supply ripple The result of the simulation shows that the longitudinal magnetic field of the electron cooling device should be compensated by "compensation solenoid", otherwise it will cause transverse coupling, and the vertical oscillate will increase. The tune ripple form is the sine ware with the frequency of 50Hz which is equal to that of the industrial frequency. Tune shift will be induced by the power supply ripple. All above mentioned factors will affect the accumulation and may cause the beam lose. Transverse spectrum analysis is a powerful tool for probing those effects.

INTRODUCTION

HIRFL-CSR is a new ion cooler-storage-ring system in China's IMP (Institute of Modern Physics); it consists of a main ring (CSRm) and an experimental ring (CSRe). The overall layout of the HIRFL-CSR can be seen in figure 1. The heavy ion beams from HIRFL will be first injected into CSRm, accompanying with the accumulation, e-cooling and acceleration, finally extracted to CSRe for many internal-target experiments [1]. The overall layout of HIRFL-CSR can be seen in Figure 1. Two electron coolers located in the long straight sections of CSRm and CSRe, respectively, are used for ion-beam accumulation and cooling. In order to obtain high density beam, different cases involving accumulation must be analyzed. Spectral analysis is a powerful tool to complete this work.

SIMULATION AND ANALYSIS PROCESS

According to the theory of spectrum [2,3] and the parameters of HIRFL-CSR, simulations were done to investigate how to get higher intensity beam and avoid beam loss.

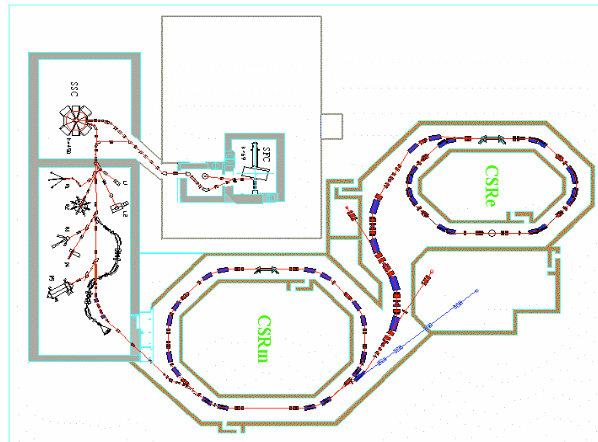

Figure 1: The layout of HIRFL-CSR.

Ion Beam Initialization

First of all, a number of particles with certain distribution must be initialized. The parameters of ions and Twiss at the Cooler adopted in the simulation are shown in Table 1[4].

Table 1 Parameters of Simulation

Ions:	12C6+
Energy:	7 (MeV)
Tune x:	3.62
Tune y:	2.61
Beta x:	10.5 (m)
Beta y:	16.6 (m)
Emittance x:	150 (π mm.mrad)
Emittance y:	25 (π mm.mrad)

According to the parameters mentioned above, the Gaussian distribution ion beams are adopted in the simulation.

Ring Matrix and Different Effect

In this paper, the transform matrix is calculated from its lattice parameters mentioned above. The betatron coordinates are transformed in accordance with the coefficients of the ring matrix. The electron cooling device is considered as a thin lens [5]. In this case the ion angle variation is calculated as

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$$\Delta\vartheta = \frac{F}{MC^2\beta^2\gamma} L_{cool} N_{turn},$$

Here F is the cooling force; M is the ion mass, L_{cool} is the length of the electron cooling device and N_{turn} is the revolutions number. The ion coordinates are not changed inside the cooler. Some possibility may occur during the accumulation such as the non-compensated longitudinal magnetic field. In addition, the level of power supply ripple is also an important factor that will affect the accumulation result. All those effects mentioned above are included in the next simulation.

SIMULATION RESULT AND DISCUSSION

Cooling Time and FFT (Fast Fourier Transform) Spectrum

In HIRFL-CSR, the electron cooling is a powerful tool for the accumulation, so the transverse cooling time is given in the simulation first. The initial angle of the electron beam is assumed as 5×10^{-4}[6]. The calculation of the electron cooling effect is based upon the cooling force. According to the result, the vertical cooling time is about 0.3s, and the horizontal cooling time is about 0.6s (The cooling time was calculated as the time it took to cool the emittance value to its 1/e). Fig. 2 shows the transverse emittance decreased with the time. Meanwhile, we can take the particle coordinates as a discrete signal in the time domain and transform this signal into its frequency domain. Then the information about betatron motion of the beam can be analyzed. The fractional value of tune in two dimensions is 0.62 and 0.61.

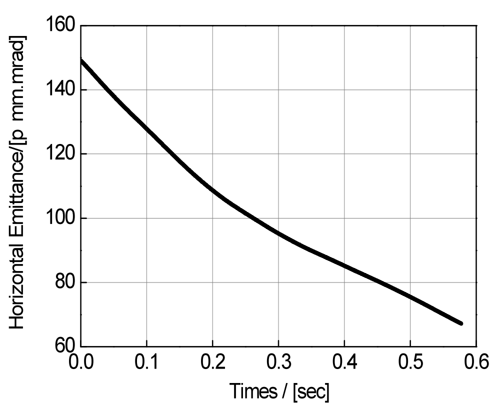

Figure 2 (a): The horizontal emittance evolution.

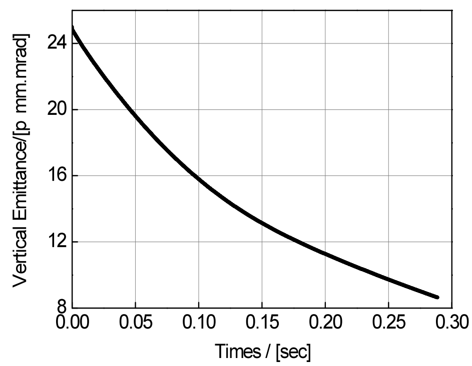

Figure 2 (b): The vertical emittance evolution.

Magnetic Field Compensation

In the electron cooling system, the longitudinal magnet field is used for the compensation deflection by the space charge of electron beam. Meanwhile, it must be compensated, otherwise transverse coupling will occur. During the operation of the machine under the parameters (Table 1), the current of magnet field power is usually 48A (390×10^{-4} T). If there is no other compensated solenoid, the horizontal tune shift is 0.00547 and the other one is 0.00867. Meanwhile we can see the coupling effect between the horizontal and the vertical directions from the FFT result, shown in Fig. 4. Fig. 5 is the tune shift result under different magnet fields. So in order to avoid beam loss, there are “compensation solenoid” in HIRFL-CSR used to decrease the coupling [7].

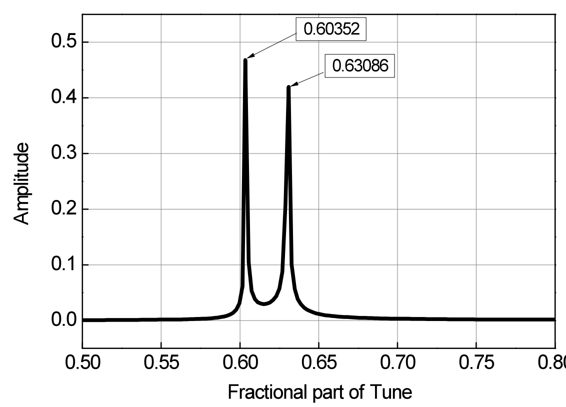

Figure 4: Spectrum under coupling effect.0.6035 is the fractional part of vertical tune, and 0.6308 is the fractional part of horizontal tune.

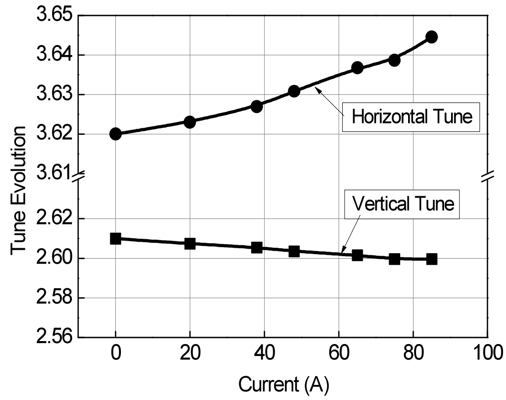

Figure 5: Tune shift under different currents.

Power Supply Ripple

In the storage ring, the causes of beam instability and "blow-up", sudden total or partial loss of beam current, may be the power supply ripple [8]. In this paper, a program was added to simulate this instability.

We assumed there is a cosine oscillation on a power supply. Its amplitude is 0.3A and its frequency is 50Hz. The transverse tune shift is 0.0075 under this modulation existence shown in Fig. 6. Fig. 7a shows the result that we take Fourier transform on the beam coordinates continuously. The horizontal axis corresponds to frequency. The vertical axis corresponds to time. The colour displays the magnitude of the oscillation. It turns out that the sideband is not a line, it is a cosine oscillation. The tune shift will increase as long as the amplitude increases during the process, finally it may cause the beam loss. Fig. 7b is the spectrum result under modulation where the amplitude increases with time. So during the operation of the ring, the level of the power supply ripple must be controlled.

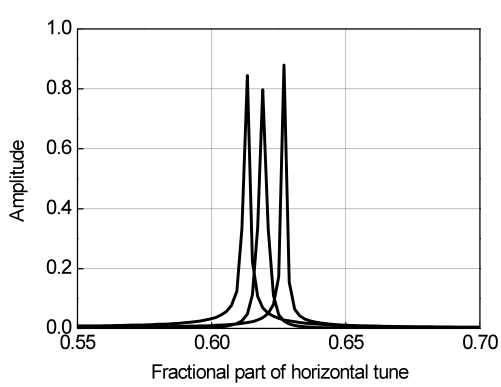

Figure 6: Tune shift under amplitude modulation.

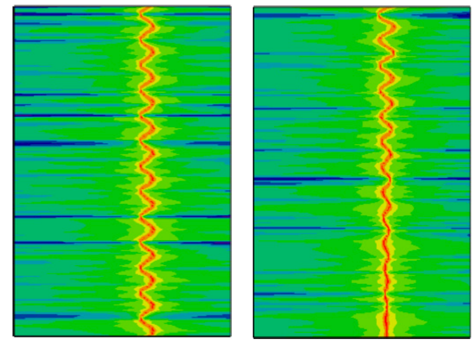

Figure 7: The spectrum under modulation.

CONCLUSIONS

Simulations under different conditions involving accumulation mentioned above have been given in this paper. Great attention must be paid to those issues in the operation to avoid beam loss. Information on the spectral behaviour of beams helps us to analyze and solve the beam loss and instability problems at the time of beam accumulation as well as during various experiments. More simulations and analyses of the spectrum in the longitudinal and transverse dimensions will be done in the future.

REFERENCES

[1] Y.J Yuan J.W XIA H.W Zhao et al Proceeding of EPAC 2008 Genoa Italy. 388-390
[2] J.Tan G.Tranquille Proceedings of EPAC 2006, Edinburgh, Scotland.1214-1216
[3] Peter Forck Schottky Noise Analysis JUAS Archamps.
[4] L.J Mao Simulation and Experiments of Electron Cooling in HIRFL-CSR 2008 IMP CAS.
[5] BETACOOL Physics Guide. http://lepta.jinr.ru/bet-acool.
[6] Y.N RAO HIRFL-CSR electron cooling 1997 IMP CAS
[7] A.V.Bubley, et al. Nuclear Instruments and Methods in Physics Research A 532 (2004) 413-417.
[8] Bruce C.Brown. MI Power Supply Control Issues for Magnets with Hysteresis. Fermilab Report. 1997