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THE SIMULATION STUDY OF SPACE CHARGE EFFECTS FOR CSNS LINAC

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Abstract

China Spallation Neutron Source (CSNS) is a high intensity accelerator based facility. Its accelerator consists of an H- injector and a proton Rapid Cycling Synchrotron. The injector includes the front end and linac. The RFQ accelerates the beam to 3MeV, and then DTL accelerates it to 80MeV[1]. The space charge effect is the most important cause of emittance growth and beam loss due to the low beam energy and the high peak current. The paper performed simulation studies on the space charge effects at the LINAC by using three-dimensional code IMPACT-Z. The emittance evolution is studied in the point of view of the singe-particle dynamics and multi-particle dynamics with different peak beam current. The effect of mismatch is studied by simulation, and the emittance growth with different mismatch factor are given.

INTRODUCTION

The design beam power of the China Spallation Neutron Source (CSNS) is 100 kW at Phase Ⅰ, and it has upgrade potential of 500kW. Correspondingly, the design peak current of linac are 15mA and 30mA. In such a high intensity linear accelerator, the space chare effects is a very important research topic. The significance of the space-charge fields is not only that they reduce the effective focusing strength, but also the nonlinear terms, a consequence of the deviations from charge-density uniformity, cause growth of the rms emittance, which degrades the intrinsic beam quality. One consequence of space-charge-induced emittance growth is the formation of a low-density beam halo surrounding the core of the beam, which can be the cause of beam loss, resulting in radioactivation of the accelerating structure[2]. The interaction between a large number of charged particles is very complex, multi-particle tracking code provides a very effective means for the exploration of space charge effects. In this paper, three-dimensional code IMPACT-Z[3] is taken to study the space charge effects on MEBT and DTL, and this simulation also includes initial mismatch of beam.

SIMULATION STUDY OF SPACE-CHAREGE EFFECTS ON DTL

CSNS/DTL consists of four accelerating cavity with a total of 156 cell, the length among the cavities is designed to maintain longitudinal continuity. Transverse magnetic focusing lattice is FFDD, all quadrupole magnets arrangement can be approximated as periodic focusing structure. By tracking the position of the particle in phase space after each periodic structure, emittance growth can be analysed on microscopic view.

Beams that are in equilibrium in the focusing channel of a linac experience no emittance growth. Unfortunately, beams observed in linac numerical simulations are rarely in equilibrium. The space-chare force in high-current beams is typically the major cause of rms emittance growth. Four different space-charge mechanisms can be identified[4]: charge redistribution, the injected beam is not rms matched, space charge resonances that couple longitudinal and transverse oscillations, the periodic-focusing structure resonantly excite density oscillations in the beam.

Emittance Growth with Different Current

In the simulation, the initial distribution of particles is 6D water bag, the number of macro particles is 100,000, the currents of beams are respectively 0mA, 15mA and 30mA. Figure 1 is a comparison of the emittance evolution with different current of beam along linac.

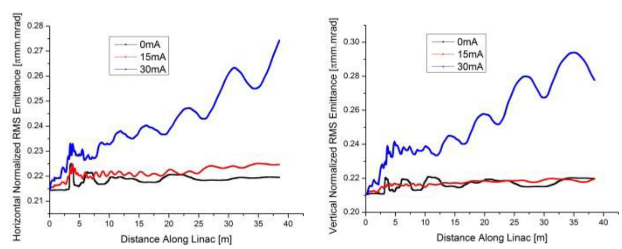

Figure 1: Left: beam horizontal RMS emittance growth along linac. Right: beam vertical RMS emittance growth along linac.

Figure 1 shows that beam's RMS emittance growth is very small with current of 15 mA , and oscillation of emittance is gradually levelling off. However, when the intensity reaches 30mA, emittance growth becomes apparent and increase the proportion of about 30%. In a strictly periodic focusing structure , without considering the impact of space charge effects, a single particle's trajectory after periodic cells is an ellipse in phase space. Because the particles are accelerated in DTL, the actual focusing structure is a quasi-periodic lattice. Therefore, without considering the space-charge effects, the trajectory of particles should be an approximation of an elliptical shape.

In the horizontal direction, for example, the position x and the spread angle x' of particles are normalized by

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c/ω and m_0c . Among them, c , ω and m_0 are representatives of the vacuum speed of light , bunch frequency and rest mass. Three particle are chose from the core to the edge of the bunch by emittance with current of 0mA, 15mA and 30mA. Meanwhile, the position of these particles in phase space is recorded after every FFDD periodic lattice in DTL. The position of three chosen particles in phase space with corresponding current is given in Figure 2. As can be seen from the Figure 2, since the DTL's magnet arrangement is not strictly periodic structures, so single particle's trajectory in phase space is approximately maintained an elliptical shape. When the current intensity increasing, the space-charge repulsion force enlarges, and individual particle's phase-ellipse increase, especially for the particle in core, the change is more obvious. Due to the nonlinear space-charge force, with the beam transport and accelerate in DTL, compressed bunch tends to evolve into a core of decreased density and other low-density particles around the core. Therefore, with the current intensity increasing, the trajectory of particles in core changes most obviously. Space-charge effects lead to a significant change of emittance of particles in core.

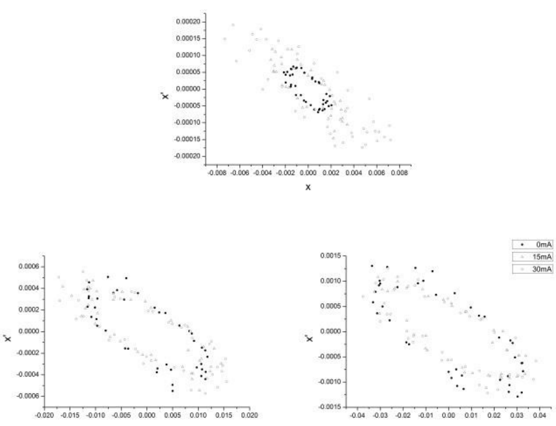

Figure 2: Up : position of particles in beam core in phase space, Bottom left: position of particles in the middle of beam in phase space, Bottom right: position of particles in the edge of beam in phase space.

The Effect of Mismatch on Beam

In a real accelerator, the change of focusing structure and the mismatch of injection will cause a mismatch between beam and transport structure, resulting in oscillation of beam's envelop. When the oscillation frequency of some particles and the oscillation of beam-core meet 1:2, it will form a so-called parametric resonance. Particles, whose resonance amplitude increase may be kicked outside the beam bunch, will form beam halo, leading to the growth of emittance[5].

For comparing space-charge effects on initial beam with different mismatch factor[6], this paper takes current of 15mA for example, and performs simulation on beam with mismatch factor of 1.1, 1.3, 1.4 and 1.5. The initial distribution and number of beam are same as the last section.

Through tracking trajectories of specified particles in DTL, we can see how the emittance evolves on microscopic view. The simulation have chosen 5 particles in beam-core and 5 particles in beam-edge and recorded the trajectories of these particles with different mismatch in vertical phase space. The coordinates of particles are aslo normalized as same as last section. In the case of beam matched, the initial coordinate of five beam-core particles at the entrance of DTL are respectively （0.3972687E-03 ，0.3753150E-04） ，（0.1544064E-03 ，0.1063141E-03） ，（0.3813250E-03，0.7590302E-04），（0.2010241E-03，0.5347696E-04），（0.7237914E-04，0.4443773E-04）. The coordinates of five beam-edge particles at the corresponding position are respectively （0.1093214E-01，0.9639752E-03），（-0.1081101E-01 ，-0.9183724E-03），（0.9057361E-02 ，0.1204612E-02），（-0.9715749E-02 ，-0.1225402E-02），（0.1146746E-01 ，0.5332417E-03）. Figure 3 shows the vertical trajectories of specified beam-core particles after every focusing periodic structure in DTL with initial matched. Figure 4 shows the vertical trajectories of specified particles in beam-core with different mismatch factor.

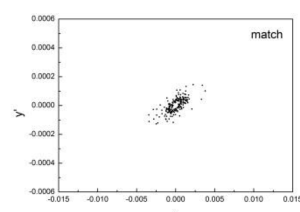

Figure 3: The position of beam-core particles in phase space when the beam is matched.

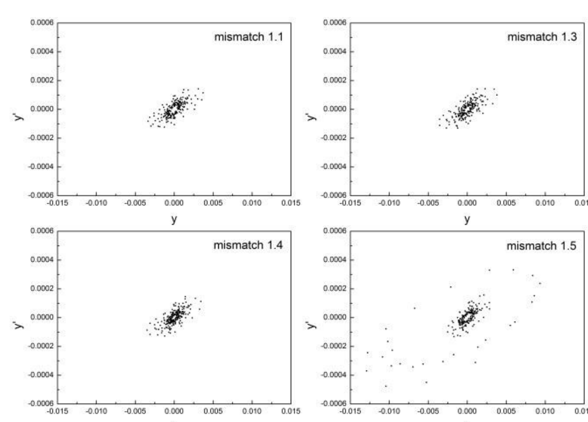

Figure 4: The position of beam-core particles in phase space with different mismatch factor.

As can be seen form the Figure 4, when the beam's initial mismatch factor increases from 1.1 to 1.4, the trajectories of particles in beam-core change little. Until the mismatch factor increasing to 1.5, the trajectories of particles in phase space enlarge significantly. Due to the

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envelop oscillations caused by mismatch, particles get free energy, and lead the trajectories evolve into the larger ellipse representative of larger emittance.

Under the same conditions, we record the trajectories of beam-edge particles. Figure 5 shows the vertical trajectories of specified beam-edge particles after every focusing periodic structure in DTL with initial matched. Figure 6 shows the vertical trajectories of specified particles in beam-edge with different mismatch factor. As the mismatch factor is increased, the phase-space ellipse of particles' trajectories corresponding become larger. Rather than the beam-core particles , as in the mismatch factor of 1.5, the phase-space ellipse changed significantly.

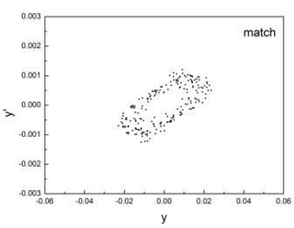

Figure 5: The position of beam-edge particles in phase space when the beam is matched.

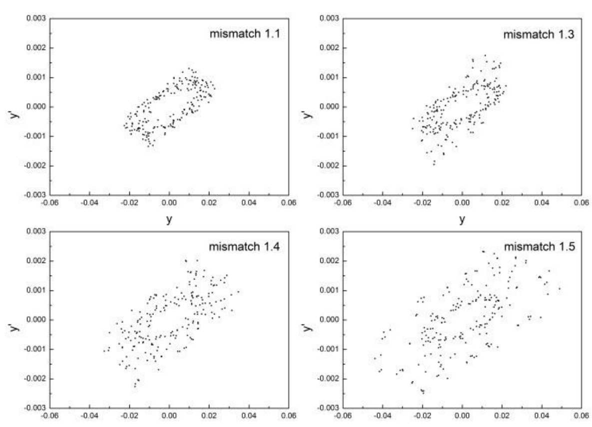

Figure 6: The position of beam-edge particles in phase space with different mismatch factor.

CONCLUSION

In this paper, three-dimensional space-charge code IMPACT-Z is taken to study the space-charge effects on CSNS linear accelerator. The beam's growth of emittance is given and analyzed with the current intensity of 15mA and 30mA.

In the case of current intensity of 15mA, and based on the FFDD focusing structure of DTL, the evolution of beam emittance is analyzed on single-particle dynamics.

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