論文の内容の要旨

Evaluation and Compensation of Betatron Resonances for High-Intensity Proton Synchrotrons

（大強度陽子シンクロトロンにおける

ベータトロン共鳴の評価と補正）

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In proton synchrotrons, the beam loss derived from the betatron resonances is one of key issues for stable beam operation. Especially, for the high-intensity beams, the serious effects come from both the sextupole-driven resonances and the space-charge-induced resonances. This dissertation proposes methods to compensate these resonances. They are verified through the simulations and the measurements performed in the main ring synchrotron (MR) of Japan Proton Accelerator Research Complex, which is one of the world-highest beam-intensity proton synchrotrons.

We discussed the main source of the integer resonance in MR, and the effects of the resonance on the beam core. We measured the turn-by-turn transverse beam sizes which grew due to the space-charge-induced resonances. A clear difference of the emittance growth between the structure resonance $\nu_x = 21$ and the nonstructure resonance $\nu_x = 22$ was observed in the measurements. These results showed that the space charge effect was the main source for the resonance $\nu_x = 21$. The measured emittance growth strongly depended on the tune. It gave us the knowledge about the relations between the resonances and the tune spread distribution. The results were well reproduced by the tracking simulation including the space charge effects using a particle-in-cell algorithm.

We developed a novel method to compensate the sextupole-driven third-order structure resonance $\nu_x - 2\nu_y = -21$. The new optics for the compensation makes use of the symmetry of the synchrotron and optimizes the vertical phase advance in the arc section. The compensation was confirmed by the aperture survey simulations and also demonstrated by the three kinds of measurements. The first experiment was the horizontal and vertical coupling measurement derived from the resonance. The coupling was observed only for the optics without the compensation. The second experiment was the beam loss measurements. The beam loss around the resonance was clearly reduced using the optics for the compensation. The third experiment was the Fourier analysis of the dipole oscillation in the transverse planes. We observed the Fourier spectra derived from the resonances, and showed that their peaks were clearly suppressed in the optics for the compensation. The three measurements were consistent with the results of the space charge simulations.

It was revealed that each resonance driving term can be weakened by changing the vertical phase advance in the arc section. This method preserves the original tune, and keeps the straight sections dispersion-free. Through the calculations of the on-resonance conditions, the most influential space-charge-induced resonance to the beam loss was specified as $8\nu_y = 171$ in the present neutrino user operation of MR. It was confirmed by the scan of the vertical phase advance in the arc section. The resonance driving term of the resonance $8\nu_y = 171$ correlated the beam loss during the scan. The advantage of the new optics was also supported by the experiments. The beam loss was reduced about 16% compared to the present optics in the injection period of MR.