Dynamic estimation of emittance growth with tune depression and nonlinear field energy factor during longitudinal bunch compression for heavy ion inertial fusion driver

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In general, the radial matched beam is according to an equilibrium condition, and depends on the radial (transverse) confinement force and the ratio of repulsion forces between the space charge potential and the thermal pressure [1-3]. During longitudinal bunch compression, parameters of charged particle beams are changed, and the beam current is also increased due to the increase of the charge density. Not only thermal equilibrium distribution but also the linear-Courant-Snyder invariant distributions such as Kapchinskij-Vladimirskij (KV), waterbag (WB), Gaussian (GA), parabolic (PA), and semi-Gaussian (SG) distributions, the radial density profile is changed with increase of the beam current during the longitudinal pulse compression [4]. Finite nonlinear field energy factor produces the emittance growth, because the space charge potential can be thermalized.

The possible emittance growth was written as a function of the nonlinear field energy factor which depends on the radial density distribution and the tune depression [5,6]. The equilibrium radial density profile is redistributed according to the balance between the space charge and thermal potentials. The possible emittance growth was estimated with the thermal equilibrium distribution [7], and has the maximum value in a low tune depression regime [8], as a static analysis. However, the beam current increase due to the longitudinal bunch compression causes dynamically the unbalanced state.

For this reason, one of factors for emittance growth is resulted with the redistribution of density profile caused by the longitudinal pulse compression. Wangler *et al* showed the differential equation of emittance growth with change of the nonlinear field energy factor [2,3]. As a result, if the change of the nonlinear field energy factor is clear, the emittance growth can be evaluated. In this study, the emittance growth based on Wangler's differential equation is evaluated with the nonlinear field energy factor. Also, multi-particle simulation shows the emittance growth, and is compared to the above estimation.

The dynamic emittance growth during the beam transport was estimated theoretically as a function of the tune depression and the nonlinear field energy factor with various initial particle distributions. The tune depression was given by the initial beam parameters and the beam current including the bunch compression. The nonlinear field energy factor was obtained by the numerical simulation examples. In comparison with the analytical and numerical simulation results, the analytically estimated emittances were larger than the numerical result. In the initial distribution with the space-charge-induced instability, the integrated possible emittance growth was not applicable. However, the overestimation is 14 % as the highest case, and the beam for the distribution with the space-charge-induced instability is an especial case, such as KV distribution. Consequently, it is expected that the dynamic estimation of possible emittance growth as a function of the tune depression and the nonlinear field energy factor with the bunch compression model is useful to design the particle accelerator complex such as the heavy ion inertial fusion driver.

References

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