ESTIMATION AND SUPPRESSION OF ABERRATIONS IN EMITTANCE EXCHANGE BASED CURRENT PROFILE SHAPING

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Abstract

The longitudinal current profile manipulation has been explored for many applications including THz radiation, FEL and advanced acceleration schemes. Especially, collinear dielectric wakefield accelerations require a microbunch shaping for a high transformer ratio. We have studied aberrations from the emittance exchange based current profile shaping to preserve the high transformer ratio. All second order aberration terms in the double dog-leg emittance exchange beam line are discovered. Aberration patterns from each aberration sources like second order terms, space-charge, and CSR and their effect on the transformer ratio are estimated analytically. These aberration sources and corresponding patterns are confirmed using a particle tracking code GPT. Simple method to suppress each aberration will be presented too. All calculation in this work is done with a double dog-leg emittance exchange beam line.

ABERRATION SOURCES: SECOND ORDER

The content in this proceeding will be published on the journal, so it only provides brief introduction of each contents.

EEX based bunch shaping method can provide perfect exchange of the profile between initial horizontal and final longitudinal under the linear beam dynamics. However, ignored factors including higher order terms and collective effect generate aberration on this ideal profile. In the case of second order terms, governing equation for the shaping can be described as,

$$\begin{aligned} z_f = {} & \kappa\xi x_0 + (\eta + \kappa\xi(L + L_D + L_c/4)x_0{}' + C_1 x_0^2 + \\ & C_2 x_0 x_0' + C_3 {x_0'}^2 + C_4 z_0^2 + C_5 z_0 \delta_0 + C_6 \delta_0^2 + \\ & C_7 x_0 z_0 + C_8 x_0' z_0 + C_9 x_0 \delta_0 + C_{10} x_0' \delta_0 + \\ & C_{11} y_0^2 + C_{12} y_0 y_0' + C_{13} y_0'^2, \end{aligned} \tag{1}$$

where x_0 and x_0' are the beam coordinate at the entrance to the EEX beam line, and C_1 to C_{13} are the coefficient for each second order coordinates. Depending on the correlation to x_0, these second order terms can be categorized to random, correlated-random, correlated cases, and each category generates its own aberration on the ideal profile.

ABERRATION SOURCES: COLLECTIVE EFFECTS

Collective effect always change the longitudinal momentum. So if there is any non-zero R_{56} term in the transfer matrix, collective effect can affect on the longitudinal current profile. In the case of EEX, this situation is little more complicated because of TDC in the middle of beam line. Therefore, we can analyse how these collective effects propagate and change the ideal profile. Change on the longitudinal position can be written as,

$$\Delta z_f = \xi \Delta\delta_2^{\eta'=0} + \xi \Delta\delta_2^{\eta'\neq 0} + \xi(1 + \kappa\eta')\Delta\delta_1^{\eta'\neq 0}. \tag{2}$$

EFFECT ON IDEAL PROFILE

Equation 1 and 2 show the relation between variation on the ideal profile and aberration sources. If we consider the aberration sources as a perturbation on the ideal beam transport, one can imagine the perturbation function P(ζ) which is defined by what portion of particle in ideal position move to the perturbed position. By definition, integration of P over the whole domain should be unity, and perturbed profile can be described as a convolution of P and ideal profile.

Each aberration sources has their own perturbation function P with specific domain, and it generates a unique aberration pattern on the ideal profile. Aberration pattern and corresponding transformer ratio drop for several perturbation functions are described in [1].

SUPPRESSION OF ABERRATION

There can be many different method to suppress the second order effect [2]. One of the simplest method is introducing cancelation between the terms in Eq. 1. For example, $C_1 x_0^2 + C_2 x_0 x_0' + C_3 {x_0'}^2$ terms can cancel each other if initial horizontal slope satisfies the specific condition. In the same way, vertical and longitudinal slopes generates cancelation, and we can suppress the second order effect up to some level.

For the collective effect case, we suggest other way to suppress it. According to Eq. 2, all collective effects affect on the longitudinal current profile through R_{56} of second dogleg. If there is a special configuration which satisfy the EEX condition and has zero R56 at the same time, collective effects cannot generate any aberration on the ideal profile. Since we did no find this ultimate option yet, we simulated other option which is reducing R56 by decreasing bending angle. Compared to 20 deg bending, 12 deg bending suppress the CSR almost factor of 10 and it was not clear as CSR but space charge effect was also suppressed compared to 20 degree case.

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