EFFECTS OF QUADRUPOLE WAKE FIELD ON RF FOCUSING IN LINEAR COLLIDERS.

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1. INTRODUCTION.

It's known that transverse wakefield effects and the beam 'heating up' prevent small emittance preservation.

The use of an energy spread to damp the oscillation of the core of the bunch was first described by Balakin [1] (BNS damping). But efficiency of this method decreases at the final focus where the energy spread is to be reduced.

Another way to meet the damping criterion is to use a focusing field which has a variation along the bunch. For this purpose part of the accelerating sections are given nonsymmetric apertures (slots instead of circular holes) which are placed alternately vertically and horizontally at a proper period length. The slot apertures produce RF quadrupoles of considerable strength without appreciable loss of shunt impedance for acceleration. In this case the spread in betatron oscillation, necessary for BNS damping, can be introduced without any energy spread.

Usually, the damping criterion takes into account only dipole wakefield which is proportional to the distance between the path of the exciting charge and the axis of the structure, but independent of the transverse position of the particle on which it acts. The reason is that in symmetric structures there are other higher order wakefields which depend on higher powers of the distance between the path of the exciting and following particles and the axis of the RF structure, but whose influence on transverse dynamics is negligible.

But in azimuthally nonsymmetric structures (ANS) there is an accelerating field with strong quadrupole component used for RF focusing. So we can expect a high enough quadrupole component of wakefield.

In this paper the use of ANS in cases when BNS criterion fulfilling becomes difficult because of energy spread limitation is investigated. Two problems are pointed out below, the first being that of quadrupole wakefield utilization for beam focusing, the second being that of RF generator and wake fields interaction.

2. ELECTROMAGNETIC FIELDS.

Electromagnetic fields in the ANS can be analyzed in detail in case of the slotted rectangular waveguide. In such structures slow LE mode waves and a fast LM mode waves propagate [2]. In the lower band in-phase waves include both longitudinal (accelerating) and transverse quadrupole components, while anti-phase waves include a dipole component thus being useless for acceleration.

The same considerations are preserved in a slotted circular waveguide, in a waveguide with elliptical cross-section and hyperbolically-shaped irises.

Electromagnetic properties of such structures have been studied rather in detail.

3. WAKEFIELDS IN THE ANS.

If particles travel with velocity $v=c$, focusing gradient can be calculated based upon Panofsky-Ventzel theorem and expression for the longitudinal field. In the region of high frequencies so-called optical resonator model can be applied. A. Sessler developed the formula of radiation losses based on analogy between a set of finite plates with circular holes and a pair of circular mirrors. To estimate radiation fields in this frequency region one can make use of equivalent optical resonator for iris-loaded structure, suggested by Weinstein [3].

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4. BETATRON WAVELENGTH SPREAD IN THE ANS.

Expression for wake fields and external electromagnetic ones achieved allow us to investigate the bunch motion in each particular azimuthally asymmetrical structure.

Calculations show that dipole wakefield may amplify the influence of accidental misalignments of both accelerating and focusing systems, that can lead to large emittance growth and even beam loss.

Quadrupole wakefield can make nonlinear spread of betatron wavenumbers along the bunch. Note, that it can 'disturb' BNS criterion for bunch coherent oscillations.

Large enough quadrupole wakefield can result from the structure asymmetry variation. This can be used for particles focusing. Provided that quadrupole wakefield is linear vs longitudinal coordinate inside the bunch, its influence on transverse dynamics is similar to that of quadrupole magnets. Wakefield nonlinearity along the bunch leads to wavenumber spread of this new 'magnetic-RF' focusing system even in case of a monoenergetic bunch.

Taking into account all the above said, charged particle motion equation will be:

$$m\,c^2 \frac{\mathrm{d}}{\mathrm{d}z}\left[\gamma(s,z)\,\frac{\mathrm{d}x(s,z)}{\mathrm{d}z}\right] = q x(s,z) \times \left\{ cG_{rf}\sin\phi(s,z) + \int_0^s \mathrm{d}s'\rho(s')W_1^q(s-s') + cB' \right\} + q\int_0^s \mathrm{d}s'\rho(s')W_1^d(s-s')x(s',z) \qquad (1)$$

with $G_{rf} = \dfrac{1}{2\pi f}\,\dfrac{\partial^2 E_{zo}(x,0)}{\partial x^2}$ and $B' = \dfrac{\mathrm{d}B_y}{\mathrm{d}x}$

gradients of RF and magnetic field respectively, m and q the particle mass and charge, γ the normalized energy, W_1^d and W_1^q the transverse dipole and quadrupole wake potentials. z is the coordinate along the linac, s is the longitudinal position in the bunch (from head to tail), x is the particle transverse offset.

5. WAKEFIELD QUADRUPOLE (WFQ).

Quite a number of such accelerating - focusing structures is possible:

A. Both accelerating and wakefield focusing exist at the lowest mode.

This version seeming to be simple in technology, has some disadvantages:

- Quadrupole component growth can be accompanied by accelerating properties degradation. Thus, varying of slotted rectangular waveguide sizes results in a significant growth of quadrupole component (that is the best) and unfortunately falling of group velocity value more than 10-fold and corresponding filling time growth.

- Since quadrupole component of accelerating field and first mode of wakefield are oppositely directed and, therefore, are subtracted from each other, betatron wavenumber spread along the bunch resulting from the WFQ diminishes.

B. WFQ on higher modes.

In some accelerating structures a quadrupole component corresponding not to the mode used for acceleration but to the higher modes, for instance, to the second mode, is excited. Example of such a structure is elliptical waveguide having elliptical irises. RF source excites structure on the first mode, no RFQ effect appearing in it. WFQ exists but on the second mode. Thus, accelerating and WFQ become separated.

C. Accelerating and WFQ are separated in space.

The main structure of this construction being a conventional iris-loaded waveguide, some passive high gradient ANS are inserted between sections. Unfortunately, this result in accelerating gradient reducing. It may be useful to combine such passive cavities with quadrupole magnets.

6. CONCLUSION.

Influence of wakefields on transverse dynamics of charged particles in linear colliders has been analyzed. Problem of betatron wave length spread producing has been discussed, some ways of its realization having been proposed. Interaction between quadrupole components of external and wake field has been considered. The new focusing element referred to as wakefield quadrupole (WFQ) has been proposed. All mentioned above allows us to conclude that application of the ANS in high energy collider designing seems to be promising.

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