ANALYSIS OF WAKE FIELDS ON TWRR ACCELERATOR STRUCTURE IN PNC

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Abstract

A high power CW (Continuous Wave) electron linac has been developed so as to accelerate 10 MeV–100 mA beam, and its injector section has been completed in 1996 at PNC. It is essential for higher beam acceleration to reduce the beam instability caused by the space charge effect and the beam-cavity interaction. Both are important for PNC linac, because an accelerator with a high beam loading generally has a low accelerating gradient.

In this paper, beam induced fields for the regular section with PNC accelerator structure are examined by means of a numerical wake field analysis. The BBU start current is estimated in the relationship of the wake potential to space charge force in injector section.

Introduction

The development of a high current electron accelerator is being carried out to target to treat high level nuclear wastes via photo-nuclear reaction which is selective and clean more then the spallation reaction. The elementary design and the experiments [1–3] for the high current linac are in progress using L-band RF source which is effective to a high beam loading. The traveling wave accelerator with an RF feed back called Traveling Wave Resonant Ring (TWRR) is employed to get higher energy transfer with a shorter accelerator length, the reasonable cost, and the ease of the maintenance. The accelerator structure has a constant gradient disk loaded type and accelerate 80 pC charge per bunch for 100 mA average current. The accelerating gain from PNC structure is 1.3 MeV which is so low compared with S-band linac that the effect on the beam such as a microwave instability may cause undesirable beam broadening in longitudinal and transverse direction at lower than usual beam current.

In the regular section which beam energy is over than 3 MeV in PNC linac, the beam instability originates from the interaction with the accelerator structure. The analysis for this interaction is recently developed by means of a wake field approach for both circular and linear accelerators. Monopole and dipole components of wake field a nd related loss factors were calculated by ABCI [4] and MAFIA [5] T3 in order to have the potential and voltage compared with the accelerating condition. Finally, the BBU start current was estimated by the scaling of the wake voltage with the voltage and the space charge parameter of the behavior in the envelope equations.

Definition and Calculation

When charged particle passes through a structure with the speed of light c, it produces the electromagnetic field. The wake fields $W_{\|}$ and $W_{\perp}$ [6, 7] both for monopole and dipole components are described as

$$W_{\|} = -\frac{1}{Q}\int \mathrm{d}z\, E_z\left(r,\theta,z,(z+s)/c\right) ,$$

$$W_{\perp} = -\frac{1}{Q}\int \mathrm{d}z\left(E_{\perp} + c\times B\right)\left(r,\theta,z,(z+s)/c\right)$$

where EZ,⊥, and B are the electric and magnetic fields produced inside the cavity, and Q and s are the bunch current and the bunch coordinate, respectively. The coordinate inside the cavity is represented in cylindrical in this case. The associated loss factors k_0 and the induced voltage ΔV are presented as

$$k_{\|} = -\frac{1}{Q}\int \mathrm{d}s\,\lambda(s)V_z(s) ,$$

$$k_{\perp} = -\frac{1}{Q^2}\int \mathrm{d}s\,\lambda(s)V_{\perp}(s) ,$$

$$\Delta V = 2Q\,k_{\|}$$

where λ is a bunch distribution. $V_{z,\perp}$ is the wake voltage derived by the total beam bunch and the wake potential for the longitudinal and transverse in each. These quantities except the induced voltage are ready to several codes for numerical calculation.

The actual parameters for the calculation used for the beam and the accelerator structure is summarized in Table 1. The typical dimensions of the accelerator structure used are a = 50, b = 90, t = 8 and D = 24 mm, which are exactly or approximately equal to the actual structure dimensions for PNC linac. The beam bunch shape is assumed filamentary and gaussian shape in the longitudinal direction. Numerical calculation was done mainly by ABCI because of the less demand of cpu time, while MAFIA was used for 3-dimensional structures which is not available for ABCI. In the case of off-centered beam, MAFIA is suited because of the symmetry free input for the beam parameter.

Monopole and dipole component were estimated to examine the dependence of the bunch shape, the cell distance and cell shape distance.

Characteristics of Wake Fields for PNC linac

The analysis was carried out for the cases of a single cavities and the accelerator structure consists of many cells in order to make the effects in PNC linac clear.

Table 1 Parameters of wake field analysis

Iris *(a)*	90 (mm)
Boa *(b)*	50 (mm)
Disk thickness *(t)*	8
Pulse Length	0.3 ~ 200 (mm)
Periodic distance*(D)*	24 ~ 64 (mm)
Charge of single bunch *(Q)*	80 (pC)
Bunch length	0.3 ~ 200 (mm)
Beam displacement	0 ~ 20 (mm)

Case of Single cavity

In the case of 2.5 mm bunch seen in Fig. 1, there exists one down warding swing which is essentially only a spike in this situation. This picture is magnified for an only shot to display the potential on the beam bunch. Figure 1 has the abscissas which is presented by volt. The gradient of the curve has a down swing at first which means the gradient of the wake field is negative, which can cause to have an attractive force on particles in the right-shoulder in the bunch. The bias is changed around 10 cm bunch length. The wake potential for 10 cm and 1 cm are 10 V and 50 V in each for each 80 pC of the single bunch. the voltages are small enough to consider the stability for PNC linac.

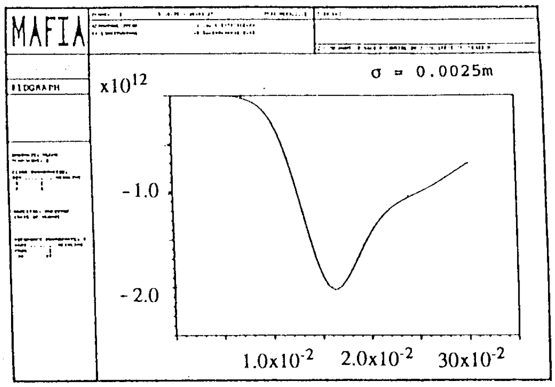

Fig. 1 Wake voltage from single cavity.

The analysis of the potential dependence for an off-cantered beam shows that there is basically only a spike both in the longitudinal and transverse wake fields. But MAFIA calculation may neglect calculation of higher frequency area, because of luck of cpu time. This picture notices also that the beam bunch gets an attractive force for the longitudinal wake field at first and a repulsive force for the transverse. The shapes of the potential are the same but the amplitudes are different. The loss factor normalized to a single bunch current and an induced transverse voltage is summarized in Table 2. The deflection voltage for 1 cm off-centered filamentary beam with bunch length of 0.3 cm is almost –200 V which corresponds to 6 KV/m in the beam pipe. This potential is not so strong compared with the potentials in the beam pipe in present colliders like SLC and designed value for SSC. Total loss of a wider beam is reduced for transverse case, while the factor is enhanced for the longitudinal. The energy emission is clearly mainly by longitudinal process. Effectively there is no significance for such a small energy loss into cavity for PNC linac.

Table 2 Loss factor and induced voltage in a single bunch for beam displacement.

Displacement (cm)	Loss factor* (V)***	Induced voltage** (V)
σ = 1 cm		
0.5	–17.4	112.0
1.0	–61.02	10.0
2.0	–243.8	420.0
3.0	–548.4	630.0
σ = 0.3 cm		
0.5	–56.8	89.9
1.0	–199.9	168.8
2.0	–798.0	338.9
3.0	–1792.5	511.0

* Longitudinal.

** Transverse.

*** Normalized to a single bunch current.

Case of Accelerator structure for PNC

The examples of wake potentials and the impedances are pictured in Fig. 2 for the longitudinal and transverse wake field resulted from changing the cell displacement. The effect is totally capacitive because of actual bunch length and the speed of an electron beam. The patterns of the potential change very little in different cell numbers. This is caused by that Fourier component of the wake field has stronger fundamental than high harmonics, which can be travel inside the accelerator guide. This seems plausible because the impedance spectrum has a strong peak around 1.25 GHz which mode is 2¹/3. The dependence of Fourier component for the bunch length between 0.3~1.0 cm is nearly constant. The strength of the longitudinal wake potential is basically smaller than the gradient from RF in monopole case. In the dipole case, it gets larger, but still is coherent with bunching effect as mentioned in single cavity case. It is notable from general analysis that in the case of 3.3~10 cm bunch length in which the bunch length is nearly equal to the depth of the cavity, there is strong resonance which is chanced by the accelerator structure. It is seen in the impedance calculation that the resonance of wake field is build by 1.9 GHz RF in the transverse wake potential.

From a numerical evaluation, the transverse spike amounts to –270 V/pC, which correspond to –2.2 kV per bunch. This value is smaller than 100 kV order which appears in modern colliders. Qualitatively, just like a theory of a electron synchrotron, the tune shift by space charge is also applicable to a linac. In the scaling the space charge parameter ξ in the envelope equation from the value of modern colliders to one for PNC linac, the wake transverse voltage is 100 times higher than the voltage from 0.1 A beam. However, the space charge parameter for the wake voltage for 1 cm radius beam is 10^{-12} and still 10^{-2} smaller than beam defocusing value emerged in colliders. The margin from 0.1

A is order of one hundred. Therefore, from above comparison, BBU starting current is assumed around 5 A for PNC linac.

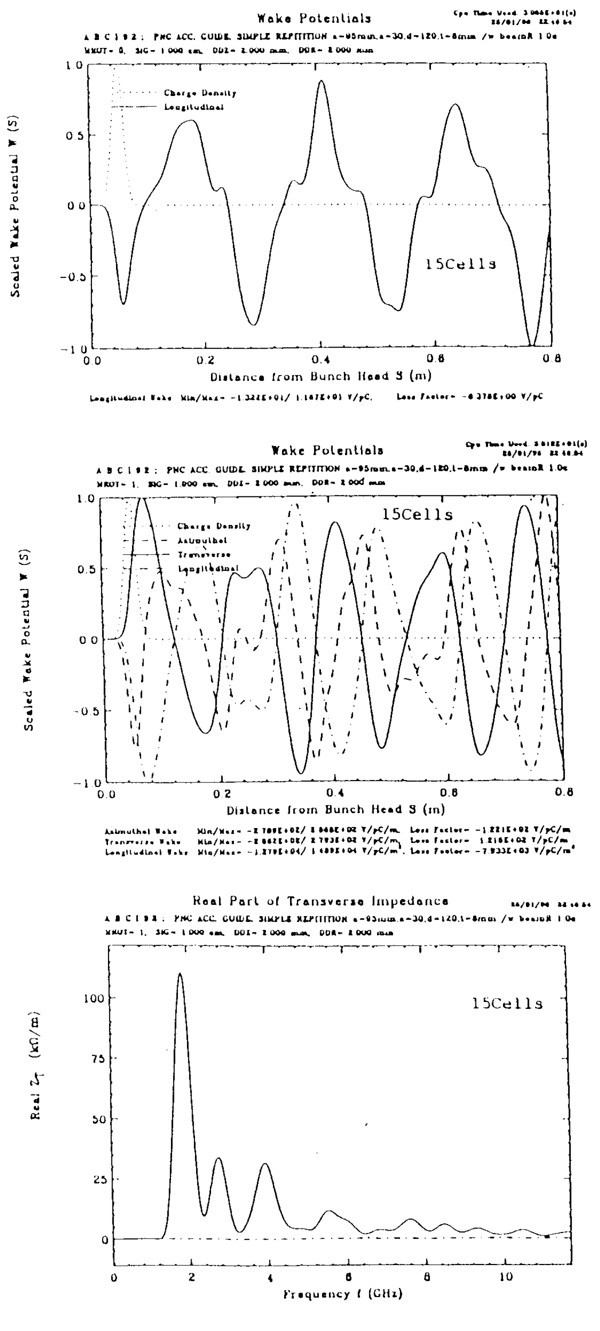

Fig. 2 Wake potential from PNC accelerator structure.

Summary and Conclusion

The longitudinal wake field has one down swing followed by many smaller oscillation in the beam condition of PNC linac. It may assist phase stability if the attractive force and repulsive wake can be controlled so as to synchronize with RF bucket. Transverse wake field is 100 times higher than the space charge force but still considerably lower than the wake field of present linear colliders. The wake field in the accelerator guide for PNC linac is formed from the coherent sum of single cells. The longitudinal wake has the same period as RF frequency. The dipole component has –2.2 KV, which is the highest potential of all transverse field. The transverse wake potential in PNC structure is essentially not so high that BBU by the transverse component is expected not to start up to 5 A.

There is a possibility that the longitudinal instability comes first because of phase instability. It is important to observe the bunch lengthening which is common phenomena called microwave instability known circular accelerators. The accumulation of wake field should be estimated for more accurate estimates for the BBU for TWRR. It is important to analyze an overlap integral of higher frequency from the dispersion relation in TWRR which may have a resonance.

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