BUNCH-BY-BUNCH PHASE MODULATION FOR LINAC BEAM LOADING COMPENSATION*

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Abstract

If the linac is loaded by a high intensity, long pulse multi-bunch beam, the energy of the beam drops with time during the pulse within the accelerating structure filling time [1, 2]. The bunch phase modulation method is introduced to compensate the beam loading effect. In this method the bunch phase in the RF accelerating field is changed bunch-by-bunch, the bunch energy gain in the RF filed gradually grows up, which cancels out the drop due to beam loading. The relationship between the beam phase distribution and the linac parameters is calculated in this paper.

BEAM LOADING EFFECT

When a bunch train passes through a travelling wave accelerating structure, the loaded accelerating fields U_{acc} is defined by [3].

$$U_{acc}(t) = U_{rf}(t)\cdot\cos\varphi - U_b(t) \qquad (1)$$

Where U_{rf} is the accelerating voltage conducted by input RF power(unloaded accelerating voltage), φ is the bunch phase in RF filed, U_b is the beam loading voltage,

There are two kinds of travelling-wave accelerating structure–constant impedance and constant gradient, normally used in linac. In case of constant impedance structure, the U_{rf} and U_b is expressed by

$$U_b(t) = \begin{cases} I\cdot R_M[(L-z-\frac{1}{\alpha})(1-e^{-\alpha z})+z] & t<T_F \\ I\cdot R_M\cdot L(1-\frac{1-e^{-\tau}}{\tau}) & t\ge T_F \end{cases} \qquad (2)$$

$$U_{rf}(t) = \begin{cases} \sqrt{2\alpha P_0 R_M}\cdot L(\frac{1-e^{-\alpha\cdot v_g\cdot\tau}}{\tau}) & t<T_F \\ \sqrt{2\alpha P_0 R_M}\cdot L(\frac{1-e^{-\tau}}{\tau}) & t\ge T_F \end{cases} \qquad (3)$$

$$z = v_g\cdot t \qquad \tau = \alpha L$$

Where I is beam current, TF is the filling time, RM is shunt impedance per length, L is the length of accelerating structure, α is attenuation coefficient, P_0 is RF input power, vg is group velocity.

U_b is the sum of each bunch induced voltage U_i. The attenuation and superposition of bunch induced voltage is shown in Figure 2.

$$U_b = \sum_{i=1}^{n} U_i \qquad (4)$$

*Work supported by NFSC-CAS(11079034)
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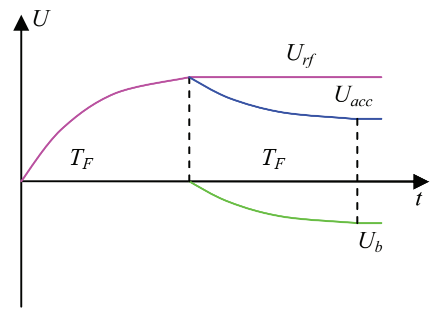

Figure 1: Transient beam loading effect.

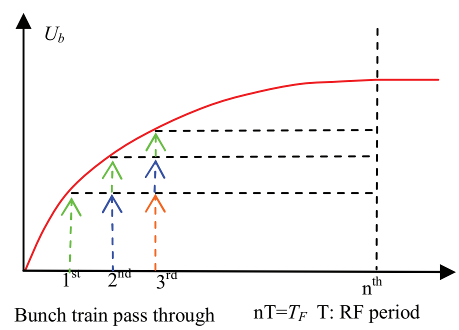

Figure 2: Attenuation and superposition of bunch induced voltage.

Some methods are used to compensate the transient beam loading. For a short pulse beam, the beam is injected before RF power is filled up (early injection method) [4]. In case of long pulse beam, the amplitude or phase of RF power is ramped to keep the U_{acc} constant during the filling time of beam injection [5, 6].

PRINCIPLE OF PHASE MODULATION METHOD

We propose the bunch phase modulation method to compensate the transient beam loading. The idea is that the bunch phase (φ) in the RF accelerating filed is changed bunch-by-bunch, therefore the bunch energy gain in the RF filed gradually changes. If the trends of the gain change is exactly contrast of the rise up of beam loading, all bunches will obtain the same energy.

Since the bunch phase shifts continuously, the beam loading is the vector superposition of all bunch's induced voltage, which is shown in Figure 4.

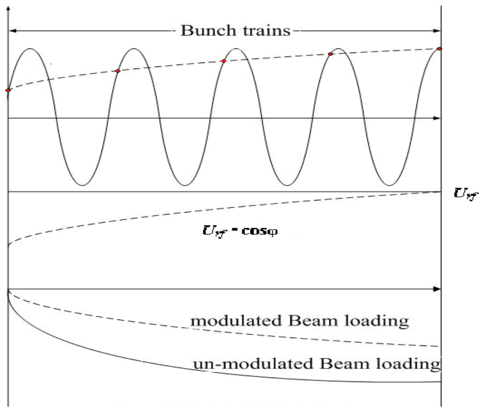

Figure 3: Principle of bunch phase modulation.

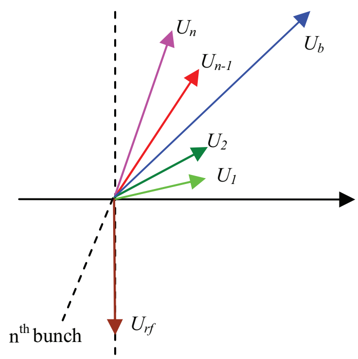

Figure 4: Vector diagram of phase modulated bunch.

CALCULATION OF THE BUNCH PHASE DISTRIBUTION

In order to calculation the beam loading of multi–bunch with different phase, we define

$$u_n = U_b(nT) - U_b((n-1)T) \quad (5)$$

Where T is RF period time.

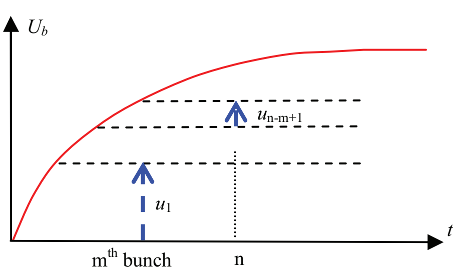

Figure 5: Bunch induced field attenuating with time.

When a bunch passes through the accelerating structure, its induced voltage in the structure is u_1, and then attenuates to u_n after nT times. So that at the moment when the n^th bunch enter the accelerating structure, the voltage of the m^th bunch is

$$u_n^m = u_{n-m+1} \quad (6)$$

All bunches will obtain the same energy gain U_{const}.

For the No.1 bunch with phase φ_1

$$U_{const} = U_{rf}\cos\varphi_1 - u_1$$

and the No.2

$$U_{const} = U_{rf}\cos\varphi_2 - u_1 - u_2\cos(\varphi_1 - \varphi_2)$$

Therefore the No. n

$$U_{const} = U_{rf}\cdot\cos(\varphi_n) - \sum_{i=1}^{n} u_n^i \cdot \cos(\varphi_i - \varphi_n) \quad (7)$$

A MATLAB code is programmed to find out the optimum phase distribution, the parameters of constant impedance accelerating structure listed in Table 1 come from the HLS (Hefei Light Source) 200 MeV Linac. The beam pulse length is assumed as the filling time (TF), the relative bunch amount is 2370. The calculating result is shown in Fig. 6-8.

Table 1: Accelerator Parameters

L /m	3
T_F /μs	0.83
α	0.177
Freq. /MHz	2856
R_M / MΩ/m	60
U_{rf} /MV	30MV

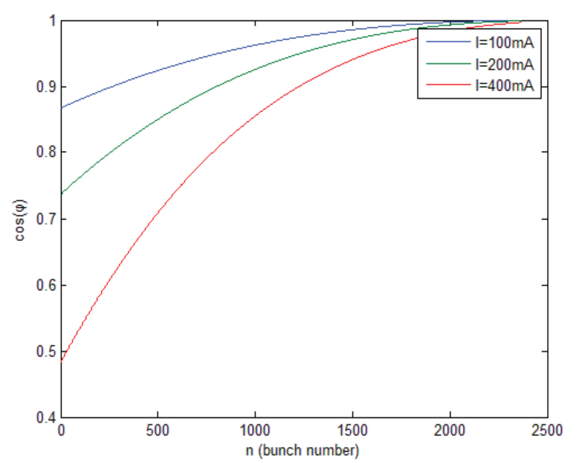

Figure 6: cosφ *vs* n

In Figure 8 the blue line (100mA modulated) is nearly coincident with the red one (100mA un-modulated). It shows that when the beam intensity is lower, the phase difference between bunches is so small that the vector superposition is similar to the direct superposition. In this case the bunch phase can simply calculated by

$$\cos\varphi_n = \frac{U_{rf} - U_b(T_F)}{U_{rf} - U_b(nT)} \quad (8)$$

ISBN 978-3-95450-122-9

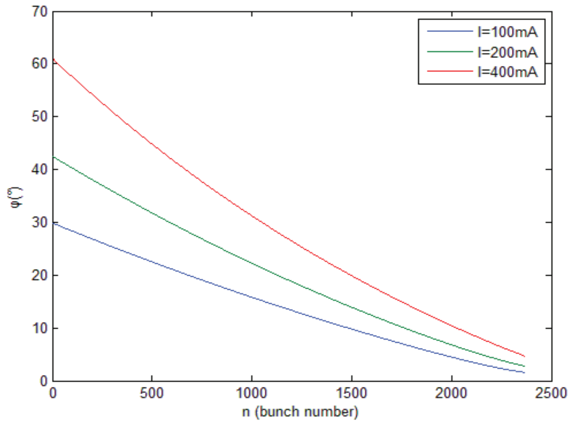

Figure7: bunch phase distribution.

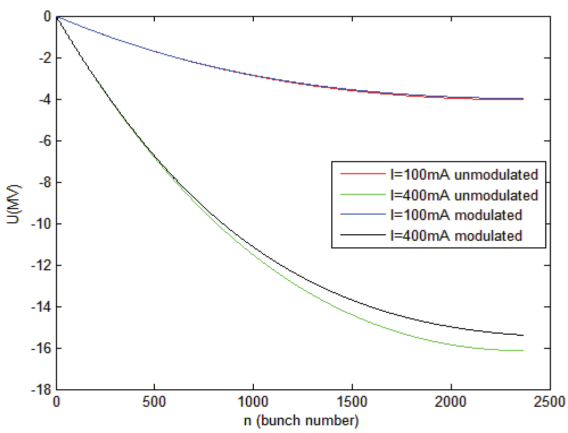

Figure 8: modulated and un-modulated beam loading.

CONCLUSIONS

The bunch by bunch phase modulation is a very interesting method to compensate the transient beam loading. The advantage of this method is that the compensation is global. If all of the accelerating sections in a linac adopt the identical structure, their beam loading will be compensated simultaneously. It would be a simple and cheap resolution for the larger linac such as linear collider. But how to realize the bunch phase modulation is a very complicated problem. At present we are developing a bunching system with the low-Q and wide-band cavity, the rf phase modulated signal can apply fast on it, the bunch phase will be modulated in the bunching procession.

REFERENCES

[1] S.H. Kim, et al., "Transient beam loading compensation in L-band travelling wave accelerating structure with intense electron beam", LINAC2010.

[2] C. Adolphsen, et al., "Beam Loading Compensation in the NLCTA", PAC97, Vancouver, BC, Canada.

[3] C. Nantista, C. Adolphsen, Calculating RF Profiles for Beam Loading Compensation of Arbitrary Current Profiles, NLC-note #25, 1997

[4] Z. Li, et al., "A combined ΔT +ΔF beam loading compensation scheme for power saving", PAC99.

[5] Z.D. Farkas and P.B. Wilson. Ramping Profile for Exact Beam Loading Energy Compensation in the NLC Detuned Structure, NLC-Note #4, SLAC, 1994.

[6] M. Satoh, et al., "Beam test of initial beam loading compensation for electron linacs", Proc. EPAC02, Paris, France, June 3-7, 2002.