Bunchlengthening in the ATF Damping Ring

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Abstract

The paper summarizes results on the numerical impedance study of the vacuum components in the ATF damping ring which is being commissioned. It is shown that wake potential in the damping ring is inductive. With the longitudinal impedance evaluated, we estimated behaviors of bunch lengthening for a single bunch in the ATF damping ring with a Vlasov equation approach.

1 INTRODUCTION

A current dependent bunch lengthening has been observed in the damping ring which is being commissioned. Bunch lengthening can impose a significant limitation on the stored bunch current. It is required to operate the ring below the longitudinal microwave instability threshold. To achieve this without increasing the longitudinal emittance significantly, it is necessary estimate the impedance and investigate problem of bunch lengthening of the damping ring.

We calculate the effective inductance to get an estimate of chamber element's relative importance for bunch lengthening. In the earlier stage of design of the ATF damping ring, M. Takao et. al. estimated longitudinal impedance in the damping ring[1]. However, because vacuum components in the constructed ring have different ones with the earlier designed ring, we reestimated impedance and aspect of bunch lengthening in the constructed ring. For this purpose, this paper summarizes results of the impedance study of the components in the damping ring. We identified the important inductive and resistive elements of the vacuum chamber in the ring and estimated their contribution to the total ring impedance. It shown that the ring is inductive. The work was performed with available numerical codes such as MAFIA, ABCI and MASK30.

Average bunch shape due to potential well distortion was estimated for the ATF damping ring as function of current. We also estimated bunch lengthening in the ATF damping ring that includes both potential-well distortion effect and microwave instability for a single bunch in the damping ring with the estimated impedance.

The paper is organized in the following way. In Sec.2, we estimated the impedance due to various vacuum elements in the damping ring. In Sec.3, potential well distortion of bunch shape for various beam intensities for the ATF damping ring are shown. In Sec.4, we show some behaviors of bunch lengthening in the damping ring with the impedance obtained in Sec.2.

2 CALCULATION OF THE IMPEDANCE OF ATF DAMPING RING

2.1 Parameters of ATF Damping Ring

The parameters of the ATF damping ring, which are necessary in estimating the impedance and bunch lengthening of the ring, are listed in Table 1.

Beam Energy	E	1.3 GeV
Cicumference	L	138.6 m
Lattice Type		FOBO
Energy Spread	σ_ϵ	5.467×10^{-4}
Bunch Length	σ_o	6.8 mm
Accelerating Frequency	f_{RF}	714 MHz
Harmonic number	h	330
RF Voltage	V_{rf}	0.20 MV
Revolution Frequency	f_{rf}	2.164 MHz
Momentun Compaction	α	0.00195
Damping Time	τ_z	20 ms

2.2 Impedance of Components

In this section, we summary impedances of various vacuum components in ATF damping ring. Impedances are obtained by the using of code MAFIA, ABCI and MASK30, taking driving bunch as Gaussain bunch with the nominal bunch length $\sigma_o = 6.8$ mm. Table-2 gives the summary of impedance for the elements that are inductive and resistive to a 6.8 mm bunch at a ring voltage of 0.2 MV. By summing up all the $|Z_{||}/n|$ values in Table 2, we estimate the total $|Z_{||}/n|$ to be 0.23Ω. There are objects in the ring which are resistive, most important components of which are rf cavities and extraction kicker.

By adding up the all wake potentials with the current distribution of a 6.8 mm Gaussain bunch, we can obtain total wake potential. The total longitudinal wake potential in ATF damping ring is plotted in Figure 1, which shows clearly inductive.

Components	Number	$\lvert Z_{\parallel}/n \rvert$ (Ω)	L(nH)
BPM	96	0.064	4.8
Normal Bellows	56	0.02	1.568
Elliptic Bellows	8	0.0058	0.46
Ext. kicker Bellow	1	0.01411	
Ext. kicker Bellow	1	0.01017	
Wiggler Mask	8	0.00096	0.0713
Mask in straight sec.	8	0.047	3.544
120 mm Tapers	2	0.0093	0.70
170 mm Tapers	2	0.008	0.602
Septum	1	0.0082	0.6224
Injec. kicker taper	1	0.0015	0.1203
Injec. kicker step	1	0.00008	
RF cavitity	2	0.03144	0.687
RF absorber	4	0.0089	0.671
Total		0.23	13.9

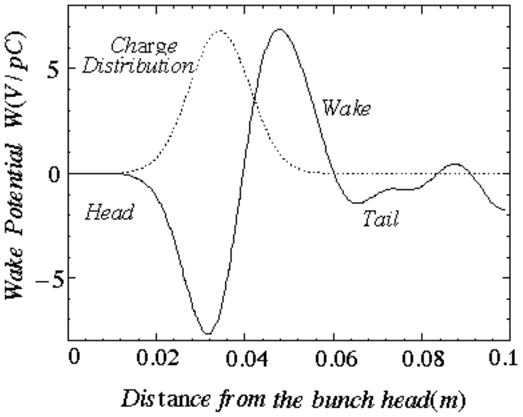

Figure 1: Total longitudinal wake potential for 6.8 mm beam in ATF damping ring.

3 POTENTIAL WELL DISTORTION

The self-consistent beam current distribution in an electron machine, below the turbulent threshold, is given by[2]

$$I(t) = K(-\frac{t^2}{2\sigma_o^2} + \frac{1}{\dot{V}_{rf}\sigma_o^2}\int_o^t V_{ind}(t')dt'), \qquad (1)$$

with σ_o the natural bunch length, $\dot{V}$ the slope of the rf voltage at the position of the bunch and V_{ind} the transient induced voltage. In our notation a smaller value of t signifies an earlier point in time, with $t = 0$ the synchronous particle. The induced voltage V_{ind} is given by

$$V_{ind}(t) = -\int_0^\infty W(t')I(t-t')dt', \qquad (2)$$

with $W(t)$ the longitudinal Green function wakefield. The value of the normalization constant K in Eq.(1) is such that the complete integral of $I(t)$ is equal to the total charge in the bunch Q. If we know the Green function wakefield then Eq.(1) can be solved numerically to give the current distribution of the bunch in the presence of wakefields. Since V_{ind} at time t depends only on the current at more negative (earlier) times, the solution of Eq.(1) is straightforward if we begin at the head of the bunch (where V_{ind}=0) and proceed toward the tail. Taking the derivative of both sides of Eq.(1) yields an alternative form of it:

$$\frac{\dot{I}}{I} = -\frac{t}{\sigma_o^2} + \frac{V_{ind}}{\dot{V}_{rf}\sigma_o^2}. \qquad (3)$$

In what follows, all distances will be given in terms of σ_o. Thus the independent variables becomes $x = t/\sigma_o$.

Figure.2 shows the calculated bunch shapes due to potential well distortion in the ATF damping ring as a function of the number of particles in a bunch. We present the bunch shapes for bunch populations of N = 1,3,5 and 7 $\times 10^{10}$. The horizontal axis is $x = t/\sigma_o$. The vertical axis gives $y = IZ_o/(\dot{V}\sigma_o)/10^8$ with Z_o=377 Ω As can be seen, the bunch shapes are shifted forward due to inductive ring.

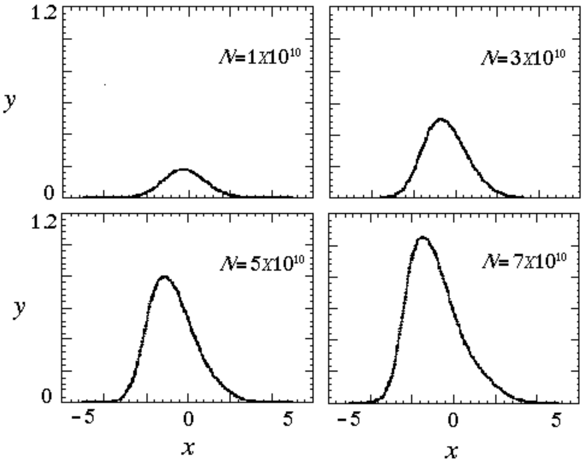

Figure 2: Calculated bunch distribution due to potential-well distortion for various beam intensities in the ATF damping ring when $\dot{V}_{rf} = 0.2MV$.

4 BUNCH LENGTHENING

The bunch length from the nominal value can be changed by two mechanisms. One mechanism is the potential well distortion that affects equilibrium shape of a beam due to the longitudinal wake potential. The mechanism is a static one. The deformed bunch distribution can be obtained by solving the Haissinski equation. The change of a bunch distribution due to potential well distortion can be either lengthened or shortened depending on the wake potential.

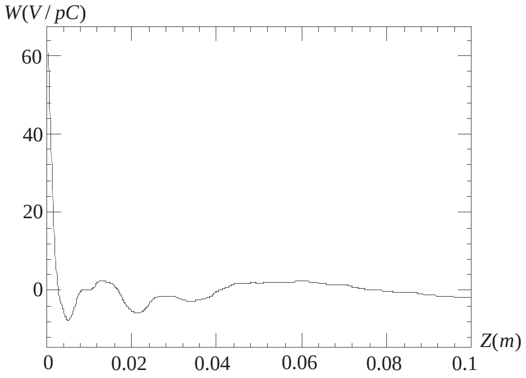

Figure 3: The Green function wake used to represent the current ATF damping ring.

Another mechanism is the microwave instability and has a threshold for bunch lengthening. K.Oide and K.Yokoya have developed an instability theory which includes the effects of potential-well distortion and microwave instability. It is possible to calculate the bunch lengthing according to their theory[4].

4.1 The Green Function Computation

We need Green function wake of the damping ring in order to calculate bunch length. However, it suffices if we can obtain the wakefield of a bunch that is very short compared to the natural bunch length in the ring, and that has been calculated out to a sufficient distance behind the driving bunch. For our Green function, we calculated the wake potential of a 1 mm Gaussain bunch for components of various vacuum chamber in the damping ring. However 2 mm Gaussain bunch, in the calculation by code MAFIA, was used for the components of taper due to limitations in the computer memory available to us.

All the individual contributions were added up and the wake potential that represents the entire ring is shown in Figure 3. Here, the part on front of bunch center ($z < 0$) was reflected and added to the back, a transformation that preserves the real part of the impedance.

4.2 The Instability Threshold

At some bunch population, there is a threshold current for the onset of the instability. The effect of this instability in an electron machine is to increase the energy spread of the equilibrium distribution. This is obviously a nonlinear process. As the bunch length increses, the bunch peak current decreases which decreases the longitudinal forces. Radiation damping then serves to reduce the bunch length. The competition between radiation damping and quantum excitation together with longitudinal instability leads to some equilibrium energy spread.

We estimate the threshold intensity of the longitudinal single bunch instability with the eigenmode method including the potential well distortion described in Ref.4. This method determines the threshold at the point where the growth rate becomes bigger than the radiation damping rate. Using the wakefield of Figure 3 we take 6 azimuthal space harmonics and 60 mesh points in amplitude to represent phase space. Figure 4 shows the calculated bunch lengthening in the damping ring as a function of the number of particles in a bunch. As can be seen, there is bunch lengthening due to the potential well distortion and the microwave instability takes place at $N = 3.3 \times 10^{10}$. Figure 4 also shows the average values of energy spread as functions of N.

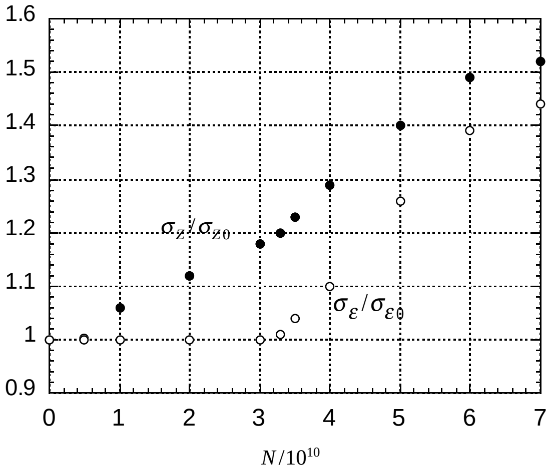

Figure 4: Bunchlengthening in the ATF damping ring.

5 ACKNOWLEDGMENTS

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