IMPEDANCE MEASUREMENT OF ATF DR

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Abstract

The purpose of the damping ring in the KEK accelerator test facility (ATF) is to develop the technologies to achieve a lower emittance beam that required in the future linear collider such as JLC.

To avoid the unacceptable emittance growth, vacuum chambers were designed to have a low impedance to suppress single bunch instabilities. The actual impedance of the ring was evaluated by measuring the intensity dependence of the bunch length. We report the results of the present impedance measurement of the ATF damping ring.

1 IMPEDANCE

1.1 Vacuum Chamber and Impedance

Vacuum chambers for the ATF damping ring, circumference is 138.6 m, were designed to achieve a low impedance ring [1]. For two arc sections of the ring, we keep the chamber cross section as a circle of 24 mm diameter [2]. All gaps were shielded with a finger contact and a metal-ring gasket. For the straight sections, there are many objects that changes the chamber cross section such as cavities, photon masks, wiggler and septum chambers.

The contribution to the impedances of these vacuum components were estimated [1, 3, 4] by using numerical code ABCI, MAFIA and MASK30. Table 1 shows the summary of this estimation.

Table 1: Impedance sources in the ATF damping ring; the bunch length was assumed to be 6.8 mm.

Components	Number	L(nH)
BPM	96	4.80
Bellows	64	2.03
Photon Masks	16	3.61
Tapers	5	1.42
Septum	1	0.62
RF cavity	2	0.69
RF absorber	4	0.67
Total		13.9

By adding up the all wake potentials calculated in this estimation and multiplying them with the number of each component, we got the total longitudinal wake potential as shown in Fig. 1. It shows the total contribution is clearly inductive. Therefore we proceed the analysis with an inductive impedance model.

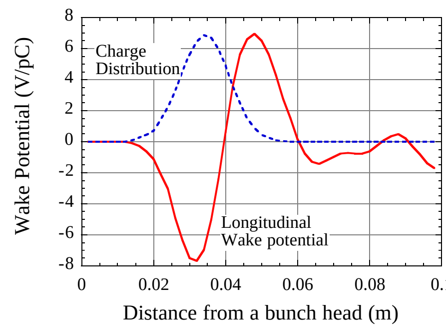

Figure 1: Total longitudinal wake potential in ATF damping ring.

1.2 Inductive impedance

The self-consistent beam current distribution in an electron machine, below the turbulent threshold, is given by [5]

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

with σ_o the natural bunch length, $\dot{V}_{RF}$ the slope of the RF voltage at the position of the bunch and V_{ind} the transient induced voltage. Taking the derivative of both sides of Eq.(1) yields an alternative form of it:

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

For purely inductive object the induced voltage is given by $V_{ind} = -LdI/dt$, with the constant L the inductance. Eq.(2) can be written as

$$\frac{dy}{dx} = -\frac{xy}{1+y}, \quad (3)$$

with the variables of $x = t/\sigma_o$, $y = LI/(\dot{V}_{RF}{\sigma_o}^2)$. The complete integral of y, the normalized charge Γ, becomes

$$\Gamma = \int_{-\infty}^{\infty} dx\, y = \frac{LQ}{\dot{V}_{RF}{\sigma_o}^3},$$

where Q is a total charge in the bunch. The numerical solutions of Eq.(3), for several values of Γ, give the bunch length variation as a function of current Γ as shown in Fig.2. We use the function of Fig.2 to get the inductance from the measured bunch lengthening data.

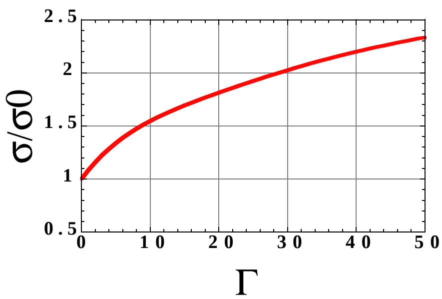

Figure 2: An inductive impedance: the bunch length variation as a function of Γ.

2 BUNCH LENGTH MEASUREMENTS

2.1 Data Acquisition

We took the bunch profile by using the Double-Sweep Streak Camera (Hamamatsu C5680). This camera captures the SR lights from a dipole magnet in the ring and updates the picture with a specified trigger signal. In this experiment, it was fixed to 400 ms after the beam injection. In a picture, the time resolution in the longitudinal profile is 2 ps and we can add 11 bunch images continuously by changing the image position with a time interval of 1.8 ms. The beam current was measured by using the DC current transformer (DCCT) located in the straight section.

Data taking system of the streak camera is running on the local computer, therefore we have to transfer the streak data to the ATF main control system to store them with a beam current data. In order to guarantee the beam coincidence of streak data and DCCT data without any change of data taking system, the ring was operated as a beam storage mode. Typical beam lifetime in this experiment is more than 100 seconds. The uncertainty of an actual beam current for SR images is less than 1.4 % even if we have a maximum expected trigger mismatch between them.

2.2 Analysis

Longitudinal profiles of the beam are fitted to an asymmetric Gaussian function given by

$$I(z) = I_0 + I_1 \exp\left(-\frac{1}{2}\left(\frac{(z-\bar{z})}{(1+sign(z-\bar{z})A)\sigma}\right)^2\right),$$

where I_0 is offset, I_1 is a scale factor of the asymmetric Gaussian and A is an asymmetric parameter. Fig.3 shows the longitudinal bunch profile under the cavity voltage of 0.3 MV and the number of particles per bunch (ppb) of 5×10^9. Solid line shows the fit results and plots show the data.

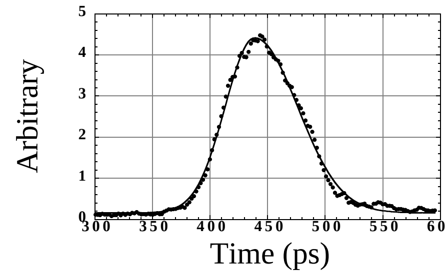

Figure 3: Longitudinal bunch shape at Vc=300kV and bunch intensity of 5×10^9 ppb.

Streak camera has a intensity dependence due to the space charge effect on the photo cathode. In this experiment, measurement was carried out with a usual setting of a streak camera. After that we check the intensity dependence by adding the ND filters at cavity voltage of 0.4 MV. It was found that the data need the 20 % correction at the bunch intensity of 6×10^9 ppb so that we assume the correction factor with a bunch intensity N as $\sigma_Z = \sigma_{meas}(1 - (0.2/6 \times 10^9) \times N)$.

2.3 Results

We took some set of data by changing the cavity voltage from 0.2 MV to 0.4 MV. Fig.4 shows the bunch length σ_Z variation as a function of the bunch intensity. Each solid curves show the results of the fit with a function of Fig.2. Results of these fitting were summarized in Table 2.

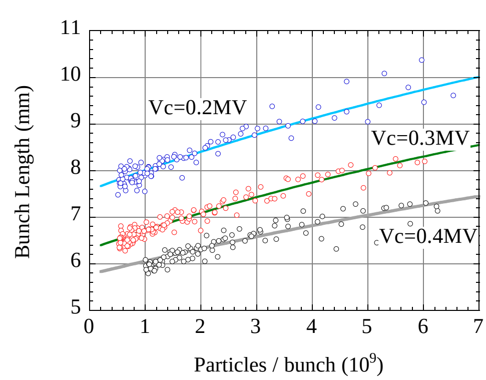

Figure 4: Measured bunch length as a function of the bunch intensity. Curves show the fitting results

The systematic error due to the intensity correction was estimated by comparing the data with and without the ND filters at the cavity voltage of 0.4 MV. It was found to be 15.4 nH.

Table 2: Results of the bunch lengthening fitting.

Cavity voltage (MV)	L (nH)	σ_{Z0} (mm)
0.2	54.5 ± 3.3	7.55 ± 0.07
0.3	53.8 ± 1.7	6.29 ± 0.04
0.4	43.1 ± 2.0	5.75 ± 0.04
Average	50.0 ± 1.2	
0.4MV with ND filter and no correction	36.2 ± 8.3	5.97 ± 0.15

The average inductance of the various cavity voltage obtained as 50.0±1.2 (fit) ±15.4 $(sys.)$ nH. This result is four times larger than that estimated from the wake potentials 13.9 nH.

2.4 Potential well distortion

We have estimated the threshold of the microwave instability by a Vlasov method which includes a potential well distortion [6], by using the calculated wake functions shown in Fig.1. Results shown in Fig.5(a), predicts 10 % of bunch lengthening due to the potential well distortion around the nominal beam intensity of the present operation $\sim 7 \times 10^9$ ppb.

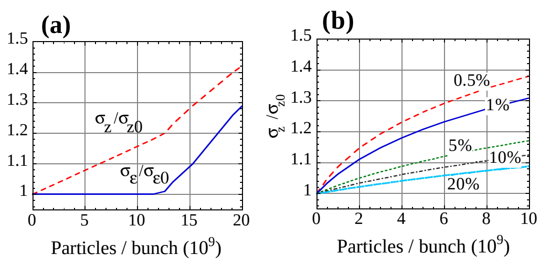

Figure 5: Estimation of bunch lengthening at energy 1.3 GeV. (a) by potential well distortion, (b) by intra-beam scattering.

Further Fig.5(a) shows the instability threshold around the beam intensity of 1.2×10^{10} ppb. In the recent beam operation, we have no data to show the instability. If we succeed to store the beam more than 1.2×10^{10} ppb in the next operation period, we may observe some instability.

2.5 Effect on the intra-beam scattering

Other possibility to increase the bunch length is the intra-beam scattering. We have evaluated this effect by using the SAD code [7]. Fig.5(b) shows the effect of the intra-beam scattering as a function of bunch intensity with various coupling values at the cavity voltage of 0.3 MV.

The measured emittance values, are reported in another paper [8]. If the coupling is around 1 %, this is the design value of the damping ring, the bunch length will be increased by 20∼30 %. In this case, an inductance fitting gives the similar value of the impedance calculated from the wake potentials, it becomes 17.8 nH. Touscheck lifetime measurement in the ATF damping ring [9] suggests the similar amount of coupling.

The estimation using the SAD code does not take into account the bunch lengthening due to the potential well distortion. Therefore the effect of intra-beam scattering is smaller than the above estimation.

3 SUMMARY

The impedance measurement of the ATF damping ring was carried out by using the streak camera system. Measured bunch lengthening show the inductance of the ring is

$$50.0 \pm 1.2\ (fit) \pm 15.4\ (sys.)\ \ nH,$$

and it is four times bigger than that of the expected impedance from a calculation of the wake potentials. Further we need to reduce the systematic error by optimizing the condition of the streak camera system.

If the coupling is smaller as that of the design, we can not neglect the effect of the intrabeam scattering because the emittance of the ATF damping ring is very small. It leads the same amount of the bunch lengthening due to the inductive impedance that estimated from the calculation of the wake potentials.

4 ACKNOWLEDGEMENT

The authors would like to thank all members of the ATF collaboration. We also express thank to Prof. Kihara and Prof. Takata for their continuous supports and encouragements.

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