POSSIBILITY OF PRECISE WAKEFIELD MEASUREMENT AT ATF EXTRACTION LINE

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Abstract

Measurement of wakefield is planned at the Extraction Line from the Damping Ring of ATF, Accelerator Test Facility at KEK. In this experiment, 'residual' long-range transverse wake field excited by multi-bunch beam will be measured, and will be compared with theoretical calculation of wakefields with cell-to-cell misalignment. The residual wakefield which is induced by cell-to-cell misalignment of structure. Because the multi-bunch beam from the Damping Ring is expected to be stable and extremely low emittance, we can measure a small transverse kick of 10 nrad by using 500 nm resolution BPMs and optimized optics of the extraction beam line.

1 INTRODUCTION

In the linac of the KEK JLC design [1], the bunch train which is 85 bunches of $7.2\text{x}10^9$ electrons and 1.4 ns bunch spacing. In this multi-bunch design it is important to control the long-range transverse wakefields generated in the accelerating structures of the linac. The transverse modes of the accelerator cavities cause the multi-bunch beam break-up instability. As of today, a variety of structure schemes have been developed to reduce (detune or damp) the effect of dipole wakefields. One is the detuned structure (DS) in which the dipole modes will be canceled by spreading the frequencies of the relevant modes in the structure [2]. Another scheme, such as the damped-detuned structure (DDS) is being studied at SLAC [3]. A heavily-damped or a medium-damped structure based on the choke-mode structure has also been developed recently [4]. In the choke-mode structure, all of the higher-order modes are heavily damped.

The wakefield can be calculated by existing computer programs within certain limitations. So it is important to compare the result of the theoretical calculations with measurement using real beam. Until now, measurement of the wakefield suppression have been made on X-band detuned structure (DS) at Argonne's Advanced Accelerator Test Facility (AATF) [5] and detuned damped structure (DDS) at ASSET [6]. In ASSET, the measurement of wakefields was performed by using two bunches (electrons and positrons) which were injected into the system with individual control of the bunch timing and intensity. This experiment measured wakefield which was proportional to beam offset.

Our plan is to do the measurements of wakefields at KEK in the diagnostics section of the extraction line from the ATF damping ring (Figure 1). This damping ring is designed to generate extremely low emittance and stable multi-bunch beam. Using this low emittance beam, the measurement with high sensitivity will be expected. The purposes of this experiment are the measurement of the residual wakefield which is induced by cell to cell misalignment of structure, when beam goes through the average center of the structure and single bunch blow up will be minimized. It is important to check theoretical calculation of transverse wakefield with cell to cell misalignment. The superposition effect of long-range transverse wakefield excited by multi-bunch beam will also be compared with the result of theoretical calculation.

2 TRANSVERSE WAKEFIELD MEASUREMENT

2.1 Long-range transverse wakefields

The key requirement of this measurements is that its sensitivity to the long-range transverse wakefield is below the tolerance on the wakefield strength in the KEK JLC design. It is difficult to characterize the limit on wake function. However, the criterion of wakefield strength that emerge from recently studies is less than 1.0 MV/nC/m^2 at each bunch location assuming r.m.s. misalignment of about 10 μm [7]. When the beam offset to the structure center is 10 μm and wake function per unit length for 1.3m-long structure with its cells perfectly parallel to the beam is 1.0 MV/nC/m^2, the transverse kick amounts to 25.4 nrad/structure assuming the bunch charge and the beam energy are 3 nC and 1.54 GeV, respectively.

Furthermore, if the cell-to-cell misalignment is comparable to the offset of the beam with respect to the structure, the effect of the misaligned cells cannot be ignored and it becomes important to study the effective kick from the cell misalignment in the structure.

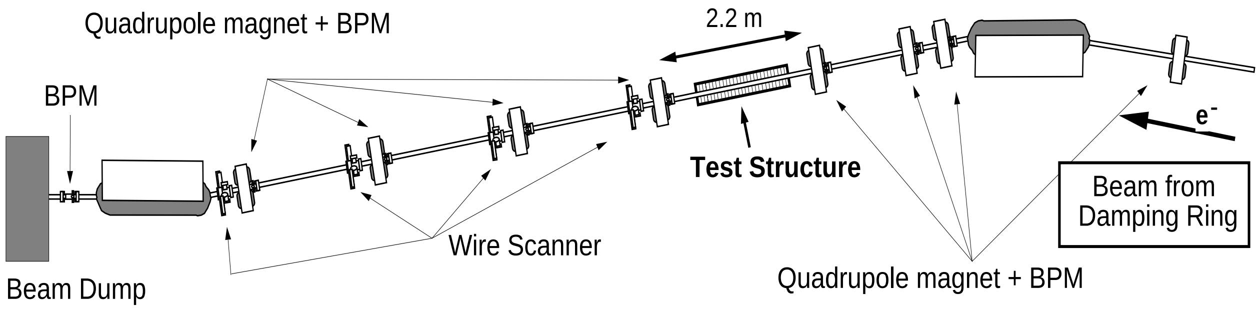

Figure 1 Layout of the ATF extraction line

2.2 Layout of Extraction Line and Measurements

The layout of the extraction line is shown in Figure 1. The measurement of wakefields will take place at the latter half of the extraction line. This linear region is diagnostics section and is dispersion free. The structure will be installed before the diagnostics section and will be mounted on a remotely controllable support. All quadrupole magnets are equipped with internal high resolution beam position monitors (BPMs). These are stripline type, because these have to measure a bunch-by-bunch beam positions. Some wire scanners located at the diagnostics section.

Firstly the Twiss parameters at the test structure and measurement points are optimized. Then single bunch blow-up by beam position jitter at the structure will be minimized by moving the test structure using the active mover support and observing beam profile using the wire scanners. Finally bunch-by-bunch beam positions are measured by BPMs downstream of the structure. The monitors for individual bunches with 2.8 ns bunch spacing have been developed at ATF 80 MeV pre-injector [8][9].

2.3 Optics

Let Twiss parameters of the structure position (S_1) be α_1 and β_1, and those at the position of the BPM to measure transverse kick (S_2) be α_2 and β_2. The transfer matrix from the structure to the measurement point is given by

$$R(s_1/s_2)=\begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{\beta_2}{\beta_1}}(\cos\psi+\alpha_1\sin\psi) & \sqrt{\beta_1\beta_2}\sin\psi \\ -\left[\frac{(1+\alpha_1\alpha_2)\sin\psi+(\alpha_2-\alpha_1)\cos\psi}{\sqrt{\beta_1\beta_2}}\right] & \sqrt{\frac{\beta_1}{\beta_2}}(\cos\psi-\alpha_2\sin\psi) \end{pmatrix} \quad \text{---(1)}$$

where ψ is phase advance from S_1 to S_2. R_{12} should be big to detect small transverse kick by long-range wakefields in the structure. Beam size at the BPM ($\sqrt{\varepsilon\beta_2}$) should be small for the resolution of measurement, while beam size at the structure ($\sqrt{\varepsilon\beta_1}$) should also be small for minimizing the effect of short-range wakefield induced by beam position jitter. To get the big R_{12}, β_1, β_2 and phase advance from S_1 to S_2 should be optimized.

2.4 Sensitivity

Define the sensitivity at the BPM to measure transverse kick of long-range wakefields as follows.

$$ROS=\frac{Beam\ offset\ by\ long-range\ wakefield}{\sqrt{(net\ beam\ size)^2+(beam\ size\ blowup)^2}} = \frac{\Delta y_{long}}{\sqrt{(\sigma_{y2})^2+(\Delta y_{short})^2}} \quad (y: vertical\ direction) \quad \text{----(2)}$$

This ROS is the ratio of the beam offset by long-range transverse wakefields to the beam size at the BPM. When the value of ROS is big, this measurement will be easy. Here, beam offset by long-rang wakefield (Δy_{long}), the net beam size (σ_{y2}), beam size blow-up by beam jitter and short-range wakefield (Δy_{short}) are given by

$$\begin{aligned} \Delta y_{long} &= R_{12}(s_1/s_2)\times\Delta y'_{long} \\ \sigma_{y2} &= \sqrt{\varepsilon\beta_{y2}} \quad \text{--------- (3)} \\ \Delta y_{short} &= R_{12}(s_1/s_2)\times\Delta y'_{short} \end{aligned}$$

where $\Delta y'_{long}$, $\Delta y'_{short}$ and ε are kick angle by long-range and short-range wakefield at the structure and emittance of beam at BPM, respectively. We assume that all bunches in a pulse have the same injection error, and ignore bunch-by-bunch jitter. From these equations and transfer matrix from S_1 to S_2, ROS is independent of β_2. And optimum β_1 which make ROS maximum is derived from bunch charge, beam energy, beam position jitter and strength of short-range wakefield at the structure. When single bunch wakefield is assumed as $W_T(s)\approx 2\sigma_z\cdot 1.3\times 10^{20}[V/C/m^3]$ [10], the optimum β_1 is given in the case of two particle model by

$$\beta_1 \approx \left[\frac{\Delta y_{jitter}}{\sigma_y}\cdot\frac{q}{2}\cdot W_T(2\sigma_z)\cdot\frac{L}{E}\cdot\sin\psi\right]^{-1} \quad \text{--------- (4)}$$

where Δy_{jitter}, σ_y and σ_z are the position jitter at the structure, the vertical and longitudinal beam size at the structure, respectively. Maximum ROS is given by

$$ROS_{\max.} = \frac{\Delta y'_{long}}{\sqrt{2\varepsilon_y \cdot \frac{\Delta y_{jitter}}{\sigma_y} \cdot \frac{q}{2} \cdot W_T(2\sigma_z) \cdot \frac{L}{E}}} \quad \text{---------} \quad (5)$$

when $\sin\psi$ is equal to 1, i.e. phase advance from S_1 to S_2 is $\pi(n+1/2)$ (n: integer).

The beam position jitter at the structure contributes to the error on the signal measurement. Extremely low emittance of ATF's (ε_{ny}=30 nm) and stable beam has an advantage in getting a high sensitivity. However, our long bunch length (σ_z=5 mm) has a disadvantage from the effect of the short-range transverse wakefields on the measured bunch motions. To minimize this effect, length of the witness bunch should be as small as possible.

2.5 Resolution of measurement

To measure much smaller transverse kicks by long-range wakefield, the beam offset at BPM due to the transverse kicks must be larger than the resolution of BPM. For example, let the transverse kick ($\Delta y'_{long}$) be 10 nrad, and the extracted beam from the damping ring has the following parameters in Table 1.

Table 1 : ATF design parameters

Beam energy	E	1.54	GeV
Bunch charge	q	3.0	nC
Particles/bunch	N	1-3	10^{10}
Bunch spacing	t_b	2.8	ns
Bunches/train	N_b	10-60	
Bunch length	σ_z	5.0	mm
Horizontal emittance	ε_{nx}	4.3-5.1	μm
Vertical emittance	ε_{ny}	30	nm

The beam position jitter at structure is assumed to be $0.1\sigma_y$. In this case, ROS_{max} is equal to 5.4×10^{-3}. For the resolution of BPM is 0.5 μm, β_2 has to be larger than 425 m which means vertical beam size 65 μm at the BPM. A design of the beam optics which satisfied the above requirements was actually done, as shown in Figure 2. The resolution of BPM is also realistic value with 2.8 ns bunch spacing [11].

Even in the case that the pulse-to-pulse or bunch-by-bunch beam jitters are larger than the resolution of BPM and cannot be ignored, by measuring the orbits of all bunches in a pulse at the same time in diagnostic section, this measurement is free from the problem of the beam position jitter. Then we can still measure the much smaller transverse kick by residual wakefield.

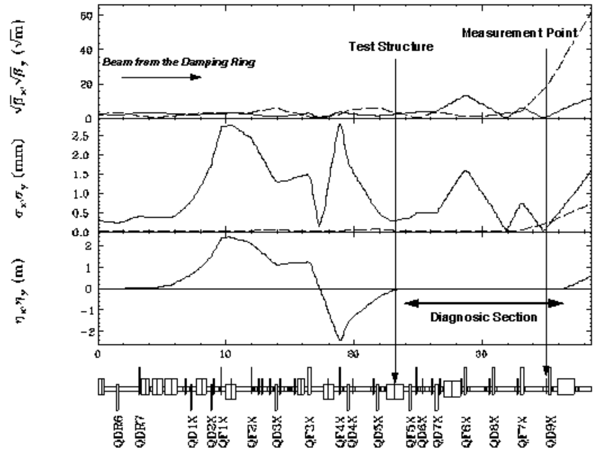

Figure 2 Optics of the ATF extraction line

3 CONCLUSIONS

At the ATF extraction line, the precise transverse wakefields measurements will be able to perform using extremely low emittance beam, high resolution BPMs and optimized optics of the extraction beam line. The experimental study of wakefields in an accelerating structure with cell-to-cell misalignment will be performed with using ATF multi-bunch beam.

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