ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-TUAA007

EVALUATION OF WAKEFIELD MITIGATION FOR UPGRADING THE ATF FINAL FOCUS BEAMLINE

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Abstract

The KEK-ATF is an R&D facility for the final focus system to develop the nanometer beam technology required for the International Linear Collider. The vertical beam size growth as a function of the bunch intensity was observed at the virtual interaction point (IP), which is mainly caused by wakefield. ATF is the best research environment for the study of wakefield effects on the nanometer small beam. The evaluation results of wakefield effects show that cavity BPM and vacuum flange have strong effects on the small beam. We are planning to upgrade the ATF-FF beamline to reduce wakefield effects on the small beam. First, an internal shield was inserted into the vacuum flange, one of the strong wakefield sources, to evaluate the mitigation of the wakefield effect. As a result, it was demonstrated that the wakefield effect of the ICF70 flange can be mitigated by the RF shield to the same level as that of a straight pipe.

INTRODUCTION

The KEK-ATF (Accelerator Test Facility) is an R&D facility for the final focus system to develop the nanometer small beam (small beam) technology required for the International Linear Collider (ILC) [1]. ATF consists of LINAC, Damping Ring (DR), Extraction (EXT) beamline and Final Focus (FF) beamline [2, 3]. Figure 1 shows the layout of the beamline after the DR. A low emittance beam is generated at DR [4,5] and focused with the EXT and FF beamline to focus the electron beam to 37 nm at the virtual interaction point (IP) [6]. Table 1 shows the nominal beam parameters for the nanometer small beam study. In 2016, it was confirmed that the vertical beam size at IP reached 41 nm [7].

Wakefield is an electromagnetic field generated by charged particles passing through a structure in a beamline that has geometrical shape changes. The excited wakefield acts as a kick to the backward of the bunch, distorting its distribution. It induces the bunch position change and the beam size growth. It is important to study the wakefield effects on the beam to develop advanced accelerators that require small beam technology. ATF is the best research environment for the detailed evaluation of wakefield effects on the small beam because the nanometer small beam with low emittance is generated, and the bunch center position and beam size can be measured using high-precision monitors [8–10].

The vertical beam size growth as a function of the bunch intensity at the IP has been observed at ATF, which is mainly caused by wakefield. We are planning to upgrade the FF beamline to mitigate wakefield effects on the small beam by reducing the wakefield source from the beamline. The impacts of the ICF70 flange, which is one of the strong wakefield sources, as a single component of the wakefield source were experimentally evaluated. In addition, The wakefield mitigation by inserting an internal RF shield into ICF70 flanges was confirmed. This paper reports the evaluation results and the current status of the work to upgrade the beamlines to reduce the effects of the wakefield.

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Table 1: Nominal Beam Parameters for the Small Beam Study

Parameter		Unit	Value
Beam energy	E	GeV	1.3
Max. bunch population	Q	$10^9 e^-$/bunch	20
Bunch length	σ_z	mm	7
Energy spread	σ_E	%	0.08
Vertical emittance	ε_y	pm.rad	12
Beta function at the IP	β_y	mm	0.1

IMPACTS OF EACH WAKEFIELD SOURCE ON THE SMALL BEAM

Table 2 lists wakefield sources (the vacuum components, beam monitors, collimators, etc.) in EXT and FF beamlines and the amount of installations. The excited wakefield on each wakefield source was calculated by GdfidL, which is an electromagnetic field simulation code [11]. In addition, a new wakefield model was constructed to evaluate the wakefield effects on the small beam [12]. The impact of each wakefield source on the small beam caused by the orbit fluctuation is expressed as $W_{y,j}(y = 1\text{mm}, z) \sum_i \beta_{y,j,i}$ [13] Figure 2 shows the evaluation result of wakefield effects on the small beam of each type of wakefield source. It illustrated that cavity BPM and ICF70 flange have strong effects on the small beam.

EVALUATION OF THE WAKEFIELD MITIGATION AS A SINGLE COMPONENT

The cross-section of the ICF70 flange is shown in Fig. 3. We planned to insert a cylindrical RF shield made of stainless steel, as shown in Fig. 3, into the ICF70 flange to hide the gap. In this section, we described the evaluation results of the wakefield effects caused by the ICF70 flange on the small beam and mitigation by the RF shield. The effects were evaluated by the orbit response method as a single component of Wakefield source [14–16].

The effect of the wakefield kick caused by a single wakefield source on the beam can be quantified by the orbit response downstream from the wakefield source. This method

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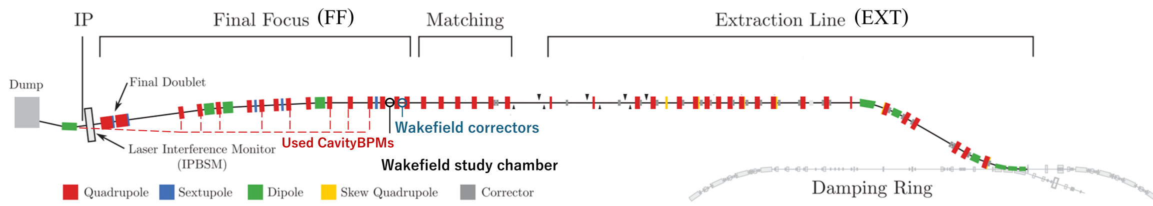

Figure 1: The layout of extraction (EXT) and final focus (FF) beamline.

Table 2: Wakefield Sources in EXT and FF Beamline

Name	Location	Amount
Vacuum Port	EXT	15
Bellows	EXT	34
Optical Transition Radiation Monitor	EXT	4
Septum magnet chamber	EXT	3
Stripline BPM	EXT,FF	13
Stripline kicker	EXT	2
Rectangular chambers	EXT	4
Vacuum Flange (ICF70)	EXT, FF	223
Reference Cavity	EXT, FF	2
Cavity BPM (CBPM)	EXT, FF	25
Gate valve	EXT, FF	4
Shielded Vacuum Flange (ICF70)	FF	20
Shielded Bellows	FF	34
shielded Vacuum Port	FF	13
Collimator	FF	1
Wakefield corrector	FF	1
Wakefield Study chamber	FF	1
Vacuum Flange (ICF114)	FF	12
Vacuum Port (ICF114)	FF	2

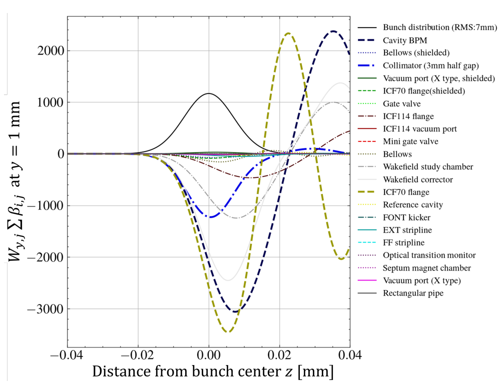

Figure 2: Analytical estimation of the wakefield effects of each type of wakefield sources with orbit fluctuation to the beam size (horizontal axis: the distance from bunch center, vertical axis: the impact of the wakefield kick on the vertical beam size at IP as $W_{y,j}(y = 1, z) \sum_i \beta_{y,j,i}$ [12].

measures the position change of the bunch center from the reference orbit at BPM (Δy) downstream of a movable wakefield source when changing the position of the movable wakefield source (y_m) on the beamline. Then, the strength of the wakefield kick is derived as averaged wake potential ($\overline{W_y}$) from the position change Δy and the term of the transfer matrix from the movable wakefield source to an arbitrary BPM (R_{34,BPM_i}). The average wake potential is defined as $\overline{W_y}(y_m) \equiv \int W_y(y_m, z)\lambda(z)dz$,where $W_y(y_m, z)$ is the wake potential [17] and $\lambda(z)$ is normalized charge density satisfied $\int_{-\infty}^{\infty} \lambda(z)dz = 1$. In addition, the measured average wake potential is explained as

$$\overline{W_{y,i}}(y_m) = \overline{\Delta y_i}\frac{1}{R_{34,\mathrm{BPM}_i}}\frac{E}{eq}, \quad (1)$$

where q is the total bunch charge, E is the beam energy.

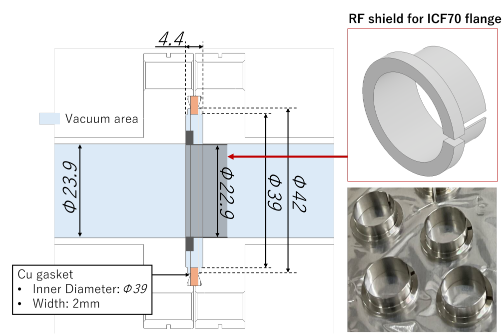

Figure 3: The schematics of the cross-section of the ICF70 flange and inserted RF shield.

Wakefield Study Chamber

A vacuum chamber, which we called a "wakefield study chamber", was installed as a movable wakefield source (Fig. 4) in 2022 [12]. Metal blocks, which have the internal structure of the target wakefield source, are set into the chamber to produce the target wakefield source. The chamber is mounted on the remote position adjustment mover, which is adjustable ±10 mm (1um step) to the vertical direction.It is possible to control the strength of the wakefield kick by changing the position of the chamber. Two bellows are connected at each end of the chamber.

For the evaluation of the impacts of the ICF70 flange on the small beam, thirteen stainless steel blocks with the internal geometry of the ICF70 flange (Fig.3) were installed into the wakefield study chamber. In practice, the blocks were arranged as shown in Fig. 6. In addition, RF shields were inserted into each ICF70 flange block to assess their effectiveness of wakefield mitigation (Fig. 5). For comparison, a straight pipe was installed instead of the metal blocks.

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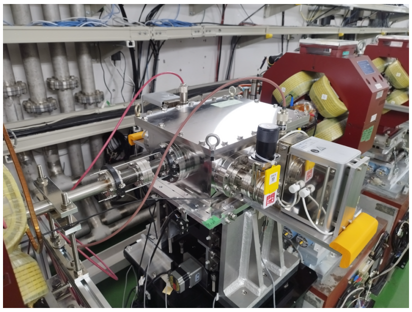

Figure 4: Installed wakefield study chamber as a movable wakefield source.

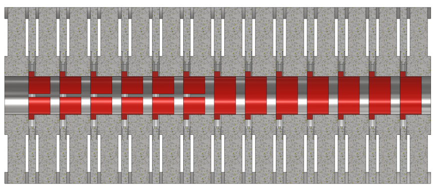

Figure 5: Schematics of the experimental setup for the evaluation of wakefield mitigation by RF shield of the ICF70 flange. 13 SUS blocks with internal geometry of ICF70 flange with RF shield (Red parts in the figure).

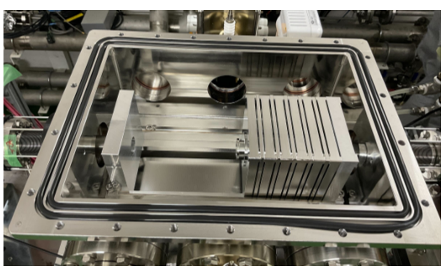

Figure 6: Installation view of the placing metal blocks into the wakefeild study chamber.

Evaluation Results of the Wakefield Mitigation by the RF Shield of the ICF70 Flange

We evaluated the wakefield effects of ICF70 flange (with and without RF shield) and straight pipe by tracking simulations using a computer code SAD [18] and experiment with different configurations of the wakefield source as shown in Fig. 7. The plotted averaged wake potential represents the mean values obtained from nine BPMs located downstream of the wakefield study chamber (Fig. 1). The results indicated that inserting an RF shield into the ICF70 flange can reduce the wakefield effects to a level comparable to that of a straight pipe.

The wakefield effects of all ICF70 flanges with RF shielding on the small beam were estimated as shown in Fig. 8. The estimations suggest that the wakefield effect could be reduced to approximately 1/30 of the unshielded case. However, an insertion-type RF shield remains a 0.5 mm step (Fig. 3). We are planning to upgrade a beamline that consists of clamp chain-type flanges, which can eliminate the step at the flange connection, and ICF flanges with insertion-type RF shields. We will evaluate their wakefield mitigation effects as further work. The wakefield effects caused by the orbit distortion or misalignments of wakefield sources could be compensated by wakefield correction benches with other movable wakefield sources [19]. The collimator and CBPMs would remain as the major wakefield sources. Further studies will be conducted on combinations of wakefield correction benches that can compensate for these effects.

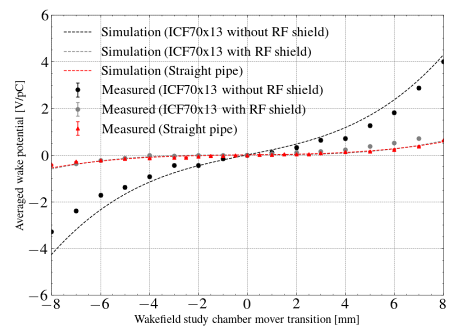

Figure 7: The comparison of the simulation and experimental results of the wakefield effects of single wakefield source with different setups of wakefield source.

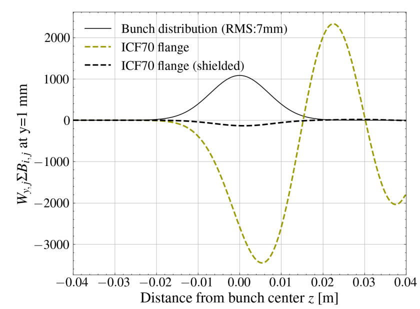

Figure 8: Analytical estimation of the wakefield effects of ICF70 flange with and without RF shield. The effect is mitigated to approximately 1/30 by the RF shield.

CONCLUSION

ATF is the best research environment for the detailed evaluation of wakefield effects on the small beam. Wakefield effects caused by the ICF70 flange on the small beam and mitigation by the RF shield were evaluated by the orbit response method with the wakefield study bench. The results indicated that inserting an RF shield into the ICF70 flange can reduce the wakefield effects to a level comparable to that of a straight pipe. The estimations suggest that the wakefield effect could be reduced to approximately 1/30 of the unshielded ICF flange case. We are planning to upgrade the FF beamline to mitigate wakefield effects on the small beam by reducing the wakefield source from the beamline. We are planning to upgrade a beamline that consists of clamp chain-type flanges, which can eliminate the step at the flange connection, and ICF flanges with insertion-type RF shields. As further works, we will evaluate their wakefield mitigation effects and combinations of wakefield correction benches.

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