NUMERICAL CALCULATIONS OF SHORT-RANGE WAKEFIELDS OF COLLIMATORS*

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Abstract

The performance of future linear colliders are limited by the effect of short-range collimator wakefields on the beam. The beam quality is sensitive to the positioning of collimators at the end of the linac. The determination of collimator wakefields has been difficult, largely because of the scarcity of measurement data, and of the limitation of applicability of analytical results to realistic structures. In this paper, numerical methods using codes such as MAFIA are used to determine a series of tapered collimators with rectangular apertures that have been built for studies at SLAC. We will study the dependences of the wakefield on the collimator taper angle, the collimator gap as well as the bunch length. Calculations are also compared with measurements.

1 INTRODUCTION

Wakefields generated by collimators in the collimation system may limit the performance of future linear colliders. Short-range wakefields can cause beam emittance growth and energy spread. Experience from SLC showed that the beam quality was sensitive to the positioning of the collimators at the end of the linac [1]. Therefore, accurate determination of collimator wakefields is essential during the design and operating phases of a collider.

The determination of collimator wakefields has been difficult. Experimentally, there were very few measurement data available from existing linacs such as the SLC. Analytically, the calculation is difficult and usually applies in a regime that is far different from the realistic geometry of the collimator [2]. Numerical methods are possible using codes such as MAFIA [3]; however, the validity of the result still needs to be confirmed. A series of collimators were built and measured for their wakefields in the SLAC linac in the year of 2000 [4]. The measured wakefields agreed reasonably well with MAFIA simulations, but were quite different from analytical results. In this paper, we will use MAFIA to calculate the wakefield and will study its dependences on the taper angle, the bunch length as well as the collimator gap. We will investigate both the transverse and longitudinal wakefields. Also, only the geometrical wakefield is considered, while the wakefields due to resistive walls and surface roughness are ignored in this study.

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2 NUMERICAL CALCULATIONS

2.1 General consideration

The numerical calculation of the wakefield of a collimator is not as straight-forward as that of a cavity. For a cavity, one can accurately determine the wakefield by a finite integration along the cavity gap using the so-called indirect method. Since the collimator protrudes into the vacuum chamber, one obtains the wakefield by integrating along the beam axis using the so-called direct method. This method generates large numerical noises as a result of field singularity of the beam along the beam path. To suppress these noises, a separate run with the beam is carried out for the smooth vacuum chamber without the presence of the collimator. One then obtains the wakefield by subtracting the smooth vacuum chamber wakefield from the direct collimator wakefield.

In our simulations, we use a new direct method implemented in MAFIA. By accurate treatment of the beam current, the method enables one to obtain the wakefield in a single run by integrating along the beam axis without introducing unwarranted numerical noises. We found that the results obtained by this method agreed well with the previous direct method using subtraction. Furthermore, comparison with measurements will be a testbed for the validity of this method.

2.2 The MAFIA model

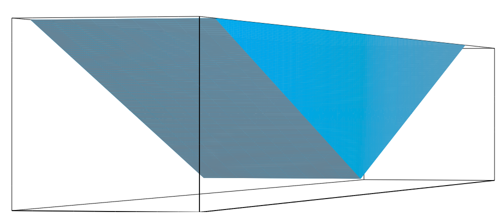

Figure 1: MAFIA model of the collimator.

The details of the apparatus setup for measurements of the collimator wakefields have been discussed elsewhere [5]. The collimators are in a vacuum chamber with square cross section, 3.8 cm wide and 3.8 cm high. The collimators are 3.8 cm wide, and have vertical tapers at both ends with a small gap for the beam to pass through. A typical MAFIA model of the collimator is shown in Fig. 1. Only one quarter of the structure needs to be simulated by taking advantage of symmetry.

One crucial aspect of maintaining accuracy in the simulation is to ensure the taper modeled smoothly without the introduction of a stair-case mesh normally encountered in finite-difference methods. The aspect ratio of mesh steps will become large especially for shallow tapers. In this situation, the calculation will become inaccurate even though the taper can be modeled exactly. The collimators that we have simulated have a taper angle ranging from 200 mrad to 600 mrad. It appears that the aspect ratios of the tapers are still small enough to be modeled accurately. The Next Linear Collider (NLC), for example, will have much shallower tapers. Time domain methods using unstructured grids may be required to obtain accurate results (for example, see [6]).

3 TRANSVERSE WAKEFIELD

3.1 Wakefield

The transverse wakefield of the collimator with a gap 3.8 mm (taper angle of 335 mrad) for a bunch length of 0.65 mm is shown in Fig. 2. The kick factor, k_t, is computed by integrating the transverse wakefield per beam offset with the bunch shape. One can obtain the deflection from the following formula

$$y' = \frac{Nr_e}{\gamma} k_t y, \qquad (1)$$

where y is the beam offset, N the number of electrons in the bunch, r_e the classical electron radius, and γ the relativistic factor. For the measurements, $N = 2 \times 10^{10}$ and $\gamma = 2.33 \times 10^3$. The calculated deflection for the collimator is 3.80 μrad/mm, which is in good agreement with the measured value of 3.72 μrad/mm. This provides us with a very good benchmark case so that we can extend our calculations to other cases. In the following, we will present the results for the dependences of the deflection on different geometrical and bunch length parameters. Whenever measured data are available, they are shown and can be compared with calculations.

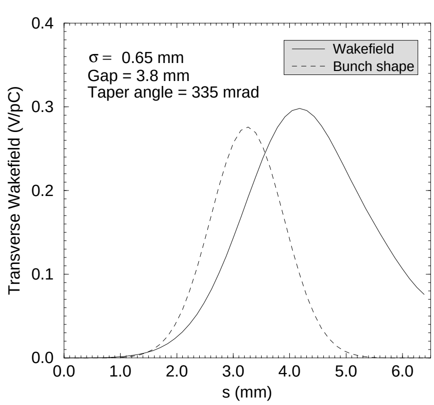

Figure 2: Transverse wakefield of the collimator.

3.2 Dependence on taper angle

The deflection as a function of the taper angle for $\sigma = 0.65$ mm is shown in Fig. 3. The taper angle range is 200-600 mrad. The agreement with measured data are reasonable. The simulated results show a less than linear dependence on the taper angle. This should be compared with the analytical result [2], which has a linear dependence.

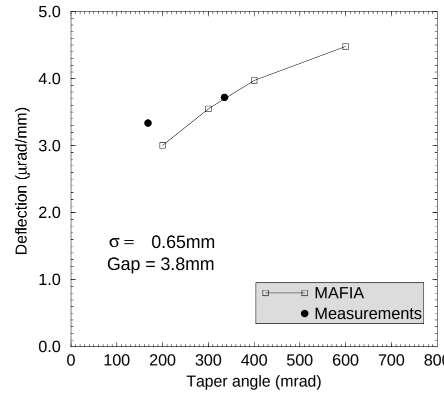

Figure 3: Deflection vs. taper angle

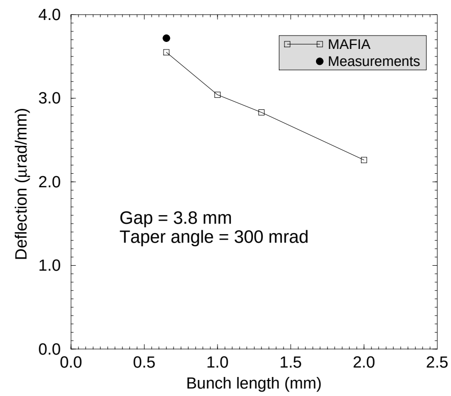

Figure 4: Deflection vs. bunch length.

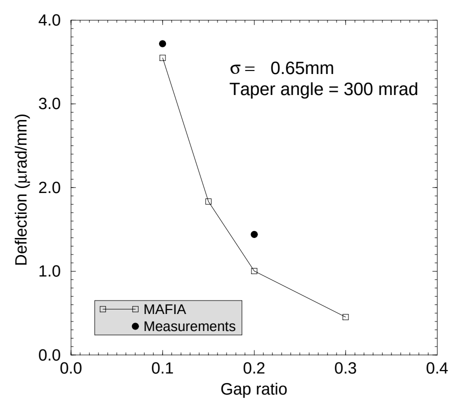

Figure 5: Deflection vs. gap ratio.

3.3 Dependence on bunch length

The deflection as a function of the bunch length is shown in Fig. 4. The bunch length range is 0.65-2 mm. The deflection increases as the bunch length decreases. The dependence is very close to $1/\sqrt{\sigma}$ while the analytical result has an $1/\sigma$ dependence.

3.4 Dependence on gap size

The deflection as a function of the gap ratio (gap size/chamber height) for $\sigma = 0.65$ mm is shown in Fig. 5. The gap ratio range is 0.1-0.3. The agreement with measured data is quite good. The deflection decreases rapidly with an increase in the gap size. It shows a dependence similar to the analytical prediction which has an inverse linear dependence on the gap size for small gap ratios.

4 LONGITUDINAL WAKEFIELD

4.1 Wakefield

The longitudinal wakefields for bunch lengths of 0.65 mm and 2 mm are shown in Fig. 6. For $\sigma = 0.65$ mm, the short-range wakefield looks resistive while for $\sigma = 2$ mm, it appears more inductive in nature. By integrating the longitudinal wakefield with the bunch shape, one can obtain the loss factor. In the following, we will present the dependence of the loss factor on various parameters.

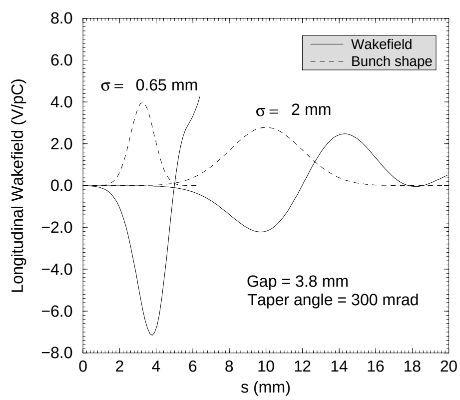

Figure 6: Longitudinal wakefields of the collimators.

4.2 Dependence on taper angle

The loss factor as a function of the taper angle for $\sigma = 0.65$ mm is shown in Fig. 7. The loss factor is not very sensitive to the change in the taper angle for the fixed gap which is large compared with the bunch length.

4.3 Dependence on bunch length

The loss factor as a function of the bunch length is shown in Fig. 8. The loss factor falls sharply with the an increase in the bunch length. For long bunch lengths, the wakefield becomes more inductive and the loss factor tends to zero.

4.4 Dependence on gap size

The loss factor as a function of the gap ratio for $\sigma = 0.65$ mm is shown in Fig. 9. The loss factor drops sharply with an increase in the gap size. When the bunch length is small compared with the gap, the loss factor has a small value.

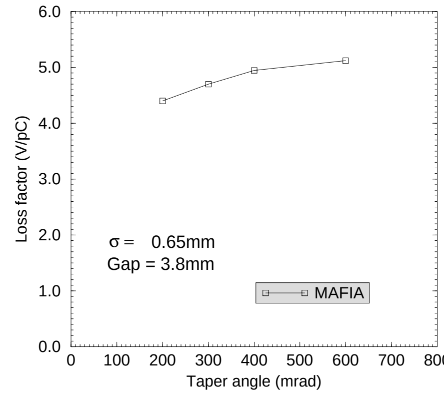

Figure 7: Loss factor vs. taper angle.

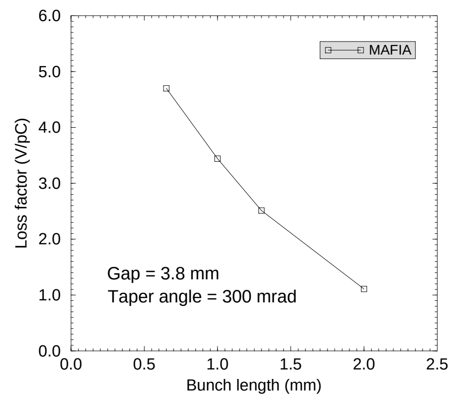

Figure 8: Loss factor vs. bunch length.

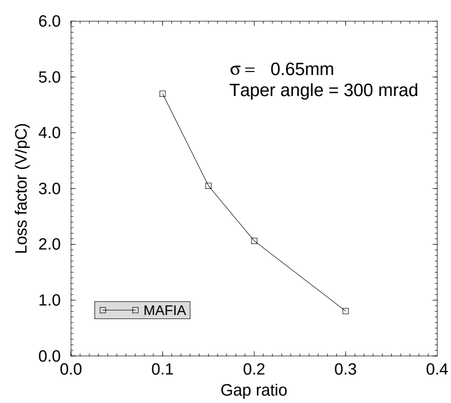

Figure 9: Loss factor vs. gap ratio.

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