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CALCULATION OF THE WAKE POTENTIALS AND SIMULATION OF BUNCH LENGTHENING IN BEPC

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Abstract

Bunch lengthening is the main obstacle to the luminosity upgrade of Beijing Electron Positron Collider (BEPC). The wake potentials for the main impedance elements, such as the 4 RF cavities, the 4 separators, the 6 kickers and the 40 "race-track" bellows, are computed with the computer codes ABCI and 3-D MAFIA. Bunch lengthening is estimated with the simulation program TRISIM. The calculated wake potentials and the simulation results are summarized in graphs and tables. Although they correctly show an increase of bunch length with current, it is smaller than the one observed. This may indicate that not all contributing impedances have yet been identified.

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1 Introduction

It is strongly desired to upgrade the luminosity of the Beijing Electron Positron Collider (BEPC) for high precision and low cross-section physics experiments, such as the Ds experiment currently being performed. One of the most effective ways is to implement a mini-β scheme which could provide a luminosity gain by a factor 3[1]. However, the bunch length should be reduced to at least 3 cm in order to meet the design requirements of the mini-β scheme. The bunch length had been measured with a streak camera for different situations which yield a rather strong bunch lengthening in BEPC[2]. In order to understand more about the bunch length behavior in BEPC, impedance calculation and simulation studies for bunch lengthening have been performed.

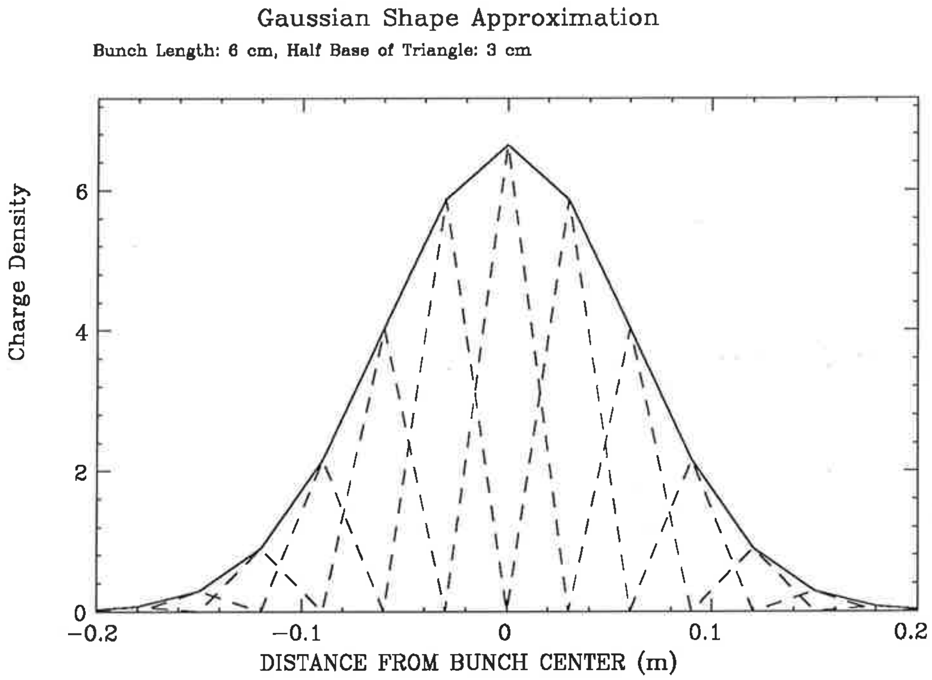

Figure 1: Approximation of a Gaussian Distribution by Triangles

From a previous study of the impedances in the BEPC storage ring[3], the main contributing elements are the RF cavities, the kickers, the separators and the "race-track" bellows. Different types of bellows and other elements make only small contributions. The wake potentials and loss factors are calculated by ABCI[4] if the geometry has an axial symmetry, and by 3-D MAFIA[5] when the geometry has not. The simulation of longitudinal effects is done by TRISIM[6] which approximates a real bunch shape by a superposition of basic elements of triangular shape. Fig. 1 demonstrates the approximation of a Gaussian bunch (with standard deviation σ_s) by the superposition of triangles with half base length of $1/2\ \sigma_s$. The wake potentials are simply proportional to the height of the triangles if their basis are the same. Thus, the wake potential calculated for one triangle can be used for all of them, which makes the method very convenient. A particle will experience a kick from the wake field when it goes through an impedance element. RF acceleration, synchrotron radiation damping, and quantum excitation effects are included in the simulation.

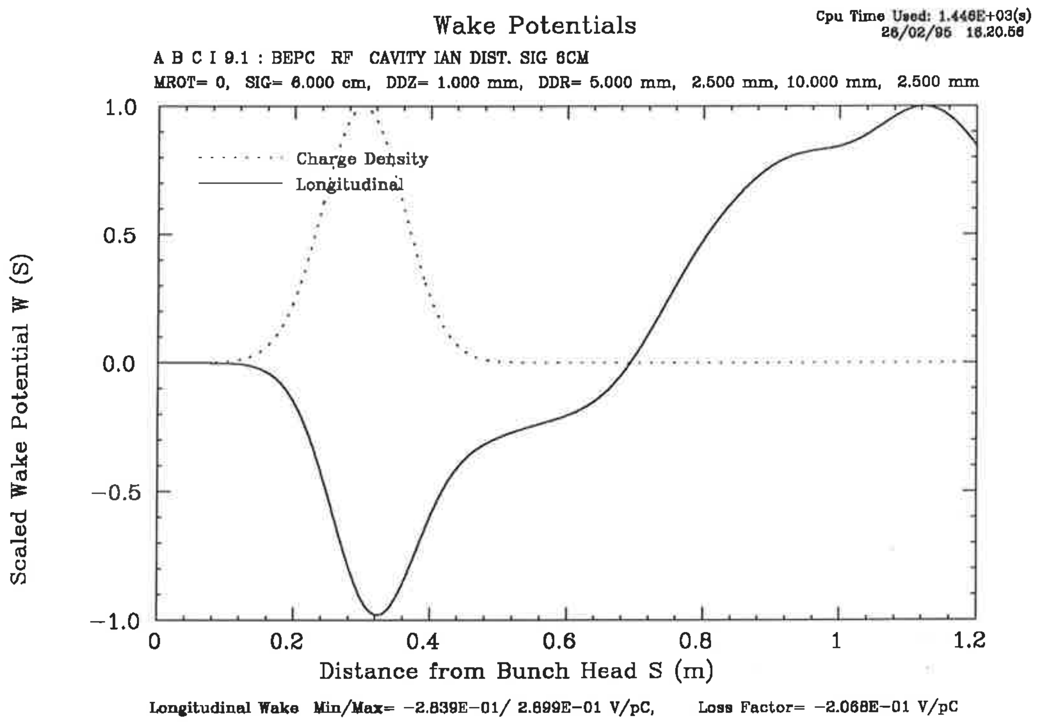

Figure 2: Wake Potential of Gaussian Bunch due to the Cavity

2 Wake Potential and Loss Factor Calculations

In LEP, the impedance comes mainly from the RF cavities and the (shielded) bellows due to their large numbers. However, BEPC is a quite small storage ring and many elements can contribute significantly to its total impedance. According to a previous study, the main sources of impedances are the RF cavities, the kickers, the separators and the "race-track" bellows. Hence, the wake potentials for them are calculated using published geometries[7].

Table 1 lists the loss factors of the bunch for different impedance elements.

Table 1 Loss Factors for Different Impedance Elements (σ_s=6cm)

Element	Loss Factor (V/pC)	Number	Total Loss Factor (V/pC)
RF Cavity	-0.2068	4	0.8272
Kicker	-0.0116	6	0.0699
Separator	-0.0076	4	0.0304
"Race-Track" Bellow	-0.00123	40	0.0492

2.1 Wake Potentials of a Gaussian Bunch

The typical RMS bunch length in BEPC is about 6 cm. Thus, a Gaussian bunch with σ_s= 6 cm is used to calculate the wake potentials. The calculated wake potentials are shown in Figs. 2 to 5. Since the RF cavity has axial symmetry, its wake potential is computed with the code ABCI. The wake potentials of the other 3 elements are computed by 3-D MAFIA due to the lack of axial symmetry. The results have been compared to those obtained with ABCI using an axially symmetric geometry. When the inscribed circle is used for the radius of a cylinder replacing two plates, the results agree reasonably well.

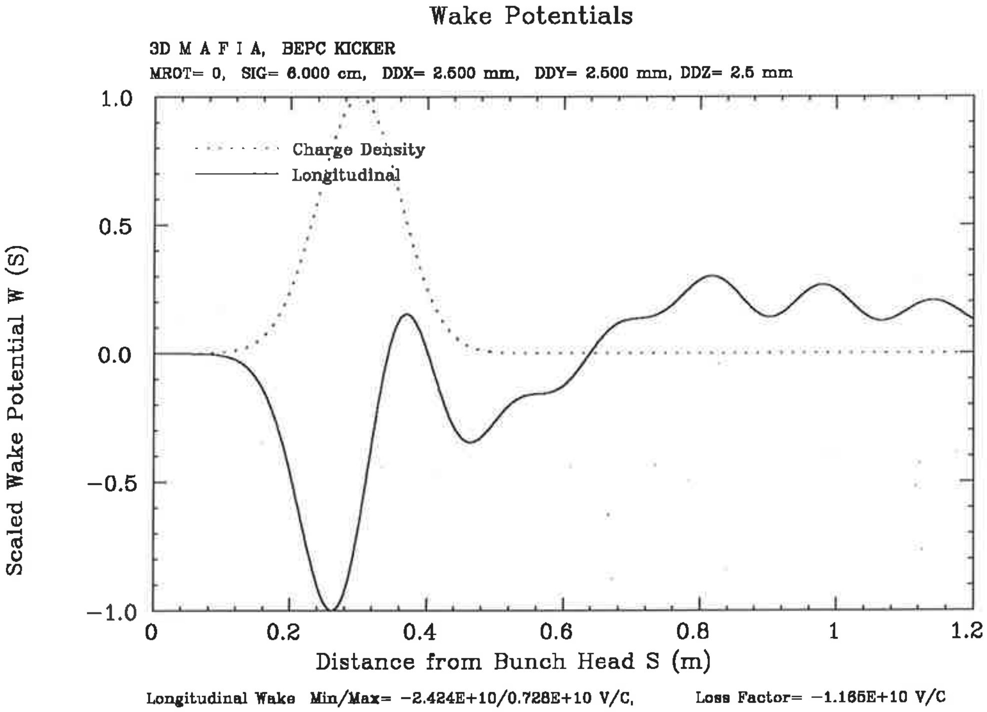

Figure 3: Wake Potential of Gaussian Bunch due to the Kicker

2.2 Wake Potential for Triangular Bunch

The (half) base of the triangle is taken to be σ_s=3cm. The calculated wake potentials for this triangular shape are shown in Figs. 6 to 9. These are used in TRISIM for simulation.

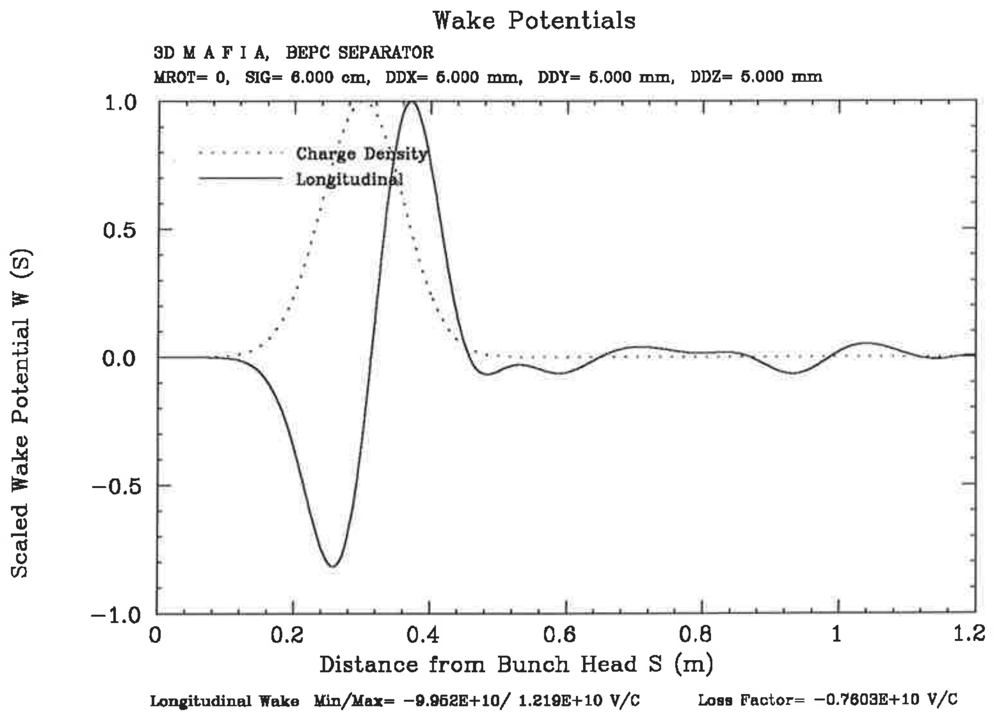

Figure 4: Wake Potential of Gaussian Bunch due to Separator

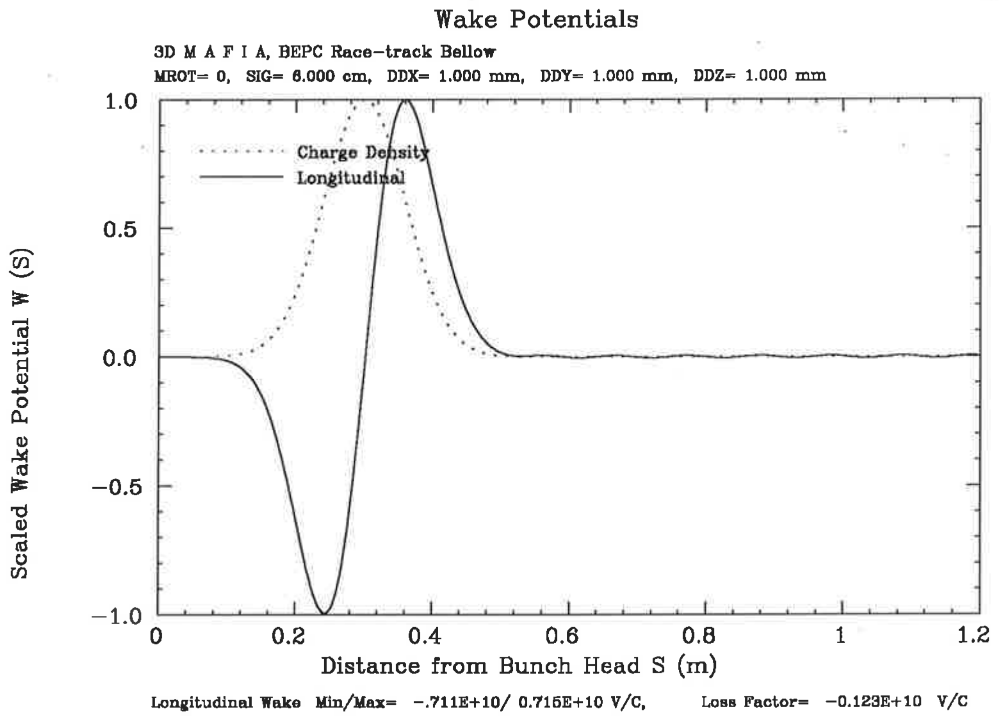

Figure 5: Wake Potential of Gaussian Bunch due to the "Race-track" Bellows

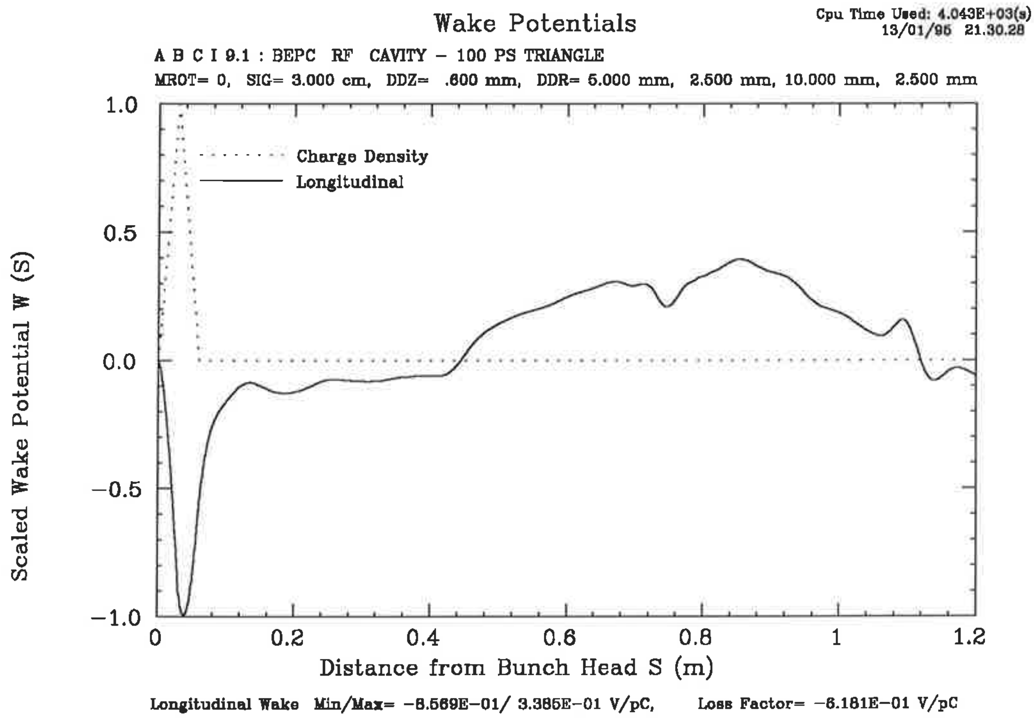

Figure 6: Wake Potential of Triangular Shape due to the RF Cavity

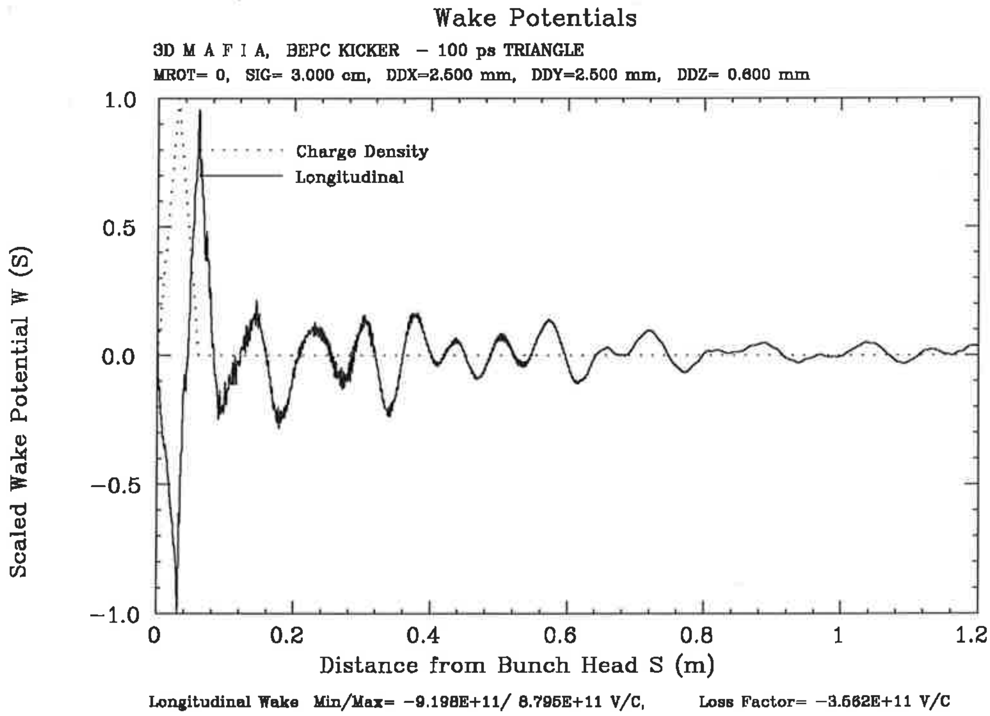

Figure 7: Wake Potential of Triangular Shape due to the Kicker

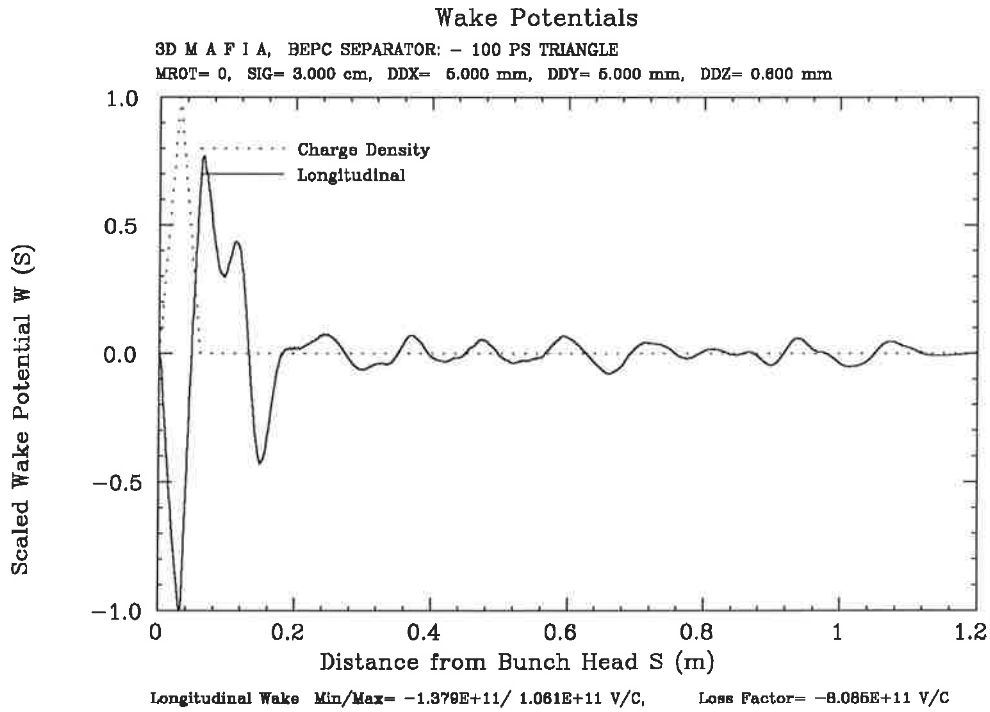

Figure 8: Wake Potential of Triangular Shape due to the Separator

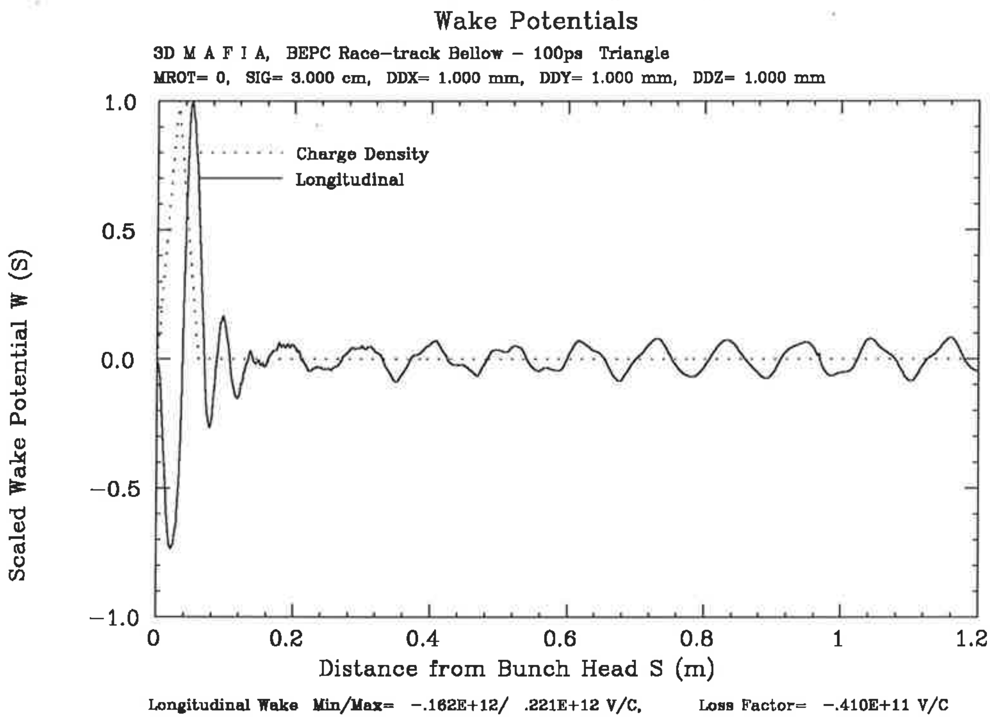

Figure 9: Wake Potential of Triangular Shape due to the "Race-track" Bellows

3 Simulation with TRISIM

3.1 Position of the Impedance Elements

In the simulation, the bunch length is observed at the Interaction Point. The 4 RF cavities, the 4 separators, and the 6 kickers are located in TRISIM according to their real positions (see Table 2). The "race-track" bellows are all concentrated at the injection point since there is a rather large number of them, and thus it would be quite time-consuming to treat them one-by-one.

Table 2 gives the position data.

Table 2 Position of the Impedance Elements

Element	Distance from Observation Point (m)
Separator 1	6.38
RF cavity 1	9.60
RF cavity 2	11.85
Kicker 1	47.85
Kicker 2	58.55
Race-track Bellows	60.10
Kicker 3	72.35
Separator 2	113.82
Separator 3	126.58
Kicker 4	168.05
Kicker 5	181.85
Kicker 6	192.55
RF cavity 3	228.55
RF cavity 4	230.80
Separator 4	234.02

3.2 Simulation at Different Energies

Simulations have been done for injection energy (1.3 GeV) and for operation at 1.55 GeV and 2.015 GeV, where most of the experiments are done. Figs. 10 to 11 show the simulation and experimental results. The disagreement which appears will be discussed in the summary.

3.3 Simulation for Different Impedances

Two kickers have been removed from the tunnel of BEPC in order to reduce the total impedance. The bunch lengthening effects with and without these 2 kickers are shown in Figs. 12 and 13. There seems to be no evident reduction of bunch length when the 2 kickers are removed.

Bunch lengthening has also been investigated after removal of all "race-track" bellows. Figs. 14 and 15 show the simulation results with and without these bellows. Only a small shortening can be seen which is not considered significant.

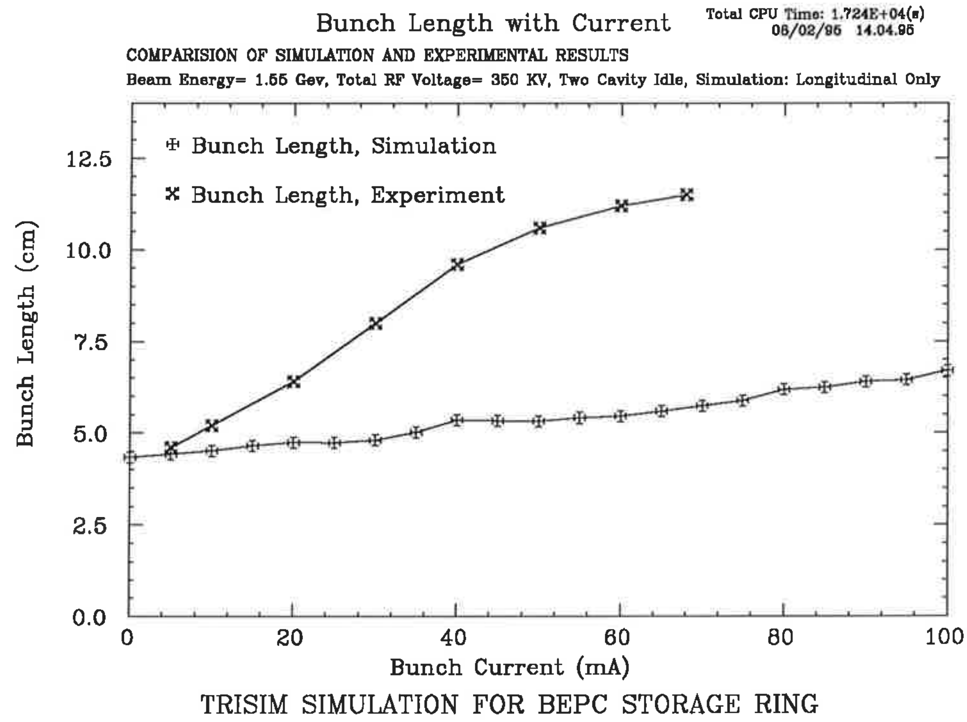

Figure 10: Comparision of Simulation and Experimental Results (1.55 GeV)

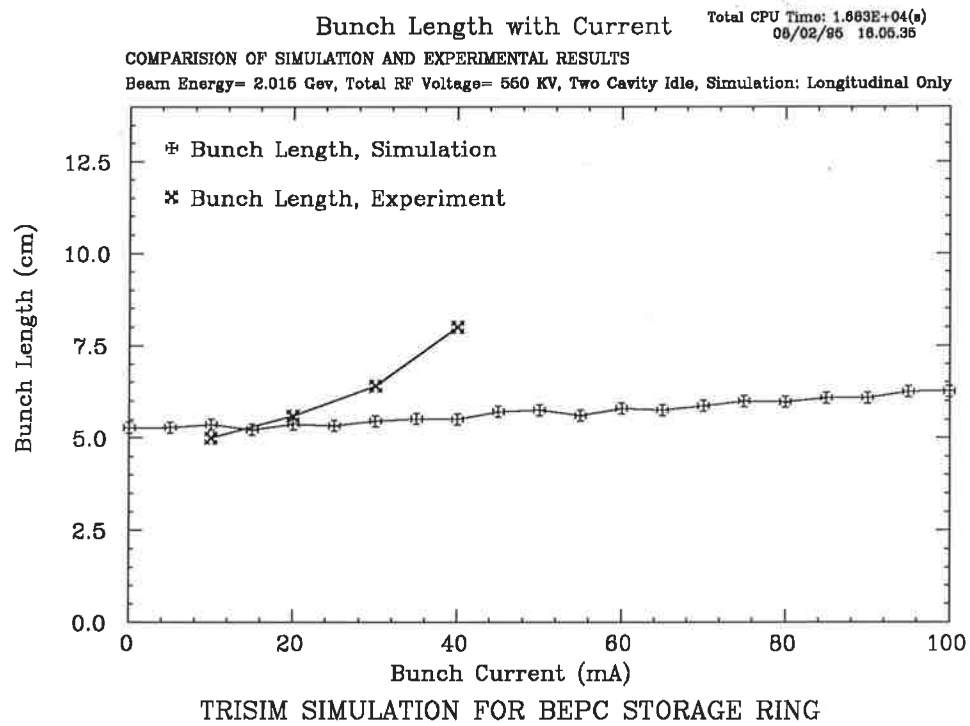

Figure 11: Comparision of Simulation and Experimental Results (2.015 GeV)

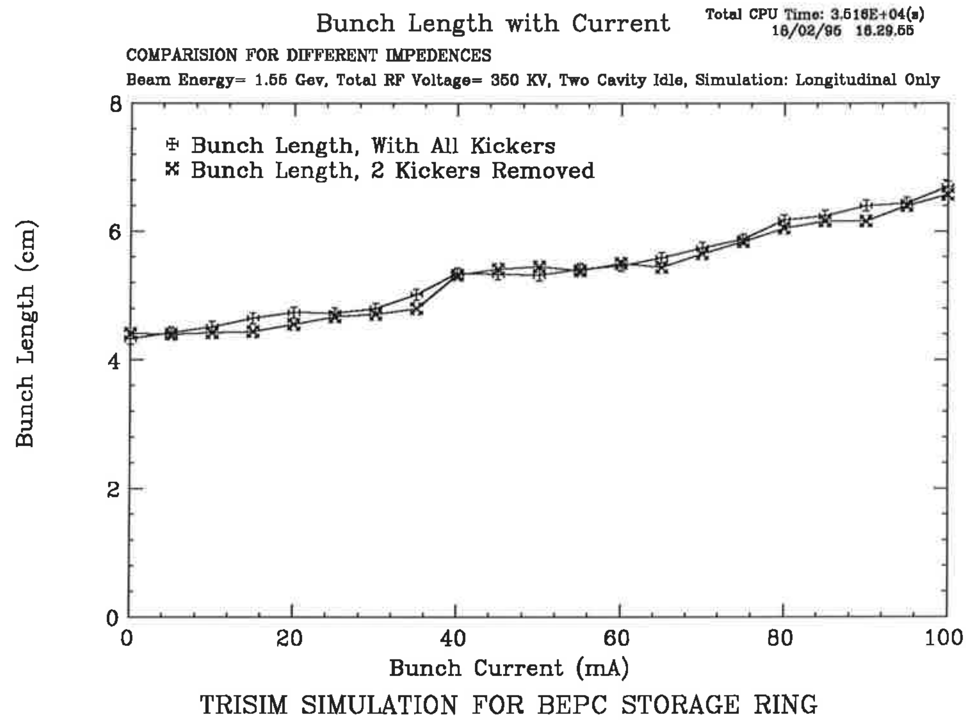

Figure 12: Simulation with and without Removal of 2 Kickers (1.55 GeV)

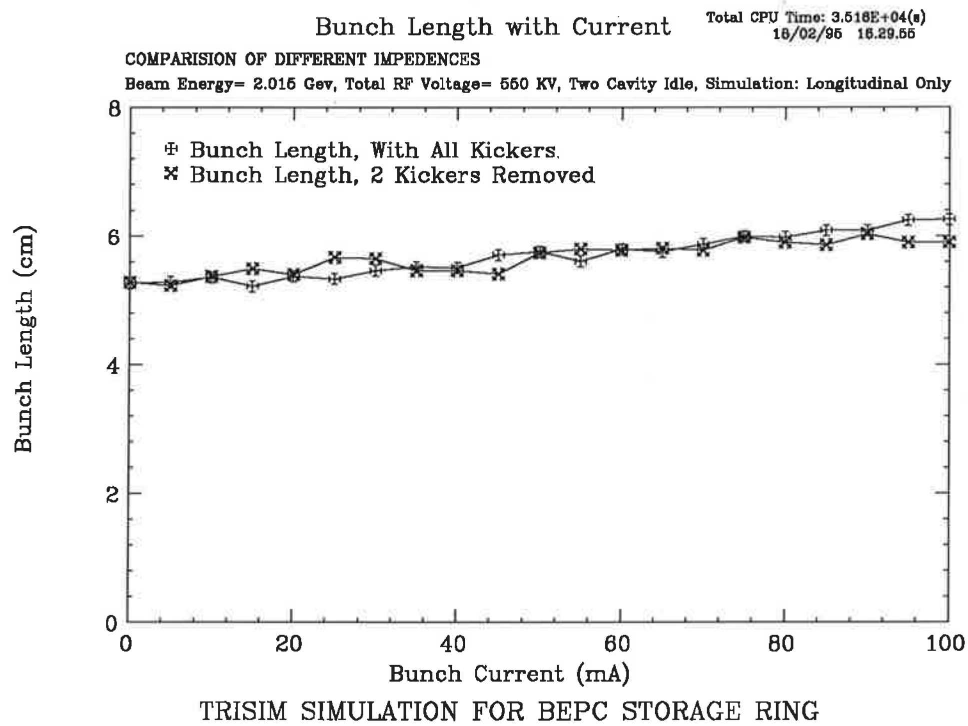

Figure 13: Simulation with and without Removal of 2 Kickers (2.015 GeV)

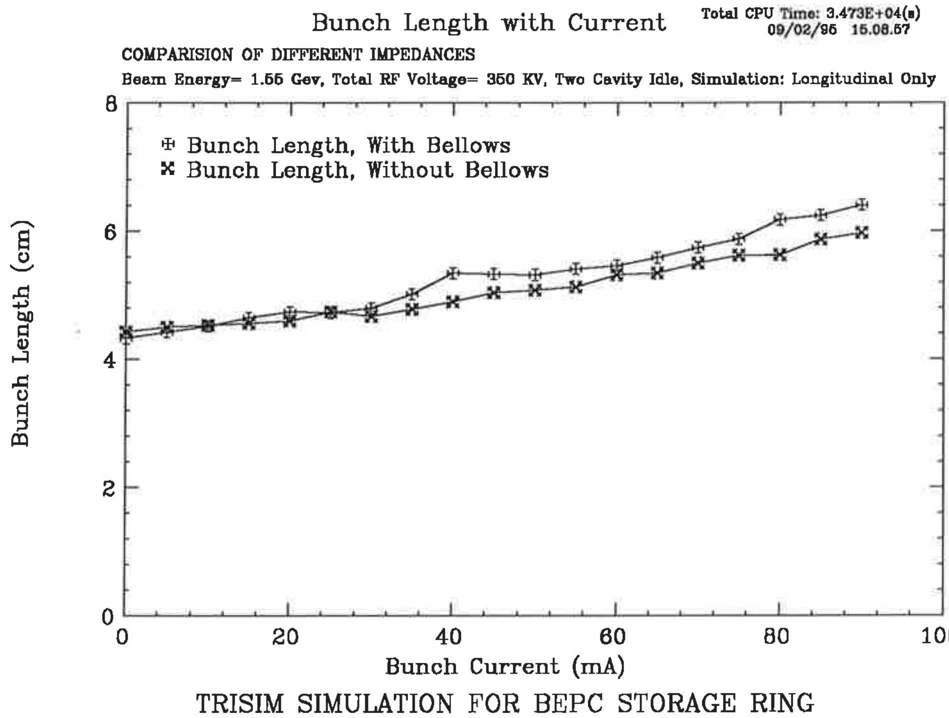

Figure 14: Simulation with and without Bellows (1.55 GeV)

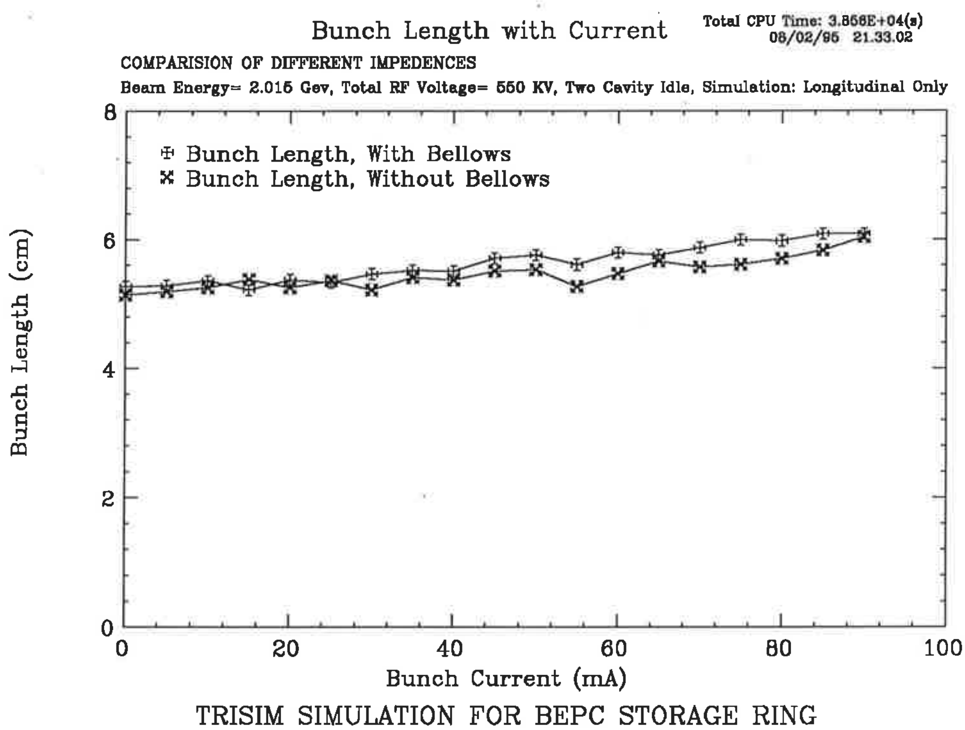

Figure 15: Simulation with and without Bellows (2.015 GeV)

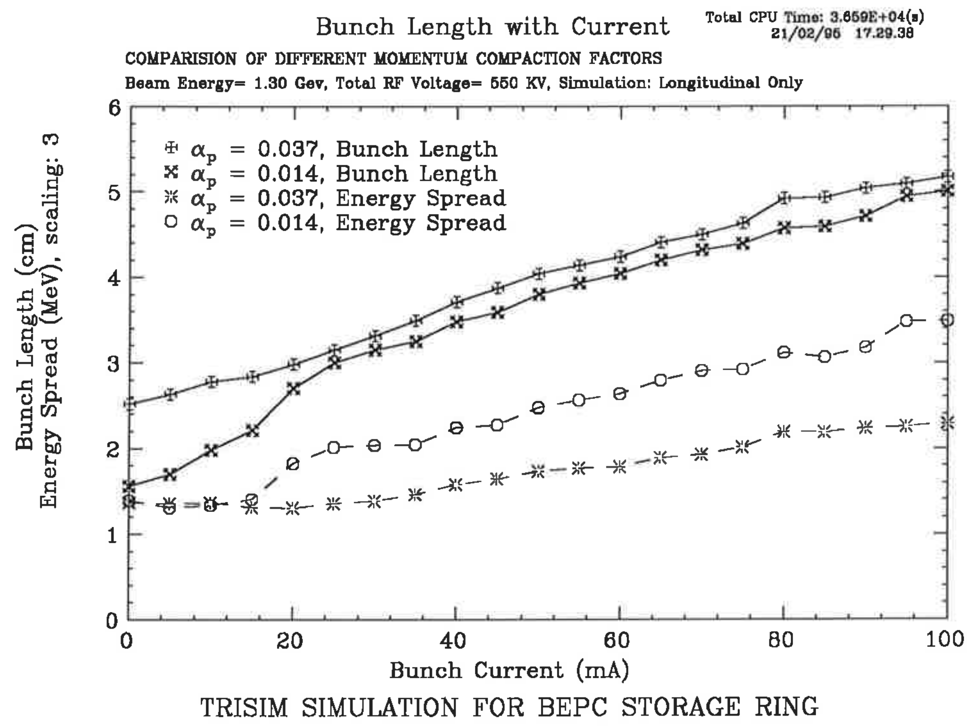

Figure 16: Simulation for Different Momentum Compaction Factors

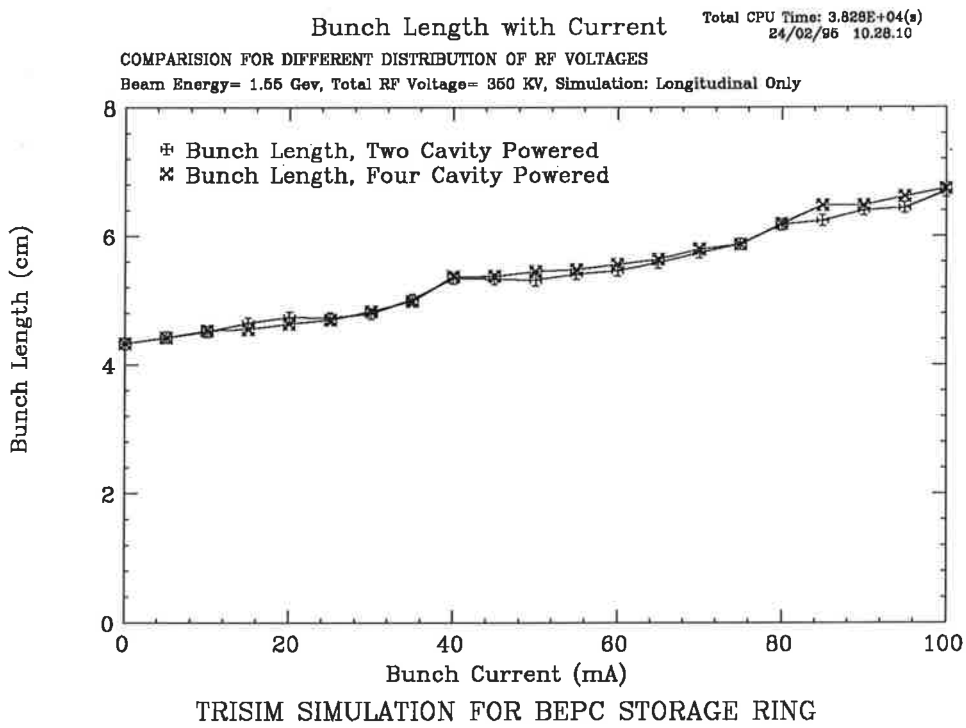

Figure 17: Simulation for Different Distribution of RF Voltage

3.4 Simulation for Different Momentum Compaction Factors

Machine experiments at 1.3 GeV (injection energy) have been done in BEPC with different momentum compaction factors. One mode of operation is for collision with a momentum compaction factor α_p=0.037, another one is for synchrotron radiation with α_p=0.014. The simulation results are shown in Fig. 16. Although computed bunch lengthening is weaker than the measured one, the simulation gives the correct behavior, i.e. small α_p yields a shorter bunch length when the current is low. However, when the current is above the turbulent threshold, the bunch length for small α_p grows much faster, and finally becomes approximately the same as that for the larger α_p.

3.5 Simulation for Different Distribution of RF Voltage

Bunch lengthening with the same RF voltage, but applied at different RF stations, has also been investigated. Only a small difference appears as indicated in Fig. 17. Furthermore, simulation with different RF voltages has been done and the results are shown in Fig. 18.

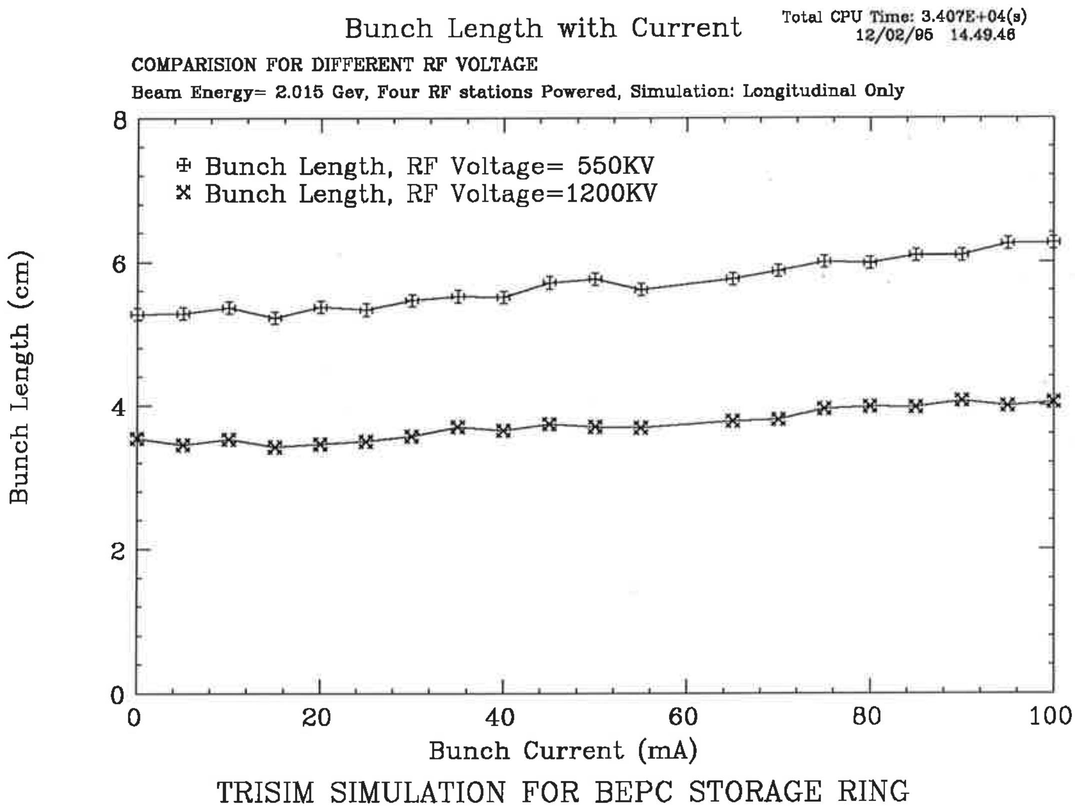

Figure 18: Simulation for Different RF Voltages

4 Summary

The wake potentials for various impedance elements have been calculated. From Table 1, we can see that the RF cavities contribute the largest part to the total loss factor. Bunch lengthening has been computed by simulation and was found to be weaker than the measured effect in BEPC. This may be caused by the rough approximation of the bunch shapes, the lack of consideration to the multi-turn effect and insufficient impedance elements. If the half-base of the triangle would be changed from $\sigma_s/2$ to $\sigma_s/4$, the approximation of the bunch shape should be improved. If more impedance elements were considered, the simulation results would become better. Test has been made with all impedances doubled which gives better agreement with experiment. Multi-turn effects, however, can not be included in the TRISIM simulation presently.

Since the RF cavities dominates the impedance in this simulation, it will be reasonable that there will be little effect for removing 2 kickers or removing all the "race-track" bellows. In order to get a more realistic simulation, more work should be done to improve the impedance model and the bunch shape approximation put into simulation.

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