THE COMPARISON OF A NEW BEAM-TRACKING CODE TO THE ACCELERATION TEST

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Abstract

A new beam-tracking code using a 3D electro-magnetic field map of a linac is being developed. In this code, beam dynamics including non-linear and dipole effects can be easily estimated based on simulated field maps provided by commercial 3D analysis software. To verify the code, we manufactured an IH-linac and acceleration test of the linac was carried out with proton beam. The simulated results were compared with the tested acceleration performances.

INTRODUCTION

Recently, interdigital-H linear accelerators (IH-linacs) are being used commonly as injectors for heavy ion synchrotrons instead of Alvarez linacs [1]. Because the IH-linac has an advantage of high shunt impedance particularly in the low-energy region. In general, beam dynamics simulation in an IH-linac is carried out under the reconstructed electric fields. The electric field in one gap can be simulated by a 2D-electric simulator. However this simulated field cannot be applied directly to the beam dynamics calculation. In the IH structure, the induced field strength of each gap was strongly coupled due to TE mode operation. Therefore, a cold test model measurement has to be needed to determine relative field strength of the each gap. Moreover, in many cases, radial field components are derived from div**E**=0 in the cylindrical symmetry condition. Since the IH-linac has asymmetric structure RF cavity, the above assumption is not good enough to estimate the beam dynamics. For instance, a large dipole component exists in the gap field. To compensate the distortion, asymmetric bulges at the drift tube were considered [2-3].

In the decade, 3D-numerical simulators became more reliable and enabled us to estimate the entire TE mode cavity. Therefore we have been developing a new simulation code which uses realistic 3D electric-fields obtained from 3D numerical simulators. Since the 3D-fields can be directly applied to the particles motion, there are no restrictions due to symmetric assumption or matrices approximations. Also, the time consuming model measurements are not necessary to modify the electric fields.

T.I.TECH.-IH-LINAC

To verify the new code, an IH linac has manufactured [5] and has tested at the Tokyo Institute of Technology (T.I.Tech.). The main parameters of the linac are summarized in Table 1. The linac was designed to accelerate C4+ ions from 39 keV/u to 1.9 MeV/u with an operation frequency of 98.2 MHz. The geometric dimensions of the linac tank are 560 and 1280 mm in inside diameter and in length, respectively. An asymmetrically ridged resonator was adopted. A photograph of the inside view of the linac is shown in Fig. 1.

Table 1: Main Parameters

Acceleration Particle	$^{12}C^{4+}$
Input Energy	39 keV/u
Output Energy	1.9 MeV/u
Operation Frequency	98.2 MHz
Number of Cell	22
Cavity Length	1280 mm
Diameter of Cavity	560 mm

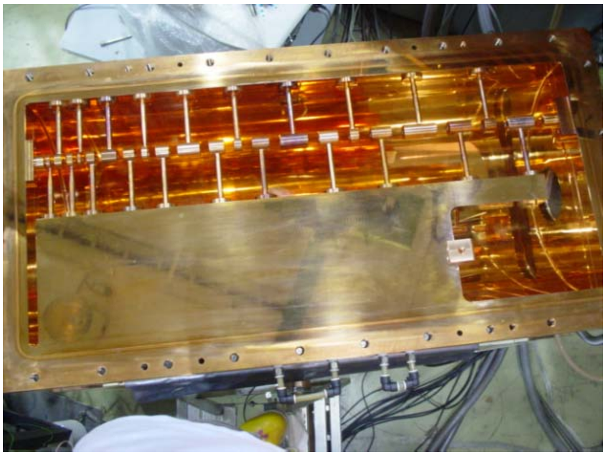

Figure 1: Photograph of the T.I.Tech.-IH-LINAC.

DIPOLE COMPONENTS INVESTIGATION

The IH-linac was simulated by an electromagnetic field program SOPRANO, which is an analysis RF solver for the OPERA-3d [4]. For the simulation, the cavity was replaced by one cylindrical tank. As the longitudinal cut plane through the ridge is a symmetry plane, only one half of the cavity was simulated. Restrictions in memory size and computation time determine a rather coarse mesh in the drift tube region. In the present conditions, meshes are divided to 1 mm step in a gap and 2 mm in a drift tube region.

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For investigation of the dipole components at each DTL cell, an averaging electric component was compared; a small circle line was drawn at the center of the gap and the each electric field (Ex, Ey, Ez) on the line was expanded to compare the fundamental term.

Fig. 2 shows the results of the radial fields components (Ex,Ey) with comparison to a longitudinal electric field component (Ez) at each gap. Since the simulation carried out using the symmetric boundary condition at the longitudinal cut plane, the proportion of Ex/Ez indicates the error of this condition. The proportion of Ey/Ez increases to a maximum of 8.3 % along with the acceleration axis. Since the gap length is larger at the high energy region, the stems mounted on the ridge affect to electric fields between the drift tubes. It should be noted the beam is affected by distortions from the stems, however, they do not shift from the beam axis for 8.3% because of π-mode operation in the IH-lianc.

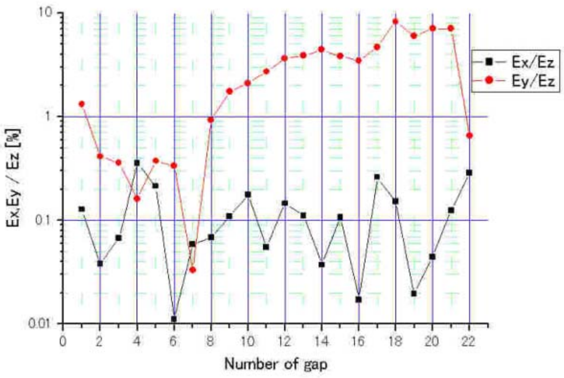

Figure 2: The radial electric-field in the Linac.

DEVELOPMENT OF 3D BEAM DYNAMICS SIMULATION CODE

We have been making a simulation code to calculate the beam dynamics including the dipole components in the IH-linac. In this code, beam particles are directly affected by 3D-electric fields obtained from a 3D-numerical simulator and transported through the linac by Runge-Kutta method used time as the independent variable. The integration step-size was 5 degrees, corresponding to 36 steps through a DTL cell.

Fig. 3 shows the calculation results of phase oscillation in the bunch beam and Fig. 4 shows the parallel beam orbit injected from 39 keV/u and accelerated to 1.9 MeV/u. The synchronous particles oscillate around the axis and extracted shifting to 0.05 mm from the original acceleration axis. On the other hands, oscillation particles steadily shift from the original axis to 3.4 mm at the exit of the linac.

The calculation accuracy depends on the resolution of the 3D electric fields and Runge-Kutta methods. In the present condition of the memory size, it is hard to increase number of meshes in the whole of the linac. The first gap can be selected to increase number of meshes and compared to present electric fields. Fig. 5 shows the comparison of longitudinal electric fields. This figure indicates that the accuracy of the fields used to calculate beam dynamics is ± 2 %.

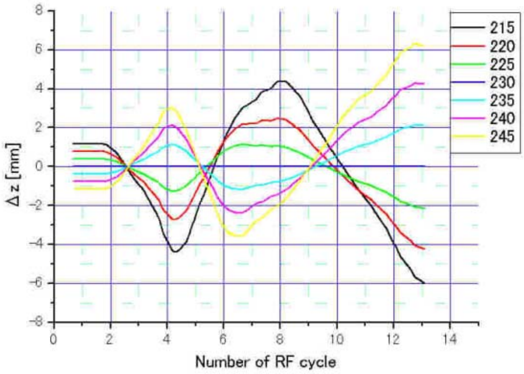

Figure 3: The graph of the phase oscillation. The numbers mean RF phase[degree].

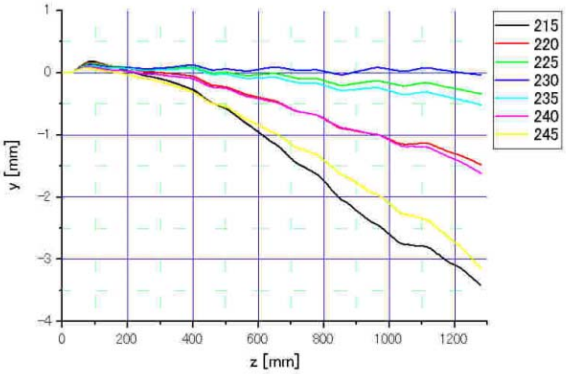

Figure 4: The parallel beam orbit in the Linac

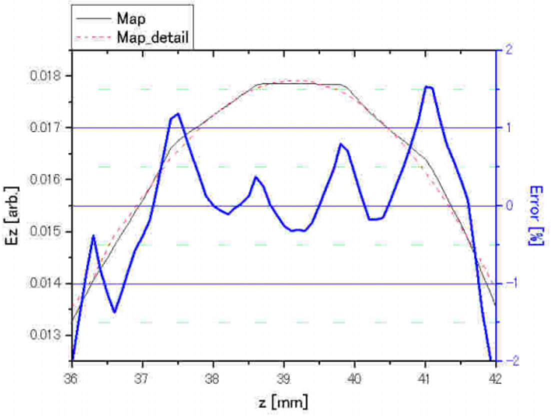

Figure 5: The comparison of longitudinal electric-fields

COMPARISON OF THE SIMULATION AND THE TEST

The code also has an ability to calculate the beam dynamics in the IH-linac including non-linear components and overlapping of the electric fields of neighbored gaps. It has also another unique point to calculate the whole particles dynamics injected into an IH-linac because an existing calculation code can handle only bunch beam dynamics. We compared the results of the simulation to an acceleration test using the IH-linac. This linac was manufactured as a high efficiency linac from low energy injection, which is much smaller than normal injection energy region for DTL, to high energy extraction which is nearly fifty times of the injection energy. It is hard to calculate the beam dynamics accurately using some existing calculation code because there is overlapping of the electric fields of neighbored gaps in the drift tube at the low energy region and the electric fields distribution is different from injection energy region and there are dipole components in the acceleration gaps at a high energy region.

Fig. 6 shows the beam acceleration calculated by the new calculation code. Although the bunch beam accelerates at the each acceleration gap, some particles transport trough the linac with some energy. Fig. 7 shows the comparison with the results of the simulation and acceleration test. The main extraction beam and other transported beam are well in agreement with each other.

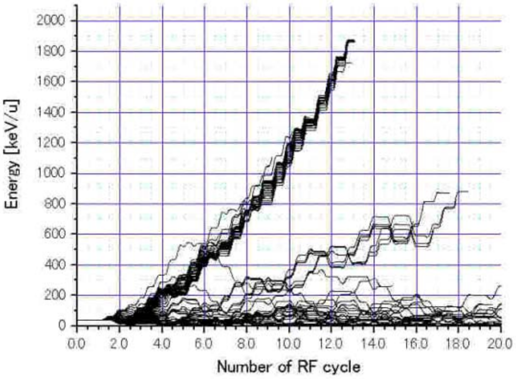

Figure 6: The calculation result of particle accelerations

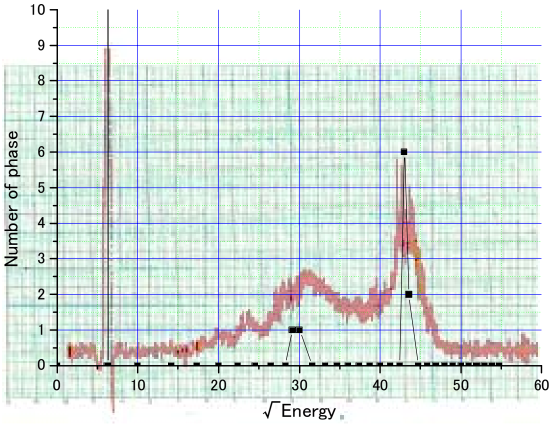

Figure 7: The comparison of the acceleration spectrum

SUMMARY

This is the first observation of the beam dynamics including the dipole components in the IH-linac. In particularly, the stems influence to the acceleration gaps and the dipole components occurred at the high energy region. The new calculation code demonstrated the beam dynamics including the dipole, non-linear and overlapping compared to the acceleration test results.

Although, the calculation code has a problem for a resolution of 3D-electric fields in the present conditions, this code is likely to prove extremely useful for investigate the beam dynamics in all accelerator simulated by 3D-numerical simulator.

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