# ALTERNATING-PHASE-FOCUSED LINAC WITH INTERDIGITAL H-MODE STRUCTURE FOR MEDICAL INJECTOR

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*Abstract*

A compact injector consisting of a Radio Frequency Quadrupole (RFQ) linac and Interdigital H-mode Drift Tube Linac (IH-DTL) for medical accelerators was designed. A model cavity of IH-DTL was constructed and electric field distributions were measured. The measured distributions were compared with those calculated by a three dimensional field solver. With the comparison, accuracy of the solver was discussed. The RFQ linac has been constructed. The final design of IH-DTL is in progress. Construction of the entire compact injector will be completed by the end of this year, and a beam test will be performed.

## INTRODUCTION

Cancer therapy using high-energy carbon beams from Heavy Ion Medical Accelerator in Chiba (HIMAC) has been carried out since June 1994[1]. Due to the successful clinical trials over more than ten years, several projects on construction of accelerator complexes dedicated to the cancer therapy were proposed over the word. Since these accelerator complexes are large in its size, development of compact and cost effective accelerators is needed to establish standards of the hospital-based complexes.

The medical accelerator consists of an injector, synchrotron ring, beam transport lines and treatment system. Among these devises, the injector takes a large part of the accelerator complex. For HIMAC, a total length of the injector reaches to more than 32m. Therefore, development of a compact injector plays a key role in designing the compact complexes. As a candidate of the compact injector, we propose a combination of a RFQ linac and IH-DTL having an operating frequency of 200 MHz. A schematic drawing of the compact injector is shown in Figure 1. For a beam focusing of IH-DTL, a method of Alternating- Phase-Focusing (APF) will be used. Major parameters of the linacs are listed in Table 1.

An idea of the IH structure was first proposed in 50s[2]. Although it is known that the shunt impedance is higher than that of Alvarez linacs at the energy region below 10 MeV, IH-DTL has not been used for many decades. One reason is that an electric-field distribution could not be calculated with existing two-dimensional electromagnetic field solvers, because the field distribution in an IH cavity depends strongly on its total structure of the cavity.

Table 1: A summary of the major parameters

| Parameters | RFQ | IH-DTL | |
|---|---|---|---|
| Injection energy | 0.01 | 0.6 | MeV/u |
| Extraction energy | 0.6 | 4 | MeV/u |
| Operating frequency | 200 | 200 | MHz |
| q/m | 1/3 | 1/3 | - |
| Cavity length | 2.5 | 3.5 | m |
| Cavity diameter | 0.4 | 0.4 | m |
| Maximum surface field | 23.6 | 23.6 | MV/m |

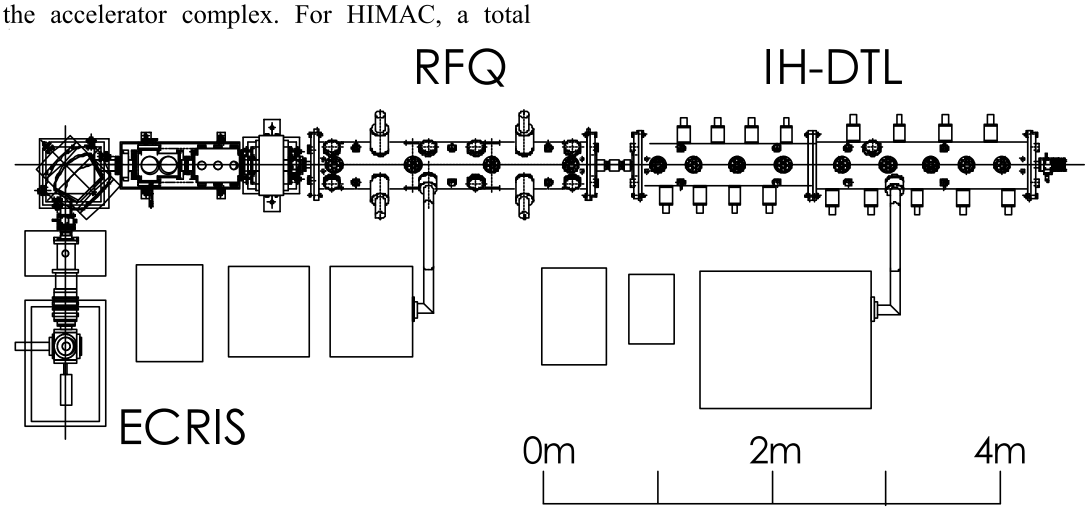


Figure 1: A schematic drawing of the compact injector.

With advent of three-dimensional electromagnetic field solvers, it became possible to calculate the field distribution directly. Although these solvers were recently applied to calculate electromagnetic field distributions of several IH cavities, accuracy of these solvers was not confirmed. Therefore we constructed a model cavity of IH-DTL and measured its electric-field distribution. The measured distribution was compared with that calculated. With the comparison between the measured and calculated electric-field distributions, the accuracy of the solver is discussed.

## MODEL CAVITY

A full scale model of IH-DTL was constructed. It consisted of a cylindrical cavity and two ridges which mounted on the top and bottom inside of the cavity. All the cavity components were made of deoxidized copper. A picture of the model is shown in Figure 1. Inside of the cavity, sixty eight drift tubes were mounted alternatively on the top of the two ridges. Because of the APF method, a structure of the drift tubes is quite simple; it was composed of a tube and supporting stem. An inner and outer radius of the tube is 7 mm and 14 or 15 mm, respectively. No additional focusing element such as quadrupole magnets was installed in the cavity.

Table 2: Major parameters of the model cavity

| Parameters | Value | Units |
|---|---|---|
| Number of cells | 68 | - |
| Cavity length | 3.2 | m |
| Inner diameters | 285-334 | mm |
| Inner radius of drift tubes | 7 | mm |
| Outer radius of drift tubes | 14-15 | mm |
| Maximum gap voltage | 365 | kV |
| Maximum surface field | 23.6 | MV/m |
| Estimated input power (70% Q) | 430 | kW |

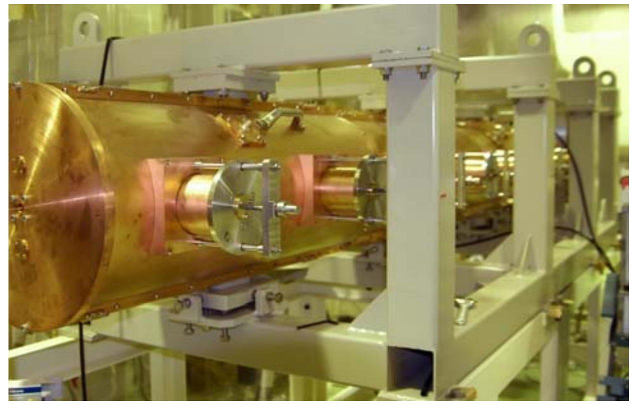

Figure 2: A picture of the full-scale model cavity.

To avoid possible voltage breakdowns, maximum surface fields around the drift tubes were designed to be about 23.6 MV/m corresponding to 1.6 times of Kilpatric limit ($E_{Kilpat}$). Under this condition, the total length of the cavity was 3.2 m. The characteristic of the beam dynamics designed for the cavity was presented elsewhere[3]. The major parameters of the model cavity are summarized in Table 2.

An axial component of electric fields along the center of the beam axis was calculated with a three-dimensional electromagnetic-field solver, Micro Wave Studio (MWS). In the solver, the cavity structure can be modelled in the three dimensional space and the electromagnetic field distribution can directly be calculated. Number of mesh cells used in the calculations was approximately 2 millions. It took about 12 hours for the each calculation. The calculated electric-field distribution is plotted by the dashed curve in Figure 3. The field distribution was almost flat over the cavity, although the field falls appreciably at the first few gaps.

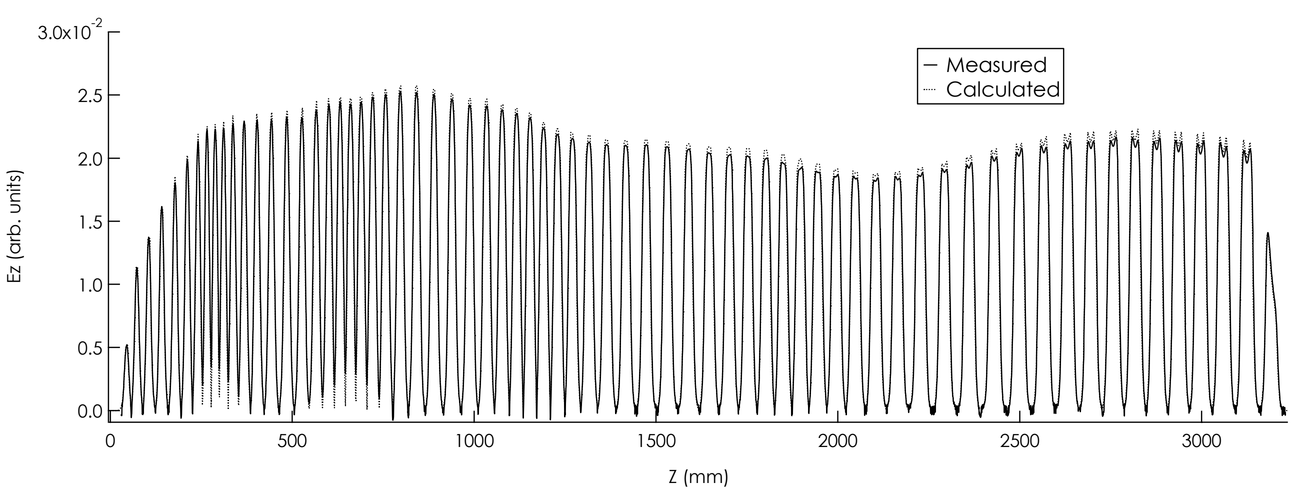


Figure 3: An axial component of electric fields along the center of the beam axis. The solid and dashed curves show the measured and calculated electric fields, respectively.


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The axial component of the electric field on the center of the beam axis was measured with the perturbation method[4]. The method utilizes a field perturbation caused by inserting a sphere in the cavity. The sphere was threaded with a polyethylene string which diameter was approximately 210 μm. The string was looped through the cavity and strained with weights. A stepping motor attached to the one of pulleys was used to lead the string. With the stepping motor, the position of the sphere in the cavity was controlled.

Because the IH cavity is operated in a $TE_{111}$ mode, there would be a certain magnetic flux in between the gaps. Therefore, we used the sphere made of barium titanium oxide ($BaTiO_3$) having a diameter of 5 mm. Subsequent measurements using an aluminium sphere having the same diameter gave an appreciable difference in the voltages of the first few gaps, whereas no remarkable difference was observed for the other gap voltages.

The measured electric field along the center of the beam axis is plotted by the solid curve in Figure 3. The electric-field distribution was adjusted with tuners to reproduce the calculated electric-field distribution shown by the dashed curve in Figure 3. As seen in the figure, the measured and calculated distributions are in good agreement with each other. The measured resonant frequency of the cavity was 200.04 MHz which was comparable to the designed frequency of 200 MHz.

Having integrated the electric field along the beam axis shown in Figure 3, the voltages of the each gap can be obtained as shown in Figure 4. The open and filled circles show the measured and calculated voltages, respectively. With the comparison between the measured and calculated voltage, we found that the voltages over the cavity agreed within 2 % of accuracy. We note here that the measured voltages agreed with those calculated within 5 % without the adjustments of the voltage with the tuners.

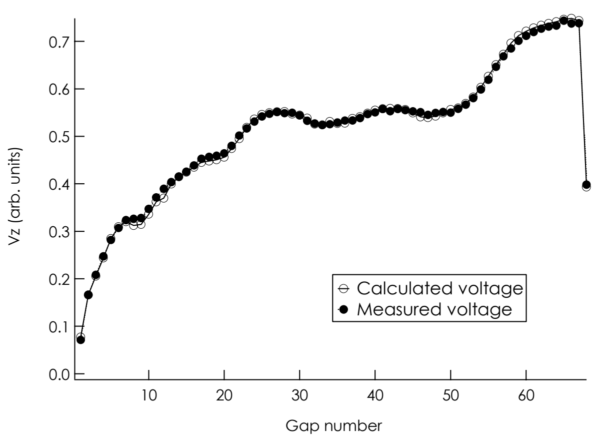


Figure 4: Gap voltage distributions along the center of the beam axis. The filled and open circles show measured and calculated voltages respectively.

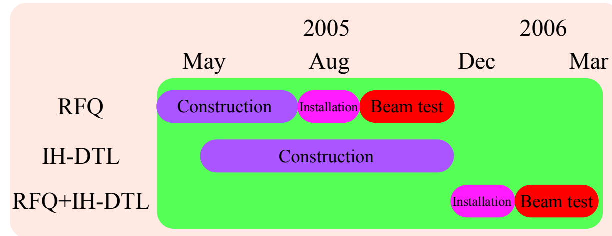


Figure 5: Future plan on development of the compact linac.

## FUTURE PLAN

The future plan on the development of the compact injector is shown in Figure 5. The compact ECR ion source and injection line had already installed in the experimental area. The construction of the RFQ linac is in progress and will be completed in this July. The RFQ linac will be installed in this August and beam tests will be performed. After the final design of IH-DTL was made, we will construct IH-DTL by this November. Then, beam tests of RFQ and IH-DTL will be performed at beginning of 2006.

## SUMMARY

The compact injector consisting of the RFQ and IH-DTL having the operating frequency of 200 MHz was designed. The full-scale model of the cavity for IH-DTL was constructed, and the axial component of the electric field was measured. The electric field distribution was also calculated with the three-dimensional field solver. With the comparisons between the measured and calculated gap voltages over the cavity, we found that they agreed within 5% of accuracy. Having adjusted with the tuners, the gap voltage over the cavity can be tuned within 2%. The final design of IH-DTL is in progress. The construction of the compact injector will be completed by the end of this year, and the beam test will be performed.

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