THE ACCELERATION TEST OF THE APF-IH LINAC

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Abstract

An IH linac with Alternating Phase Focusing scheme has been fabricated to study a high efficiency cavity for a medical accelerator injector. This linac was designed to accelerate C4+ ions from 39 keV/u up to 1.9MeV/u. In order to test this linac, a test stand was just assembled which consists of a P.I.G. ion source, bending magnets and focus lenses. The total length of the test stand is less than 5 m including 1.5 m of linac tank length. The operation frequency of the cavity is 97.6MHz. We will report linac design, fabrication and the test bench.

INTRODUCTION

Now tumor therapy is being one of major applications of hadron accelerators. Typically a chain of linacs occupies large area in tumor therapy facilities. For instance, an injector of HIMAC (Heavy Ion Medical Accelerator in Chiba; Japan), consists of RFQ linac and Alvarez linac, accelerates C4+ ions up to 6MeV/u and the length is over 30 m[1)]. In particularly such a medical accelerator complex, not only machine performance but also construction cost and operation cost are very important. Therefore compact and reliable linac design is needed. For this purpose, we designed an Interdigital-H mode linac with alternating phase focusing (APF) as a new high efficiency cavity for the injector. The IH structure has an advantage of high shunt impedance in low energy region. The technique of APF has been proposed for the design of short low beta structures, because its inherent focusing capability could eliminate the need of external transverse focusing by drift tube quadrupoles[2)-5)].

DESIGN

Initial parameters were determined for C4+ acceleration. An injection energy, output energy and operation frequency are 2 MeV/u, 40 keV/u, and 100 MHz respectively. Electric field strength in gaps is limited by twice of Kirpatric's limit and an acceleration ratio is 5MeV/m. Based on this condition, a length of the linac is 1.5m long. A number of cell was determined as 22 which was given by the linac length divided by an average cell length (about 70mm).

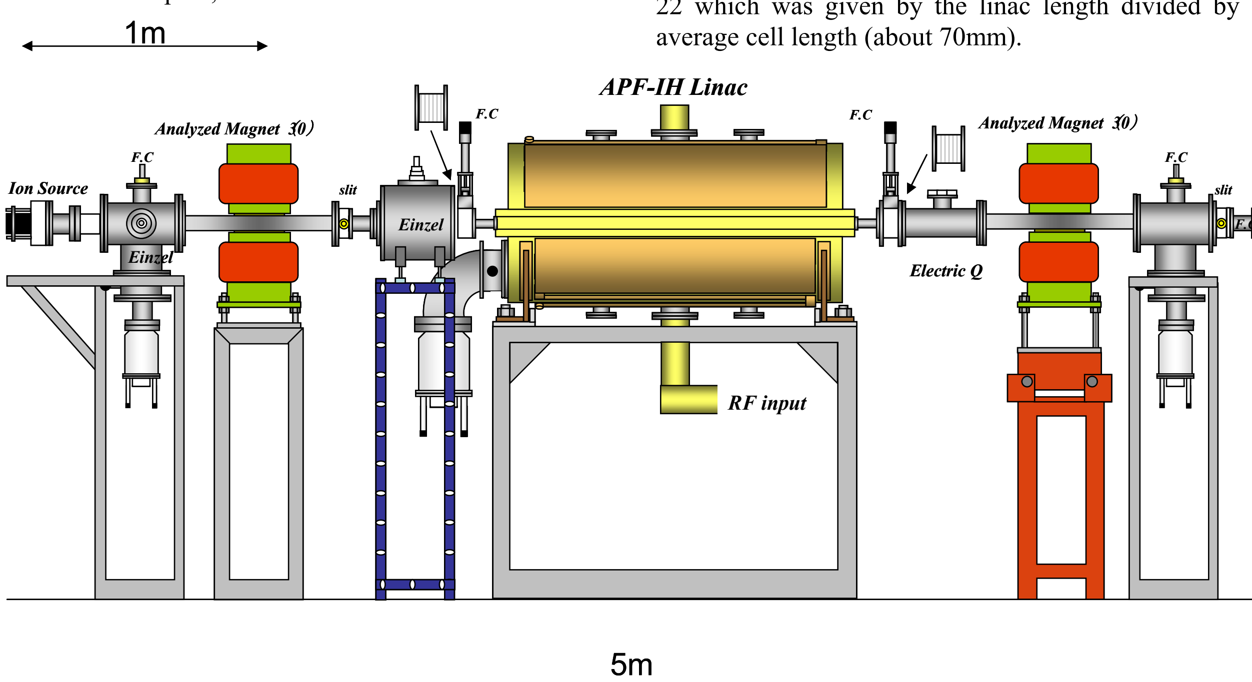

Figure 1: Acceleration test bench.

A total acceleration voltage was divided into cells keeping constant electric field distribution. Then, we optimized to find a best phase pattern working APF effectively by means of a matrix code using thin lens approximation. The results are shown in Figureure1. Next, we calculated 3D electric fields by a 3D-calculater (High Frequency Structure Simulator: H.F.S.S.) to find an end ridge tuner length to get required voltage distribution. The length of cut area was expected as 120mm. We made a half-scale cold model to check the distribution by perturbation method; a small Aluminium ball are put into the gap by a stepping motor controlled by LabVIEW and measured the electric fields by a variation of the frequency. The result is shown in Figureure2 and the final main parameters are shown in table1. Based on these parameters, a beam dynamics was calculated again.

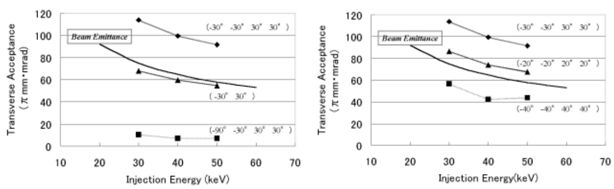

Figure 2: The comparisons of several phase pattern.

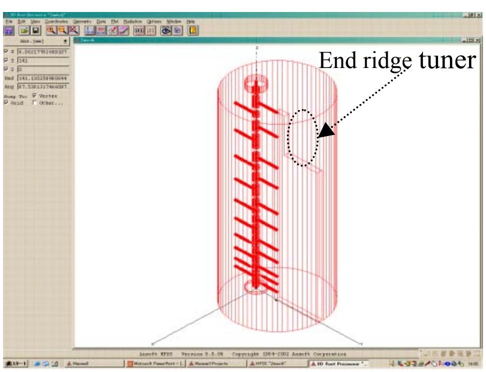

Figure 3: End Ridge tuner length=120mm by H.F.S.S.

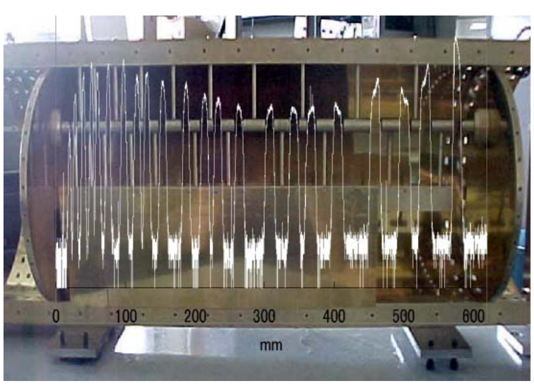

Figure 4: The electric field distribution by model test.

Table 1: Main parameters of the linac

Acceleration Particle	q/A ≥ 1/3
Input Energy	39 keV/u
Output Energy	1.9 MeV/u
Operation Frequency	97.5 MHz
Synchronous Phase	-30 , -30 ,+30 ,+30
Number of Cell	22
Cavity Length	1280 mm
Diameter of Cavity	ϕ560 mm
Focusing Sequence	-30 , -30 ,+30 ,+30
Dia. of drift tube	ϕ38, ϕ14

MANUFACTURE

The cavity was separated into 3 parts for easy fabrication and easy modification of the drift tubes. The middle plate was manufactured from single stainless plate by NC machining centre within ±0.1mm error. After plating Cu, the drift tubes were aligned and the length of each gap was lined as under ±1%. The top and bottom vessels were also manufactured and checked vacuum before assembling. After gathering each part, the frequency and the Q-value were indicated as 97.60MHz and about 10000 respectively by a Network Analyzer.

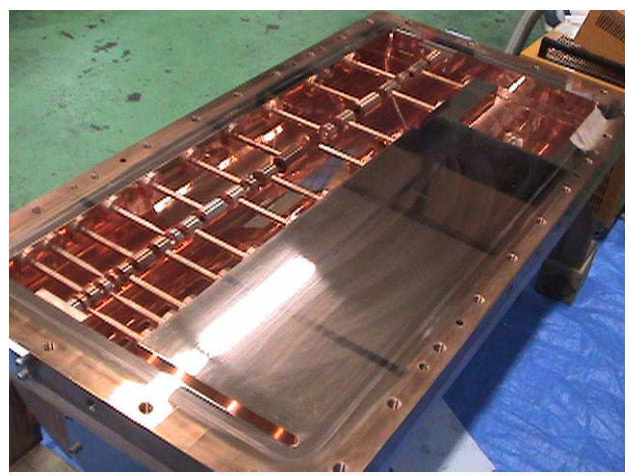

Figure 5: Photograph of the linac.

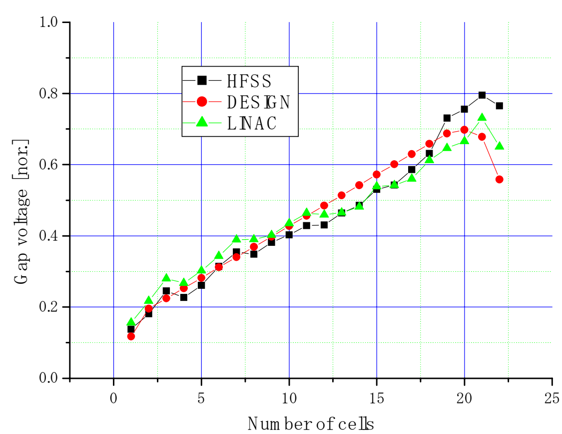

Figure 6: Comparison of the gap voltage distribution.

ACCELERATION TEST BENCH

A shunt impedance of the linac is expected as 215MΩ/m and a required RF power is 134 kW to accelerate C4+ ions. At current facility, only 30 kW power supply is available, so we will use protons for acceleration test; it will need about 14kW of RF power. The whole length of an acceleration test bench using proton is less than 5m including the 1.5m linac (Figure.1). We use P.I.G. ion source to supply protons. An extraction voltage is 15kV and an acceleration tube accelerates the beams up to injection energy. This ion source was newly manufactured and then the emittance was measured using a pepper pot and a micro channel plate. The obtained emittance was 0.04 mmmrad(nor.). For low energy beam transport, there are bending magnet to select only proton, and focusing lenses before and after the magnet. Extraction energy is analyzed by another bending magnet after focusing by an electric quadrupole. There are slits after the each magnet to improve the resolution.

The resonance frequency of the cavity is 97.6MHz, however the power supply can provide within 100±2MHz. So, we change the frequency to output 97.6MHz efficiently modifying the tuning plate. Figureure 8 shows the power at this frequency. The power is almost half compared to the capacity but enough to accelerate protons. We succeed to input the power into the linac about 14kW without sparking. Figureure9 shows the analyzed beam when the power is input. Unfortunately the analyzing magnet need to be modified to measure fully accelerated beams due to heavy saturation. In this measurement, the RF power was swept with 1 kHz repetition. A small peak appeared at 1.3 MeV seems partially accelerated protons with a particular condition which was given by lower RF fed power. Similar phenomena had been observed in our experience.

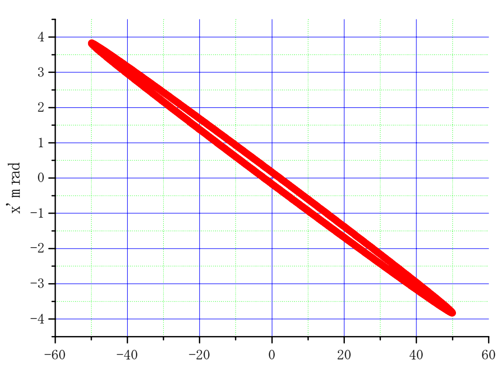

Figure 7: Emittance from the ion source.

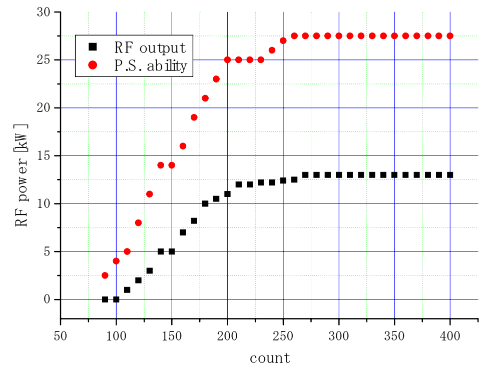

Figure 8: Ability of the RF power suply.

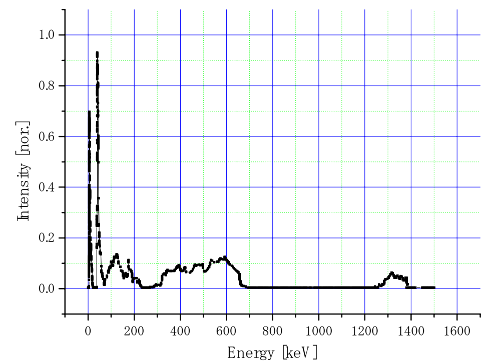

Figure 9: Analyzed beam when the RF power input.

SUMMARY

We designed and manufactured the new high efficiency cavity for the cancer therapy injector. The beam dynamics were calculated by a thin lens approximation matrix code. The RF structure of the linac was designed by a 3D-calculator (H.F.S.S.) and confirmed by the scale model. The cavity was machined by a NC machining centre and after Cu plating, drift tubes were aligned under ±1% error. In order to test the new IH linac, all devices for proton acceleration test were aligned under ±0.5mm error. After tuning of RF feed line, required RF power was successfully input without sparking. We are almost ready to commission the linac.

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