DESIGN STUDY OF C^{6+} HYBRID SINGLE CAVITY LINAC FOR CANCER THERAPY

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Abstract

A new type Linac, HSC (hybrid single cavity) linac for cancer therapy, which configuration combines RFQ (Radio Frequency Quadrupole) accelerating structure and DT (Drift Tube) accelerating structure is being finished designs and simulations now. This HSC linac design has adopted advanced power-efficiency-conformation, IH (Interdigital-H) cavity which acceleration efficiency is extremely high in the low-middle energy region [1], and has also adopted advanced computer simulation technology to evaluate cavity electromagnetic distribution.

The study purpose of this HSC linac is focus to design of injector linac for synchrotron of cancer therapy facilities. In this paper, we will report the detail designs and simulations of four structures which had been adopted to simulation for cavity optimization.

INTRODUCTION

The study purpose of HSC linac research is design of a new type injector linac for synchrotron of cancer radiotherapy facilities with DPIS (Direct Plasma Injection Scheme) by laser ion source [2]. The largest feature of HSC linac is that its structure combined RFQ accelerating structure and DT accelerating structure into one IH cavity could accelerate C^{6+} ions up to 2-3MeV/u from 25keV/u in 2-3 meters. But this structure would also make cavity electric field distribution difficult to evaluate. For application compared with conventional acceleration system, the system applied HSC linac has an excellent space effect and simplified effect of operation because of compact size by coupled complex acceleration electrode and integrated the peripheral device. The image of HSC linac is shown as Fig.1.

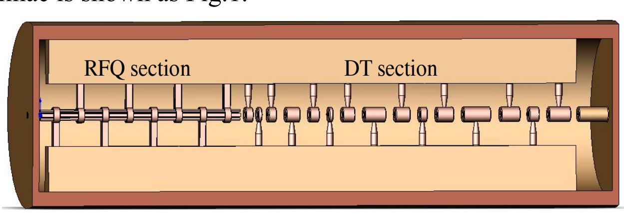

Figure 1: Inner image of HSC linac.

In this work we finished the designs and simulations of 10mA HSC model which could accelerate C^{6+} ions up to 2.0 MeV/u from 25 keV/u in 2 meters with lower 100kW feeding power. The operation frequency of HSC linac is 100MHz. For the RFQ section which could accelerate C^{6+} ion up to 220keV/u from 25keV/u, its length and diameter are 665.58 mm and 303 mm, for the DT section which include 16 cells and could accelerate C^{6+} ion up to final energy from 220keV/u, its length and diameter are 1120.42 mm and 650 mm.

The soft PERMTEQ and PMLOC (Pi-Mode Linac Orbit Calculation) were adopted to calculate orbit computation (RFQ and DT), and the soft MW- S (Microwave Studio) was adopted to evaluate cavity electromagnetic field distribution.

The linac cavity design in this work had implemented an advanced power-efficiency-configuration, APF-IH structure, which has high acceleration efficiency in the low-to-middle energy region.

And for linac fabrication, a integral-cut method which has no need of alignment is adopted a 5-axis (NC) numerical control machine to fabricate the integral main frame (including acceleration structure which includes drift tubes, stems and ridges).

HSC LINAC DESIGN PARAMETER

RFQ Design and DT Design

In this HSC linac design, 4 rod IH type RFQ structure, which was design to accelerate C^{6+} ions up to 220keV/u form 25keV/u, was adopted. This structure is suitable to accelerate heavy ions and suitable to use for HSC linac IH cavity. The exit phase spectrum and energy spectrum designs of 20mA RFQ calculated by PARMTEQM are convergent design. The beam profile at RFQ exit is shown as Fig.2.

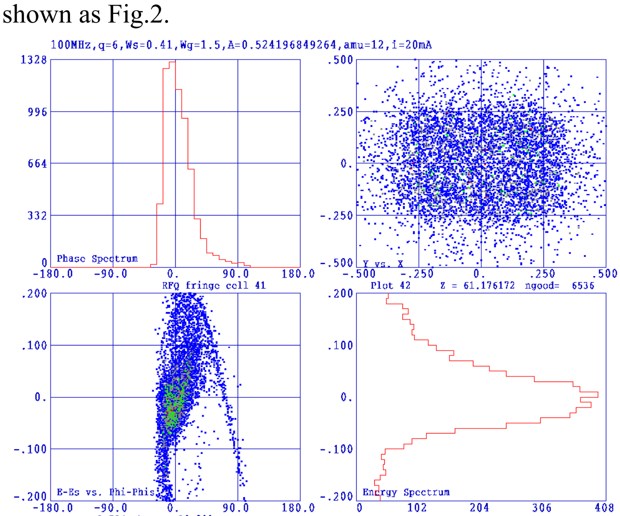

Figure 2: The beam profile at exit of RFQ.

The designs of phase spectrum and energy spectrum are adopted convergent design for following DT injection.

This 20mA RFQ design includes 41 cells in total length of 665.58mm. The transmission of beam is 65.4%. The main parameters are listed in Table 1.

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Table 1: Main Parameters of RFQ Design for HSC Linac

Charge to mass ratio (q/A)	6/12 (C^{6+})
Operation frequency (MHz)	100
Input energy (keV/u)	25
Output energy (keV/u)	220
Cell numbers	31
Length (mm)	679.58
Rod radius (mm)	6.1 ($0.75r_0$)
Transmission	65.4%
Synchronous phase	$-90^0 \rightarrow -30^0$
Maximum field (Klpt.)	1.8

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For DT design, which was design to accelerate C^{6+} ions up to 2MeVeV/u form 220keV/u, was based on PMLOC which was developed by thin lens theory and matrix method. The beam was focused by APF (Alternative Phase Focus) method.

Fitting for design target of 2-3 meters HSC linac, the DT design of HSC linac is adopted 16 cells. The DT design parameters are listed in Table 2.

Table 2: Main Parameters of DT Design for HSC Linac

Charge to mass ratio (q/A)	6/12 (C^{6+})
Operation frequency (MHz)	100
Input energy (keV/u)	220
Output energy (MeV/u)	2
Cell numbers	16
Length (mm)	1120.42
Bore radius (mm)	8
DT radius (mm)	24
Synchronous phase	$-60^0,-30^0,30^0,30^0$

HSC LINAC DESIGN SIMULATION

HSC Linac Basic Feature

The initial HSC model which was only combined RFQ structure and DT structure (same to Fig.1) was used to investigate the HSC linac basic feature simulated by MW-S. The results of initial HSC model simulation showed that the E (electric) field is focused in the connection parts of 4-rod and first DT. Shown as Fig.3, beam in gap of rod and 1st DT will be subjected to strong accelerating force, and it should be considered that discharge could be led to high voltage and beam acceleration could be received negative influence by unbalance electric distribution.

And because the C (capacitance) in RFQ section is much stronger than DT section and it could be considered that the C in whole HSC linac is focused in RFQ section, so RFQ section shows sensitive in the E field distribution. Shown as Fig.4, the increasing necessary power change in RFQ side is much bigger than power change in DT side when the cavity diameter was shortened in RFQ side and DT side. And it could be expected that the decreasing change in RFQ power is also much bigger than DT power when cavity diameter was shortened in same length.

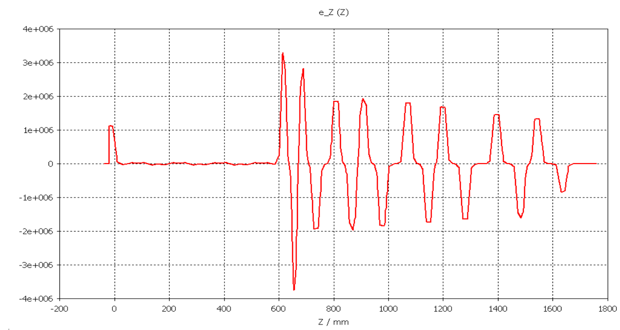

Figure 3: Axial electric field distribution simulated by Microwave studio.

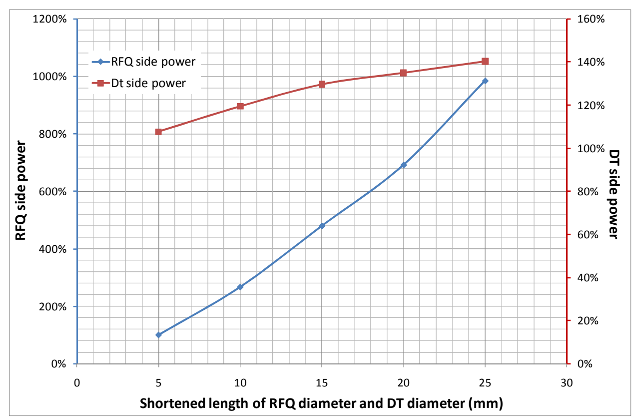

Figure 4: Power change in RFQ side and DT side with shortened length of cavity diameter.

Design for E Field Matching Section

For reducing this concentrated E field distribution, a Q magnet triplet (QMT) structure, an end rod additional radial match (ARM) structure, a drift tube finger (DTF) structure and a ground base plate (GBP) structure had been designed and discussed. The QMT structure is traditional DT design method, but in this research The QMT stem was design to short-circuit in horizontal direction for reducing the concentrated E field distribution. The ARM structure is expected to reduce the end rod capacitance and to focus the beam for DT injection. The DTF structure is designed to a short circuit in rod and 1st DT, and this structure is also expected to create a Q field for beam focus. The GBP structure is only design to a short- circuit by horizontal supporting stem and the beam phase in the gap between GBP and 1st DT is design as -60^0 which could be focused by APF (Alternative Phase focusing) method.

These structures and the MW-S simulation results are shown as following Fig.5. All these QMT structure, DTF structure and GBP structure can reduce the concentrated E field distribution and gain a wanted axis E field distribution. But the E field distribution in the ARM structure shows worse distribution which is locally concentrated in RFQ side. The reason for this ARM structure E field distribution could be considered that the increased magnetic flux amount which is induced by lengthened cavity length of the RFQ side exerts a much significant influence on E field than the influence caused by decreased C.

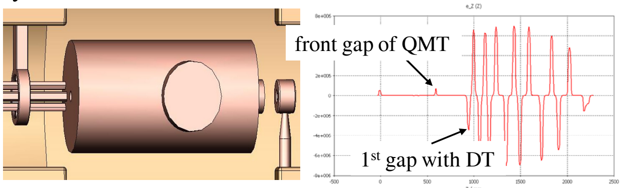

Image of QMT structure and axis E field distribution

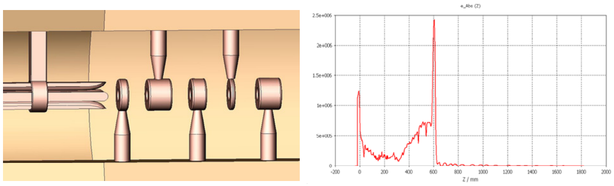
Image of ARM structure and axis E field distribution

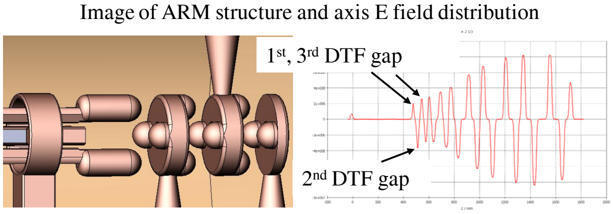

Image of DTF structure and axis E field distribution

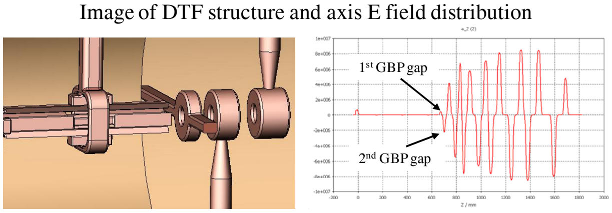

Image of GBP structure and axis E field distribution

Figure 5: Four type structures and the axis E field distributions simulated by MW-S.

Power Simulation

For cavity simulation, the relations of mesh and power & frequency were investigated firstly shown as Fig 6. According to simulation, (1) the frequency has an increasing trend with meth growth. In this HSC cavity case, the frequency of 35 million mesh simulation is 1 MHz bigger than 1.7 million mesh; (2) opposite to stable DT power (necessary power for accelerating C^{6+} ions up to 2MeV/u from 220keV/u), half power is reduced for RFQ side acceleration from 5 million mesh; (3) the simulated Q value has not big vibration. It could be considered that 1.7 million mesh is enough to calculate frequency and 5 million mesh is necessary for power calculation. And the reason could be considered that the C in RFQ is focusing and lower mesh (less than 5 million) is not enough for calculation of electric distribution.

The frequency is proportion to capacitance (have a equation of $f \propto 1/\sqrt{LC}$) and the power is square proportion to voltage which is a proportion of capacitance ($P \propto V^2, V \propto 1/C$). In case of insufficient capacitance calculated by lower meth, the inaccuracy of power is bigger than frequency.

Based on these results, electromagnetic simulation of the HSC cavity is simulated in over 5 million meshes.

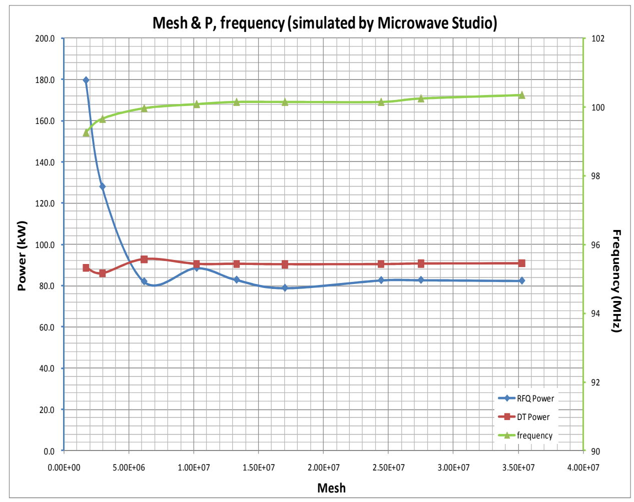

Figure 6: simulated results of relation of mesh and power & frequency.

But for difficult to fabrication in the ARM structure and based on the orbit calculations for Trans (transmission) and the power simulations which are listed as Table 3, the GBP structure is adopted to combine into the HSC linac finally. And the total inner length of HSC linac was adjusted to 1800 mm.

Table 3: Summary of Four E Field Matching Structure

Structure	**Length** (cell)	**Fabrication**	**DT-Trans** (%)	**Power** (kW)
QMT	9	Hard	31	111.5
ARM	3	Easy	×	82.6
DTF	3	Easy	7.9	86.6
GBP	1	Easy	29.7	94.0

SUMMARIES AND FUTURE PLAN

We have being studied a new HSC type linac which is a practical and efficient machine to accelerate high intense ion beam. We discussed the E matching designs for reducing the concentrated electric field distribution and investigated relation of meth and power & frequency.

Including detail cooling route, the final HSC linac design had been finished. The CAD data had been sent to the factory where HSC linac will be fabricated as a center plate and two semicylinders, and also will be assembled by sandwich method. The acceleration test will be operated in this November.