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LOW POWER TEST OF A HYBRID SINGLE CAVITY LINAC*

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Abstract

A Hybrid single cavity (HSC) linac, which is formed by combining a radio frequency quadrupole (RFQ) structure and a drift tube (DT) structure into one interdigital-H (IH) cavity (see Fig.1), is fabricated and assembled as a new type injector for cancer therapy synchrotron according to the culmination of several years' researches [1-4]. It also can be operated as a CW (continuous wave) test injector of neutron source for boron neutron capture therapy. The injection method of the HSC linac adopt a direct plasma injection scheme (DPIS), which is considered to be the only method for accelerating an intense current heavy ion beam produced by a laser ion source. According to numerical simulations, the HSC linac could accelerate a 6-mA C^{6+} beam which meets requirement of the needed particle number for cancer therapy use ($10^{8\sim9}$ ions/pulse). The injection system adopted HSC injector with the method of DPIS can make the existing multi-turn injection system and the stripping system unnecessary. Details of the measurements and evaluations of the assembled HSC linac are reported in this paper.

INTRODUCTION

The purpose of this HSC linac research is to achieve the design of a new injector linac for use in a synchrotron at cancer radiotherapy facilities by utilizing the direct plasma injection scheme (DPIS), which is considered as the only method for accelerating a high current heavy ion beam that is possibly produced a by laser ion source [5-8]. The most significant features of the proposed cavity are on the hand the combination of an RFQ section with a DT section. On the other hand it provides the acceleration of bare corbon ions from 25 keV/u to 2 MeV/u within a total length of only 1800 mm. The HSC has been designed and fabricated. According to simulations, the HSC linac could accelerate a 5.98 mA C^{6+} ion beam, which contains sufficient ion numbers for cancer therapy. Direct accelerating and injecting C^{6+} ions make an unnecessary of use of the existing carbon foil which has some demerits for ion beam. And because the use of DPIS which could offer a high beam current or sufficient numbers of ions for cancer therapy, the existing multi-turn injection system would be also unnecessary. The core parts of HSC were shaped from a piece of block copper by using 5-axis numerical control (NC) machine tools. Now, the HSC linac had transported to Institute of Modern Physics (IMP), Chinese Academy of Sciences, where will provide a 250 kW power source and a high current LIS for further HSC research.

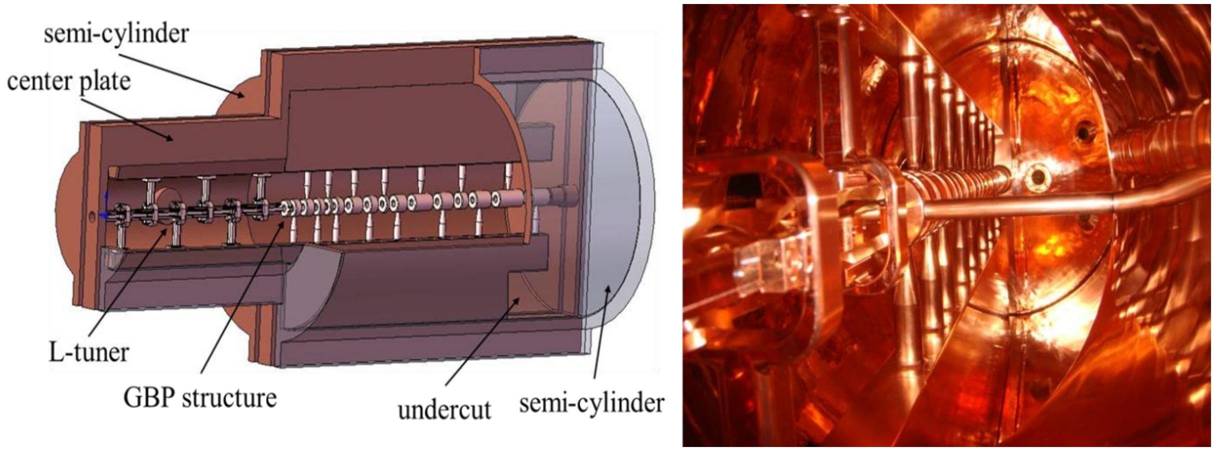

Figure 1: Before and after assembly images of the HSC linac.

DESIGN AND MANUFACTURE

In addition to the main part of the HSC linac, which included a 4-rod RFQ section and a 16-cell DT section, a ground base plate (GBP) was designed to combine the RFQ and DT sections. An alternative phase focusing (APF) structure was adopted for the beam focus in the end of the RFQ and DT sections. To achieve the design target of less than 2 m in length, a substandard RFQ transmission, which was calculated to be 65.4% of the input, was adopted. The DT transmission, which was calculated to be 45.7% of the RFQ output (DT input), was 5.98 mA. The GBP structure consisted of horizontal stems and was a normal DT similar to the remaining DTs. The design of the GBP structure did not consider beam

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focus and acceleration in the GBP gap, but a -60° phase designed by the APF method was adopted for 1st DT gap that followed. The sensitivity of the RFQ side EM field demanded a high accuracy in the fabrication and alignments. Any error or inaccuracy would have a severe influence on the acceleration in the HSC linac. For this reason, an existing L-tuner was inserted in the RFQ side to control the E field distribution of the HSC cavity. The detailed designed parameters are shown in Table 1.

The most distinctive feature of the HSC fabrication lies in the core accelerating parts, including all the DTs, DT-stems, both ridges of the RFQ side and the DT side, and all the rods and stems of the RFQ, were shaped by NC machines from a massive piece of copper. The accuracy of the core parts assembly was found to be less than 20 micrometers using alignment tools, which were also shaped by the NC machines. A sandwich type assembly method shown in the left part of the Fig. 1 was adopted, and the right part of Fig. 1 shows an image of the interior of the HSC linac after assembly was completed. The fabrication period was considerably reduced by using this shaping method. All the parts were shaped in three weeks and the assembly was easily finished in a few hours. With this fabrication method, it is also easy to create a better cooling effect. Another merit of this method is that parts fail could be replaced rapidly in case of factual operation.

Table 1: Main Parameters of HSC Linac

	RFQ section	DT section
Charge to mass ratio	6/12 (C^{6+})	
Frequency (MHz)	100	
Total length (mm)	1800	
Power (kW) (MWS)	93.98	
Q value (MWS)	14577	
Undercut length (mm)	150	
Maximum field	1.8 (Kipat.)	
Number of cells	41	1+16
Synchrotron phase	-90→-30	0, -60, -30, 30, 30
Input energy (keV/u)	25	220
Output energy (keV/u)	220	2000
Transmission	65.4%	45.7%
Input current (mA)	20	13.1
Output current (mA)	13.1	5.98
Cavity diameter (mm)	280	650
Cavity length (mm)	679.58	1120.42

LOW POWER RF TEST

The main purpose of the low power RF test was to measure the RF properties and the E field distribution of the HSC cavity. Especially the matched E field of RFQ section and DT section which was designed as a 0 value has to be checked. During the test, the HSC cavity exhibited a resonance under the condition of microwave frequency is approximately 100.49 MHz which was within 0.5% of the designed value of 100 MHz; the measured Q value was 95% of the simulated value, which was considered as a new world record.

The E field strength of the HSC cavity was measured by means of the bead perturbation method. In this research, the E fields in the DT and RFQ sections were measured respectively, because the beam bore in the DT section is larger than the average aperture radius of the RFQ. In order to measure precisely E field distribution, several perturbation balls, i.e., 3.17 mm, 4.5 mm, and 8 mm diameter balls, were used to measure the E field strength as shown in Fig. 2. All values shown in Fig. 2 have been normalized to the largest value measured in the experiment, which indicates that the measured E field strengths show good agreement with the simulated values. The simulated results were obtained using Microwave Studio (MWS).

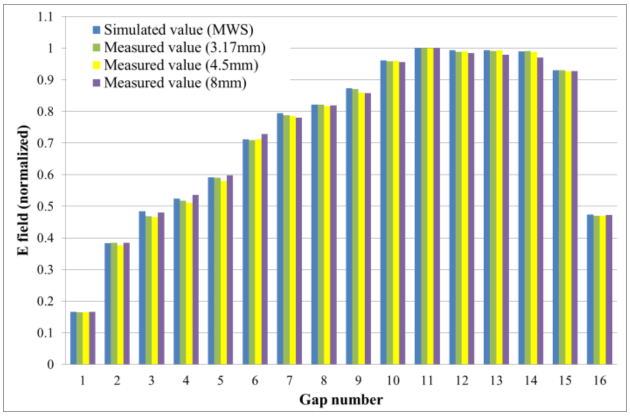

Figure 2: Simulated and measured E field strengths along the beam axis in the DT section. Each measurement was normalized to the largest value recorded during the test.

In this research, the center position of two RFQ rods could not be measured directly. A new position which was 5 mm from the beam axis was adopted to measure the E field in the RFQ section using the 3.17 mm perturbation. Both the average value of the measured and simulated E field in the RFQ shown in Fig. 3 were normalized to 1. In Fig. 3, the triangular and rhombic symbols represent the measured and simulated peak value of E field in the DT gaps, respectively. It is clear that there is no peak in the first gap between the RFQ rods and the GBP, as was expected (see the phase design of the 1st gap in Table 1); it is also clear that most of the measured and simulated peak strengths of the E field in the DT gaps are similar except the value of the fifth gap where an error of approximately 5% is observed. This error could be due to the fact that the distance of the phase change in the fifth gap is only 120 degree (-30 degree to 30 degree), which resulted in the lengths of the fourth DT and the fifth gap being the shortest in the design, and therefore the measurements were more sensitive.

The E field strength in the RFQ section was purposely designed to be higher than the desired ideal distribution, which is lower 3% than the designed value. This is because the location of the L-tuner was designed in the RFQ section. Figure 4 shows two measurements of E field strength between two rods using the 3.17 mm perturbation; the green line shows the E field strength before inserting the L-tuner and the blue line shows the E field strength after inserting an L-tuner with a maximum length of 12.9 mm. The blue line is approximately 4% lower than the green line, which implies that the ideal E field strength between the two rods could be adjusted by controlling the length of the L-tuner inserted. Both of these two measurements express the four rod-structures (the radial matcher (RM) structure, the gentle buncher (GB) structure, the accelerator structure, and the additional EXITFF structure) clearly. In Fig. 4, the value of the average E field strength before tuning was normalized to 1. After L-tuner tuning, the change of the E field strength in the DT section shows the changed E field strengths in the DT section were also 3 % higher than the simulated values, which fits the simulated results closely, and the cavity frequency only increased 0.01 MHz when the maximum length L-tuner was inserted.

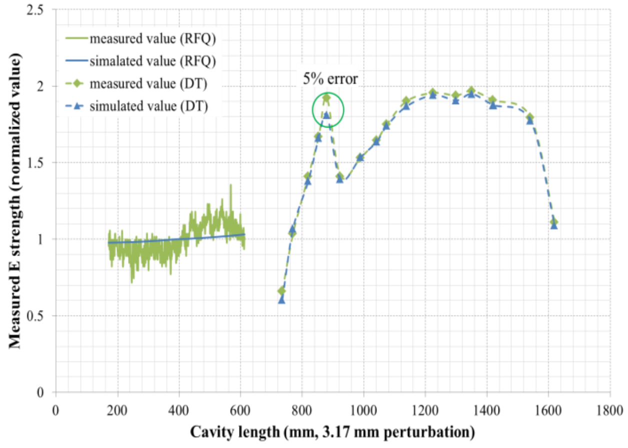

Figure 3: A comparison of the measured and simulated E field strength along the axis of the new position of perturbation.

The shunt impedance calculated based on perturbation measurements was 115.4 M/m, which is 94.4% of the MWS simulated value of 122.2 M/m. 94.4% of the shunt impedance percentage is very close to 95% of the Q value percentage. The shunt impedance value of 115.4 M/m for the HSC structure cavity is the highest value when compared to other linac structures within the same beam velocity region [9].

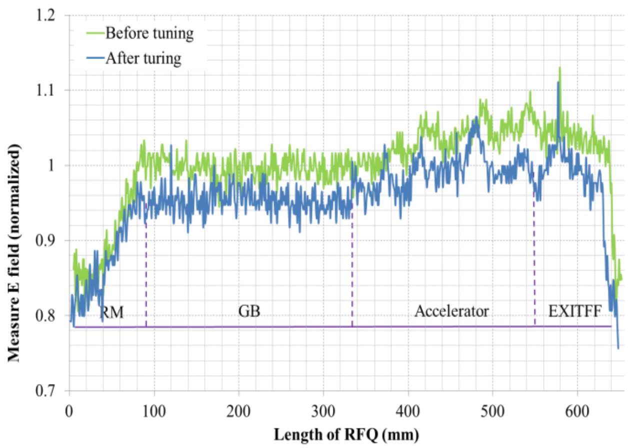

Figure 4: Measurements of the E field strength between two rods before and after tuning.

All of these measured results, including the fitted frequency, suitable E field distribution in the cavity, and a good tuning effect, imply that the HSC cavity was successfully designed and assembled. The results also show that this convenient assembly method by using module design and numerical shaping could simplify the assembly process for accelerators with a higher accuracy, which is important for increasing the applications and use of accelerators.

FUTURE PLAN

A high power test system was already built in IMP, and the ageing of HSC was also finished in a few weeks ago. The DPIS test and the high power accelerating test will be operated in next few months.

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