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NEW TYPE OF INJECTOR FOR CANCER THERAPY

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Abstract

We performed a compact design for 100 MHz Hybrid Single Cavity (HSC) for injector of cancer therapy. The proposed designs are conventional four-rod structure and DTL in a single IH cavity. This compact linac injector, running in frequency of 100 MHz, accelerates C^{6+} beams with 20 mA from 0.02 MeV/u up to 4 MeV/u. The total length of HSC is designed less than 4 meters.

INTRODUCTION

Compared with traditional structure, firstly, the HSC model consists of RFQ structure and DT structure without MEBT. Secondly, the IH structure provides the higher shunt impedance and acceleration gradient. In the structure, E-field is focused in the connection parts of 4-rod and first DT.

For DTL section, the section adopts the Alternative Phase Focus (APF). The DTL section with APF can achieve three-dimensional focusing without the installation of quadrupole lenses into the drift tubes.

Further, traditional injector has a complex control system and huge injector. Compared with traditional types, HSC adopts Direct Plasma Injection Scheme (DPIS). The DPIS could easily create enough C^{6+}ions to the linac by adjusting the distance from target to laser.

BEAM AYNAMICS

In this part, the beam dynamics ware divided into 3 sections, RFQ section, DTL section, and HSC section [1][2]. For RFQ section, it accelerates the C^{6+} with 20 mA from 0.02 MeV/u up to 0.6 MeV/u. The DTL section accelerates C^{6+} from 0.6 MeV/u up to 4 MeV/u. For RFQ section was designed by RFQGen code. DTL section and HSC ware designed by PIMLOC code. More details will be given in the next.

RFQ Section and DTL Section

The RFQ section is divided into 4 section: radial matching section (RMS), shaper section (SH), gentle buncher section (GB), and accelerator section (ACC) [3]. The length of IH-RFQ is short 1 m. The original main parameters ware given in the Fig. 1.

We want the length of RFQ to be as short as possible, meanwhile, ensure the acceptable transmission and beam quality. To achieve the aims and realize an efficient bunching for RFQ section, we adopt some basic ides, as follows: Firstly, we must vary the transverse focusing strength B along the beam direction because of the corresponding space-charge conditions at different positions.

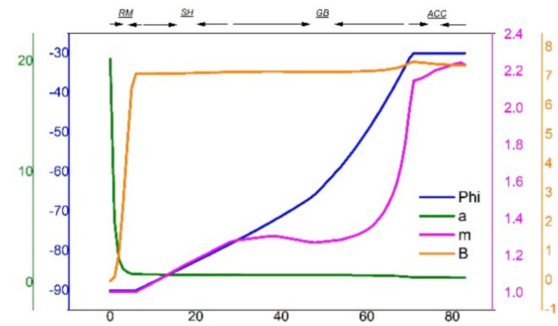

Figure 1: The original parameters in RFQ section.

Traditionally, the transverse B should be increasing with the space-charge force until the transverse defocusing force is weakened. After that it should go down. Secondly, the evolution speeds of the synchronous phase and the modulation parameters can also improve the bunching process.

When we followed the important conditions. We can get the optimized parameters, shown in Fig. 2.

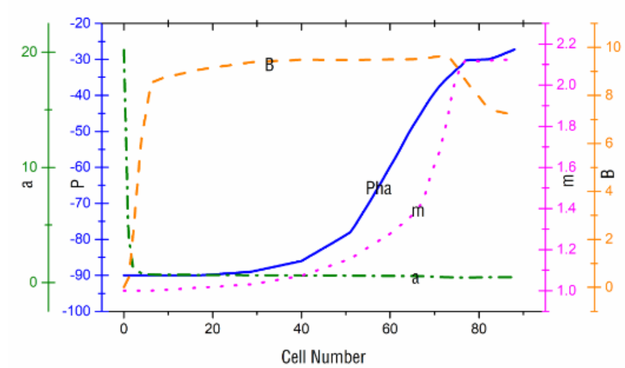

Figure 2: The optimized parameters in RFQ section.

Figure 3 gives the transmission efficiency, which almost over 95%, at last cell.

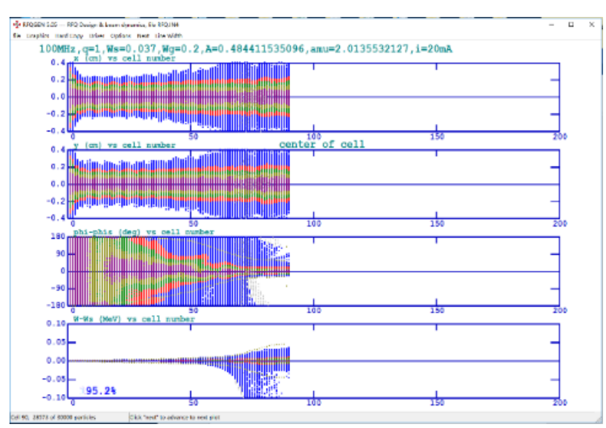
Figure 3: Transmission efficiency at last cell.

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And, we can't ignore the beam losses, both longitudinal and transverse losses. In order to reduce the beam losses, increasing the longitudinal acceptability in the first several cells is effective way. As shows in Fig. 4, beam loss have been significantly reduced after optimized.

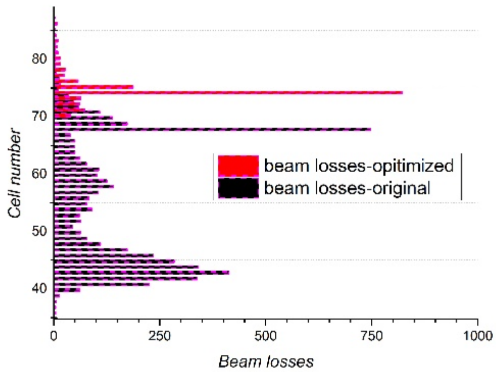

Figure 4: Beam losses of original and optimized designs.

The main parameters of RFQ and the final parameters are summarized in Table 1.

Table 1: Design Parameters of the RFQ Section

Parameters	Value
Inter-vane voltage	85 (kV)
Vane length	1050 (m)
Synchronous phase	-90° to -30°
Modulation factor	1 to 2.1
Transmission efficiency	95.2 %
Ellipse parameters (Alpha x, y)	1.8456, -1.3395
Ellipse parameters (Beta x, y)	18.0319, 13.0393 (cm/rad)
Ellipse parameters (Emit, u, rms x, y)	0.9089, 0.8803 (cm-mrad)
Ellipse parameters (Emit, u, rms z)	0.0712 (MeV-deg)

The output of RFQ section is adopted convergent design for following DT injection, shown in Table 2.

The most important theory in DTL section is Alternative Phase Focus (APF) principle. Drift tube linac (DTL) with APF is a compact version, which was discovered in 1953, compared with the traditional DTL. It can achieve three-dimensional focusing without the installation of the quadrupole lenses into the drift tube. It means that inter-gap RF field is used to achieve not only acceleration but also beam focusing in APF DTL [4][5][6]. On the one hand, if the synchronous phase greater than 0 degree, it will mainly offer transverse focusing, which is higher than longitudinal focusing. On the contrary, it mainly offers longitudinal focusing. But, we can't deny the fact that it is small longitudinal acceptance in DTL. So, the number and value of negative phase must be increased in the first several gaps. The Fig. 5 gives the phase in each gap.

Table 2: The Input Parameters of DTL

Parameters	Value
Ellipse parameters (Alpha x, y)	1.8456, -1.3395
Ellipse parameters (Beta x, y)	18.0319, 13.0393 (cm/rad)
Ellipse parameters (Emit, u, rms x, y)	0.9089, 0.8803 (cm-mrad)
Ellipse parameters (Emit, u, rms z)	0.0712 (MeV-deg)
Δ w	0.03 (MeV)
Δ p	30 (Deg)

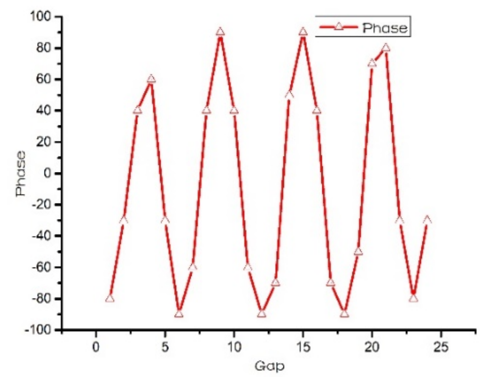

Figure 5: The phase in each gap.

The voltage in each gap and the length of each gap were given in Fig. 6. when we change the length of gap and coefficient, the length of DT is changed subsequently. To insure the minimum length of DT over 1 mm, length of gap was restricted no more than 40 mm.

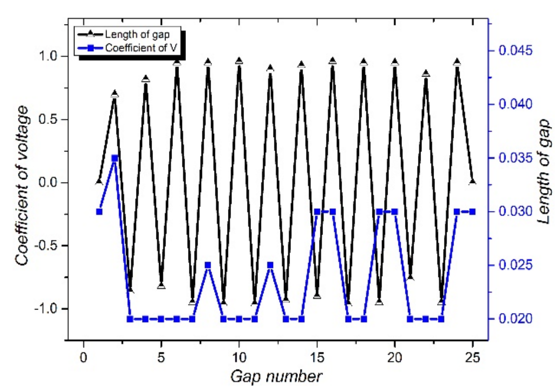

Figure 6: The voltage and length of gap in each cell.

The number of simulated particles is 10000. After setting the basic parameters in PIMLOC and tracing the particles, we could get the results of simulations, shown in Table 3, which was calculated by PIMLOC to satisfy the whole design requirements.

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Table 3: The Parameters in DTL

Parameters	Value
Voltage	199.2 kV
Cell number	24
Length	1853 mm
Bore radius	13 mm
DT radius	30 mm
Minimum length of DT	13 mm

The minimum length of DT is over 1 cm, which is satisfied to Engineering requirements. The output at the end was given in Fig. 7. Transmission efficiency is over 90%.

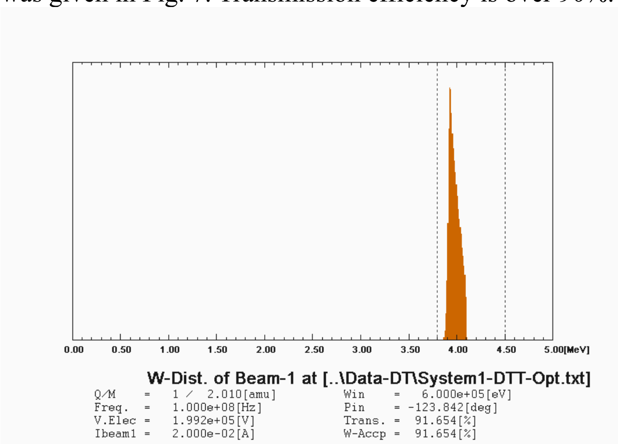

Figure 7: The output at the last gap.

HSC Section

The parameters of HSC were determined by the output parameters of RFQ section and DTL section. But, the distance between exit of RFQ section and first DT (L-RFQ-DT) is the vital important for the transmission efficiency. The transmission efficiency was changed along with the distance. In our research, the maximum transmission efficiency occurred at range of 30 mm to 60 mm.

Secondly, Length of ion source to RFQ section (L-IS) is also an important factor. The injection phase is related to the two factor, L-RFQ-DT, L-IS. So, the appropriate length is vital important to the whole HSC.

The output of HSC was shown in Fig. 8, which was satisfied the design aims. The transmission efficiency is over 80%.

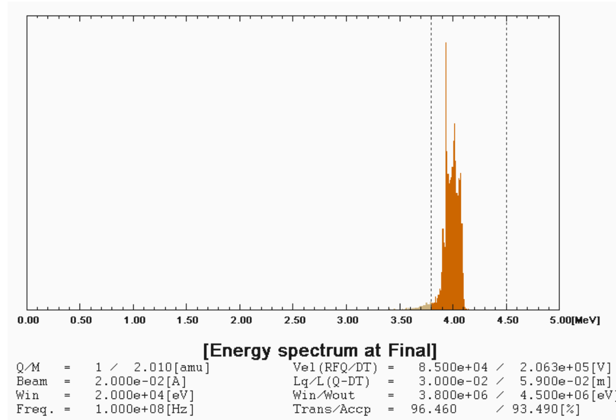

Figure 8: The results of HSC.

After optimizing the main parameters of HSC, the final parameters are summarized in Table 4.

Table 4: The Final Parameters in HSC

Parameters	Value
L-IS	10 (mm)
L-RFQ-DT	59 (mm)
L-Pure-Q	30 (mm)

SUMMARY AND FUTURE PLAN

We have 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.

In the next step, we will optimize multi-physical fields of HSC by ANSYS.

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