THE COMPARISON OF ADS INJECTOR II WITH HWR CAVITY AND CH CAVITY

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Abstract

High current superconducting proton linac is being studied for Accelerator-driven System (ADS) Project hold by the Chinese Academic of Sciences (CAS). The injector II, which will accelerate proton beam from 2.1 MeV to 10 MeV, will be operated with superconducting cavity. At low energy part, there are two alternative choose, one is HWR cavity, the other is CH cavity. In this paper, the comparison of design with the two type cavities will be presented in view of beam dynamics.

INTRODUCTION

Nuclear energy as a kind of clean energy will be widely used in Chinese energy program in the future. But one of the serious problems is how to handle radioactive waste produced by nuclear plants. ADS, which is the effective tool for transmuting the long-lived transuranic radionuclides into shorter-lived radionuclides, is being studied in the Chinese Academy of Sciences. The roadmap of the project is shown in Fig. 1.

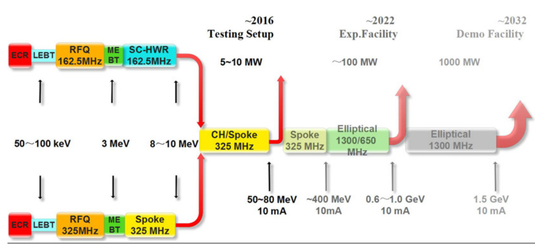

Figure 1: The roadmap of China CAS.

To ensure technical feasibility in the low energy section, two injectors for the superconduction linac are studded during the first step. One of the injectors, that is Injector II, is been designed and fabricated at Institute of Modern Physics(IMP) of the Chinese Academy of Sciences.

For Injector II, there are two type cavities, superconduction HWR cavity and superconduction CH cavity, are under studied in IMP. In this paper, the results with HWR cavity and CH cavity in view of beam dynamics are presented.

THE MAJOR PARAMETERS OF INJECTOR II

Injector II is composed by LEBT, RFQ, MEBT and superconduction section. The proton with energy 35KeV will be extracted from ions source. Then the proton will be accelerated by RFQ to 2.5MeV. The superconduction section will accelerate proton from 2.5MeV to 10MeV. The basic parameters of Injector II are listed in Tab 1.

Table 1: The basic parameters of injectorII.

Parameter	Value	Unit
Particle type	Proton	
Operation frequency	162.5	MHz
Operation mode	CW	
Beam kinetic energy	10	MeV
Beam current	10	mA

As shown in the Tab 1, the designed beam current is 10mA and the operation mode is CW. So far there is no such a high current CW superconduction machine running on the world. Some design rules and methods are used to the beam dynamic design.

DESIGN RULES FOR THE HIGH CURRENT PROTON LINAC

The design of the SC section of Injector II has been performed with the following rules for the high intensity proton linac so as to avoid emittance growth and envelope instability.

(1) The phase advance at zero current beam in transverse σ_{t0} and longitudinal σ_{l0} should be lower than 90° per focusing period to avoid envelope instability at high current[1].

(2) Avoid the nonlinear parametric resonance when $f_{particles} = f_{mode}/2$, where $f_{particles}$ is the betatron frequency and f_{mode} is the mode-oscillation frequency[2].

(3) The wave number in transverse and longitudinal, κ_{t0} and κ_{l0}, which means the strength of focusing force in each period, should change smoothly along the whole linac. This will decrease the risk of mismatch and make the linac less sensitive to the beam current. This rule is very important at transition section where the periods are broken due to the practical limit in cryo-module length or change of SC cavity family. The wave numbers κ_{t0} and κ_{l0} are expressed as fellows[3].

$$\sigma_{t0} = \frac{\kappa_{t0}}{L_0}, \sigma_{l0} = \frac{\kappa_{l0}}{L_0} \tag{1}$$

where L_0 means the length of focusing period.

(4) To avoid the energy exchange between transverse and longitudinal direction by space charge resonances, the work point of each cell should be at the location far from the unstable area[4].

(5) The matching between transitions section should be proper to avoid the formation of beam halo. The envelope should be as smooth as possible at the transitions and keep off high peaks in envelop along the linac.

THE DESIGN AND SOME SIMULATION RESULTS WITH HWR AND CH CAVITY

For the superconduction section, the superconduction HWR cavity and superconduction CH cavity are used to accelerate proton to 10MeV. The design and some results with code TraceWin[5] are shown below.

The design and simulation results with HWR cavity

The initial emittance is obtained from the output of the RFQ simulation. 50,000 particles, that are initialized as Gauss distribution, are tracked at zero and 10mA. Some simulation and analysis results are presented as follows.

The phase advance and envelop along the SC section The transverse and longitudinal phase advance at zero current in each focusing period are depicted in Fig. 2.

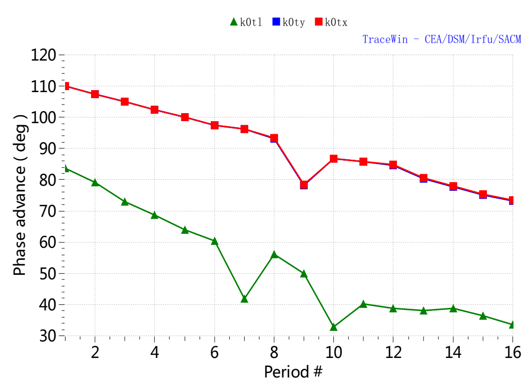

Figure 2: The phase advance of each period at zero current of HWR design.

There are some jumps at the transition section because the periodic lattice is broken by splitting cryo-module into two parts. There are four cavities and three solenoids that are adjoined adjusted to do the match between two cryo-modules in order to avoid high peak to appear at transition section in both transverse and longitudinal planes.

The rms envelop along linac is plotted in Fig. 3. For the beam is symmetric in x and y direction, the envelopes of x and y are the same as shown in the above part. While in blew part, the vertical axis is RMS bunch length in degree. Also we can see that the envelope at the transition section is smooth and there is no high peak. This means the match section is not sensitive to errors.

The acceptance of the SC section with HWR cavity The longitudinal acceptance of the SC section is analyzed

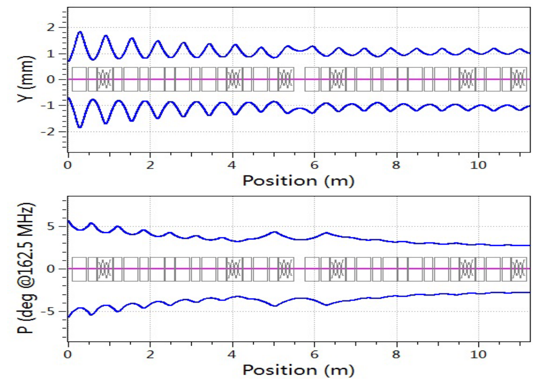

Figure 3: The envelope at 10mA current along z.

with code TraceWin at zero current. The initial longitudinal emittance is set to be large enough. In our analysis, particles, whose energy spread is larger than 0.5MeV and the phase spread is larger than 120°, are set as lost particles. These particles that can track through the lattice are used to calculate the acceptance. The acceptance is plotted in Fig. 4.

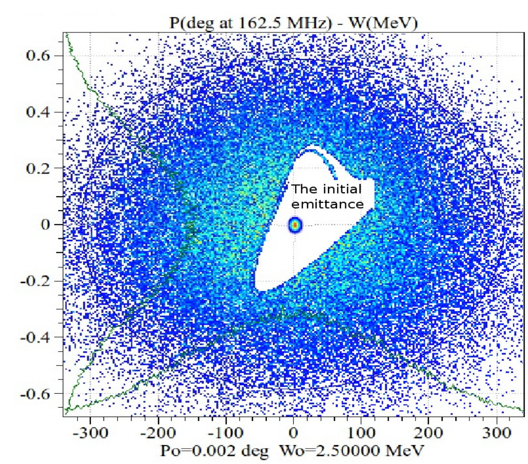

Figure 4: The acceptance of the SC section.

As shown in Fig.4, the blank part is the acceptance of the linac at 162.5MHz. In the chart, the horizonal axis is phase spread in degree and the vertical axis is energy spread. The the emittance is also plotted in the center of acceptance. The ratio of the acceptance and the emittance is about 20 times. So there is a large margin of the acceptance.

The design and simulation results with CH cavity

The superconduction CH cavity, which was first proposed by IAP[6], has developed rapidly resent years for its high acceleration gradient at low energy section. In our original design, seven cavities are used, While after the first cavity, there is a big growth of emittance in both transverse and longitudinal. To reduce the emittance growth, another cavity which is the same with the first cavity, is use to accelerate proton slowly. Some results with eighth cavities are presented below.

The phase advance of each period at zero beam current are also plotted in Fig. 5.

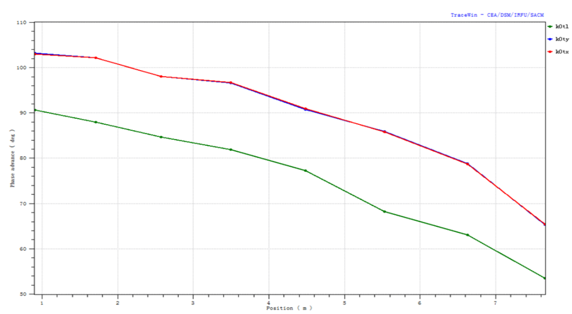

Figure 5: The phase advance of each period at zero current of CH cavity design.

From Fig 6, we can see that the phase advance alone the linac changes smoothly. And for the total length is about 8 meters, there is just one cryo-module need. So there is no transition section before 10MeV. This is very beneficial at low energy section.

The envelope in transverse and longitudinal direction is shown in Fig. 6.

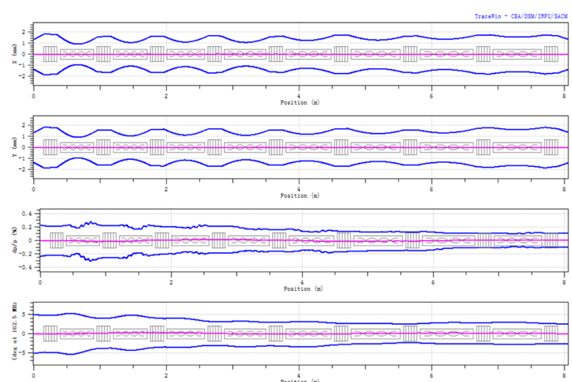

Figure 6: The envelope in transverse and longitudinal direction of CH cavity design.

From Fig 6, the envelope in both transverse and longitudinal changes smoothly.

For the longitudinal acceptance of CH cavity design, we can use the ration of synchronous phase and rms bunch length to characterize. The synchronous phase of CH cavity design is set to be around 30°. From Fig 6, we can see the max rms bunch length alone linac is 5°, the ratio is 6 times.

SUMMARY

The comparisons of main parameters between the two designs are listed in Tab 2. From simulation results, we can see that for HWR cavity design the beam dynamic is better than CH cavity design in both transverse and longitudinal. The reason is that in transverse, HWR cavity design is strong focusing than CH cavity design, which means the transverse beam rms envelope is kept to low value for HWR cavity design. So the bunch can be transported in linear electrical region. For longitudinal, HWR cavity design has a advantage that it has a large flexibility in adjust the synchronous phase because the dependent cavity, HWR cavity has a large velocity acceptance. While for there are more cells in each CH cavity, the velocity acceptance will be smaller. There is no much space for us to adjust the cavity to do the match in longitudinal.

Table 2: The basic parameters of injectorII.

Parameter	HWR design	CH design
Focusing period	16	8
Number of cavities	16	8
Aperture(mm)	20	15
Number of solenoids	18	10
Total length(m)	12.25	8
ϵ_t growth(%)	3.2	8.7
ϵ_l growth(%)	2.0	2.7
E_{pk}(MV/m)	26	22.7
B_{pk}(mT)	52	21.7
Magnet field(T)	3.6	2.8

According to the simulation results, the HWR cavity design will be first choice to ensure the flexibility in beam commission and good beam quality at low energy part. While CH cavity has a high acceleration gradient at low energy part. This is an attractive future. So CH cavity design as an alternative design is also being studied in IMP.

REFERENCES

[1] Martin Reiser, Theory and Design of Charged Parcle Beam 2nd, Wiley, New York.2008

[2] C.K.Allen, K.C.D.Chan, P.L.Colestock et al., Beam-Halo Measurements in High-Current Proton Beams, Physical Review Letters, V89,Number 21,2002.

[3] S.Nath, K.Crandall, E.Gray etl, Beam Dynamic Aspects for the APT Integrated Linac, Vol.1,1997,1162-1164.

[4] Thomas P.Wangler, RF Linear Accelerators 2nd,Wiley, New York.2008

[5] D.Uriot, TraceWin documentation, http://irfu.cea.fr/Sacm/logiciels/index3.php, 2011.

[6] H.Podlech, U.Ratzinger, H.Klein, C.Commenda, H.Lieberman, A.Sauer. Superconducting CH structure, PHYSICAL REVIEW SPECIAL TOPICS-ACCELERATORS AND BEAMS, 10, 080101, 2007.