A PRELIMINARY DESIGN OF A SUPERCONDUCTING ACCELERATING STRUCTURE FOR EXTREMELY LOW ENERGY PROTON WORKING IN TE210 MODE*

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Abstract

For the application of high intensity continuous wave (CW) proton beam acceleration, a superconducting accelerating structure for extremely low β proton working in TE210 mode has been proposed at Peking University. The cavity consists of eight electrodes and eight accelerating gaps. The cavity's longitudinal length is 368.5mm, and its transverse dimension is 416mm. The RF frequency is 162.5MHz, and the designed proton input energy is 200keV. A peak field optimization has been performed for the lower surface field. The accelerating gaps are adjusted based on KONUS beam dynamics. Numerical calculation shows that the transverse defocusing of the KONUS phase is about three times smaller than that of the conventional negative synchronous RF phase. The beam dynamics of a 10mA CW proton beam is simulated by the TraceWin code. The simulation results show that the beam's transverse size is under effective control, while the increase in the longitudinal direction is more serious. The reason is that the minend gap is not a 0.5βλ structure, and the input phase should be carefully chosen, so that the beam can timely get re-bunched at the end of the minend gap. The EM design and dynamics simulation is under further optimized.

INTRODUCTION

The radio frequency quadrupole (RFQ) has been applied with great success to a variety of ion accelerators as a low energy front end [1-4]. Also, the crossbar H mode (CH) cavity, which is a multi-gap drift tube accelerating structure, has been demonstrated to be possible for superconducting operation [5-8]. By combining the advantages of the RFQ and the CH cavity, a accelerating structure working in TE210 mode, which is designed to operate in a superconducting state and to allow the acceleration of an intense proton beam with extremely low β at relatively high effective accelerating gradient, is proposed at Peking University. As can be seen from Fig. 1, the 4 vanes connected to the cavity wall are cut by elliptical cylinders, which results in longer electrical length to reduce the cavity's transverse dimension. The electrodes are connected by two stems with the vanes of the same electrical potential. The cavity consists of eight electrodes and eight accelerating gaps, including the gap between the first electrode and the cavity end plate, which is called the minend gap. Also, the electrodes are perpendicular to one another, so there is no quadrupole asymmetry effect, which may have an impact on the transverse beam envelope. The RF frequency of the cavity is 162.5MHz, and the designed proton input energy is 200keV. The cavity's longitudinal length is 368.5mm, and its transverse diameter is 416mm. By this arrangement, the TE110 mode, which may cause the problem of strong mixing between the quadrupole modes, is short circuited along the whole cavity. Overall, the cavity is topologically equivalent to a coaxial transmission line, terminated by a short at both ends. The magnetic field bunches up and down along the cut-vanes, while the electric field is mainly concentrated in the interelectrode capacitance area.

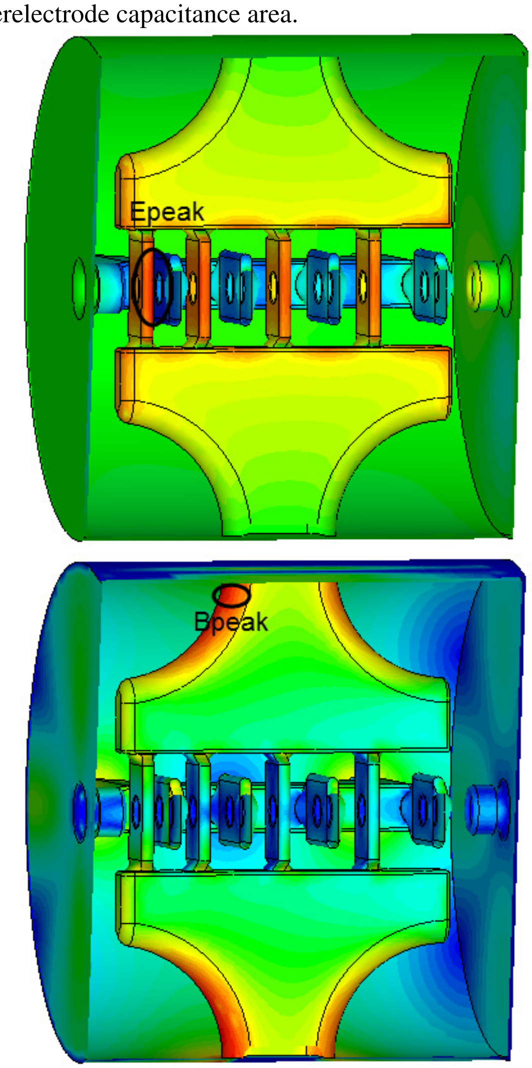

Figure 1: The surface EM fields of the cavity.

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This paper describes the structure and the operating principles of the cavity. A peak field optimization has been performed for the lower surface field. The adjustment of the accelerating gaps based on KONUS beam dynamics is presented. Also, the transverse momentum change of the proton has been calculated. Finally, the beam dynamics of a 10mA CW proton beam is simulated by TraceWin code [9].

EM OPTIMIZATION AND KONUS ADJUSTMENT

The peak electromagnetic field is an important issue for this superconducting structure. In order to prevent field emission and magneto-thermal breakdown, the conventional electromagnetic field restriction is 35MV/m and 70mT, respectively.

For this cavity, the magnetic field bunches up and down along the cut-vanes, and the location of the peak magnetic field is as marked in Fig. 1. By increasing the thickness of the vanes to 40mm, a peak magnetic field of 41.4mT is obtained.

Because the designed proton input energy is very low, the gap between the first two electrodes is short, which may result in high peak electric field in the first gap, as shown in Fig. 1. A proton energy gain of 1MeV in a total length of about 370mm is set as the cavity's design goal based on the preliminary design results. So the peak field optimization is performed mainly to reduce the cavity's peak electric field under this design objective. By simulating the influence of the structural parameters in the interelectrode capacitance area on the cavity's peak field which can be seen in Figure 2, the peak electric field is reduced to 28.3MV/m, which gives a sufficient margin with respect to the limit of 35MV/m.

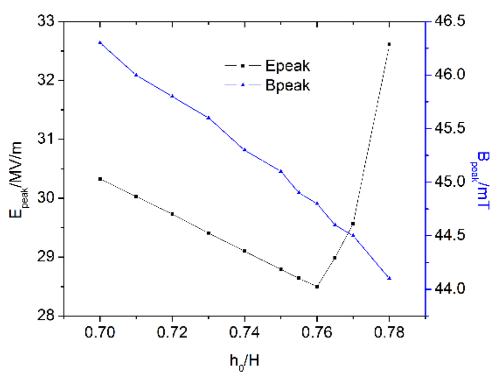

Figure 2: Peak electric field dependence on vane height h_0 is shown as an example during one step of the optimization.

The low energy proton can sustain acceleration throughout the cavity, making the velocity change significantly, so the variation of the proton velocity must be specifically considered. Unlike conventional linacs operated at negative synchronous RF phase, the accelerating gaps of this cavity are adjusted by phase sweeping based on KONUS (Kombinierte Null Grad Struktur) beam dynamics [5]. The first four gaps are operated at negative synchronous RF phase to provide longitudinal focusing. The subsequent gaps are 0^0 sections which can minimize the transverse defocusing effect. Numerical calculation shows that the proton's output energy is 1.16MeV, which basically meets the design goal for energy gain.

The proton's transverse momentum change with both KONUS phase and conventional synchronous negative RF phase has also been calculated. The calculation shows that the transverse defocusing strength with the KONUS phase is about three times smaller than that with a conventional negative synchronous RF phase of -30^0.

TRACEWIN SIMULATION

The numerical calculation results above show that the overall gap RF defocusing effect with the KONUS phase is indeed reduced. But the calculation does not take the space charge force into consideration, and also assumes that the proton's direction of motion remains unchanged throughout the cavity. Also, the transverse and longitudinal action that a passing beam suffers is a cumulative effect. So next the TraceWin code will be used to analyse the beam dynamics of a 10mA CW proton beam. For ease of simulation, the phase ellipse in every phase space is set to be standard. The lattice structure consists of 6 elements, which are shown in Figure 3. The basic parameters of the simulation are listed in Table 1.

Table 1: Basic Parameters of the Cavity Simulation

Parameters	Value
Input energy	200keV
Output energy	1.16MeV
Frequency	162.5MHz
Input x_{max}	4mm
Input x'_{max}	5 mrad
Input transverse emittance	0.083 π mm mrad
Output x_{max}	4.7mm
Output x'_{max}	3.28 mrad
Output transverse emittance	0.083 π mm mrad
Input z_{max}	2.1mm
Input z'_{max}	0.5 mrad
Input longitudinal emittance	0.0044π mm mrad
Output z_{max}	44.1mm
Output z'_{max}	69.4 mrad
Output longitudinal emittance	0.0047π mm mrad

Figure 3 (a) shows the envelope variation in the x direction along the lattice structure. The specific envelope variation of z' in the z direction in the minend gap is

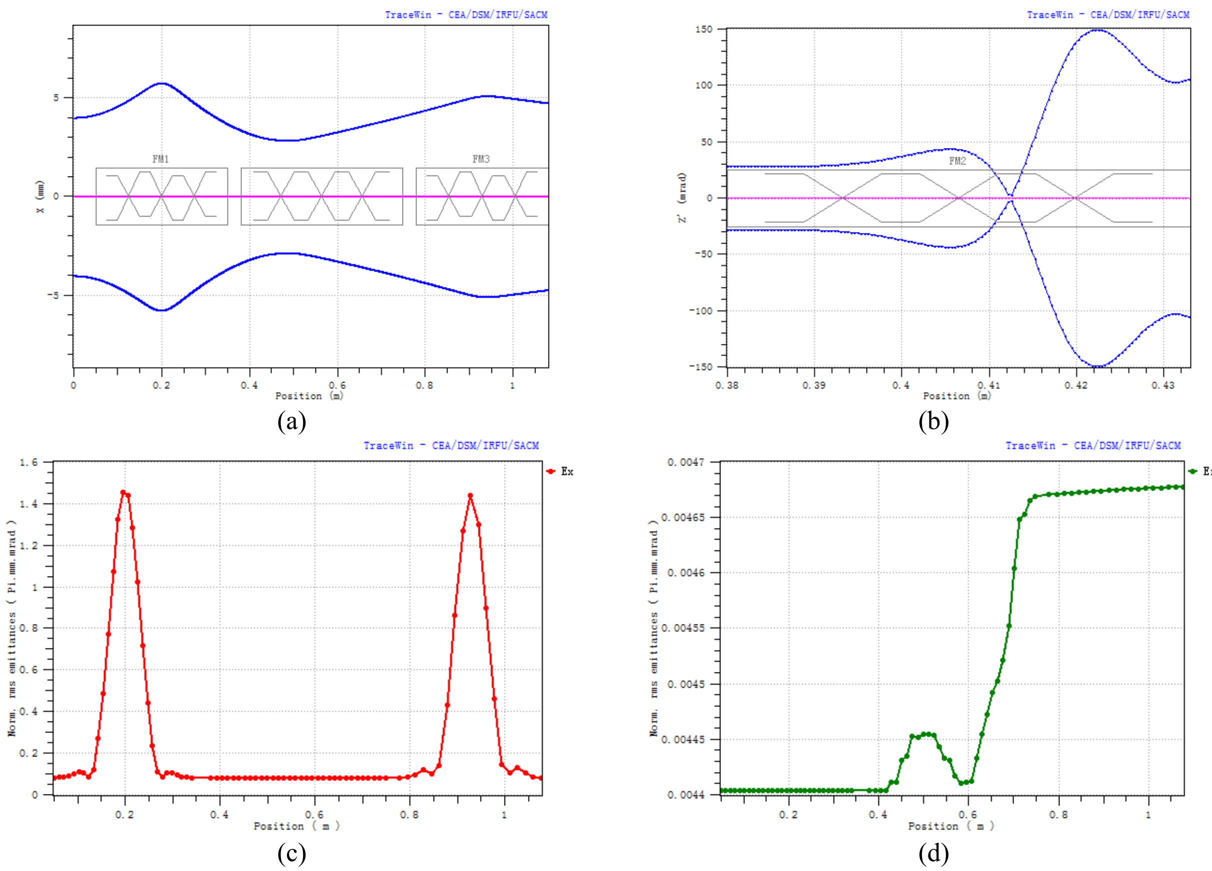

Figure 3: (a) Envelope variation in the x direction along the KONUS structure. (b) Specific envelope variation in the z direction when the beam passes the minend gap. Evolution of the normalized rms emittance in (c) the transverse direction and (d) the longitudinal direction.

shown in Figure 3 (b). It should be mentioned that the minend gap is not a 0.5βλ structure, the longitudinal motion in the minend gap should be considered carefully. Unfortunately this problem was not taken into consideration in the preliminary design of the cavity. It can be seen that, the beam experiences bunching effect too late. So the beam cannot timely get re-bunched at the end of the minend gap. This can also be reflected in Figure 3 (d), where the divergence of longitudinal emittance in the minendgap results in a peak in the first four gaps section.

The normalized rms emittance at the exit of the lattice structure in the transverse direction remains almost unchanged compared with that of the input beam. Due to the acceleration in the longitudinal direction, the normalized rms emittance in the longitudinal direction increases by about 7%. Both the TraceWin simulation and the numerical calculation shows that the proton's output energy is 1.16MeV, resulting in a relatively high effective accelerating gradient of 2.6MV/m.

In addition, reducing the length of the first accelerating gap to meet the KONUS requirement, however, will raise the peak electric field. Also, the minend gap is not a 0.5βλ structure, and the input phase should be carefully chosen, so that the beam can timely get re-bunched at the end of the minend gap.

As an attempt, a new input phase was chosen but without changing the accelerating gaps. In such condition, the beam can timely get re-bunched at the end of the minend gap, which results in a much smaller divergence in the longitudinal direction. The z_{max} was reduced to 7.2mm and the z'_{max} was reduced to 26.1mrad. The EM design and dynamics simulation is under further optimized.

CONCLUSION

For the application of high intensity and CW proton beam acceleration, a new superconducting accelerating structure for low energy protons, working in TE210 mode, has been proposed based on KONUS beam dynamics. TraceWin code has been used to analyse the beam dynamics of a 10mA CW proton beam with the input energy of 200keV. The simulation results show that the beam's transverse size is under effective control, while the increase in the longitudinal direction is more serious. The reason is that the minend gap is not a 0.5βλ structure, and the input phase should be carefully chosen, so that the beam can timely get re-bunched at the end of the minend gap. On the whole, the EM design and dynamics simulation should be further optimized.

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