A New Structure with Continuous RF Acceleration and Focusing

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ABSTRACT

A new design for an accelerating structure in which charged particles experience continuous acceleration and focusing is proposed. The structure is excited in the TM mode (not RFQ TE mode). Our calculations show high intercell coupling for the rf flow at no loss of efficiency in comparison to other rf structures. This makes the structure insensitive to manufacturing and misalignment errors. Manufacturing, assembly, and tuning should not be difficult. Our design can be scaled to operate over a broad range of wavelengths and can be made from superconductive material. Our calculations show that the structure can efficiently accelerate a wide range of particles, from low velocity ions to high energy electrons. Thus, it can bring particles from energies of several MeV (right after RFQ pre-acceleration) to hundreds of MeV. Our conclusions are based on the results of three-dimensional numerical simulations.

INTRODUCTION

Many particle accelerators, such as linear colliders, FELs, high beam current accelerators, and so on, require very high quality, low emittance beams. In addition to low emittance, it is advantageous if the beam is under continuous transverse focusing to minimize particle losses during beam transport. This transverse focusing counteracts the de-focusing effects of space charge forces in the beam.

Several very effective schemes have been developed that use magnetic fields for focusing. However, at low particle velocities, magnetic focusing becomes inefficient, and the design tends to be complicated and expensive.

A significant improvement came with the use of the RFQ accelerator, which uses rf fields for continuous acceleration and focusing, and delivers a high quality particle beam of up to several MeV of energy. At these energies, the beam can then be injected into a magnetically focused drift tube (DT) linac. The transition between the two accelerators is sensitive to the proper matching of space emittance, and without such matching, beam current losses may be significant.

In studying this problem, we concluded that an extension of the spatial focusing and acceleration principle would improve matching between two accelerators and would minimize beam loss. We have therefore designed a radio-frequency focusing (RFF) accelerating structure that fulfills requirements for a smooth transition between RFQ and DT linacs.

Our structure can be designed not just for low energy particles, but for energies up to 100 MeV. At this energy, the particles can, if desired, be injected directly to the coupled cavity (CC) linac, bypassing the use of the DT linac.

DESCRIPTION OF THE RADIO-FREQUENCY FOCUSING (RFF) ACCELERATING STRUCTURE

The design of the RFF accelerator section is shown in Figure 1. The section consists of a cylinder with a pair of specially designed plungers protruding from the cylinder wall, toward the cylinder axis. A full cavity is generated by introducing a second pair of plungers into the cylinder at a distance $L = \beta * \lambda/2$ and rotated by 90 degrees.

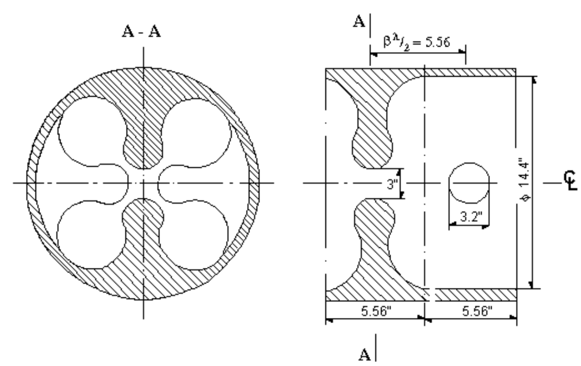


Figure 1 Cross-Section of the Structure

A cutaway view of the section is shown in Figure 2. The diameter of the cylinder is variable and is indirectly dependent on the particle velocity. For velocity v = 0.4 c, the diameter equals 36 cm, at wavelength equal to about 70 cm (425 MHz). The half-cavity on each end of the full cavity completes the design used for our computations.

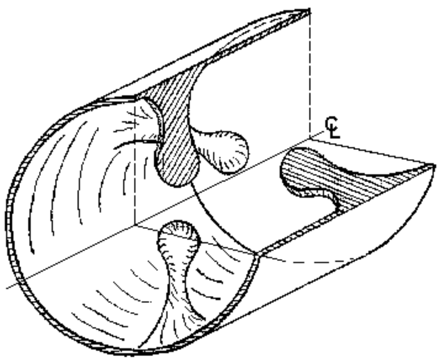


Figure 2 Cutaway View of the Section

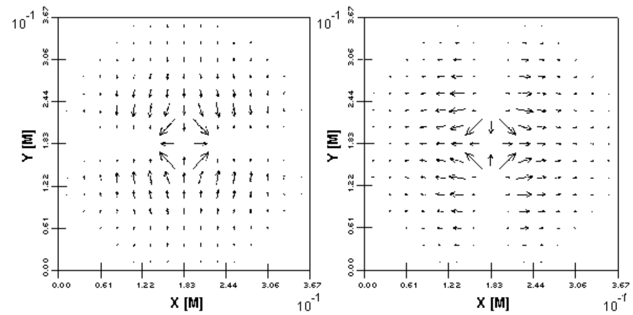
When the structure is excited in a π mode, particles traveling along the z-axis are accelerated in the space between the two pairs of plungers, and are focused as they pass through the gap between each pair of plungers. The ratio of acceleration to focusing strength can be adjusted by changing the ratio of the space between the two pairs of plungers to the thickness of the plungers. The periodicity of the structure is determined by planes of symmetry (end plates) which can be moved along the z-axis to allow calculations of additional properties of the structure.

We have identified a second, higher order mode (designated as 2π mode) that can be used for the same purposes as the π mode, but with a periodicity that covers two cavities. This mode displays excellent properties for acceleration and focusing of lower energy particles, particularly below $v = 0.2$ c. The structure has continuous radiofrequency acceleration and focusing, and is considerably less complicated than DT linacs.

The calculated intercell coupling coefficient reaches a value of 0.4, making it insensitive to manufacturing errors. Furthermore, rf tuning can be accomplished by slight changes of cell geometry. For example an increase of cylinder geometry decreases the resonant frequency of the cavity. Similarly, decreasing the gap between the pairs of plungers also decreases the resonant frequency. The separate parts of the structure are relatively easy to manufacture and assemble, and because the individual cells can be made from a single piece of metal, it is a good candidate for a superconductive structure.

RESULTS OF THE COMPUTATION

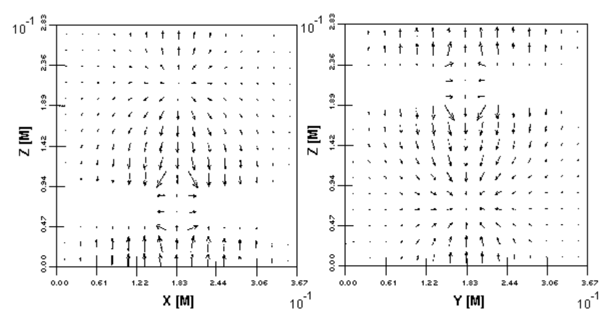
We performed calculations using our three-dimensional, finite difference code developed for an 80486-based IBM PC. The calculated fields of the representative section are shown in Figure 3. Figure 3a illustrates our calculations of



a) Z = 7.06 cm b) Z = 21.2 cm

Figure 3 Vector Plots of E_X,E_Y Fields in X,Y Plane

the E_X and E_Y components in the X,Y plane at the position of the first pair of plungers. Similarly, Figure 3b illustrates the E_X and E_Y components in the same plane at the position of the second (Y-direction) pair of plungers (half wavelengths apart in the Z-direction and rotated 90°). In both cases, the focusing components of E fields are indicated

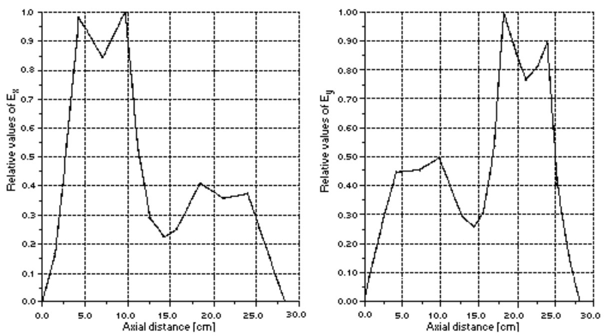


a) E_X,E_Z at X = 0 cm b) E_Y,E_Z at X = 0 cm

Figure 4 Vector Plots of Fields in X,Z and Y,Z Planes

by arrows. In Figures 4a and 4b, we show the E_Z accelerating component in the X,Z and Y,Z planes, respectively.

In Figure 5, we show field profiles in several planes of the cavity. Figure 5a illustrates the focusing component E_X as a function of axial distance Z. The high value of E_X occurs in the space between the first pair of plungers, while its value is much smaller in the gap of the second pair. The values of the E_Y component are reversed: in the gap of the first pair of plungers, E_Y has a small value, while its value peaks in the space between the second pair of plungers. This is shown in Figure 5b.



a) Relative E_X Field vs. Z   b) Relative E_Y Field vs. Z

Figure 5   Field Profiles

Figure 6 shows the accelerating component E_Z along the Z-axis, where one can see the periodicity of the accelerating field. Figure 7 shows the value of field component E_X across the cavity in the X direction, taken in the middle of the cavity in the Z direction.

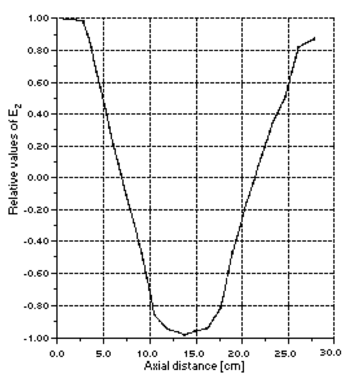


Figure 6   Relative E_Z Field vs. Z

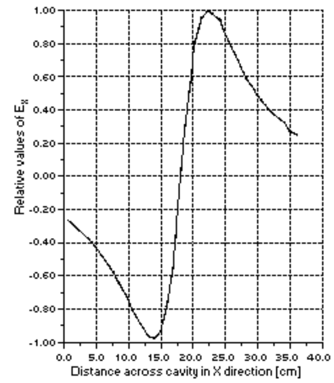


Figure 7   Relative E_X Field vs. X, in the Axial Center of the Cavity

CONCLUSION

Our RFF accelerating structure offers efficient transport of particles for a wide range of energies. The ease of manufacturing and tuning makes the structure attractive for a variety of applications, and the simplicity of our design makes it possible to explore its use in superconducting accelerators.

At this time, we have no results of calculations for the tracing of particle trajectories in the structure section. However, based on our preliminary analysis, we have concluded that beam quality will be preserved after transport of the beam through the chain of RFF sections. We expect to continue our study in this direction.

ACKNOWLEDGMENT

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