Beam Dynamics Studies of Four-gap Low-beta Superconducting Resonators

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Abstract

The four-gap superconducting resonators which have been developed at Argonne for use in the low-beta positive ion-injector for ATLAS [1] have potential applications for ions with velocities less than 0.007c and q/m less than 0.1. It was previously observed that at low velocities these structures can be focusing in both longitudinal and transverse phase spaces due to an inherent alternating-phase-focusing property [2]. Studies are underway to determine the optimum combination of multi-gap structures and solenoids at low velocity and low q/m. In this paper we present the results of acceptance studies for the first three resonators at the front of the positive-ion injector linac, with and without the focusing solenoids. These studies include the effects of higher-order distortions in longitudinal and transverse phase spaces since minimizing such aberrations is very important for most nuclear physics applications of such accelerators.

I. INTRODUCTION

The new positive-ion injector (PII) linac for ATLAS uses 18 4-gap superconducting niobium resonators [1] to accelerate ions as heavy as uranium from initial velocities of about 0.008c [3] [4]. The successful performance of this new linac has led us to investigate possible extensions of this technology to even lower velocities, with potential applications in the acceleration of radioactive beams. We are first investigating the details of the beam dynamics at the low velocity end of this linac, with special emphasis on the transverse and longitudinal acceptances and nonlinearities. (see paper Ga9 of this conference [5].) Figure 1 is a schematic of the first two types of resonator at the entrance of the PII linac.

Figure 1: The first two of the four types of superconducting resonators in the PII linac; they are 48.5 MHz quarter-wave structures. The I1 type (left) has an effective length of 10 cm, in which the beam energy more than doubles.
II. ALTERNATING-PHASE FOCUSING

Due to the rapid velocity increase in the first few gaps of this linac, as shown in Figure 2, there is an inherent alternating-phase focusing aspect to the beam dynamics [2] [6]. Figure 3 illustrates that the transverse focusing for an argon beam is so strong that an initially diverging beam is brought to a waist within the first 10 cm. Figures 4 and 5 illustrate more schematically the transverse and longitudinal focusing properties of the first two resonators for both argon and uranium beams.

![Graph showing the evolution of a transverse phase space ellipse through the II resonator.](image)

Figure 2: The velocity, beta, of a uranium beam entering the II resonator at about 0.0086 and leaving at about 0.0134. The gradient is 4.5 MV/m over the 10 cm effective length of the cavity.

III. NONLINEARITIES

The low velocity end of the PII linac consists of the following components: solenoid, II resonator, solenoid, II resonator, solenoid, second II resonator, etc. We have done calculations to compare the acceptances of the linac, in longitudinal and transverse phase spaces, for this standard configuration and for the case with the first three superconducting solenoids turned off. "Geometrical" and "linear" acceptances were evaluated [5]. Although the acceptances are significantly greater with the solenoids, the results without look promising enough to search for more optimum configurations. Since the present calculations
have been done with the actual linac configuration, it will be straightforward to test these predictions with actual beams in the near future. Figure 6 shows the predicted degree of distortion after three resonators for a uranium beam with no transverse focusing between them.

IV. FUTURE STUDIES

These studies will be continued, to develop the optimum combination of resonators and transverse focusing elements. Experimental studies will be done to test the predictions. As we gain experience with and understanding of the dynamics of these linac structures, more cost effective solutions will almost certainly evolve. For the first stages of acceleration of radioactive beams structures capable of accelerating ions with q/m values much less than the present 0.1 will be necessary. It appears that the PII technology will also be useful in this lower velocity, lower q/m regime.

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REFERENCES