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 focussing in both longitudinal and transverse phase spaces due to an inherent alternating-phase-focussing 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 focussing solenoids. These studies include the effects of higher-order distortions in longitudinal and transverse phase spaces since minimising 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.

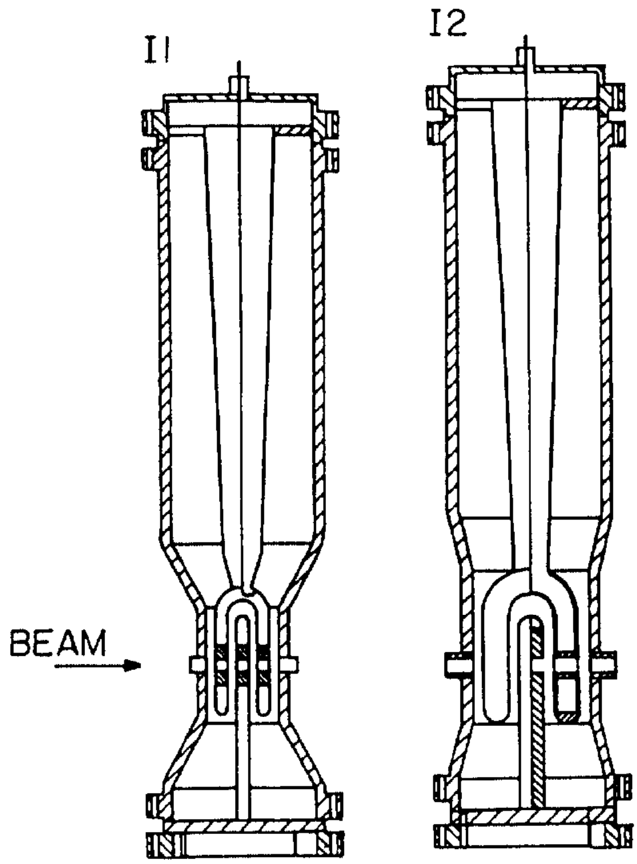

Figure 1: The first two of the four types of superconducting resonators in the PII linac; they are 48.5 MHz quarter-wave structures. The I1 type (left) has an effective length of 10 cm, in which the beam energy more than doubles.

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II. Alternating-phase Focussing

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 focussing aspect to the beam dynamics [2] [6]. Figure 3 illustrates that the transverse focussing 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 focussing properties of the first two resonators for both argon and uranium beams.

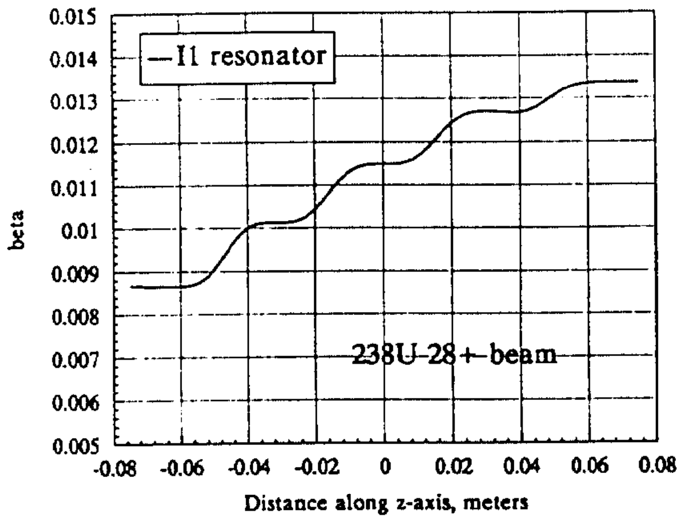

Figure 2: The velocity, beta, of a uranium beam entering the I1 resonator at about 0.0086c and leaving at about 0.0134c. The gradient is 4.5 MV/m over the 10 cm effective length of the cavity.

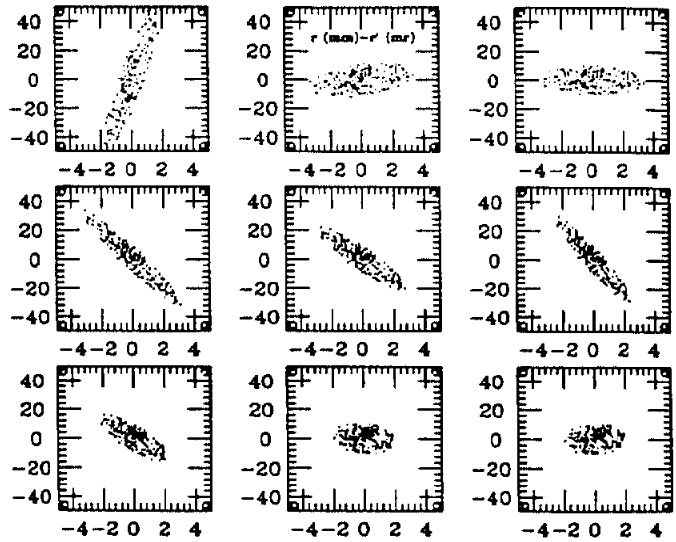

Figure 3: The evolution of a transverse phase space ellipse through the I1 resonator. The beam is $^{40}Ar^{12+}$ and it is diverging slightly as it enters the the resonator, at the upper left box of the figure. (The beam is travelling left to right starting at the upper left and then from the top to bottom rows.) The very strong transverse focussing of the first gap is seen in the top row. In each box the vertical axis is divergence in mr and the horisontal is sise in mm. The calculations are the results of raytracing with up to third order terms in the resonator electric field distribution.

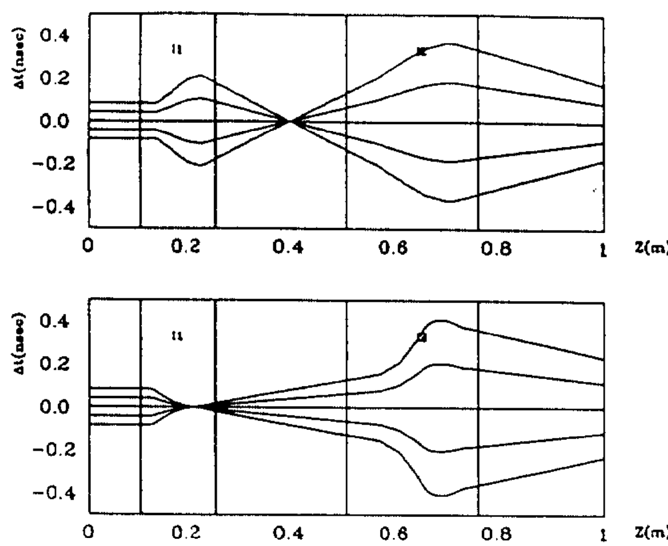

Figure 4: Raytracing of initially parallel trajectories through I1 and I2. The upper plot is for a $^{40}Ar^{12+}$ beam, and the lower is for a $^{238}U^{24+}$ beam. In this case the vertical axis is the time deviation from the central partical. In both cases the rf phases are set for longitudinal focussing.

III. Nonlinearities

The low velocity end of the PII linac consists of the following components: solenoid, I1 resonator, solenoid, I2 resonator, solenoid, second I2 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

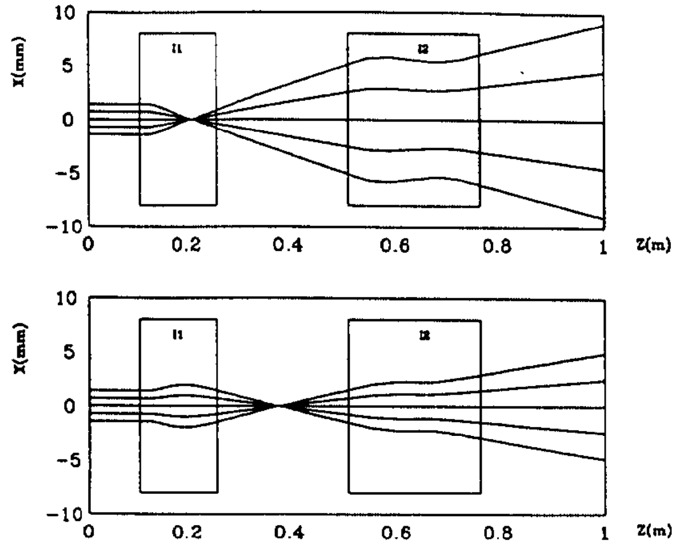

Figure 5: Plots similar to Figure 4, but in transverse phase space. The I1 resonator is stongly focussing for both beams, while I2 is only slighly focussing.

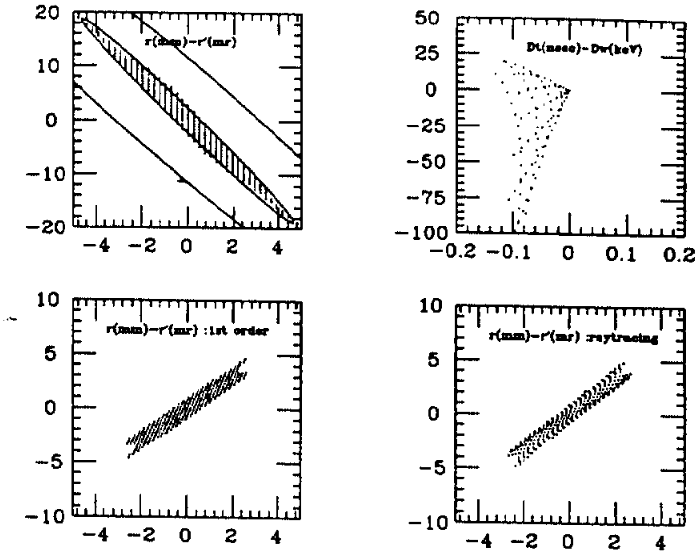

Figure 6: The shaded ellipse in the upper left box represents a transverse area of 11π mm·mr for a uranium beam entering the I1 resonator. The lower right box shows the particles transmitted, as calculated via raytracing. The lower left box shows the same particles calculated to first order only. The upper right shows the amount of emittance growth in the longitudinal coordinates in keV vertical axis and nsec horisontal axis. The initial longitudinal emittance was assumed to be sero to illustrate the coupling terms.

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 focussing between them.

IV. Future Studies

These studies will be continued, to develope the optimum combination of resonators and transverse focussing 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

[1] K.W. Shepard, *et al.*, *Proc. 1989 IEEE Part. Accel. Conf.*, IEEE#89CH2669-0(1987)974.

[2] R.C. Pardo, *et al.*, *Proc. 1987 IEEE Part. Accel. Conf.*, IEEE#87CH2387-9(1987)1228.

[3] R.C. Pardo, *et al.*, paper Mc9 at this conference.

[4] L.M. Bollinger *et al.*, *Nuclear Physics*, A553, (1993) 859c-862c.

[5] K. Joh and J.A. Nolen, paper Ga9 at this conference.

[6] L. Sagalovsky and J.R. Delayen, *Proc. 1992 Linear Accel. Conf.*, C.R. Hoffmann, Ed., AECL-10728(1992)763.