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RFQ DEVELOPMENT AT LBL

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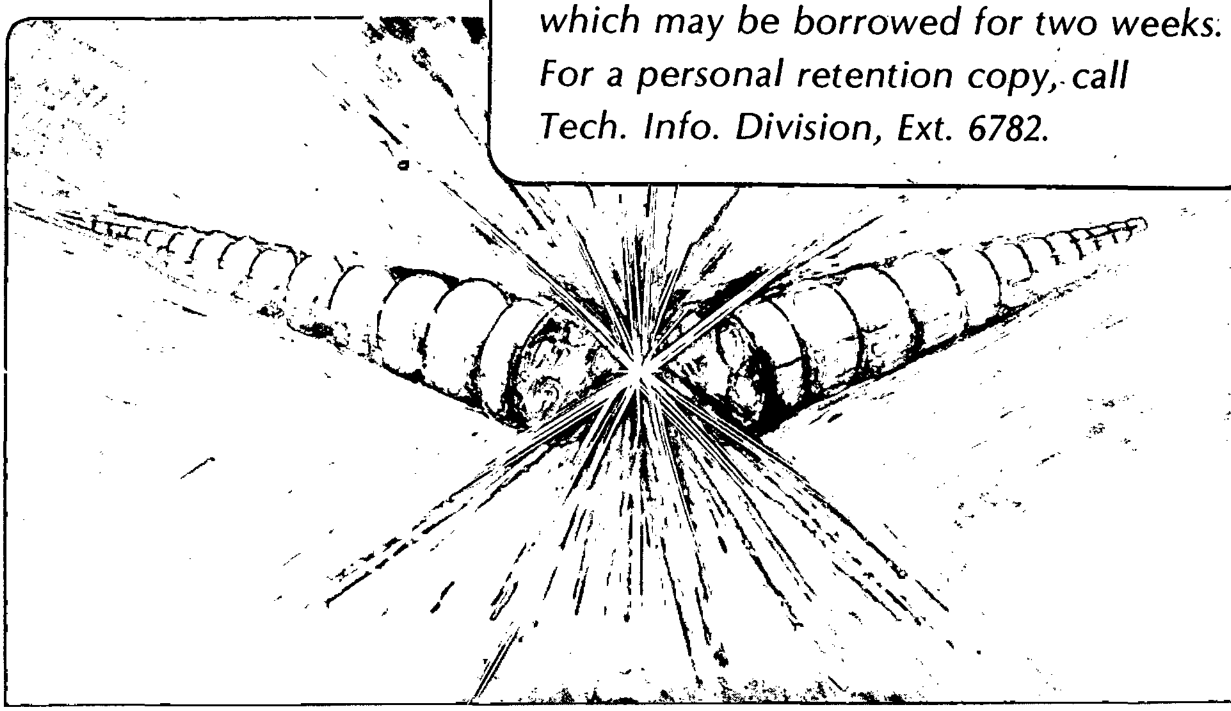

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Summary

The radio frequency quadrupole (RFQ) is a structure which can efficiently focus, bunch and accelerate low velocity ion beams. It has many features which make it particularly attractive for applications in the biomedical and nuclear sciences. There are two projects in progress at LBL where the incorporation of heavy ion RFQ technology offers substantial benefits: in the upgrade of the Bevatron local injector, and in the design of a dedicated heavy ion medical accelerator. In order to meet the requirements of these two important applications, a 200 MHz RFQ structure has been designed for ions with charge to mass ratios as low as 0.14, and a low RF power scale model has been built and tested. Construction of the high power model has begun. The status of this project is reviewed and a summary of technical specifications given.

Introduction

Heavy ions were first accelerated at the Bevatron in August 1971 using its local Alvarez linac injector in the 2 $\beta\lambda$ mode. This operating mode is used to inject 5 MeV/amu ion beams up to mass 12 (carbon) into the Bevatron. Since 1975 the SuperHILAC has also been used as an injector for heavier ion beams. This coupled mode of operation, referred to as the Bevalac, is currently used to accelerate a wide range of ions, up to mass 238 (uranium), to energies of approximately 1 GeV/amu. When used as the Bevatron injector, the SuperHILAC is time-shared with other SuperHILAC users to maximize the utilization of the overall facility.

The Bevatron experimental program is comprised of biomedical and nuclear science programs. The radiotherapy and associated biomedical research utilize beams up to mass 40 (argon), while the nuclear science program requires the complete range of available ions. Satisfying the demands of both programs requires frequent changes of ion species injected into the Bevatron. The concomittant requirement to retune the SuperHILAC and beam transfer line results in a loss of operational efficiency.

In 1981 two new initiatives were undertaken at LBL, both of which motivated the development of a heavy ion radio frequency quadrupole linac or RFQ. These are the design of a dedicated medical accelerator[1] and the upgrade of the Bevatron local injector--extending its capability up to mass 40. The RFQ performance requirements for these two applications are identical. The Bevatron local injector upgrade will greatly enhance the efficiency of the experimental program and the resulting operational experience will demonstrate the suitability of the RFQ design for a future medical accelerator facility.

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The RFQ linac has several unique properties which render it attractive to these specific applications. It has the ability to capture and bunch almost 100% of the beam from the ion source and it has a very low injection energy requirement. This latter point eliminates the need for a large Cockcroft-Walton pre-accelerator and facilitates access to the ion source. The operational simplicity of the RFQ also enhances its appeal to the medical applications of interest at LBL.

Upgrade of the Bevatron Local Injector

A schematic representation of the Bevatron local injector is shown in figure 1 before and after the proposed upgrade. The present local injector consists

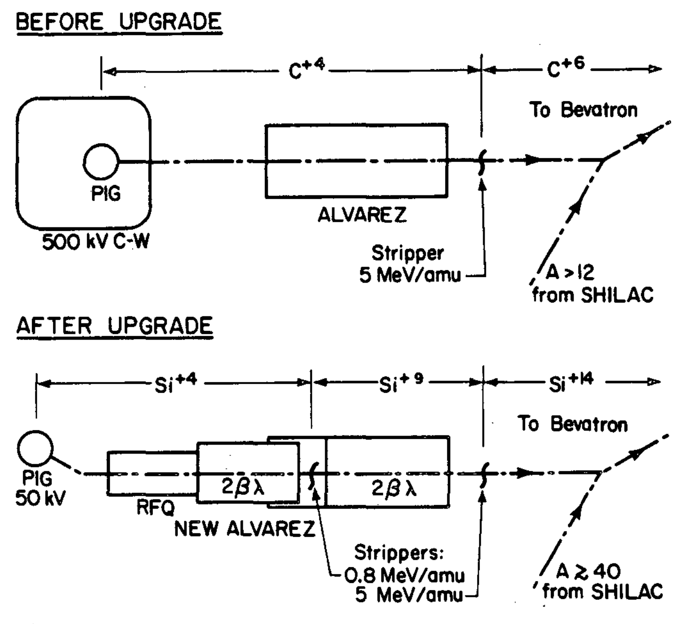

Figure 1: Configuration of the Bevatron local injector before and after proposed upgrade.

of a PIG ion source and a 500 kV Cockcroft-Walton injecting an Alvarez linac. The linac is currently operating at the limit of its voltage holding capability, and conditioning periods up to one week are necessary to achieve the required gradients. A stripping foil at 5 MeV/amu fully strips the beams prior to injection in the Bevatron.

After the upgrade, the PIG source will be on a nominal 50 kV platform. The beams from the ion source will have an energy of 7 keV/amu and charge to mass ratios as low as 0.14. Mass analysis will be performed in a short transport line which will match the beam into the RFQ. The RFQ will capture, bunch, and accelerate the beam to an energy of 200 keV/amu. A closely coupled two beta-lambda Alvarez linac will further accelerate the beam to 800 keV/amu where it will be stripped to a minimum charge to mass ratio of

0.3. Drifts tubes in the first 2 m of the present linac tank, the area now requiring the highest gradient, will be removed to accommodate this stripper assembly and part of the new pre-stripper linac. The remainder of the present linac will then be used for acceleration to the final 5 MeV/amu injection energy. All linacs will operate at 200 MHz with a duty factor of 0.002.

RFQ Cold Model

In order to study the electrical tuning of RFQ cavities and the effects of small mechanical alignment errors, a low power model was constructed and tested. This model was designed to resonate at 372 MHz, and, as it was scaled down from the final 200 MHz design in all dimensions, it has the same RF characteristics as the final design. A photograph of this model is shown in figure 2. It is a four vane cavity design similar to the proof-of-principle machine successfully demonstrated at Los Alamos[2]. The vanes were machined from jig-plate aluminum to 25 micron tolerances and have no modulations on the tips. They can be mechanically aligned by a system of pusher screws to ± 25 microns as determined by pin gauge measurements between pole tips. The cavity was made from an aluminum tube. Both the cavity and the vanes were copper plated. The bore and cavity radii are 0.108 and 8.49 cm respectively.

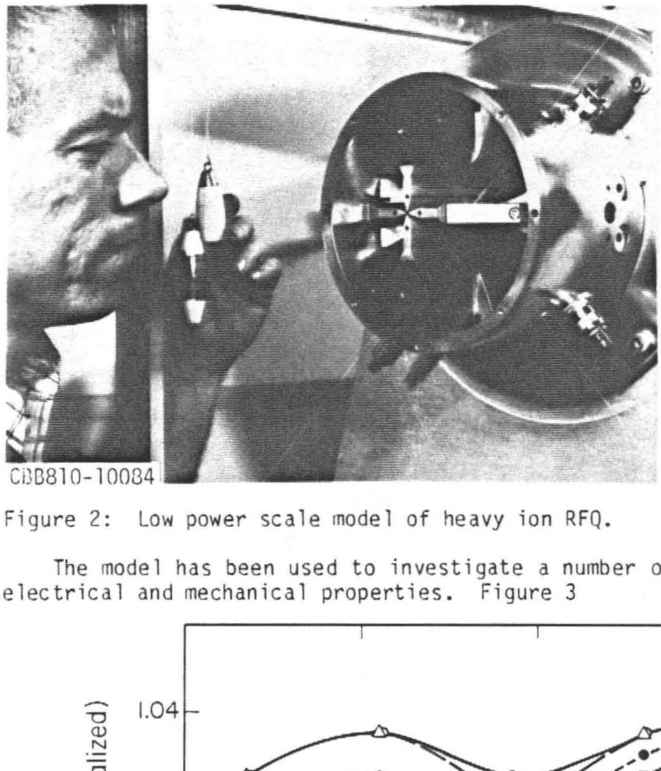

Figure 2: Low power scale model of heavy ion RFQ.

The model has been used to investigate a number of electrical and mechanical properties. Figure 3 illustrates the typical longitudinal and azimuthal field uniformity which can be achieved under well-tuned conditions. These data were taken with the model incorporating the vane coupling ring (VCR) innovation[3,4] as illustrated in figure 4, to improve the azimuthal field balance. In this case three VCR pairs located at the center and both ends of the vanes were used. As can be seen in figure 3, an overall balance of ± 3% was achieved. Without VCR's, typical balances were more than a factor two poorer. The Q of the cavity was approximately 2000. Further details of these measurements will be given in a future paper.[5]

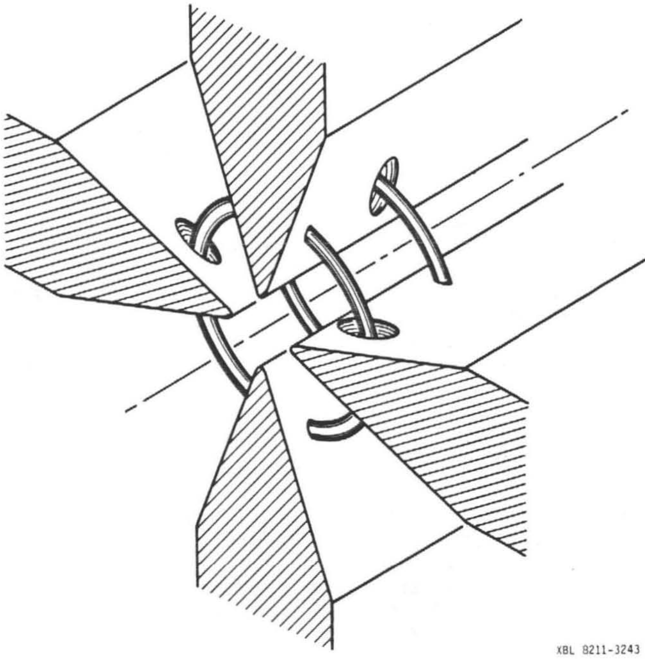

Figure 4: Schematic illustration of 1 pair of vane coupling rings.

Heavy Ion RFQ Design

The beam dynamics were calculated using the computer codes GENRFQ[6] and PARMTEQ[7]. On the basis of computer simulation of the beam dynamics for the RFQ now under construction, approximately 90% of the beam was captured and accelerated at intensities where space charge effects can be ignored. The space charge

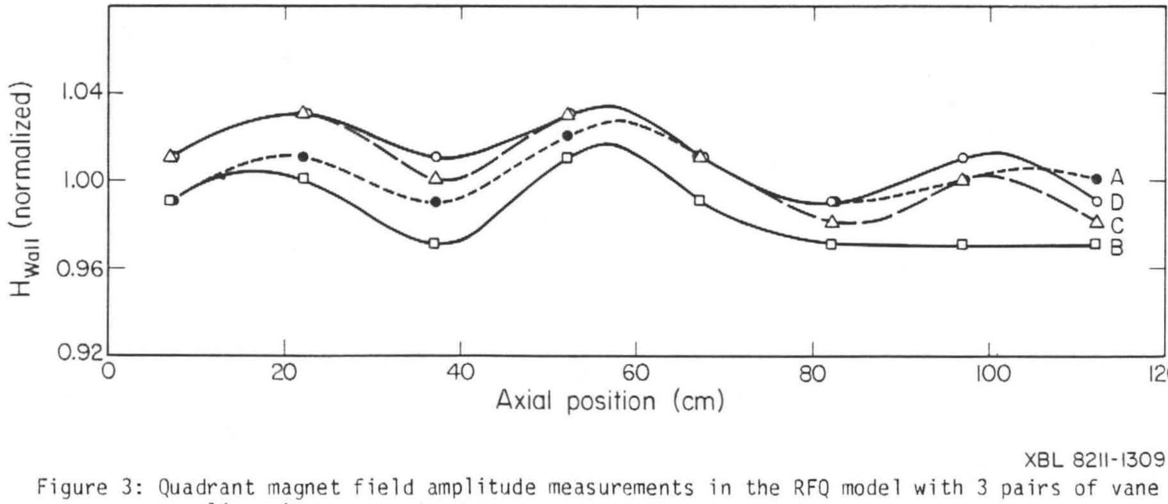

Figure 3: Quadrant magnet field amplitude measurements in the RFQ model with 3 pairs of vane coupling rings.

limit has been determined with these same simulations to be on the order of 5 emA. An exit matcher has been added to improve the matching into a following Alvarez linac. The important design parameters are summarized in Table 1.

Table 1
RFQ Design Parameters

Structure	4 vane, loop driven
Design ion	$^{28}Si^{+4}$
Frequency	199.3 MHz
Vane length	224.85 cm
Avg. bore radius (r_0)	0.254 cm
Cavity ID	15.583 cm
Input energy	7.1 keV/amu
Output energy	200 keV/amu
Total no. of cells	346
Radial matcher	6.4 cm (20 cells)
Exit matcher	63 cm (45 cells)
Normalized acceptance	0.05 pi cm-mrad
Transmission	90%
RF power	100 kW peak
Stored energy	0.6 J
Duty factor	0.002
Vane-vane voltage	51 kV
Max. surface field	29 MV/m.

Figure 5 shows a typical cross section of the RFQ and illustrates many of the mechanical design features. The vanes and cavity are made of copper plated low carbon steel. Each vane is mounted by means of six cylindrical plugs which are aligned against precision ground flats on the outside of the cavity. Axial, radial and transverse degrees of freedom are provided for precise vane alignment. Fiducial notches are located on each vane to facilitate proper location of the vane tips. A numerically controlled mill with a 96 inch (2.44 m) bed is used to accurately locate these fiducials in the same set up used to produce the modulated surface on the vane tips. A pair of copper bars is mounted near the base of each vane for coarse frequency tuning.

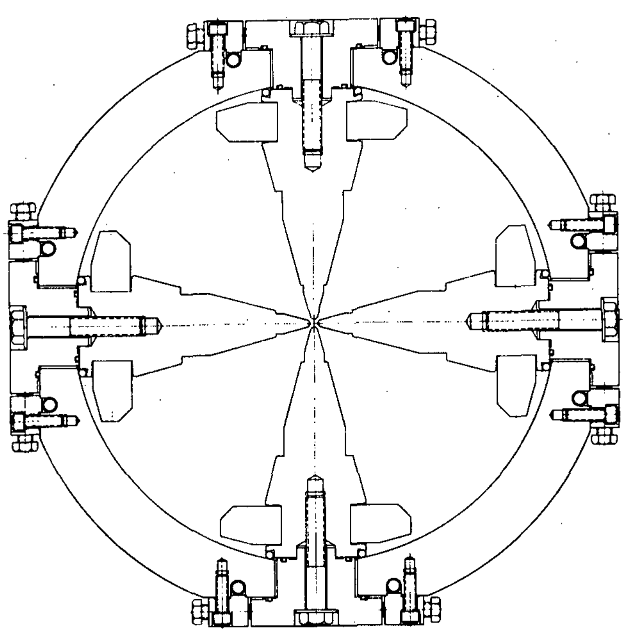

Figure 5: Typical section of LBL heavy ion RFQ.

They can be inserted or removed without disturbing the alignment of the assembly.

Using experimentally measured[8] charge exchange cross sections, a pressure requirement of 10^{-6} Torr in the beam aperture has been calculated. The cavity will be pumped from the entrance end using a turbomolecular pump, and additionally, each quadrant will be cryogenically pumped through radial ports located in the cavity 150 cm from the entrance end.

Project Schedule

The fabrication of most of the RFQ components, including all four vanes, has been completed and final assembly is expected to begin soon. Several tests will be conducted in early 1983 including low power RF tuning, vacuum and high power RF tests and finally beam acceleration and transmission measurements. The high power RF tests and beam measurements will be conducted near the Bevatron local injector in order to use the existing PIG source and RF equipment. Components for the low energy beam transport and mass analyzer are being fabricated and tested. Modifications to the present Alvarez linac and component fabrication for the new pre-stripper linac will take place in 1983. Final on-line operation of the upgraded Bevatron local injector is projected for late 1983 or early 1984.

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