LBL-18966

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

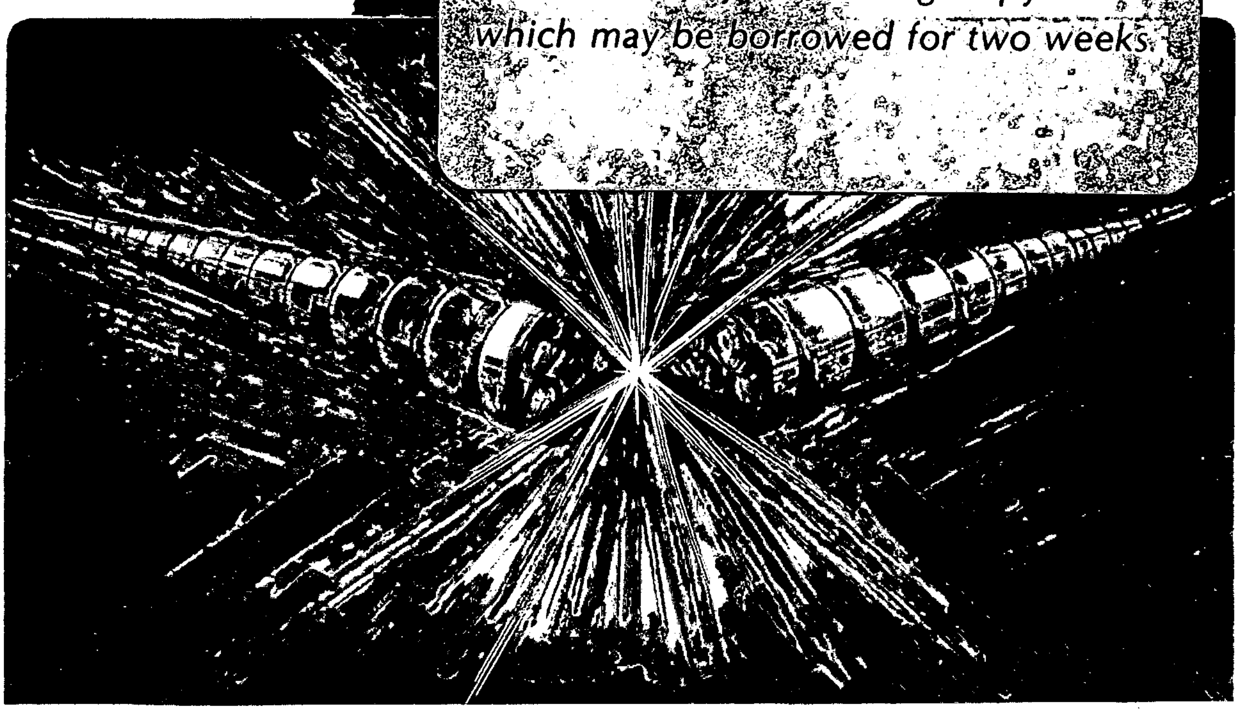
Accelerator & Fusion Research Division

Presented at the 1985 Particle Accelerator Conference, TRIUMF, Vancouver, B.C., Canada, May 13-16, 1985

A COMPACT HEAVY ION RFQ PREACCELERATOR FOR USE AT THE CERN LINAC I

R.A. Gough, J. Staples, R. Caylor, D. Howard, R. MacGill, and J. Tanabe

May 1985



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

A COMPACT HEAVY ION RFQ PREACCELERATOR FOR USE AT THE CERN LINAC I*

LBL-18966

R. A. Gough, J. Staples, R. Caylor, D. Howard, R. MacGill, and J. Tanabe
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Abstract

This paper describes the LBL contribution to a project designed to provide fully-stripped oxygen beams for acceleration in the CERN PS complex.[1] A preaccelerator for Linac I, consisting of an ECR ion source, an RFQ linac, and RF matching cavities, is being assembled as part of a collaborative arrangement among LBL, GSI, and CERN. The RFQ, designed and built at LBL, will accept analyzed oxygen +6 beam from the ECR at 5.6 keV/amu, and accelerate it to 139.5 keV/amu, the injection energy required for 2 $\beta\lambda$ operation of Linac I. Stripping to +8 will be done with a foil stripper at 12.5 MeV/amu at the exit of Linac I. The RFQ operates at 202.56 MHz and is 0.86 meters in length. The structure is stabilized with vane coupling rings, and uses a single drive loop and a single tuning loop.

Introduction

Recently, RFQ linac structures have been successfully incorporated into several working injectors.[2] The RFQ described here is part of a new preinjector that will provide light heavy ions for experiments at CERN. Together with an ECR ion source and improved beam diagnostics, this RFQ will provide beams for the study of relativistic, oxygen-induced, nucleus-nucleus reactions at PS and SPS energies.[3]

Fully-stripped oxygen beams with intensities of 10 eμA are anticipated at the exit of Linac I. The Grenoble-built ECR ion source, low energy beamline and injector diagnostics are being provided by GSI. Necessary upgrading of the beam instrumentation in the PS rings is being carried out by CERN.

The RFQ has been designed and built at LBL, using the same design concepts developed for the heavy ion RFQ at the Bevatron.[4] It is a four-vane, loop-driven structure, stabilized with 3 pairs of vane coupling rings.[5] It accepts an $^{16}O^{+6}$ beam from the ECR source at 5.6 keV/amu, and accelerates it to 139.5 keV/amu, the injection energy for 2 $\beta\lambda$ operation of Linac I. The 202.56 MHz RFQ has a total length of 86 cm. Frequency tracking is accomplished using a single, rotating loop. The peak power requirement is approximately 20 kW, and the duty factor is less than 0.1%.

RFQ Beam Dynamics

Major constraints in the design of this RFQ were the large normalized acceptance of 0.9 π mm-mrad and small longitudinal output phase space area requirements. Adiabatic capture of the beam in the RFQ starts at the low injection energy of 5.63 keV/amu, resulting in an output longitudinal phase space area of 0.28 MeV/amu - degree, which should provide good acceptance into Linac I. This injection energy implies an extractor voltage of 15 kV, which is in the optimum range for the ECR source.

To provide the large transverse acceptance, a value of 7 was chosen for the focusing parameter B, which is unusually high for a heavy ion machine. The problem of machining the modulations onto the vanes for a low velocity structure such as this is made difficult by the small inner radii of the valleys of the sinusoidal-like modulation pattern. For this design, the minimum radius varies as the inverse fourth power of the surface field, but the transverse acceptance varies as the 1.5 power, and the length as the square of the surface field. The best compromise was to select a low surface field of 25.9 MV/m (1.55 Kilpatrick) and a large focusing parameter, resulting in a minimum valley radius of 1.25 cm.

As a large fraction of the aperture will be used, the vanetip design uses a variable radius geometry, minimizing the higher order multipole components, and ensuring the full transverse acceptance. The peak surface field enhancement at the end of the prebuncher (the worst case) is 6% over an unmodulated vane.

The high value of the focusing parameter implies a large beam divergence in to and out of the structure. The beam is matched into the RFQ with a solenoid located very near the entrance. The exit beam divergence is reduced by tapering the value of B from 7 to 4 over the last 20 cm to ease the matching into the MEBT. This taper changes the local cutoff frequency of the structure by several MHz at the exit, introducing a tilt in the vane voltage distribution. This is removed, as discussed below, by tuning the end geometry of the structure.

The injector parameter requirements were satisfied with a structure 86 cm long, containing 169 cells, including 16 cells in the entrance radial matcher, and using 20 kW of peak power for a vane-vane voltage of 36 kV. Computations predict a 95% capture of the beam with a negligible transverse emittance growth. The space charge limit is about 10 emA, 100 times the actual source intensity.

Mechanical Design

The mechanical design of this machine is similar to that developed for the Bevatron RFQ. [4] A composite cross-sectional view of the structure is shown in Figure 1. Primary reference fiducial flats are precision ground onto four sides of a thick-walled, copper-plated steel cavity. Each vane is supported by 3 equally-spaced cylindrical mounting plugs with two critical engagement surfaces whose separation distance controls the radial position of the vanetip and the amount of compression placed on the spiral spring RF joint at the vane base. The transverse placement of the vane is determined by the shim thickness between the mounting plug flange and the jacking bars. These bars run down the length of the cavity and are keyed into the outside of the cavity wall. Thermal stabilization of the structure is maintained by a water tube that is captured in this keyway by the jacking bar.

Of four circular ports near the longitudinal center of the cavity, two, diametrically opposed, are used for the single drive and tuner loops. A teflon vacuum interface is used for the drive loop, and a ferrofluidic vacuum feedthrough is used for the continuously active tuner loop. Four vacuum ports are located near the entrance, one in each quadrant. Field amplitudes are monitored by two loops near the ends of each quadrant.

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Div., U.S. Dept. of Energy under Contract No. DE-AC03-76SF00098.

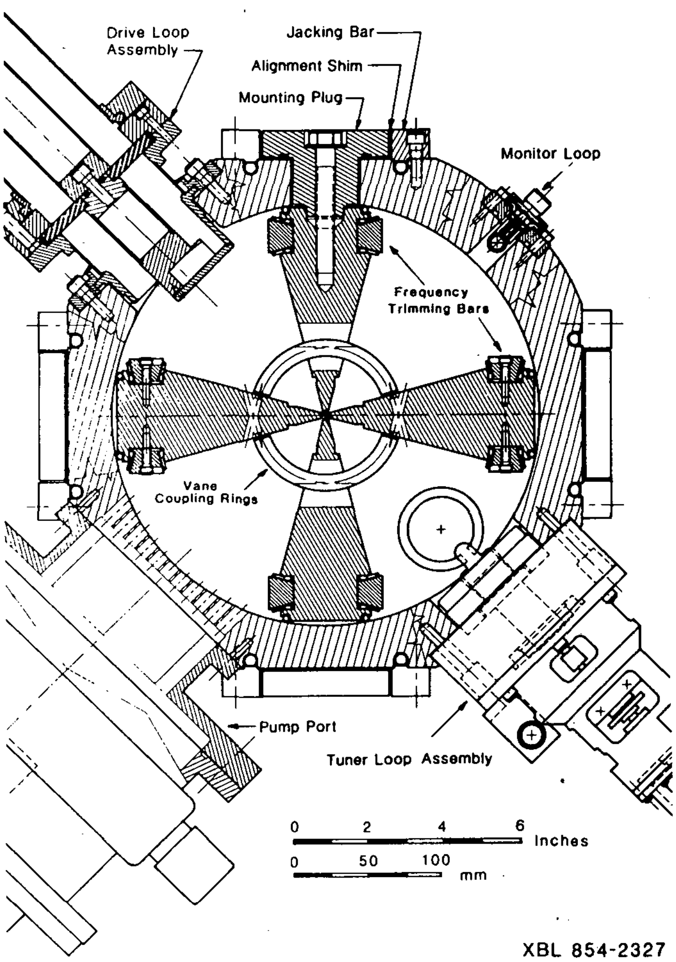


Fig. 1 Composite cross sectional view of the RFQ.

The vanes, like the cavity, are made of copper-plated mild steel. The vanetip modulations were cut on the LBL numerically-controlled milling machine in two passes of 40 and 10 mils. A fiducial surface for transverse vane alignment was cut in the same setup used to machine the modulations. Tuning bars near the base of each vane are used to trim the frequency of the structure. Finger stock, soft soldered to the bars, forms the RF joint between the bar and the vane. These bars are made of silver-plated copper and can be removed and replaced without disturbing the vane alignment. The vanes are copper-plated to a thickness of 2.5 mils everywhere except near the tip, where the 0.2 mil cyanide copper strike coat is the only finish applied to the surface.

Assembly and Alignment

The four surfaces machined on the outer wall of the cavity are flat and parallel to within 1 mil. The center line established by the four flats is within approximately 2 ± 1 mils vertically, and 1 ± 0.2 mils horizontally of the bore center line.

For assembly, eight roller bearings were mounted on the outside of the cavity permitting the structure to rotate about its axis of symmetry on two circular raceways. Each vane was placed in the cavity one at a time and its longitudinal, radial, and transverse position determined. The cavity was rotated so the vane being aligned was on the bottom. The radial and transverse placement of the vanes were measured relative to the adjacent and opposing cavity flats respectively. The radial position was measured from the crests of the vanetip modulations at the locations of the three mounting holes. The transverse vane position was measured from the fiducial notch near the vanetip to the adjacent cavity flats. In this case, two redundant measurements were possible, at each of the three locations of the the mounting holes. The longitudinal placement was determined from the entrance end of the cavity to the end of the vane.

After each vane had been positioned, it was removed, reinstalled, and remeasured to check repeatability. Calibration checks were performed at frequent intervals throughout the alignment process of all measurement apparatus. Typically, the results were reproducible and agreed with design coordinates to within a few tenths of a mil.

Following the positioning procedure for each vane individually, all four vanes were assembled into the cavity, and direct measurements of vanetip spacings were made. Opposing gaps were measured at 10 places for each vane pair. The rms deviation from predicted spacing in these 20 measurements was 1 mil. Gaps between adjacent vanetips were measured at three axial positions using pin gauges, but this measurement technique was not as reliable. Nevertheless, it was possible to confirm that adjacent gaps were correctly set to within ± 3 mils near the center and at each end.

Vacuum System

In order to reduce charge exchange losses to a few percent, a base pressure on axis in the low 10^{-7} Torr range is required. Calculations show that this can be achieved using two 1500 l/s cryopumps, each mounted on one of the four pumping ports of the RFQ cavity. Conductance restrictions in the pump port reduce the net pumping speed at the cavity to 525 l/s on each of the two pumped quadrants. The total anticipated gas load, assuming conservative unit outgassing rates of 1×10^{-9} T-l/s/cm^2 for metal surfaces, and 1×10^{-6} T-l/s/cm^2 for organics, is 5.3×10^{-4} T-l/s, and the projected pressure at the pump port is 5×10^{-7} Torr. This gas load is dominated by the (viton) o-rings. Based on experience with the Bevatron RFQ, these outgassing rates are conservative by a factor 2 to 3. Two-dimensional Monte Carlo simulations predicted the pressure on the beam axis and the pressure distribution in an unpumped quadrant. The results confirmed that all vacuum requirements could satisfied with a 2-pump configuration.

In the first high vacuum pumpdown, the base pressure measured at the cavity wall in one of the two unpumped quadrants was 3.5×10^{-7} Torr. Experience with the Bevatron RFQ suggests that further improvements in base pressure should be expected, and that operating pressures can be reached within several minutes of pumping. During the first pumpdown, the compressors were operated at 220 V, 60 Hz. For the second pumpdown, a portable generator and bucking transformers were used to verify compressor performance at 200 V, 50 Hz.

Tuneup

Because of the short length (0.57 free space wavelengths) of the structure, the sensitivity to misalignments and other factors was small, despite the small radius parameter, r_0, of 0.211 cm. Three sets of coupling rings were used to simplify the tuneup procedure, to eliminate potentially troublesome dipole modes, and to ensure that the quadrant field amplitudes remain balanced. One set was used near the center and one set at each end. A ring set consists of four copper half rings that provide a low impedance connection between diametrically opposing vanes, as seen in Figure 1. Axial separation within each set is 2.9 cm.

Azimuthal and longitudinal field amplitudes were measured by pulling a hollow polystyrene cylindrical bead (1.9 cm diam x 2.7 cm long) down each quadrant near the vanetip. With the rings installed and without any adjustments, the azimuthal field balance was found to be symmetrical to within ± 2%, over the entire ± 100 kHz range of the tuner loop. A small axial tilt, due in part to the exit radial matcher, was removed by adjusting the end wall positions. Final end wall spacings of 1.59 cm (entrance) and 2.86 cm (exit) were established within a few hours, producing the field distribution shown in Figure 2.

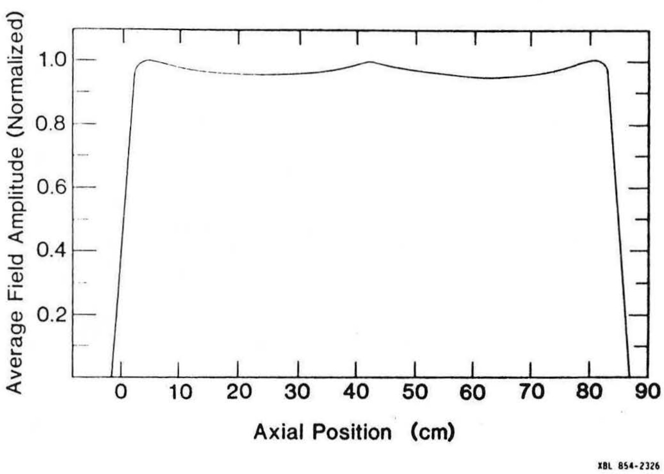


Fig. 2 Longitudinal field variations measured by bead pull perturbation techniques.

The presence of the coupling rings introduces a local increase in the capacitive loading of the structure, resulting in a significant shift in its resonant frequency, and accounting for the local maxima seen in Figure 2. The frequency shift observed with the middle set of coupling rings removed was 5.2 MHz leading to a variation in axial field amplitude of 4%.

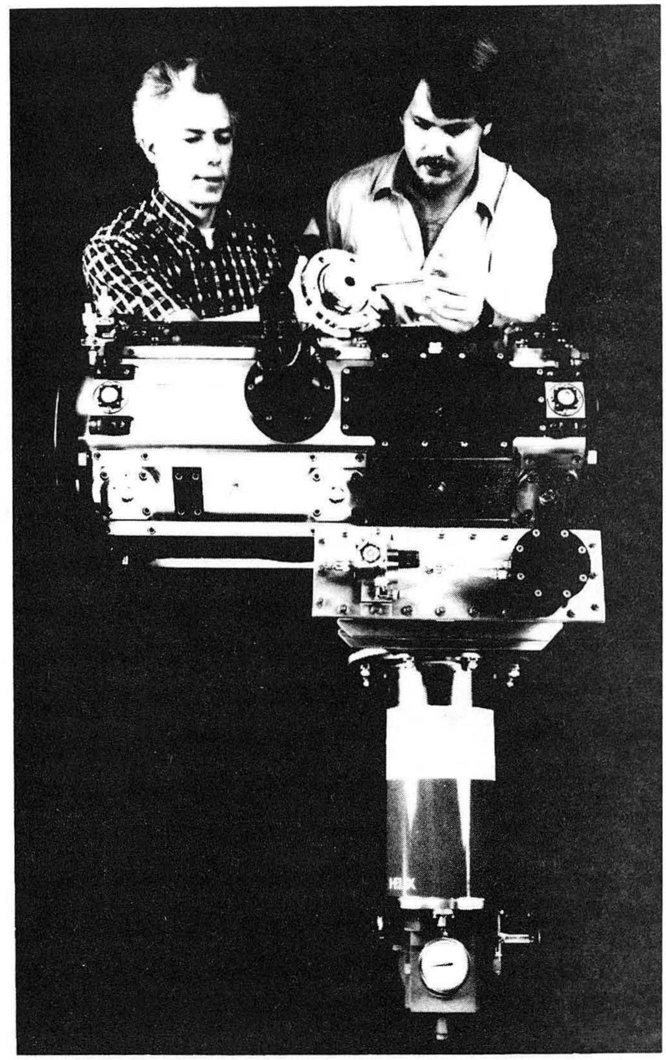
The tuning bars on the sides of the vanes brought the resonant frequency to the desired value of 202.56 MHz. The unloaded Q of the structure is around 5000. Experience with the Bevatron RFQ suggests that this may increase as much as 30% after RF conditioning.

Conclusions

An RFQ linac for Q/A = 0.375 heavy ions has been assembled, tuned and vacuum tested. The structure is shown in Figure 3. Testing the RFQ at full RF power is now underway at LBL prior to shipping to GSI in June 1985. Here, the ECR ion source, RFQ, and other components of the preinjector will undergo beam tests continuing through November 1985. Then it will be transported to CERN for installation at the Linac I site.

Acknowledgments

The authors wish to acknowledge the substantial contributions of S. Abbott in mechanical design, the able mechanical assistance of B. Wright in fabrication and assembly, and the help of J. Galvin in the reduction of alignment data. In addition, the excellent support provided by the LBL machine and plating shops is gratefully acknowledged.



CBB 855-3622

Fig. 3 Photograph of the fully assembled RFQ.

References

[1] N. Angert et al, "A Heavy Ion Injector for the CERN Linac I", Proceedings of the 1984 Linear Accelerator Conference, Seeheim (May 7-11, 1984), p 374.

[2] BNL, Saclay, CERN, and LBL all have operated RFQ linacs as part of a synchrotron injector.

[3] R. Stock, "Study of Relativistic Nucleus-Nucleus Reactions Induced by ^{16}O Beams of 9 - 13 GeV per Nucleon at the CERN PS", Proceedings of the Bielfeld Workshop on Quark Matter Formation and Heavy Ion Collisions (May 1982) p 557, Edit M. Jacob and H. Satz.

[4] R. Gough, "Design and Operation of the LBL Heavy Ion RFQ Linac", Proceedings of the 1984 Linear Accelerator Conference, Seeheim, Germany (May 7-11, 1984) p 68; LBL-17349.

[5] H. Lancaster et al, "Vane Coupling Rings Simplify Tuning of the LBL RFQ Accelerator", Proceedings of the 12th International Conference on' High Energy Accelerators, Fermilab, Batavia, Il (Aug 11-16, 1983) p 512; LBL-16502.