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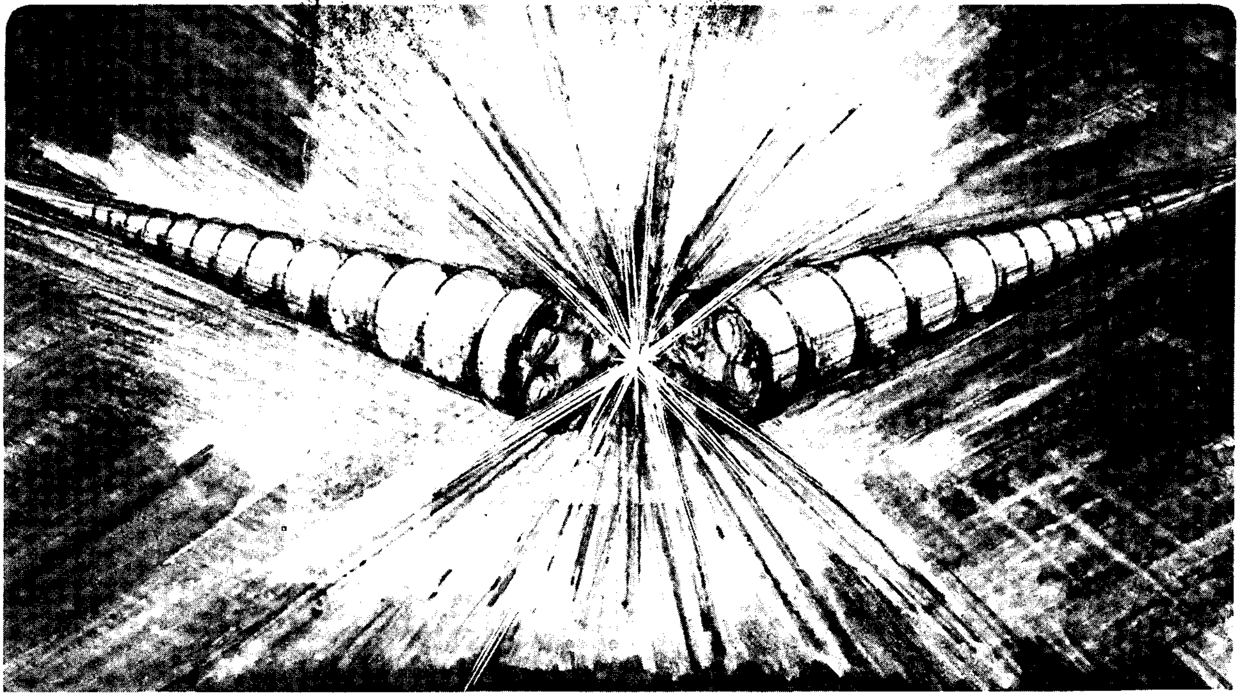

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DISCLAIMER

INITIAL OPERATION OF THE LBL HEAVY ION RFQ*

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Abstract

The LBL heavy ion RFQ accelerator, a 200 MHz structure that accelerates an ion with $q/A \geq 1/7$ from 8.4 to 200 keV/n, has now passed all its acceptance tests. This machine is unique in several respects: it uses coupling rings between vanes to stablize the azimuthal field distribution, it incorporates a vane mounting system that simplifies vane alignment, it uses no end tuners or power distribution manifold, and it needs only one r.f. feed loop. The beam performance of this machine is reported in this paper.

Introduction

For some time there has been a need for an improved local injector for ions up through argon at the Bevalac, primarily to reduce the load on the SuperHILAC as an injector, and to provide for the overall biomedical program load. The present injector, a 20 MeV proton linac operated in the $\beta\lambda$ mode for protons and in the $2\beta\lambda$ mode for heavy ions, provides beams of carbon, alphas and protons. To provide heavier ions, this linac will be extensively modified[1] by removing the first 23 cells and adding a new front end consisting of an RFQ and a $2\beta\lambda$ Alvarez linac. The disassembly of existing injector components is starting in July 1983, just after the completion of the acceptance tests of the RFQ linac. The total injector upgrade is scheduled for completion in early spring 1984.

RFQ Linac Specifications

The new RFQ,[1-4] designed and constructed at LBL, accelerates a beam with $q/A \geq 1/7$ from 8.4 to 200 keV/n at an operating frequency of approximately 200 MHz. The 224 cm long vanes consist of 346 cells distributed for design purposes into 7 separate sections: input radial matcher, shaper, prebuncher, buncher, booster, accelerator, and exit radial matcher. The vane-vane voltage is 51 kV, r_0 is 0.254 cm, and the focusing parameter B is 2.7, except in the exit radial matcher, where it is gradually reduced to 1.8. The normalized acceptance is 0.05π cm-mrad with an emittance increase through the structure of less than a factor of 2. The surface field is 27 MV/m, (1.85 times Kilpatrick's criterion[5]) near the tip of the vanes with a local maximum of 29 MV/m at the end of the prebuncher. A variable transverse radius of curvature geometry is used[6].

Cavity Field Distribution

The cavity uses a conventional 4-vane geometry with three pairs of coupling rings[7,8] electrically shorting opposing vanes together. This arrangement stabilizes the azimuthal field distribution so that the only necessary tuning is the adjustment of the longitudinal field distribution. No individual end tuners are needed. The field is flattened longitudinally by adjustment of the end wall positions. The presence of the rings produces local field maxima, equal at each set of rings, with the field between the rings decreasing to 92% in the first half and to 88% in the second half of the structure.

The cavity Q is 5950, about half of the theoretical value of 12500 with perfect copper and no joint losses. The power requirement for full gradient is approximately 155 kW, compared to the calculated power of 142 kW for a Q of 5950 and an amplitude of the accelerating spatial harmonic A_{10} of 93% of the theoretical value of the accelerating parameter A.

The cavity initially conditioned to 75% gradient in about a day and to maximum field in about one more day. The maximum field is held with a few sparks per minute when pulsed for 1 millisecond twice a second. Conditioning is held overnight, but over a quiescent period of a few days, some reconditioning is required. One significant lock level is encountered at 31% of full field.

The tips of the vanes have a 0.2 mil copper plate over a mild steel surface. The copper is expected to eventually sputter away, but the low magnetic field in this area will not result in significant lowering of Q. The appearance of the vane tips after running shows many small pock marks out to about 4 mm from the maximum field point on the vane tip, and a general darkening of the surface. No evidence of sparking is seen on the vane coupling rings. The vacuum system is all cryogenic, and viton O-rings are used throughout the structure.

Measurement Setup

The RFQ was installed in the 20 MeV linac area for the acceptance tests as shown in Figure 1. The sputter PIG source for the 20 MeV injector provided a variety of beams, ranging from protons to silicon with the major part of the testing done with nitrogen ions. The 460 kV Cockcroft-Walton was replaced by a 60 kV power supply and all but one gap in the accelerating column was shorted out. The beam from the ion source and gap was focused by a solenoid and a quadrupole doublet, deflected by a 70° magnet, and focused into the RFQ by a quadrupole 4-plet. R.F. power was provided by a 300 kW amplifier. A 50° spectrometer with a momentum resolution of ±0.125% was provided after the RFQ, along with the usual Faraday cups and emittance measurement devices.

Transmission Tests

The transmission of accelerated beam as a function of the r.f. excitation is the most basic

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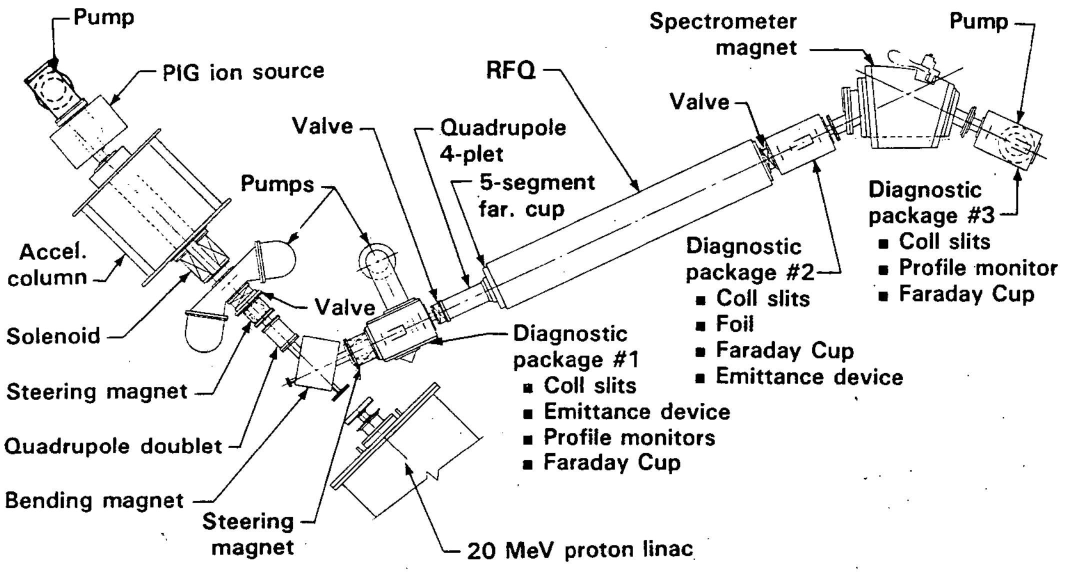


Fig. 1

Experimental set-up for the RFQ beam tests

XBL 837-2869

test of a linac. The transmission curve is shown in Figure 2. The output energy is centered on 200 keV/n. Both a foil with a range of 196 keV/n and the spectrometer with the slits set for an energy acceptance of several percent were used for these measurements.

The design input energy is 8.4 keV/n, requiring a 59 kV accelerating potential for a Si^{+4} beam. The transmission as a function of input kinetic energy, along with the calculated values, is shown in Figure 3.

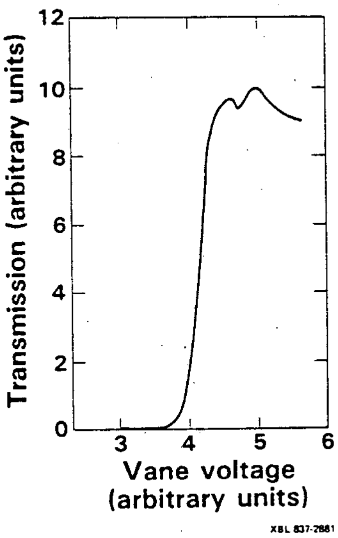


Fig. 2: Transmission of fully accelerated N^{+3} beam as a function of vane voltage.

For a small emittance input beam (about 0.02π cm-mrad), transmission of accelerated beam was as high as 86%, but for most of the data taken, at a larger input emittance close to the design value, transmission was usually in the 60-70% region. This represents about 75% of the calculated transmission of 86%. The matching of the beam into the RFQ with the 4-plet has proven difficult to optimize in practice, and is believed to be responsible for most of the shortfall.

Output Energy Spectrum

The absolute energy calibration of the spectrometer was obtained to better than 0.5% by drifting an unaccelerated beam of precisely known energy through the unexcited RFQ to calibrate the bend angle of the spectrometer, and then extending this calibration to other energies by measuring the magnet field level as a function of excitation. The remnant and hysteresis effects were significant corrections in absolute energy measurements to 0.5% accuracy.

The absolute output energy at design excitation was measured to be 205.1 keV/n at an operating frequency of 202.4 MHz, the frequency used during these tests. (The operating frequency is easy to change without changing the field distribution in the cavity, and this will be done when the new Alvarez tank frequency is determined.) Correcting this measured output energy to the design frequency of 200 MHz results in a value of 200.3 keV/n, comparing favorably to the predicted output energy of 200.9 keV/n.

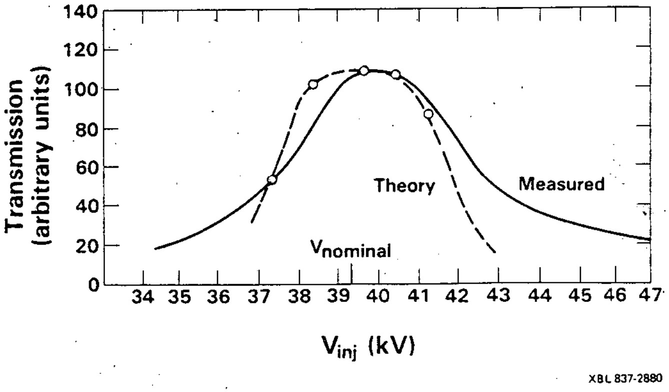
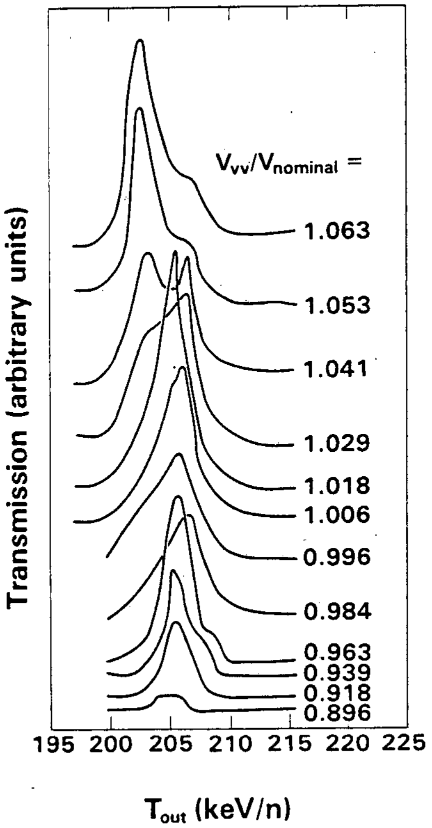


Fig. 3: Theoretical and measured transmission of N^{+3} beam as a function of injection energy.

The output momentum spread is 0.8% FWHM at nominal gradient. This can be reduced to 0.5% FWHM at slightly reduced gradient without significantly reducing the transmission. At higher gradient, the spectrum broadens into two peaks separated by about 0.8% $\Delta p/p$, one or the other peak being favored as the gradient is increased. The results are summarized in Figure 4. Spectra measured at the edge of the beam were found to be the same as those measured in the core. The energy spectrum up to about twice design gradient was measured using He$^+$ and H$_2^+$.



XBL 837-2878

Fig. 4: N^{+3} energy spectra for several values of the vane-vane voltage V_{VV}.

Two persistent satellite peaks were discovered in the output energy spectrum at 136 and 152 keV/n, comprising less than 5% of the beam. The presence of these peaks is not understood. The energies are not characteristic of a transition between different parts of the structure, and they persist over a large range of operating gradients. No unaccelerated drift-through of beam is seen at any gradient which produces beam accelerated to full energy.

Emittance Measurements

The emittance of the beam presented to the entrance of the structure was measured, primarily to determine the characteristics of the ion source. The emittance of the input beam was collimated to normalized values of 0.037π cm-mrad in the x-plane and 0.045π cm-mrad in the y-plane at the 90% contour. The design normalized acceptance is 0.05π cm-mrad in both planes at the 100% contour.

The output emittance within an elliptical boundary, measured at the 90% contour is 0.078π cm-mrad in the x-plane and 0.064π cm-mrad in the y-plane. The betatron parameters in both planes are in agreement with the predicted values if the output location is assumed to be 2.7 cm upstream of the actual end of the structure.

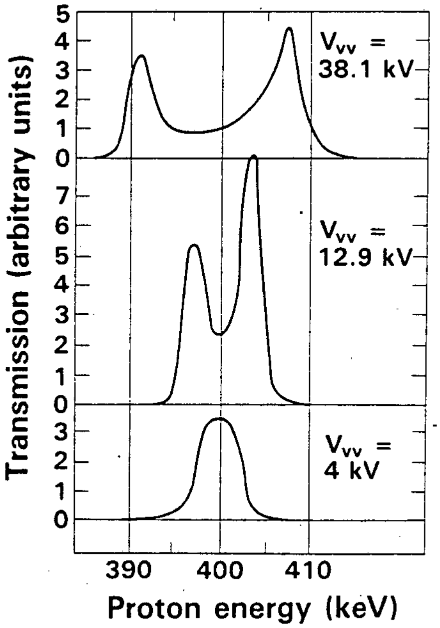
Drift-Through Experiment

The present RFQ structure will be located upstream of a 2βλ Alvarez cavity. This precludes proton operation in the βλ mode of the Alvarez linac as the RFQ does not have a mode in which it can accelerate protons at twice its design velocity. However, full energy (βλ) proton operation can be obtained by providing protons of the proper energy to the entrance of the Alvarez structure from an external source by drifting them through the RFQ. This uses the RFQ as a transport channel without significantly altering the energy or energy spread of the proton beam. The transport properties of the RFQ were investigated, paying particular attention to the effect on the energy spectrum of the drifted beam.

Two experiments were conducted: on a 3 keV/n N^{+3} beam, 60% of the normal input velocity, and on a 400 keV proton beam, 41% higher than the normal output velocity. At no time was either beam synchronous with the structure. Values of B from zero up to 20 were examined for the proton beam, covering the entire width of the stability passband.

The low energy drifted beam was captured and transmitted with a 35% efficiency. The input matching was not optimized in this case. The momentum spread was a constant 0.5% FWHM at the two values of B of 0.52 and 2.0 that were used. The transmission curve was broad and smooth from B = 0.2 up to the maximum B used of 2.4. No shift in the mean energy of the input beam was observed.

The transmission of protons from B = 1 to 20 was measured. The transmission reached 50% with an attempt at matching into the RFQ. As in the low velocity case, no shift in the mean energy of the input beam was observed, but the energy spectrum exhibited two peaks with a reduced core, as seen in Figure 5. The maximum observed width at B = 14 was



XBL 837-2879

Fig. 5: Output energy spectra of the drift-through 400 keV proton beam for three different values of the vane-vane voltage V_{VV}.

a full momentum width of 2.9% with a peak separation of 2.1%, decreasing approximately as the square root of the excitation. This is apparently an energy spread introduced statistically by the presence of longitudinal field in the structure. As the transmission is above 45% for a wide range of excitation, a full momentum width of 1.5% is easily obtainable, satisfying the requirement for an efficient transport system for fast protons from an external source.

Conclusions

The RFQ has satisfactorily passed all its acceptance tests. The measured transmission and energy spectrum fit predicted values well. The possible use as a transmission channel for high energy protons has been proven. The installation of the RFQ in its final configuration as a Bevatron injector with the new and upgraded Alvarez linacs will be completed in early 1984.

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