RFQ LINAC STRUCTURE DEVELOPMENTS AT CRNL

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Summary

Modeling studies of RFQs for a 300 mA cw proton accelerator are continuing at CRNL. Initially, low power models of the four-vane structure with standard end terminations were extensively investigated. Later, results of simple rf dipole experiments led to studies of two new RFQ termination schemes, the double dipole (in which two opposing vanes were shorted at both ends) and the folded dipole (in which one set of opposing vanes was shorted at one end, the other vane set shorted at the other end). Various end tuner configurations were also tested, including radial end tuners and Bourdon tube mechanisms for remote positioning. Finally, a versatile low power RFQ model has been built to study rf properties with reproducible vane geometry.

Introduction

The accelerator breeder program at CRNL presently requires a design for a 300 mA cw RFQ proton accelerator[1] with an output energy of 2 MeV. The unit will probably operate at 108 MHz, be approximately 4.5 metres long and use approximately 1.5 MW of 100% duty cycle rf power. These requirements put one into a new regime of design constraints, and, as the following arguments show, suggest new areas of study.

Both the structure length and the inclusion of cooling channels in all components result in much larger mechanical errors than can be tolerated on present small bore RFQs. Also, although every component must be cooled, there will likely be significant changes in mechanical dimensions from heating at turn-on. Both facts put increased emphasis on quantifying the field imbalances caused by mechanical errors, on designing inherent stability into the system, and on developing dynamic stabilizing and frequency adjustment techniques.

Large space charge forces in the input beam necessitate a large focusing device as close as possible to the input vane tips. This leaves very little space for conventional end tuners or their drive mechanisms, and thus new end tuner configurations are required. However, experience has shown that movable rf components relying on fingerstock should be eliminated from high current regions, including end tuner units.

These requirements are being investigated both through experimental and theoretical modeling studies, and the progress to date is presented.

Four Vane RFQ with Standard End Tuners

Several short (550 mm) low power RFQ models were used to study mode frequencies and azimuthal and longitudinal tuning for a selection of lengths and bore hole diameters. A condensed list of the main results follows:

(a) If the end plates are moved progressively closer to the vane ends (thus reducing the end area and inductance) the dipole mode frequencies become equal to and then higher than the quadrupole frequency. When all three are roughly equal, serious mode interference occurs.

(b) Dual rf drive in opposite quadrants strongly suppresses dipole mode excitation.

(c) Increasing the vane cutback of the end region area lowers all mode frequencies.

(d) A simple tuning scheme was derived which, in the case where the quadrupole frequency is highest, predicts the tuner movements necessary to correct a given average azimuthal asymmetry. Under conditions where the dipole frequencies are higher than the quadrupole, the tuning scheme is reversed.

New Termination Configurations for the 4-Vane RFQ

Two new RFQ termination configurations, the folded dipole and the double dipole (Fig. 1 (a) and (b)), were studied because they promise increased field stability against perturbations. At each end of the RFQ structure, one set of opposite vanes are shorted to each other, having much the same effect as putting half straps[2] at the ends of the RFQ.

Both configurations have the advantages of halving the number of end tuners required and of providing accurate, fixed mechanical positioning of two vane tips at each end. In common with the GSI split coax structure[3], they both have the seeming disadvantage of introducing an axial rf electric field in the tapered input region. However, if this transition region is spread over a few $\beta\lambda$ cells (or rf oscillation periods) in a predetermined way, the effect should be tolerable[4].

Both configurations were studied using a 500 mm long, 135 mm diameter RFQ with 1 mm bore hole radius, 1 mm vane tip radius, and a cutback area equal to 60% of the half quadrant area.

The Folded Dipole RFQ Resonator Configuration

For the folded dipole configuration (Fig. 1(a)), the frequencies of the two lowest dipole modes lie well above the lowest quadrupole frequency. The mean quadrupole-dipole separation was 11 MHz, for a quadrupole frequency of 429 MHz. For the standard four vane RFQ configuration, the mode separation would be $\approx$ 2 MHz for this small bore radius. Thus the folded dipole configuration reduces considerably the possibility of mode interference.

The influence of the four end tuners on the average azimuthal field in each quadrant was studied and the following "tuning rules" were deduced while maintaining zero net frequency shift:

(1) To increase the fields in two adjacent quadrants, one inserts the tuner common to the two quadrants and retracts the other tuner at the same end.

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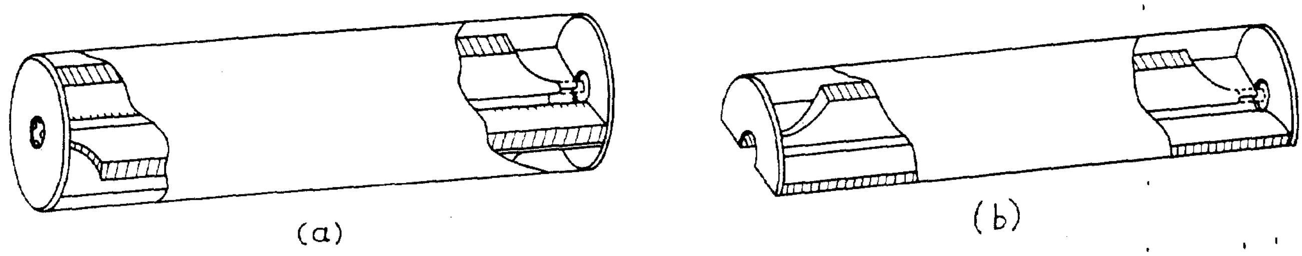

Fig. 1 Cutaway diagrams showing two new end termination configurations which increase field stabilities - (a) folded dipole, (b) one half of a double dipole.

(2) To level an imbalance in opposite quadrants, one inserts the two tuners common to the low field quadrant and retracts the two common to the high field quadrant.

(3) The frequency may be changed without affecting the average azimuthal distribution if all four tuners are moved in unison.

A measurement was made of the sensitivity to an azimuthal perturbation by inserting a full length rod in one quadrant, thus decreasing its area by 1.36% and increasing the quadrupole frequency by 0.20%. The field was 8% low in the perturbed quadrant and 8% high in the opposite one. The direction of asymmetry is opposite to that predicted by SUPERFISH, and the stability against azimuthal perturbation is a factor of three better than predicted by SUPERFISH.

The Double Dipole RFQ Resonator Configuration

The double dipole configuration may be regarded as made up of two single resonators (Fig. 1(b)) coupled to each other through the common slot. When the two dipoles are assembled to form an RFQ, the lowest modes split into only two coupled modes, the lower in frequency being the dipole configuration, the higher the quadrupole. The measured mode separation was 13 MHz, suggesting a coupling constant of 3%. (A set of vanes with a 6.3 mm bore radius yielded a 5.5% coupling constant.)

Properties of the end tuners were measured for the double dipole configuration. As before, any increase in an end tuner capacitance lowers the frequency of both modes. Inserting all four tuners from 4.5 mm to 1.8 mm gap spacing (minimum vane-to-vane gap = 0.85 mm) produced 0.3% frequency change while introducing $\leq \pm 1\%$ mean azimuthal asymmetry. Thus a large frequency shift can be produced while maintaining azimuthal symmetry.

The average azimuthal asymmetry introduced by inserting a single tuning plunger is compared with the asymmetry produced by inserting a metal rod in one quadrant (Fig. 2). The azimuthal tilts introduced were comparable although the frequency shifts caused by the perturbations were opposite in sign. However in both cases the frequency of the bottom resonator is increased relative to that of the top resonator. The general theory of perturbed coupled resonators shows that for the high frequency mode (the quadrupole in this case) the field will increase in the resonator whose individual frequency is increased. The converse is true for the lower mode. This explains why, for the folded dipole configuration, the sign of the field tilt is opposite to that predicted by SUPERFISH - the quadrupole is actually the lowest mode, whereas SUPERFISH predicts it to be the highest.

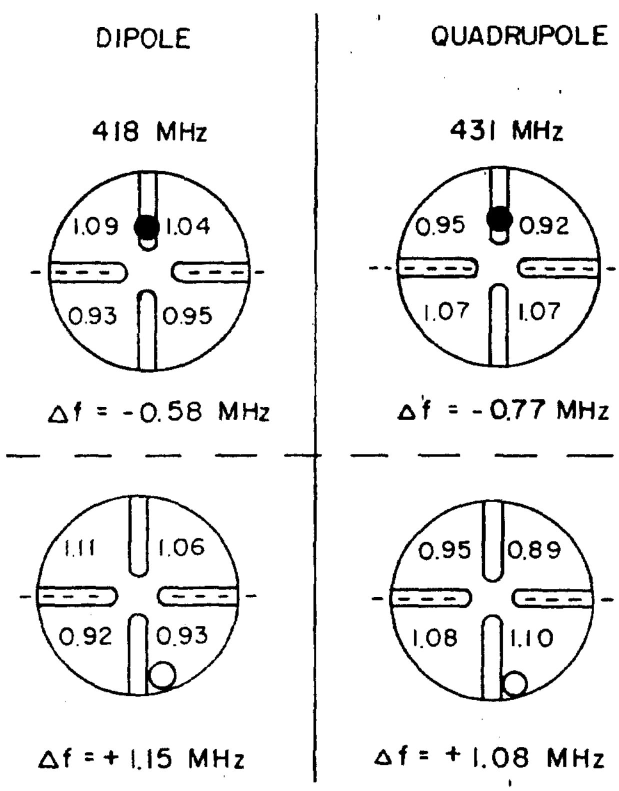

Fig. 2 Schematic representation of the average azimuthal field tilt produced by (a) inserting the indicated tuning plunger, (b) a metal perturber rod in the indicated quadrant. The dotted line indicates the upper-lower dipole division.

Radial End-Tuning Plungers

Both of the low power models used to test the two new end configurations had radial end tuners as shown in Fig. 3. Adequate frequency and field tilt adjustment ranges were obtained while using a minimum tuner gap spacing of twice the vane-to-vane gap - sufficient to minimize sparking in the tuner region.

With radial end-tuning in which the vane tips actually project through the RFQ end wall, one could break a long structure into shorter units, which would improve azimuthal stability and make smaller, separately tunable assembly units. This is essentially the method used on the GSI multiple tank split coax RFQ structures[3].

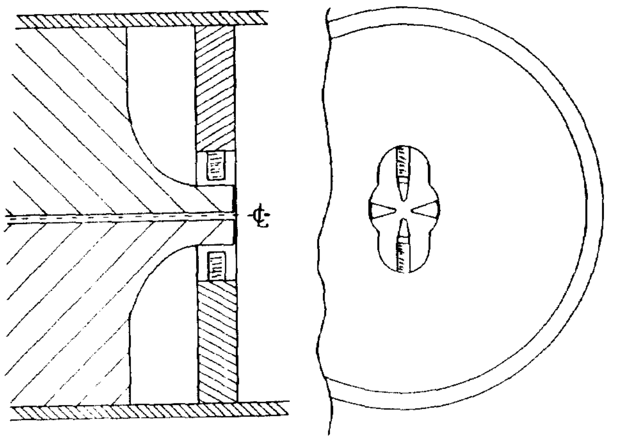

Fig. 3 Side view section and end view of the radial end tuner configuration used to test the new terminating methods.

Bourdon Tube End Tuners

The Bourdon tube principle provides an elegant way of reproducibly moving a component in an rf structure without use of a sliding metal-to-metal contact. Several end tuners, based on the Bourdon principle, were constructed and tested on RFQ models (Fig. 4). The main problem with the present 270 MHz design is the small movement ($\approx$ 1 mm) obtained for pressures up to two-thirds of the tube material yield stress. For a 270 MHz, 2.3 m long RFQ this produces a tuning range of $\leq$ 0.15 MHz.

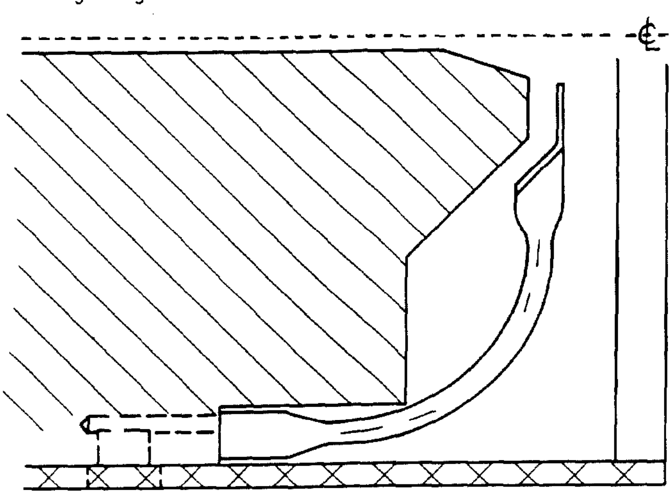

Fig. 4 A schematic view of the Bourdon tube end tuner test arrangement.

A Picture Frame RFQ Cold Model

A versatile RFQ cold model using the "picture frame" vane support principle has been built (Fig. 5). The system allows a single vane to be removed and reinserted to within 25 microns of its original position without detailed measurement or adjustment. The side plates, the vane tips and the end tuner assemblies may all be removed, modified and reinserted reproducibly without disturbing the vanes. This vane mounting technique is a promising method of assembly for high power structures where mechanical tolerances are necessarily large.

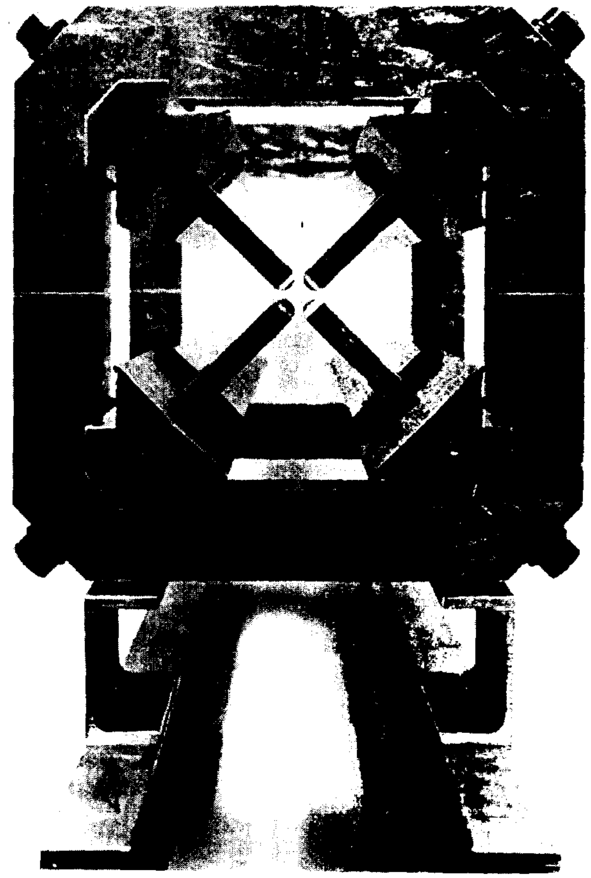

Fig. 5 An end view of the low power "picture frame vane mount" RFQ model.

Conclusions

The two new end termination schemes, the folded dipole and double dipole, are practical alternatives to the standard RFQ termination scheme, and provide increased stability against azimuthal field imbalances.

Radial end tuners are a practical way both to avoid space restrictions at the input to an RFQ and to provide easy access to the tuners. They also make feasible the division of a long RFQ into smaller separately tunable but strongly coupled substructures.

The Bourdon tube principle has been used as a method of tuning rf structures without the use of sliding metal-to-metal contacts. However, the method may only be practical where a small tuning range is required. The "picture frame" vane mounting technique has been found to provide very stable yet easily adjustable individual vane positioning, independent of side plate or end tuner adjustments.

References

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4. L.W. Funk, CRNL, private communication.