A 'Square Wave' RF system design for the TRIUMF cyclotron

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ABSTRACT

The unique features of the rf resonator assembly of the TRIUMF accelerator allow the addition of higher harmonics to the fundamental cavity mode, with a consequent increase in phase acceptance and an order of magnitude decrease in rf frequency stability and magnetic field tolerances in the cyclotron. Only the third harmonic of the fundamental for which the rf cavity changes from a shorted ¼ λ line to a ¾ λ line will be used, since the improvement in phase acceptance decreases rapidly with increasing harmonic content. This improvement can be seen by comparing the phase acceptance of the beam with first harmonic acceleration alone (–5° to +55°) to acceptance with the addition of the optimum amount of third harmonic (+45° to –45°).

The resonant cavity will be supplied with the requisite 1·5 mW of rf power by means of a resonant transmission line from a final power amplifier consisting of parallel 7560 triodes. With third harmonic excitation of the optimum amount the full width of the energy should be within ±25 keV in an rf phase width of 11°. This corresponds to a microscopic duty factor of 6% with separated turn acceleration.

1. INTRODUCTION

The flat topping of the rf wave on the dee structure has advantages for both the injection and the extraction of high quality beams in isochronous cyclotrons (Craddock).[1] The usual difficulties of large voltage variations along the

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accelerating gaps do not occur in the TRIUMF accelerator due to the simple, clean configuration of the dee structure (Fig. 1) which consists of two quarter wave shorted lines completely enclosed by the vacuum tank and centred between the pole tips in the relatively large 20-in gap.

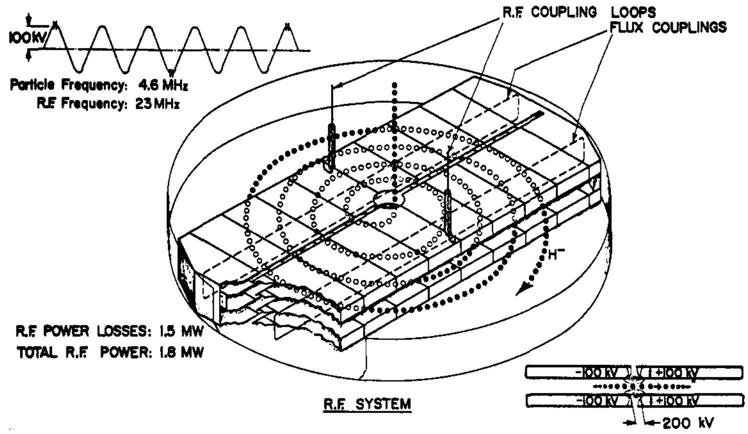

Fig. 1. An isometric view of the resonators and coupling loops in the vacuum tank of the cyclotron

A schematic of the structure is given by Warren[2] which shows how the two resonators separated by the accelerating gap of 6 in are positioned.

2. MODEL RESONATORS

The resonators have been modelled in copper-covered plywood at half scale and have been driven by two separate coupling loops and two separate transmitters operating at frequencies of 48 and 144 MHz. A coupling loop in one side of the structure easily excited the whole system in either the push-push or push-pull mode, due to the relatively large coupling capacitance of the accelerating gap. The two modes were separated by a frequency difference of 1·5 MHz and with a measured Q of 4500 for the fundamental. No difficulty was experienced in selecting the desired push-pull mode.

The injection of both the first and third harmonic of the basic cavity of frequency proved to be relatively easy. As seen in the pictures of the oscilloscope measurements made of the voltage at the dee gap by using a small capacitance probe and a Tektronix 454 oscilloscope (Fig. 2), various values of amplitudes of the rf and varying phase relationships were obtained with no difficulty. Fine tuning was done by small adjustments at the output stages of the transmitters as the power was coupled through resonant transmission lines having a characteristic impedance of 50 ohms. The characteristic impedance of the shorted line which constitutes the cavity is about 1 ohm. The phase relationships were measured using a Hewlett-Packard vector voltmeter and a sampling circuit constructed by R. Gummer of the TRIUMF rf group. Even with no external feedback in the system, excellent phase stability was achieved, due in

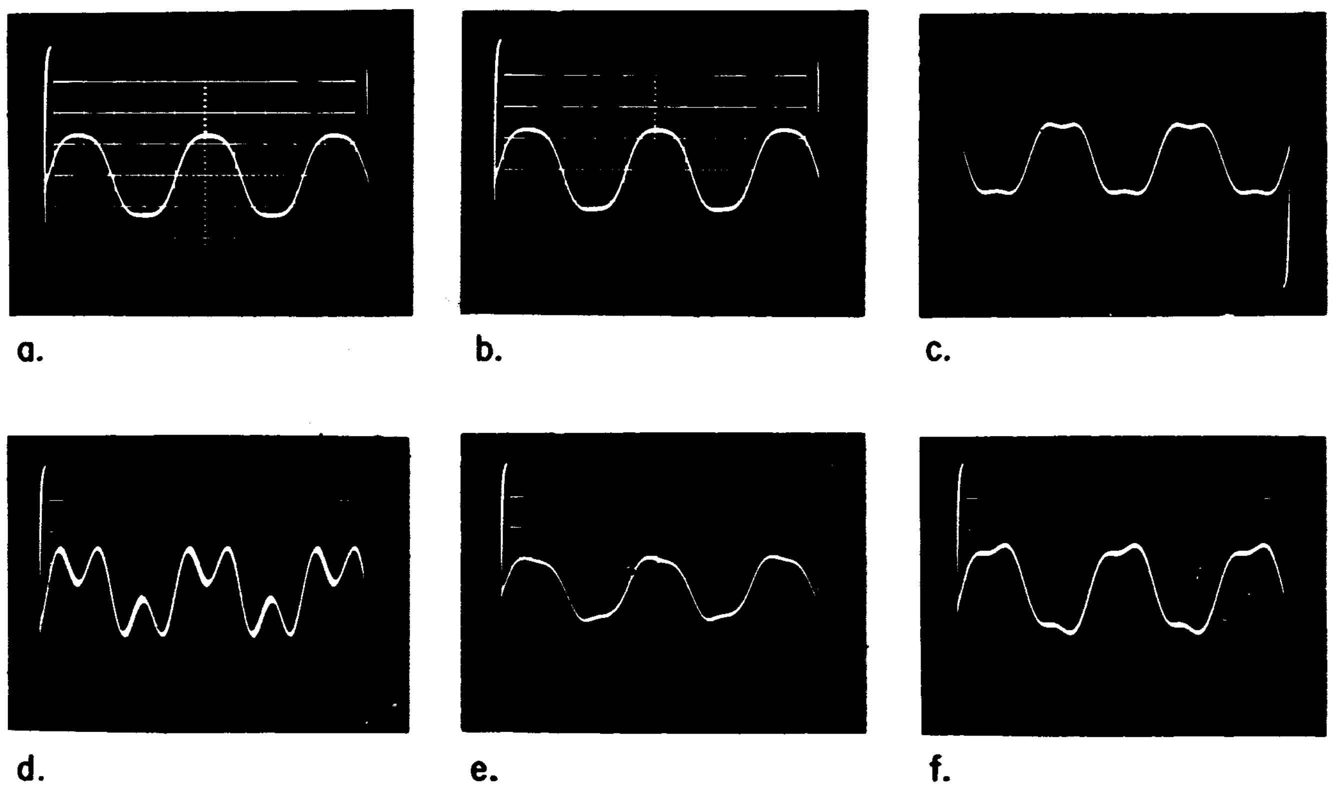

Fig. 2. Rf waveforms as measured at the accelerating gap for varying values of third harmonic amplitude and phase. The percentage of third harmonic varies from 3% through 30% in the first four frames. The phase is varied from 30° lead to 30° lag in the last two frames.

part to the coupling between the two power amplifier systems. The phase difference from dee to dee did not exceed 0·5° over a large variation in dee-to-dee voltage. The system was run at a voltage of 500 V on the dee in the fundamental mode. The third harmonic amplitude was varied from 0% to 20% of the fundamental.

3. TUNING

Fine tuning of the cavity was investigated using two differing approaches. The length of the shorted dee line was varied by using shorting plungers at the shorted end. Since the machine magnetic field can be adjusted to allow isochronism and focusing to be maintained to higher energies at reduced beam current (Auld),[3] the rf frequency must be adjustable by 3%. Capacitor plates at the open end of the cavity structure make this change possible, as seen in Fig. 3. The Q remains constant and the frequency variation is accomplished

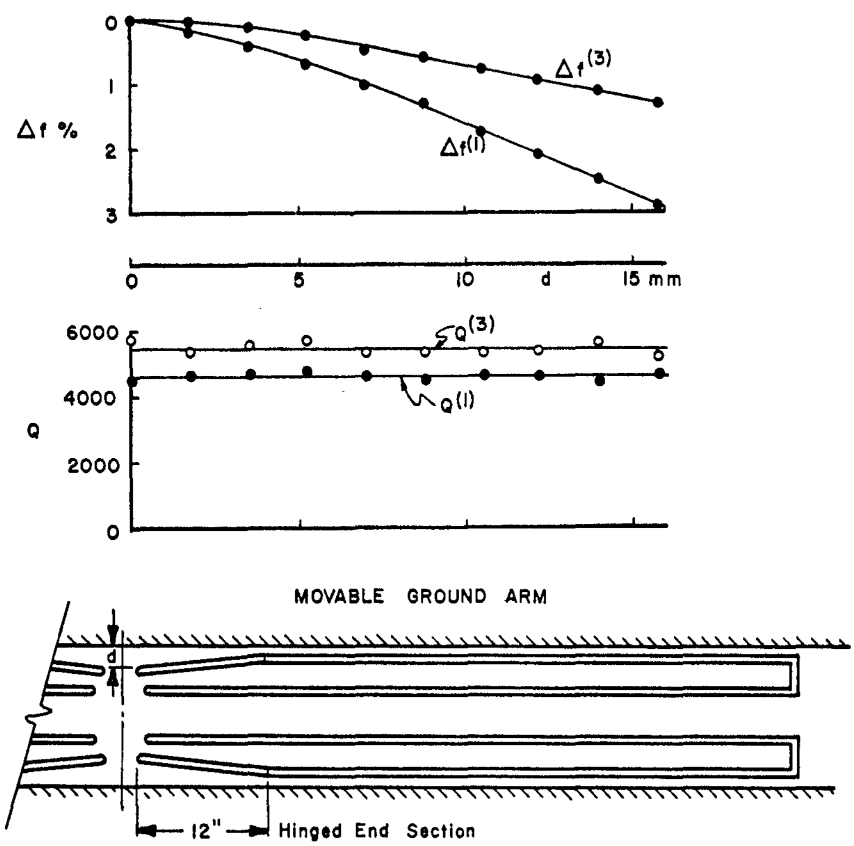

Fig. 3. Variation of the resonant frequency and Q *of the cavity with the motion of capacitor tuning plates at the accelerating gap*

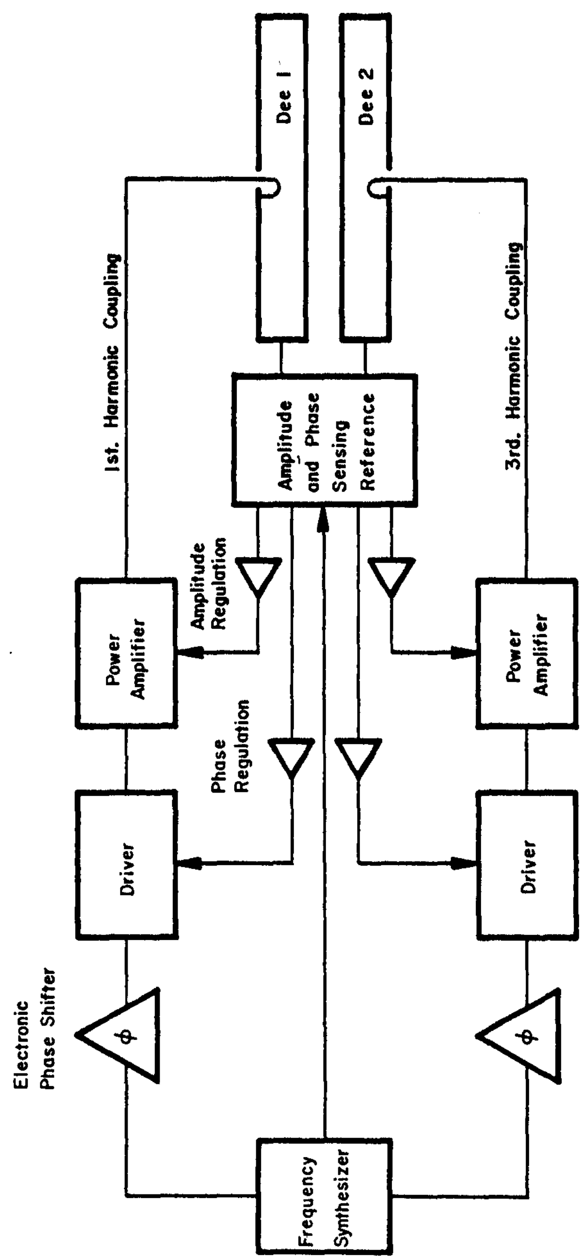

Fig. 4. Schematic of the power amplifier system to be used in the full-scale cyclotron rf cavities

by a 0·6 in motion of the front end of a 12-in-long panel at the resonator tips.

Since the resonator is constructed of sectors 32 in wide electrically connected at the root and the tips, but separated by a 0·1-in gap over the remainder of their 10-ft length, cross modes are discriminated against. The voltage uniformity as measured by calibrated capacitance probes at the resonator tips was well within the allowable machine tolerances and did not exceed 1% from the centre to the outside of the dee structure.

4. FULL SCALE CAVITIES

The full-scale resonator structure having dimensions of 55 ft by 21 ft will require 1·2 MW to supply the ohmic losses at 100 kV on the dees. It will be driven by four parallel 7560 high power triodes operating at 23 MHz nominal first harmonic frequency and one 4C X 25 000A at 72 MHz nominal third harmonic frequency. A frequency synthesiser having a stability of 1 part in 10^9 will supply the required rf driving signals through two electronic phase shifters and power amplifiers to the final driving stages, shown schematically in Fig. 4. Amplitude and phase feedback will be used to maintain an amplitude stability of 1 part in 10^4 and a phase stability of $0{\cdot}2^\circ$ on the cavities.

REFERENCES

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2. Warren, J. B., 'The TRIUMF Project', Proceedings of this Conference, p. 73.
3. Auld, E. G., Oraas, S., Otter, A. J., Mackenzie, G. H., Richardson, J. R., and Burgerjon, J. J., 'Design of the 4000 ton Magnet for the TRIUMF Cyclotron', Proceedings of this Conference, p. 111.