A NEW AND IMPROVED RF RESONATOR SEGMENT FOR THE TRIUMF CYCLOTRON

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Summary
Fluctuations at TRIUMF directed toward higher currents, separated turns and extraction of H⁻ beam require a resonator structure of greater mechanical stability. Studies have led to the design and installation of a new resonator structure with increased stiffness and reduced vibration amplitude. Measurements with a newly designed segment installed in the TRIUMF cyclotron have led to more accurate determination of the RF leakage power (excitation of RF modes in the beam space).

Introduction
Operation of the TRIUMF H⁻ cyclotron with an acceleration frequency of 23 MHz, i.e. the fifth harmonic of the orbit frequency, means the dee structure can be entirely included within the 55 ft (18 m) diameter acceleration region as shown in Fig. 1. The dee in this case looks more like two opposing quarter wave coaxial stubs that have been flattened to fit in the magnet gap. Practical construction and handling considerations dictated that each dee be made of a number of segments. Forty segments per dee are used in this case, 20 mounted on the bottom of the vacuum tank and 20 on the lid.

A cross section through a dee is shown in Fig. 2. The root structure is the shorting plane. The leveling arm is used to adjust the elevation of the hot arm tip. Figure 3 is an expanded view of a segment. When mounted on the bottom of the cyclotron vacuum tank, a single segment looks much like a diving board 32 in. (.81 m) wide and 122 in. (3.1 m) long. The cantilever strongback mechanically supports the hot arm copper panel 4 in. (10.2 cm) from a similar ground panel. Together the hot arm and ground panels correspond to the inner and outer conductors respectively, of a coaxial line. A 4 in. (10.2 cm) separation between the upper and lower hot arms defines the beam region.

A consequence of acceleration on the higher harmonic is that the cavity resonator defined by the upper and lower hot arms can have resonant modes near the operating frequency. One mode in particular, the TM₃₁₀ mode, can be excited by an imbalance in the dee voltage. The result is a standing wave pattern that produces current maxima in segments 4 to 5 (segments are counted 1 to 10 starting at the centre). These currents flow in the uncooled aluminum strongbacks, causing non-uniform strongback temperatures in the range 35°C to 135°C, when the hot arm copper panel is at its operating temperature 0°C. The resulting mechanical distortions lead to an unbalanced accelerating structure and increased leakage.

Structural modifications made to the hot arm in the past, improved the ability to control the RF leakage into the beam gap and have allowed TRIUMF to operate reliably at beam currents approaching 200 μA. Now, however, with the plans for increased beam current, and H⁻ extraction, methods for adding a third harmonic to the dee voltage for flat-topping are being developed. This implies greater RF phase and amplitude stability requirements and consequently greater mechanical stability of the dees.¹,² Mechanical vibrations caused by water flow in the RF panels cause variations in the dee voltage and phase. The fundamental frequency of the cantilever vibration is ~ 4.8 Hz with a peak-to-peak amplitude of ~ 0.001 in. (25 μm) at the tip (resonator segment 6,7). To achieve a required dee voltage stability of 80 ppm for 3rd harmonic operation the vibration amplitude must be <.0002 in. (5 μm) peak-to-peak.¹,² This requires an improvement in dynamic tip stability of at least five for any new resonator segment design.
Dynamic stability vibration analysis was performed by the use of a Vibra-Metrics model 1030 accelerometer and a Nicolet model 500 FFT Spectrum Analyser. Modal analyses were performed on an octant of resonator segments in the tank and on a single hot arm in the lab to relate dee mode shapes with those of a single segment. The hot arm fundamental cantilever mode dominates tip motion in both instances. Turbulent water flow in the hot arm panel was identified as the principal mechanical driving force with the cyclotron water system also contributing to the vibration. A development program undertaken to determine what strongback features are important for the reduction of tip vibration and what improvements in the TRIUMF dees was feasible, demonstrated in laboratory models and order of magnitude reduction in tip vibration amplitudes and lead to the following prescription to minimize tip vibration:

1) Maximize structural damping.
2) Maximize the fundamental vibration frequency.
3) Use, if possible, austenitic stainless steel as structural material (high density and modulus of elasticity).
4) Use parallel longitudinal cooling tubes on the RF panel.

The New Prototype Resonator Segment

Following the development program a design specification for a new dee segment was prepared in June 1984 with the object of building and installing one segment in the cyclotron tank early in 1985. The primary design objectives were:

1. Compatibility. The new segment should be compatible with adjacent segments, mounting and water interfaces and remote handling equipment.
2. Dynamic Stability. The design should incorporate features necessary to minimize tip vibration levels.
3. Thermal Stability. The design should incorporate a water cooled strongback or strongback cover sheets to reduce the effects of RF leakage on tip deflection.
4. RF Panel Optimization. The new RF panel should incorporate a streamlining of water flow to minimize panel excitation and tip vibration.
5. Long Term Stability. The design should exhibit adequate reserve against deformation or creep.
6. Flatness. The hot arm structure should be prestressed to ensure a straight cantilever structure and RF panel within 0.040 in. (0.1 mm).

This phase of the program demanded changes only to the hot arm hence the original ground arm, root and tip were reused with minor modifications. The hot arm structure utilizes the original 316SS fabricated leveling arm modified to bolt to the new strongback cantilever structure, which consists of 4 extruded aluminium L-beams with integral flow passages, riveted with hole filling blind rivets to upper and lower cover plates that taper from the root to the tip in steps (Fig. 4). A special assembly fixture was designed with 10 contour clamping stations where all the elements are held rigidly prior to riveting, and the correct profile is introduced ensuring flatness when cantilevered.

The new RF panel consists of a 0.032 in. (0.8 mm) thick copper sheet with 304 S.S. tubes soldered to the panel with Certanium 34 solder. The tubes, flattened for low profile and high contact area, are arranged longitudinally in seven parallel loops with common manifolds rather than the original design of three paths in series in a serpentine pattern (Fig. 5). Note the difference in the water passageway shape compared with the Roll Bond Panel of the original design. Adjustable hangers, designed to allow for thermal expansion, attach the panel to the strongback and permit a high degree of panel flatness to be achieved. Final assembly of the segment is accomplished by bolting the ground panel and root to the hot arm and joining the aluminum to steel manifold tubes through the use of CRYOFIT couplings.

Laboratory Testing

The new hot arm assembly was mounted on a test fixture simulating tank mounting conditions. Vibration measurements were taken at the tip at various water flow rates and compared with measurements of the original configuration. It must be noted however that the water supply system to the cyclotron cannot be utilized at the test stand and the frequency spectrum of the inlet pressure is different from that of the city water supply that was used. With the same conditions in both tests, the tip vibration amplitudes at the fundamental frequency f_n were as follows (units are inches, peak-to-peak):

<table>
<thead>
<tr>
<th>Tip Amplitude</th>
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<tr>
<td>1. Original Segment Without Damper</td>
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<tr>
<td>2. Original Segment With Damper</td>
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<tr>
<td>3. New Segment (Without Damper)</td>
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Other characteristics were as follows:
Stiffness

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<tbody>
<tr>
<td>1.02</td>
<td>32</td>
<td>55</td>
<td>4.7</td>
<td>149</td>
<td>143</td>
</tr>
</tbody>
</table>

A typical spectrum of tip vibrations of the new hot arm in the test fixture is shown in Fig. 6. Flatness of the new hot arm profile measures within ±0.040 in. (±1 mm) and an even better control can be achieved by a final adjustment of the contour stations of the assembly fixture.

Tank Testing

Prior to the new resonator segment installation the highest temperature of a resonator segment strongback was found in lower quadrant III resonator segment 5. This location was selected for installation of the new segment in order to subject it to the highest leakage current.

Vibration measurements in the cyclotron were initially made with the lid up (i.e. in air). Tip vibration levels of the new hot arm (unlatched from adjacent hot arms) were higher than those achieved in the test stand. Two possible causes were: differences in the water systems and drive input from the other vibrating hot arms. Figures 7 and 8 show a comparison of the new segment unlatched with an original unlatched (segment 5, quadrant 2). The following tip vibration measurements were taken at $f_n$. Units are inches, peak-to-peak.

1. Original Segment Tips unlatched/no damper 0.0026
2. Original Segment Tips unlatched/with damper 0.0005
3. Original Segment Tips unlatched/with damper 0.0005
4. New Segment Tips unlatched 0.00057
5. New Segment Tips latched 0.00024

Note the complete suppression of the second modes at ~15 Hz with new hot arm, see Fig. 7.

An accelerometer was installed in the new hot arm and at two other comparable locations in the tank. Measurements with the cyclotron operational confirmed measurements 3 and 5 above.

Operational experience since the segment installation has provided new thermal information and a more accurate measure of the leakage heat loading on the new strongback. A thermocouple array was installed on the upper and lower strongback surfaces and at the water manifolds. Measurements on the beam side of the strongback indicated a maximum temperature of 35°C and a temperature difference with respect to the bottom of $10^\circ$C resulting in a tip deflection of 0.4 in. (1 cm) away from the beam plane. The water temperature rise of 1.6°C on the beam side of the strongback (due to RF leakage) corresponds to a 1500 watt heat load. After mechanically correcting for the thermal deflection of the tip, overall satisfactory operation of the resonator was achieved.

Conclusions

The installation of the new resonator segment with better temperature monitoring instrumentation, has improved the knowledge of the RF leakage power in the beam gap. Dynamic stability was improved even with a single new segment illustrating the stabilizing effect of a stiff, streamlined water flow design. Tank measurements indicate that tip instability resulting from thermal loading can be avoided by thermal isolation of the cantilever structure. This suggests incorporation of a separate, thermally isolated and cooled, beam side panel. The other design objectives were met successfully.

Acknowledgement

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References

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[2] R.E. Worsham et al., 10th Int. Conf. on Cyc., East Lansing 1984. 'System for Flat-topping the RF Voltage at TRIUMF.'