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RF IMPEDANCE OF THE ACCELERATING BEAM GAP AND ITS SIGNIFICANCE TO THE TRIUMF RF SYSTEM

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Abstract

The RF system at TRIUMF is now operating with the highest Q, the lowest RF leakage into the beam gap, the best voltage stability, and the lowest resonator strongback temperatures ever measured since it was first put into operation. This paper describes the calculation of the RF impedance of the beam gap and its correlation to the RF problems encountered, which eventually led to modifications to the flux guides and resonator tips to accomplish the improved operation of the RF system.

Introduction

Because of the somewhat circular shape and enormous size (diameter greater than a wavelength at 23 MHz) of the vacuum tank, as well as the physical layout of the resonators and other components inside the tank (Fig. 1), the RF impedance of the beam gap along the dee varies from an inductive impedance at the centre to a capacitive impedance at the outer radius of 304 in., crossing through a zero impedance at a radius of 235 in. (resonator #8). The fact that the RF impedance of the beam gap is zero at this point is significant *only* if a voltage is developed across this impedance. A voltage will be developed across the impedance if the resonators are not properly aligned. The result is RF leakage into the beam gap. RF leakage into the beam gap has been a major problem for some time with respect to the operation of the cyclotron. Although this leakage represents only a small fraction of the power fed into the resonators a significant amount of RF power is propagated into the beam gap to cause sagging of the resonator tips due to overheating of the resonator support structures (strongbacks) and damage to diagonistic probes and other components.

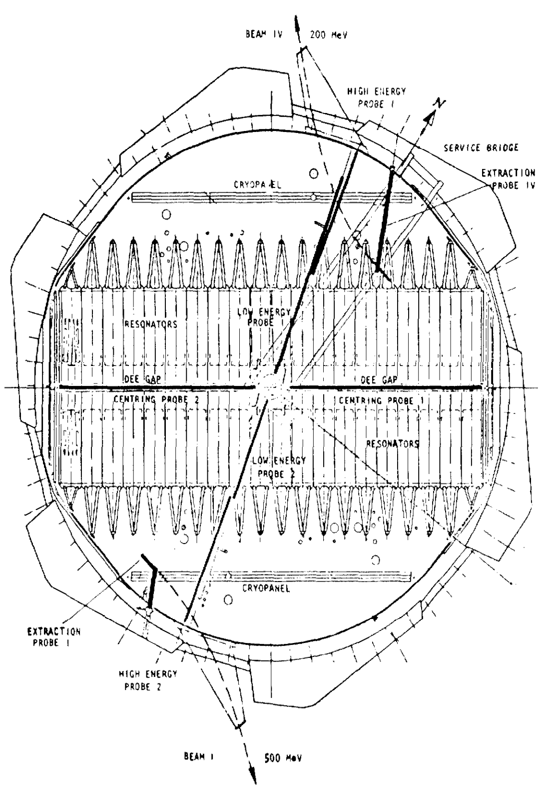

Fig. 1. Resonator layout in tank.

Beam Gap Impedance

Figure 1 shows the physical layout of the resonators and other components in the tank. Although the leakage current would tend to curve through a path of least resistance to the tank wall, as a first approximation it was assumed that the leakage currents flow perpendicularly to the beam gap. A cross section of the vacuum tank is shown schematically in Fig. 2, depicting the different sections of different characteristic impedances that the leakage currents would encounter. Z01, Z02, Z03 and Z05 were calculated directly as a function of spacing between upper and lower structures. Z04 is an average of Z03 and Z05. The beam gap impedance was calculated by assuming a short circuit at the tank wall and rotating the short circuit impedance through the various lengths of different Z0's (using a Smith chart) to determine the reflected impedance at the beam gap. The results are shown in Fig. 3 curve #1.

Correlation of Calculations to the RF Leakage Problem

The fact that the RF impedance of the beam gap at resonator #8 is a short circuit is significant *only* if a voltage is developed across the short circuit impedance. If the resonators are aligned electrically there will be no voltage developed from upper to lower resonators. The voltage probes for electrically aligning the resonators were aborted early in the design stages because of mechanical problems. Since

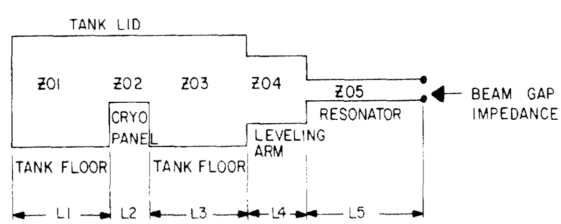

Fig. 2. Schematic cross-section of upper and lower structures.

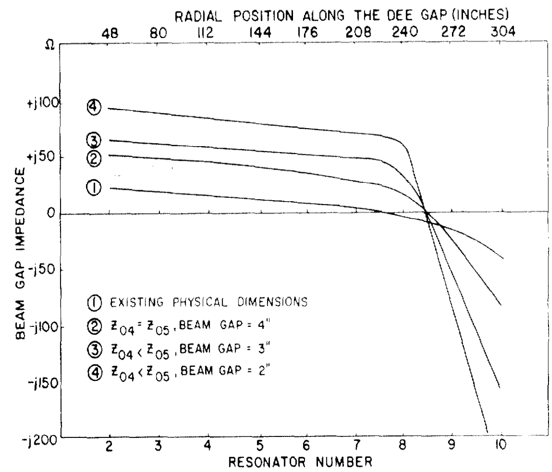

Fig. 3. RF impedance of the beam gap along the dees.

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this leaves us with no means of electrically aligning the resonators there will obviously be some electrical misalignment in the RF system causing up-down voltage asymmetry.

Because we can have a voltage developed across the beam gap due to up-down voltage asymmetry, then the impedance of the beam gap at a particular resonator will determine the amount of power that will be radiated into the beam gap by that particular resonator. It has been known for some time that most of the RF leakage into the beam gap is due to voltage asymmetry at the dees, but only after analyzing the results from newly installed thermocouples and RF pick-up loops, along with the calculations of the RF impedance of the beam gap, was it realized how sensitive the RF leakage was to the adjustment of the resonators in the outer region, especially #8 resonators. The sensitivity of the #8 resonators themselves would agree with the fact that the RF impedance of the beam gap at the #8 resonators is low. If we now take a look at some of the other RF problems we can see further correlation of the low RF beam gap impedance at #8 resonators to these problems.

On two occasions lead vibration dampers, which are mounted at the tips of the resonators to reduce mechanical oscillations, melted and on both occasions they were in the critical area of #8 resonators. The lead dampers have since been replaced with copper. Tip-to-tip (tulips) and segment-to-segment (M foils) contacts have failed at various times with 95% of the failure in the critical area of #8 resonators. The temperatures of the resonator strongbacks and the probe housings are very sensitive to the adjustment of #8 resonators. RF pick-up on the high energy probe appears as a d.c. offset on the current signal. This d.c. offset was eliminated by critically adjusting #8 resonators. Glow discharges and sparks were eliminated by adjusting the #8 resonators. The #8 resonators became so important that their adjustment mechanisms were motorized and controlled from the RF room.

Possible Solutions

The most obvious solution would be to eliminate the short circuit impedance at resonator #8 to make RF leakage into the beam gap less sensitive to resonator alignment. The results of several calculation attempts to do this are shown in Fig. 3, curves 2, 3, and 4. Since the existing physical layout of components allows movement in one direction only (i.e. makes the beam gap smaller) no solution was able to eliminate the short circuit impedance. However, one can change the slope at which the impedance changes from an inductive to a capacitive impedance. This would improve the situation but one would have to consider the work involved and whether it would be a wise move to decrease the beam gap.

Faced with maintaining the existing physical layout a great deal of effort was put on mechanical alignment reliability of the resonators and the alignment equipment. Although some improvement was obtained the RF system was still unstable and very sensitive to tip adjustment and enviromental conditions.

The next approach was to try to improve the mechanical and electrical coupling between top and bottom resonators and between adjacent resonators in order to make the overall system a much stiffer system.

In order to appreciate the existing mechanical design one must go back to the basic design of the 'dees'. The dees are evolved from a section of coaxial transmission line as shown in Fig. 4. A resonator structure of this size, with an accelerating gap over 53 ft long, would obviously have to be constructed in segments. Models were used in arriving at the final design of 80 resonator segments. Results of measurements on the first half-scale copper sheath models confirmed that from an RF point of view the upper and lower row of resonator segments are tightly coupled by the RF magnetic flux when flux guides are used, and it is not necessary to provide a physical electrical contact between the upper and lower row of resonators. This was an advantage from the machine point of view because it meant that there was no obstruction in the beam gap median plane at the tank wall. The general philosophy at TRIUMF has been not to install anything in the tank that would protrude into the median plane. Recent model tests showed that one way of reducing the up-down voltage asymmetry was to connect the upper and lower rows of resonator segments together with a physical electrical connection rather than depending on the magnetic flux coupling only. The upper and lower voltages would then tend to seek a common level. However, because of the large structure there would still be some up-down voltage asymmetry. Installing such a connector would create a remote handling task and would have to be considered in the design of such a connector.

For mechanical considerations and to prevent arcing between adjacent resonator segments, the tips of the resonator segments are tightly coupled electrically to allow unbalanced currents to flow, but mechanically they are loosely coupled. An outline view of a dee, as seen from the accelerating gap, is shown in Fig. 5(a), depicting the flux guides and the individual resonator segments perfectly aligned. Figure 5(b) shows the more practical random alignment which may occur, limited by the mechanical structure of the resonator segments themselves and our alignment equipment. Considering the RF accelerating gap itself, it was assumed, and rightly so, that the random misalignment would average out. However, no consideration was given to what would happen in the beam gap. As a result, in the initial stages of commissioning the RF system, it was felt that the central region area was the most critical area from a beam dynamics point of view, and great effort was put into aligning the centre segments and the segments closest to the centre to a tight tolerance of ±0.020 in., allowing a greater tolerance on the outer resonators to as much as

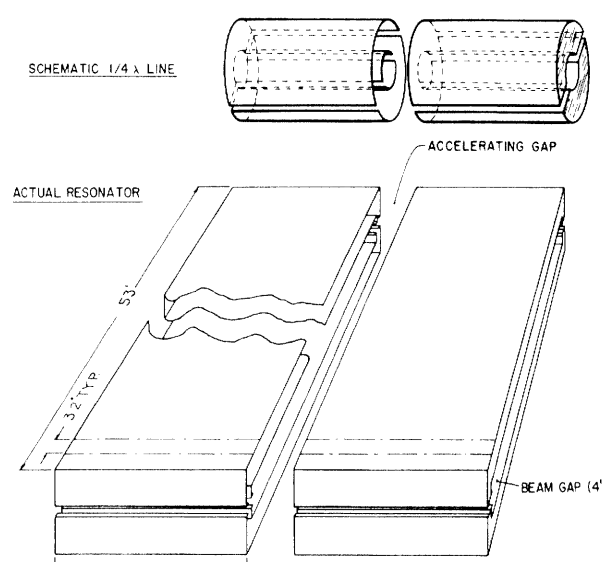

Fig. 4. The TRIUMF resonator derived from a simple quarter- wave stub.

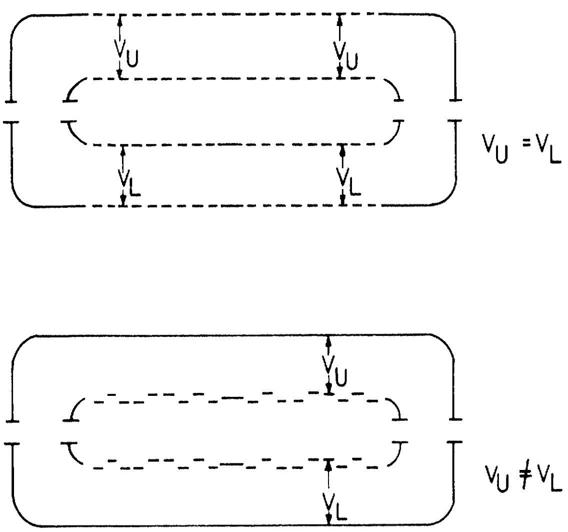

Fig. 5. Outline view of a dee as seen from the accelerating gap. (a) Resonators ideally aligned, (b) resonators realistically aligned.

±0.080 in. A tolerance of ±0.080 in. implies that we could have as much as a 2% difference in voltage between a pair of upper and lower resonators if the tolerances accumulated for that particular pair of resonators. It was felt that if the resonator segments were tightly coupled mechanically as well as electrically it would make for a stiffer overall system and reduce the voltage asymmetry.

These two modifications—electrically connecting the upper and lower rows of resonators by way of the flux guides and tightly coupling adjacent resonators mechanically—were implemented in the fall shutdown.

The result of these two modifications, along with drastic retuning of the resonators, made it possible to improve the Q by 20%, to reduce the RF leakage into the beam gap by an order of magnitude, to drastically reduce the temperatures of the resonator strongbacks, and to greatly improve the RF voltage stability on the dees.

One interesting observation was that the electrical alignment to make these improvements did not agree with the mechanical alignment indications. Since mechanical alignment deals only with the tips of the resonators one can only conclude that each resonator panel is distorted differently due to previous overheating or metal fatigue, and the mechanical alignment of the tips of the resonators are no longer an indication of the electrical alignment. As a result the position of the upper and lower ground arm tuning tips are not symmetrical and the operating frequency is too low. In order to operate the cyclotron a deviation from the optimum tuning position of the ground arm tips is necessary. During the next shutdown the hot arms will be adjusted to compensate for the ground arm position asymmetry and to bring back the operating frequency range for nominal ground arm tip positions.

Conclusion

An important milestone was reached in understanding and controlling the RF leakage into the beam gap. There is still the problem of developing a reliable electrical alignment system in order to further increase the reliability and stability of the machine.

Reference

R.L. Poirier and M. Zach, 'TRIUMF RF System', IEEE Trans. NS-22(3), 1253 (1975).