A 35 MHZ SPIRAL RE-BUNCHER CAVITY FOR THE TRIUMF ISAC FACILITY

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Abstract

A full-scale prototype of a 35 MHz re-buncher cavity was built for the ISAC project at TRIUMF. The re-buncher will be operated in cw mode to maintain the beam intensity and quality. Due to the longitudinal space limitation in the beam line, a compact spiral structure was constructed and investigated to determine it's parameters. Natural frequencies and vibration amplitudes were measured. Vibration amplitudes of the spiral structure with 10 liter per minute water flow are two orders of magnitude lower than the allowable values. Measurements also show that the shunt impedance of the structure is 370 kΩ with a Q of 2740 at a resonant frequency of 39.5 MHz. MAFIA simulation predicts the resonant frequency, Q and shunt impedance to be 39.8 MHz, 5520 and 686 kΩ respectively. Due to poor rf contacts of the prototype cavity, measured Q is much less than that predicted by MAFIA, however, R/Q values of the prototype and simulation are 135 and 124 respectively. Construction details and final dimensions of the spiral for 35 MHz will also be presented.

1 INTRODUCTION

A radioactive ion beam facility is currently being built at TRIUMF. The linear accelerator complex consists of an RFQ [1] operating at 35 MHz and a DTL [2] operating at 105 MHz. In order to match the longitudinal beam characteristics between the RFQ and the DTL, a re-buncher cavity operating at 35 MHz has been specified in Table 1. A 20 cm space restriction in the longitudinal direction and moderate voltage requirements on the drift tube, led to the choice of a spiral cavity [3], after studying other design options [4]. The structure is a two and a half turn spiral mounted in a circular tank. The spiral is shorted to the tank at the root and the drift tube is mounted on the other end at the center of the spiral. The design takes into account the mounting of quadrupole magnets on both sides of the re-buncher and a diagnostic box attached to the up stream end of the cavity. MAFIA was used to determine the desired resonant frequency and the frequency sensitivity of the various mechanical dimensions. One of the major concerns for this type of cavity is the mechanical stability during operation. A prototype cavity was fabricated to investigate the mechanical properties of such a spiral. One of the main advantages of the spiral structure is its self-supporting feature and does not require an insulator. Vibrations amplitudes of the spiral structure, with 10 liters /min water flow, were measured to be two orders of magnitude lower than the allowable values.

Table 1: Parameters of the MEBT re-buncher

Description	Value
Resonant frequency, f	35.0 MHz
Velocity (=βc)	0.018%
Accelerating voltage, V	30 kV/gap
Beam aperture, diameter	20.0 mm
Length of cavity, βλ	154.3 mm
Voltage stability	± 1%
Phase stability	± 0.3%
Tuning range	± 2%
Maximum longitudinal length	200 mm
Vibration amplitude	±0.1 mm
Operation	cw

2 DESIGN

2.1 Spiral

3D MAFIA was used to simulate the spiral and obtain the desired resonant frequency with optimum shunt impedance. It was found that a ratio of 2.0 between the width of the spiral in the xy plane to the pitch of the spiral gave optimum shunt impedance. The ratio of the tank depth to the depth of the spiral in the z-axis (beam axis) also affects the shunt impedance. Although a higher ratio gives higher shunt impedance, the spiral depth was chosen to be 3 cm to provide better mechanical stability. The variation of resonant frequency and shunt impedance with depth of the spiral is shown in figure 1.

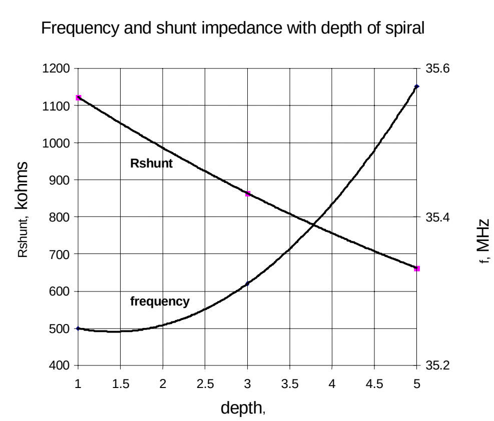

Figure 1: Graph of Rshunt and frequency Vs depth of spiral in z-axis

The spiral is housed in a 91.4 cm diameter tank. Although the optimum diameter is 96.5 cm, to reduce cost of fabrication a 91.4 cm diameter was chosen in order to make it the same diameter as DTL tank #1. Table 2 gives dimensions of the spiral and the tank. Figure 2 shows the electric field strength plot obtained from 3D MAFIA.

Assuming only 75% of theoretical Q, the power required to produce 30 kV on the drift tube, is 900 watts. About 30 % will be dissipated in the end covers where the power density is 0.05 watts/cm^2. Hence, these covers are not cooled. Also, about a 20 cm length of the spiral from the drift tube mounting need not be cooled. A water flow of 6 liters/minute will be adequate to remove the heat from the rest of the spiral.

Table 2: Dimensions of the spiral and rf parameters.

Description	Value
Tank diameter	91.44 cm
Tank length external(cover to cover)	20.0 cm
Tank length internal	14.92 cm
Spiral depth (beam direction)	3.0 cm
Spiral width (x-y plane)	5.0 cm
Spiral leg radius	4.7 cm
Resonant frequency	35.4 MHz
Q	5200
R	675 kΩ
R/Q	129 Ω
Power required for tube voltage of 30 kV(at 75% Q)	900 watts

Figure 2: 3D MAFIA plot of H field

2.2 Frequency tuning

One of the major concerns is to design the re-buncher cavity such that the resonant frequency of the fabricated structure is within 1% of 35 MHz. The spiral will be made by CNC machining and hence it will not be possible to change any of the spiral dimensions after fabrication, with the exception of the spiral (root) support. The drift tube will be fabricated separately and attached to the spiral. MAFIA simulations were used to obtain the resonant frequency of 35 MHz + 1% since it is easier to lower the resonant frequency by an external capacitive tuner. The sensitivity of the spiral leg and the drift tube dimensions are listed in Table 3. The spiral cross section near the root is 5 cm X 3 cm. A circular cylinder is envisaged here where the diameter and the length can be adjusted to get the desired frequency. Also, the drift tube diameter and the gap between the drift tube and the nose cone can be adjusted for a fine frequency change. A 14 cm X 10 cm capacitive tuning plate can lower the frequency by 0.34% (120 KHz/cm) when the distance between the plate and the outer section of the spiral is changed from 5 cm to 1.5 cm.

Table 3. Sensitivity of the spiral leg and the drift tube

Description	Lower Value	Upper Value	Frequency Change
Spiral leg radius for spiral leg length of 10.4 cm	4.0 cm	6.0 cm	470 KHz/cm
Spiral leg length for spiral leg radius of 4.7 cm	5.4 cm	10.4 cm	100 KHz/cm
Drift tube outer diameter	2.25 cm	2.5 cm	160 KHz/cm
Gap between drift tube and nose cone	3.6 cm	4.6 cm	160 KHz/cm

2.3 Coupling Loop

Power will be coupled to this cavity by a coupling loop, which will be located near the root of the spiral. A loop area of 100 cm square is adequate to provide 50 Ω matching. Couplers of this kind employing tubular ceramic windows, have already being designed and developed at TRIUMF.

3 SPIRAL PROTOTYPE

A full-scale prototype was constructed mainly to measure natural frequencies of vibrations and vibration amplitudes with and without water cooling in the spiral. Also, the resonant frequency and the shunt impedance were measured on the prototype. The photograph of the prototype spiral, housed in a rectangular box is shown in figure 3.

The prototype spiral was made of 1/8” thick copper strip. In the center portion of the spiral, the cross section is a hollow square (3 cm by 3 cm); in the outer portion of the spiral, the cross section is a hollow rectangle (5 cm by 3 cm). The two and half turn spiral is supported at the base by a cylinder. Inlet and outlet for water cooling are provided at the base of the structure. Cooling water enters the structure through a hollow ½" copper tube and flows

Figure 3: Photograph of the prototype spiral.

around the hollow body of the spiral before leaving [4]. A Fast Fourier Transform (FFT) analyzer and two accelerometers were used to measure the vibrations of the spiral structure. The natural frequency of the structure was measured by applying an impulse to the spiral when it is filled with water. The vibration amplitude was measured at the drift tube with cooling water running in the spiral. Although, a flow of 6 liters/minute will be adequate to remove the heat dissipated in the spiral, the above tests were conducted with a flow of 10 liters/minute and are shown in Table 4. The vibrations measured up to 200 Hz were much lower than the allowable amplitude of vibration of 20 micron. This limit is from the voltage and the phase stability criteria (see Table 1) of the structure.

Table 4: Vibration measurement with 10 liter/minute water flow.

Axis	Frequency of vibration	Amplitude
x	5 Hz	0.6 μm
y	6.5 Hz	0.5 μm
z	8.5 Hz	1.7 μm
z	60 Hz	0.7 μm
x	96 Hz	0.5 μm

The power dissipated per unit length of the spiral has been calculated with MAFIA. A spiral length of 20 cm from the drift tube end, has a dissipation of 1 watt/cm and need not be cooled. Figure 4 shows the power dissipated along the spiral and the maximum heat is a few cm away from the junction of the leg and the spiral.

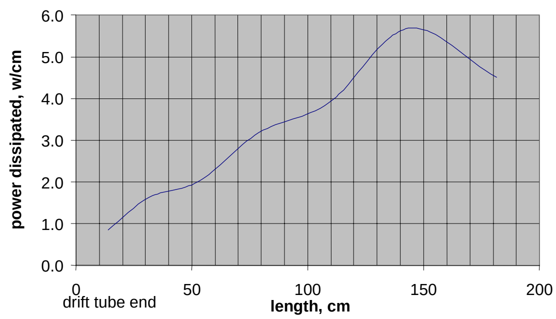

Figure 4: Computed power dissipated in the spiral.

4 DISCUSSION

The prototype cavity was built mainly to study the mechanical properties of such a structure. Although the final cavity for the MEBT re-buncher employs a different cooling option and fabrication technique, the mechanical stability should be comparable to the prototype. The cooling pipes are continuous and are soldered to pre-machined grooves on the spiral body. This removes any chance of water leak inside the cavity. The pipes are taken out from the bottom of the tank through rf and vacuum seals. The detail design is in progress with rf power test scheduled to take place by end of this year.

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6 REFERENCES

[1] R.L. Poirier, et al, "RF Tests on the Initial 2.8 Section of the 8m long ISAC RFQ at TRIUMF", LINAC98, Chicago, USA.

[2] R.E Laxdal, "The Separated Function Drift Tube Linac for ISAC", TRIUMF Design Note, TRI-DN-ISAC (Feb. 7. 1997)

[3] J. Hauser, H. Klein and A. Schempp, "Properties of Spiral Loaded Cavities", Proc. Europ. Part. Acc. Conf., Rome, Italy, June 7-11, 1988.

[4] D.Li, J.Corlett and A.K. Mitra, "A 35 MHz Re-buncher RF Cavity for ISAC at TRIUMF", EPAC 98, Sixth European Particle Accelerator Conference, Stockholm, Sweden, 22-26 June 1998

[5] A.K. Mitra and A. Chan, "Design Considerations and Measurements of a 35 MHz Spiral Re-buncher Cavity", TRIUMF Design Note, TRI-DN-98-16 (August 1998)