A 35 MHZ RE-BUNCHER RF CAVITY FOR ISAC AT TRIUMF *

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Abstract

We report a conceptual design of a 35 MHz re-buncher RF cavity for a radioactive ion beam facility (RIB) called ISAC (Isotope Separator and ACcelerator) at TRIUMF in Canada. The 35 MHz re-buncher cavity will be operating at CW mode to preserve the beam intensity. Due to the space limitations, a folded quarter-wavelength structure with two accelerating gaps may be favored although other structures have been considered. MAFIA simulations show that the folded quarter- wavelength cavity has a 1.46 MΩ shunt impedance at $\beta = 0.018$ and quality factor of 19,000. To ensure the mechanical stability of the inner conductor, ceramic support structures and possible RF windows have been considered. RF power losses on the ceramic materials as well as on the inner conductor have been studied carefully to find the best locations to place the supports, windows and possible cooling channels. Discussions on the tuner and coupling loop designs will also be presented.

1 INTRODUCTION

A radioactive ion beam (RIB) facility named ISAC (Isotope Separator and ACcelerator), funded by the Canadian federal government in 1995, is currently being built at TRIUMF. The ISAC facility consists of a thick target, an online isotope separator and a two-stage linear accelerator. The low energy radioactive ion beams of the ISAC are expected for the spring of 1999 and the accelerated beams for the spring of 2000. Two experimental areas will be available for nuclear physics studies: a low energy area will utilize the ≤ 60 keV beams from the separator; a high energy area use the beams from the accelerator. The primary objectives of the ISAC facility are the study of nuclear reactions of astrophysical interest and the investigation of fundamental interactions in nuclei. With the accelerated radioactive beams of unstable nuclei, produced by the ISAC facility, nuclear reactions which occur in explosive astrophysical phenomena, such as supernovae, will now be studied in the laboratory.

The two-stage accelerator complex consists of a RFQ (Radio Frequency Quadrupole) accelerator and a DTL (Drift Tube Linac) linear accelerator. The RFQ accelerator provides an initial acceleration of the ion beams delivered from the mass separator. The DTL will accelerate, in CW mode, ion beams with charge to mass ratio $\geq 1/6$ from 0.15 MeV/nucleon to a final energy variable from 0.15 to 1.5 MeV/nucleon. In order to match the longitudinal beam characteristics at different acceleration (energy) stages [1], a few RF re-buncher cavities are needed. In this paper we report one of the re-buncher cavity designs, a folded 35 MHz quarter-wavelength re-buncher RF cavity, which is proposed to be used for the phase rotation between the RFQ and the DTL.

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2 CAVITY SPECIFICATIONS

The 35 MHz re-buncher cavity will be operating at CW mode to preserve the beam intensities. Limited by the space available between two quadrupole magnets (see Figure 1), a double gap RF structure in the form of a loaded quarter wavelength coaxial line is favored. The design

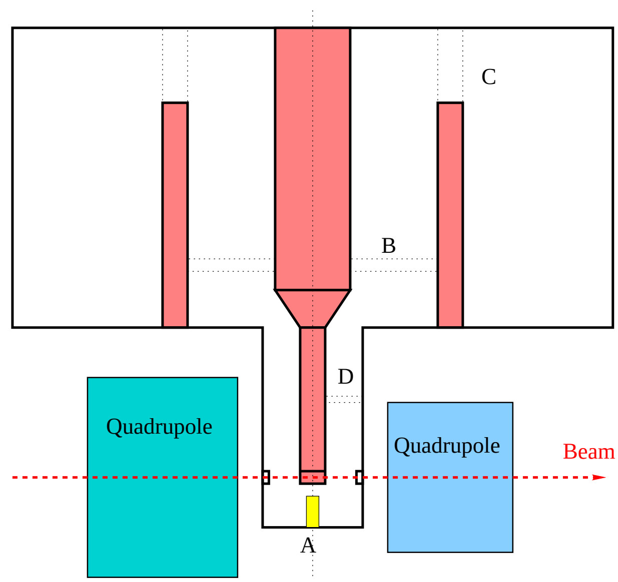

Figure 1: Schematic layout (not to scale) of the 35 MHz re-buncher RF cavity for ISAC at TRIUMF. Dotted lines and notations of **A, B, C** and **D** are reserved for possible locations of a tuner, a disk RF window, a tubular RF window and supporting ceramic rods, respectively.

needs to consider easy access and installations for both the adjacent quadrupole magnets and the cavity. The physical space available (in beam direction) for the cavity is only about 20 cm. The beam axis is at a height of 167.64 cm from the floor level. As it is shown in Figure 1 (not to scale), the whole cavity body will need to be sat on a support structure, and stay right above the two quadrupoles. To ensure a good alignment of the cavity iris with the beam line, the support structure design and mechanical stability of the cavity are important. Problems such as vacuum pressure, material stretch and the inner conductor vibrations need to be carefully studied as well. Some parameters of the cavity are listed in Table 1 for reference.

Table 1: Parameters the 35 MHz RF Cavity

Notation	Description	Value
f	Frequency	35 MHz
β	Velocity $(=\beta c)$	0.018%
V	Accelerating Voltage	50 kV
D	Beam Aperture	20 mm
H_c	Cavity Height	1.55 m
D_c	Cavity Diameter	$\sim$ 1.4 m
$\beta\lambda$	Length of Drift Tube	154.3 mm

3 THE CAVITY DESIGN

A few possible design options for the cavity have been carefully reviewed and discussed [2, 3]. It was decided that the quarter-wavelength coaxial line type is a better choice for overall considerations of shunt impedance, mechanical stabilities, compact, tuning and vacuum etc.. 2D MAFIA has been used to simulate the *EM* fields and optimize the cavity geometry as the cavity is almost a cylindrical symmetrical. 3D MAFIA model was established for the purposes of optimization of the nose cone shape and will be used for the final design. Nevertheless the 2D model should provide enough information (nose cone shape and the beam iris are considered to be a perturbation to the 2D model) at the conceptual design stage. All the simulations and discussions presented in this paper are based on the 2D MAFIA modeling. As an example, an optimized 2D MAFIA model is given in Figure 2. The optimization was reached by varying all geometry parameters possible and keeping a reasonable characteristic impedance match between the inner and outer coaxial lines at a fixed outer diameter D_c, to get the highest possible shunt impedance R and quality factor Q. Larger D_c always gives higher R and Q in general. The D_c was determined upon the compromised considerations of the costs, space and etc.. Based on the model in Figure 2, we obtained $R = 1.46$ MΩ assuming $\beta = 0.018$ and $Q = 19,000$ (copper model). It is worthy to point out that the definition we used for the shunt impedance calculation is:

$$R = \frac{|\int_0^{r_0} E_r(z_0) e^{-j\frac{\omega}{\beta c}} dr|^2}{2P}, \qquad (1)$$

since people use different definitions sometimes. Here P and $E_r(z_0)$ are power losses on cavity wall and electric field at the beam passage, respectively. Therefore 270 watts will be needed to to attain a 25 kV accelerating voltage at each gap (neglecting the power taken by the beam). To be conservative, we have assumed only 80% of theoretical Q is achieved. We also noticed that 46% of the RF power losses will be dissipated on the inner conductor. Water cooling of the inner conductor is necessary.

4 FINE TUNER

A movable plunger type tuner has been suggested for fine tuning. The most favorable location for the tuner is shown as **A** in Figure 1, where the RF current is zero, and yet sensitive enough to perturb the resonance frequency. The MAFIA simulations indicate that the tuning range can be up to 1 MHz with a minimum of 5 mm gap left between the tuner and the drift tube if assuming the tuner has the same radius as the inner conductor. The resulting electric intensity is 6.4 MV/m at the gap, still below the Kilpatric criterion of 8 MV/m at 35 MHz. The RF power losses on the tuner is computed to be about two watts, less than 1% of the total RF power losses on the cavity wall. The tuner itself does not need to be cooled.

5 MULTIPACTING EFFECTS

RF cavity performance may be plagued by the *multipacting effects*. A complete study for the multipacting effects needs to use sophisticated computer programs to track electrons in the RF fields of the cavity and search for the multipacting tracks. Many theoretical and experimental studies on this aspect are available [4]. However, many of these research studies were conducted for a particular type of the cavity geometry. A new cavity design always asks for a new study. Fortunately the cavity design we have for the 35 MHz re-buncher is a simple coaxial type. The multipacting effects in this kind of cavity is dominated by the so-called two-plate type multipacting effects. Based on the experiment results and theoretical studies [4] respect to this, without going through the complicated computer simulations, which sometime are necessary, we have carefully checked the operation zones of the cavity and made the cavity design avoid falling into the existing multipacting zones [5] observed in other experiments at normal operations.

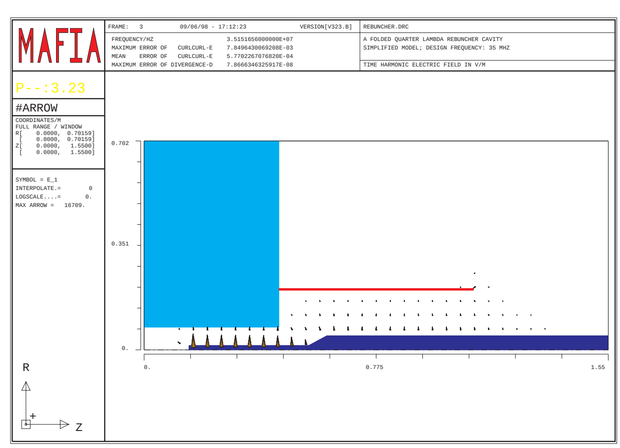

Figure 2: An optimized 2D (rz geometry) MAFIA model for the 35 MHz re-buncher RF cavity. The dimensions of the cavity shown here may not be the final, but close to. The arrows shown in the cavity are the electric field strength.

6 MECHANICAL STABILITY AND RF WINDOWS

As shown in Figure 2, the inner conductor of the cavity is long and thin. Supporting the conductor against possible mechanical instability and ensuring the good alignment are big concerns. Making the whole cavity stiff or using support structures inside the cavity were suggested as possible solutions. Possibility of using disk or tubular ceramic RF windows at locations of **B** or **C**, or ceramic support rods at **D** in Figure 1 to support the inner conductor have been studied. The advantages of having the RF windows inside the cavity are not only to provide the necessary mechanical support to the conductor, but also greatly reduce the vacuum burden of the outer coaxial line since the outer coaxial line does not need to be in vacuum anymore. The multipacting problems in the outer coaxial line will not be an issue either. However, having the RF windows inside the cavity will increase the complex of the cavity design, manufacturing, and the costs (may need to be compromised with the costs of the vacuum system). The normal operation of the cavity with a RF window, and the RF window coolings become a new issue. We have conducted the performance studies of the RF cavity with windows using the the MAFIA in frequency domain. The simulation results are listed in Table 6 with the window parameters. Where

Table 2: Simulation results with/without RF windows

Parameters	Disk window	Tubular window	No window
ϵ_r	9.0	9.0	$\otimes$
$\tan\delta$	10^{-4}	10^{-4}	$\otimes$
t_w	1.27 cm	1.27 cm	$\otimes$
Q	$\sim 16,000$	$\sim 18,000$	$\sim 19,100$
R	1.2 MΩ	1.34 MΩ	1.46 MΩ
P_{total}	326 watts	287 watts	268 watts
P_ϵ	52 watts	18 watts	$\otimes$
V_{window}	~ 29 kV	~ 22 kV	$\otimes$

t_w and P_ϵ are respectively the window thickness and the RF power losses on the windows. The P_ϵ calculations are based on the perturbation method using the *E* fields computed for the cases without lossy materials. Again we have assumed the achievable Q is 80% of the theoretical results for the power calculations. Having the RF windows inside the cavity will reduce the shunt impedance, which leads to a slight increase of the input RF power. The RF voltages at the window locations and RF power dissipation on the windows are high, which suggests that the cooling of these windows be necessary. As a compromised solution for the support of the inner conductor, we have considered to use three ceramic rods, instead of the windows, at location **D** in Figure 1. Assuming the same ceramic material is used, the RF power losses on each rod is significantly less (a few watts), cooling may not be needed. However the rods will still be at high voltage locations and the advantages from having the RF windows, such as vacuum sealing and multipacting elimination of the outer coaxial line will be lost.

7 COUPLER DESIGN

A magnetic coupling loop, fed with a 50 Ω transmission line, is suggested as the coupler for the cavity. The reason we choose the loop design is because of its simplicity and the flexibility for the coupling adjustments. A simple analytical calculation (see Equation 2) shows a small loop of 8 cm in diameter (assuming a circular loop) should be able to drive the cavity. The coupling loop area S is given by,

$$S \approx \frac{\sqrt{PR_0}}{\omega\bar{B}}, \tag{2}$$

where P is the input power, R_0, the impedance of transmission line (50 Ω) and $\bar{B}$, the average magnetic intensity in the coupling loop. It is worthy to point out that the S is independent of the P as $\frac{\sqrt{P}}{\bar{B}}$ is a constant depending on the cavity geometry only. The engineering and mechanical designs of such kind of couplers have been used and are readily available at TRIUMF. The coupler locations can be either inside or outside the tubular window location **C**, depending on the final choice of the cavity design.

8 A POSSIBLE NEW CAVITY DESIGN

To further reduce the costs of the cavity and ease the mechanical constrains from the vacuum pressure, material stretch and alignments, we propose a new cavity design using commercial available high pressure, elliptical containers to to replace the two big cylindrical vacuum vessels for the previous designs. MAFIA simulations using the dimensions for commercial available containers show that the overall performance of the cavity is, in fact, improved. The shunt impedance R and quality factor Q obtained from the modeling are 1.48 MΩ and 19,500, respectively. The cavity sizes become bigger, and are respectively 1.524 m in diameter and 1.45 m in height. The discussions on having the RF windows and the supporting rods inside the cavity remain same. Nevertheless, the mechanical requirements for the stability and alignments are less demanding.

9 REFERENCES

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