HIGH POWER TEST OF THE 35 MHZ SPIRAL RE-BUNCHER CAVITY FOR THE TRIUMF ISAC FACILITY

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Abstract

To preserve beam intensity and quality, a 35 MHz spiral two gap re-buncher cavity for the ISAC radioactive beam facility at TRIUMF will operate in cw mode. The spiral at the open end supports the drift tube and has a stem support at the bottom. The spiral is NC machined from solid copper and water pipes are soldered to the inner and outer surfaces and exit via the stem at the bottom. A 2% change in resonant frequency can be obtained by varying the diameter of a spool piece which is part of the stem. The final dimension of the spool piece is obtained from rf signal level measurement. A fine tuner is employed to compensate for the frequency change during operation. The spiral and the end plates are water cooled. The measured mechanical vibrations of the spiral were less than 1 μm with 8 liters/minute water flow. The resonant frequency and Q of the manufactured cavity were within 1% and 65% of the value predicted by MAFIA 3D simulation respectively. The cavity has been tested to full power of 1 kW to produce 30 kV on the drift tube. The results of signal level and power tests are reported.

1 INTRODUCTION

The radioactive ion beam facility at TRIUMF requires a re-buncher cavity operating in cw mode at 35.36 MHz to match the longitudinal beam characteristic between the RFQ operating at 36.36 MHz and the DTL operating at 106.08 MHz. The basic parameters of the re-buncher are given in Table 1 and the re-buncher is shown in Fig. 1.

Table 1: Basic parameters of the MEBT re-buncher

Resonant frequency, f	35.36 MHz
Velocity (βc)	.018
Charge to mass ratio	1/3 ≥ q/A ≥ 1/7
Operating energy	0.150 MeV/u
Accelerating voltage, V	30 kV/gap
Length of cavity, βλ	154.3 mm
Tank diameter	91.4 cm
Beam aperture, diameter	20.0 mm
Voltage stability	± 1%
Phase stability	± 0.3%
Vibration amplitude	± 0.1 mm
Operation	cw

Measurements of mechanical vibrations and rf properties of a prototype re-buncher [1] was used in designing the final re-buncher. The re-buncher was tuned to the operating frequency by trimming the stem radius and adjusting a fixed coarse tuner. Vibration amplitudes were measured to be two orders of magnitude lower than the allowable values. Measured resonant frequency and quality factor were in excellent agreement with the computed values. A gap voltage, 40% excess of nominal 30 kV could be maintained on the drift tube in cw mode which was limited by the power amplifier capability.

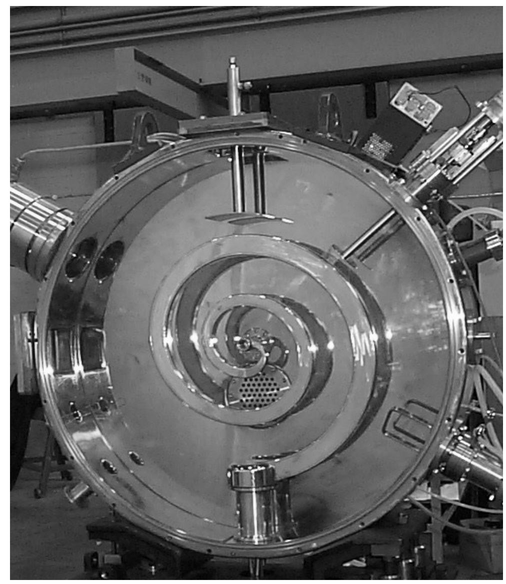

Figure 1: Photograph of the re-buncher cavity

2 DESIGN

3D MAFIA was used to simulate and design the spiral [2,3] with the specification listed in Table 1. The longitudinal space available was limited to 15.43 cm and the tank diameter of 91.4 cm is the same as DTL tank#1. The cross section of the spiral is non uniform. A constant depth of 3 cm in the z-axis (beam axis) is used whereas the width is 5.0 cm at the stem and reduces to 2.5 cm at the drift tube holder. Although, higher ratio between the tank length and the spiral depth yields higher shunt impedance, the depth of 3 cm was dictated by mechanical stability of the structure. The shunt impedance was optimized by changing the turn to turn spacing of the spiral. The length of the spiral was designed to obtain a resonant frequency 500 KHz above the operating frequency. Since the spiral is made by CNC machining, it is not possible to alter any of the spiral dimensions later. Frequency can be adjusted by changing the gap between the drift tube and nose cones, the drift tube diameters, the stem diameter and the external capacitive tuners. The magnetic field distribution in the tank obtained from MAFIA was used to calculate the position and loop area of the coupling loop. A loop, area of 65 cm^2, located at 30 degree clockwise from horizontal axis, was adequate to provide 50 Ω matching to the power amplifier. Power loss calculations of the spiral, tank wall and covers are shown in Fig. 2. 30% of power is dissipated on the

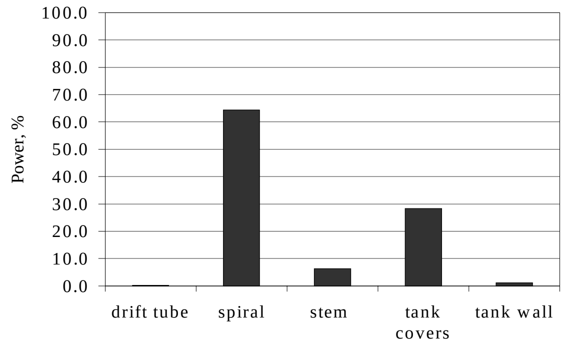

Figure 2: Calculated power loss of the re-buncher

covers and tank wall whereas 70% is dissipated in the spiral and stem. The cooling circuits and water flow are calculated from these values.

3 MECHANICAL DESCRIPTION

The structure is a two and half turn spiral which is mounted in a circular tank. The spiral is NC machined from solid copper, the tank and the end plates are made of copper plated stainless steel. Cooling pipes are soldered to the pre-machined groves on the inner and outer surfaces of the spiral and the completed assembly is copper plated. The drift tube and it's holder is CNC machined and is mechanically mounted to the open end of the spiral. Grooves are provided at the stem for rf spring contact and vacuum "o" ring. Water connections exit at the stem. A separate spool piece is attached to the stem to change the resonant frequency. The final dimensions of the spool piece are obtained from rf signal level measurements. A coarse fixed tuner and a fine movable tuner are also installed to achieve the desired operating frequency of the re-buncher. The coupling loop which is at 30 degrees from the horizontal axis and the turbo pump can be also seen in Fig. 1. Vibration frequency and amplitude of the spiral with a water flow of 8 liters/minute was measured and was found to be less than 1 µm in all the three axes. The natural frequencies of vibration of the spiral are 34 Hz, 25 Hz and 15 Hz in x, y and z axes respectively. The spiral is in the x-y plane and the beam is in the z-axis. The alignment of the drift tube is done by rotating and moving the spiral in the horizontal plane at the stem. From the alignment measurements, the drift tube holder is then machined for the final positioning of the drift tube.

4 RF SIGNAL LEVEL TEST

The resonant frequency of the re-buncher was varied by changing the radius of the spool piece which is attached to the stem. Table 2 gives the measured and the computed values of resonant frequency and Q with stem radius. The frequency sensitivity of the stem tuner was found to be 250 KHz/cm. A stem with a radius of 4.0 cm was finally installed and the measured frequency was 35.516 MHz. Since, for these measurements the end plates were bolted to the tank without rf spring contacts, measured Q was lower than expected. The expected value of Q is 65% that of MAFIA. The measured frequency was within 1% predicted by MAFIA simulation.

Table 2: frequency and Q with stem radius

	With Spool piece		Without spool piece	
Stem radius	6.5 cm		3.5 cm	
	F, MHz	Q	F, MHz	Q
MAFIA	35.764	5000	35.164	4900
Measured	36.153	2700	35.383	3200
% error	1.08		0.6	

After initial frequency and Q measurements, the spiral with cooling pipes soldered on it's outer surfaces, was copper plated. The copper plating improved the Q by 5%. The frequency of the re-buncher was further tuned by a fixed tuner. A fine tuner is also installed to compensate for frequency change due to change in temperature of the cavity. The tuner characteristics are shown in Fig. 3 and 4. The fixed tuner is mounted on the top of the tank. The distance of the fixed tuner plate from top of the spiral

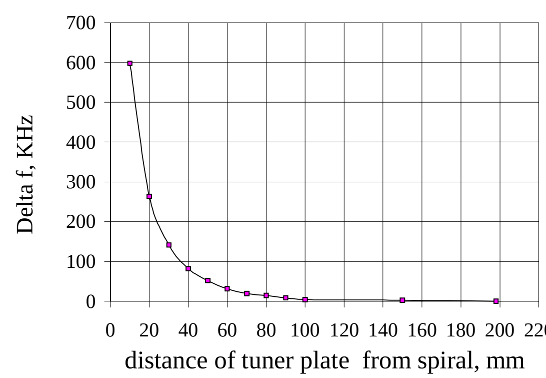

Figure 3: Characteristic of the fixed tuner

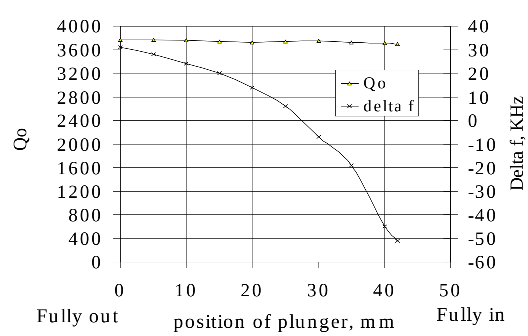

Figure 4: Fine tuner response

was changed from 1.0 cm to 19.6 cm and the resonant frequency could be lowered by 600 KHz. The fine tuner has a tuning range of 80 KHz for a total travel of the tuning plunger of 40 mm. With the fine tuner in mid position, the fixed tuner was adjusted to bring the cavity frequency to 35.40 MHz. Frequency of the cavity is further decreased by 40 KHz in vacuum so that the cavity frequency will be at 35.36 MHz under normal operating condition. The shunt impedance of 520 kΩ was obtained from R/Q and Q measurements. The measured values are given in Table 3. This value of shunt impedance was used to calibrate the rf voltage probes.

Table 3: rf parameters of the re-buncher

F	Q	R/Q	R_{shunt}	Power at 30 kV
35.4 MHz	4000	132	520 kΩ	870 W

A 10 mm diameter stycast bead with a dielectric coefficient of 20, was used for bead pull measurements. The beadpull measurement is shown in Fig. 5. The field error between gap1 and gap2 is 1.5% due to a difference of 1.0 mm between the two gaps in the beam axis.

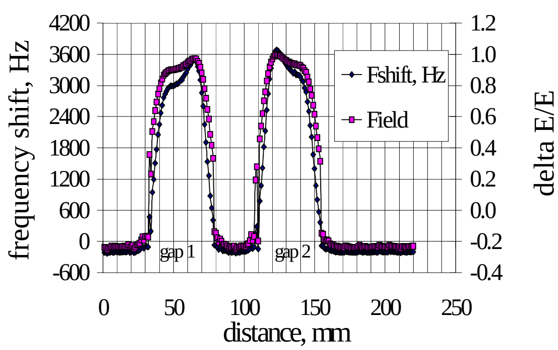

Figure 5: Bead pull measurement

5 RF POWER TEST

A 2 kW solid state commercial amplifier was used to power the re-buncher cavity. The cavity was baked for 14 hours at 55 ^{o}C and was slowly cooled down to room temperature in 2 hours. The vacuum was established at $7.5.10^{-7}$ Torr. Multipacting at 100 to 300 volts were observed between the stem of the spiral and the end plates. It took 5 hours to condition the cavity from multipacting. Both pulse and cw conditioning were used to achieve this. Nominal voltage of 30 kV/gap was obtained with 1 kW of rf power and was maintained in the cavity for 36 hours without any interruption. This long term test improved the vacuum from $7.5.10^{-7}$ Torr to $3.0.10^{-7}$ Torr at full power. The water flow through two independent cooling circuits of the spiral were 9 liters/minute and 10 liters/minute respectively and the end covers, were in series and the flow was kept at 22 liters/minute. The maximum temperature measured on the cover was 28 degree C, the inlet water temperature was 23 degree C. Fig. 6 shows the voltage at the drift tube with input power. This voltage was also calibrated by measuring emitted x-ray. Measurement shows excellent agreement of the pickup loop data, obtained from shunt impedance value and the x-ray data. Although nominal operating voltage of the re-buncher is 30 kV, 42 kV could be attained which was limited by maximum output power of 2 kW of the amplifier.

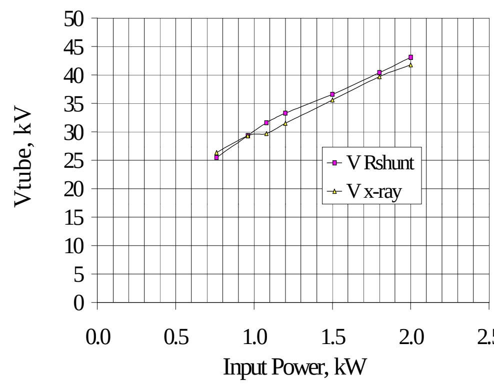

Figure 6: Voltage measurement of the drift tube

6 CONCLUSION

The re-buncher showed stable and reliable rf performance in cw mode**.** Excellent frequency stability and 40% higher voltage capability makes the re-buncher easy to operate. The re-buncher has been installed in ISAC and is now being used for initial beam test. The alignment and adjustment of the drift tube and nose cones was not trivial. Improvements have been made in the alignment procedure which can be implemented in future designs.

ACKNOWLEDGMENTS

The authors would like to thank Peter Harmer and Balwinder Waraich for providing technical assistance, Alan Wilson for detail drawing and Mindy Hapke for taking photographs. We also wish to thank Tom Rees for helping in the mechanical vibration measurements, Joseph Lu for rf measurements and Guy Stanford for mechanical engineering of the re-buncher.

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