RF TEST AND COMMISSIONING OF THE LOW AND HIGH BETA BUNCHERS FOR THE TRIUMF ISAC FACILITY

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Abstract

The high energy beam transport (HEBT) line for the ISAC radioactive beam facility at TRIUMF requires a low beta buncher at 11.78 MHz and a high beta buncher at 35.36 MHz operating in cw mode. The low beta buncher is required to bunch beams from 0.15 to 0.4 MeV/u and the high beta buncher is for beams from 0.4 to 1.5 MeV/u and are placed 12 m downstream from the DTL. The main requirement for the low beta buncher is to operate with an effective voltage of 100 kV. This three gap buncher has been realized by using two identical lumped element resonant circuits. The resonant frequency is obtained by using an inductive coil in parallel with the capacitance of the drift tube and the capacitance of the rf feedthrough. The high beta buncher is designed to operate with an effective voltage of 255 kV. This is a two-gap spiral structure similar to the rebuncher used in the medium energy beam transport (MEBT) line in ISAC. Both bunchers have been tested and commissioned to full rated power at 1.5 kW and 12 kW respectively.

1 INTRODUCTION

The beam from the DTL (drift tube linac) of the ISAC radioactive beam facility [1] is bunched with either a low beta buncher or with a high beta buncher and is delivered to various experimental stations. The DTL [2] produces beams fully variable in energy from 0.15 to 1.5 MeV/u with mass values of 3 ≤A/q< 6. The low beta buncher (β_0 =0.022), at 11.78 MHz, provides initial bunching for beams from 0.15-0.4 MeV/u and the high beta buncher (β_0 =0.032), at 35.36 MHz, provides bunching for beams from 0.4 to 1.5 MeV/u. The basic parameters of the bunchers are given in Table 1. The maximum required effective voltages from the low beta and the high beta bunchers are 100 kV and 255 kV respectively [3].

Table 1: Basic parameters of the HEBT bunchers.

Parameters	Low Beta	High Beta
Frequency	11.78 MHz	35.36 MHz
Velocity (β_0)	0.022	0.032
Energy Range	0.15-0.4 MeV/u	0.4-1.5 MeV/u
V_{eff}	100 kV	255 kV
Gaps	3	2
$\beta\lambda/2$	28.0 cm	13.6 cm
Beam aperture dia.	2.0 cm	2.0 cm
Tank length	70.0 cm	34 cm
Voltage stability	± 1.0%	± 1.0%
Phase stability	± 0.3%	± 0.3%
Operation	cw	cw

2 THE LOW BETA BUNCHER

The low beta three gap buncher employs lumped circuit components to obtain the resonant frequency of 11.78 MHz [4]. The parallel resonant circuit consists of a water cooled inductive coil, the capacitance of the drift tube and the capacitance of the feedthrough assembly. Two such identical resonant circuits, operating in push-pull mode constitute the three gap buncher. The photograph of the buncher is shown in Figure 1. An effective voltage of 100 kV is obtained by applying 30 kV to each drift tube. Since only the drift tubes are in vacuum, rf feedthroughs are required to connect the coils to the drift tubes. The feedthroughs are designed and tested to withstand 34 kV rf under cw operation. Each resonant circuit is equipped with a coarse tuner and a motor controlled fine tuner but only a single coupling loop is required to produce the nominal gap voltage. All of these devices are located in the same housing as the coils. The beadpull measurement at the push-pull mode of 11.78 MHz is shown in Figure 2, where the error between the axial electric fields in the two end gaps, computed from the measured frequency shift, is ± 0.5%. A shunt impedance of 9.6 MΩ is obtained from the beadpull measurements. The alignment of the drift

Figure 1: The low beta buncher.

tubes is within ±0.2 mm. The frequency of the push-push mode is at 12.27 MHz, which has been measured with beadpull and verified with Pspice simulation. This mode is easily identified by the absence of electric fields in the middle gap while the end gaps have maximum electric field.

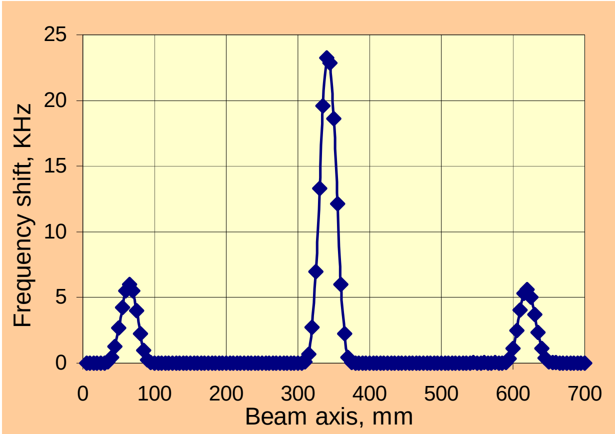

Figure 2. Beadpull measurement at the push-pull mode of the low beta buncher.

3 THE HIGH BETA BUNCHER

The high beta buncher is a two-gap structure using a spiral as the center conductor. The design is similar to the MEBT rebuncher [5], but has been redesigned and optimized for higher shunt impedance. The spiral width along the beam axis, the gap between the drift tube and the nose cones, the outer diameter of the drift tube and the tank length are the parameters that have been changed to obtain the required resonant frequency and shunt impedance. Figure 3 shows the dependence of shunt impedance, resonant frequency, Q and rf power on tank length with a constant drift tube diameter and gap. The spiral was finally designed with a 5.0 cm outer diameter drift tube, the drift tube length being 10.6 cm. A tank length of 34 cm and tank radius of 46.0 cm were chosen, where the power, computed to produce the required effective voltage of 255 kV, is 9.0 kW. The measured and computed with MAFIA values of the resonant frequency and R/Q are within 1%. The measured Q is 72% of the

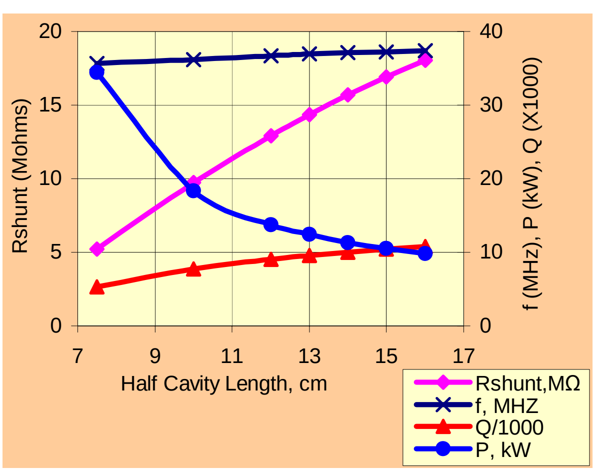

Figure 3: Optimization of high beta buncher with MAFIA

Figure 4: The high beta buncher.

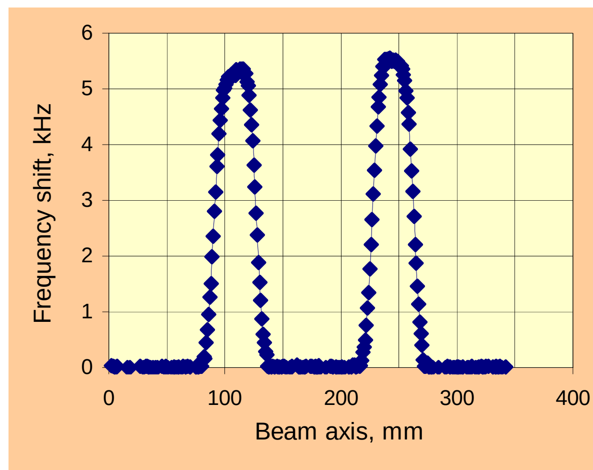

Figure 5: Beadpull measurement of the high beta buncher

calculated one. The buncher is equipped with a coarse tuner, a fine tuner and a coupling loop and these units are all water cooled. The frequency range of the coarse tuner is 670 KHz and that of the fine tuner is 200 KHz. Figure 4 shows the photograph of the high beta buncher with the tank cover open. The field error in the two gaps computed from the beadpull measurement as shown in Figure 5, is ± .08%. The measured parameters of both the bunchers are summarized in Table 2.

4 CONDITIONING AND HIGH POWER OPERATION

Buncher high power tests were performed with dedicated rf amplifiers providing output power of 2 kW and 28 kW respectively for low-β and high-β bunchers. A low level RF control system identical to the DTL [6] is used to operate the buncher amplifiers. A VSWR protection circuit has been added to the control system to reduce the rf driver output when reflected power exceeds a preset threshold level, which protects both the coupler ceramic window and the rf amplifier. The low level conditioning was carried out in an open loop self excited mode with either pulse or cw operation depending on vacuum response. The high power conditioning was performed in close loop driven cw mode. The vacuum with rf off is $4*10^{-7}$ Torr with an rf trip level of $1*10^{-5}$ Torr.

Table 2: Measured Parameters of the Bunchers

Parameters	Low Beta Buncher	High Beta Buncher
Resonant Frequency	11.78 MHz	35.36 MHz
Push-push mode	12.135 MHz	91.54 MHz
Q, unloaded	2170	6400
R_{shunt}/Q	4400	1430
R_{shunt}	9.6 MΩ	9.2 MΩ
V_{tube}	30 kV	170 kV
Power	1.5 kW	12.6 kW
Fine tuner range	±6 KHz	±100 KHz
Structure	Coil + drift tube	Spiral
Coupling loop	In air	In vacuum
Transit time factor (T)	0.8	0.75
$R_{shunt}= V_{eff}^2/P$	$V_{eff}=4.V_{tube}.T$	$V_{eff}=2.V_{tube}.T$

The low beta buncher conditioning took about 8 hours to reach a 1.5 kW power level. The only consideration was an upper voltage limit on the vacuum feedthroughs. As a precautionary measure the rf driver level was limited to restrict the amplifier output power to 1.5 kW, which corresponds to about 30 kV on the drift tube. No structure heating was observed over the whole RF power range and the resonant frequency was sufficiently stable to allow open loop frequency control in routine operation.

The high beta buncher conditioning at low power levels was accompanied by significant vacuum deterioration caused by multipactor discharge. It took 5 days to punch through the multipactoring levels and an additional 8 hours to reach the nominal power level of 12 kW. Some problems were associated with a transmission line parasitic resonance appearing just 260 kHz above the operating frequency, which was solved with a transmission line length adjustment. High voltage sparking was observed at power levels above 10 kW. It was accompanied with a substantial increase of x-ray production. Eventually the high-β buncher was conditioned and tested at levels from 5% to 106% of nominal voltage for a maximum power of 14.5 kW. At the nominal voltage the highest x-ray fields were concentrated at the beam axis and measured to be about 1000 mS/hour. At 1 m off axis x-rays were attenuated by the cavity steel structure down to 5 mS/hour. The narrow x-ray streams from pickup ports were suppressed with localized steel and lead shields.

Drift tube voltages were measured with pick-up probes calibrated by using the signal level measured values of shunt impedance R_{shunt}. Voltage calibrations were confirmed with the beam longitudinal structure measurements at the DRAGON experiment target location using a fast Faraday cup [7]. Figure 6 shows a corresponding beam time distribution at about 20 m downstream from the bunchers.

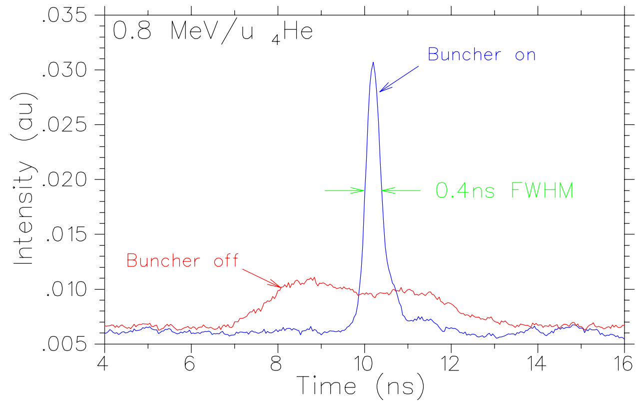

Figure 6: Beam time distribution measured on a fast Faraday cup for high beta buncher on and off.

During the beam delivery to the experiments there was no problem to start and operate the low beta buncher. The high beta buncher required 10 to 20 minutes of conditioning at startup. The very low voltage levels (down to 5%) required up to 4 hours of extra conditioning even when coming down from higher voltages.

5 CONCLUSIONS

Both bunchers operated stably at full power for more than 100 hours. During the beam delivery to the experiments the bunchers showed reliable operation in a wide range of specified voltages: 10-100 % of the nominal.

6 REFERENCES

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