DEVELOPMENT, FABRICATION AND TEST OF TRIPLE GAP SPLIT-RING BUNCHERS FOR THE TRIUMF ISAC FACILITY*

A. Vasyuchenko, A. Feschenko, A. Kvasha, A. Menshov, V. Paramonov, INR RAS,
Moscow, Russia
Y. Bylinsky, G. Dutto, R. Laxdal, A. K. Mitra, R. Poirier, TRIUMF, Vancouver, B.C., Canada

Abstract

A set of triple gap split-ring 106.08 MHz bunchers (bunch-rotator for MEBT and three DTL bunchers) was designed, fabricated and tested for the ISAC project at TRIUMF. These four devices operate at low β (1.8%, 2.3%, 2.7% and 3.3%) and deliver the peak effective voltages in cw mode of 0.07, 0.19, 0.26 and 0.32 MV respectively. The shape of drift tubes was optimized to have maximum transit time factor with the fixed value of electric field at the surface (1.5 value of Kilpatrick's criterion). 3D simulations were done to adjust optimized drift tubes with split-rings to have operating frequency and to unify dimensions of the cavities. The bunchers were fabricated in INR and successfully tested at full power in TRIUMF. Some features of the design and results of the tests are reported in this paper.

1 INTRODUCTION

Radioactive ion linac at TRIUMF [1] comprises 4 bunchers operating at 106.08 MHz: MEBT bunch rotator and 3 rebunching cavities installed after 1-st, 2-nd and 3-rd DTL accelerating tanks. Main buncher features are cw operation, high effective voltage (up to 0.33 MV) and wide particle velocity acceptance (1.8 – 4.1%). Cavity design is based on a split-ring resonator with 3 gap

Figure 1: Buncher #1 general view without tuner

accelerating structure. Full-scale prototype of such a cavity was successfully tested in 1998 [2]. This allowed structure optimization and common design for 4 new

devices, which were developed and manufactured at INR RAS. All bunchers were successfully tested at full rf power and showed reliable operation in first beam tests. General view of the buncher is shown in Figure 1.

2 GEOMETRY OPTIMIZATION

105 MHz buncher prototype [2] was designed for maximum surface electric field of $E_{smax} = 1.3E_k$, where E_k is Kilpatrick's criterion. Test results have shown cavity reliable operation up to $E_{smax} = 17$ MV/m, which is $1.5E_k$ for this frequency range. Corrected operating frequency (106.08 MHz) and increased limit for surface electric field initiated additional calculations in order to optimize structure dimensions.

Basic buncher parameters satisfying beam dynamics requirements [3] are presented in Table 1.

Table 1: Main parameters of the bunchers

		Buncher			
		Bunch-rotator	#1	#2	#3
Particle velocity	β	0.018	0.023	0.027	0.033
Aperture diameter	2a, mm	25	14	14	14
Cavity Length	L, mm	98	98	116	141
Effective voltage	U_{eff}, kV	80	190	260	330

Drift tube optimal dimensions were determined according to technique described elsewhere [4,5]. Drift tube tip radii r1 and r2 together with accelerating gaps g1 and g2 were taken as input parameters for simulations in axisymmetric 2D model (see Figure 2). Maximum surface electric field E_{smax}, transit time factor T and drift tube self-capacitance C were calculated for each set of input parameters. Then these 4-dimensional libraries (more than 2000 variants for each particle velocity β) were transformed to 2-dimensional. First of all only variants were considered with r2 satisfying condition of equal surface fields on both tip curvatures r1 and r2. Then for each r1 and g1 the outer gaps g2 were chosen satisfying criteria of equal surface fields in the central and outer gaps. Obtained in such a

way surfaces T(r1,g1), C(r1,g1) and E_{smax}(r1,g1) were analyzed in order to get maximum T for minimum C, keeping surface field within a limit $E_{smax} \leq 1.5E_k$. Optimization results are shown in Table 2, where L_1, L_2 and D_{dt} are the drift tube lengths and outer diameter respectively.
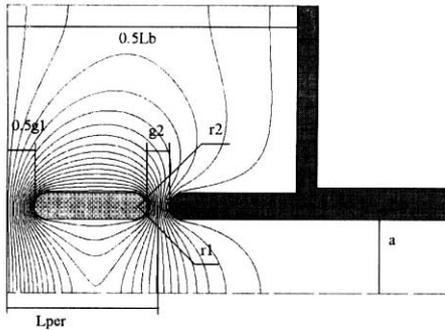
Figure 2: Drift tube geometry

Table 2: Optimization results for drift tube geometry.

Parameter	Buncher			
	Bunch-rotator	#1	#2	#3
r1, mm	2.0	3.0	3.0	4.0
r2, mm	2.5	6.5	6.5	6.5
g1, mm	9.64	9.94	12.70	18.20
g2, mm	4.03	4.31	5.46	7.87
L_1, mm	18.795	25.705	29.460	33.585
L_2, mm	21.355	14.015	16.780	19.945
D_{dt}, mm	34	33	33	35
T	0.563	0.862	0.887	0.910

Table 3: Calculated RF parameters.

		Buncher			
		Bunch-rotator	#1	#2	#3
Quality factor	Q	5784	5706	6668	7773
Shunt impedance*	R_{sh}, MΩ	5.66	9.05	11.88	15.06
Drift tube voltage	V_t, kV	35.5	55.1	73.3	90.7
Power losses	P, kW	3.56	5.36	7.24	8.74

* Shunt impedance $R_{sh} = (4 V_t)^2/P = U_{eff}^2/T^2P$.

3-dimensssional electrodynamics structure simulations were performed with the MAFIA package. At this stage main dimensions for all 4 cavities were optimized and unified: tank diameter - 550 mm, split-ring curvature – 161 mm, split ring tube diameter 25.4 mm, stem diameter: 54 mm. MAFIA resonant frequency error (up to 600 kHz)

correction was performed with a length adjustment of a split-ring straight spacer during manufacturing phase. MAFIA simulated RF parameters for all the bunchers are presented in Table 3. Table 4 shows rf loss distribution of the different buncher sections.

Table 4: Power losses distribution

	Buncher			
	Bunch-rotator	#1	#2	#3
Cylindrical wall and endplates	25.2	26.1	22.9	19.5
Nose cones	0.5	0.3	0.3	0.3
Drift tubes	0.7	0.6	0.6	0.7
Stem	4.9	4.8	5.2	5.6
Straight spacer	3.5	3.0	3.6	2.5
Cones near drift tubes	0.9	1.0	1.0	0.9
Split ring	64.2	64.2	66.4	70.5

3   MECHANICAL DESCRIPTION

Based on buncher #1 prototype test results [2], the present mechanical design has been slightly modified. Both buncher endplates are now detachable. Split ring structure is made of copper parts and brazed together in a hydrogen oven. Supporting leg demountable joint allows independent tightening of rf contact and vacuum sealing. Drift tubes are also detachable. It gives more flexibility for fine drift tube alignment on the beam axis. Both the cavity and the endplates are made of stainless steel and copper plated. Each buncher contains a tuner with capacitive coupling to the drift tubes with a tuning range of ~ 1 MHz. It is used to set the fundamental frequency and is operated by the frequency feedback loop of the rf control system to maintain the set frequency. Every buncher element has an adequate cooling.

4   SIGNAL LEVEL MEASUREMENTS

Frequency coarse tuning was achieved with split ring straight spacer length adjustment. All the bunchers were tuned to the frequency of 106.40±0.05 MHz without tuner. Figure 3 shows frequency dependence upon straight spacer length.

Accelerating field distribution and shunt impedance measurements were based on the bead pull technique. Measured values R_{sh}/Q appeared to be in a good agreement with calculated ones. Accelerating field distribution along the beam axis for all 4 bunchers are presented in Figure 4.
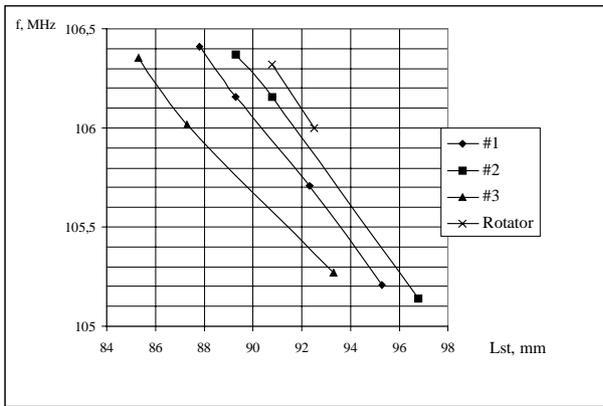
Figure 3: Buncher frequency vs straight spacer length

Measured unloaded Q-values gave the following results: bunch rotator – 4500, buncher #1 – 4200, buncher #2 – 4900, buncher #3 – 5700 being within 73-77 % from the calculated values.

Buncher mechanical stability evaluation was based on the operational mode rf phase measurements with and without external constraint vibrations. Water running through the buncher cooling channels served as a source of vibrations. Phase deviations were within $\pm 1.5°$, which coincide with an rf frequency modulation of ± 1 kHz.
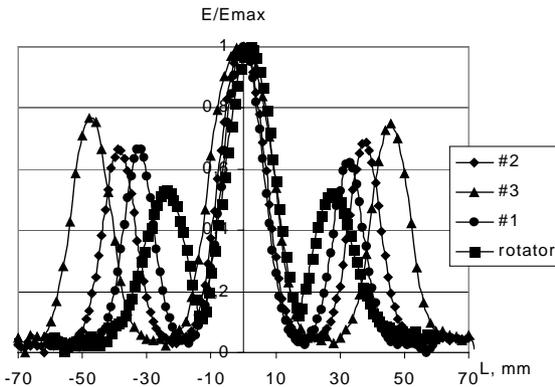
Figure 4: 3-gap buncher electrical field distributions along the beam axis.

5   HIGH POWER TEST

All the bunchers were baked out for 12-14 hours with hot water (~55°C) running through the cooling channels. It improved the vacuum from $8 - 9*10^{-7}$ Torr to $2 - 3 * 10^{-7}$ Torr.

Buncher high power tests were performed with an rf amplifier providing output power up to 20 kW. Conditioning was carried out in cw mode at the vacuum level of $5*10^{-6}$ Torr with vacuum trip level of $1*10^{-5}$ Torr. Low power conditioning was performed in driven mode for about 3 hours. It was accompanied with significant vacuum deterioration caused by multipactor discharge.

With increasing rf power 3 levels of multipactoring were observed. After the 3-rd one vacuum improved to 4 - $5*10^{-7}$ Torr and rf nominal levels were achieved within 15 minutes in self-excited mode.

All the bunchers showed stable operation with a nominal drift tube voltage for more than 100 hours. No breakdowns were detected with voltage increased by 10%. Drift tube voltage was estimated by means of calibrated pickup probes taking into account measured values of shunt impedance R_{sh}. In addition voltage crosscheck calibration was done with X-rays energy measurements. The results were in agreement within measurement accuracy [9].

5   CONCLUSION

Test results proved that the correct technical decisions were taken during the bunchers' development and fabrication. All the bunchers have been installed on the linac and commissioned [6,7]. They showed reliable operation during first few months of beam delivery to the experiment [8] in spring 2001.

6   REFERENCES

[1] P. Bricault et al. Status Report on the Construction of the ISAC Drift Tube Linac. Proc. of the 2000 Linac Conference.

[2] Y.V. Bylinsky et al. High Power Test of the ISAC Triple Gap Buncher Operating in CW mode. Proc. of the PAC-99, New York, March 29-April 2, 1999, pp. 893-895.

[3] R.Laxdal, The Separated Function Drift Tube Linac for the ISAC, TRI-DN-97-4, TRIUMF Design Note, April 1997.

[4] V.V. Paramonov. The Data Library for Accelerating Structures Development. Proc. of the Linac Conference, CERN 96-07, Vol.2, p. 493.

[5] I.V. Gonin et al. 2D Codes Set for RF Cavities Design. Proc. of the 1990 EPAC Conference, 1990, p. 1249.

[6] R.E. Laxdal et al. First Beam Test with the ISAC Separated Function DTL. Proc. of the 2000 Linac Conference.

[7] R.E. Laxdal. ISAC at TRIUMF: Status of the Post-Accelerator. Presented at PRORIB2001, Puri, India, Feb. 2001.

[8] R.E. Laxdal et al. Beam Commissioning and First Operation of the ISAC DTL at TRIUMF. This Conference.

[9] A. Mitra et al. RF Measurement Summary of ISAC DTL Tanks and DTL Bunchers. This Conference.