# A TRIPLE GAP RESONATOR DESIGN FOR THE SEPARATED FUNCTION DTL AT TRIUMF

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*Abstract*

A separated function, variable energy, drift tube linac (DTL) operating in cw mode is being built for the ISAC radioactive beam facility at TRIUMF. Longitudinal focussing is achieved by positioning 105 MHz rebunching cavities immediately upstream of the second, third and fourth IH accelerating tanks. The three devices must operate at a relatively low β (2.3%, 2.7%, 3.3%)and deliver peak effective voltages in cw mode of 0.19, 0.26 and 0.32 MV respectively. In addition the geometry must allow a large voltage dynamic range for the variable energy operation. A three gap cavity has been chosen as a trade-off between velocity acceptance and peak effective voltage. Several cavity geometries have been considered in order to identify the optimal geometry for this application. We present here a summary of the available buncher designs.

## 1 INTRODUCTION

A radioactive ion beam facility with on-line source and linear post-accelerator is under construction at TRIUMF [1]. A separated function drift tube linac (DTL) operating in cw mode is required to accelerate ions of $1/3 \geq q/A \geq 1/6$ to a final energy fully variable between 150 keV/u to 1.5 MeV/u[2]. Five independent interdigital H-type structures operating at 105 MHz and $0^o$ synchronous phase, provide the acceleration while quadrupole triplets between IH tanks provide the transverse focussing. Longitudinal focussing is achieved by positioning independently phased, 105 MHz rebunching cavities immediately upstream of the second, third and fourth IH tanks.

The rebunchers have two prime functions. In acceleration mode they are used to match the longitudinal beam characteristics to the next IH accelerating tank. In reduced energy operation the re-bunchers maintain longitudinal transport through the non-accelerating sections of the DTL. The two modes require quite different specifications. The maximum effective voltage is required during the acceleration mode while the bunching mode requires a large variation in the voltage. In addition the re-bunchers must be physically compatible with the upstream quadrupoles and a downstream diagnostic box consistent with the aim to keep the inter-tank lengths short to reduce longitudinal emittance growth due to debunching.

## 2 RE-BUNCHER SPECIFICATIONS

Both two and three gap structures have been studied. The triple gap cavities are more efficient to deliver effective voltage at the design velocity of the structure but the double gap cavity has more velocity acceptance. The efficiency of the two structures to accelerate at velocities other than the design velocity, $\beta_0$, can be calculated from the following:

- for the double gap cavity

$$TT_2 = \frac{2}{\pi}\frac{\beta}{\beta_0}\left[\cos\frac{\pi}{4}\frac{\beta_0}{\beta} - \cos\frac{3\pi}{4}\frac{\beta_0}{\beta}\right]$$

- for the triple gap cavity

$$TT_3 = \frac{1}{\pi}\frac{\beta}{\beta_0}\left[2\sin\frac{\pi}{4}\frac{\beta_0}{\beta} + \sin\frac{3\pi}{4}\frac{\beta_0}{\beta} - \sin\frac{5\pi}{4}\frac{\beta_0}{\beta}\right]$$

Here we have assumed a square field approximation with a cell length given by $\beta_0\lambda/2$. The results are displayed in Fig. 1.

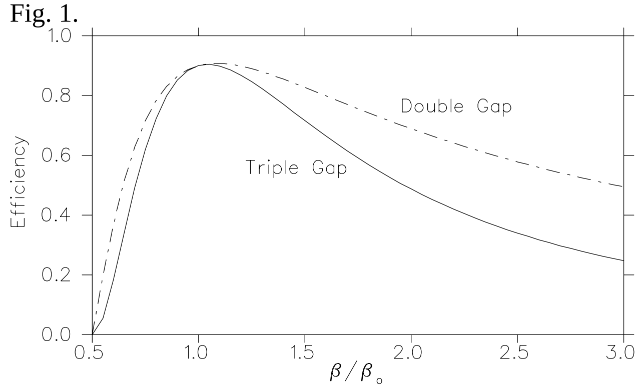


Figure 1: The acceleration efficiency, as a function of beam velocity, of both a two gap and a three gap buncher.

A summary of the buncher specifications for both the two gap and the three gap solutions are given in Table 1 for the design particle of q/A = 1/6. The effective voltage $V_{eff}$ is quoted for the design velocity. $V_T$ is the peak tube voltage. The drift tube aperture is a=14 mm and the frequency is 105 MHz for all cases.

In variable energy mode simulations[3] it was found that, for the design particle of A/q = 6, a minimum buncher setting of 30% of the values quoted in Table 1 was required. This corresponds to an absolute minimum of 15% of the quoted value for A/q = 3. This led to the specification for the re-bunchers of multipactor free operation from 10% to 100% of maximum.

| Buncher | $\beta$ (%) | $\beta_0$ (%) | L (cm) | $V_{eff}$ (MV) | $V_T$ (kV) |
|---|---|---|---|---|---|
| Double gap | | | | | |
| B1 | 1.8-2.3 | 2.3 | 6.6 | .19 | 118 |
| B2 | 1.8-3.1 | 2.3 | 6.6 | .28 | 175 |
| B3 | 1.8-4.1 | 2.3 | 6.6 | .37 | 230 |
| Triple gap | | | | | |
| B1 | 1.8-2.3 | 2.3 | 9.8 | 0.19 | 60 |
| B2 | 1.8-3.1 | 2.7 | 11.6 | 0.26 | 78 |
| B3 | 1.8-4.1 | 3.3 | 14.1 | 0.32 | 94 |

Table 1: Summary of parameter specifications for both double gap and triple gap bunchers (B1-B3) for the design particle of q/A = 1/6. The effective voltage $V_{eff}$ is quoted for the design velocity $\beta_0$. $V_T$ is the peak tube voltage.

## 3 SHUNT IMPEDANCE

The specification restricts somewhat the choice of structure. Coaxial $\lambda/4$ resonators, spiral resonators (fig. 2), split-ring resonators (fig. 3) and arc-type resonators (fig. 4) have all been considered as candidates for the buncher. All these structures have been generated with MAFIA in order to compare their shunt impedances. Similar drift tube structures are chosen for all resonators in the initial comparison. Shunt impedances and rf losses for the most challenging case, B3, are shown in table 2.

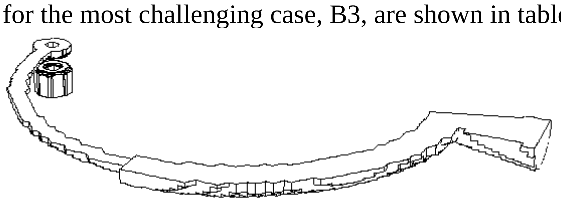

Figure 2: MAFIA plot of half of the internal part of the 2-gap spiral buncher.

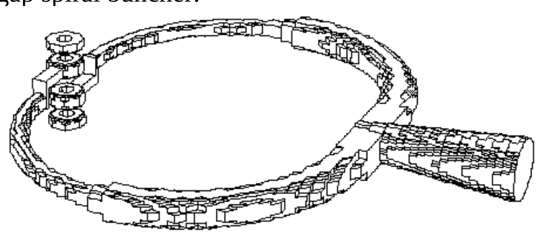

Figure 3: MAFIA plot of internal part of the 3-gap split ring buncher.

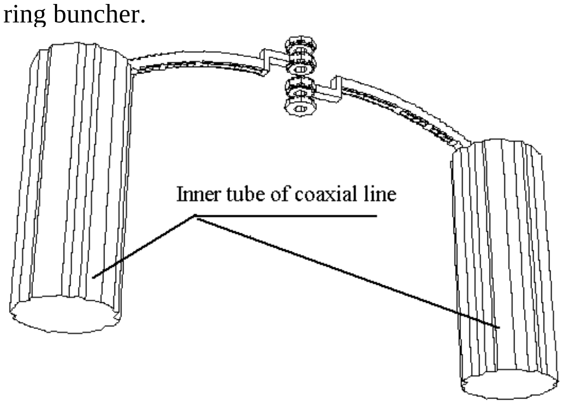


Figure 4: MAFIA plot of internal part of the 3-gap arc-type buncher.

| | Double gap | | Triple gap | |
|---|---|---|---|---|
| Structure type | coaxial | spiral | split ring | arc-type |
| $R_p$, MOhm | 6.6 | 7.4 | 14 | 21.2 |
| $P_0$, kW | 32 | 29 | 11 | 7.5 |

Table 2: MAFIA results for several buncher structures (B3 specifications). Here $P_0$ - rf losses; $R_p$ - shunt impedance:

$$R_p = \frac{\left(V_{eff}/T\right)^2}{P_0}.$$

From the table it is clear, that the 2-gap structure, either coaxial or spiral, will meet very serious problems with cooling. Also the most efficient arc-type structure was abandoned due to its large size and the absence of performance experience. On the other hand the split-ring structure is known to be quite stable against multipactor discharge and has shown good performance at very high power levels[4]. So, detailed study has been performed only for the split ring structure in order to clarify specifications for all 3 bunchers (see Table 3).

## 4 MAXIMUM ELECTRIC FIELD GRADIENT

Due to the high drift tube voltage and short gaps high surface electric fields were expected to be a problem. Maximum electric field on the drift tube surface has been estimated by solving an electrostatic problem (Poisson equations) with SUPERFISH. The gap lengths as well as the drift tube curvature have been optimized in order to reduce maximal field gradients. The central gap has been assigned to be two times longer than the two outermost ones ($Lg_c=2Lg_o$), keeping the designed inter-gap distance $\beta_0\lambda/2$ (see fig.5). It allows a slight increase in efficiency as

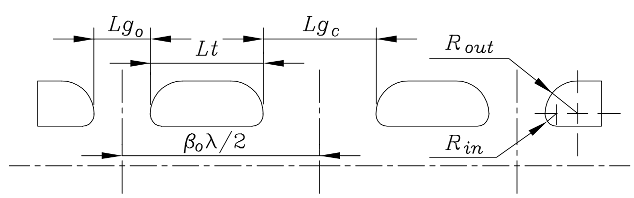


Figure 5: Drift tubes geometry for the 3-gap buncher.

well as a reduction in field gradients by 15%. The central gap length $Lg_c$ is equal to the tube length as a trade-off between acceptable surface fields and sufficient buncher efficiency. Fig. 6 shows the maximum surface field and efficiency dependencies upon the ratio $Lg_c/Lt$ for equal gap lengths (curve 1) and for optimized gaps: $Lg_c=2Lg_o$ (curve 2). The optimal ratio of the drift tube tip radii is about $R_{out}/R_{in}=3$ (see fig. 5). Finally, numbers in Table 3 represent nominal buncher parameters. In addition to the shunt impedance, MAFIA gives the following RF loss distribution among the structure units:

- cavity walls - 30%;

- drift tubes - 10%;
- supporting ring - 60%.

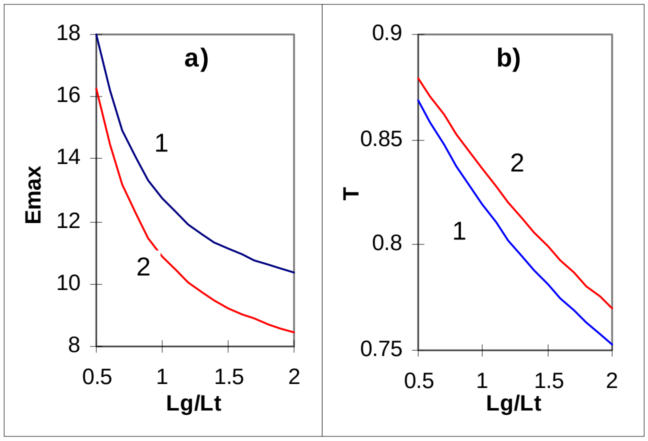


Figure 6: a) maximum surface field and b) acceleration efficiency with the ratio of gap to tube length. Curve 1: $Lg_c=Lg_o$; curve2: $Lg_c=2Lg_o$.

| Buncher | | B1 | B2 | B3 |
|---|---|---|---|---|
| $V_{eff}$ | [MV] | 0.19 | 0.26 | 0.32 |
| $Es_{max}$ | [MV/m] | 9.8 | 11.1 | 10.9 |
| $R_p$ | [MOhm] | 12.0 | 13.0 | 14.0 |
| $P_0$ | [kW] | 6.4 | 10.5 | 14.0 |

Table 3: Nominal buncher parameters. The quoted shunt impedance values are from MAFIA. The power calculations assume a shunt impedance 75% of the value quoted.

## 5 MECHANICAL DESIGN

A general view of the equipment in front of DTL tank #2 is shown in the fig. 7. The buncher will be brazed to the downstream diagnostic box due to the tight inter-tank space. Drift tubes, supporting ring as well as cavity are going to be made of copper. Principal dimensions of the structure are collected in Table 4.

| | | |
|---|---|---|
| Tank diameter | [mm] | 550 |
| Tank length | [mm] | 98 (116, 141) |
| Ring diameter | [mm] | 350 |
| Ring tube diameter | [mm] | 30 |
| Aperture | [mm] | 14 |
| Drift tube diameter | [mm] | 30 |

Table 4: Principal dimensions of the split-ring bunchers

The rf amplifier feedback system requires a frequency tuner, which will be made as a movable plate with capacitive coupling to the drift tubes. Cooling channels will go through the tank walls, including the endplates. The most heated ring will require a separated cooling circuit for each half ring with water flow of about 150 $cm^3/s$. The ring water will also cool the drift tubes.

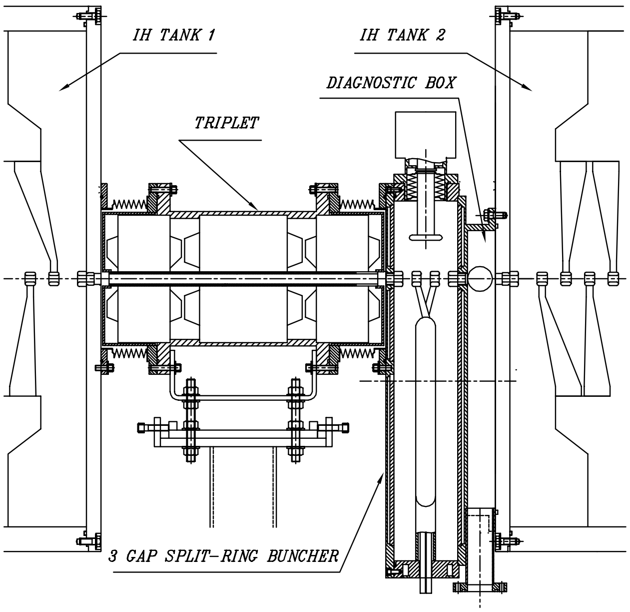


Figure 7: General view of the equipment in the inter-tank space.

## 6 CONCLUSION

As usual in the design of rf cavities the choices were made as a compromise between contradictory requirements:

- maximum effective voltage;
- minimum surface electric fields;
- minimum rf power consumption;
- minimum size along the beam axis.

The studies show that the 2-gap buncher cannot be used due to extremely high surface field and power consumption. The 3-gap buncher with split-ring structure has been chosen for all DTL bunchers. The arc-type configuration was abandoned due to its large size and absence of performance experience.

In the most challenging case maximum surface fields are moderate (≤11 MV/m) with a rather high heat load (≤14 kW). So the cooling solution together with good mechanical stability should be carefully tested.

A working prototype of Buncher 1 is scheduled to be completed by the spring of 1998.

## 7 REFERENCES


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[4] E. Muller and H. Klein, The Split-Ring Loaded RF Cavity, Nuclear Inst. and Meth. 224 (1984), p.17.