DOUBLE-GAP REBUNCHER CAVITY DESIGN OF SNS MEBT

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Abstract

A double-gap rebuncher cavity has been studied through design and analysis with computer simulations. This cavity shape is a two cell abridged form of drift tube linac (DTL), instead an omega form of existing single gap elliptical cavity. The cavity operates in TM010 mode, likewise the commonly used single-gap cavities in some medium energy beam transport (MEBT) line of proton accelerators. The new cavity is more power efficient even with slightly lower Q factor because of utilization of two interactive gaps. The breakdown field can be lowered with adjustment of gap and tube length ratio. Electromagnetic, beam envelope, and thermal simulations are presented with comparison to the properties of the conventional elliptical cavity.

INTRODUCTION

A medium energy beam transport line (MEBT) matches a radio frequency quadrupole (RFQ) beam out to the input requirement of drift tube linac (DTL) with minimum emittance growth [1]. The MEBT line of Spallation Neutron Source (SNS) was built from Lawrence Berkeley National Laboratory (LBNL) (Fig. 1) [2]. A chopper target is located at the center of the MEBT line, and four rebuncher cavities are operated to give longitudinal beam focusing. The meander line chopper deflectors are positioned in before and after the chopper target. Several quadrupole elements are also utilized for transverse focusing.

The four rebuncher cavities were designed and developed by LBNL and JP Accelerator Works, Inc. (JPAW). A 30mm beam bore is selected for the cavity one and four, and a 36mm beam bore is adopted for the cavity two and three [3]. Some important design constraints of these cavities are cavity length which is limited to 13cm, transit time factor which is quite low in low velocity of 0.073 v/c, and mechanical strength including thermal stability.

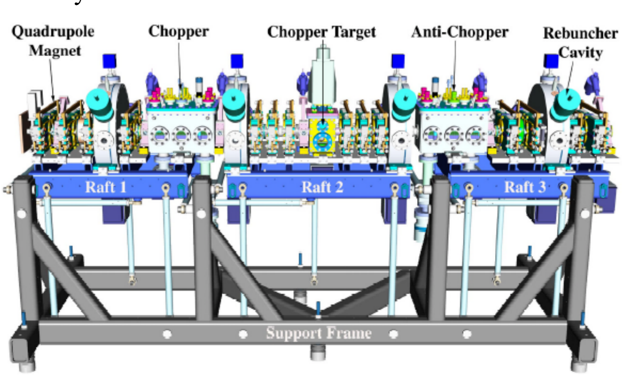


Figure 1: A layout of SNS MEBT, courtesy of D. Oshatz et all, PAC 2001.

SINGLE-GAP ELLIPTICAL CAVITY

A 2D electromagnetic (EM) simulation of elliptical cavity was performed with Superfish by LBNL [4]. The cavity was designed to have elliptical nose-cone shape with a single-gap. The gap length is 1.22cm and overall cavity length is well fitted into 13cm. Fig. 2 shows a geometric view of the elliptical cavity.

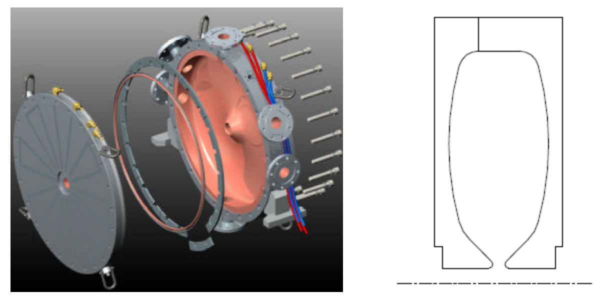


Figure 2: The JPAW elliptical cavity, courtesy of Jim Potter, Conceptual Design Report FE-EE-019.

A 3D model is also created with Autodesk Inventor [5], and imported to CST Microwave Studio (MWS) [6] for 3D EM simulation. Table 1 and 2 shows a parameter comparison of 2D, 3D results. The gap voltage, E_0TL parameter is calculated assuming 80% of Q value. For shunt impedance calculation, the last column assumes a beam pipe length of 13cm, which is different from 5.44cm of other two columns.

Table 1: Parameter Comparison (3.6cm Bore/ 8.1kW rms)

	2D (5.44cm)	*3D (5.44cm)*	*3D (13cm)*
Q	21714	21539	21496
$Z_{sh}T^2/L$	6.85MΩ/m	6.93MΩ/m	2.90MΩ/m
r/Q	17.16	17.50	17.53
E_0TL	49.3 kV	49.4 kV	49.37 kV
T (=TTF)	0.342	0.347	0.348

Table 2: Parameter Comparison (3.0cm Bore/ 28.2kW rms)

	2D (5.44cm)	*3D (5.44cm)*	*3D (13cm)*
Q	21712	21512	21377
$Z_{sh}T^2/L$	11.75MΩ/m	11.77MΩ/m	4.89MΩ/m
r/Q	29.44	29.76	29.77
E_0TL	120 kV	120.11 kV	119.20 kV
T (=TTF)	0.445	0.451	0.451

DOUBLE-GAP CAVITY DESIGN

A multi-gap rebuncher cavity is of our interest since there is a possibility that it would get more net gap voltage for given power than single gap cavity. Another advantage of multi-gap rebuncher cavity is that breakdown voltage can be reduced by enhanced transit time factor (TTF) in each gap. A general problem of multi-gap cavity is a decrease of velocity acceptance, however it is not a big issue for a bunching cavity which operates at -90° phase. As a multi-gap structure, one of inter-digital H (IH) [7], quarter wave resonator (QWR) [8], and drift tube linac (DTL) type cavities could be used for particle velocity at or around 0.073v/c.

Inter-Digital H (IH) Type

The IH type resonator operates at TE mode has high shunt impedance value in this velocity [7]. This structure is not considered in our case, because it requires long cavity length to apply vane undercut for magnetic field circulation.

Quarter Wave Resonator (QWR) Type

The QWR type cavity is considered useful based on the information of previous superconducting super collider (SSC) design example [8]. This design is not a power efficient solution for normal conducting cavity however, due to low Q value of TEM mode. Furthermore, the stem length becomes too short for our design constraints of over 3.0cm bore diameter at 402.5MHz frequency.

Drift Tube Linac (DTL) Type

The DTL type cavity became a choice for a double-gap rebuncher. This design can have high Q of TM mode with double-gap acceleration. TTF increases in this design due to smaller gap size than single-gap cavity. Therefore, the maximum electric field may be decreased while achieving similar gap voltage. The total cavity length is 13cm with 2cm of wall thickness. Fig. 3 shows a geometric view of this cavity.

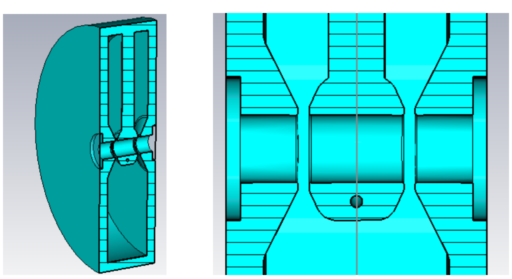


Figure 3: The DTL type cavity with double-gaps.

PERFORMANCE COMPARISON

Cavity parameters of elliptical and DTL type cavity are compared in Tables 3 and 4. 13cm of cavity length is assumed for shunt impedance calculation. This 13cm is the actual longitudinal length which each of these cavities occupy. The DTL type cavity has higher shunt impedance and transit time factor than those of elliptical one. The lower Q of the DTL type cavity can reduce resonance sensitivity and make measurement system more stable. TTF increases by about 20% for 3.6cm bore, and 15% for 3.0cm bore cavity. Achievable gap voltage E_0TL increases in the DTL type cavity due to higher TTF and double-gap acceleration.

Table 3: Parameter Comparison (3.6cm Bore/ 8.1kW rms)

	Elliptical (13cm)	*DTL Typ.(13cm)*
Q	21496	19460
$Z_{sh}T^2/L$	2.90MΩ/m	3.80MΩ/m
r/Q	17.53	25.35
E_0TL	49.37 kV	57.20 kV
T (=TTF)	0.348	0.417

Table 4: Parameter Comparison (3.0cm Bore/ 28.2kW rms)

	Elliptical (13cm)	*DTL Typ.(13cm)*
Q	21377	19677
$Z_{sh}T^2/L$	4.89MΩ/m	6.06MΩ/m
r/Q	29.77	40.02
E_0TL	119.20 kV	133.21 kV
T (=TTF)	0.451	0.517

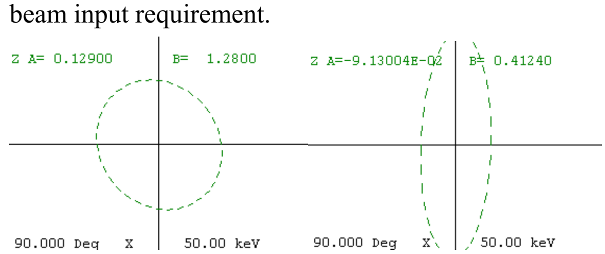
SNS operates by pulsed RF power, and the breakdown field is an important factor for reliable operation. For this breakdown field calculation, a tetrahedral meshing in CST MWS is used to have surface field more accurately. This simulation results are summarized in Table 5. Both cavities use 1.2cm of the net gap size. The DTL type cavity has lower breakdown field than the elliptical cavity with the same amount of power. Since the DTL type cavity is more efficient in terms of power, gap size can be increased while providing similar gap voltage in given power. In this way, the breakdown voltage can be even lower.

Table 5: Breakdown Voltage Limit Comparison

	Elliptical	*DTL Type*
3.6cm bore (8.1kW rms)	1.33 Kilpatrick	0.97 Kilpatrick
3.0cm bore (28.2kW rms)	2.25 Kilpatrick	1.88 Kilpatrick

BEAM SIMULATION RESULTS

Trace-3D code is used to determine required gap voltage of the rebuncher cavities. Beam line elements values which were created from LBNL [9], are utilized in this simulation. Beam input and output parameters are shown in Fig. 4. With regarding these beam parameters, required magnetic quadrupole field values and RF gap voltages are calculated. For simplicity, beam line elements before chopper target including cavities one and two are set to have fixed values. Therefore, gap voltages of cavities three and four are adjusted to meet the DTL beam input requirement.



(a) (b)

Figure 4: Longitudinal beam parameter of – (a) RFQ output, (b) DTL input.

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Table 6 shows the results of this simulation. Required gap voltages are not much different between the elliptical and DTL type cavity. Increased net gap size of 1.4cm (0.7cm per each) can be utilized in double-gap design with this gap voltage requirement. This significantly lowers the breakdown voltage.

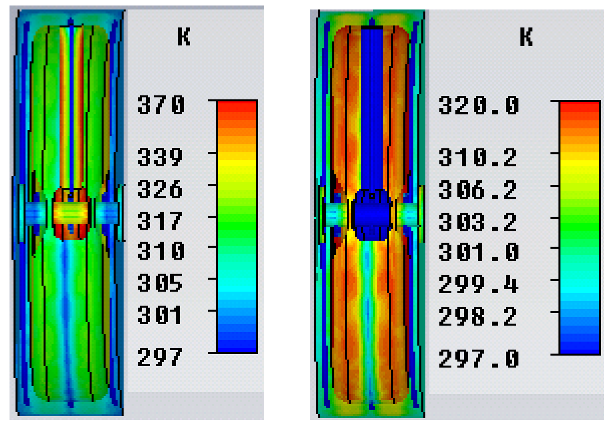
Table 6: Required Values of Gap Voltages

	Elliptical	*DTL Type*
Cavity 3 (3.6cm bore)	53.68 kV	52.34 kV
Cavity 4 (3.0cm bore)	124.09 kV	126.77 kV

THERMAL SIMULATION RESULTS

One drawback of the double-gap cavity is a high surface current density around tube stem. This results in an extra thermal design in tube. Due to small tube size for electrically efficient design, 0.4" diameter is chosen for cooling pipe in a 1" diameter stem. This pipe size is enough to induce water flow in turbulent regime. The material for double-gap cavity stem may have two candidate materials that are utilized in the simulation study. The first one is Copper, which has good thermal conductivity over 350 (W/m/K). However, machining is more difficult because of poor stiffness. The second choice is Copper plated Stainless Steel (SS) 304 which is utilized to the existing elliptical cavity. SS 304 provides good mechanical stiffness, however has poor thermal conductivity about 16 (W/m/K). Therefore, a good thermal and mechanical design is required to use this material. In this simulation study with CST Multiphysics Studio [6], SS304 material is used in cavity body to provide enough mechanical stiffness. Both Copper and SS 304 materials are tested in tube and stem parts for thermal simulation. The 3.0cm bore cavity operates at 1.72kW thermal power which is higher than 3.6cm bore cavity which operates 0.72kW thermal power. For that reason, only the 3.0cm cavity at 1.72kW thermal power is simulated in this study. The ambient temperatures are set to 24°C, and 22°C, respectively for cooling water temperatures. Water flow rate is not considered in this simulation for simplicity, and the actual temperature distribution may be slightly higher than the result. Cooling channels are imported around the side cavity walls, the tube, and the stem.

Figures 5(a) and 5(b) shows simulation results with tube and stem in SS 304 and in Copper, respectively. Maximum temperature gradient is less than 5°C in Copper tube and stem area due to good thermal conductivity. Over 60°C gradient is observed with SS 304 tube and stem. Thermal hot spot appears at tube with SS 304, and at cavity wall with Copper. To minimize electrical errors which can be caused by tube and gap size variations, using Copper tube and stem is recommended. SS304 tube may be selectively used for 3.6cm bore cavity which spends about 0.7kW thermal power. Because of heavy thermal loading at stem, cooling of cavity wall at the equator is also required. Therefore, this double-gap rebuncher cavity needs more complex thermal design than the single-gap structure.



(a) (b)

Figure 5: Temperature distribution of two gap cavity with SS304 cavity wall – (a) SS 304 tube and stem (b) Copper tube and stem.

CONCLUSIONS

A double-gap DTL type rebuncher cavity is compared with the existing single-gap elliptical cavity in SNS MEBT. The new design increases power efficiency with enhanced shunt impedance and transit time factor. This design also lowers breakdown voltage which could be a limiting factor of cavity operation. Slightly decreased Q value can give less sensitivity to the measurement system. High density of surface current on tube stem requires additional cooling channels inside stem and tube in this double-gap cavity design. Copper can be preferred material in this part, and extra cooling channel may be required for SS304 material including cavity wall.

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