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memorandum

LANSCE Division

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SUBJECT: Bunch Rotator Cavity Design for SNS

This memo reports the design of a cavity suitable for use in a multicell bunch rotator to follow the 1-GeV SNS linac.

Requirements

The total voltage gain across the rf structure is E_0TL = 4 MV, where E_0 is the average axial electric field, T is the transit-time factor, and L is the length. The actual energy of the H^- beam is 1001.5 MeV, which corresponds to a particle velocity β = 0.875081. This particle velocity fixes the length of an individual cavity to $L_{Cav} = \beta\lambda/2$ = 16.2946 cm, where λ = 37.2413 cm is the wavelength at resonant frequency 805 MHz. The total length of the bunch rotator must be that of an integral number of cavities: $L = NL_{Cav}$, where N is the number of accelerating cavities. Collaborators at Brookhaven National Laboratory have requested a bore radius of 2.4 cm for the bunch rotator.

Prevention of sparking at regions of high surface electric field sets the minimum number of cavities. A conservative design has surface electric fields no higher than about 1.5 times the Kilpatrick field, or 1.5×26.06 MV/m = 39.09 MV/m at 805 MHz. After choosing the number of cavities, we can compute the total power required from the effective shunt impedance per unit length.

Cavity design

We use the program CCLFISH in the Poisson Superfish code distribution to design the cavity shape and compute surface fields and rf power losses. Figure 1 shows the outline of a half-cell generated by CCLFISH for a coupled-cavity linac cell. The details near the nose are shown in Figure 2. These figures show a cross section of the right half of the cavity. The lower left corner of Figure 1 is the center of the cell. The full gap is g and the full length is L_{Cav}. The bore radius is R_b. The full cavity diameter is D and s is the full septum thickness between cavities. The inner-nose radius R_i connects the bore tube to an optional vertical flat segment of length F. The outer-nose radius R_o connects the flat segment on the nose with the cone angle segment. The two nose arcs are tangent if F = 0. The cavity wall has an outer corner radius R_{co} and an inner corner radius R_{ci}.

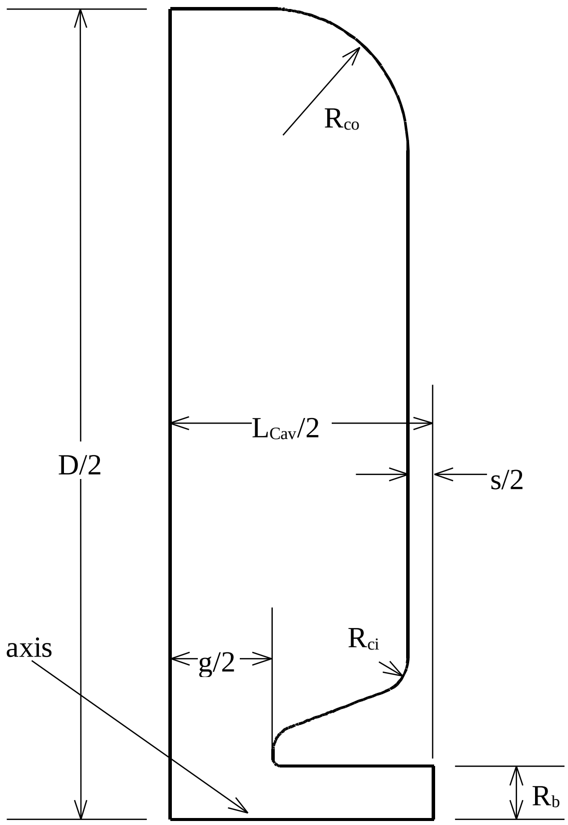

Figure 1. A CCL cavity showing most of the geometrical parameters used by the tuning code CCLFISH. For details near the nose on the cavity wall see.

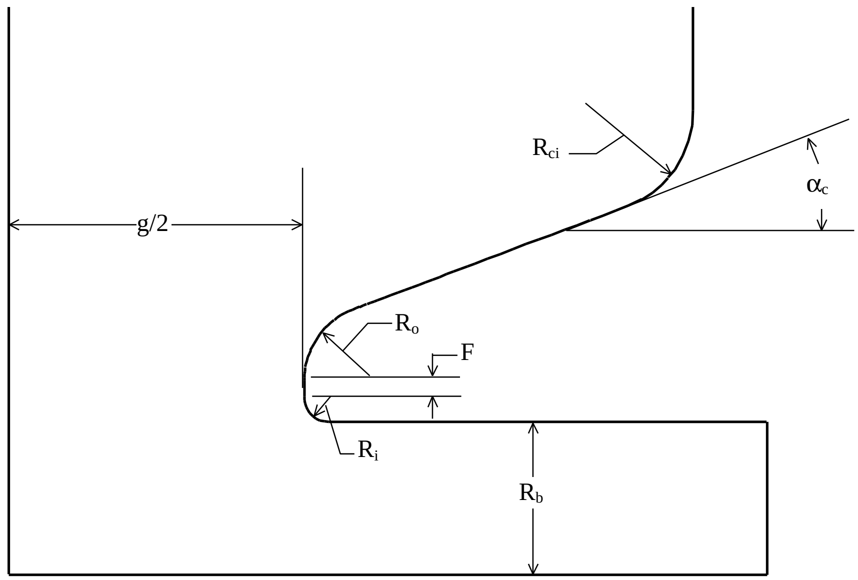

Figure 2. Detail of a nose on the cavity wall in either CCL cell.

Table 1 lists the parameters of the bunch rotator cavity and Figure 3 shows the shape of the optimized cavity. The shape is similar to the design of the high-energy cavities in the SNS linac. Figure 4 is a detail of the mesh in the region around the nose. The cavity has the same cone angle α_c = 10 degrees as the linac CCL cells. To optimize for high shunt impedance, we varied the gap g, outer corner radius R_{co}, inner corner radius R_{ci}, nose radii (keeping $R_o/R_i = 3$), and the flat length F on the nose. The ratio of 3 for the nose radii helps reduce the peak surface electric field for a given gap length. For different choices of a geometrical parameter, the CCLFISH code adjusted the cavity diameter D for resonance at 805 MHz.

The final cavity diameter will be a few millimeters smaller than the listed value to compensate for the frequency tuning effect of the coupling slot. A cavity-to-cavity coupling of 3% will be more than sufficient for the small number of cavities in the bunch rotator. The Q value and the shunt impedance in the table both correspond to 3% coupling. The quoted maximum accelerating field corresponds to 1.5 Kilpatrick.

Table 1. Bunch Rotator Cavity Parameters.

Parameter	Symbol	Value
Resonant frequency	f	805 MHz
Unloaded Q factor (@3% coupling)	Q	27,040
Operating temperature	T_{op}	90 F
Maximum accelerating field	E_0	5.78 MV/m
Transit-time factor	T	0.81766
Shunt impedance (@3% coupling)	ZT^2	44.74 MΩ/m
Cavity length	L_{Cav}	16.2946 cm
Gap length/βλ	g/βλ	0.2684
Gap length	G	8.747 cm
Cavity diameter	D	27.22 cm
Bore radius	R_b	2.40 cm
Cone angle	α_c	10 degrees
Septum thickness	s	1.0 cm
Cavity outer corner radius	R_{co}	6.35 cm
Cavity inner corner radius	R_{ci}	2.27 cm
Inner nose radius	R_i	0.07 cm
Outer nose radius	R_o	0.21 cm
Flat length	F	0.05 cm

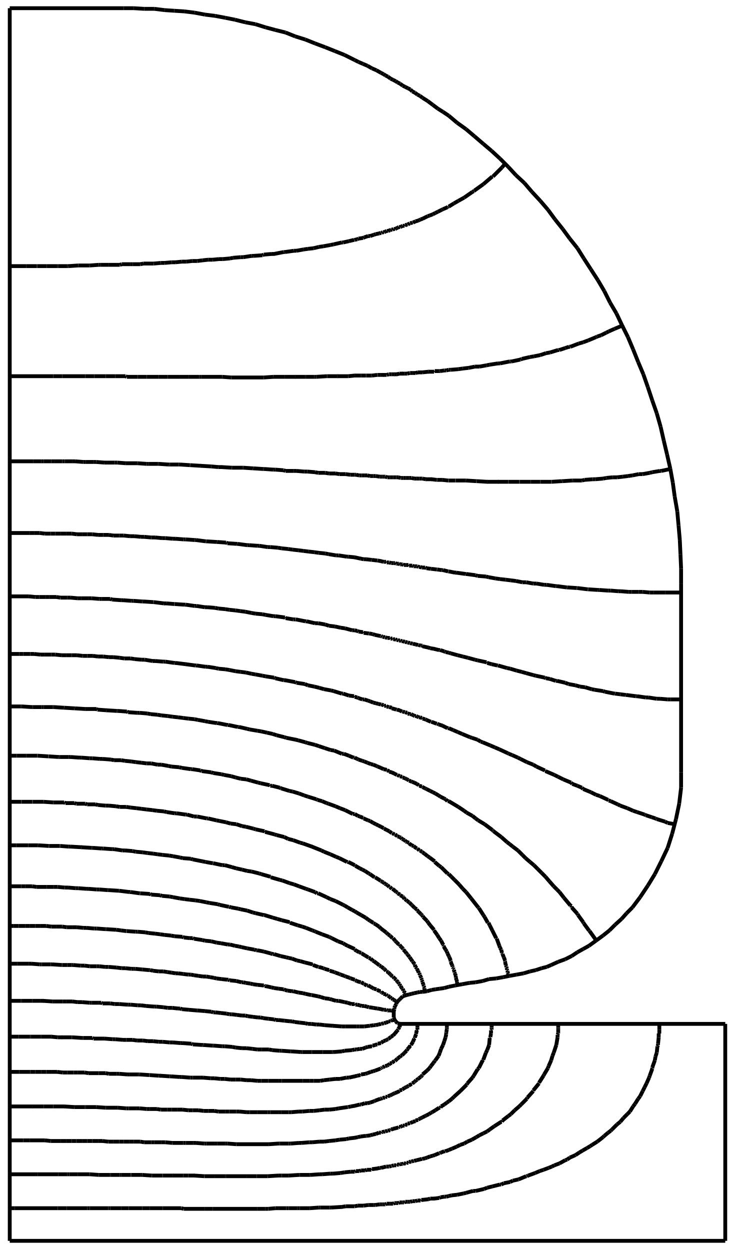

Figure 3. SUPERFISH generated cavity shape. The lines of constant magnetic field H lie along the direction of the electric field.

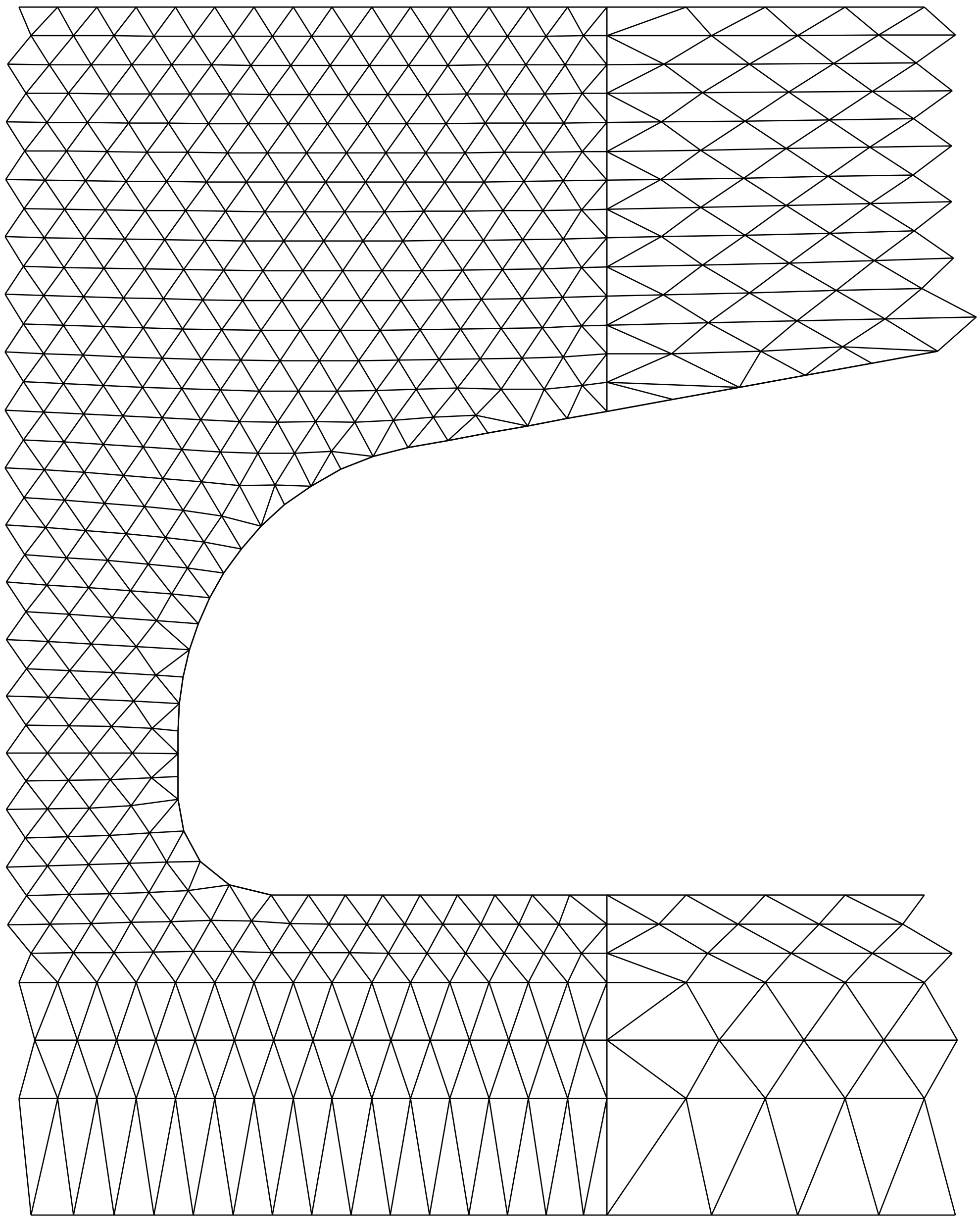

Figure 4. Expanded view of the triangular mesh near the cavity nose.

Multi-cavity structure characteristics

Table 2 shows how the average axial electric field, power, total length, and peak surface electric field vary as a function of the number of cavities in the bunch rotator. Each line in the table corresponds to a total voltage E_0TL = 4 MV. The structure must contain six or more cavities to keep the peak surface field below 1.5 Kilpatrick. The choice for the number of cavities can be made based upon length contraints in the high-energy beam transport line and on the available rf power. Adding additional cavities lowers the power requirements by reducing the field in the individual cavities, at the expense of a longer structure.

Power levels in Table 2 do not include any beam loading. Note that the required rf power varies if the structure accelerates or decelerates the beam (by operating at a synchronous phase other than –90 degrees).

There is some advantage to keeping the number of cavities small. High fields in a short structure leads to high stored energy, which reduces the sensitivity of the field amplitude to the beam chopping. An eight-cavity structure would appear to be a good choice.

Table 2. Bunch rotator characteristics for a given number of cavities.

Number of cavities	E0 (MV/m)	Total Power (kW)	Length (m)	Kilpatrick factor
5	6.00	438.94	0.815	1.559
6	5.00	365.78	0.978	1.299
7	4.29	313.53	1.141	1.113
8	3.75	274.33	1.304	0.974
9	3.34	243.85	1.467	0.866
10	3.00	219.47	1.629	0.779
11	2.73	199.52	1.792	0.709
12	2.50	182.89	1.955	0.649
13	2.31	168.82	2.118	0.600
14	2.14	156.76	2.281	0.557
15	2.00	146.31	2.444	0.520

Data Files

The SUPERFISH input and output files for the bunch rotator cavity are available in the shared directory \\pc-billen\Projects\NSNS\BunchRotator. (If you are not a member of the AOT-1 computer domain, log in to machine pc-billen.atdiv.lanl.gov by FTP as user Linac with password aot1ftp.)

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