A SPOKE RF CAVITY SIMULATION WITH MAFIA.

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Abstract

Based on Argonne experience[1] we consider a spoke cavity as an alternative accelerating structure for SC proton linacs. For this purpose we investigated this type of the structure extended to five-gap cavity to have a possibility to compare with well-developed elliptical cavities. The spoke cavity parameters (500 MHz and $\beta = v/c = 0.5$) have been chosen project independent. At the same time they are intermediate and allow making conclusions on advantages and disadvantages of this structure for lower or higher energy or frequency. The structure is optimised to achieve the lowest possible ratios E_{pk}/E_{acc} and H_{pk}/E_{acc}.

1 SPOKE RF CAVITY BASICS

A spoke RF cavity represents a series of inner conductors (spokes) crossing a straight cylindrical pipe (Fig. 1). In the fundamental accelerating mode the spokes act as a half-wavelength resonant lines with equivalent capacitance of accelerating gaps. The centre-gap to centre-gap distance in these structures is of order $\beta\lambda/2$. An accelerating π-mode electric field is similar to the elliptic cavity accelerating mode (Fig. 2). The magnetic field distribution is defined by the way the spokes installed in the cavity. In a ladder type installation magnetic field surrounds spoke ends in the opposite directions (Figs. 3, 5). In this case the spoke radius defines the strength of the magnetic field on the surface where they connect to the cavity wall. The other possible type of spoke arrangement is a cross bar configuration. Here one part of the magnetic field still circulates around spoke and the other is directed along the whole cavity length like in H-type cavity terminating in the end cells.

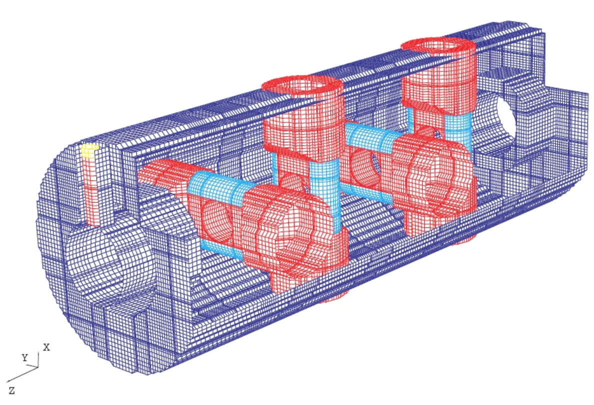

Figure 1: Spoke Cross Bar Cavity Geometry

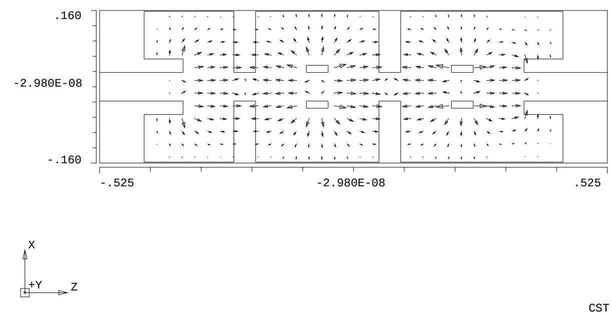

Figure 2: Electric Field in Spoke Cross Bar Cavity

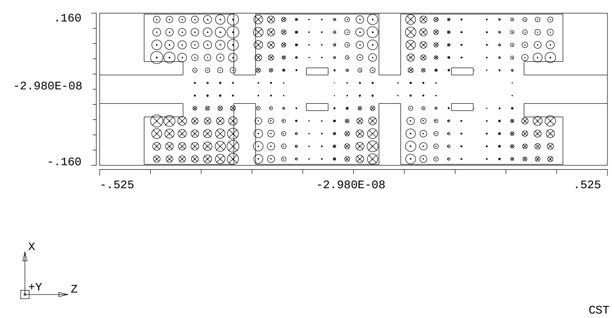

Figure 3: Magnetic Field in Spoke Cross Bar Cavity

2 SINGLE-CELL SIMULATION – SPOKE GEOMETRY OPTIMIZATION

The ladder bar spoke arrangement is the most convenient for the spoke geometry optimisation (Fig. 4). The minimum value of E_{pk}/E_{acc} corresponds to the homogeneous e-field distribution on the round spoke surface in the cavity centre (Fig. 6). It is defined by co-dimensions of spoke-to-spoke accelerating gap (in other words spoke radius in the centre) and spoke-to-cavity wall distance. The cavity h-field strength is the maximum on the spoke surface close to its end. It defines by the spoke radius in this region. In the ladder bar configuration the bigger spoke radius less space between spokes. This increases h-field on the spoke surface. This is a reason why a cross bar spoke configuration is preferable.

3 SPOKE CAVITY TUNE

Like in any RF cavity an e-field penetrates in a beam pipe. This results in an uneven e-field distribution along cavity axes (Fig. 7). To correct it one can make changes at the ends of cavity – either to reduce last gap lengths that results in the end gap capacitance grow or to add a cavity volume at the end parts of cavity. The first method equalises the Lorenz forces' acting on the last spokes, although vio-

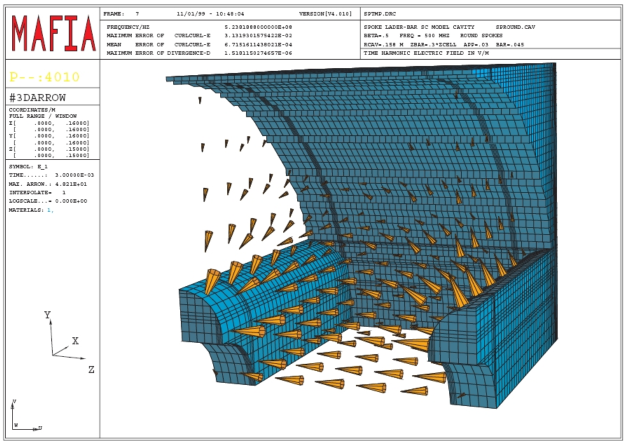

Figure 4: Electric Field in Spoke Ladder Cavity (1/4 of cell is shown)

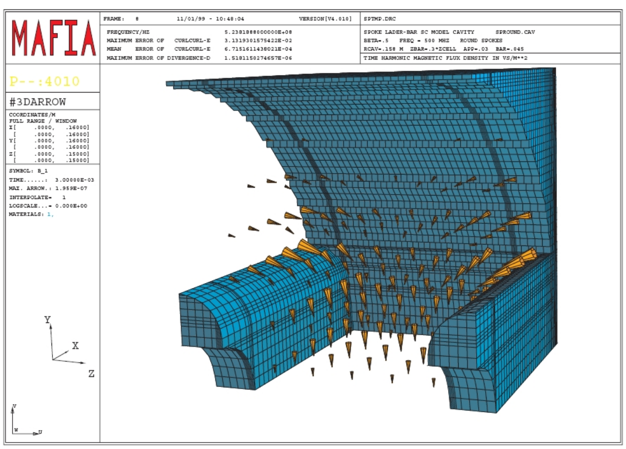

Figure 5: Magnetic Field in Spoke Ladder Cavity (1/4 of cell is shown)

lates the achieved an optimal spoke geometry leaving less space for h-field in the end cell and increases here the ratio H_{pk}/E_{acc}. The second option looks more attractive and can be used to tune cavity frequency and field distribution if to make end plates flexible. Most probably the combination of both options should be used. (Figs. 8- 9). show normalised e-field distributions for the first and second methods of field equalisation for different end electrode geometry. Here, the curves for "gap 1" correspond to the e-field in the end gaps. Max value E/E0 for the central gap is supposed a unit. These dependencies are much stronger for the last gap change. Changing parameters of the last gap geometry and end cavity volume one can reach the even e-field distribution along cavity within 5%.

4 "EXOTIC" SPOKE

One of higher order modes in the spoke cavity (Fig. 10) has the same e-field distribution along the cavity axes like the fundamental mode with a frequency of about two times larger. The main difference between modes is in a magnetic field distribution (Fig. 11) that is similar to the h-field in an elliptic cavity, which results in the higher frequency

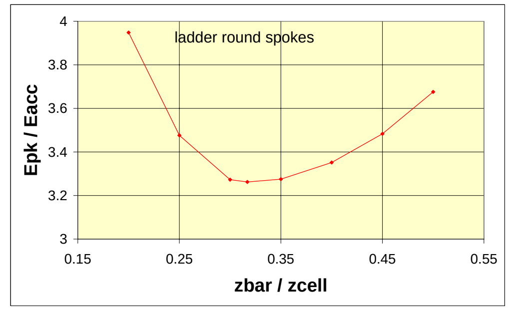

Figure 6: Maximum Electric Surface Field to Accelerating Field Ratio vs. Spoke Length

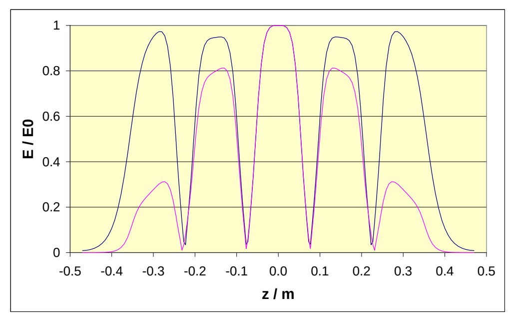

Figure 7: Electric Field Distribution in Spoke 5-Cell Ladder Cavity Depending on End Region Tune

and shunt impedance of this "exotic" mode. One of the problems with low beta RF cavity design is that in such cavity an accelerating gap is rather small, which results in a high gap capacitance. To get a relatively high cavity frequency, say 700 MHz one should strongly reduce a cavity inductance, which is essentially the cavity volume. This results in a rather small cavity tank with a complex structure inside. Making a design for a twice-lower frequency simplifies this problem. Fig. 12 compares e-fields in five-gap spoke cavity of fundamental and "exotic" modes. In this case there is no e-field profile correction in either mode. That can be interesting option to build a cavity with dimensions evaluated for lower frequency (say, 350 MHz) to use for an acceleration on 700 MHz without a frequency jump between low and high-energy parts of the accelerator.

5 FIVE-GAP SPOKE CAVITY MODEL

A simple model of five-gap spoke cavity has been built to check cavity basics. The model is a cylindrical pipe with four rectangular spokes, which can be placed either in cross or ladder way. A cavity radius is 158 mm, a spoke length along an accelerating path is 45 mm, $\beta\lambda/2$=150 mm, a spoke width is 90 mm, a cavity aperture 60 mm is kept constant along the whole cavity. The end plates are mov-

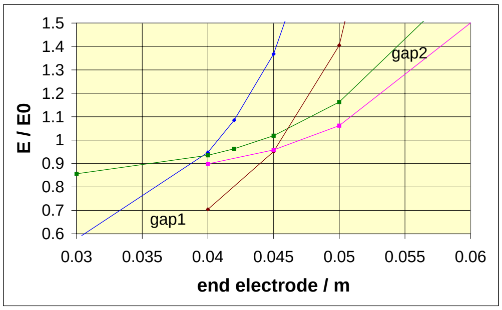

Figure 8: Electric Field in Different Gaps Relative to Central Field (end gap capacitance correction)

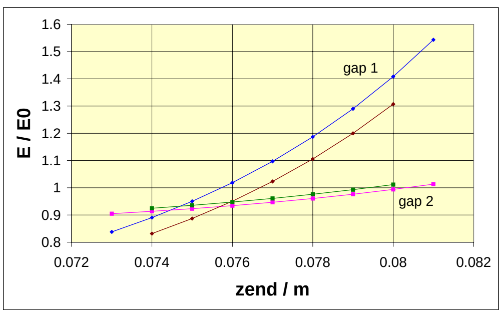

Figure 9: Electric Field in Different Gaps Relative to Central Field (end cavity volume correction)

able which allows change cavity frequency and field distribution along cavity. The coupling and measurement loops have been placed in the central gap. A perturbation method has been used for the cavity e-field distribution measurement. The calculated and measured cavity frequencies for five modes of fundamental mode band are within less then 1% to each other (Fig. 13). The measured e-field distribution differs from the simulations within 5% that is defined by the accuracy of the end plate positions (Fig. **??**).

6 CONCLUSIONS

- A spoke cavity has a more rigid structure, which is the biggest advantage to compare with elliptical cavities.
- The main RF parameters of spoke are about in the same range as for elliptical cavities, but the cavity diameter is about 50
- The ratio H_{pk}/E_{acc} is higher for spoke (should be verified more accurately while the simulated geometry in the h-field maximum region has been not perfect).
- The spoke shunt impedance is higher (although it is not very crucial for SC cavities).

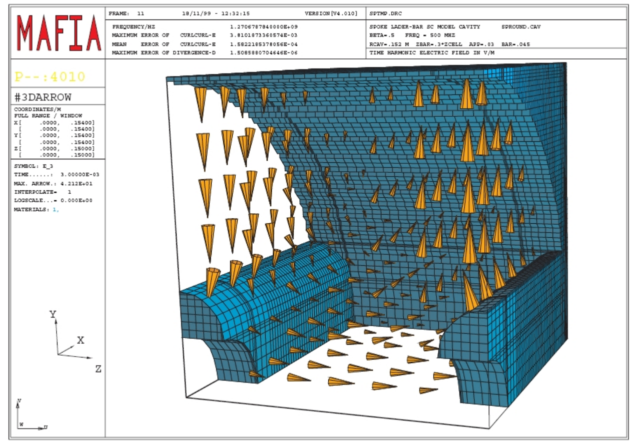

Figure 10: Electric Field of "Exotic" Mode in Spoke Ladder Cavity (1/4 of cell is shown)

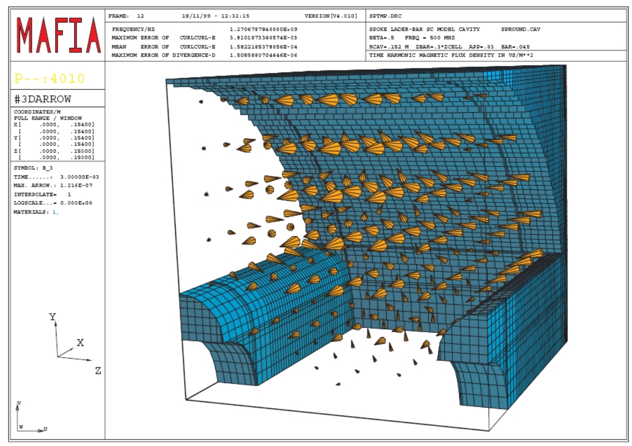

Figure 11: Magnetic Field of "Exotic" Mode in Spoke Ladder Cavity (1/4 of cell is shown)

- A group velocity of spoke (Fig. 14) is much higher than of elliptical cavities (for spoke $f_{mode2} - f_{mode1}$=10-40 MHz, for elliptical cavity $f_{mode5} - f_{mode4}$=1-3 MHz).
- Because of the difference in the cell-to-cell coupling type the spoke cavity aperture can be made much

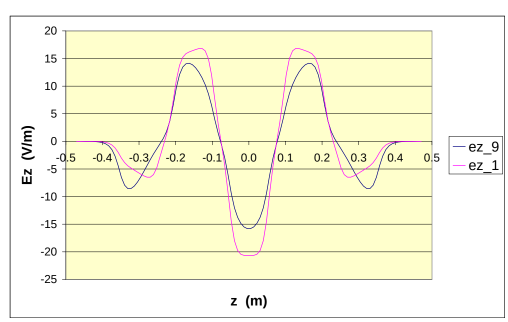

Figure 12: Electric Field Distribution of Fundamental and "Exotic" Mode 9 in 5-gap Cavity

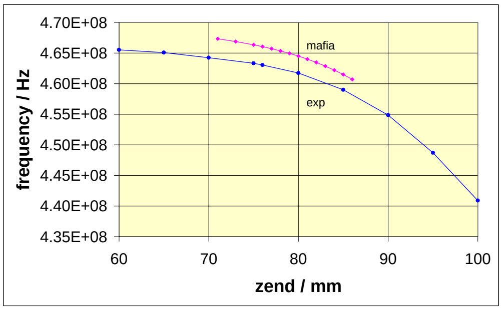

Figure 13: Fundamental Frequency in 5-Cell Cross Bar Spoke Cavity Experimental Model

Table 1: Some Parameters to Compare Elliptical and Spoke Cavities

		elliptical	**spoke**
frequency	MHz	500	500
$\beta = v/c$		0.5	0.5
diameter	cm	53.1	30.0
aperture R_i	cm	5.0	3.0
dome R_{top}	cm	3.5	
slope α	deg	7.5	
cell length	cm	15	15
ell. axes a	cm	2.06	
transit time factor		0.772	0.776
coupling	%	0.57	
E_{pk}/E_{acc}		3.13	3.21
H_{pk}/E_{acc}	Gs/(MV/m)	73.9	110.8
$R_s * Q_0$	Ohm	132	105
R_s/Q_0	Ohm/m	474	975

smaller than in elliptical cavities (only to handle the beam), which results in a cavity transition time factor increase.

- Minimisation of h-field on the cavity walls favours a cross bar configuration of spokes.
- Making a design of low-beta spoke cavity one should remember that in this case the beam pipe aperture size becomes comparable with the cell length. In this case an integral fringe e-field is a good part of an integral field in the cell, which can violate the synchronism of acceleration. To improve this situation a few gap cavity should be used.
- The geometry of spoke cavity is strongly asymmetric which results in the existence of the transversal to the beam path x- and y- electric field components (Fig. 15). The beam dynamic simulation to evaluate transversal kicks should be carried out.
- The problem of a resonance electron discharge (multipactor) is open for the spoke cavity and should be

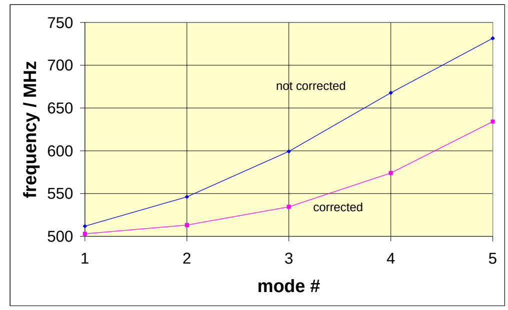

Figure 14: Spoke Cavity Dispersion Curves for Corrected and Not Corrected E-Field Distribution

checked experimentally. The absence of 3D numerical programs for such type simulations makes theoretical predictions doubtful. Basing on the practical experience one may try to make corners in the cavity round.

- The multi-gap spoke cavity has more complicated geometry and a technology of its manufacturing should be developed.

7 ACKNOWLEDGEMENTS

The authors would like to thank W. Braeutigam, S. Martin for the permanent interest, support and helpful discussions, K. Sobota, A. Richert, R. Stassen and C. Deutsch for the construction of an experimental stand and the measurements help.

8 REFERENCES

[1] J. R. Delayen et al., "Design and Test of a Superconducting Structure for High-Velocity Ions", LINAC'92, Ottawa, 1992.

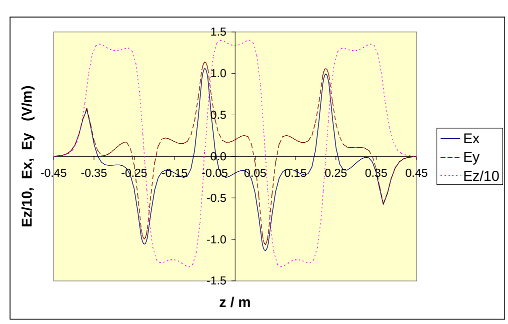

Figure 15: Electric Field Distribution in 5-Cell Cross Bar Spoke Cavity Experimental Model