A NEW CAVITY DESIGN FOR MEDIUM BETA ACCELERATION *

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Abstract

Heavy duty or CW, superconducting proton and heavy ion accelerators are being proposed and constructed worldwide. The total length of the machine is one of the main drivers in terms of cost. Thus HWR and spoke cavities at medium beta are usually optimized to achieve low surface field and high gradient. Typically, a reasonable project nowadays will limit the Ep and Bp to <35 MV/m and <80 mT, respectively; Also it is reasonable to keep dynamic heat load per cavity lower than 10W assuming it is running at 2 K. A novel accelerating structure at beta=0.5 evolved from spoke cavity is proposed with lower surface fields but slightly higher heat load. It would be an interesting option for pulsed and CW accelerators with beam energy > 200 MeV/u (β>0.57).

THE IDEA OF THE DESIGN

To reduce the maximum surface magnetic field, it is essential to reduce the surface current density, by making current evenly distributed on larger surface, or by reducing the surface current. The half-wave cavity could be described as a L-C resonance circuit as shown in Figure 1, and the current could be reduced by introducing more shunted impedance to the loop, which is, to add more "bars" to the structure: by doing that, the total inductance of each loop will be reduced, and the capacitance will be increased slower due to the increased area; to get the frequency $\omega \propto 1/\sqrt{L_{shunt}C}$ same as before, the cavity radius has to be larger to increase the inductance L; thus the current $I = V_{acc} / j\omega L$ is reduced, and the peak magnetic field is reduced accordingly. Though, one predicted drawback is lower shunt impedance: since $R/Q \propto \sqrt{L_{shunt}/C}$, it is reduced with smaller shunt inductance and larger capacitance. As long as the the power loss at the target gradient is still reasonable, it is a second order effect compared to the benefit earned by reducing the number of cryomodules and the length of the whole machine.

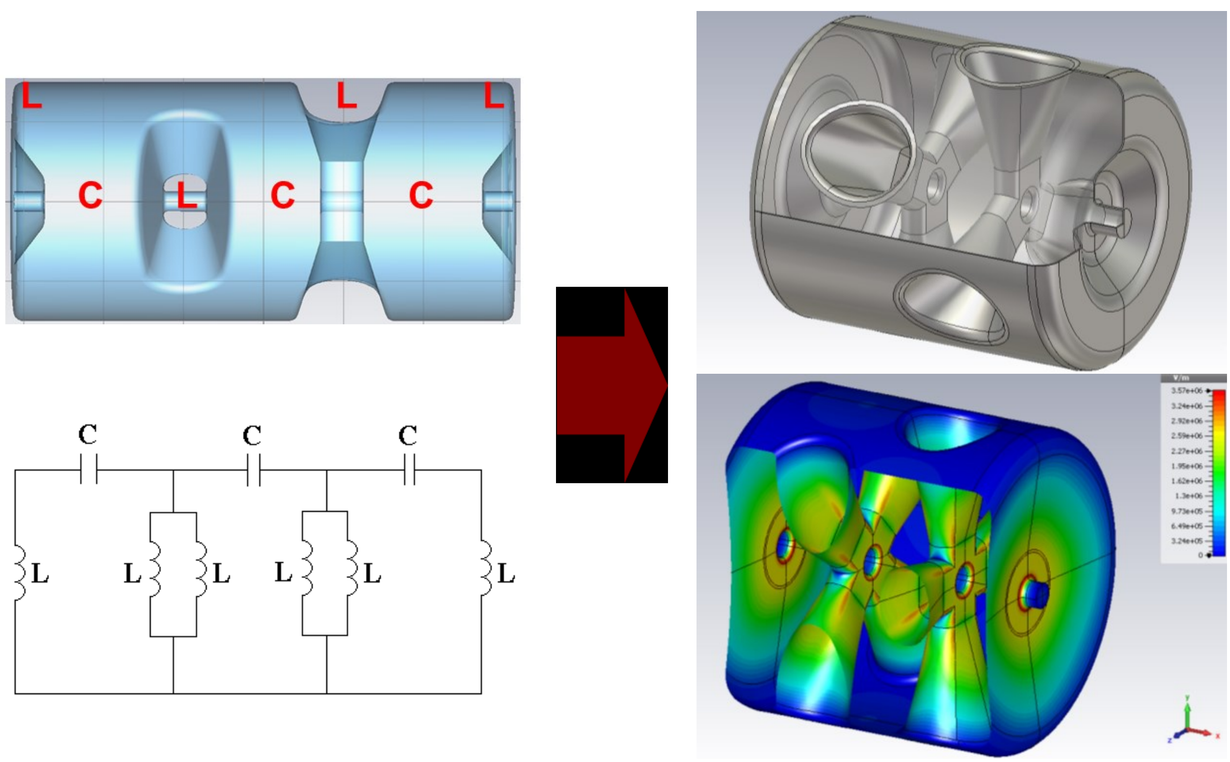

Figure 1: Reducing the shunt inductance by introducing more bars to the half-wave structure.

AN EXAMPLE DESIGN FOR ESS REQUIREMENT

ESS plans to accelerate proton from 79 MeV to 201 MeV (β=0.387~0.567) with 352 MHz double spoke cavity of β=0.5 at 2 K [1]. The spoke cavities are optimized to reduce surface field and linac length. The design goal is to keep Ep<35 MV/m and Bp<70 mT at Eacc of 8 MV/m.

By increasing the achievable gradient, not only the spoke section will get shorter, the medium-beta elliptical cavity section will also be shorter, since the first several cavities could run at a higher gradient while keeping longitudinal phase advance transition smooth [2].

The 352 MHz double spoke cavity, 3-bar cavity, and 4-bar cavity were optimized with the same beam aperture of 50mm and optimum beta of 0.5 as the ESS. The elliptical base shape of the spokes or bars are adopted, while the central part of the spokes or bars were chosen as either elliptical or race-track shape. The models were fully parameterized, and the optimization scheme was similar as described in [3].

The CST2011 Microwave Studio was used for the optimization. The Eigen-mode solver with 2nd order curved tetrahedral meshing was used. Our benchmarking results on a spherical cavity and a half wave coaxial cavity showed that a better than 98% accuracy of the surface EM fields could be expected. The parameter sweep framework in the CST was used, and a self-written macro for automatically calculating the transient time factor (TTF) curve [4], picking up the optimum beta, and tuning the frequency to the target value by changing the cavity diameter for each set of parameters was developed. We also constrained the field flatness better than 90% in the optimization process, and tuned it back manually by changing the depth of the re-entrant part at end gap if it is needed. The EM field density on surface is smaller in the end gap than in the middle gap, so a little bit stronger field in the end gap finally gives the minimum surface field.

As shown in Table 1, more than 3 cryomodules could be saved by using the new cavity design, comparing to that in the ESS TDR. The multipacting barriers of the 3-bar structure are also similar to double spoke as shown in Figure 2, which does not introduce additional difficulties to the cavity processing. Note total RF power is the same with higher gradient, so the cost saved from less number of cryomodules could be fully recovered.

Table 1: Parameters of the Optimized Cavities

	ESS TDR	JLab spoke	3-bar	4-bar
Cavity end-to-end length [mm]	787	771	657	567
Cavity inner diameter [mm]	480	459.8	556.6	636
Aperture diameter[mm]	50	50	50	50
Ep/Ea	**4.54**	**3.51**	**3.21**	**2.73**
Bp/Ea [mT/(MV/m)]	**7.27**	**7.29**	**6.51**	**6.48**
$G=Q_0/Rs$ [Ω]	133*	112	122	120
Ra/Q [Ω]	427*	457	377	298
Ra*Rs [Ω^2]	5.6e4	5.13e4	4.59e4	3.59e4
Eacc [MV/m]	**7.7**	**9.3**	**10.7**	**11.3**
Dynamic load [W]	4.3	8.0	10.2	14.5
No. of cavities saved (spoke / elliptical)	**0 / 0**	**4 / 1**	**7 / 2**	**8 / 2**
Total length reduction of linac [m]	**0**	**>6**	**>9**	**>12**

Note: effective length of 3βλ/2=0.6384m is used for gradient calculation; keeping Ep<35MV/m and Bp<70mT for operation, and assume Rs=10n Ω
* Values are not found in ESS TDR; use those in [5]

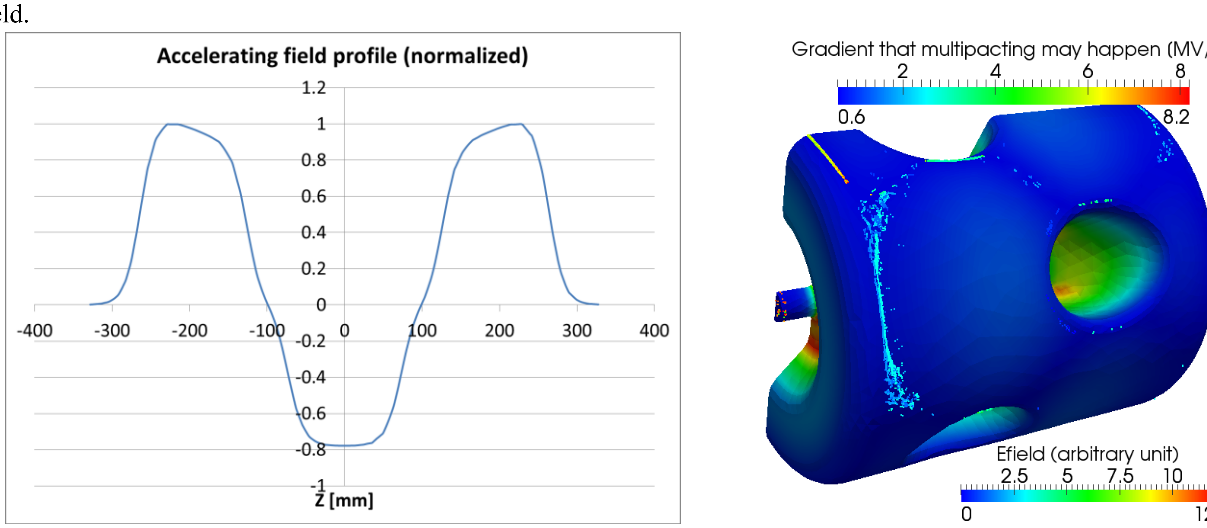

Figure 2: Accelerating field profile and the multipacting behaviour of the 3-bar structure.

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CONCLUSION

Novel cavity shapes were developed to reduce the peak surface field. Example designs were compared with the ESS TDR to demonstrate the effectiveness of saving cost on projects. They are thus interesting options for pulsed and CW low beta accelerators up to β=0.5.

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