MOPO029

Some design analysis on the low-beta multi-spoke cavities

F. He*#, H. Wang*, R. A. Rimmer*, K. Zhao#

*Jefferson Lab, Newport News, VA 23606, USA

#Peking University, Beijing, China

Abstract

The spoke cavities have achieved promising gradients worldwide, which make them good candidates for accelerating low beta proton and ions. Although, there is still a space to further optimize them, especially for multi-spoke cavities.

The design and optimization are re-considered based on the total capital and operational efficiencies over a given beta range. An initial result of the 3D EM design optimization by the CST MWS code for a double-spoke, beta ~ 0.5 cavity is reported. An equivalent circuit for the double-spoke cavity is also developed.

Optimization goal

Instead of tracking the particle, the performance of the cavity with a given β range can be taken into consideration at EM design phase, if the accelerating phase is fixed from cavity to cavity:

$$Ncavity(\beta_1,\beta_2)=\frac{m_0c^2}{qV_0\cos\varphi}\int_{\beta_1}^{\beta_2}\frac{\beta\gamma^3}{TTF(\beta)}d\beta$$

So we can define the accelerating efficiency of this cavity from β1 to β2 as:

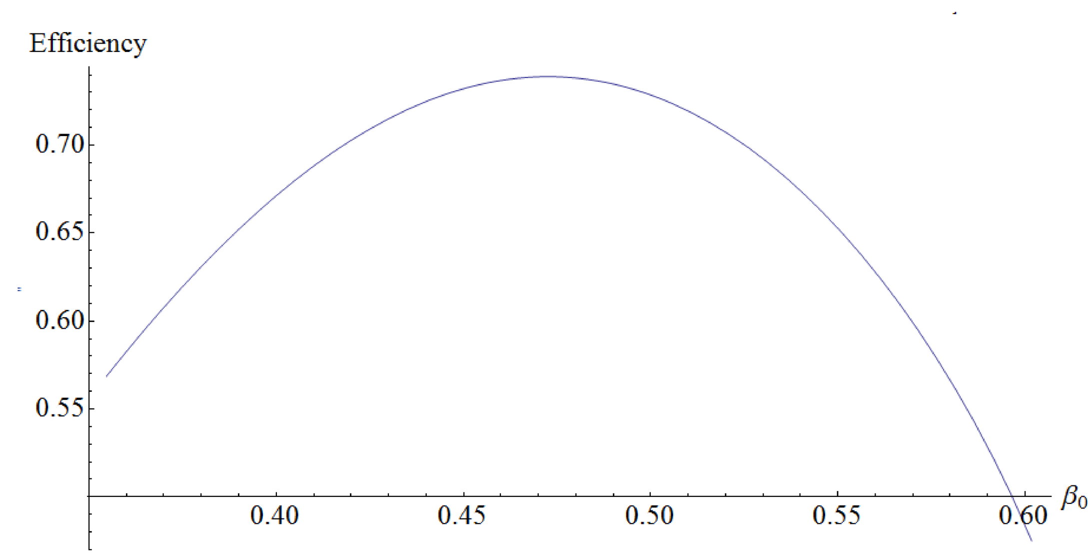
$$Eff(\beta_1,\beta_2)=\frac{\Delta E_k}{qV_0\cos\varphi Ncavity}=\frac{\gamma_2-\gamma_1}{\int_{\beta_1}^{\beta_2}\frac{\beta\gamma^3}{TTF(\beta)}d\beta}$$

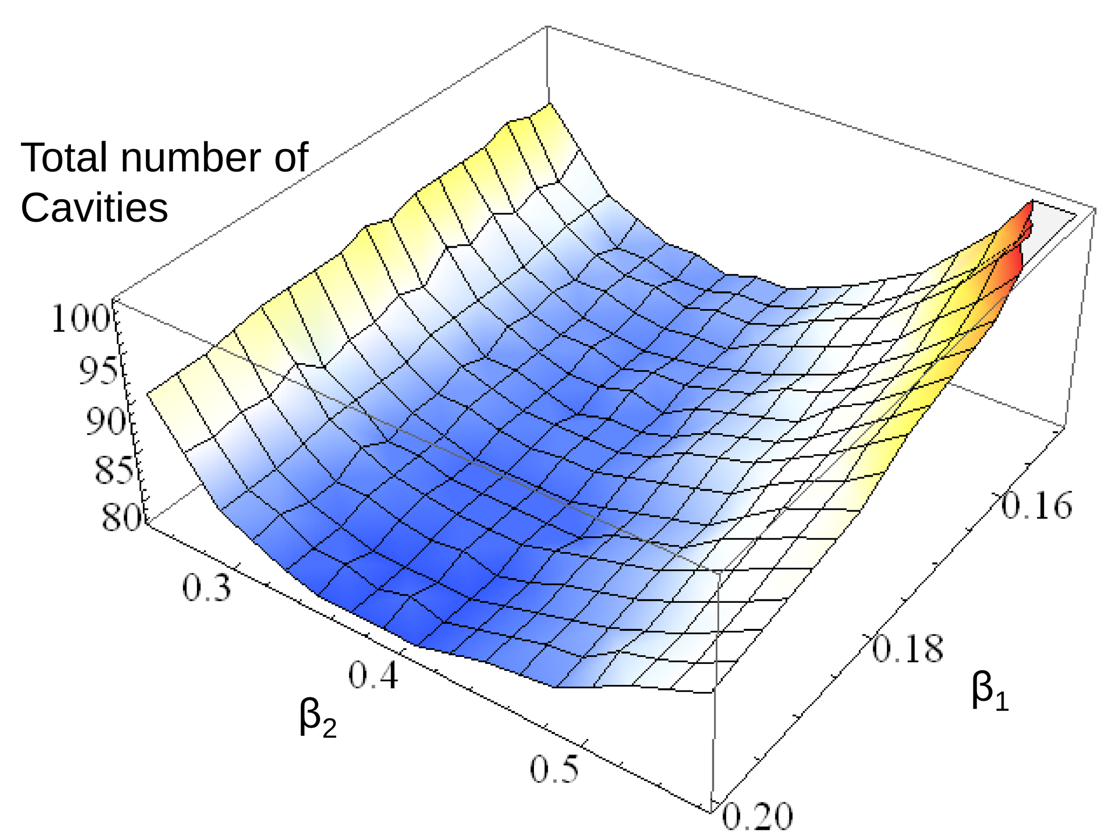
The efficiency can be seen as an averaged TTF in the β range.

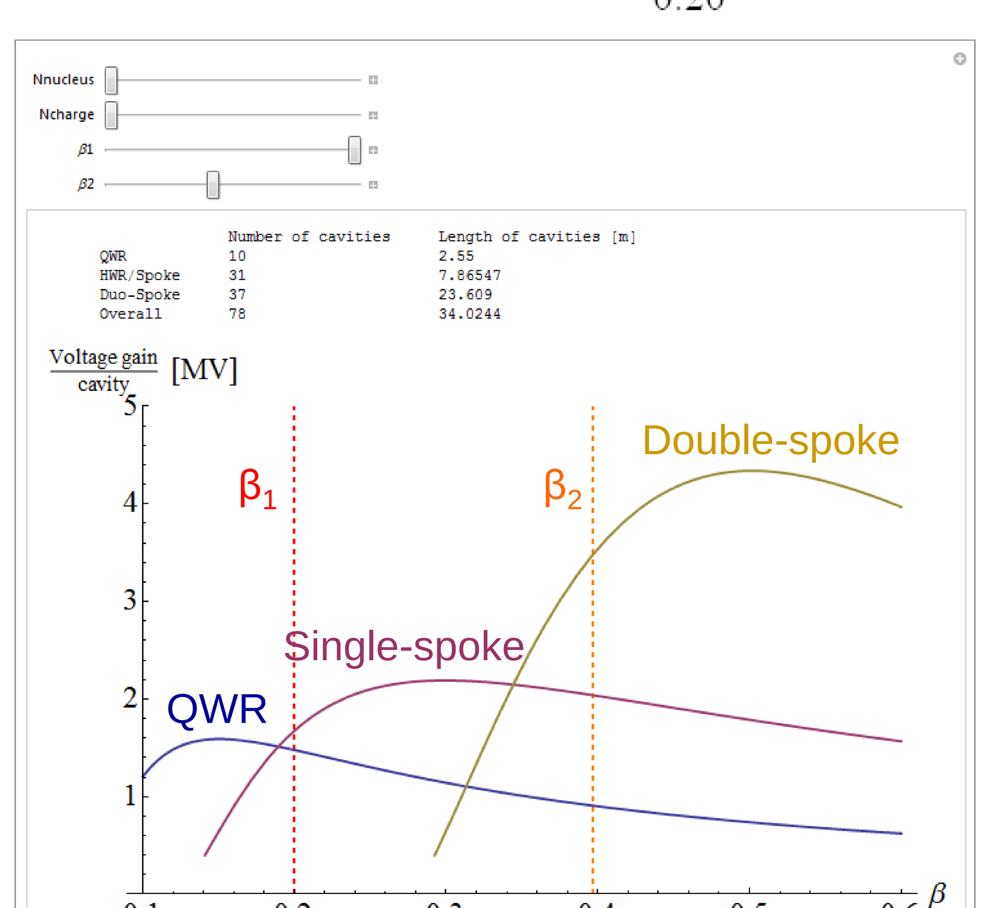
The tested performance limits of existing spoke cavities are Ep~30-80Mv/m, Bp~80-130mT. So the EM design goal is suggested to be set as:

- Pulsed machine: Minimize $Ep/(V_0*Eff)$, while keeping Bp/Ep<2.6 mT/MV/m (state of art) or <1.5 (pushing limit)
- CW machine: Maximize $(R/Q)_0*(Eff)^2$, while keeping Bp and Ep ratio less than some chosen value.

Typical optimized design of a low beta Linac RF operated on crest is shown on the right: QWR at 170MHz from β=0.1 to β1, Single-spoke at 340MHz from β1 to β2, and Duo-spoke at 340MHz from β2 to 0.6







EM design of multi-spoke cavity

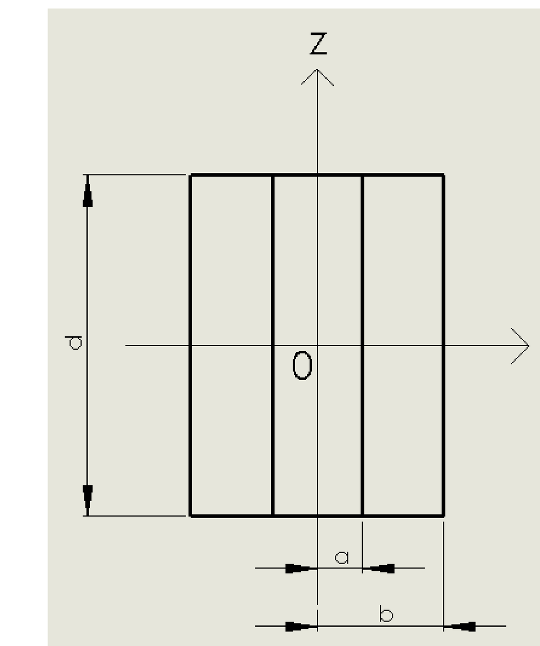
Benchmark of codes

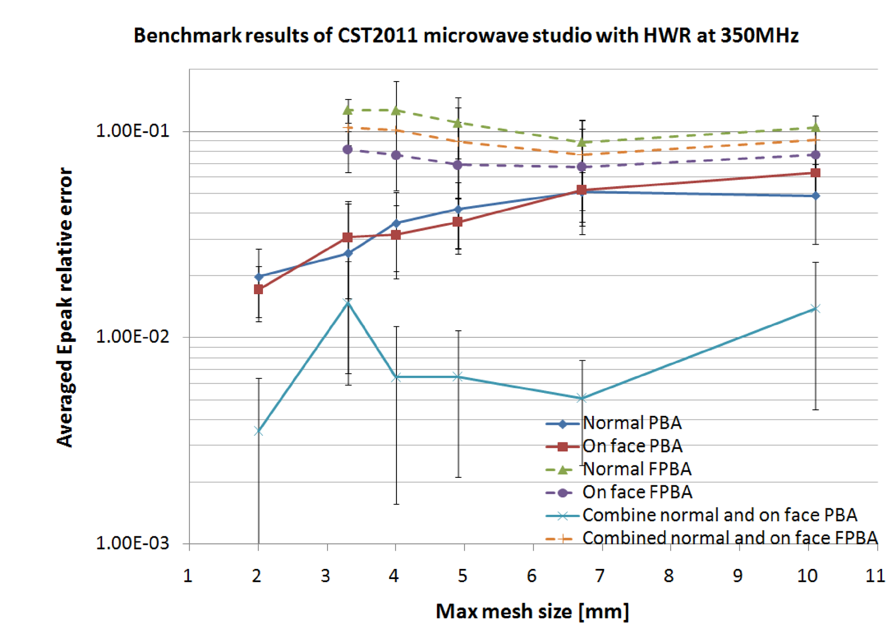
It was found that the CST2011 MWS could achieve an accuracy of better than 1% for peak surface field of spherical cavity with frequency 2-5GHz and max mesh step 2mm, while the HFSS13 could achieve accuracy 1e-5. Though, for the TEM structure, the CST2011 performs much worse, maybe due to larger curvature of the structure. So, for the spoke cavity with beam aperture, we suppose around 10% error with a reasonable mesh density.

Initial result of the double-spoke cavity

A Duo-spoke cavity at 352MHz with βmax ~ 0.5 is chosen as our first prototype shape, and it is optimized by minimizing Ep/Va at β_0 while keeping Bp/Ep<1.5 mT/(MV/m).

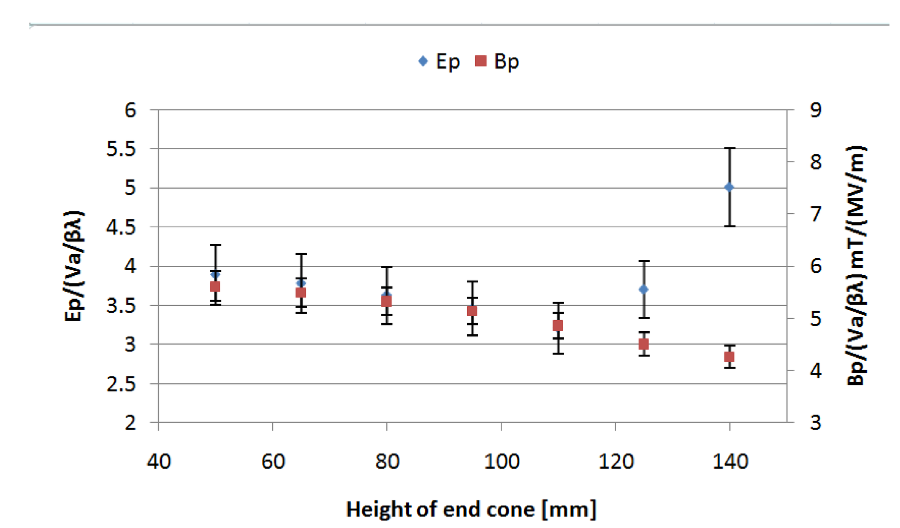
The impacts of spoke dimension, vessel radius and iris-to-iris distance have been described (e.g. [1]), Our calculation confirmed the published conclusions. One accomplishment is that the shape of end-cone contributes a lot to the cavity efficiency since it affects the field flatness as well as the length of the cavity. The optimized shape is not necessarily with a prefect flat field profile. We did not optimize it too much , which is limited by CST's field accuracy.

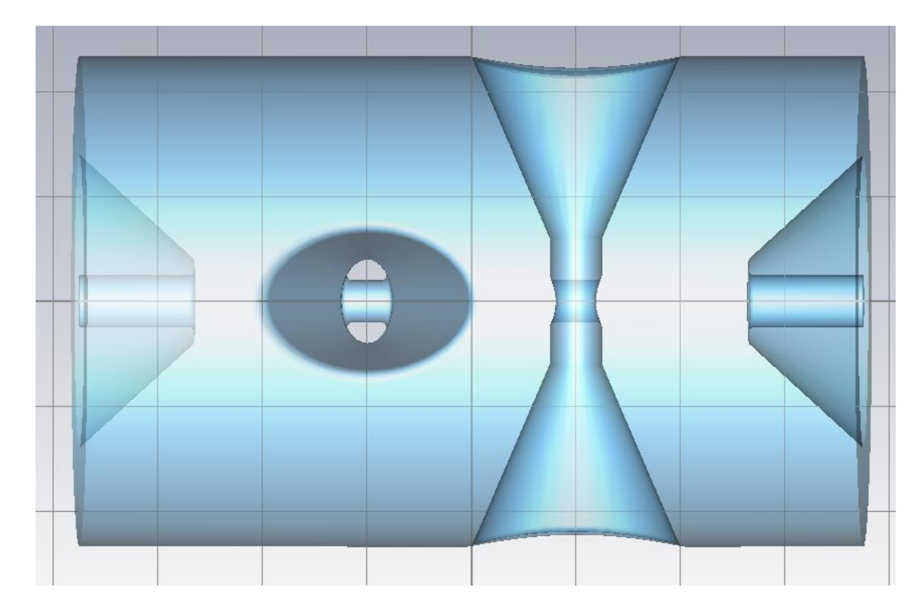


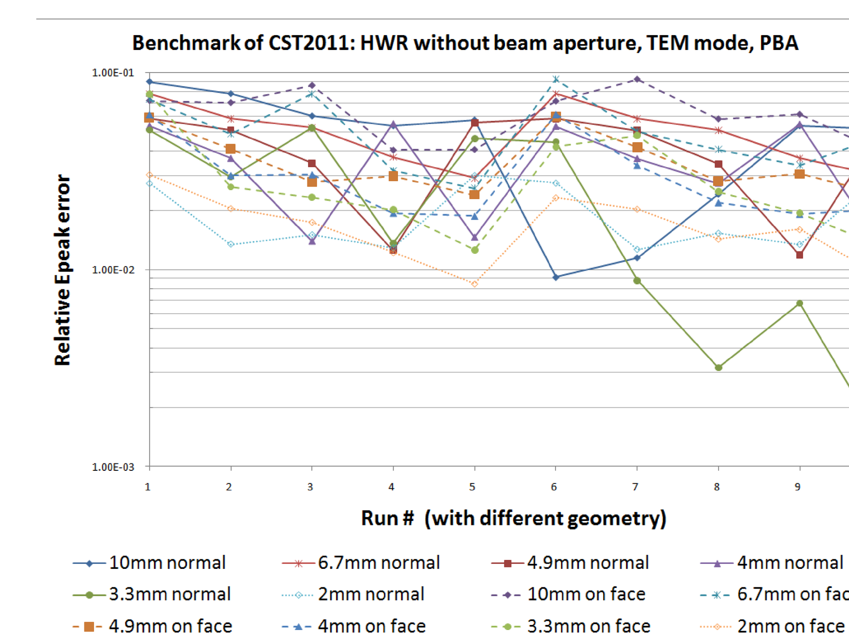


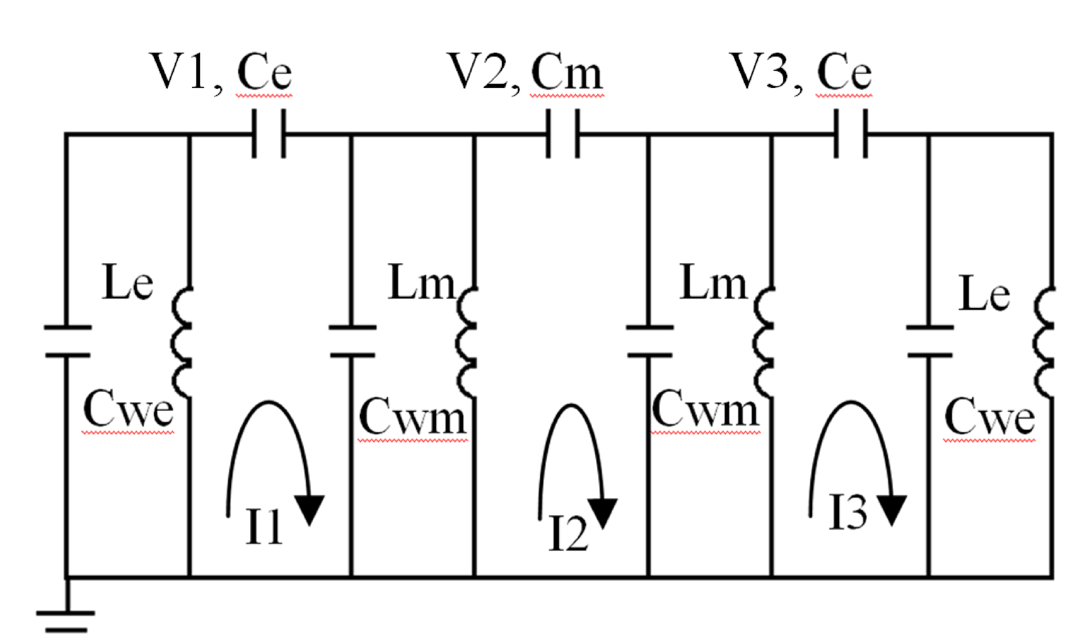
Double-spoke cavity parameters

Frequency	β_0	Cavity length	Ep/Va/Lcavity	Bp/Va/Lcavity	G*R/Q
352 MHz	0.5	750 mm	5.6	8.5 mT/MV/m	5.86e4 Ω^2









Equivalent circuit model

An equivalent circuit model for double-spoke cavity is built. The capacitor between spokes, end covers, and vessel wall, as well as the inductance of spokes and end covers are modeled. By noticing the special field profile of π mode to π/3 mode, the resonance frequency can be derived; and it has been confirmed that electric energy equals to the magnetic energy stored in the loop with the roots solved. Moreover, it is found equivalent that a flat π mode exists and Le(2Ce+Cwe)=Lm(2Ce+2Cm+Cwm).

The reverse process has also been done: if we have numerically calculated the three resonance circular frequencies, and voltage ratios of middle to end gap for π mode and π/3, and the R/Q of any one of the three modes, then all the circuit parameters can be solved.

Reference :

[1] J.R. Delayen, et al, "Design of Superconducting Spoke Cavities for High-velocity Applications", PAC11, 2011

ACKNOWLEDGEMENT :

This research was conducted at Thomas Jefferson National Accelerator Facility for the Department of Energy under grants DE-AC05-06OR23177.

北京大学 Peking University

Jefferson Lab

Contact: feisi@jlab.org

SRF2011 CHICAGO

JSA