DESIGN OF SUPERCONDUCTING SPOKE CAVITIES FOR HIGH-VELOCITY APPLICATIONS

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Abstract

Superconducting spoke cavities have been designed and tested for particle velocities up to $\beta_0 \sim 0.6$ and are currently being designed for velocities up to $\beta_0 = 1$. We present the electromagnetic design for two-spoke cavities operating at 325 MHz for $\beta_0 = 0.82$ and $\beta_0 = 1$.

INTRODUCTION

Accelerating charged particles from $\beta_0 = 0.6$ to $\beta_0 = 0.8$ has typically been accomplished using elliptical cavities. Single and multiple-gap spoke cavities offer several advantages over their elliptical counterparts. The diameter of a spoke cavity is on the order of the half the rf wavelength, whereas the diameter of an elliptical cavity is twice that. This allows for either smaller physical dimensions at the same operating frequency or close to half the operating frequency for the same physical diameter. Since the BCS surface resistance is proportional to the square of the rf frequency, spoke cavities could allow for 4 K operation as well as a higher voltage gain over a wider range of velocities [1, 2]. We report here on the design of double-spoke 325 MHz cavities for $\beta_0 = 0.82$ and 1.

ELECTROMAGNETIC DESIGN

High surface fields in superconducting cavities can have detrimental effects on performance. If the surface magnetic field is too high, quenching can occur and if the surface electric field is too high, field emissions can be induced. When comparing the performance of cavities, we often refer to the normalized surface fields, E_p/E_{acc} and B_p/E_{acc}, where E_p is the peak surface electric field, B_p is the peak surface magnetic field and E_{acc} is accelerating electric field which is defined here as

$$E_{acc} = \frac{\Delta W(\beta_0)}{\beta_0 \lambda} \quad (1)$$

where $\Delta W(\beta_0)$ is the energy gain at the optimal velocity. Minimizing these fields is often the first step in cavity design, and the results of which are presented here.

Optimization of Peak Surface Fields

The cavity's radius and iris-to-iris length are approximately determined by the operating frequency and desired β_0. The peak surface fields, however, depend greatly on the shape and dimensions of both the spoke base and the spoke aperture region. All of the results presented are at a frequency of 325 MHz and $\beta_0 = 0.82$ and $\beta_0 = 1$.

Figure 1 shows the spoke parameters discussed here. For convenience, we will refer to the elongated dimension of the spoke (base or aperture, elliptical or racetrack) as either being longitudinal or transverse with respect to the beam line. Both the spoke base and aperture region have

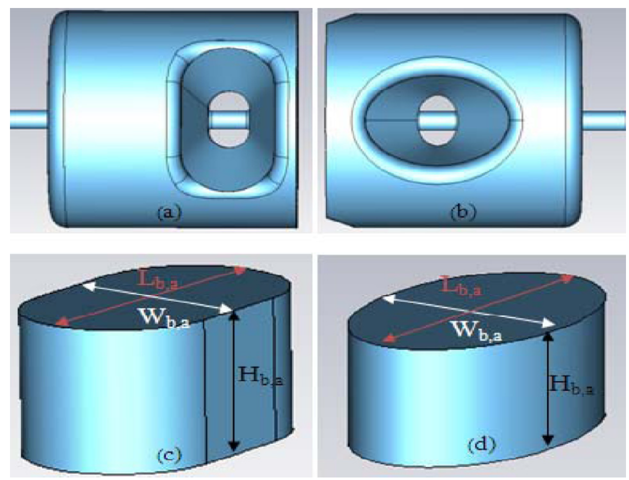

Figure 1: CST MWS view of half the cavity with a transverse racetrack design at the base and aperture (a) and longitudinal ellipse at the base and transverse ellipse at the aperture (b). Racetrack part of spoke (c) and elliptical part of spoke (d). The dimensions of each carry a subscript a or b which refers to either the aperture or base.

been investigated with the elliptical, cylindrical, and racetrack geometries.

Spoke Base

The magnetic field of the fundamental accelerating mode in a spoke cavity is more concentrated near the outer conductor's surface and encircles the spokes. The size and shape of the spoke base region can thus have a strong effect on the peak surface magnetic field. The spokes run radially through the cavity, so changing the size of the base does have an effect in the beam-line region as well since the spoke tapers down to the center. In figure 3, the normalized magnetic field is shown as a function of the spoke base dimensions. The dimension is normalized to the rf wavelength corresponding to a frequency of 325 MHz. More detail on the optimization procedure can be found elsewhere [3].

For a longitudinal spoke base orientation, the length of the spoke base is changed beginning from cylindrical to a value at which the spoke is close enough to the outer wall

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that the surface fields become very high. From figure 2, we see that there is a simple relation between the spoke base width and the normalized magnetic field for the longitudinal orientation. For the transverse spoke base orientation, again, we begin with a cylindrical shape and now increase the width until this dimension is close to the diameter of the cavity. From Fig. 2 and 3 we see that as we increase the width of the spoke base, both the normalized magnetic and electric fields continue to go down until they reach a constant value.

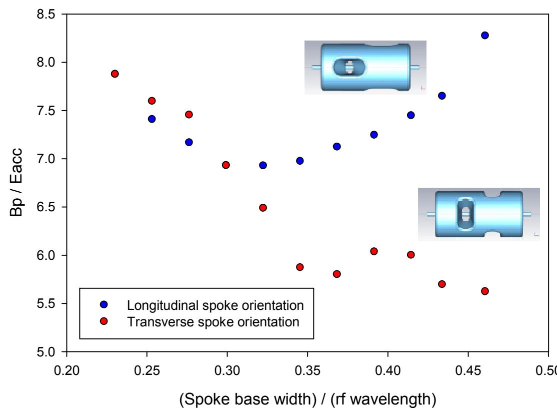

Figure 2: Normalized surface magnetic field as a function of the spoke base dimensions.

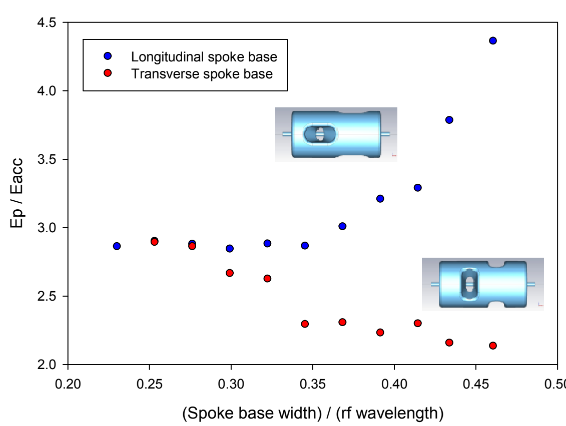

Figure 3: Normalized surface electric field as a function of the spoke base dimensions.

Figures 2 and 3 show similar trends, which is why we have chosen a transverse spoke orientation for the base.

Spoke Aperture

The electric field of the fundamental accelerating mode of a spoke cavity is of course concentrated at the accelerating gaps along the beam path. The shape and dimensions of the spoke aperture region thus have a great impact on the peak surface electric field. Figure 4 shows how the normalized electric field varies as a function of the spoke aperture dimensions. The variation was taken by fixing the transverse length of the aperture while increasing the longitudinal width. Figure 5 shows how both the normalized electric and magnetic fields change as the spoke aperture width to length ratio is varied.

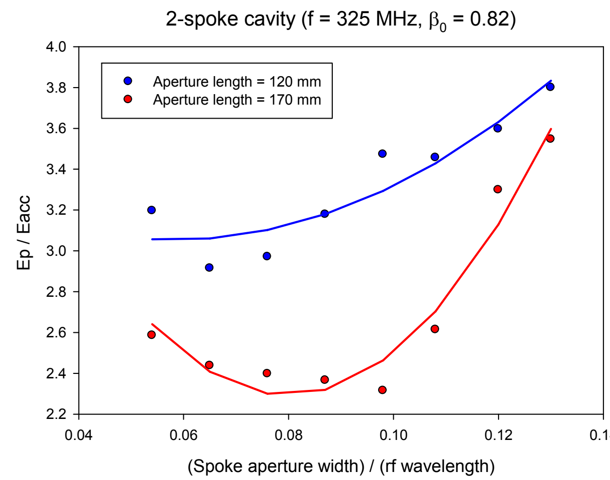

Figure 4: Normalized surface electric field as a function of spoke aperture dimensions.

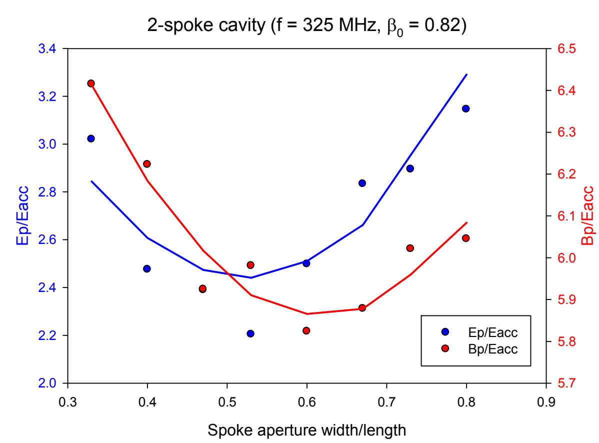

Figure 5: Normalized surface magnetic and electric fields vs. the ratio of spoke aperture width to length.

Spoke Separation

In low-β structures made with several loading elements (multi-spoke, split-ring or twin-quarter-wave for example), the side gaps are approximately half the size of the central gap. We find that, as the β of the cavity is increased, the optimal size for the side gaps, i.e. the one that minimizes the surface fields, increases to become closer to the size of the central gaps.

The normalized surface electric and magnetic fields as a function of spoke separation are shown in figure 6. The dependence of the accelerating field profile on the spoke separation for three points in figure 6 are shown in Fig. 7. The overall accelerating voltage for the three cases are comparable, so it would appear that there is some benefit to be had by not strictly balancing the fields in each cell. We choose to have the spoke separation slightly below $\beta_0\lambda/2$ in order to reduce the peak surface electric and magnetic fields.

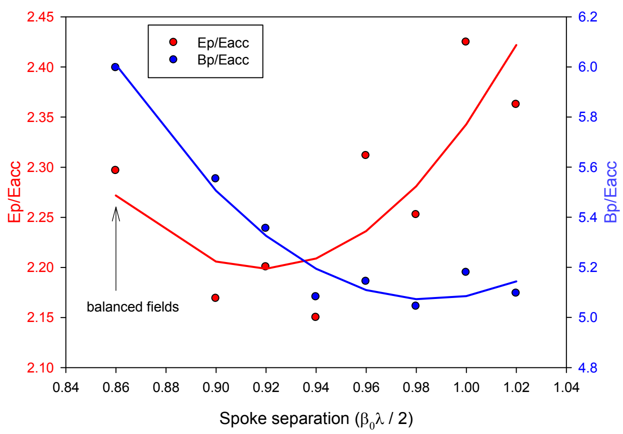

Figure 6: Normalized surface magnetic and electric fields vs. the spoke separation distance.

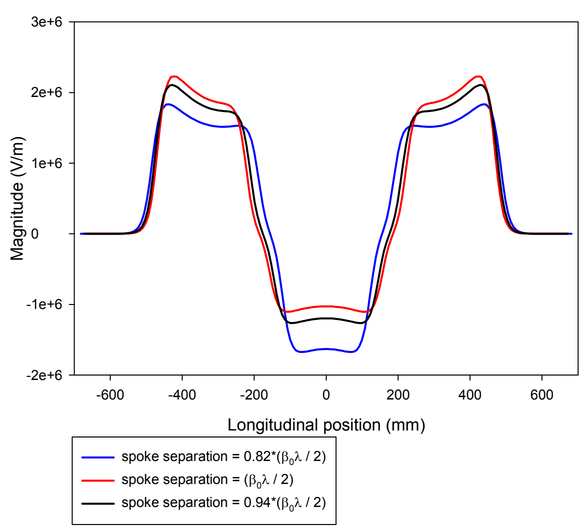

Figure 7: Longitudinal electric field profile of the fundamental accelerating mode for different spoke separation distances.

The physical dimensions are presented in table 1 and the rf properties we have simulated thus far for the 325 MHz, $\beta_0 = 0.82$ and $\beta_0 = 1$ are given in table 2.

Table 1: Physical Dimensions

Parameter	β_0 **= 0.82**	β_0 **= 1.0**	**Units**
Cavity diameter	629	642	mm
Iris-to-iris length	956	1178	mm
Cavity length	1136	1370	mm
Aperture diameter	60	60	mm

Table 2: RF parameters

Parameter	β_0 **= 0.82**	β_0 **= 1.0**	**Units**
Frequency fundamental mode	325	325	MHz
R/Q	543	621	Ω
Geometrical factor	167	188	Ω
E_p / E_{acc}	2.49	2.27	
B_p / E_{acc}	5.4	5.32	mT/(MV/m)
B_p / E_p	2.17	2.34	mT/(MV/m)

At E_{acc} = 1 MV/m and reference length = $\beta_0\lambda$

CONCLUSION

The optimization for high-β_0 spoke cavities is ongoing. For both frequencies and values of beta we are optimizing, we find that transverse spoke base and aperture orientations seem to produce the lowest surface fields. Our results are promising and indicate the need for further research in this area, which we are pursuing.

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