DESIGN OF LOW-FREQUENCY 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 and $\beta_0 = 1$.

INTRODUCTION

Accelerating charged particles from $\beta_0 = 0.5$ to $\beta_0 = 1$ 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 a two-spoke 325 MHz cavity designed for $\beta_0 = 1$.

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

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

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. The optimization of the spokes has been discussed elsewhere [3]. In this report we present the results of various parameter optimizations and focus how these parameters affect both the surface fields and the shunt impedance.

Figure 1 shows some of the cavity parameters discussed here. When referencing the spokes, we will refer to the elongated dimension of the spoke (base or aperture) as either being longitudinal or transverse with respect to the beam line. Both the spoke base and aperture region have been investigated with the elliptical, cylindrical, and racetrack geometries.

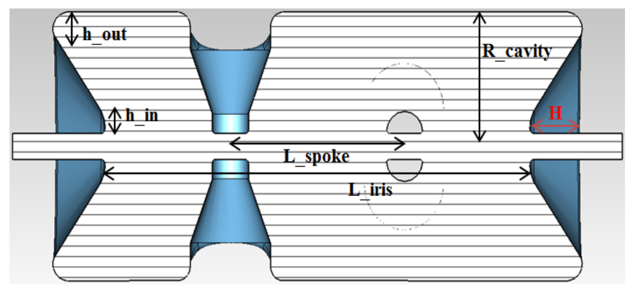

Figure 1: CST MWS cut-away view of the two-spoke 325 MHz, $\beta_0 = 1$ cavity.

Surface Magnetic Field

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 1, we see that h_out can be used to optimize the peak surface magnetic field. When optimizing any of the parameters, it is important to also consider maximizing the shunt impedance while trying to minimize the peak surface fields. In the case of parameters such as h_out, which do not impact the surface fields as greatly as the spoke parameters, we find that there can be a small gain in shunt impedance while obtaining a mild reduction in peak surface fields. The length and width of the spoke base have a much more significant effect on both the surface magnetic field and R/Q * G. In figure 2, it is clear that the transverse length of the spoke base (in this case, racetrack geometry is used) can increase the shunt impedance while decreasing the normalized magnetic field.

**Work supported by U. S. DOE Award No. DE-SC0004094
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H is a parameter, as can be seen in figure 1, which has an effect on both the normalized magnetic and electric fields. Figure 3 shows how the normalized magnetic field and R/Q*G changes for a varying H.

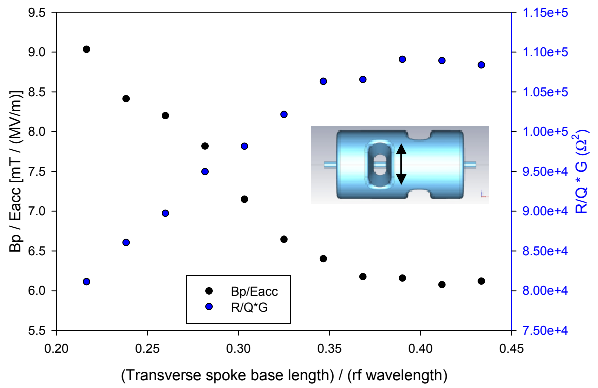

Figure 2: Normalized surface magnetic field and R/Q * G as a function of the transverse spoke base length.

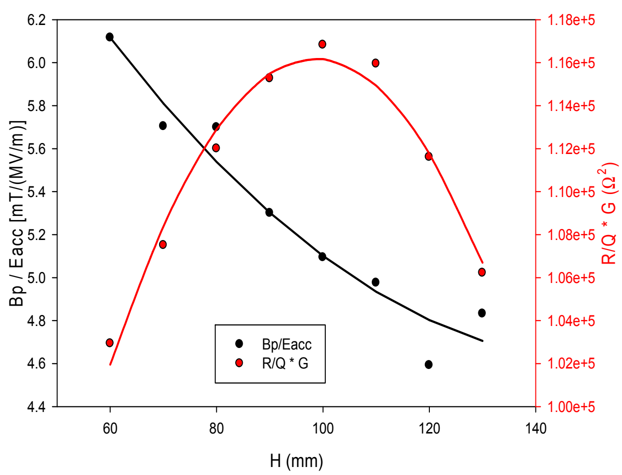

Figure 3: Normalized surface magnetic field and R/Q*G vs. H.

Again, the value of H that gives the minimum peak surface field does not necessarily give the maximum shunt impedance.

Surface Electric Field

The electric field of the fundamental accelerating mode of a spoke cavity is 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. Again the optimization of the spoke aperture has been discussed elsewhere [4]. Here we will look at the parameter in Figure 1 identified as H as well as how the spoke aperture dimensions affect the shunt impedance.

The parameter H changes the overall length of the cavity, but does not change the iris-to-iris distance. In figure 3 it is clear that as this parameter increases, the normalized surface magnetic field decreases. The opposite is actually true for the normalized electric field as can be seen in figure 4.

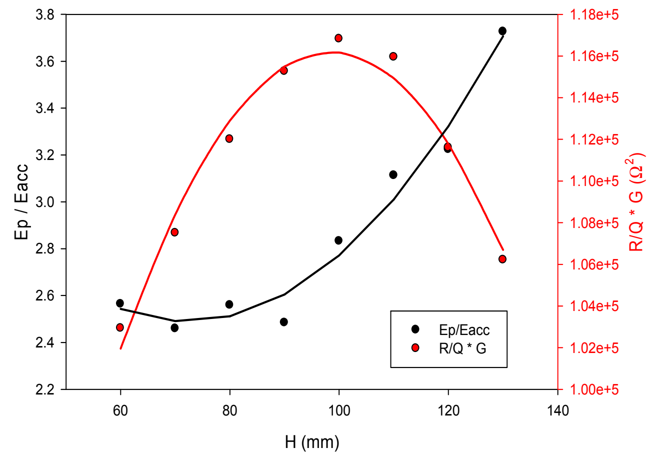

Figure 4: Normalized electric fields and R/Q*G vs. the parameter H.

In minimizing the normalized electric field, the spoke aperture region is very influential. It can be seen in figures 4 and 5 that the minimum normalized electric field does not coincide with the dimensions which produce the highest shunt impedance.

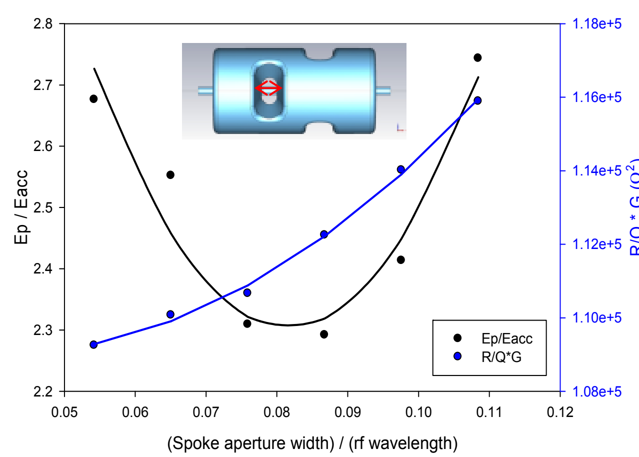

Figure 5: Normalized electric fields and R/Q*G vs. the spoke aperture width normalized to the rf wavelength.

Depending on the application, some compromise in the peak fields may have to be made in order to accommodate higher shunt impedance. The physical dimensions are presented in in table 1 and the rf properties we have simulated thus far for the 325 MHz, β_0 = 1 cavity are given in table 2.

Table 1: Physical Dimensions, 325 MHz two-spoke cavity

Parameter	**$\beta_0 = 1.0$**	**Units**
Cavity diameter	644	mm
Iris-to-iris length	1179	mm
Cavity length	1371	mm
Aperture diameter	60	mm

Table 2: RF parameters, 325 MHz two-spoke cavity

Parameter	**$\beta_0 = 1.0$**	**Units**
Frequency of 0 mode	325	MHz
R/Q	621	Ω
Geometrical factor	188	Ω
E_p / E_{acc}	2.28	
B_p / E_{acc}	5.34	mT/(MV/m)
B_p / E_p	2.34	mT/(MV/m)
Energy Content	0.66	J

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

HOM PROPERTIES

The mode types can be classified as accelerating, deflecting, or TE-type (meaning a strong H_z field component along the beam axis and negligible transverse electric field). If we define the longitudinal direction (that which the beam propagates in) as *z*, then one of the spokes is oriented parallel to the x-axis, while the other is oriented parallel to the y-axis. Deflection occurs in both the *x* and *y* directions because the fields throughout the cavity are not strictly in either the x- or y-directions but rather contain components in both. An example of this can be seen in figure 6.

Table 3: Two-spoke cavity modes for $\beta_0 = 1$

Mode type	**325 MHz Cavity Frequency (MHz)**
Accelerating	325, 328.3, 352, 422, 455.6, 536, 565, 623.7, 624.5, 692, 692.8
Deflecting	402.5*, 469*, 481*, 545.7*, 584.6*, 587, 599, 604*, 611.5*, 615.8, 646.5*, 658
TE-Type	626.5, 700
*indicates degenerate modes	

The electric field profiles for the x- and y- components (along the beam line) for the first degenerate deflecting modes (402.5 MHz) are shown. In this example, the x-component of the first in the pair (M4) is the reflection about the y-axis of the y-component of the second in the pair (M5). Additionally, the y-component on M4 is a reflection about the y- and x-axis of the x-component of M5.

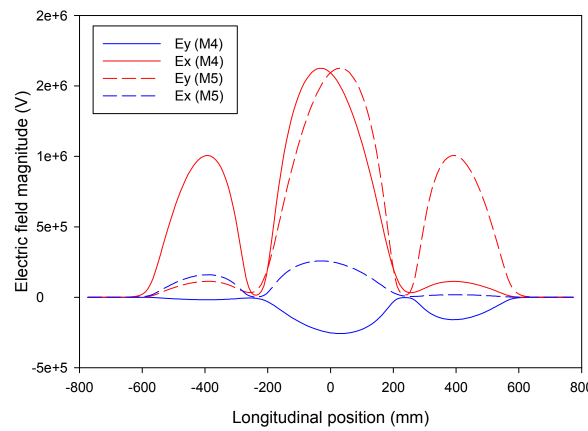

Figure 6: Transverse electric field profiles for the first degenerate pair of deflecting modes (M4 and M5).

Table 3 is a summary of the HOM frequencies and mode-types for modes up to about $2f_0$.

CONCLUSION

The optimization for high-β_0 spoke cavities is ongoing. A great deal of investigation has been done to minimize the surface electric and magnetic fields for multiple frequency, high-β_0 spoke cavities, some of which have been reported on previously [3, 4]. We are now refining our studies in order to maximize the shunt impedance while sacrificing as little as possible in surface fields. In addition, the HOMs of the β_0 = 1, 325 MHz two-spoke cavity are currently being investigated in detail.

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