ISBN: 978-3-95450-217-2 doi:10.18429/JACoW-ERL2019-WEPNEC14

ELECTROMAGNETIC DESIGN OF A SUPERCONDUCTING DUAL AXIS SPOKE CAVITY*

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Abstract

Dual axis superconducting spoke cavity for Energy Recovery Linac application is proposed. Conceptual design of the cavity is shown and preliminary optimizations of the proposed structure have been carried out to minimize the ratio of the peak magnetic and electric fields to the accelerating voltage. The new design and future work are discussed.

INTRODUCTION

In order for the ERL based sources of coherent THz and X-ray radiation to be widely accepted a truly compact (10 m^3), high average current ERLs are required. The demand for the compactness and efficiency can be satisfied by superconducting RF Energy Recovery Linear accelerators (SRF ERL).

The application of two-axis cavity made of identical elliptical shaped RF superconducting accelerating cells for the ERLs applications was proposed by Noguchi and Kako in 2003 [1] and was revisited by Wang, Noonan, and Lewellen in 2007 [2, 3]. The advantage of the asymmetric dual axis system to localise HOMs was only recently realised [4-6] and it was suggested to use for a number of the ERL based applications.

The spoke cavity, originally invented for acceleration of ions and protons, can be used for electron acceleration and there is a growing interest in applications of the multispoke cavities [7]. In this paper, we present the conceptual design of the dual axis asymmetric spoke cavity, optimizations of the cavity shape and preliminary results of the cavity studies. The attractive features of RF superconducting spoke cavities include: 1) the operating frequency of the spoke cavity mainly depends on the spoke length; 2) high cavity stiffness reduces the fluctuation of the cavity resonant frequency due to microphonics; 3) the minimisation of the frequency fluctuations can decrease the required RF power and soften the tolerances required for the construction of the HP input coupler. The spoke cavity is compact as compared with conventional elliptical cavity and if the outer size of a spoke cavity is similar to that of the elliptical cavity, the operating frequency of the spoke cavity is nearly half of that the elliptical cavity. There are a number of advantages of using the low frequency including possibility of utilization of the solid-state power sources as well as operation at higher 4.2 K temperature. Cell coupling of the spoke cavity is stronger than that of elliptical cavity and higher coupling coefficient means robustness with respect to the manufacturing inaccuracy and higher mechanical stability. The fields on the outer surface of a spoke cavities can be relatively small allowing for both the fundamental power coupler and higher-order mode couplers to be located on the outer surface rather than on the beam line. This means better "packing" as couplers are on outer conductor. We note that the tuning of a spoke cavity is complex and demonstration of the ideal design is outside the scope of this work. The aim of this paper is to demonstrate conceptual design with the fields comparable to those observed for a single axis spoke cavity. We focus on a several concepts of the dual axis spoke cavity design and discussion of the advantages and disadvantages of the structures. The schematic diagrams showing merging of the two cavities into the dual axis spoke structure is presented on Fig. 1.

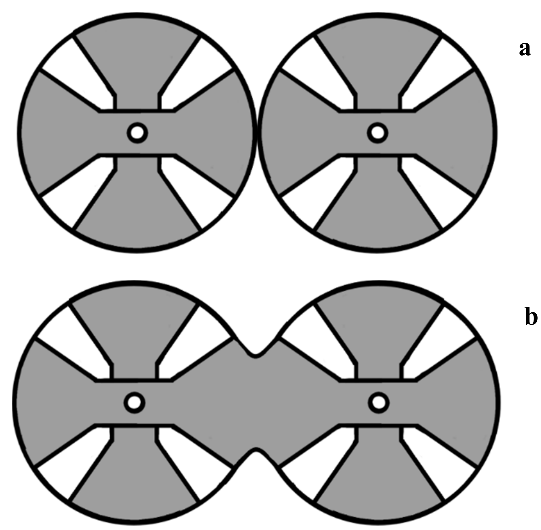

Figure 1: Schematic illustration of observing the dual axis spoke cavity via merging of two cavities (a) before merging and (b) after merging.

TUNING PROCESS

High surface fields in superconducting cavities are highly undesirable because of the detrimental effects on the cavity and ERL performance. At high surface magnetic fields, quenching can occur, and high surface electric fields can cause electron field emission and RF breakdown. As a result, when comparing the performance of the cavities, normalized surface fields are often discussed.

Spoke cavities have a large number of geometric parameters which often influence RF properties. The cavity optimization, therefore is multi-parametric process with a large parameter space to be explored. As a result, the tuning of the cavity to satisfy many parameters takes place in several stages.

* The reported study was funded by RFBR according to the research project 18-302-00990

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Stage 1: Single Axis Spoke Cavity

In order to get initial geometrical parameters of the structure the tuning of a single period, single axis spoke cavity (Fig. 1a) has to be performed. In Fig. 2a the cell tuned. to frequency of 325 MHz is shown. One notes that at this frequency the solid-state RF power supplies are now available. Spoke parameters were optimized in order to achieve E_s/E_a and B_s/E_a values as in [7]. Distribution of electric and magnetic field on the cavity surface are presented in Figs. 2b and 2c. Electrodynamic characteristics of this structure are presented in Table 1.

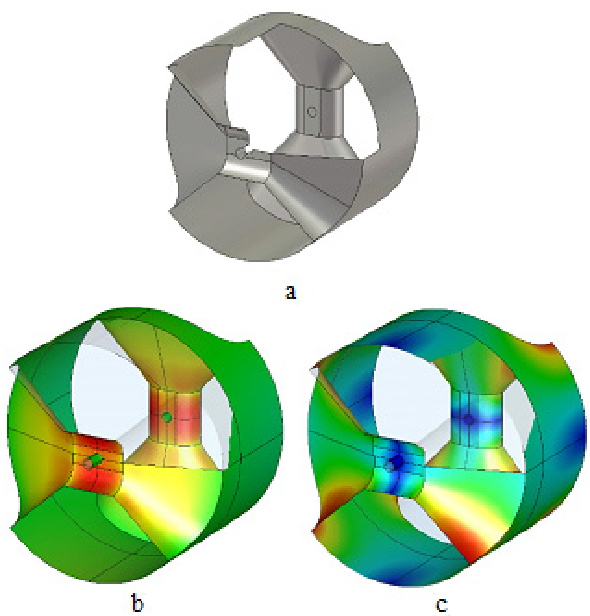

Figure 2: Single axis spoke cavity (a); distribution of electric (b) and magnetic (c) field on the cavity surface.

Stage 2: Bridge Region

The second goal was to tune the bridge region of the structure i.e. the region where the two cavities are merged. Distribution of the electric and magnetic fields on the cavity surfaces are presented on Figs. 3a and 3b.

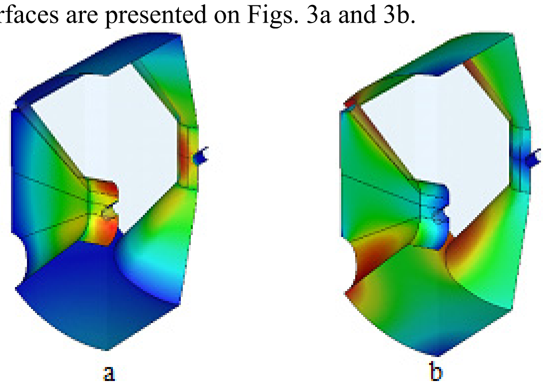

Figure 3: Distribution of electric (a) and magnetic (b) field on the cavity surface.

We note that the operating frequency of the merged structure is 3 MHz different from the initial structure but this can be compensated by changing geometry of the base of the spokes i.e. possible minor alteration without change of the main geometry. Electrodynamic characteristics of this structure are presented in Table 1.

Stage 3: Single Period of Dual Axis Spoke Cavity

The single axis spoke cavity and bridge region were connected to form a single period dual axis spoke cavity. The distributions of electric and magnetic fields on the cavity surfaces are presented on Figs. 4a and 4b.

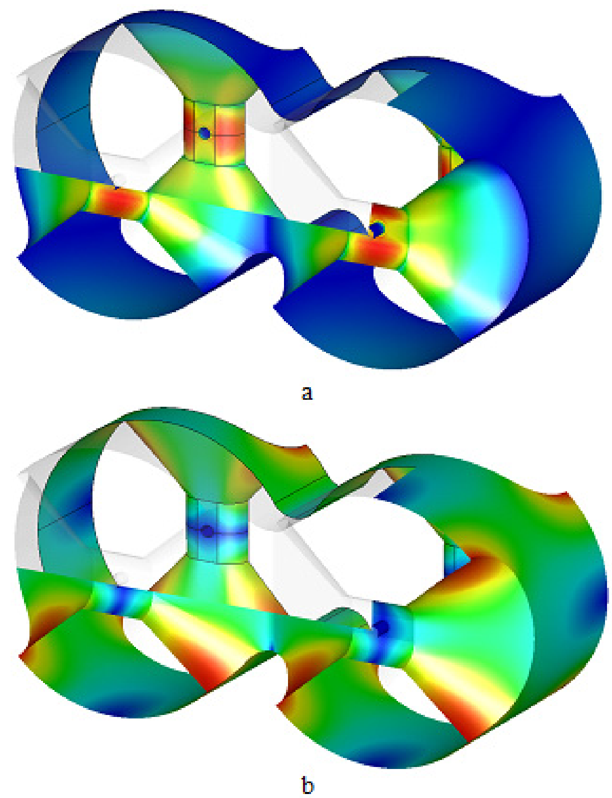

Figure 4: Distribution of the electric (a) and magnetic (b) fields on the cavity surfaces.

The EM characteristics of this structure are presented in Table 1.

Table 1: Electromagnetic (EM) Characteristics of the Single Cell Spoke Cavity, Bridge Region and the Single Period of Dual Axis Spoke Cavity

EDC	Single	Bridge	Dual
f, MHz	325	322.88	324.492
R/Q, Ohm	207.7	208.7	103.64
Es/Ea	2.84	2.84	2.81
Bs/Ea, mT/MV/m	7.82	7.85	7.78
V^*, MB	6.5e5	6.5e5	4.6e5

*At stored energy J = 1 W

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It can be noted that E_s/E_a and B_s/E_a are almost the same for the single and dual axis spoke cavities.

Stage 4: End Cavities Tuning

After merging the sections, the tuning of the end cavity cells (Fig. 5) has been performed.

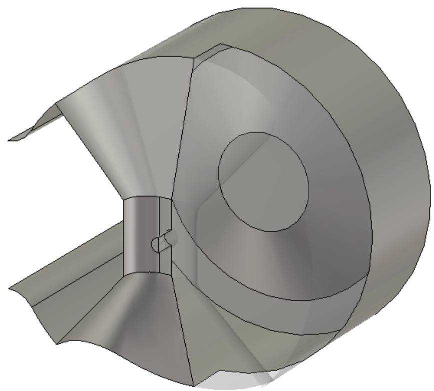

Figure 5: The end cell of the dual axis spoke cavity.

The EM characteristics of this structure are presented in Table 2.

Table 2: Electrodynamic Characteristics of End Cell of Dual Axis Spoke Cavity

Parameter	End cell
f, MHz	326.55
R/Q, Ohm	235.1
Es/Ea	2.69
Bs/Ea, mT/MV/m	6.63
V*, MB	6.9e5

*At stored energy J = 1 W

Stage 5: Final Assembly

Finally, to construct the cavity all the parts have been assembled (Fig. 6).

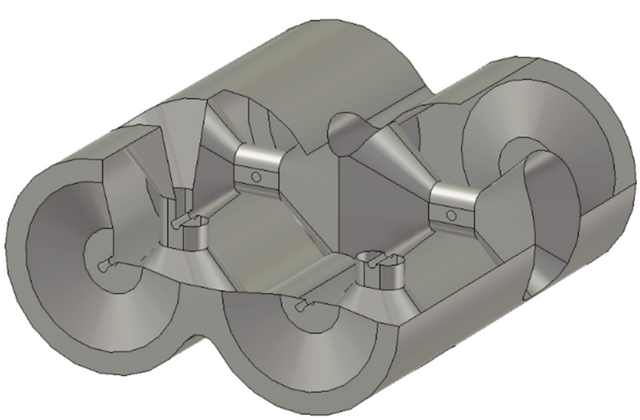

Figure 6: Dual axis spoke cavity.

The contour plots of the electric (a) and magnetic (b) fields in the dual axis spoke cavity are presented in Fig. 7.

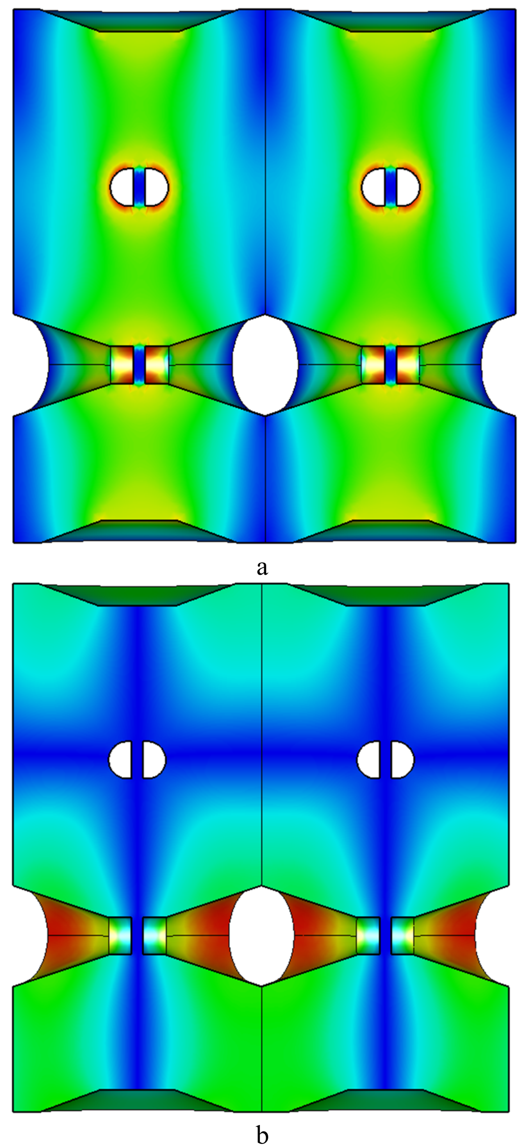

Figure 7: The contour plots illustrating the distribution of electric (a) and magnetic (b) field in dual axis spoke cavity.

The distributions of the electric fields on the both axis of the structure are presented on the Fig. 8.

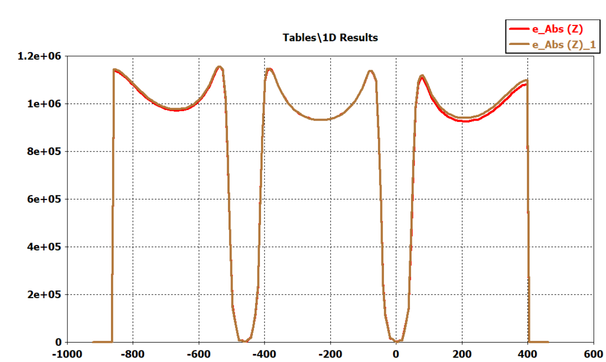

Figure 8: The distributions of the electric fields on the both axis of the structure.

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The EM characteristics of the assembled cavity are presented in the Table 3:

Table 3: The EM Characteristics of the Cavity

Parameter	**Full cavity**
f, MHz	326.73
R/Q, Ohm	336.21
Es/Ea	2.82
Bs/Ea, mT/MV/m	7.38
V^*, MB	8.3e5
k_{cc}, %	5.8
*At stored energy J = 1 W	

CONCLUSION

The concept of the dual axis spoke cavity is presented and the steps of its optimizations are shown. The cavity design is complex and requires gradual optimizations of all the parts. During the optimization the values of the E_s/E_a and B_s/E_a has been achieved to be almost the same as for a conventional single axis spoke cavity.

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