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OPTIMIZATION OF DUAL AXIS ASYMMETRIC CAVITY FOR ENERGY RECOVERY LINAC

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Abstract

Optimization of the dual axis asymmetric cavity was performed to minimize the ratio of the peak magnetic and electric fields values to the accelerating voltage, to increase the distance between operating and neighbouring modes as well as to reduce the manufacturing cost of the cavity. To reach the goals several solutions have been suggested bringing the ratios to the acceptable values and leading to simplification of the manufacturing of the structure.

INTRODUCTION

Conceptual design and preliminary RF studies of dual-axis asymmetric RF cavities for energy recovery LINAC has been recently carried out at Oxford and JLab [1-5]. The concept of using two different axes for acceleration and deceleration was known [6,7] but it is only recently the use of asymmetric configuration for acceleration and deceleration of the beam to isolate higher order modes (HOMs) excited in different sections has been suggested [4,8,9]. The objectives were to confine HOMs excited at each pass to either of the axis reducing the feedback between accelerating and decelerating beams and thus increasing BBU start current aiming at creating ERL capable of driving electron beam with an average current above 1 Ampere. The preliminary RF studies at JLab of a single cell dual axis SCRF cavity [1-3] demonstrated very promising results while at Oxford the theoretical and preliminary experimental studies of dual-axis 7 cell cavity had been carried out [4,5].

In this paper we present the results of the theoretical studies carried out to optimise the cavity design and improve the understanding of the cavity parameters on its performance. The overall aim of these studies is to move from the conceptual design to technical drawings enabling the next step – manufacturing and test of SCRF cavity.

ORIGINAL DESIGN OF THE CAVITY AND CHALLENGES

In Fig. 1 the schematic of the original structure made from tesla-type (TT) cells on both axis is presented. The cells on one axis are slightly different than on another. We denote this structure as TT&TT. Recently it was recognised that one of the issues is high picks of the electric (E_p) and magnetic (B_p) fields on the surface (subscript p) of the resonant cell (see Fig. 1), frequency proximity of operating f_0 and nearest parasitic f_p mode with $\Delta f = 0.505$ MHz (Table 1) in pass band and high probability of multipacting discharges due to flat surfaces of the coupling cell.

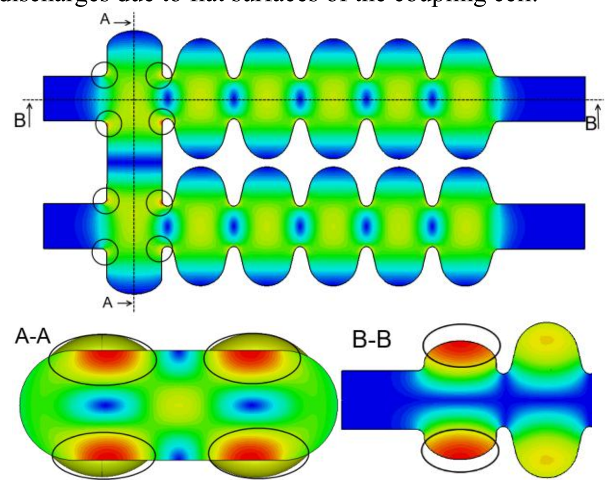

Figure 1: Contour plots of electric (top figure) and magnetic (bottom figure) fields showing the high intensity fields on the surface of the bridge cell.

First we looked at alternative to tesla type (TT) cells. It was suggested that low-loss (LL) cells [10-11] might be a good alternative as they were originally designed to allow high current transportation [11-12] and complete substitution of TT cells with the low-loss cells has been carried out. The substitution led to increase of the field on the surface of the bridge, the distance between modes did not change and the operating field amplitude along the axes became lower. As a result the overall field ratios i.e. field on the surface to the accelerating field on the axis (E_a) have increased $E_p/E_a = 3.22$ and $B_p/E_a = 7.12$ by nearly 20% reaching very high values. Taking this into account the use of solely LL-cells was not persuaded further.

In order to simplify the manufacturing of the structure by reducing the number of forms that are necessary for the machining it was proposed to use a combination of different types of cells (Fig. 2): TT-cells along one axis and LL-cells along second axis (TT&LL). Availability of the forms to stamp the parts, gained experience of making such cells assures relative easiness and quick manufacturing and testing the cells. These features allow minimisation of the cost and research/application risks.

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The field structure of the operating mode along the axes (Fig. 2) are shown. We note that the frequency of the operating mode (Table 1) as well as its structure did not change while the distance between the modes increased by 0.1MHz to 0.6MHz i.e. by 20%. The fields ratios were also improved as compared with the original design to E_p/E_a =2.77 and B_p/E_a =6.1 (Table 1).

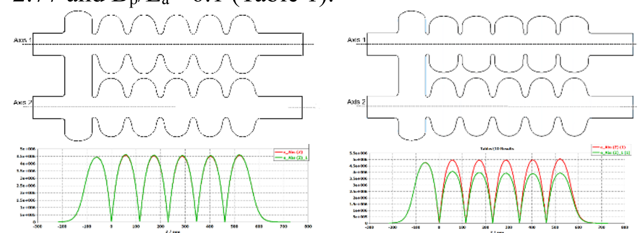

Figure 2: Schematic of TT&TT (left) and TT&LL (right) structures (top) and E_z field distribution along both axis (bottom).

Form Fig. 2 it can be seen that though the operating modes field amplitudes are flat along both axes, the field amplitudes on each axis is now different. This feature can be beneficial for energy recovery. For example, the injected beam is accelerated along the axis with LL-cells. In this case the beam dynamic is less sensitive to beam trajectory deviation from the centre meaning that for the same transvers displacement the transverse kick received by the beam due to HOMs generated will be smaller, while decelerating the beam along the section combined from TT-cells and applying high amplitude field allows improving the efficiency of the energy recuperation. This may also bring the energy of the beam at the dump to below the energy of the injected beam significantly reducing the load on the beam collector.

Table 1: Electordynamic Characteristics for Different Sets of Asymmetric Dual Axis Structures

	TT& TT	TT& LL	TT&L L (TT)	LL&TT (LL)
f_0, GHz	1.3	1.3	1.3	1.3
f_n, GHz	1.2995	1.2994	1.2994	1.2993
E_p/E_a	2.85	2.77	2.78	2.85
B_p/E_a, mT/MV/m	6.23	6.1	6.13	6.35
R/Q_1, Ohm	330	395	380	381
R/Q_2, Ohm	335	277	289	291
V_{z1}, MV*	1.63	1.79	1.76	1.76
V_{z2}, MV*	1.65	1.50	1.53	1.54
R/Q_1, Ohm	249	188	203	211
R/Q_2, Ohm	241	305	281	296

*at 1J stored energy

Table 1 compares the parameters of the cavities discussed i.e. original (made only from TT cells) and combined (LL&TT) cavities. The achievements were not as dramatic as expected however the partial improvements of some of the EM parameters stimulated new design studies to improve further the parameters.

In the attempt to increase the separation of the nearest modes and to reduce the number of stamping forms he last cell on one of the axis has been substituted with the cell from the second axis. In Fig. 3 the cavity with such substitutions are shown and the modified cavities indicated as TT& LL(TT) and LL&TT(LL) and their operating modes electric fields distributions along the axes are show (Fig. 3). With such a substitution it is clear that in spite the fact that the fields in the last cells are now matched the amplitudes along the cavity axis are different allowing application of different fields for acceleration and deceleration.

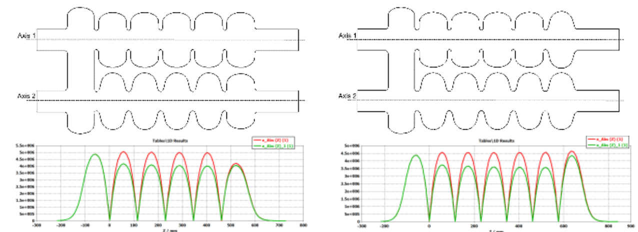

Figure 3: Schematic of TT&LL(LL) (left) and TT&LL(TT) (right) structures (top) and E_z field distribution along both axis (bottom).

The parameters for these structures are shown in the Table 2. One notes that the best field ratios and R/Q observed for the TT&LL(TT) structure. However one may point out that these improvements of the fields ratios are still relatively modest and the fields on the surface are still high E_p/E_a =2.78 and B_p/E_a =6.1 mT/(MV/m) promoting multipacting and further reduction of these ratios is important to assure the cavity reliable operation. To reduce it the optimisation of the geometry of the coupling bridge cell similar to one carried out at JLab [1-3] has been conducted.

OPTIMISATION OF THE BRIDGE CAVITY

To couple both accelerating and decelerating sections the racetrack-like resonant cell (bridge) has been proposed. The cavity design was to simplify the manufacturing of the cavity, to demonstrate the validity of the original concept while the detailed studies of the system needed to make technical design and drawing to construct the operating SCRF cavity were outside the original scope. As soon as the initial task was successfully completed and new comprehensive studies including the field strength on the surfaces of the bridge cell and the uniformity of the transverse field on both axis (to avoid the possible kicks due to field gradient) were initiated. The work strongly benefited from studies carried out at JLab [1-3].

The bridge cell optimisation goals were to: decrease the transverse field components on beam axis; reduce amplitude of magnetic and electric fields on the surface of the cell and further separate the operating mode from its neighbours. To achieve these the following steps to change the original cavity coupling cell (Fig. 4) were taken: the parameters which define the geometry of the structure have been varied and in particular the radii of the cell; the waist in the middle of the bridge has been made to push the magnetic field out while allowing to maintain the frequency position of the cavity operating mode unchanged; the "flat"

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parts of the original bridge cell which are difficult to manufacture from niobium using conventional technology and would potentially promote and increase the probability of the development of the multipacting discharges were removed from the final design and substituted with the curved surfaces. After the optimisations carried out the bridge cell design is similar to that of JLab cavity design [1-3]. In Fig. 4 final view of the bridge cell and iteration steps from initial bridge to the final design are shown.

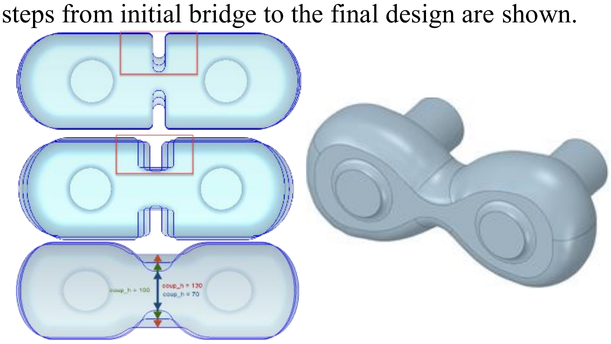

Figure 4: Iteration steps from initial bridge to the final design (left) and final design (right).

The carried out optimisations were significant and led to remarkable improvements of the cavity performance (Table 2) and resulted overall in the reduction of the fields on the surface electric field by 20% and magnetic field by 30% bringing them to conventional and "safe" values which are accepted for the conventional accelerators.

Table 2: RF Characteristics for Different Sets of Asymmetric Dual Axis Structures With New Bridge

	TT&TT	TT&LL (TT)	LL&TT (LL)
f_0, GHz	1.3	1.3	1.3
f_n, GHz	1.29954	1.29942	1.29938
E_p/E_a	2.33	2.28	2.57
B_p/E_a ,mT/MV/m	4.54	4.47	4.63
R/Q_1, Ohm	328	406	385
R/Q_2, Ohm	332	273	287
V_{z1}, MV*	1.65	1.82	1.78
V_{z2}, MV*	1.66	1.49	1.54
R/Q_{1n}, Ohm	263	196	222
R/Q_{2n}, Ohm	254	338	325

*at 1J stored energy

We note that the distance between the operating and the neighbouring modes as well as the difference between (R/Q)s of the modes on the first and second axis are defined by the cells on each axis and namely this underlines the importance of optimisation both the bridge cell and the cell along accelerating and decelerating sections.

CONCLUSION

In this paper we discuss the steps taken to optimise the cavity presenting and discussing the cavity design and performance before and after optimisation. The mode structures were analysed and their R/Q parameters were compared. The final design of the cavity is shown and preparation of the technical drawings to manufacture the SCRF cavity is under development.

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