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Design of coupler for the NSLS-II storage ring superconducting RF cavity

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DESIGN OF COUPLER FOR THE NSLS-II STORAGE RING SUPERCONDUCTING RF CAVITY

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Abstract

NSLS-II is a 3GeV, 500mA, high brightness, 1 MW beam power synchrotron facility that is designed with four superconducting cavities working at 499.68 MHz. To operate the cavities in over-damped coupling condition, an External Quality Factor (Qext) of ~ 65000 is required. We have modified the existing coupler for the CESR-B cavity which has a Qext of ~ 200,000 to meet the requirements of NSLS-II. CESR-B cavity has an aperture coupler with a coupler "tongue" connecting the cavity to the waveguide. We have optimized the length, width and thickness of the "tongue" as well as the width of the aperture to increase the coupling using the three dimensional electromagnetic field solver, HFSS. Several possible designs will be presented.

INTRODUCTION

One of the possible candidates for the SRF cavities we are considering for the National Synchrotron Light Source - II (NSLS-II) project is a cavity designed by Cornell University and manufactured by ACCEL (Research Instruments). This cavity is called CESR-B cavity. This is an open cavity with the two ends connected to the beam pipe. RF power is supplied to the cavity through a rectangular waveguide connected to the beam pipe via an RF coupler on one side of the cavity [1]. Fig. 1 below shows the cavity, beam tubes and cavity coupler-waveguide assembly in the top view. Fig.1 does not show "flutes" in the beam tube which are present in the actual module. As we are interested only in the fundamental mode, we can neglect the flutes to simplify the model.

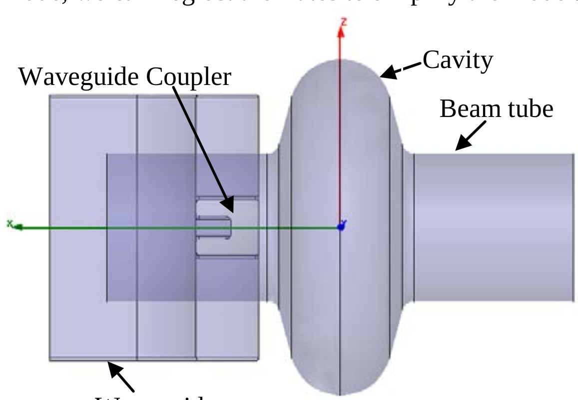

Fig.1 *Top view of a CESR-B cavity, beam tube, coupler and waveguide assembly*

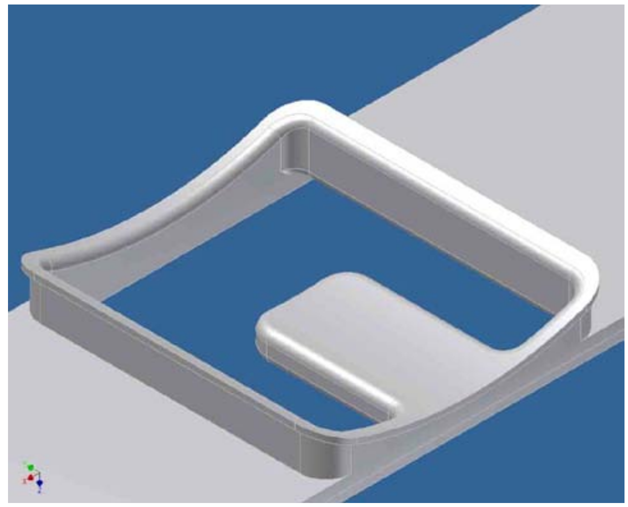

Fig. 2 *Coupler tongue inside coupler box at the top end of the waveguide assembly which opens into the beam tube.*

Fig. 2 shows how the coupler tongue is constructed inside the coupler box. At the top of the waveguide that connects to the cavity beam pipe, the waveguide is covered with a flange. At the centre of the flange, an opening is made and a coupler box is constructed such that the top of the coupler box is flush with the beam tube and opens into the beam tube. The tongue is a rectangular box whose top face is a convex surface and whose radius is equal to the radius of the beam tube. In other words, the top face of the tongue coincides with the inner surface of the part of the beam tube that is removed to attach the coupler box. The tongue is connected to the coupler box in cantilever fashion as shown. This coupler was first designed by Padamsee's group at Cornell [1]. Later, the CESR-B cavity external Q was calculated by V. Shemelin and S. Belomestnykh using Microwave Studio and Mafia [2].

BENCHMARKING HFSS

The cavity, coupler and waveguide were modelled in HFSS based on the dimensions provided by Cornell. The simulations were run for various lengths of the tongue and compared with the calculated and measured results provided by ACCEL (Research Instruments). The maximum angle deviation of the mesh elements was fixed at 3 degrees with curvilinear elements. Maximum delta frequency for convergence was chosen to be 2%. All the surfaces were assumed to be perfect conductors. The waveguide was terminated in a matching impedance corresponding to the waveguide impedance at 500 MHz (522.117 Ω). The Q_{ext} values obtained from the simulations are shown in Fig. 3 as green diamond shapes superimposed over the simulation results from ACCEL for changing tongue length [3]. The red horizontal lines correspond to the average measured Q_{ext} for the tongue lengths of the Cornell design and Shanghai Synchrotron Radiation Facility (SSRF) design. The difference between Cornell and SSRF design is only in the length of the coupler "tongue". For Cornell design the length is 57mm and for SSRF it is 66mm. We can see that for the Cornell design, the Q_{ext} obtained in our simulations using HFSS is closer to the average measured results. The red horizontal lines in Fig. 3 represent the average measured Q_{ext} for the Cornell design and SSRF designs.

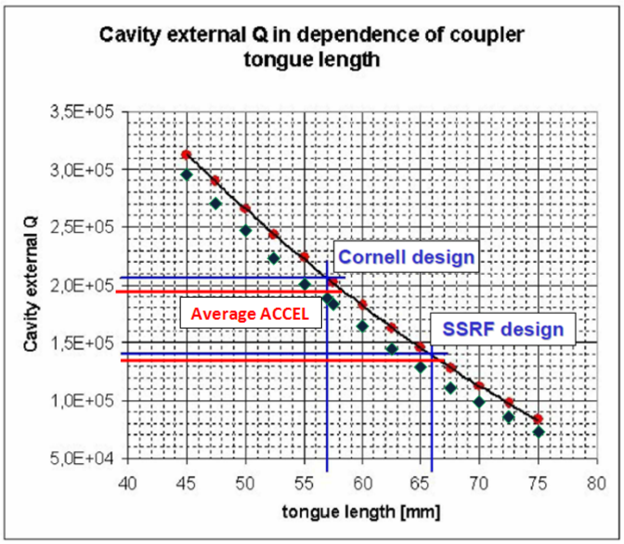

Fig. 3 *Cavity external Q as predicted by HFSS (green diamonds) for increase in length of coupler tongue shown along with the simulation results provided by ACCEL*

DESIGN OF COUPLER TO LOWER THE Q_{EXT} TO 65000

We have conducted several simulation studies to find effective ways of increasing RF coupling between the waveguide and cavity by changing the shape and dimensions of the tongue. We have found that the Q_{ext} can be reduced by increasing the length of the tongue (as can be seen from Fig.3), increasing the width of the tongue or by reducing the thickness of the tongue. We have also found that the Q_{ext} can also be reduced by moving the coupler and waveguide assembly closer to the cavity. Three possible ways of achieving the required Q_{ext} are tabulated in the table below along with the Cornell and SSRF designs of the coupler.

Both Cornell and SSRF designs have an aperture width of 91mm with the tongue width of 37mm. One way of achieving the required Q_{ext} is by changing the shape of the tongue from rectangular cross section to a wedge shaped cross section as shown in the Fig. 4. Fig. 4 also shows the electric field distribution in a plane cutting across the middle of the tongue in parallel to the axis of the cavity. This can be achieved by increasing the width of the front end to 70mm and back end of the tongue to 53mm. Also, the width of the aperture is increased to 100mm.

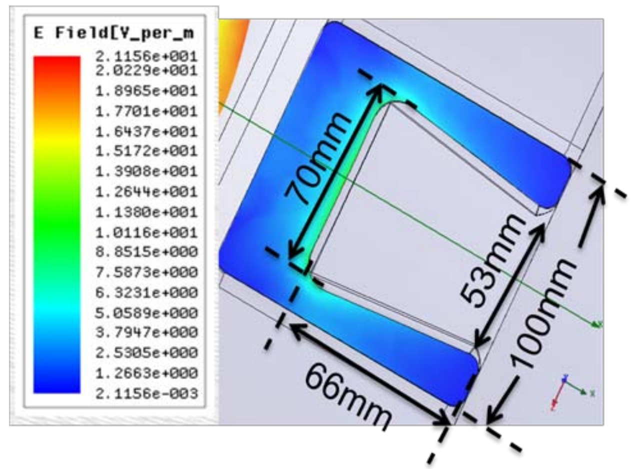

Fig. 4 *Wedge shaped tongue to increase coupling. The RF electric field is normalized to 2.5V when integrated along the axis of the cavity.*

We have also found another geometry for the coupler that can achieve the required Q_{ext} ~ 65000 by using a rectangular cross section tongue similar to Cornell and SSRF design but with increased width of the aperture and a wider tongue as shown in Fig. 5. We have aimed to keep the length of the tongue to be no more than the SSRF design in order to keep the RF electric field around the front of the tongue to be well below vacuum break down levels.

There is another interesting way that can increase the coupling between the waveguide and cavity if the rectangular waveguide is depressed along the broad-side as shown in Fig. 6. This idea was suggested by Mark deJong of Canadian Light Source [4]. Such a depression in the waveguide acts effectively as a single stub tuner. In order to minimize the effects of vacuum break down and multipacting, the "single stub tuner" should be smoothed all over, and we shall call it a "smooth stub". For the coupler tongue length equal to 66mm (the same length as SSRF design) and dimensions of the smooth stub shown in the figure, a Q_{ext} of ~61000 can be obtained.

We have chosen a rectangular shaped tongue coupler shown in Fig. 5 for the SRF cavity in the NSLS-II project as it resembles (in shape) existing couplers at other facilities like Cornell and SSRF. A rectangular shaped coupler minimizes perturbations in RF fields compared to other shapes of the coupler considered which can reduce the risk of multipating.

In Table 1 we have tabulated some of our results for the various couplers considered. The last two columns in the table are the peak potential difference (V_g) between the tongue and the aperture wall and the RF losses in the coupler region ($C_{w,loss}$), that includes the surface of the tongue and the aperture wall, respectively, under the condition that the electric field integrated along the length of the axis of the cavity is 2.5 MV. For the NSLS-II design we have considered, it can be seen that the coupler gap voltage (V_g) is comparable to the case of Cornell and SSRF cases and is well within vacuum break down voltages. The RF power loss in the coupler walls ($C_{w,loss}$) is also low enough for the helium cooling system to handle.

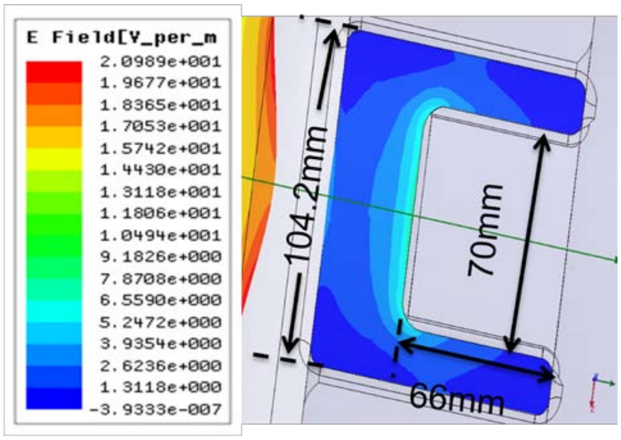

Fig. 5 *Rectangular shaped tongue with increased tongue width and increased aperture width to increase coupling. The RF electric field is normalized to 2.5V when integrated along the axis of the cavity.*

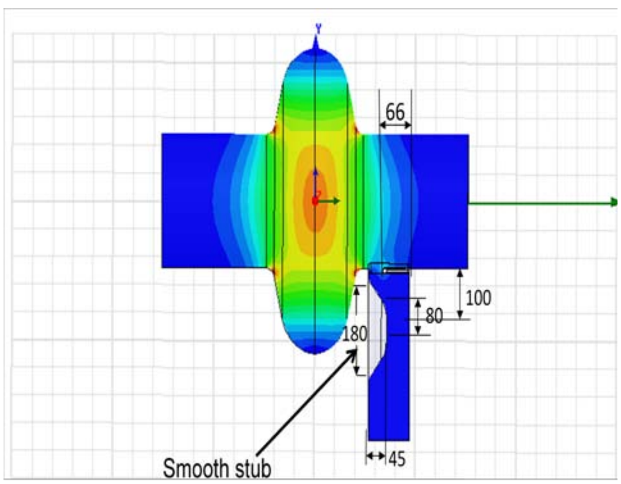

Fig. 6 *A "smooth stub" in the waveguide can also lead to increase in coupling. Dimensions shown in mm.*

VERIFICATION OF RESULTS WITH CST MICROWAVE STUDIO

We have verified the coupler design shown in Fig. 5 using CST Microwave Studio. The Q_{ext} results closely correspond to those obtained using HFSS. The Q_{ext} predicted by HFSS is 65,190 while CST microwave studio predicts 65,028. We have used hexahedral mesh type with 40 lines per wavelength in the Microwave Studio simulation using the Eigen mode solver for the calculations..

Tongue type	**L**	**W_b**	**W_f**	**t**	**b**	**Q_{ext} (10^3)**	**V_g (kV)**	**$C_{w,loss}$ mW**
Cornell	57	37	37	12	91	225	48.95	13.1
SSRF	66	37	37	12	91	153	59.13	17.9
Wedge	66	53	70	11.9	100	65.7	73.37	41.4
NSLS-II	66	70	70	11.9	104	65.2	72.6	42.3
Smooth stub	66	37	37	12	91	60.8	55.35	19.2

Table 1 *Coupler dimensions for various possible design. All lengths in mm. L, W_b,, W_f and t are the length, width at the back, width of the front and thickness of the tongue respectively. b is the width of the aperture window. V_g is the peak potential difference between the tongue and the aperture wall and $C_{w,loss}$, is the RF loss in the coupler walls for an acceleration voltage of 2.5 MV per cavity*

CONCLUSIONS

We have modified the coupler of the CESR-B cavity to be used in the storage ring at the NSLS-II project using HFSS and verified using CST Microwave Studio. Using a combination of increasing the length and width of the coupler tongue and increasing the width of the aperture, the external Q of the cavity coupler was decreased to ~65000 as required for the design of the NSLS-II storage ring design.

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