ADJUSTABLE INPUT COUPLER DEVELOPMENT FOR SUPERCONDUCTING ACCELERATING CAVITY

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Abstract

The coaxial-type input couplers for Energy Recovery Linac type injector cavity simulation results are presented. These twin devices are to feed superconducting cavity with 2x75 kW RF power in continuous wave regime at 1.3 GHz operating frequency. The cavity external quality factor adjustment is provided. The electrodynamical and thermal simulations were done for the modified coupler able to transmit the RF power up to 2x250 kW. The heat load to cryogenic system was decreased to tolerable level by coupler design optimization.

INTRODUCTION

The upgrade plans of Energy Recovery Linac (ERL) include the boost of injector cavity electromagnetic field strength. This makes the input power coupler to dependably transmit substantially increased RF power from distribution system to accelerating cavity. The RF power increase up to 500 kW in continuous wave regime is challenging. The existing twin coaxial-type coupler was developed for operation at 150 kW power (75kW per each unit) [1,2]. The input power increase for the cavity is not simple scaling task. The existing coaxial input coupler design has physical limits. Further power increase needs the use of new technical solutions.

The most troublesome issue presented by the development of raised performance coupler was to keep the thermal load introduced by it to cryogenic system. The set of numeric codes (Microwave Studio and HFSS) were used to ensure the coupler electrodynamical properties are within certain limits determined by ERL injector design. The coupler matching was done for each design considered while external quality factor adjustment range kept in mind.

To get the data on coupler thermal properties on certain RF power level the simulations were done using ANSYS code supplied with custom-made macros allowing the thermal and electrodynamic problems linking.

Simulated temperature distribution for the coaxial line for the case of 250kW CW power is transferred through coupler designed for 75kW operation It is seen that the bellows especially the “warm” one has the excessive temperature. The long bellows having rather thin walls could hardly provide sufficient heat flow and it causes insufficient bellows middle area cooling. Moreover both the heat conductivity is reduced and the copper resistance increased with temperature growth thus leading to the extra heat generation. At this power level the antenna tip temperature also rises. This could lead to heat flow to cavity cryogenic zone growth due to infrared radiation from antenna tip. The heat loads to different cryogenic zones are too high for cryogenic system.

The bellows overheating could be avoided by another (third) outer bellows added in design as nitrogen-cooled heat sink. But this leads to more complex design. The antenna tip heating could be diminished by making its shaft solid or at least tube shaped with thick walls. As the side effect this will increase the antenna weight and the extra stress to the ceramics appear.

As the result the maximal transferred power for the existing coupler design is limited to 100...150kW CW (200..300kW CW for twin coupler).

SINGLE BELLOWS COUPLER DESIGN

The simulations show that local bellows overheating with power increase is the main issue. For external quality factor adjustment it is enough to have only one bellows allowing the antenna tip movement. The coupler design featuring only one bellows is presented in Fig. 1. According to simulation results this coupler will provide adequate heat loads to cryosystem during the operation. The design is more compact because only one bellows cooling is necessary.

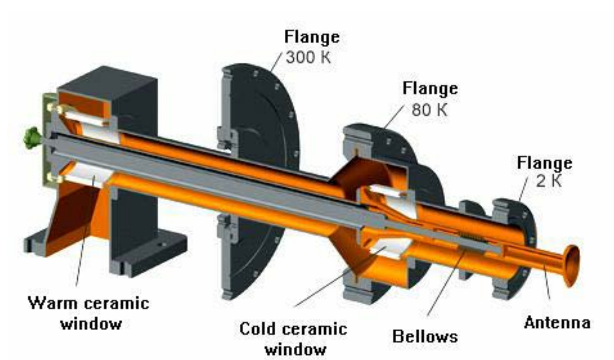

Figure 1: Single bellows coupler.

LOOP-CAPACITIVE COUPLER

The bellows length reduction is possible only for modified antenna. The antenna movement is to be smaller keeping the same Qext factor adjustment range.

Fig. 2 presents the loop-tipped antenna coupler conceptual design. External quality factor value is adjusted by capacitive gap between inner conductor and antenna tip variation. The most preferable way is to use superconducting antenna. It can be made of bulk niobium, or niobium plated stainless steel. This leads to considerable reduction of heat loads to liquid helium area.

The overall inner conductor length is reduced by antenna tip separation. So the heat flow to nitrogen cryogenic zone and ceramic window mechanical stress will be reduced.

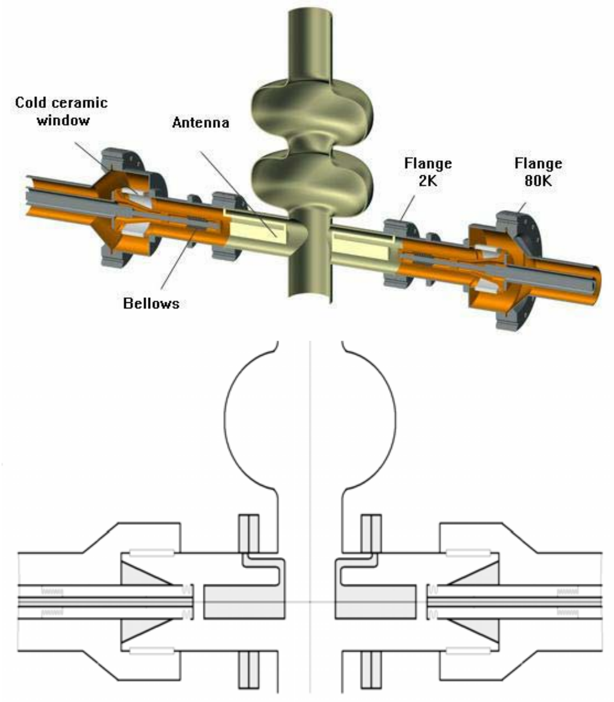

Figure 2: Coupler with capacitive element conceptual design.

External quality factor was calculated using two approaches: first by ANSYS simulation of cavity 3D model and the second by HFSS code in TW regime.

For simulations by ANSYS the special macros was created for model generation and simulation run with electric and magnetic boundaries in reference plane across coaxial line [3]. The simulation resulted in electromagnetic fields values. Special routines were implemented for improving the simulation accuracy.

The coupler simulation results obtained using ANSYS are presented on Fig. 3.

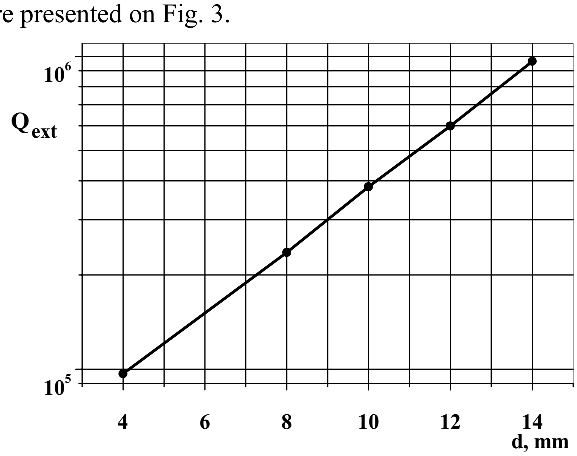

Figure 3: The Q_{ext} dependence on gap width. ANSYS simulation data.

Coupler matching in TW regime and Qext dependence study were done using HFSS code. The 3D model used for simulations included two cell SC cavity and coupler coaxial part ending with loop-shaped antenna. The simulations were done in narrow frequency range close to operating one. Fig. 4 presents the Qext dependence on gap width.

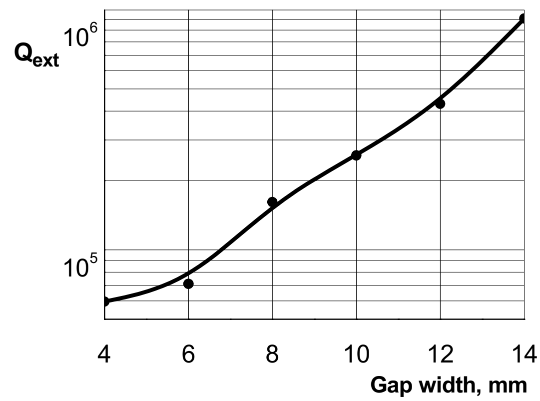

Figure 4: Dependence of Q_{ext} of a twin coupler on the gap width. HFSS data.

The ANSYS code provides more reliable result because this code allows more flexible mesh control being very important for this task.

As it could be seen the external quality factor ten times variation is achieved with 10mm gap width change. This value could be decreased with modified shape antenna. The coupler featuring shorter movement range yielding high Qext adjustment could be designed and manufactured. The movement precision is achievable by fine treaded screw. Travelling range reduction will allow the shorter bellows used thus the entire central conductor assembly will be more rigid and its side play will be substantially lower.

Fig. 5 illustrates the electric field strength distribution in the coupler region.

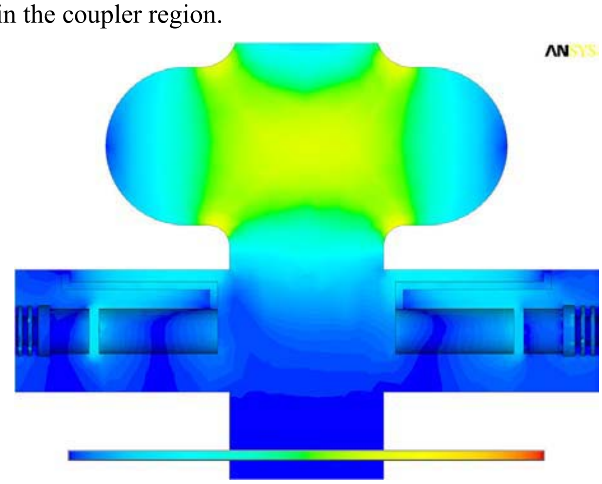

Figure 5: Antenna electric fields distribution.

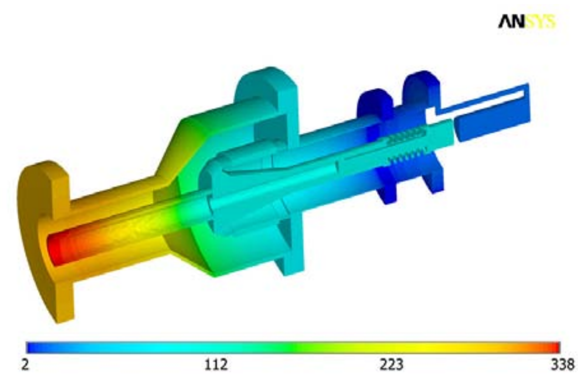

Figure 6: Temperature map of loop-capacitance coupler.

Fig. 6 presents the simulated temperature distribution for the 2x250kW CW power transmitted. The heat flows to cryogenic zones are summarized in Table 1.

Heat flow to the helium cryogenic zone is greater than in previous design. It is caused by losses on antenna surface having direct connection with cavity flange. Minor thermal load to the 4.2K zone variation is caused by changes in coupler design having outer conductor length changed.

Table 1: Heat load caused by coupler feeding 250kW

Cryogenic zone	Existing design	One bellows coupler	Capacitive coupler with loop antenna
Helium, 2K	0.65	0.55	0.79
Helium, 2K	6.6	9.6	10.6
Nitrogen, 80K	355.0	178.7	119.8

TRANSVERSE KICK CALCULATION

The transverse kick caused by field asymmetry could be very severe problem. The simulations show that there is no transverse field components along the cavity axis. Using the method described in [4] the transverse kick values were calculated for different offsets from cavity axis in coupler plane and orthogonal plane.

Fig. 7 presents the real and imaginary part of kick for different offsets.

As it is seen from Figs. the kick value increases for bigger offset and for 5 mm distance from cavity axis is 7% of accelerating field influence. In the plane orthogonal to the coupler coaxial line the real and the imaginary part is the same as in Fig.7.

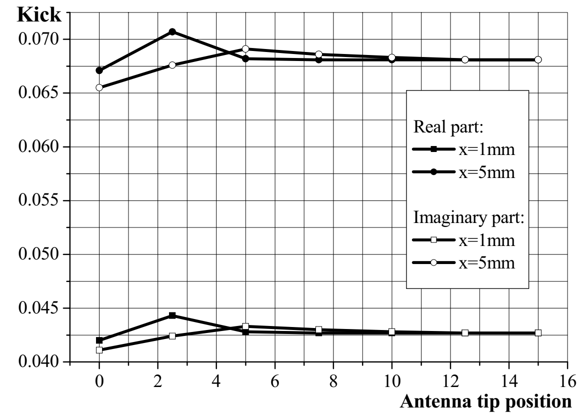

Figure 7: Kick real and imaginary part for different offsets of cavity axis in plane along the coaxial line.

CONCLUSIONS

The existing coupler design for ERL injector cavity confining with respect to transmitted power are evaluated. The elements limiting the coupler thermal performance are determined.

Two ways of coupler performance improvement by coupler design modification are proposed. The first one is mainly based on the existing design with antenna tip unchanged. By eliminating several bellows the heat load to cryogenic system is reduced to acceptable limits. More advantageous is the second coupler design proposed. This coupler has fixed loop shaped antenna tip. External quality factor adjustment in necessary range is provided by relatively small variation of capacitive coupling assembly located in coaxial line area.

The simulations of kick caused by field asymmetry in beamline area was done.

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