INPUT COUPLER DEVELOPMENT FOR SUPERCONDUCTING CAVITY 500KW CW POWER FEED*

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Abstract

The coaxial-type input coupler for Energy Recovery Linac injector cavity simulation results are presented. This device is to feed the superconducting cavity with 150 kW RF power in continuous wave regime at 1.3 GHz operating frequency. The thermal simulation was done for the modified coupler able to transmit the RF power up to 500 kW. The basic coupler design was changed thus lowering the heat load to injector cryogenic system. Coaxial type design with external Q_{ext}-factor adjustment with variable capacitive antenna was considered.

EXISTING COUPLER DESIGN POWER LIMITS

Existing twin coaxial input coupler is designed for 150 kW CW power (75 kW per coupler) [1]. Next stage of the work is to increase input power to 500 kW CW. 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.

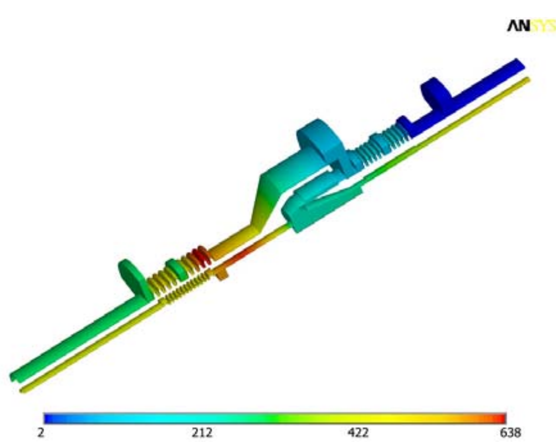

Figure 1: Temperature map of existing design coupler, K.

Fig. 1 shows simulated temperature distribution for the coaxial line for the case of 250 kW CW power is transferred through coupler. The simulation was done using ANSYS code. It is seen that the bellows especially the "warm" ones have 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 presented in Table 1.

Table 1: Existing design coupler heat loads.

Helium, 2 K	0.65 W
Helium, 4.2 K	6.6 W
Nitrogen, 80 K	355.0 W

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..150 kW CW (200..300 kW CW for twin coupler).

SINGLE BELLOWS COUPLER DESIGN

With transmitted power increase the bellows became the performance limiting elements. Nevertheless they could not be excluded from the design because the antenna tip must be movable to provide the external quality factor tuning. The single bellows design is proposed as the optimal way to overcome the problems specified. It is based on the similar one evaluated earlier as concept for TESLA coupler. The only bellows is located in inner conductor in "cold" area. Fig. 2 presents the simulated temperature distribution for the 250 kW CW power transmitted. The heat flows to different cryogenic zones are summarized in Table 2.

This coupler bellows is to be liquid or gas nitrogen cooled during the operation. It can be done by pumping nitrogen from doorknob side or to use coaxial stub located in the area of former "warm" bellows. The other way to decrease bellows temperature is to split it with additional heatsink added in between having low thermal resistance to shaft, as it has been done with outer bellows in current design.

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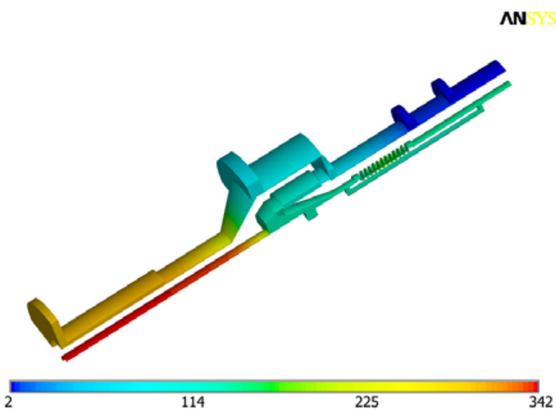

Figure 2: Temperature map of coupler coaxial part with single bellow, K.

Table 2: Single bellows coupler heat loads.

Helium, 2 K	0.55 W
Helium, 4.2 K	9.6 W
Nitrogen, 80 K	178.7 W

The further design improvements are in thermal decoupling optimization between nitrogen and helium cryogenic zones along with the possible bellows position alteration. The coaxial line inner conductor cooling system is also to be studied.

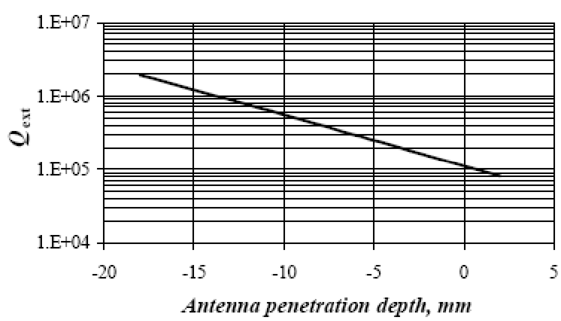

Figure 3: Dependence of Q_{ext} of a single coupler on the penetration of the antenna tip into the cavity beam pipe. The Q_{ext} of a twin coupler is twice as low.

Also, as a possible way to decrease bellows heat loses is to use shorter bellows. But there are strict requirements for external quality adjustment and therefore antenna movement range [2]. This dependence is presented on Fig. 3. Additionally the bellows has limited squeeze and extension ability. Therefore bellows length reduction under certain limit is hardly achievable. Further bellows length diminishing could be done with antenna yielding the same Q_{ext} adjustment range by reduced traveling provided by its shape changed.

LOOP-CAPACITIVE COUPLER

Fig. 4 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 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.

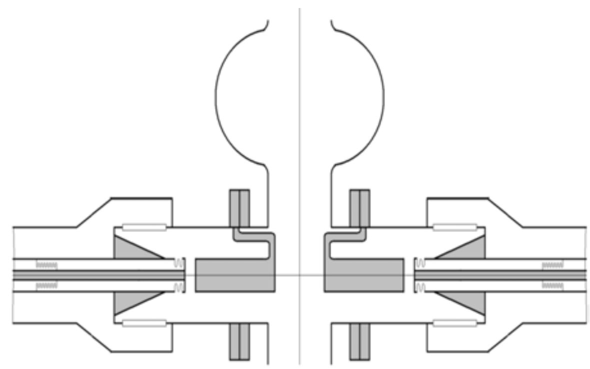

Figure 4: Loop-capacitive coupler design.

The coupler electrodynamical simulation and optimization were done using HFSS code. The external quality factor could be obtained using known formula

$$\frac{1}{Q_L} = \frac{1}{Q_{ext}} + \frac{1}{Q_0}.$$

In case of loss-free cavity unloaded Q_0 is infinite and external Q-factor equals to loaded quality Q_L. Thus external quality factor value could be obtained from reflection on frequency dependence for arbitrary port. The external quality factor dependence on gap width is presented on Fig. 5.

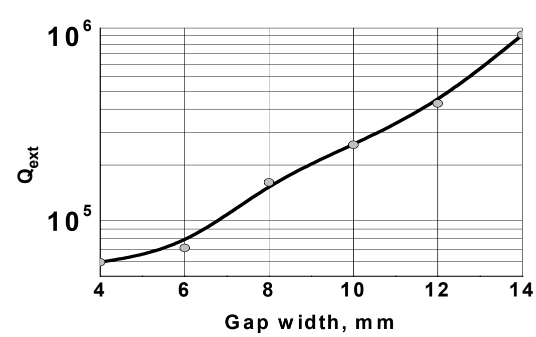

Figure 5: Dependence of Q_{ext} of a twin coupler on the gap width.

As it could be seen the external quality factor ten times variation is achieved with 10 mm gap width change rather

15 mm in existing design. So the bellows could be made 30 percent shorter. The latter value could be lowered with antenna of modified shape. The coupler featuring lowered movement range yielding high Q_{ext} adjustment could be designed and manufactured. The movement precision is achievable by fine treaded screw. Traveling 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.

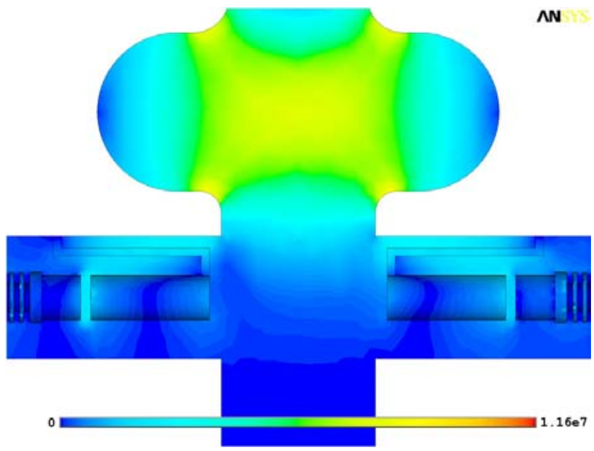

Figure 6: Antenna electric fields distribution.

Fig. 6 shows the electric fields distribution in coupler to cavity transition area. Field strength in antenna part could be lowered by the holder shape optimization. The design with holder connected directly to cavity instead of the flange is possible.

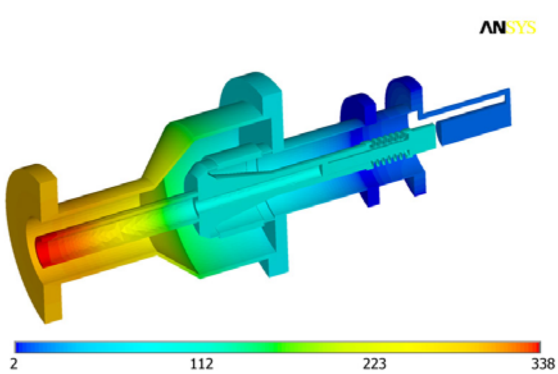

Figure 7: Temperature map of loop-capacitance coupler, K.

Fig. 7 presents the simulated temperature distribution for the 250 kW CW power transmitted. The heat flows to cryogenic zones are summarized in Table 3.

Table 3: Loop-capacitance coupler heat loads.

Helium, 2 K	0.79 W
Helium, 4.2 K	10.6 W
Nitrogen, 80 K	119.8 W

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 4.2 K zone variation is caused by changes in coupler design having outer conductor length changed.

CONCLUSION

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. More appreciable transmitted power increase is achieved by the second coupler design proposed having fixed loop shaped antenna tip and capacitive Q_{ext} tuning assembly.

REFERENCES

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[2] V.Veshcherevich, I.Bazarov, S.Belomestnykh, M.Liepe, H.Padamsee, V.Shemelin, "Input coupler for ERL injector cavities", Presented at the PAC 2003, Portland, OR, May 12–17, 2003.