CAPACITIVE HIGH POWER INPUT COUPLER FOR SUPERCONDUCTING CAVITIES POWER

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Abstract

The results of calculation of 500 kW input coupler for superconducting accelerating cavity. The input coupler is built on base of loop antenna. The input coupler allows us to adjust external Q-factor in range of 10-times.

INTRODUCTION

The first version of 1300 MHz 2×75 kW CW input coupler [1] has been developed for ERL [2]. Another construction of input coupler with one bellows was considered to increase the power up to 2×250 kW CW. This construction allows us to reduce local overheating of the bellows without excessive complication by means of cooling of just one bellows, used for adjusting of coupling coefficient. Following reducing of the heat loss can be achieved by reducing of bellows length and by changing of antenna geometry shape, allowing to have needed external Q-factor range (10-times) at short antenna stroke.

The variant of dual input coupler with loop antenna is shown in Figure 1.

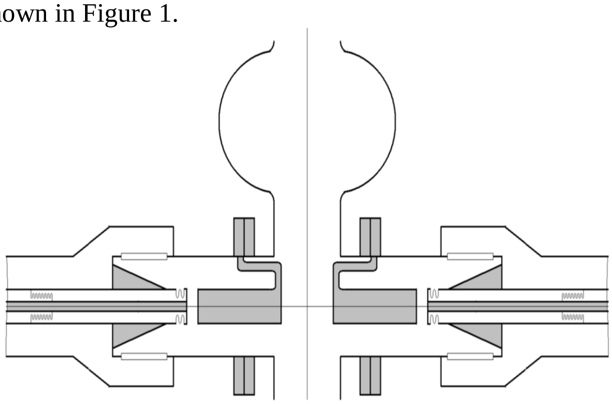

Figure 1: Dual input coupler with loop antenna.

The changing of external Q-factor is achieved by means of changing of capacitance gap between the inner conductor of the coaxial line and the antenna. The separation of the antenna from the inner conductor leads to reducing length of the inner conductor and therefore to reducing of power loss in the liquid Nitrogen area and to reducing of mechanical strength to the ceramics. This is preferable to have superconducting antenna. This allows us to reduce the power loss in the Helium area.

In distinction from the one bellows design with external Q-factor adjusting by means of dipping of the antenna into the cavity drift tube using the bellows, the coupling regulation element is the gap between the antenna and the inner conductor. The antenna is a part of inner conductor of the coaxial line connected to the cavity flange by means of S-shaped conductor. The capacitance gap between two parts of the inner conductor is the element regulating external Q-factor.

CALCULATION OF EXTERNAL Q-FACTOR

The calculation of external Q-factor depending on capacitance gap between the inner conductor and the antenna is needed. The calculation of external Q-factor was carried out using 3D simulation programs: ANSYS for resonant method calculation and HFSS for traveling wave calculation.

The special macros for ANSYS calculation has been developed. This macros creates and simulates the resonance models with electric and magnetic walls in the reference plane of the coaxial line. After calculation the field amplitude at the surface of the external conductor was found. To reduce the calculation error the field was calculated in each node along the whole azimuth and then averaged. Such approach allows us to reduce the influence of so called once-punctured solution point. Another macros has been created allowing the calculation of the energy stored in the cavity. Originally the number of finite elements has been determined, which are needed to get certain result. 1% error is reached at 110,000 elements approximately. The following calculation was carried out at this mesh. The result is represented in Figure 2.

The tuning of the input coupler using traveling wave model was carried out on base of HFSS applied programs. The HFSS macros of 3D two-cell model with the input coupler including the coaxial part and the loop antenna has been created for calculation of external Q-factor Q_{ex} of the model depending on antenna dipping into the cavity drift tube. Then HFSS electrodynamics calculations have been carried out for different capacitance gap between the inner conductor of the coaxial line and the antenna. These calculations have been done in the frequency range close to the cavity resonance frequency. Transmission in this model has been calculated as a function of the frequency. The absolute error of external Q-factor calculation is 5% at 40,000-50,000 elements. External Q-factor depending on the gap g between the inner conductor of the coaxial line and the antenna calculated with HFSS is shown in Figure 2. The external Q-factor of the model with single input coupler is twice higher.

As this is seen in Figure 2, the results of two calculation methods are different, especially in small gap g area. This is coupled with mesh effect. It seems ANSYS result is more certain, as ANSYS allows us to use more flexible mesh partition in the antenna area and therefore to reduce mesh effects.

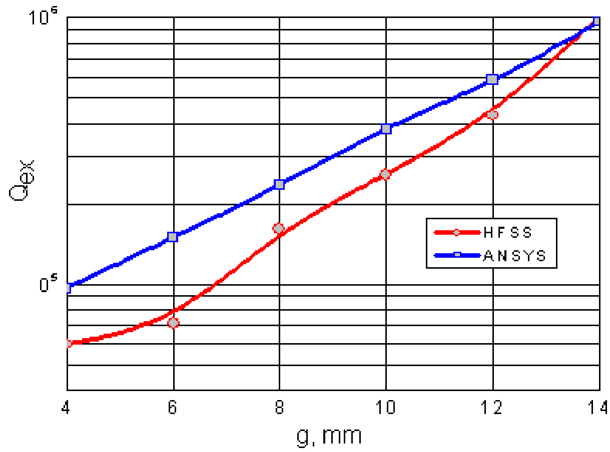

Figure 2: External Q-factor of dual input coupler depending on the gap g between the inner conductor of the coaxial line and the antenna.

The external Q-factor can be changed 10 times by means of changing of the gap g by 10 mm.

HEAT CALCULATION

The results of ANSYS heat calculation of the loop input coupler are shown in Figure 3 and in Table 1.

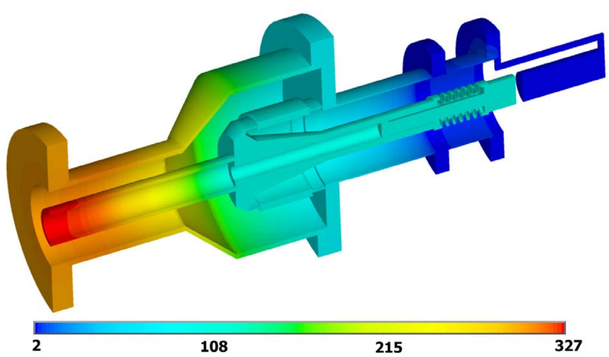

Figure 3: Temperature distribution (K) in coaxial part of the input coupler.

Table 1: Power loss in the cryogenic areas if the input coupler.

Helium 2 K	2.27 W
Helium 4.2 K	9.7 W
Nitrogen 80 K	117.3 Вт

As this is seen from Table 1, the power loss in 2K Helium area is significant in this input coupler design. This is coupled with the connection of the antenna to the cavity flange.

The antenna is made of Niobium. It is superconducting. Nevertheless its resistance is not zero (10 nOhm at frequency 1300 MHz and temperature 2 K).

The temperature of the antenna loop is 3.0-3.5 K, which is significantly less than 9.2 K (Niobium superconducting temperature limit).

Relative high power loss is coupled with high electric field in the antenna area (see Figure 4), which leads to high surface current in the wall and therefore to high power loss.

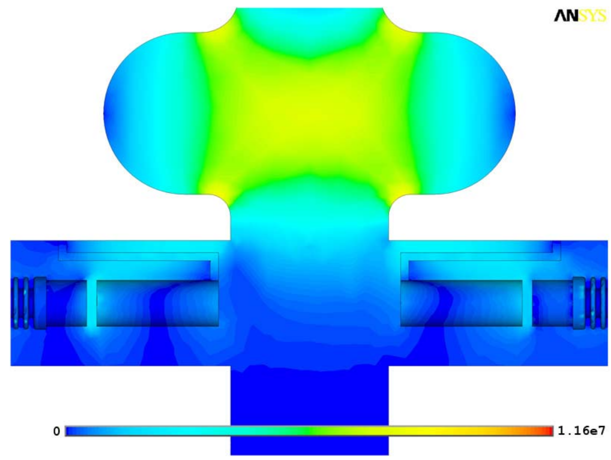

Figure 4: Electric field distribution in the cavity and in the antenna area.

OPTIMIZATION OF LOOP SHAPE

Several variants of the coupling loop have been calculated for minimization of electric field in the antenna at keeping external Q-factor adjustment range.

The relative max electric field in the input coupler equaled to max electric field on the antenna surface divided by max electric field in the coaxial line

$$\gamma = \frac{E_{\max}}{E_{coax}}$$

as well as external Q-factor adjustment range have been calculated for input coupler models, shown in Figure 5.

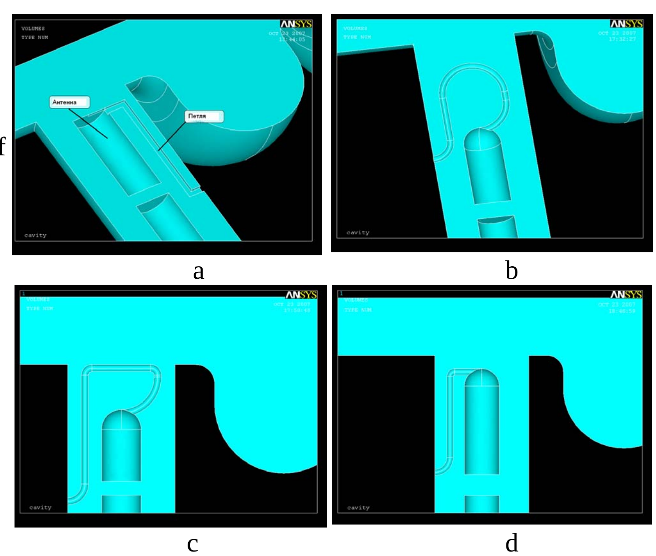

Figure 5: Different shapes of the input coupler loop.

Original model shown in Figure 5a has significant power loss in the antenna area and significant electric field γ=11.8.

The input coupler design shown in Figure 5b allows us to have minimum γ. But external Q-factor is too high because too low coupling.

Required value of external Q-factor can be got in the input coupler design shown in Figure 5c. However it has too high electric field γ=22.

Best result is shown in the input coupler design of Figure 5d: γ=2.24. The external Q-factor of this design depending on capacitance gap g at different antenna length L is shown in Figure 6.

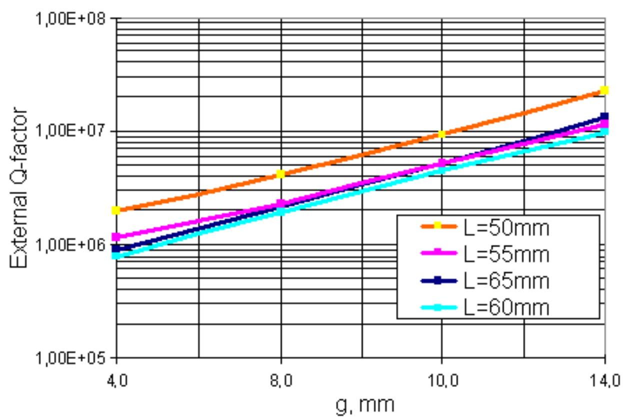

Figure 6: The external Q-factor of design shown in Figure 5d depending on capacitance gap g at different antenna length L.

The heat calculation has been done for the input coupler designs shown in Figure 5 as well as for another designs, for example with cone antenna. Design of Figure 5d shows minimum power loss equaled to 0.57 W.

Distributions of electric field in the input coupler design of Figure 5d is shown in Figure 7.

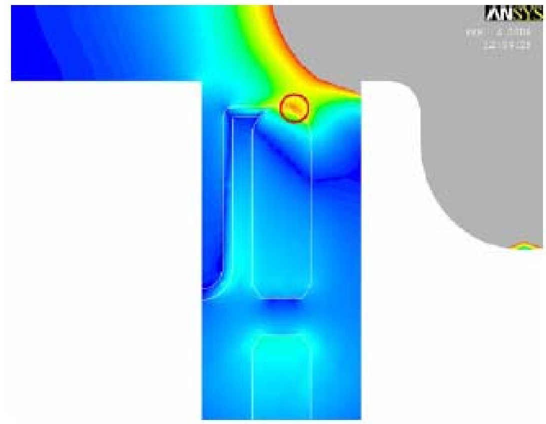

Figure 7: Distributions of electric field in the input coupler design of Figure 5d.

Distributions of power loss in the input coupler design of Figure 5d is shown in Figure 8.

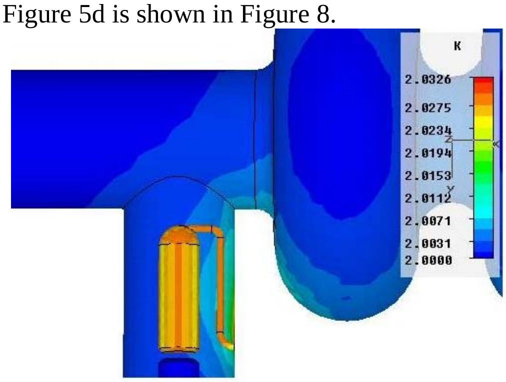

Figure 8: Distributions of power loss in the input coupler design of Figure 5d.

CONCLUSIONS

The loop input coupler has been considered. The changing of external Q-factor in the range of 10^5-10^6 is reached by means of changing of the capacitance gap between the inner conductor of the coaxial line and the antenna by 10 mm. The power loss in the input coupler is 0.07 W in 2 K area, 9.7 W in 4.2 K area and 117 W in 80 K area.

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