THERMAL CALCULATIONS OF INPUT COUPLER FOR CORNELL ERL INJECTOR CAVITIES

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Abstract

The thermal calculation results of input coupler for Cornell ERL injector cavities are presented. A twin-coaxial coupler of TTF-3 type was chosen for 2×75 kW RF power transfer [1]. The TTF-3 coupler is intended for high pulsed and low average power transmission, therefore revisions of its design were proposed. New coupler configuration provides thermal losses not exceeding 0.2 W at the temperature of 2 K, 3.7 W at 5 K and 75 W at 80 K. Design changes were made in the regions of "cold" and "warm" bellows. In particularly, bellows separation with insertion of an additional heat sink was proposed. Electrodynamic simulations were carried out by means of MicroWave Studio and HFSS computer codes, thermal calculations were made using ANSYS code.

1 INTRODUCTION

Parameters of the coaxial input coupler for a two-cells superconducting cavity of a linear accelerator with energy recovery are presented in Table 1.

Table 1: Main parameters of the input coupler.

Operating frequency	1.3 GHz
Maximum power transmitted to matched load (CW)	75 kW
Cold coaxial line impedance	60 Ohm
Warm coaxial line impedance	46 Ohm
Coax line outer diameter	62 mm
Q_{ext} tuning range	$9.2\times10^4...8.2\times10^5$
Antenna tip moving range	≥ 15 mm
Thermal load for 2K cryogenic zone	< 0.2 W
Thermal load for 5 K cryogenic zone	< 3.7 W
Thermal load for 80K cryogenic zone	< 75 W

The TTF3 coupler was used as a baseline design for the new coupler. Some modifications were made in the design. Dimensions of coaxial lines and cold ceramics were changed along with bellows attachment elements. In the new design both "warm" and "cold" ceramic windows are of the same radius, but have different heights.

For thermal simulations, the coupler was divided at the 300 K flange connected to cryostat tank. One model includes the coaxial-to-waveguide transition with "warm" window, the other one includes the coaxial line with "cold" window (see Fig. 1). Cooling of the inner conductor is achieved by forced airflow. Both parts were matched for minimal reflection. A computer code ANSYS was used for thermal simulations. Temperature dependences of thermal conductivity and electrical conductivity of materials were taken into account.

Originally, 3D meshes for thermal and RF models of the coupler contained common nodes on a metal-vacuum interface. Calculation of a 15-degree segment of the axially symmetric part of the coupler with rounded bellows convolutions took about 15 hours on a P4/2800MHz/2GB computer. To perform optimization of parameters, it is desirable to have a single-calculation time of less than an hour. Therefore, a 3D RF model and a 2D thermal model were developed for the axially symmetric part of the coupler.

The meshes for RF and thermal problems are created independently for increasing calculation accuracy. The transfer of RF losses from the RF model to the thermal one is done by an ANSYS macro developed for this purpose. Simulation time for a 15-degree segment of the RF model and 2D thermal model is about 30 minutes. It allows doing many simulations and performing optimization in reasonable time. Also, in the 2D thermal model it is possible to take into account radiation heat transfer without a substantial increase of calculation time.

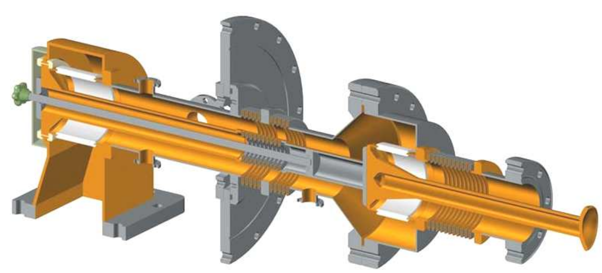

Figure 1: Input coupler for the ERL injector.

2 COAXIAL PART OPTIMIZATION

The excessive heating of the warm bellows in the outer conductor up to 800 K at 75 kW makes the original design totally unacceptable without additional cooling. To improve cooling, the warm bellows was divided into two parts with an extra 300 K heat sink. In order to lower the thermal load on 5 K cryogenic zone, several different designs of cold bellows were considered.

At first, a regular bellows was examined. The model, used for simulations, consisted of the loss-free coaxial line with bellows attached. The 5 K and 80 K heat sinks were located at the bellows ends on the outer surfaces of bellows welding rings. This design is shown in Figure 2.. The following parameters of the bellows were varied: its length, the number of convolutions, and the thickness of the copper plating.

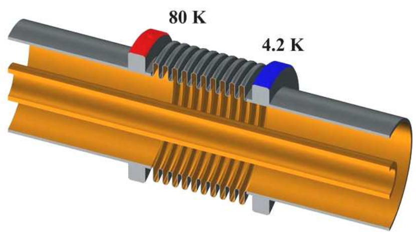

Figure 2: Model of a regular cold bellows.

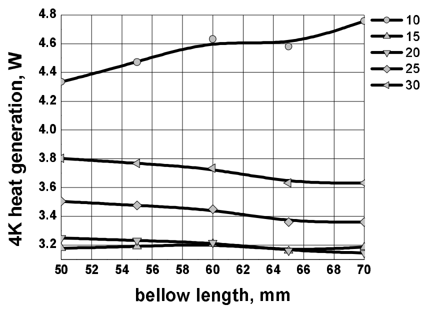

Figure3: Dependences of heat generation wattage on bellows length.

Figure 3 presents the heat leak vs. length for an 11-convolution stainless steel bellows for different thickness of the copper plating, ranging from 10 to 30 microns. A 50 mm long bellows with 15 micron copper plating would be the optimal one. The full coaxial line of the coupler with this bellows was simulated. The heat generation values are summarized in Table 2.

Table 2: Heat flow at heat sinks for the coupler model with the regular bellows design.

Flange 2 K	0.18 W
Heat sink 5 K	3.19 W
Total loss at 80 K	66.5 W

The second design considered has the bellows, divided in half with a ring placed in-between and an additional 80 K heat sink (see Fig. 4). The latter is to be attached to bellows connecting ring via a thermal resistance element. A stainless steel disk represented this element in simulations to simplify the model.

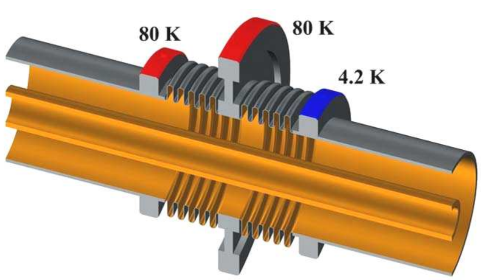

Figure 4: Cold bellows model with an additional 80 K heat sink.

Dependence of the heat flow to the 5 K heat sink on the thickness of the thermal resistance disk is presented in Figure 5 for different thickness of copper plating of the bellows between 5 K and 80 K flanges.

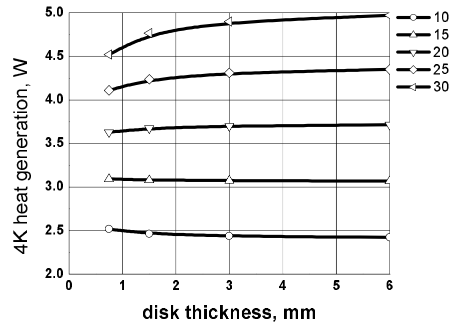

Figure 5: Heat flow to the 5 K heat sink for the design with bellows bi-sectioned.

The lowest heat flow corresponds to the 10-micron copper plating on the bellows and the 6 mm thick heat resistance. The full coaxial line of the coupler with this cold bellows design was simulated. The simulation results are presented in Table 3.

Table 3: Heat flow at heat sinks for the coupler model with an additional 80 K heat sink at a cold bellows.

Flange 2 K	0.17 W
Heat sink 5 K	2.45 W
Total loss at 80 K	69.2 W

For simplicity reasons and due to space constrains, it was decided to use a regular bellows with the wall thickness of 0.2 mm.

The use of a hollow antenna allows to lower mechanical stress on the ceramics. On the other hand, heat conductance from the antenna tip is decreased resulting in additional heating. To determine the influence of this additional temperature increase on the heat flow to 2 K zone, heat calculations were carried out, which take into account infrared radiation. Dependence of the heat flow to 2 K zone on the antenna wall thickness is shown in Figure 6.

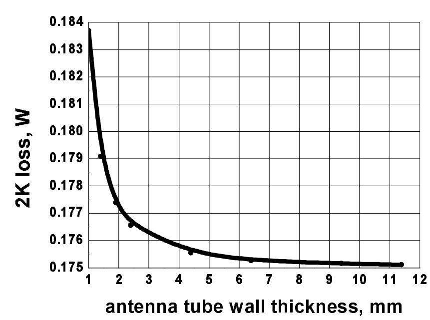

Figure 6: Heat flow to 2 K zone.

The heat flow at 2 K flange caused by conduction heat exchange and the heat flux on cavity walls, caused by infrared radiation from antenna-head, were taken into account.

Final simulation results for the coaxial part are presented in Figure 7 and Table 4.

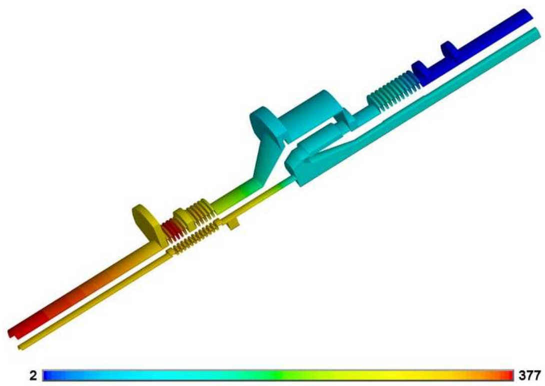

Figure 7: Temperature map of the coaxial part.

Table 4: Heat flow at coupler components.

Flange 2 K	0.17 W
Heat sink 5 K	3.53 W
Total loss at 80 K	70.6 W

3 "DOOR KNOB" SIMULATIONS

Two approaches can be used for calculation of thermal characteristics of the waveguide-to-coaxial transition: physical environment in ANSYS or manual calculation of microwave surface and dielectric losses from electromagnetic fields.

The first approach was the optimal one in this case because a 3D model was to be simulated and the solution transfer could be done using ANSYS resources. Another favorable feature of this method is that multistage iterative simulations are not required due to small temperature variations and minor variations of material properties within the operating temperature range.

The same algorithm was used both for doorknob and coaxial part simulations. However, an error message appeared after the transfer of the results from RF module to thermal module while using this method. A non-correct matrix making caused the error. This matrix is necessary for solving a final elements problem. At the same time the heat and microwave calculations were successful if performed separately. Thus the error is related to the built-in solution transfer function. As it is difficult to determine simulation parameters causing this error without having an access to source codes, we decided to use a manual solution transfer algorithm.

A "3D microwave-to-3D heat model" macro similar to the described above "3D-to-2D" macro was written. As we performed debugging, it was found that simulation time dramatically increases with change from a 2D model to a 3D one. The simulation time is the largest for arrays that include calculation data processing. To solve this problem, the routine using Delphi language was created. This led to the significant decrease of the simulation run time. The accuracy of the method was checked on a coaxial waveguide model and the obtained results were found in full agreement with analytical data. Agreement was better than 3–5% for surface loss and 0.01–0.1% for dielectric loss. The calculation results of the waveguide-to-coaxial transition are shown in Figure 8.

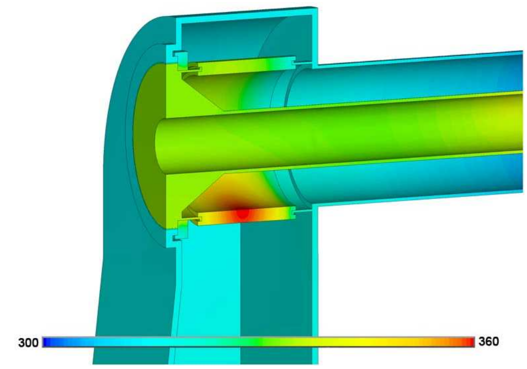

Figure 8: Temperature map of waveguide-to-coaxial transition.

The maximum temperature of ceramics is no higher than 90°C. The rectangular waveguide is heated up to 40°C. All metal parts were assumed to be made of copper to improve heat conductance. The material of some parts could be changed to stainless steel if it is necessary.

4 CONCLUSION

The TTF3-design-based model of the ERL injector input coupler was created. Thermal simulations showed that the TTF3 coupler requires considerable changes to reduce heat leaks in CW regime. The changes include the bellows, the inner conductor of coaxial line, and the pillbox around the cold ceramic window. The coupler model has the optimal geometry in terms of heat leaks to cryogenic system.

5 REFERENCES

[1] V. Veshcherevich, et al., "Input coupler for ERL injector cavities," *Proceedings of the 2003 Particle Accelerator Conference*, pp. 1201-1203.