Study of thermal interaction between a power coupler and a 700 MHz superconducting cavity

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Abstract

Superconducting Radio-Frequency (SRF) elliptical bulk niobium cavities (f=700 MHz) will be used as accelerating structures in the high energy section (185MeV-600MeV) of the proton LINAC driver in Accelerator Driven System. The power coupler (PC) needed for these resonators should transmit a 150 kW CW RF power to a maximum 20mA protons beam. The estimated average values of the RF losses in the coupler are 130 W (respectively 46 W) in the inner (respectively outer) conductor in SW mode. Due to such high values of RF losses, it is necessary to design very carefully and optimize the cooling circuits in order to efficiently remove the generated heat and to reduce the thermal load to the cavity operating at T=2 K.

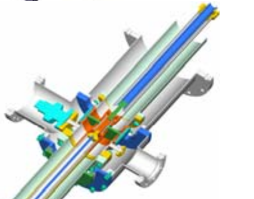
An experiment simulating thermal interaction between the power coupler and a 700 MHz SRF five cells cavity was performed in the CRYHOLAB test facility in order to determine the critical heat load that can be sustained by the cavity without RF performance degradation. Experimental data are compared to numerical simulation results obtained with the finite element code COSMOS/M. These data also allow us to perform in-situ measurement of thermal parameters (thermal conductivity, thermal contact resistance) and they were used to validate numerical simulations of PC thermal model.

eXperimental Accelerator Driven System (XADS) for nuclear waste transmutation

Energy : 600 MeV CW Protons Linac
Beam current intensity : 6 mA - 20 mA

High Energy Section

SRF elliptical cavities: β=0.65, f=700 MHz, E_{acc}=10MV/m, Lacc=0.5m, Q_0= 2.10[11] @2K
Material: 1) Cavity : RRR=200, 2) Beam tube and coupling port: RRR=40



2 windows built by TOSHIBA

Main Characteristics of the coaxial Power Coupler (PC)

Frequency (MHz)	700
RF Power (kW)	150 (CW)
Impedance (Ω)	50
External Conductor Diameter (mm) Wall Thickness (mm)	Cu/S.S 100 2
Inner Conductor Diameter (mm)	OFHC copper 43

GOAL : Transmission of 150 kW CW RF power at f= 700 MHz to a Protons Beam

Average RF losses (Joule Heating)
-Inner Conductor(IC) : PIC= 65 W (TW mode) and 130 W (SW mode)
-Outer Conductor (OC): POC= 23 W (TW mode) and 46 (SW mode)

Average dielectric RF losses in the window : P_W ~ 12W

Static losses (static conduction) from room temperature to 2K circuit : P_{static} ~ 7W

Maximum heat flux by thermal radiation from CI to CX : P_R ~ 8W

Design and calculation of 2 cooling circuits to remove heat loads

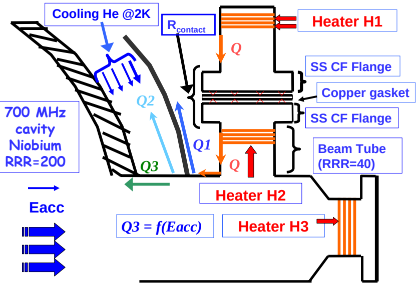
1) Water circulating Circuit at 288K in an annular space around the IC

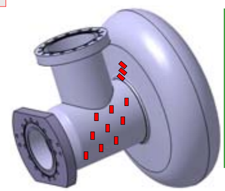
2) Supercritical Helium in a coil brazed around the OC with the appropriate flow

Study of the thermal interaction between the PC and the SC 700 MHz elliptic cavity

Main objectives of the experiment:

- Determination of the amount of heat loads that can be sustained by the 700 MHz cavity without any degradation of RF performance.
- Measurement of some thermo-physical properties like beam tube thermal conductivity and thermal contact resistance in coupler port.
- Validation of 3D finite elements thermal computation using the COSMOS/M code
- Evaluation of heat quantities Q1, Q2 and Q3 from experimental data and thermal simulation results

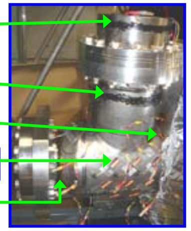


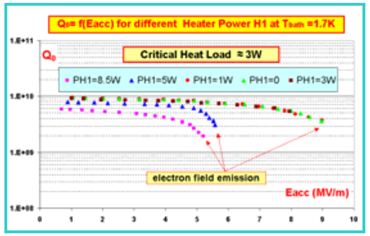


Thermometers locations on isotherms computed with finite elements code COSMOS

Sensors types and number :
-15 Allen-Bradley calibrated between 1.5K<T<77K
-4 Pt100

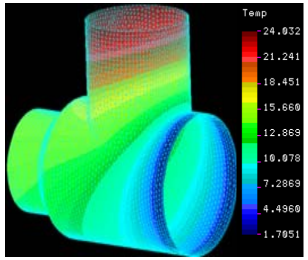
2 tests has been performed at 4.2K (without RF) and 1.7K (with RF) in CRYHOLAB test facility for SRF cavities





RF results analysis

Computed isotherms in the beam tube and coupling port region PH1=8.5W



Total power P_T dissipated in the cavity wall

$$P_T = P_{cavity} + P_{HOM} + P_{beam\ tube}$$

the cavity (1.7K <T< 1.9K) : Tavg=1.8K

$$Rs(n\Omega) = 9.10^{-5}\frac{1}{T} f_{GHz}^2 \exp(-\frac{18}{T}) + R_{res}$$

the beam tube (4K <T< 22K) : Tavg=13K

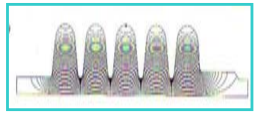
$$Rs = \sqrt{\frac{\mu\omega\rho(T)}{2}}$$

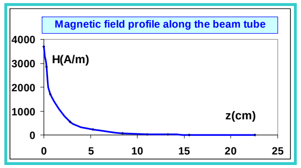
$$\rho_{Ph}(T) = 6.5\ 10^{-14} T^3\ \Omega.m \quad for\ T \le 25\ K$$

$$\rho(T) \cong \rho_{Ph}(T) + \rho_{imp}$$

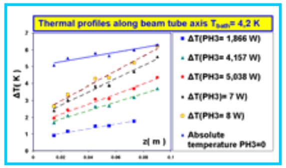
$$P_{beam\ tube} = \frac{1}{2} Rs \iint H_S^2 dS$$

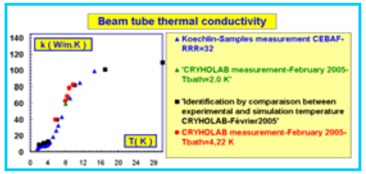
Superfish RF Simulation: TM010 mode





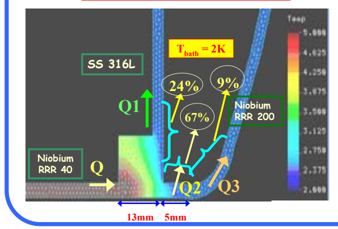
Thermal conductivity measurements





Thermal balance at the junction Beam tube/LHe Tank/Cavity Iris

2D axisymetrical thermal model

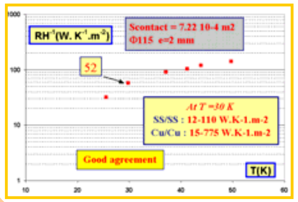


$$Q1 = \iint_{S\ tank} H_k.\Delta T.dS$$

ΔT = T-T_{bath}
H_k (T): Kapitza conductance

- $k_{niobium}$= f(T), Niobium RRR 40 and RRR 200 are given by experimental data, k_{ss} = f(T).
- Temperature values given by the three sensors on Helium tank help us to rebuilt thermal isotherms near the junction beam tube, SS tank and cavity iris.
- Main part (91%) of the static heat load is removed by Superfluid Helium in the beam tube/LHe Tank region. Only about 9% of the total goes to the cavity.

Thermal contact resistance measurement (RH)



$$R_H = \frac{\Delta T}{(Q/A_C)}$$

$$R_H^{-1} = \frac{1}{e\Delta T}\int_{T1}^{T2} k(T)dT$$

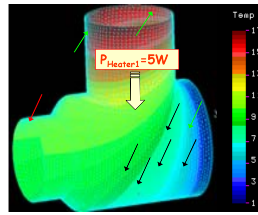
RH is an important parameter for the PC thermal model and there are not enough data in literature about it

RH^{-1} is equivalent to a very small value of thermal conductivity through a section S with a thickness e

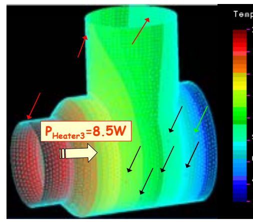
RH^{-1} depends strongly of the applied contact pressure and the temperature

Validation code by comparison between experimental and simulation temperature values Use of H1,H3

Temperature distribution with Heater 1 for Tbath=1.7K and $P_{Heater1}$=5W



Axisymetrical model with Heater 3 for Tbath=1.7K and $P_{Heater3}$=8.5 W



Relative deviation between measured and computed temperature field is less than 25 % for most thermometers

Thermal shell model describes the thermal behavior of the simulated system with a sufficient accuracy