DISCUSSION OF POSSIBLE EVIDENCE FOR NON-LINEAR BCS RESISTANCE IN SRF CAVITY DATA TO MODEL COMPARISON

P. Bauer, N. Solyak, Fermilab, Batavia, USA    G.L. Ciovati, TJNAF, Newport News, USA    G. Eremeev, Cornell University, Ithaca, USA    A. Gurevich, University of Wisconsin, Madison, USA    L. Lilje, DESY, Hamburg, Germany    B. Visentin, CEA, Saclay, France

Powerful RF cavities are now being developed for future large-scale particle accelerators from high purity sheet niobium (Nb) superconductor, reaching peak RF surface magnetic fields of up to 180mT. The basic model for a Q-slope in SRF cavities is the thermal feedback model (TFBM), the result of the exponential dependence of the Nb BCS surface resistance on temperature and the dependence of the RF power dissipation on the surface resistance. Most important for the validity of the TFBM is what surface resistance contributions (beyond BCS) are included. Here we discuss if the non-linear correction to the BCS resistance as recently proposed by Gurevich could be one of them, comparing TFBM calculations with experimental bulk Nb cavity data from DESY, CEA, J-Lab, Cornell and FNAL.

The Thermal Feedback Model (TFBM):
The steady state heat balance equation (Eq.1) contains conduction and generation terms. The differential in the generation term reflects the fact that the RF heating is concentrated in a very thin surface layer. The RF power dissipated per unit area in the cavity depends on the RF magnetic field amplitude $H_{RF}$ and the temperature dependent RF surface resistance $R_s(T)$ as given in Eq. 2. The equation assumes that the loss is due to the RF shielding currents only and neglects the contribution by electric surface fields. The solution of Eq. 1 depends on the surface temperatures on both sides of the niobium sheet. The temperature on the RF exposed side, $T_m$, drives the Kapitza interface conductance. They can be derived exactly from the boundary conditions (Eqs. 3 & 4) for a given $H_{RF}$, $T_m$ and $R_s(T_mH_{RF})$. We used a computer program to calculate the exact, numerical solutions of Eqs. (3-6/4). The strong temperature dependence of the BCS resistance is at the core of thermal feedback. The increase of the surface resistance with field is the result of a feedback process during which the surface temperature increases due to RF heating while the RF heating increases with surface temperature. The TFBM is only as good as the surface resistance and thermal parameter models that are put in.

### Surface Resistance

The RF surface resistance of bulk, high purity Nb is usually defined as a sum of BCS resistance ($R_{s,BCS}$), and residual resistance ($R_{r}$). A phenomenological fit of the linear $R_{s,BCS}$ is given on the left ($\alpha T^2 e^{-\pi^2 h_f^2/4k_B^2 T^2}$). As recently discussed by A. Gurevich the BCS contribution increases at fields approaching the critical field as a result of distortions of the electronic band structure in the superconductor. The first critical field correction term to BCS goes with $C(T_s)$, a constant of order unity in Nb at ~2 K, that can be calculated from material parameters.

The figure shows different model implementations of the thermal conductivity of polycrystalline, high purity Nb, consistent with experimental data. Instead of using a full-blown model (such as Kosechin and Bonin for instance) we used a simple fit. Note that this fit assumes a "mild" phonon peak. Similarly we used a phenomenological fit for the Kapitza interface conductance, such as proposed by Mittag, for $T-1.4K$.

### Thermal Properties

The conductivities and thermal diffusivities estimated from high field data are shown in the figure. The non-linear BCS resistance contribution decreases with temperature and increases with frequency. We observed that the CEA C-103 and J-Lab-DSCS cavities, which were tested at lower temperatures than the others (discussed here), show a medium-Q slope that is more pronounced than that which can be predicted even with the addition of the non-linear BCS resistance in the TFBM. Reduced thermal parameters cannot explain this discrepancy. Could that indicate that the increase of non-linear BCS resistance is underestimated? Is it that at very low temperature the resistance is not BCS dominated anymore and some "other" process takes place? At frequencies beyond 2 GHz, the experimental data are well-described using only linear BCS resistance and residual resistance in the TFBM – see the case of the Fermilab 3rd harmonic cavity, which operates at 3.9 GHz. In this case the TFBM with linear BCS only predicts even the exact quench field. This discrepancy is surprising since the high frequency regime is BCS resistance dominated! Does this indicate that the non-linear BCS resistance model as formulated here overestimates the non-linear BCS resistance increase at higher frequency? Or is this an indication of a more fundamental flaw of the non-linear BCS model?