Numerical Simulations of Superconductor Stability against Quench

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***Abstract*—Focus of this paper is on superconductor stability under disturbances, when the materials are already close to a phase transition. Numerical simulations are applied to multi-filament, BSCCO 2223 and to thin film, coated YBaCuO 123 superconductors. The results shall contribute to improve understanding of the physics behind superconductor stability and quench, and to which extent stability is coupled to decay of residual electron pairs and relaxation under temperature run-away.**

Keywords—Superconductor, transient temperature field, critical temperature, phase transition, relaxation, stability, temporal localisability, thermal diffusivity

I. INTRODUCTION

Under disturbances, a superconductor may experience a sudden, most undesirable phase transition (a quench) from superconducting to normal conducting state. Quench may lead to damage or even to catastrophic conductor failure. A superconductor is stable if it does not quench. Disturbances are responsible for a variety of losses, like transformation of released mechanical to thermal energy under a sudden conductor movement or absorption of high energy, particle radiation, or fault currents. Permanent disturbances may result from flux flow losses if transport exceeds critical current density.

Quench can be avoided by application of stability models to design and operation of a superconductor. A variety of standard, analytic stability models has been suggested in the literature; they usually assume worst case conditions or apply safety margins. The models essentially are energy balances that work safely as long as the superconductor is far from phase transitions. But quench is a short-time physics problem; it proceeds on time scales of milliseconds and less. Numerical calculations, instead of elementary, stationary heat balances, then are more suitable. This is the subject of this paper.

II. METHODS

Transient Finite Element, in combination with Monte Carlo and Radiative Transfer calculations have been applied to simulate superconductor states in multi-filament BSCCO 2223 and coated YBaCuO 123 thin film superconductors. The calculations incorporate a microscopic stability tool and an improved flux flow resistance model.

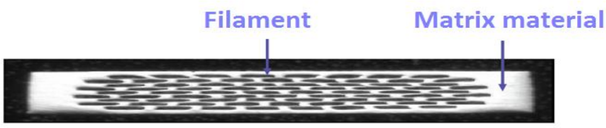

Figure 1a Cross section of the 1G BSCCO 2223/Ag Long Island multi-filamentary superconductor. The figure is taken from Marzahn (2007).

III. RESULTS

- Under transient disturbances, superconductor temperature neither is uniform in the total superconductor/matrix cross section nor is it uniform within filaments of multi-filamentary superconductors (Figure 1b).

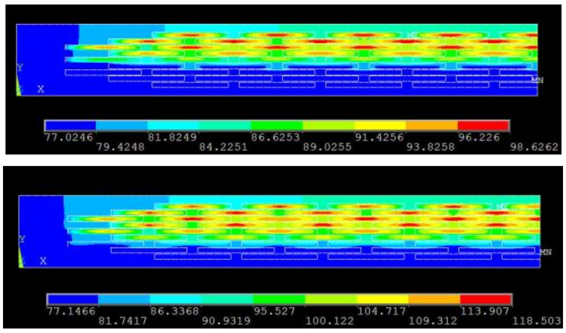

Figure 1b Temperature field (nodal temperatures) in the cross section of the BSCCO 2223 multi-filamentary conductor (compare Figure 1a). Because of symmetry, only the left half of total conductor cross section needs to be shown. Results are given at t = 1.8 ms (top, with all temperatures below critical temperature, T_{Crit} = 108 K at zero magnetic field), and at t = 2.1 ms (below), after start of the disturbance (a sudden increase, within 2.5 ms, of AC transport current to a multiple of 20 times its nominal value. Figures 1b and 2 are taken from previous work of the author (see References listed below).

- Local superconductor temperature, dT(x,y,t)/dt, under transient disturbances may increase within short periods by rates of up to 10^8 K/s
- Flux flow and Ohmic resistances, under transient temperature fields, are time dependent. There is no permanent sharp separation between resistive and inductive current limiting
- Quench always starts locally, which means stability is not uniform within the conductor cross section
- Distribution of transport current in a superconductor then is not like laminar flow but the current may percolate through the conductor cross section.

Most interestingly, decay rates of residual electron pairs under temperature run-away *decrease* the more (and, in parallel, relaxation times *increase* the more, Figure 2), the closer the conductor approaches the phase transition. This finding severely questions the existence of a uniquely defined critical temperature (see http://arxiv.org/abs/2102.05944).

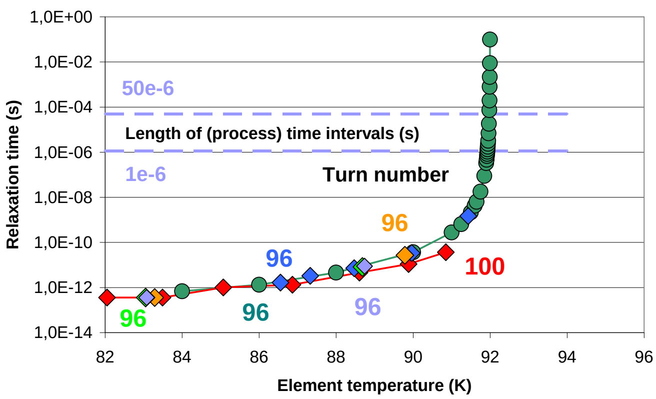

Figure 2 Relaxation time (the time needed to obtain a new dynamic equilibrium after a disturbance in the centroids of turns 96 (light-green, lilac, orange and blue diamonds, respectively) and 100 (red diamonds). The turns belong to a coil prepared from a coated YBaCuO 123 thin film superconductor of standard architecture (superconductor film thickness is 2 µm). The disturbance originates from transport current density locally exceeding critical current density (the corresponding flux flow losses increase local conductor temperature and finally lead to a quench). As soon as Finite Element temperature exceeds 91.925 K, coupling of all electrons in this thin film superconductor to a new dynamic equilibrium can no longer be completed within ntegration times of 1 or 50 µs.

IV. REFERENCES

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