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Addendum to Technical Note No. 52 on "Magnet Quench Effects on Copper-Plated Beam Tubes in SSC Dipoles".

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Addendum to Technical Note No. 52 on
"Magnet Quench Effects on Copper-Plated Beam Tubes in
SSC Dipoles".

In Technical Note No. 52 results of calculations were presented on deflections of and stresses in copper-plated SSC dipole beam tubes during magnet quenches. At that time the plating thickness was to be $t_{cu} = 0.004''$. Meanwhile this has been reduced to $t_{cu} = 0.002''$. The result of a calculation for the new thickness is presented here, together with a previous result for the heavier plating, and some discussion.

To summarize, during a quench the dipole field B begins to decrease slowly, thus with small $\dot{B}$. With time, $\dot{B}$ then increases to a maximum value at a much reduced B.

The current density per azimuthal centimeter, j_1, induced in the copper plating is proportional to $\dot{B}$ and is distributed following a $\cos\theta$ function (θ measured from the mid-plane).

j_1 is also inversely proportional to the copper plate resistance R which is a function of the copper temperature T and of field B (magneto-resistance).

Depending on the decrease of the resistivity $\rho(T, B)$ between room temperature and magnet operating temperature, the "resistivity ratio" (with $B = 0$) remains constant up to 15 to 25 K beyond which it decreases rapidly.

For the present problem, it was found that during quenches copper temperatures rise well above the mentioned limits. Thus for the given conditions one must first calculate T as a function of time. Also calculated must be the total field acting in the copper plating, consisting of main and induced fields.

To calculate T, one must also decide how much of the stainless steel beam tube wall thickness t_s participates in dissipating the produced heat. The larger the participating fraction of t_s, the cooler the copper plating will remain, therefore the larger the induced current. Calculating the heat diffusion rate into the stainless steel, one finds that a good assumption is to use the full wall thickness. One may ask whether some of the induced heat might not leak into the helium in the coil cooling passage, resulting in a reduction of the calculated copper temperature. The beam tube is insulated from the passage, and the trim coil is wound around it. So there is no direct leakage path into helium, except for small helium pockets trapped inside the insulation. It is easy to show that their effect is negligible in spite of the large heat capacity of helium. Most important, however, is the fact that the helium in the coil cooling passage also warms up considerably during a quench due to the considerable temperature increase of the coil, and therefore it is not likely to absorb heat from the bore tube. Indeed, some heat from the helium may even leak back into the beam tube wall, which might reduce the here calculated stresses and deflections somewhat.

Besides dimensions and elastic moduli, the maximum deflections and stresses are, finally, all proportional to the maximum value of $B\dot{B}/R\,(T,B)$. In the following Table we list also the previous results for $t_{cu} = 0.004''$ for comparison. It has been assumed that the copper plating is well-fused to the stainless steel tube. This does not affect the results very much (t_{cu} is much smaller than t_s), but is will show whether or not the copper plating will yield. Calculations were made for unsupported beam tubes and for tubes supported at or near the midplane.

	UNSUPPORTED			SUPPORTED		
t_{cu} (inch)	σ_{SS} (kpsi)	σ_{cu} (kpsi)	w (inch)	σ_{SS} (kpsi)	σ_{cu} (kpsi)	w (inch)
0.002	46	35	0.011	7	5	0.0010
0.004	64	49	0.016	15	13	0.0014

σ_{SS} = maximum stress in stainless steel tube

σ_{cu} = maximum stress in copper plating

w = maximum deflection

Quench field: 6.6 T

Resistivity ratio: 400 (because of the particular effect of the magnetic field B on the "effective" resistivity ratio, the $B = 0$ ratio has relatively little effect on the results).

Beam tube wall thickness $t_s = 0.040''$

For $t_{cu} = 0.002''$ we have also obtained

$$f(\theta) = 107 \cos\theta \text{ (psi)}$$

for the pressure distribution acting outward on an unsupported tube. For a supported tube we find

$$\phi = 208\text{lbs/inch}$$

for the force (per inch length) exerted on the support (allowing zero motion). In order to permit azimuthal helium circulation, the support is not continuous, but may cover only half the beam tube length. Thus the force on the support becomes 416 lbs/inch. Furthermore, the width of the support may only cover 3/8$''$ total around the midplane. Therefore the pressure exerted on the coil is 1100 psi. This pressure will compress the edge insulation of the conductors as well as the coil (which radially has a low elastic modulus). Besides, for insertion of the beam tube (which carries the trim coils which will also be compressed by ϕ) the initial fit cannot be completely tight. Therefore the actual stresses and deflections will be between those shown for the unsupported and supported cases, perhaps about half-way between. In any case, even for the unsupported case $\sigma_{SS} = 46$ kpsi can easily be tolerated by the cold "Nitronic 40" steel, including also the calculated maximum helium quench pressure around the tube of about 12 atm, or even the maximum magnet design pressure of 20 atm which would add 5 kpsi to σ_{SS}.

For the unsupported case $\sigma_{cu} = 35$ kpsi would result in yielding of the copper which, for free annealed copper at helium temperature begins at about 12 kpsi. Tests at BNL (Skaritka, Prodell, Ganetis) have shown so far that copper yielding does not appear to result in damage to the copper plating.

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