QUENCH SIMULATION FOR 16T DIPOLE BUILT AT TEXAS A&M UNIVERSITY

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1. QUENCH CODE

A 16 Tesla Nb_3Sn block-coil dual dipole and its prototype are being developed at Texas A&M University [1]. Quench protection system for the magnet is, of course, one of our concerns. Although there is a number of quench codes reported in literature, most of them are written to model a specific magnet. To our knowledge, the only commercially available quench codes are OPUS [2] and QUABER [3]. In OPUS the magnetic field calculations and the quench simulator are incorporated in one finite element package. The local magnetic fields and inductive couplings of the coils are accurately recalculated during the quench. However, being otherwise very general and robust OPUS deals only with the solenoidal magnets. QUABER has only been used at CERN and we have not yet had an opportunity to evaluate it. Therefore to facilitate the design of quench protection we have developed a new code for a magnet of general geometry with an arbitrary number of coils and with the provision for heaters and switches.

The algorithm is based on adiabatic assumption which allows to integrate the equation for the temperature distribution in a coil and express it as an implicit function of miits. This function is tabulated for each coil and is used to calculate the peak temperature in the coils. Quench propagation is described in terms of time-dependent longitudinal quench velocities and transversal turn-to-turn quench jump steps. The circuit equations are solved by inverting the circuit inductance matrix and integrating the resulting set of equations by the Runge-Kutta method. The average magnetic fields seen by the coils are calculated using the transfer functions.

This algorithm is rather standard and closely resembles the one implemented in QUCERN [4]. However, in implementing it the care has been taken to parametrize the data so that the program can be used for different magnets with little further programming.

To check our code we have simulated the coil described in [2]. As with any quench code the results of simulations depend critically on the input assumptions. To make a meaningful test of our program we therefore used the same input data as had been used in [2] for OPUS simulation. We found our results to be in a good agreement with both, OPUS and the experiment.

2. QUENCH RESULTS

The prototype 16T dipole is 1 m long, has two bores with three coils and stored energy of 1.03 MJ per bore. A 2D view of the magnet with the field lines is shown in Fig.1.

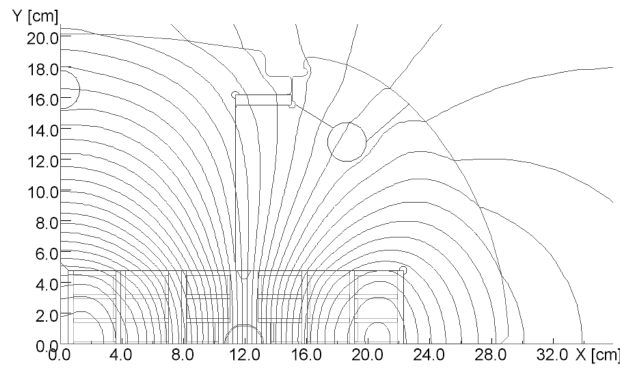

Fig.1. 2D view of the magnet with the field lines.

Main coil parameters are summarized in Table 1. The data on cable which will be used for the winding of coils are given in the Table 2.

Table 1. Coil Parameters.

Coil	Outer	Middle	Inner
Op. Current (A)	8650	8650	8650
Peak field (T)	9.45	13.29	16.18
J in Nb_3Sn (A/mm^2)	2300	1462	592
Turns per bore	102	96	50
Inductance per bore (mH)	11.496	6.948	1.078

Table 2. Cable Parameters.

Cable	Outer	Middle	Inner
Strand diameter (mm)	0.6081	0.6950	1.1583
Cu/Sc ratio	2.095	1.244	0.515
Filament size (μm)	6	6	6
Number of strands	40	35	21
Cable thickness (mm)	1.2571	1.4178	2.2749
Cable width (mm)	12.537	12.537	12.537

The calculated miits curves for the coils are shown in Fig.2. The cable of the inner coil being substantially thicker can take more miits than the cable of outer and inner coils.

Electrical circuit adopted for the quench protection circuit is shown in Fig.3. Besides the dump resistors each coil has a stainless-steel heater tape attached to it (not shown in the figure) which quenches all the turns at the end of a coil once the quench has been detected. Three current supplies are used in order to operate the dipole in a dynamic range of 1 to 20 by means of current programming. At 16T field the current in all coils is the same, 8650A and power supplies PS1 and PS2 are disconnected.

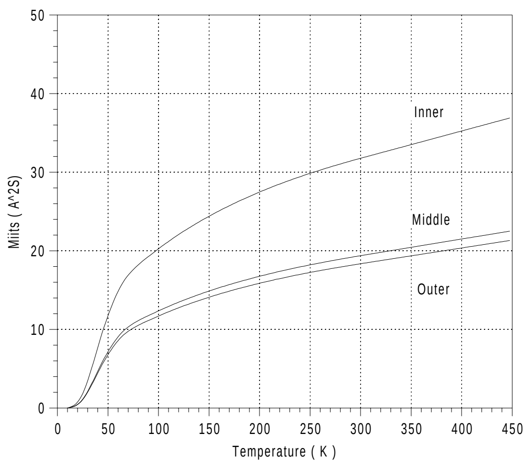

Fig.2 Miits curves.

Our simulations at 16T field indicate that the quench circuit in Fig.3 will adequately protect the coils within some range of the values of the dump resistors. The peak terminal voltage is defined by the value of the dump resistor R3 and therefore it should be of the order of 0.1 Ohm or less in order to keep the voltage below 1kV. The hot spot temperature rise, current in the coils and the coils resistances of the magnet with R1=1, R2=0.5 and R3=0.1 Ohm are shown in Figs. 4, 5 and 6. In this simulation the quench has been started in the inner coil. The heaters have been fired in 10 ms and quenched 10 cm long portion of every turn of all three coils. The power supply has been disconnected 50 ms after the quench initiation.

With these conservative assumptions the highest temperature in the conductor is only 112K, peak terminal voltage is 832V and peak resistive voltage is 118V. Approximately 20% of the stored energy is dissipated in the coils and the rest is taken mostly by the resistor R3.

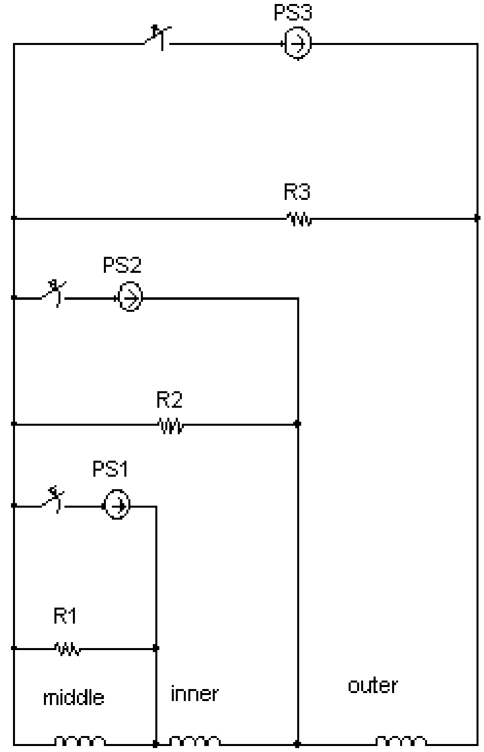

Fig.3 Quench circuit.

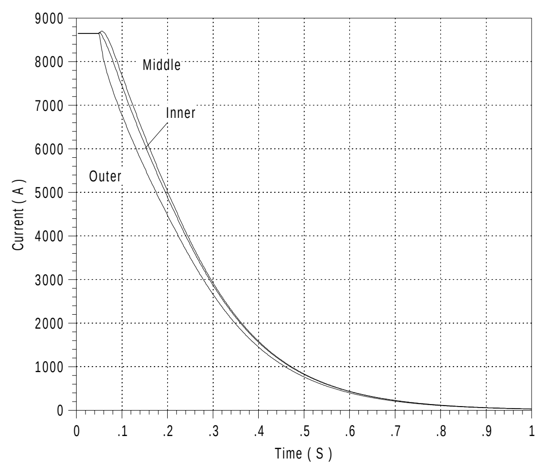

Fig.4 Current profiles.

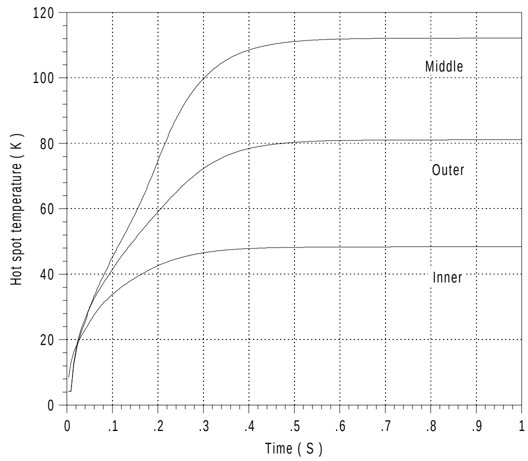

Fig. 5 Temperature rise.

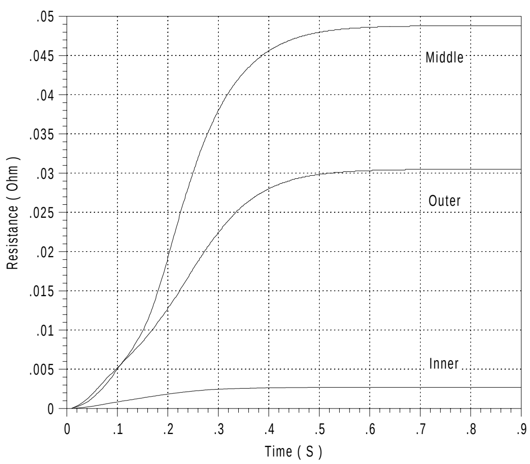

Fig. 6 Coil resistances.

The simulations of the 15 m long version of the dipole with the same circuit show that in order to keep the temperature low, the heaters must initiate quench at a larger part of the coils. The calculated peak temperature in the extreme case when the entire stored energy is evenly dissipated into the coils is 125K. Faster quench will however lead to a problem of large induced and resistive voltages. At this point we note that the stress management design of the magnet utilizes a laminar spring to control the preload given to each block of coil in the support lattice [1, 5]. The spring is sealed so that it is not filled with epoxy during impregnation. If we open the springs at each end of the magnet after the impregnation, they can provide a distributed matrix of helium flow channels which carry helium exactly where it is most needed. This configuration forms in effect an open-geometry cable-in-conduit coil geometry with its advantages for the quench protection.

3. SUMMARY

The results of the quench simulations of 16T 1m long prototype dipole being developed at Texas A&M University are presented. The protection of the prototype doesn't seem to be a difficult problem and can be accomplished by means of the dump resistors and heaters. Protection of the longer version of the dipole is a more difficult task. However, the laminar springs introduced into the each coil block for the stress management [5] can also provide cooling channels which should bring liquid helium into thermal contact with the cable. This effect might simplify the task of quench protection but experimental measurements are needed before we can draw any conclusions.

4. REFERENCES

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[2] S. Pissanetzky, D.M. Latypov, "Full featured implementation of quench simulation in superconducting magnets", Cryogenics, 1994, **34**, p.795.

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[4] A.D. McInturff, "QUCERN users manual", CERN, Internal Note EMA 89-12, 1989.

[5] P.M. McIntyre et al., "Stress management in high field magnets", in Proceedings of this conference.