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STUDY OF HEATER EFFICIENCY IN THE ATLAS BARREL TOROID MAGNET

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The ATLAS Barrel Toroid Magnet will consist of eight flat superconducting coils cooled in the indirect mode. The total energy stored in this 26 meter long toroid reaches 1080 MJ. An essential element of the magnet safety consists in the set of quench heaters. They initiate the internal dump of the stored energy which is therefore dissipated rather uniformely in the windings, preventing the coils from damage. In order to check the heater efficiency, a transient heat transfer analysis has been performed. The 3D model computes the thermal evolution, the quench propagation velocities and the energy dissipation.

1. INTRODUCTION

The Barrel Toroid Magnet (BT) is part of the magnet system of the ATLAS detector under study for LHC experiments, and will provide the magnetic field required by the muon spectrometer. The CEA/Saclay is responsible for the design of this magnet, which was reported in 1997 [1].

It will consist of eight flat superconducting coils and will extend over a length of 26 meters with an inner bore of 9 meters and an outer diameter of 20 meters. The total energy stored in the Barrel Toroid reaches 1080 MJ.

In order to get a good stability, the superconducting cables of NbTi are imbedded in pure aluminium stabilizer. The coils are fully impregnated and cooled in the indirect mode by means of a forced flow of two-phase helium within cooling pipes welded onto the coil casing.

An essential element of the magnet safety consists in the set of heaters, which initiate quench of the coils, causing the stored energy to be dissipated rather uniformely in the windings, preventing the coils from damage by overheating or overvoltage.

This paper focuses on the thermal study of the heater action. In order to check the heater efficiency, a transient heat transfer analysis has been performed on a 3D model of the coil. Using the RALTRAN code [3] adapted to this heater study, this model computes the thermal evolution, the quench propagation velocities, the energy dissipation ... and provides the characteristics of the heater (dimensions, electrical power) necessary to initiate and propagate quenches without any coil deterioration.

2. THE ATLAS BARREL TOROID MAGNET and its PROTECTION

A section of winding and coil casing is shown in Fig. 1. The coil is composed of two double pancakes, in a race-track shape, glued inside two grooves machined in an aluminium alloy casing, and closed by two cover plates (in the same alloy). In the BT configuration, the helium cooling pipes are located in the coil casing near the top and near the bottom of the pancakes. Conductor and magnet parameters are given in Table I.

TABLE I
ATLAS BARREL TOROID
Main parameters

Overall Dimensions:		
Inner bore	9.4	m
Outer diameter	19.5	m
Axial length	26	m
Number of coils	8	
Winding:		
Pancakes/coil	4	
Turns/pancake	30	
Operating current	20.5	kA
Operating temperature	4.7	K
Total ampere turns	19.68	MAT
Stored energy	1080	MJ
Peak field	3.8	T
Conductor:		
Size overall	57 x 12	mm^2
Insert cable:		
Number of strands	38	
Strand diameter	1.3	mm
Design current at 5 T	58	kA
RRR* alu-stabilizer (@ B=0T)	800	
Length/coil	6756	m
Length/turn	56.3	m
Total length	56	km

*Residual Resistivity Ratio

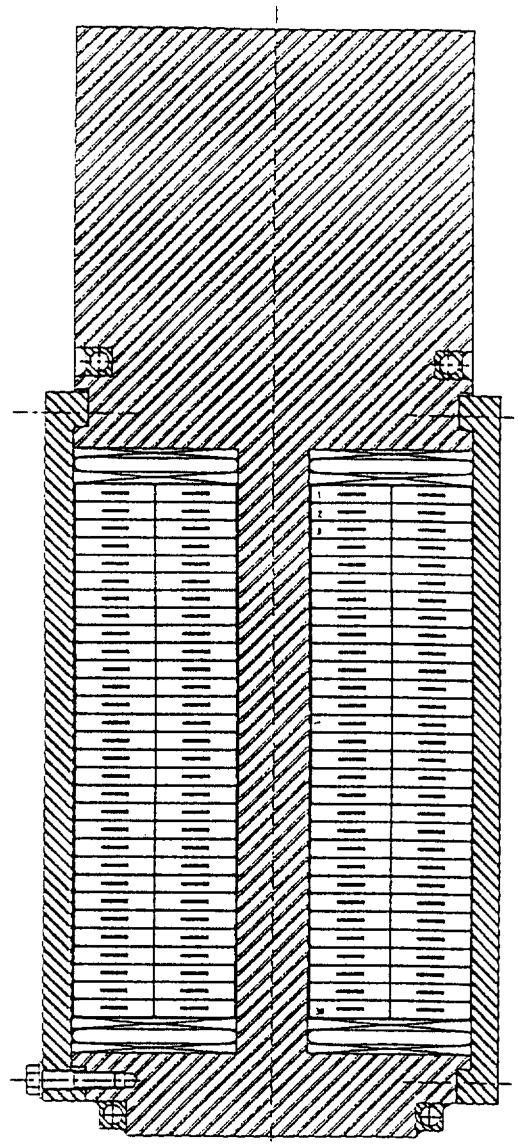

Fig. 1 Section of winding and coil casing

The protection of the toroid is based on the concept of the "internal dump". Each coil pancake is equipped with two quench heaters (one at both ends) used for the fast discharge of the magnetic energy. In this case, the windings are turned into resistive state by the heaters, hereby the stored energy is dissipated in the whole volume of the conductor. The time constant of the current discharge is about 80s [2].

3. THE RALTRAN CODE

The RALTRAN code was originally developed at Rutherford Appleton Laboratory for stability studies, and its characteristics are described in ref [3] . Recently this "RAL forTRAN" code has been adapted at RAL to study the End Cap Toroid safety system of the ATLAS LHC detector. At CEA, a "Saclay version" was written to study the quench heaters of the ATLAS Barrel Toroid.

The aim of this code is to compute the quench propagation in a superconducting coil. The transition is initiated by a local heat flux. The main features are described below and in Fig.2. The results will be discussed on the graphs produced.

3.1 The Model: longitudinal and transverse conduction

In a single pancake, we consider N conductors with a length L and a cross-section area A (including the electrical insulation). They are located side-to-side in the same plane. Each conductor is divided into cells thermally linked. The quench heater itself is not modelised (and hence its temperature is not calculated). Its action is simulated by putting a heatflux on a given length of conductor.

3.2 Transition and current diffusion

Above the transition temperature (1), the power generation due to Joule effect is introduced in the considered cell. The transition of the cell is reversible. Other complementary terms related to the current diffusion could be calculated (the analytical function is given by an external calculation). In a conservative approach of the safety system of the BT, this effect is not included in this study.

3.3 Coil box (or shell)

A second plane parallel to the previous one (under layer) modelises the thermal link with the coil box. In the same manner, it is divided into cells connected together and with the nearest conductor cell. The cooling circuit is simulated on some cells by fixing their temperature (at 4.7 K for instance).

3.4 Symetry

The whole model describes a quarter of the coil cross-section (so by symetry the whole section). In the direction along the conductors, the heater elements should be put at the center of a half-length of conductor, in order to observe a symetrical heat diffusion. This is a necessary condition, because the conductor extremities are not connected in the model (as in reality, the coil is a continuous spiral).

3.5 Boundary Conditions

Two first and two last layers of dummy conductors have been placed in order to correctly describe the thermal flux on the sides. They do not contribute to Joule effect.

3.6 Hypothesis

The coil current is considered as a constant, as it is decreasing more slowly than heat diffusion. Hence there is no eddy current in the coil box walls.

3.7 Outputs

This code gives as results the quench propagation velocity, the position of the quench at any time, the percentage of coil quenched and the power dissipation in the coil as a function of time. (cf figures)

Dummy												
Dummy												
N												
N-1												
N-3												
...												
...												
...												
3												
2												
1						*Heater*						
Dummy												
Dummy			...	...	*L/2*	...	...					*L*

Fig.2 N conductors divided into cells thermally linked

(1) - *The transition temperature Tt is considered as equal to the mean value between the sharing current temperature Tsc and the critical temperature Tc: Tt = (Tsc+Tc)/2 . This for the nominal current Icoil and for a mean value of the magnetic field (defined as the half of the peak field Bp/2).*

4. QUENCH PROPAGATION IN ATLAS BT

The Fig.3,4 show the curves and values for two values of the current, one sees rather different behaviours, as the aluminium resistivity (i.e. the internal Joule effect) and the transition temperature are different as given in Table II.

At 20500 A, a power of 100 W on a heater length of 0.200 m is quite well to get the transition on the whole coil in about 10 s. Whereas, at 10000 A, 45 s are necessary on the same heater to obtain the same state with 100 W.

The behaviour at low current is the most critical and will dimension the heater. But at 2000 A there is no safety probleme, as the stored energy, which decreases as the square of the current, cannot endanger the coils.

TABLE II

Current	Peak Field	Tcs	Tc	Al-RRR
20500 A	3.85 T	6.69 K	7.67 K	520
15000 A	2.82 T	7.42 K	8.10 K	650
10000 A	1.88 T	8.04 K	8.48 K	765
5000 A	0.94 T	8.63 K	8.84 K	880
2000 A	0.38 T	8.98 K	9.06 K	950

4.1 BT geometrical data used in the model

The resistive heaters are parallel to the conductor turn No 1.
The average coil casing thickness is given equal to 25 mm.
The half-length per conductor turn is 28.2 m.
The insulation thickness between conductor turns is 0.80 mm.
The minimum insulation thickness to the ground plane (casing) is 1.40 mm.

5. CONCLUSION

This study of ATLAS BT quench heaters takes place in the Quench Analysis presented in the ATLAS BT Technical Design Report [2], and has to be completed with other calculations to take into account the variation of the current over a long period (500s):

- evolution of current, resistance and temperature given by TRANSIT code [4].
- or by spreadsheet model codes [5].

Another way under study at Saclay is a comparison between the experimental results of a "Thermokinetic mockup" and a local 3D Finite Element Analysis modelling a quench heater in a part of coil casing [2,7]. This will give all the parameters necessary to dimension correctly the quench heaters regarding the safety of the magnets.

7. ACKNOWLEDGMENT

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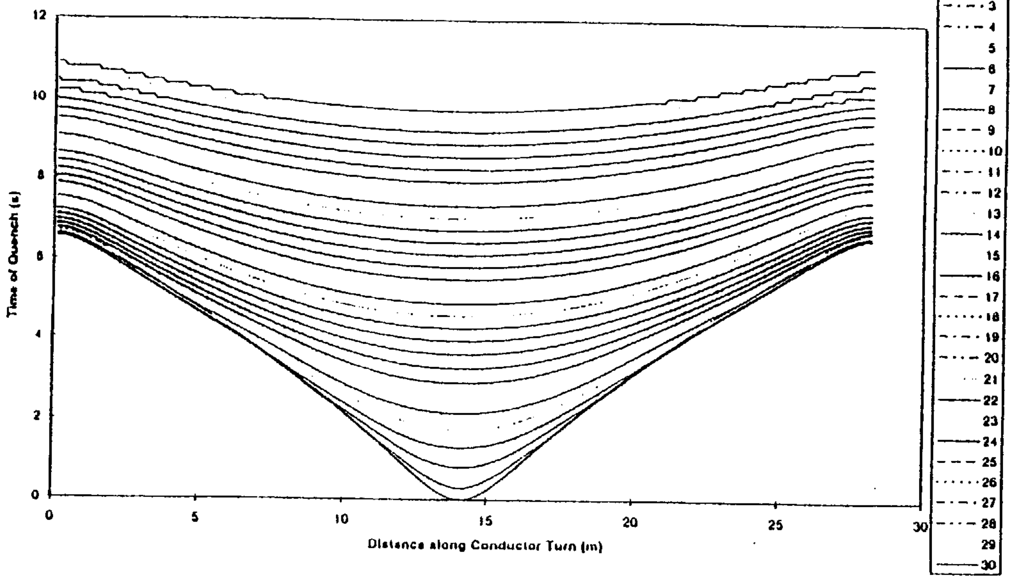
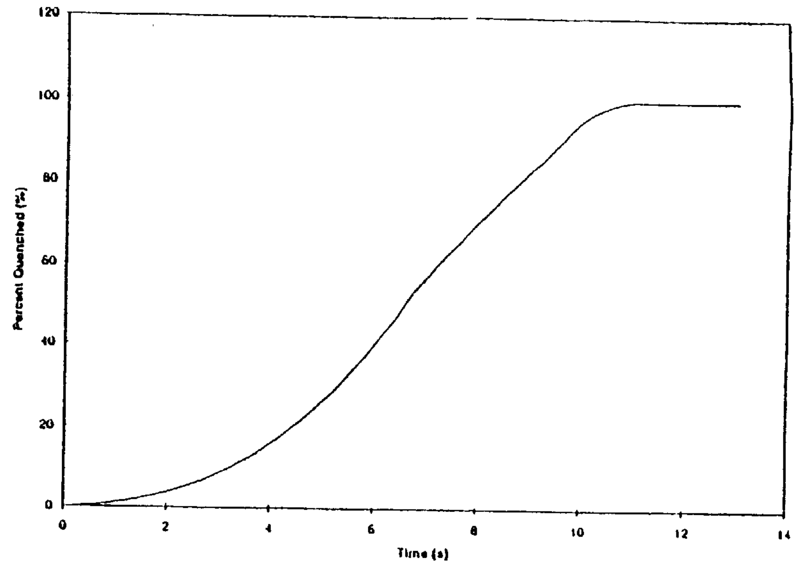
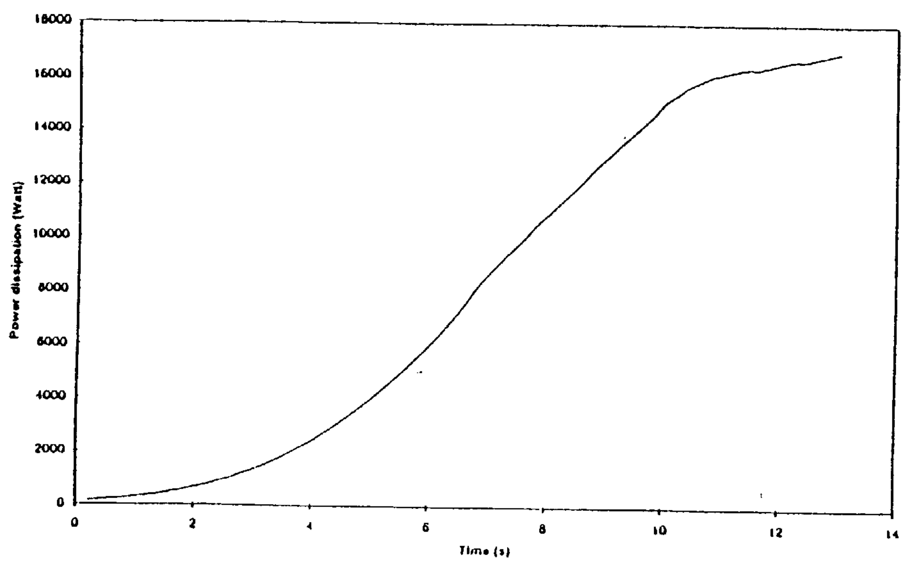
Time of Quench as a function of Distance along Conductor Turns



Percentage of Coil Quenched as a function of Time



Instantaneous Power Dissipation in Coil as a function of Time



Longitudinal Propagation Velocity:

Distance along conductor (m)	16.1	19.1	22.1	25.1
Velocity (m/s)	1.59	1.82	2.03	2.17

Transverse Propagation Velocity:

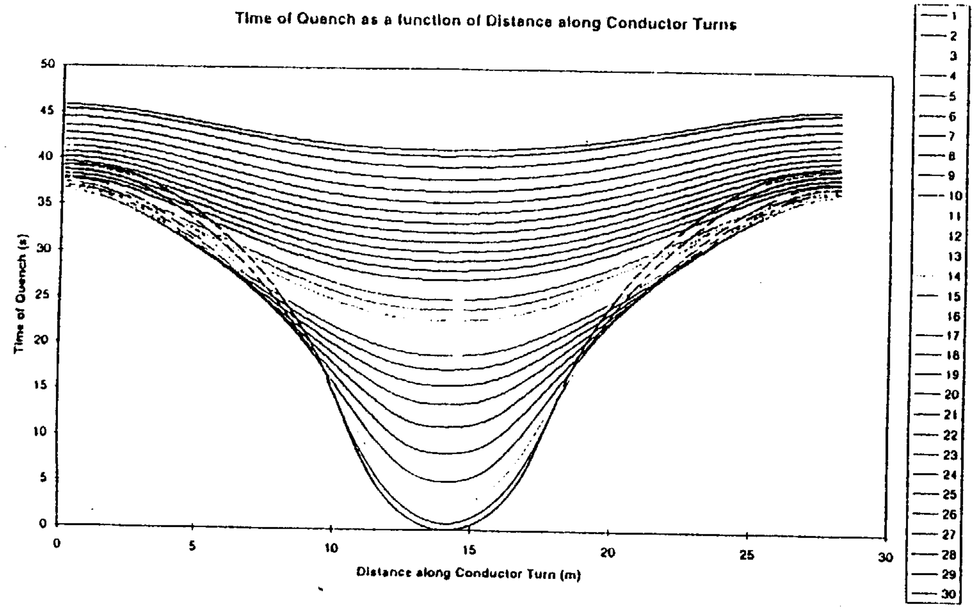
Conductor turn	3	6	9	12	15	18	21	24
Velocity (m/s)	.0245	.0312	.0365	.0394	.0410	.0420	.0425	.0424

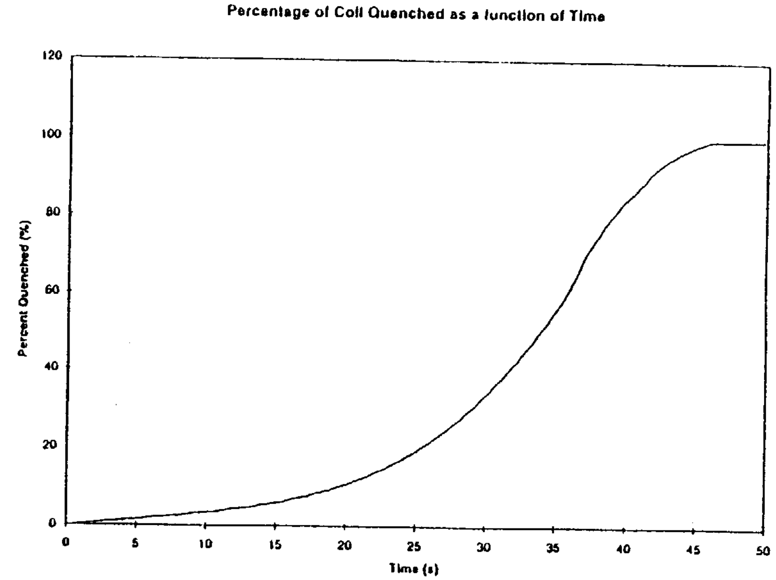
Propagation time to boundary:

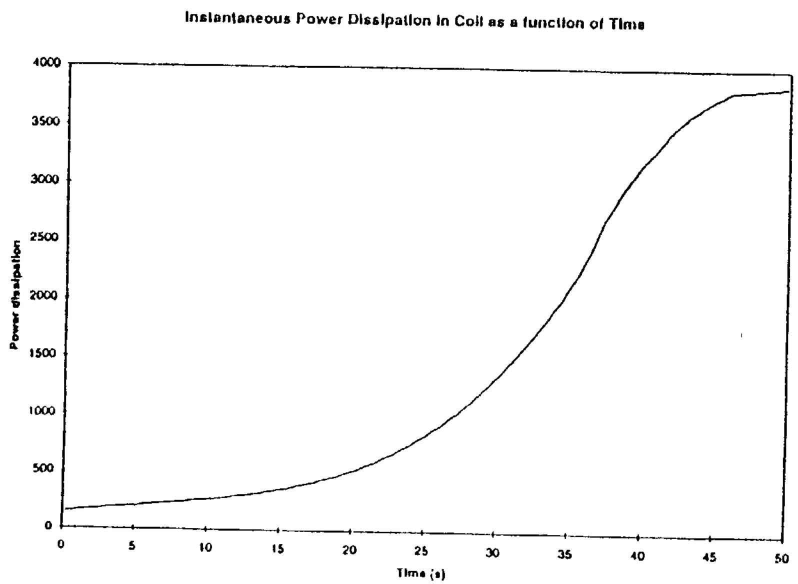
Longitudinal 6.68 s
Transverse 9.73 s
Quench time (100 % normal): 10.9 s

Quench-heater:
100 W, continuous pulse, longitudinal, length 0.2 m
Bounded to conductor turn number 1, centered at 14.1 m along conductor
Cooling Circuit:
Helium cooling circuit fitted to shell next to entire length of conductor turns at both extremities of the pancake.

Figure 3 - Quench from 20500 A and 100 w Quench-heater







Longitudinal Propagation Velocity:

Distance along conductor (m)	16.1	19.1	22.1	25.1
Velocity (m/s)	0.334	0.181	0.369	0.733

Transverse Propagation Velocity:

Conductor turn	3	6	9	12	15	18	21	24
Velocity (m/s)	.0071	.0045	.0073	.0099	.0115	.0124	.0126	.0119

Propagation time to boundary:
Longitudinal 36.5 s
Transverse 41.2 s
Quench time (100 % normal): 45.8 s

Quench-heater:
100 W, continuous pulse, longitudinal, length 0.2 m
Bounded to conductor turn number 1, centered at 14.1 m along conductor
Cooling Circuit:
Helium cooling circuit fitted to shell next to entire length of conductor turns at both extremities of the pancake.

Figure 4 - Quench from 10000 A and 100 w Quench-heater

8. REFERENCES

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[2] ATLAS Barrel Toroid TDR - CERN/LHCC/97-19 (1997)

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