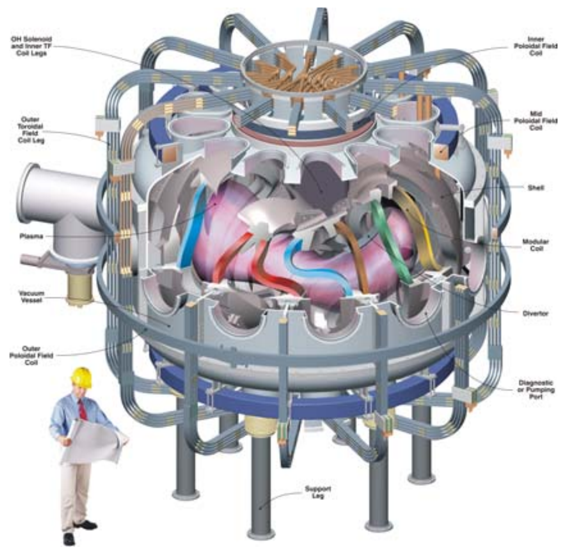
COOLING DESIGN AND ANALYSIS OF THE QPS MODULAR COIL WINDING PACKS

K. D. Freudenberg[1], P. Goranson[2], F. Dahlgren[3]

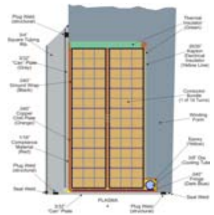
[1] Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN 37831, USA
[2] DevTech, 204 Elmhurst Dr, Oak Ridge, TN 37830, USA
[3] Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08502, USA

A study has been performed on several modular coil coiling schemes for the Quasi-Poloidal Stellarator (QPS). The modular coils provide the primary magnetic field within QPS and consist of flexible cable conductor wound on a cast and machined winding form and vacuum impregnated with cyanate ester resin. Twenty coils and associated winding forms are connected at assembly into a toroidal shell structure. Each winding is encapsulated in an outer layer of groundwrap insulation and ultimately by a thin stainless steel vacuum cover. The purpose of this study is to evaluate the cooling response of the coils after a 1-T pulse has been imposed on the conductor for 1.5 s. The first case examines the use of exterior cooling via tubes outside the winding pack which uses copper cladding as the primary medium for heat transfer. The finite element program ANSYS is used to model a cross section of the modular coil bundle and all of its components (insulation, copper conductor, and the stainless steel support structure and shell). Thermal loading from the pulse is modeled as temperature-dependent heat generation, resulting in a 40 C rise in conductor temperature after the pulse. A primary focus of the model is to determine the location and specific number of cooling tubes required to adequately cool the modular coil. Geometric considerations due to available space, installation and ease of assembly are considered when placing the tubes in the theoretical model. The second concept explored is an internally cooled modular coil concept where the coolant flows through each copper conductor individually through a small copper tube that is built into the conductor during manufacturing. The internally cooled concept undoubtedly has an advantage in terms of heat transport capacity but it may be geometrically challenging to wind the stiffer conductor around the tight bends of the QPS coil trajectories. Fluid flow calculations are used to determine the diameter of the tube and the time and flow required to cool the conductor. Additionally, a Fortran routine is used to plot the speed of the cooling wave along the length of the conductor as it cools after the pulse.



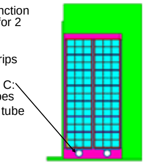
Copper Cladding Outer Cooling Analysis

Copper Cladding Concept: One Cooling Tube at Corner



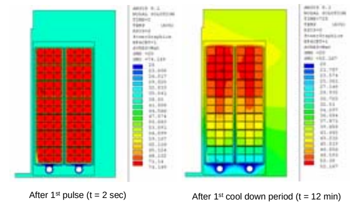
Cladding Concept: Model and loading

- Applied Heat Gen as a function of temperature/resistivity for 2 sec.
- Applied thermal contact resistance between Cu strips (estimated at 25%)
- Coolant temperature = 20 C: Applied to two Copper tubes
- Geometry represents two tube configuration
- Start temperature = 40 C



Material Properties	FEA Color	Cp (J/kg K)	K (W/m K)	Density (kg/m^3)
Winding cable	blue	364	12.000	6705
Copper	red	364	380.0	8940
Insulation	purple	1460	0.15	1800

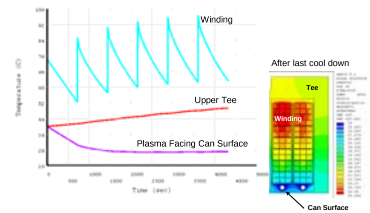
Cladding Concept: Temperature Profiles



After 1st pulse (t = 2 sec)

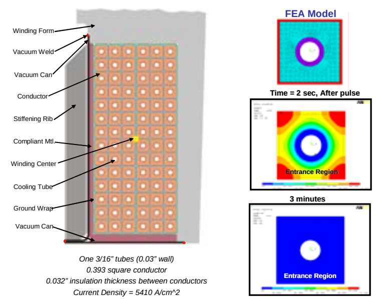
After 1st cool down period (t = 12 min)

Cladding Concept: Temperature vs Time for 6 Cycles



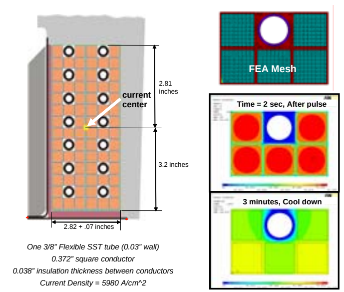
Inner Cooling Tube Thermal Analysis

Concept I: Each Conductor has an Imbedded Cooling Tube



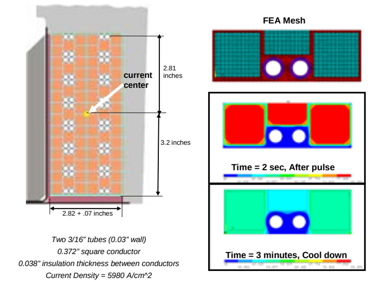
One 3/16" tubes (0.03" wall)
0.393 square conductor
0.032" insulation thickness between conductors
Current Density = 5410 A/cm^2

Concept II: Flexible SST Tubing Replaces Conductor



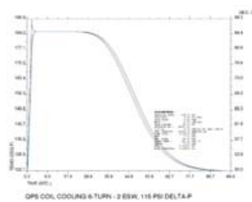
One 3/8" Flexible SST tube (0.03" wall)
0.372" square conductor
0.038" insulation thickness between conductors
Current Density = 5980 A/cm^2

Concept III: Smaller Copper Tubing Replaces Conductor

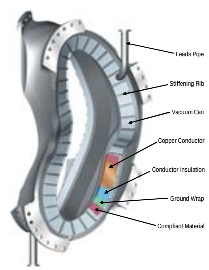


Two 3/16" tubes (0.03" wall)
0.372" square conductor
0.038" insulation thickness between conductors
Current Density = 5980 A/cm^2

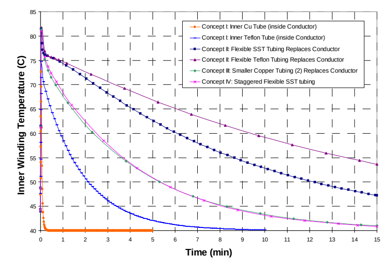
Imbedded Tube Coolant Exit for a 90' Coil Length



Isolated Winding



Inner Cooling Concepts Thermal History



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