CARE Insulation Meeting Report

(CERN, March 22-23, 2005)

Sara Mattafirri

LARP Collaboration Meeting

Port Jefferson

April 6 - 8, 2005

Outline

- Insulation Presently employed in Nb_3Sn Magnets
- Issues & Potential Limitations
- Development of Insulation Materials
- Innovative Insulation Materials, Discussion
- Radiation Resistance of Insulation Materials, Discussion
- Radiation Hard Insulation, FY06 Proposal
- Summary

Insulation Presently employed in Nb_3Sn Magnets

LBNL Baseline Scheme

***Vacuum Impregnation Resin/Fiber Composite*:**

Reinforcement: S2-Glass sleeve weaved before application on cable (thickness ~125 μm)

VPI Resin: Epoxy (CTD 101K)

Use: Conductor, Interlayer and Ground Insulation (fiber in form of tape or cloth)

G10 and Plasma Sprayed Al_2O_3 also used for ground insulation

Fermilab Baseline Scheme

***Vacuum Impregnation Resin/Fiber Composite*:**

Reinforcement: Dry Ceramic Tape (CTD CF 100) or S2-Glass Tape (125 μm) + Ceramic Liquid Binder (CTD 1008X)

VPI Resin: Epoxy (CTD 101 K)

Use: Conductor, Interlayer, Wedges and Ground insulation (fiber in form of tape or cloth)

Issues & Potential Limitations

Epoxy resin/S-glass Composite

Radiation Resistance:

•Interlaminar shear strength approaches operating value after ~ 100 MGy (test performed on epoxy/glass samples irradiated at 1.8 x 10^{18} n/cm^2 En>0.1 MeV + γ ray; damage at resin/fiber interface, *Egusa 1991*); need to relate this data to HEP applications: damage, for a fixed dose, depends in general on radiation type, energy spectrum and material

•Epoxy resin has relatively high gas evolution (1.4 cm^3/g MGy)

Large Scale Production and Long coils fabrication

Epoxy resin/Ceramic Tape Composite

Radiation resistance:

•Radiation Damage of the composite has not been determined yet;

•Epoxy resin has relatively high gas evolution

Expected lower Shear Strength

Insulation Materials Development (1)

<u>US industries</u>, supported by the **<u>DOE SBIR</u>** program, are working to develop Rad-Hard insulation for **Fusion** and **HEP** magnet applications.

VPI Resin/Glass Composites – CTD

<u>Cyanate Ester Resin</u>:

Improved Radiation Resistance

General properties comparable to conventional resin and expected compatibility with coil manufacturing procedures

<u>Cyanate Ester + Epoxy Resin:</u>

Lower cost, but generally lower pot life

<u>Development of new, Lower Cost Rad-Hard polymer matrix</u>

Expected higher radiation resistance and low gas formation (test scheduled in 1 – 2 years)

Improved mechanical performance at 300 K

VPI Resin/Inorganic Fiber Composites - CTD

<u>Ceramic</u> or S-Glass tape + liquid binder converted to ceramic after SC heat treatment. Impregnated with epoxy resin after HT.

Lack of data about radiation resistance. Work is ongoing to improve matrix/fiber cohesion strength.

CTD: Composite Technology Development

Insulation Materials Development (2)

Inorganic Insulation Materials – MSU (work supported by NSF, DOE and the State of Michigan)

Metal Oxide Insulated CICC, proposed for high power and high neutron flux applications (such as the Rare Isotope Accelerator (RIA))

Polyimide Matrix, Proposal – FT

Glass fiber and Polyimide + Ceramic loading matrix

MSU: Michigan State University; FT: Fraivillig Technologies

Insulation Materials Development (3)

European Laboratories are working to develop insulation as a part of the **NED** (Next European Dipole) Insulation Development and Implementation Program.

Conventional Organic matrix\Fibre Composite - CCLRC

Goal: Improve Durability during coil manufacturing and improve performance

Investigate Sizing and Fibre options (S-Glass, S-Glass + polyimide sizing, Quartz+ polyimide sizing)

Measured Work of fracture, shear strength, breakdown voltage of insulation samples

Future steps: Fibre and sizing development, winding tests, radiation damage tests of matrix materials, novel materials – nanofiller

Innovative Ceramic Matrix\Fibre Composite– CEA Saclay, DAPNIA

Pre-Preg: S-Glass Tape + Ceramic matrix

Future steps: Mechanical properties assessment, implementation and test in a coil

CCLRC: Council for the Central Laboratory of the Research Councils, Rutherford Appleton Laboratory

CEA: Commissariat a l`Enérgie Atomique

Development of Insulation for Nb_3Sn Magnets, Discussion

Some Goals and Guidelines

- Compatibility with Long Coil fabrication and Large Scale Production
- Radiation Resistance issues need to be addressed with respect to HEP applications
- Insulation thickness needs to be minimized (should not exceed the present ~ 250 μm turn to turn value)

Materials

Matrix:

- Cyanate Ester has been identified as promising VPI resin (radiation resistance improved), but expensive.
- Cyanate Ester + Epoxy is cheaper but has lower pot life.

Reinforcement:

- Quartz (higher work of fracture)
- S-Glass sleeve weaved directly on cable
- Investigate possibility of using a single fiber filament wrapped on the cable, coating the cable (potentially polyimide) and using resin to fill the voids.

Insulation Test, Discussion

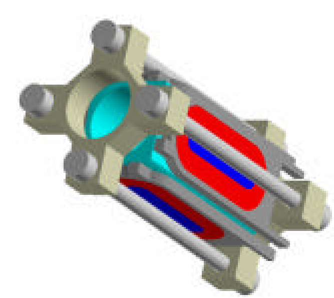
Post screening tests on insulation material need to be performed in a **realistic** configuration: The insulation should be processed in the same way as it is processed during magnet fabrication and should be tested in conditions that simulate magnet operation.

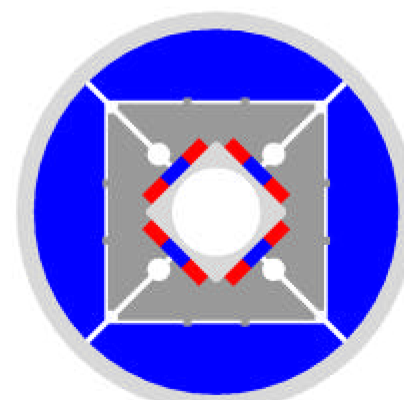
Insulated Cable Stacks have been identified as viable post screening samples.

Proof of Principle test needs to be performed in a **magnet** (sub scale quadrupole as viable lower cost option).

MTS machine for cable stack mechanical test, LBNL

Sub-Scale Quadrupole Magnet





S. Mattafirri

Radiation Resistance of Insulation Materials, Discussion

Specific Radiation Resistance studies have been performed for Fusion Magnets Insulation:

- Samples (matrix/fiber composite) irradiation is performed under realistic conditions at reactors (radiation type, energy spectrum and total dose match as close as possible the one absorbed during operation).
- Interlaminar Shear strength has been identified as the "weakest" property.
- Lack of data about Gas Evolution Effects on magnet operation (somebody claimed this mechanism has determined catastrophic failure of several magnets).

Present Issues

Energy spectrum and radiation type absorbed by the insulation, has not been assessed or reported yet.

Radiation Resistance of Insulation Materials, Discussion

Further Development Needed

•Implementation of Rad-Hard materials in a Magnet (reinforcement and impregnation procedures)

•Test of mechanical, electrical and heat transfer properties of rad-hard insulation in conditions that simulate magnet fabrication and operation

•Assessment of Radiation Damage and Limits of Conventional and Rad-Hard Insulation with respect to HEP applications

•Assessment of peak dose and energy spectrum absorbed by the insulation (quadrupole first configuration)

•Irradiation experiment optimization, in terms of irradiation time, number of samples that can be irradiated in a run, irradiated area and irradiation uniformity, given the dose, radiation type and energy spectrum, sample dimensions and materials

•Study of Gas evolution Effects on magnet operation

Irradiation Options

Samples Irradiation should be carried out preferentially in realistic conditions.

Need to Investigate in detail the potential of some irradiation facilities (LBNL, Fermilab, MIT, …) and reactors as irradiation source.

Nb_3Sn Magnets Rad-Hard Insulation, FY06 Proposal

Main Objectives and Features, FY06

- Development of Insulation Procedures for new rad-hard materials (on ~ 2 m cable stack samples) and fabrication of cable stacks samples
- Test of mechanical (shear strength and Young Modulus along radial and azimuthal direction), electrical and heat transfer properties

20 k$ + 0.5 FTE = 110 k$

- Assessment of peak dose (range), radiation type and energy spectrum absorbed by the insulation

if IR model (Quad first) is available: 0.2 FTE = 36 k$

- Optimization of irradiation experiment and residual dose rate assessment (conceptual)
- Gas evolution effects on magnet operation -- to determine eventual failure mode and effects on re-training of the magnet-- (experiment planning)

5 k$ + 0.5 FTE = 95 k$

- Sub-scale coil fabrication (selected insulation)

14 k$

Further Development

FY07 Statement of Work, Preliminary

•Test of sub-scale coil insulated with selected rad-hard material (to be performed in sub-scale quadrupole magnet)

•Insulation radiation damage studies:

- •Irradiation of insulated cable stacks (selected insulation materials)
- •Post irradiation Tests (mechanical, electrical, heat transfer properties)
- •Test of gas evolution *effects* on magnet operation (to assess eventual failure mode, and impact on re-training)

Summary

- US Industries, supported by DOE, and European Laboratories supported by the NED program are developing innovative insulation materials to improve radiation resistance of Nb_3Sn magnets for HEP application.
- US Nb_3Sn magnets R&D Groups need to test the new rad-hard materials in conditions that simulate magnet operation and ultimately implement them in magnets.

Future meetings on insulation materials, between NED participants, US National Laboratories and US industries have been proposed at conclusion of the CERN Insulation Workshop.

A proposal to start R&D on Radiation Hard Insulation in FY06 has been presented and discussed.

Presentations and full list of participants of the Topical Meeting on Insulation, CERN, March 22-23, 2005:

http://amt.web.cern.ch/amt