R&D Overview for FIRE's TF and PF Coils

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Introduction

- FIRE has relatively modest R&D requirements since it is a cryo-cooled copper magnet tokamak and can draw upon a great deal of existing data from CIT/BPX, ALCATOR C-Mod, IGNITOR, and other high field, copper magnet tokamaks.

- **Planned R&D concentrates on items which permits higher performance, higher reliability, and helps to keep costs as low as possible.**

Planned Areas of R&D

1. Copper conductor characterization and design criteria
2. Copper conductor joint development
3. Radiation resistant insulating materials
4. Characterization of low friction insulating materials for interfaces between CS coils.
4a. Characterization of high friction insulating materials for the inner legs of the TF coils.
5. Development & testing of the compression ring preload mechanism.

1. Copper Conductor and Design Criteria

Background:

- The data base requires assessment and extension for plates of the size to be procured for the full scale TF and PF conductor. The properties assumed requires validation.

Inner Leg of the Wedged TF baseline design-

- C17510 BeCu (70% IACS) in thick plate (36mm) form is used in the inner leg. The principal stresses are primarily axial tension and azimuthal compression.

- Outer TF coil legs use OFHC copper in thick plate form. This task will verify that the plate properties can be obtained in the thicknesses required.

Central Solenoid Coil: Both concepts use C10200 copper in thick plate (38mm) form. Rolled or forged copper discs are required to meet strength requirements.

R&D Task:

- Obtain samples from full size plate stock and carry out a mechanical testing program to assure that static mechanical properties and crack growth properties at room and LN2 temperatures are adequate..

2. Conductor Joint Development

Background: Both the baseline and alternate TF coil designs require a high strength joining process which does not result in an annealed zone.

- C17510 BeCu is used in the inboard leg of the TF coils and C10200 copper for the balance of the coils.
- A cost effective, reliable high strength joining method for the material transition is essential.

R&D Task:

◈ Develop manufacturing processes and carry out a mechanical testing program to assure adequate mechanical properties and to validate design criteria for the joints. Potential candidate processes include friction stir welding and e-beam welding.

3. Radiation Resistant Insulating Materials

Background:

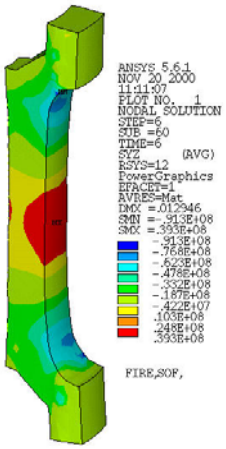
- The peak insulation radiation dose in FIRE is 1.3 x 10^{10} rads at the midplane of the TF coil on its high field side. A recent series of tests by CTD on cyanate ester composite, and cyanate ester hybrids with polyimide and bismaleimide resin showed compressive strengths remaining above 1.2 GPa out to fast neutron fluences of 5 x $10^{22}/m^2$, corresponding roughly to 2 x 10^{10} rad.
- This is a high leverage R&D item, since it has the potential to permit more full power D-T shots and may permit the experimental program to be expanded with possibly only a minor impact on costs.

R&D Task:

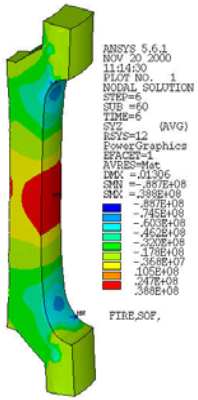
- We plan to continue to collaborate with CTD on their SBIR effort to develop high radiation resistant insulating materials with good processing characteristics.

4. TF Inner Leg Insulation Frictional Requirements

Run #60 Mu=.3 at TF sides, SYZ Max=39.3



Run #61 Mu=.2 at TF sides, SYZ Max=38.8



<u>TF Inner Leg Torsional Shear vs. TF Wedge Face Insulation Friction</u>

(Run #60 Mu=.3 at TF sides, SYZ Max=39.3 Run #61 Mu=.2 at TF sides, SYZ Max=38.8) –data shown is for the 2.0 m. machine; forces are lower for the 2.14m. Machine)

- Torsional Shear Stress Distribution in the Inner Leg Indicates Amount of Slippage/Fretting
  - Continuous Axisymmetric Contours Indicates No Slippage; "Spots" Mid Build Indicate Bending Shear and some Slippage at the Wedge Surface
- Planned R&D: Verify the coefficient of friction and where slippage may occur and verify adequate wear characteristics for 5 X life by testing.

4a. Low Friction Insulation Characterization

Background: Criteria used in the design of the TF and CS coil systems require that selected interface areas retain a desired level of either low or high friction during operation.

Segmented Central Solenoid in both Wedged and Bucked & Wedged Designs-

- FIRE employs a segmented CS with a variation of currents among the 5 coils in the stack during a pulse.
  - Adjacent coils in the CS operate with different temperature and electromagnetic load profiles during a pulse.
  - Adjacent coils will strain differently and relative radial motion between coils in the CS will occur.
  - Interface must lock the coils azimuthally, maintain the coils co-axial, and allow relative radial motion with low friction.

R&D Tasks:

- Prototypes of the interface areas will be fabricated and tested under simulated operating conditions to verify operation and adequate life.

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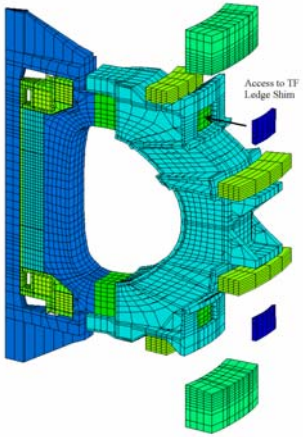


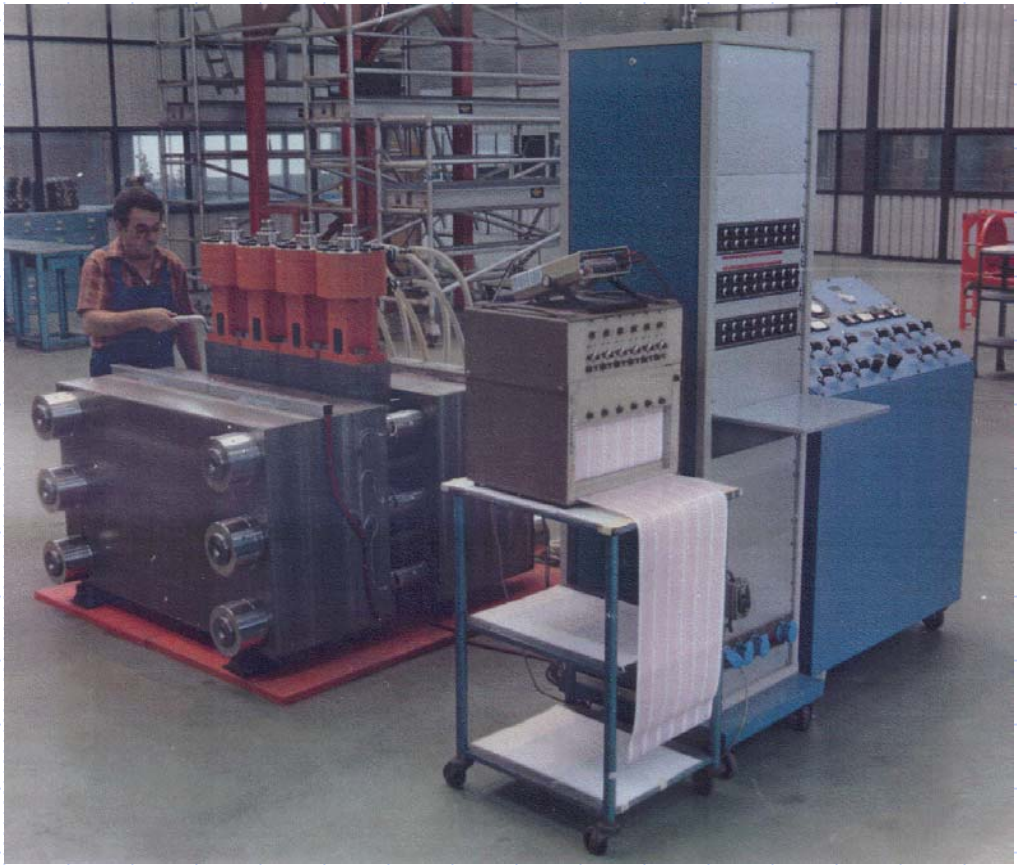
5. Ring Preload Jacking System

Background: Both the Wedged and the Bucked and Wedged TF coil designs use large steel rings outboard of the TF coils. The rings are pre-loaded at assembly using radial jacks to augment the wedge compression at the inboard faces of the TF coils and provide compression between the faces of the outboard intercoil structures during operation. The space available is very limited. Three jack concepts have been identified:

1. **A mechanical system (proposed for IGNITOR) consisting of opposing wedges**
2. **Stainless steel bladders with hydraulic fluid**
3. **Commercial "Enerpac" jacks**

R&D Task: Select one primary concept plus one back-up. Mock-up and test under expected operating conditions simulating assembly, cooldown, operational pressures, and temperatures.

IGNITOR Ring Preload Mechanism Design May Be Adoptable to FIRE



IGNITOR Preload Mechanism Being Tested

TF R&D Costs and Schedule

R&D Item	Schedule	Materials & Supplies $K	Engineering Hours	Total Cost $K (FY 02)
TF Conductor and Joining	February 2003-September 2004	521.76	1440	675.41
Criteria Development	October, 2002-September, 2004	64.02	5000	597.52
Radiation Resistant Insulation Development	October, 2002-September, 2004	170.72	3000	490.82
High Friction Insulation Characterization	October, 2003-September, 2004	85.36	1000	192.06
TF Mock Ups and Prototypes	October, 2004-September, 2006	640.20	1500	800.25
Critical Area Development	October, 2003-September, 2005	533.50	2000	746.90
			Total:	3502.96
			25.5% Contingency:	893.26
			Total with contingency:	**4396.22**

FIRE PF R&D Costs and Schedule

R&D Item	Schedule	Materials & Supplies $K	Engineering Hours	Total Cost in $K 2002
PF Conductor and PF Mfg. Methods Development	February 2003-September 2005	122.71	720	212.90
Low Friction Insulation Materials Characterization	October, 2003-September, 2004	224.07	800	309.43
PF Mock Ups for Vendor Qualification	October, 2004-September, 2005	400.13	1000	506.83
			Total:	1029.15
			25.5% Contingency:	262.43
			Total with contingency:	**1291.59**