The SMC (Short Model Coil) Nb_3Sn program:

Computations and comparison with strain gauges measurements

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Outline

1. The FE Model
2. Position of strain gauges
3. Assembly configurations
4. Mechanical measurements VS. FE model
5. Mechanical measurements
6. Conclusions

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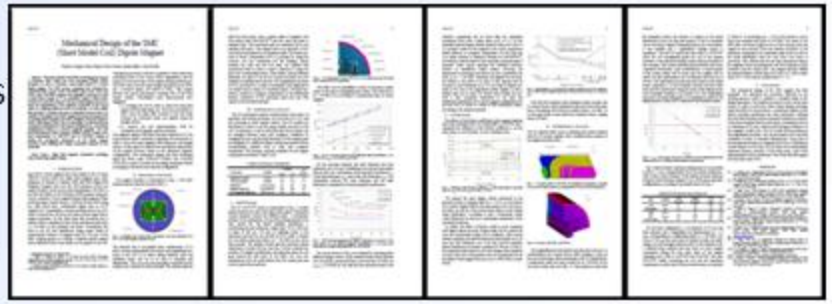
Magnetic Design

- The magnetic field computations have been cross-checked between CAST3M, OPERA, and ANSYS
- Peak field B_{max} located in the center of the straight section of the racetrack
- Significant margin compared to the ends
- Two end spacers on each side of the coil pack
- Use of non-magnetic pole

P. Manil, *et al.*, "Magnetic design and code benchmarking of the SMC (Short Model Coil) dipole magnet," *IEEE Trans. Applied Superconductivity*, vol. 20, issue 3, pp. 184-187, 2010

Mechanical Design

- The mechanical computations have been cross-checked between CAST3M and ANSYS
- Shell-based structure using bladders and keys
- Lateral pre-stress is applied by pressurized bladders
- Axial pre-stress is provided by two aluminum rods
- Stresses remain controlled in every part of the assembly



F. Regis, *et al.*, "Mechanical design of the SMC (Short Model Coil) dipole magnet," *IEEE Trans. Applied Superconductivity*, vol. 20, issue 3, pp. 204-207, 2010

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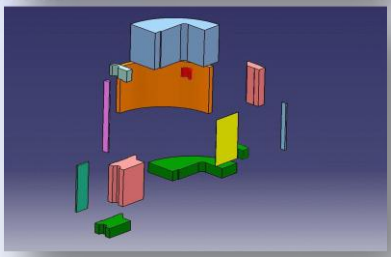
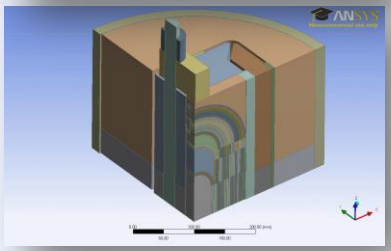
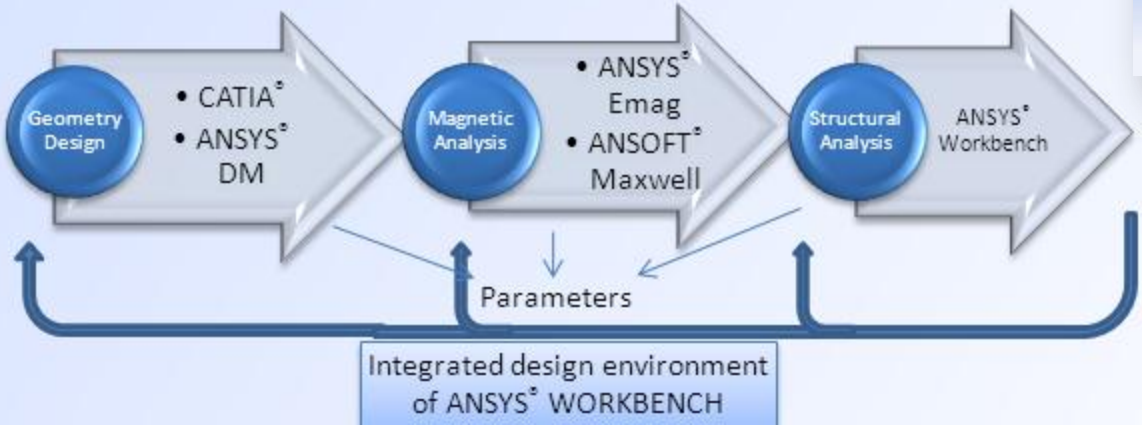
- Transition from ANSYS Classic to ANSYS Workbench

Why?





- Ability to control all used software from the same platform.
- Direct use of *CATIA* files along with their parameters . Bi-directional linkage to *ANSYS Workbench*.
- Ability to control all parameters and the expected results , through the *Design Exploration Table*.
- Fully parametric design that allows any geometry changes to be applied directly .
- The implementation of *ANSOFT MAXWELL* in ANSYS Workbench allows direct transfer of the Lorentz Forces, between models with different meshes.



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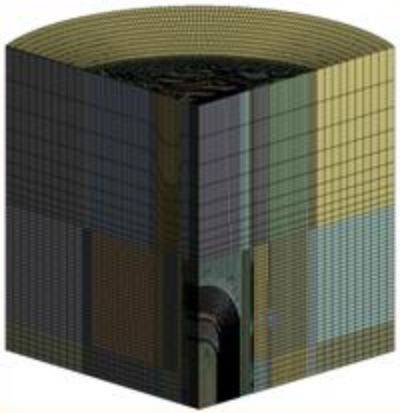
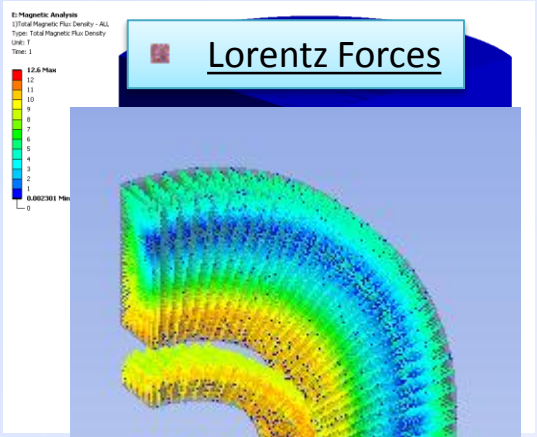
Computations and comparison with strain gauges measurements

3D Magnetic Analysis

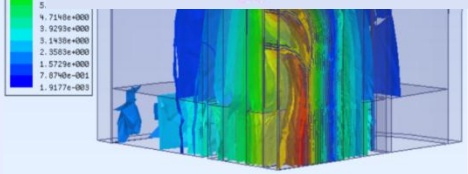
- Mesh
- Magnetic Flux Density
- Load Line @ 4.2 K

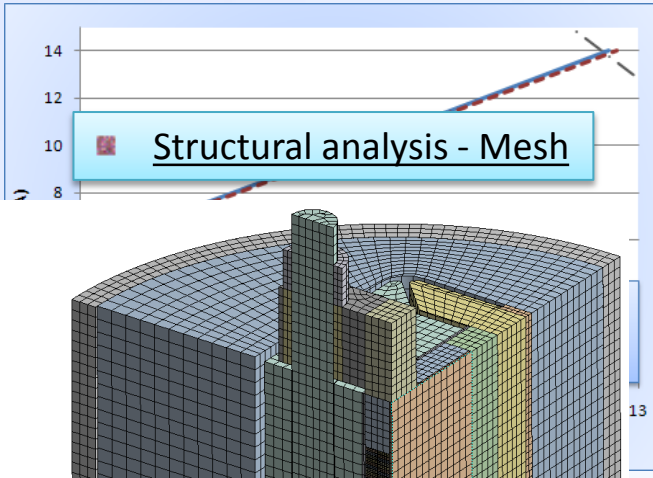
ANSYS





- Lorentz Forces



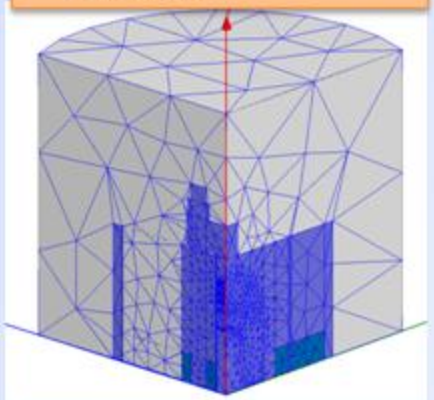


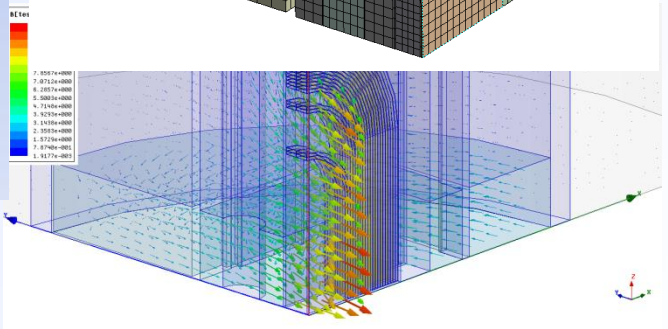
- Structural analysis - Mesh

Different:

- Mesh densities
- Element types
- Solution setups
- Algorithms

MAXWELL





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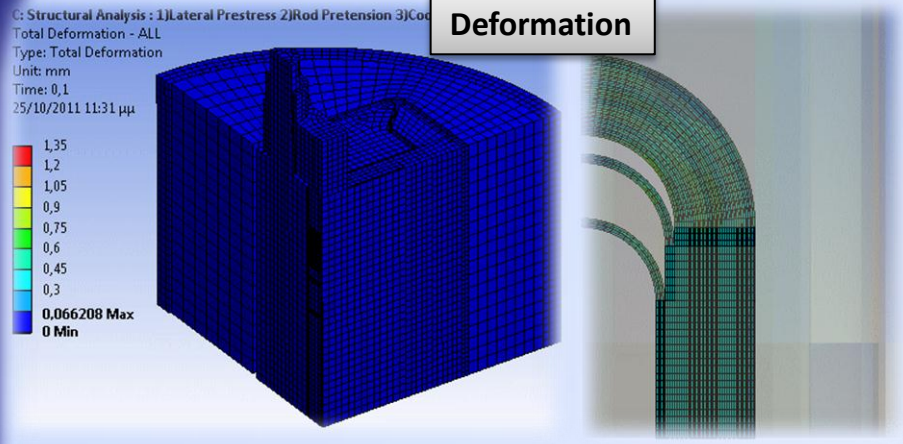
Computations and comparison with strain gauges measurements

3D Structural Analysis → SMC3 Assembly June 2011

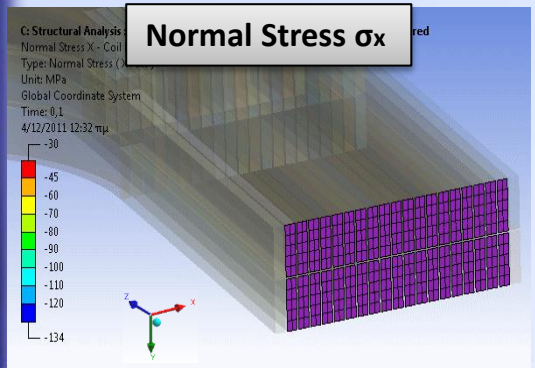
4 Load Steps :

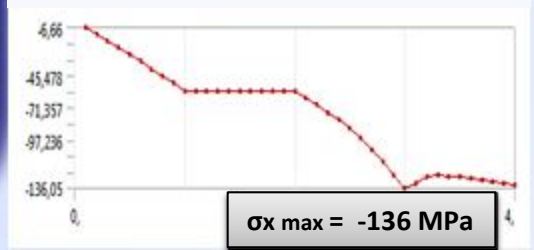
1) Lateral Pre-stress
2) Axial Pre-stress
3) Cool Down
4) Powered @ 12.6 T

Deformation



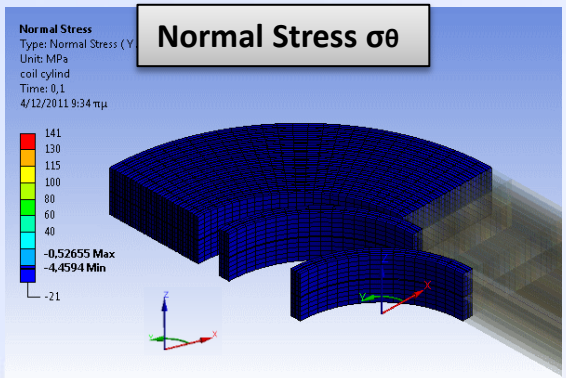
Normal Stress σx

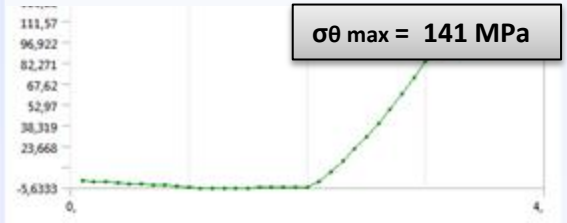




σx max = -136 MPa

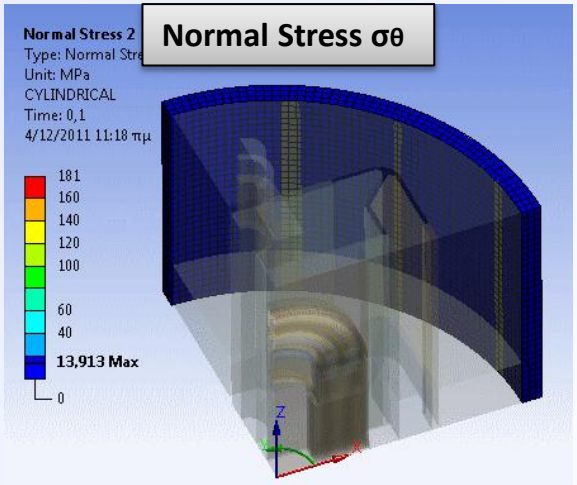
Normal Stress σθ





σθ max = 141 MPa

Normal Stress σθ



σθ max = 181 MPa

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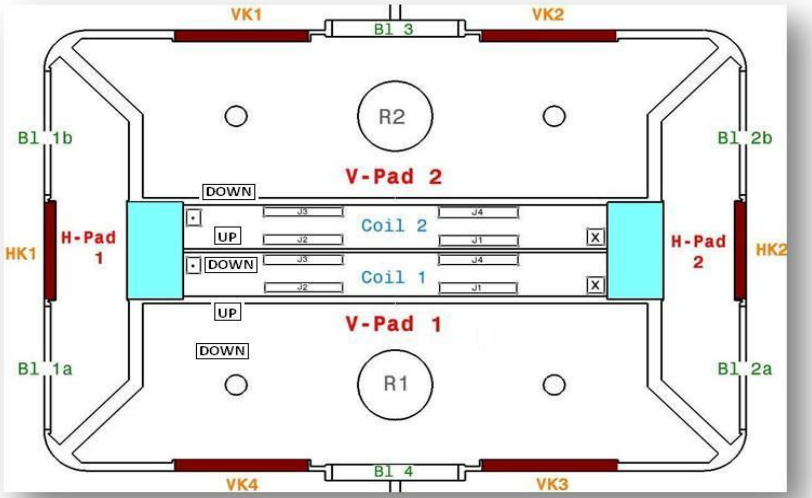

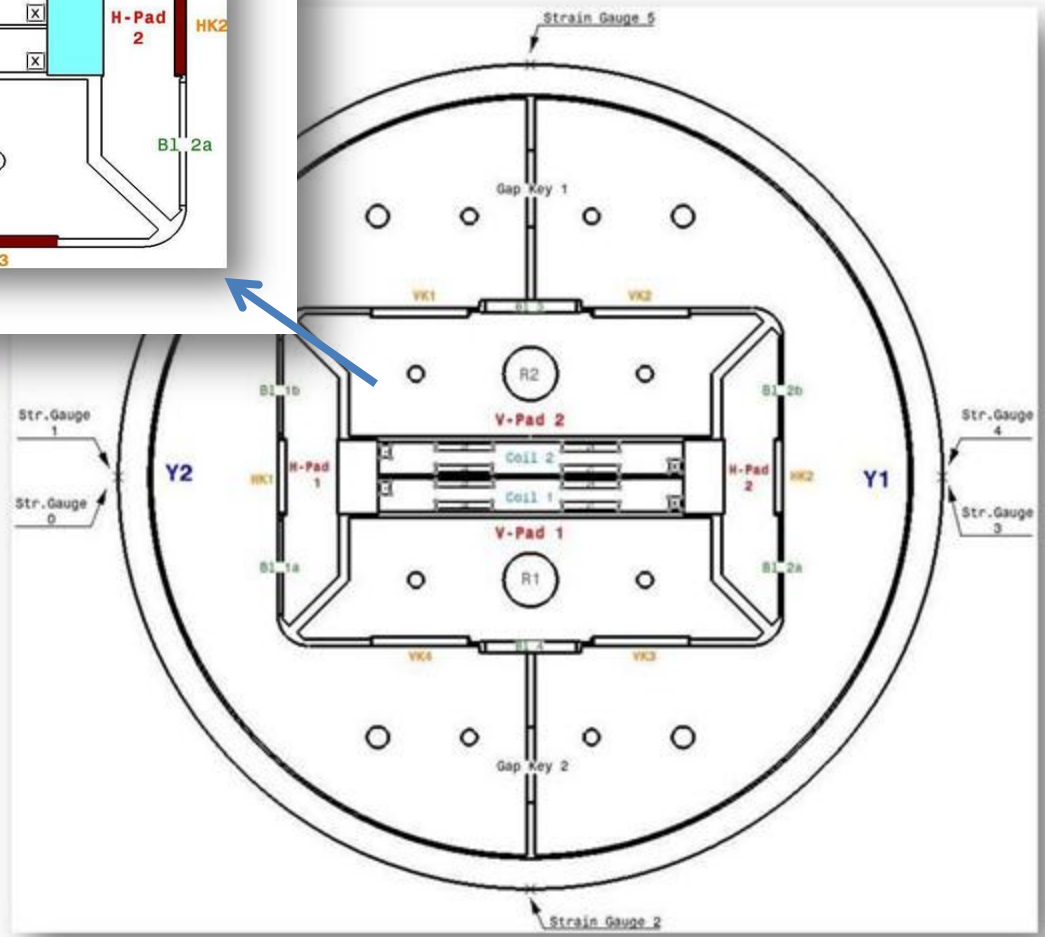

Acronyms Explanation	
J	Strain Gauges @ Coil Packs Connectors
V-Pad	Vertical Pad
H-Pad	Horizontal Pad
VK	Vertical Keys
HK	Horizontal Keys
Bl	Bladders
R	Rods
Y	Yoke Half
Gap Keys	Gap Keys @ Yoke
. x	Current Flow Direction

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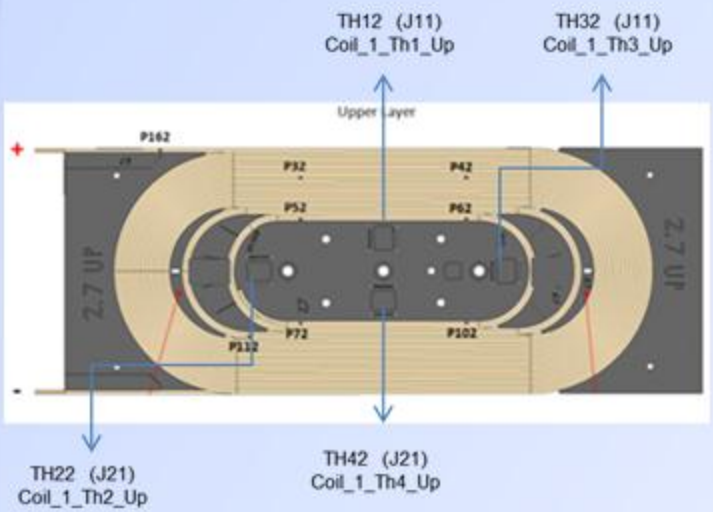
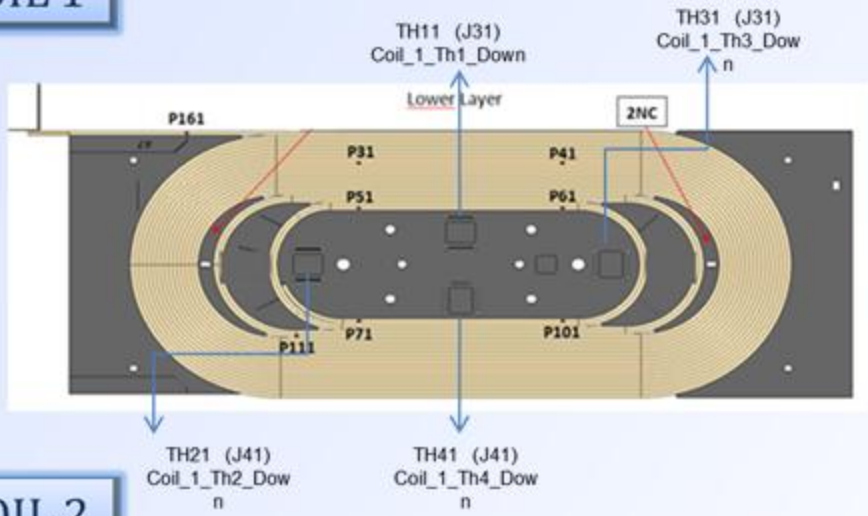
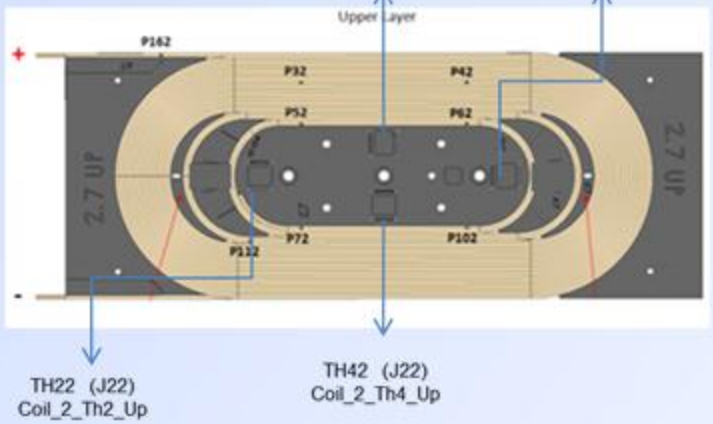
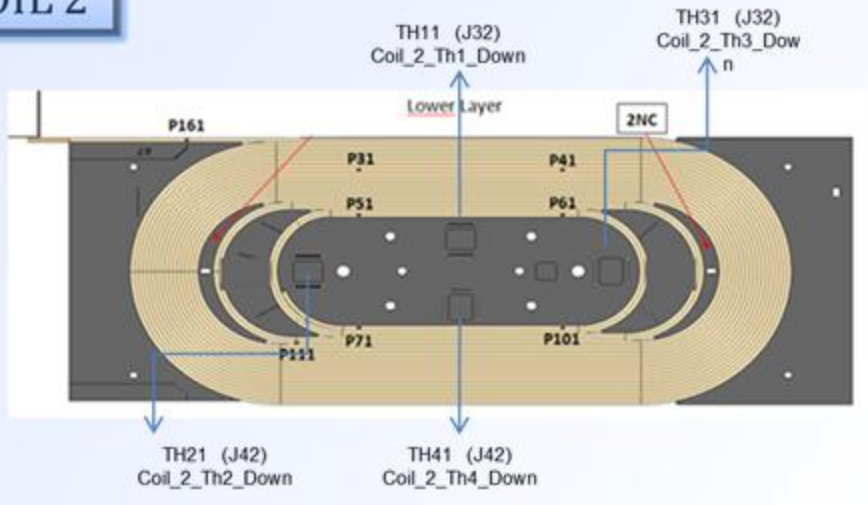
COIL 1





COIL 2





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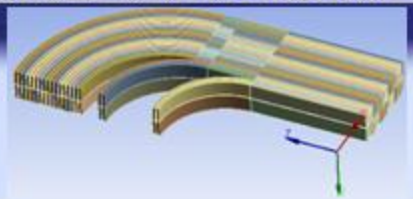
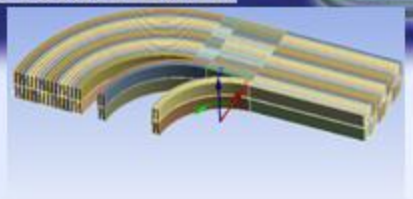
SMC3 Assembly June 2011

SMC3 Assembly September 2011

SMC3 Assembly November 2011

Computations and comparison with strain gauges measurements





	FEM/Measured (Avg.) Shell-Azim.strain [μm/m]			FEM Coil stress (Straight Section - MidPlane) [Mpa]									FEM Coil stress (Heads) [Mpa]								
Shell, 0,3_ Thet Avg.	300K	4.2K	Iss	300 K			4.2 K			Iss			300 K			4.2 K			Iss		
				σx	σy	σvm	σx	σy	σvm	σx	σy	σvm	σr	σθ	σvm	σr	σθ	σvm	σr	σθ	σvm
500 →	500 / 500	1386 / 1320	1395 / 1275	-55	-17	44	-133	-33	145	-130	-57	155	-47	-5	47	-148	84	196	-125	141	185
340 →	340 / 340	1100 / 1196	1150 / 1228	-34	-14	24	-123	-28	132	-116	-53	140	-30	-4	30	-141	88	187	-120	145	175
673 →	673 / 673	1598	1608	-68	-20	55	-146	-38	154	-146	-61	165	-58	-7	59	-157	82	205	-133	139	193

FINAL CONDITION @ 293 K – SMC3 June 2011

VK 1 (mm)	VK 2 (mm)	VK 3 (mm)	VK 4 (mm)	HK 1 (mm)	HK 2 (mm)	Rod 1 (μm/m)	Rod 2 (μm/m)	Shell_0_T (μm/m)	Shell_3_T (μm/m)
6.65	6.9	6.5	6.8	10.5	10.5	82	44	541	477

FINAL CONDITION @ 293 K – SMC3_ November 2011

VK 1 (mm)	VK 2 (mm)	VK 3 (mm)	VK 4 (mm)	HK 1 (mm)	HK 2 (mm)	Rod 1 (μm/m)	Rod 2 (μm/m)	Shell_0_T (μm/m)	Shell_3_T (μm/m)
6.65	6.8	6.5	6.8	11	10.7	55	32	706	648

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Quench History

SMC3 Assembly June 2011

No change in the assembly configuration

SMC3 Assembly September 2011

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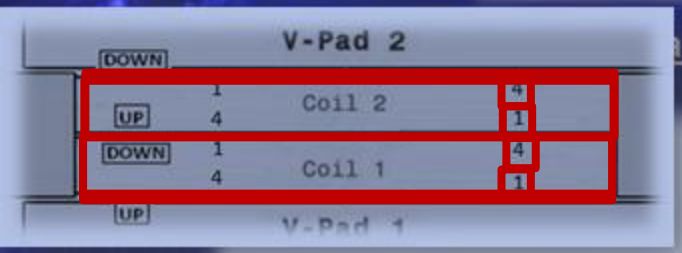
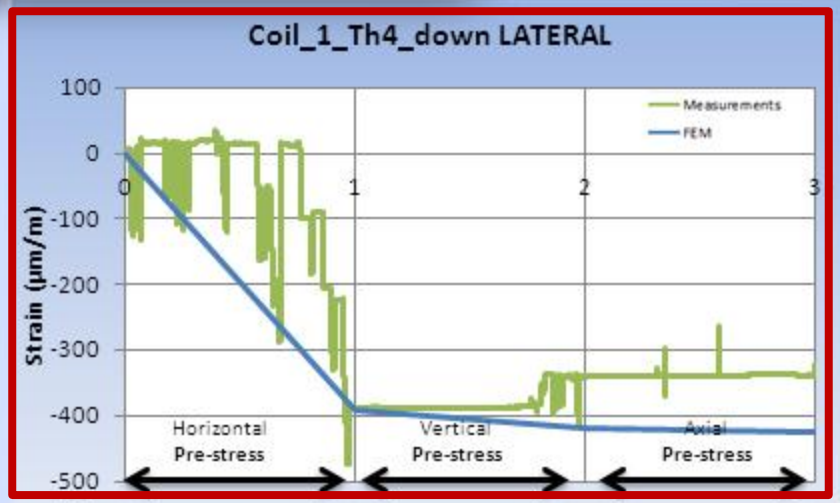
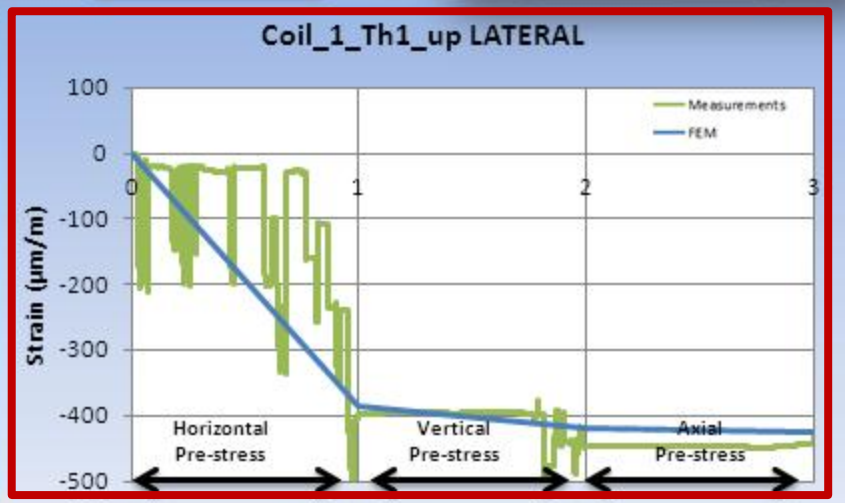


and comparison with strain gauges measureme

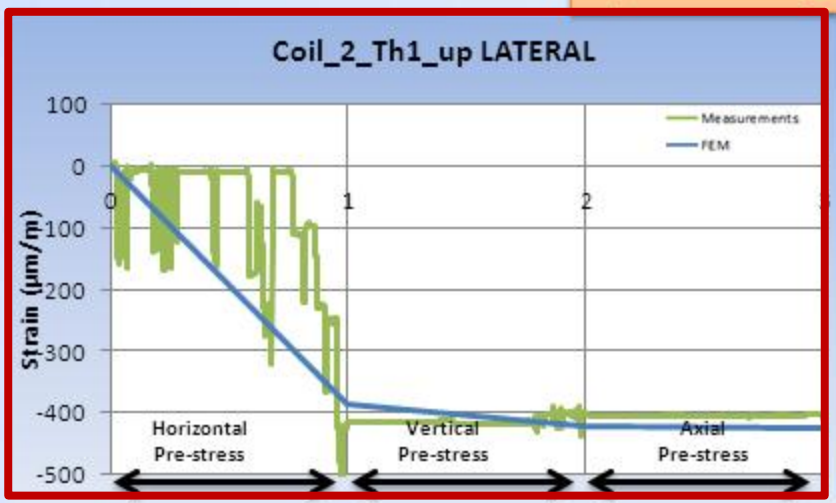
Mechanical Measurements Vs. FEM

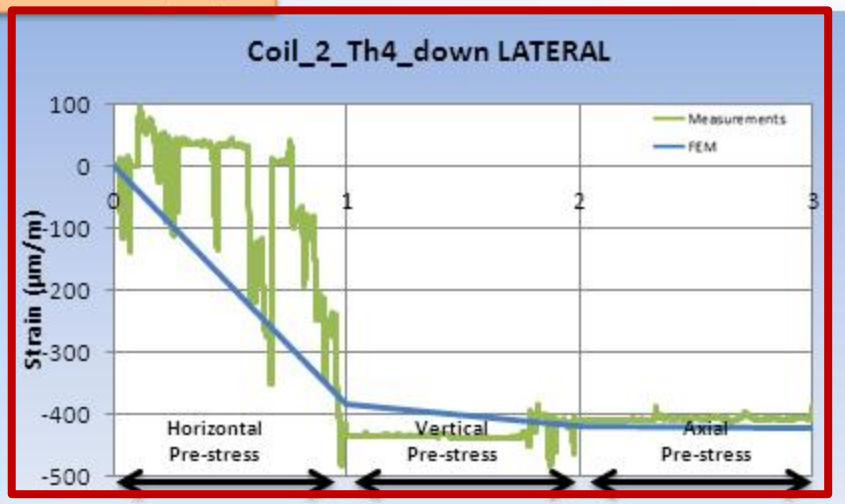
SMC3 Assembly
June 2011





Expected Value @ 300K : ~ -420 µm/m





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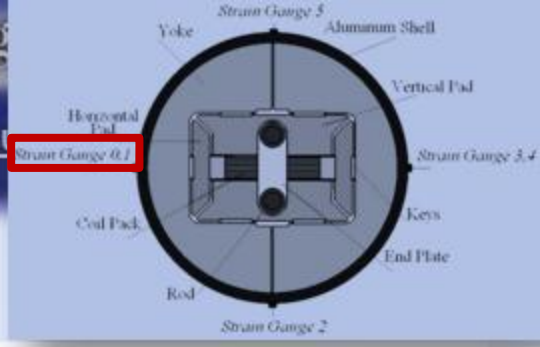
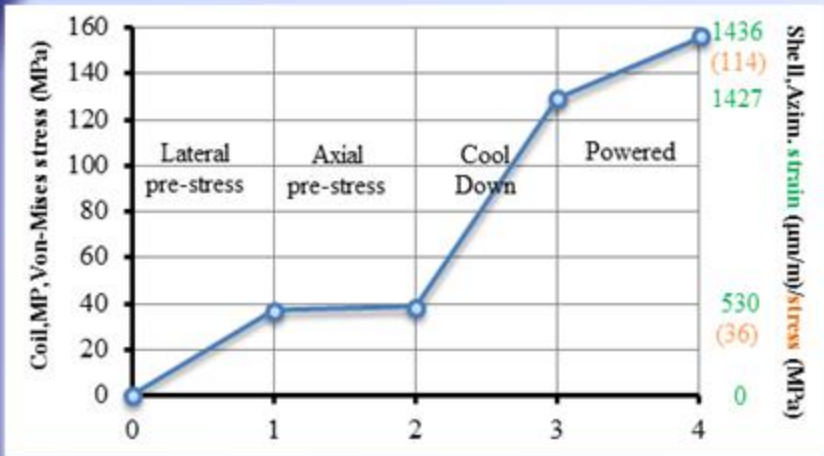
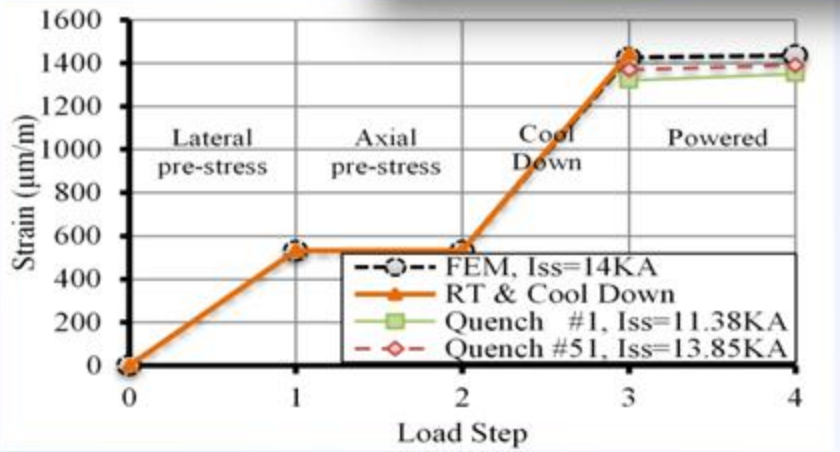


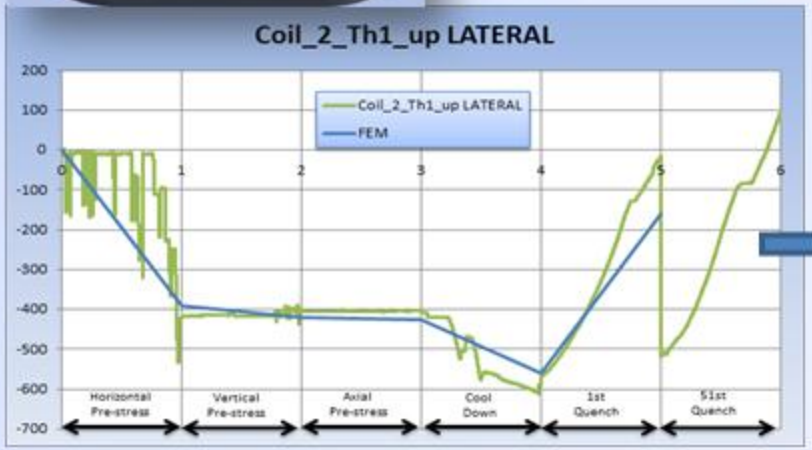
Shell

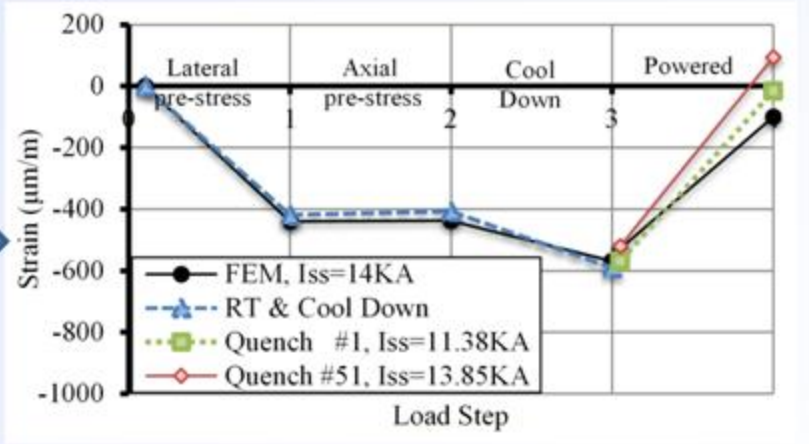




Frictionless Model !!!

Island





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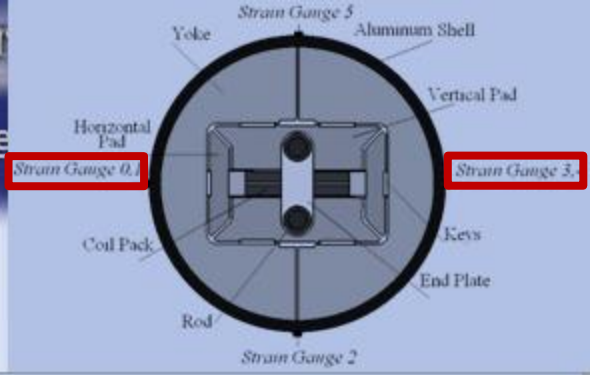
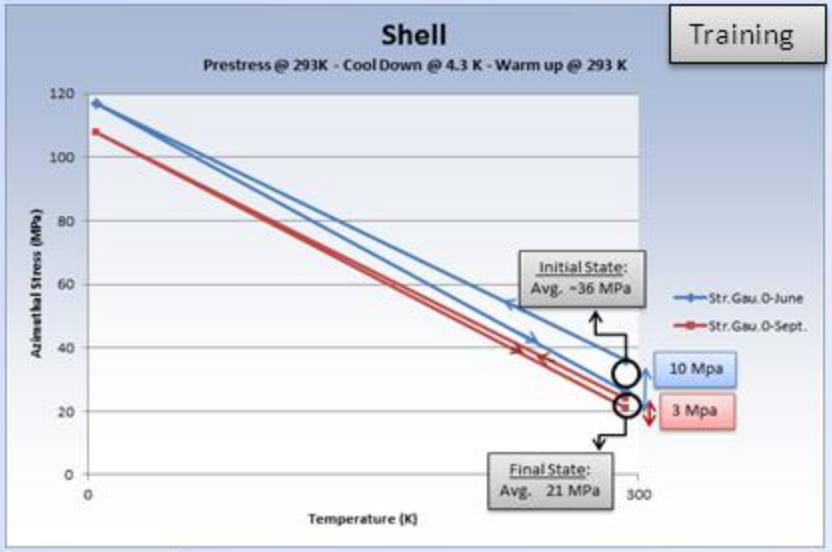
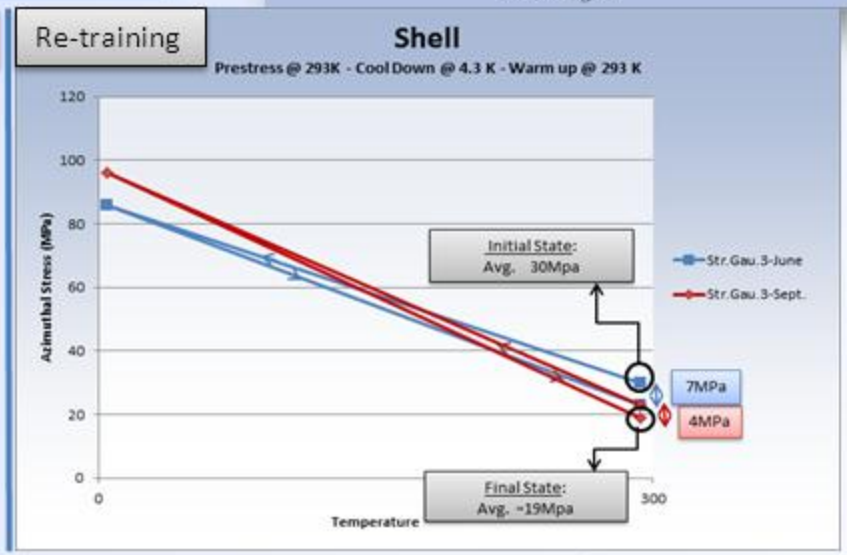
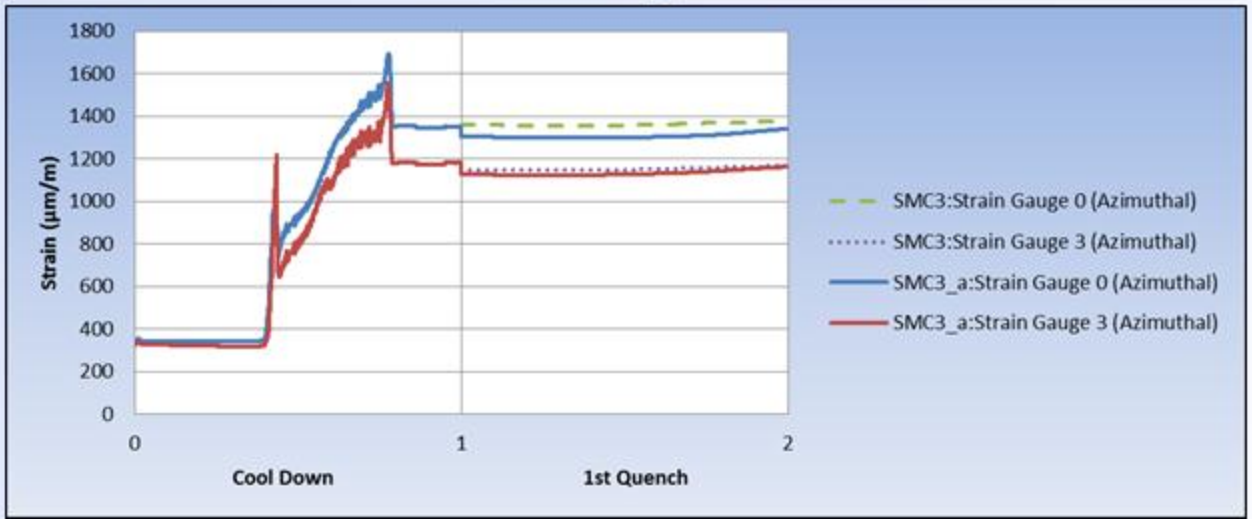
Mechanical Measurements









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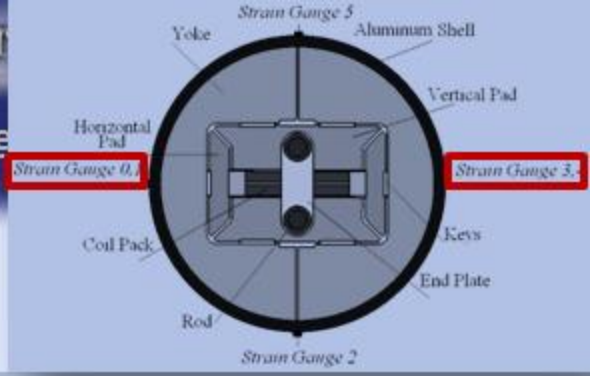
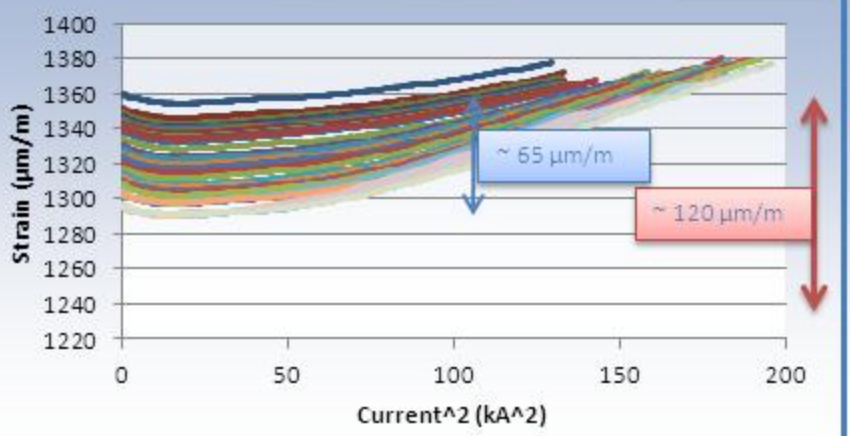
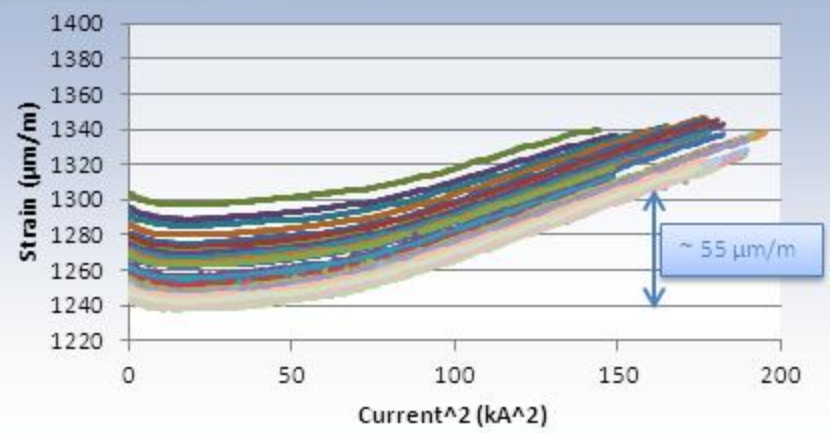
Mechanical Measurements

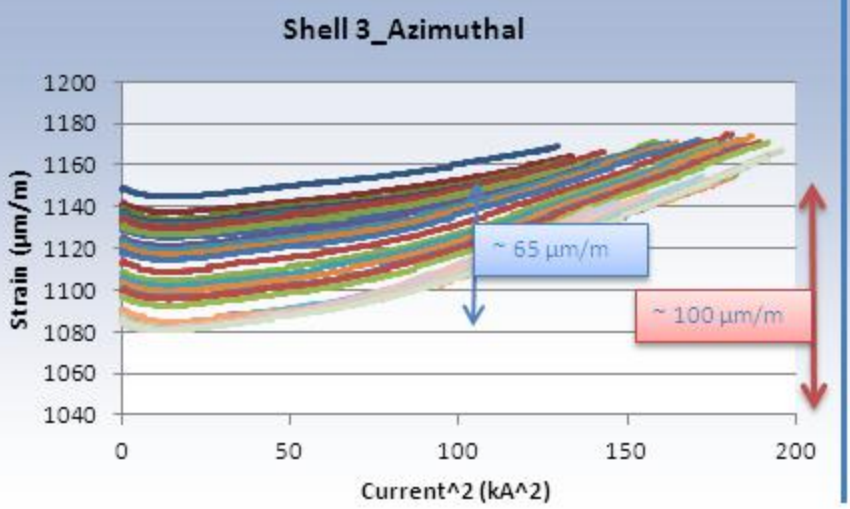


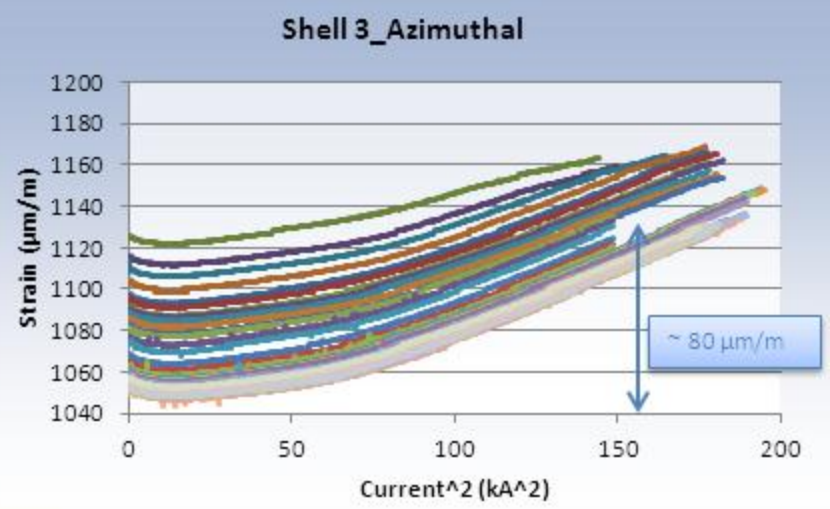
Training

Re-training









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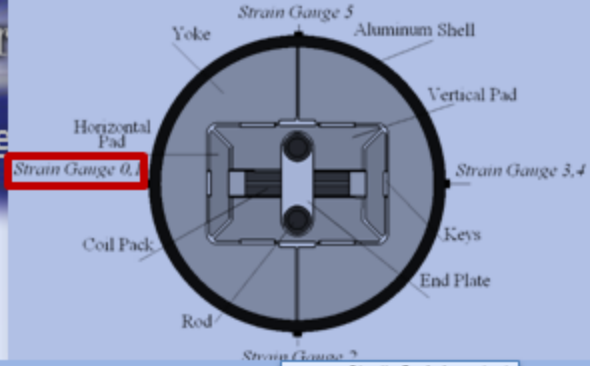
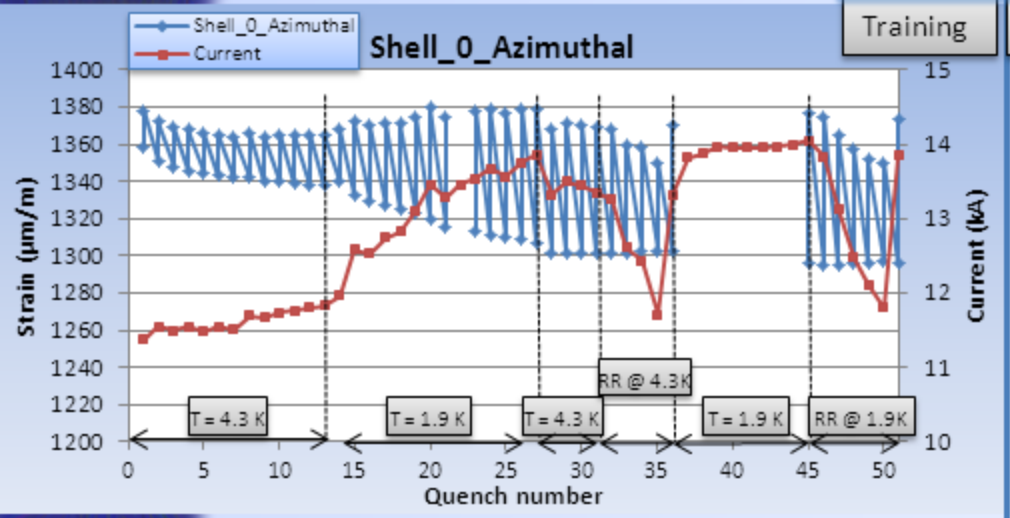
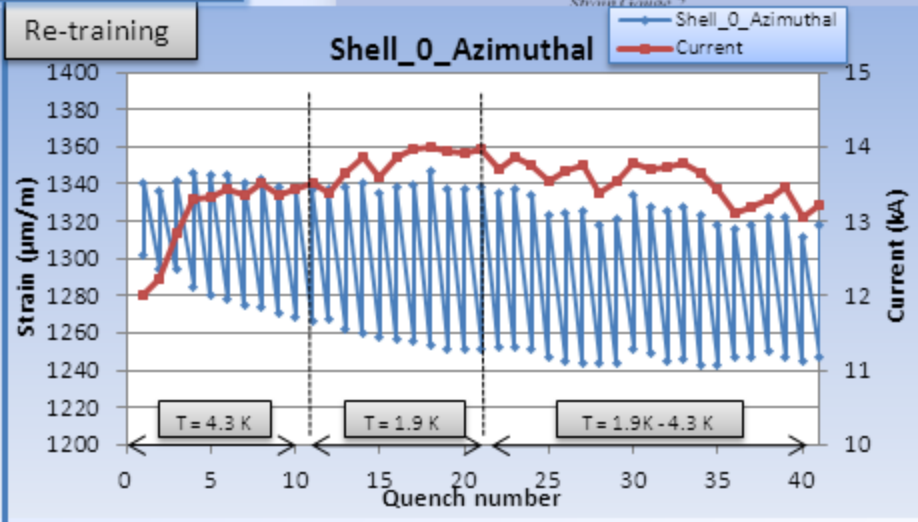
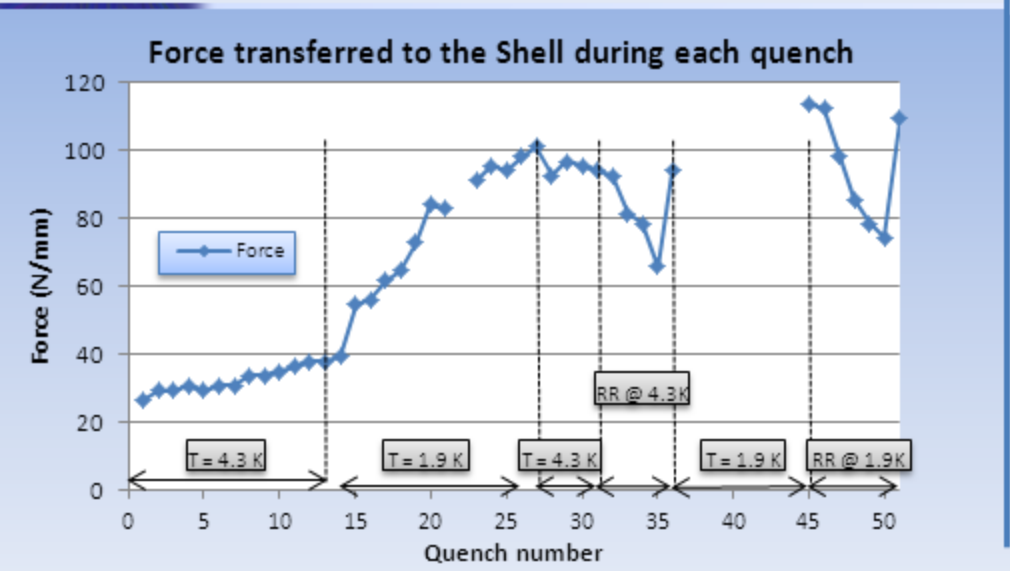


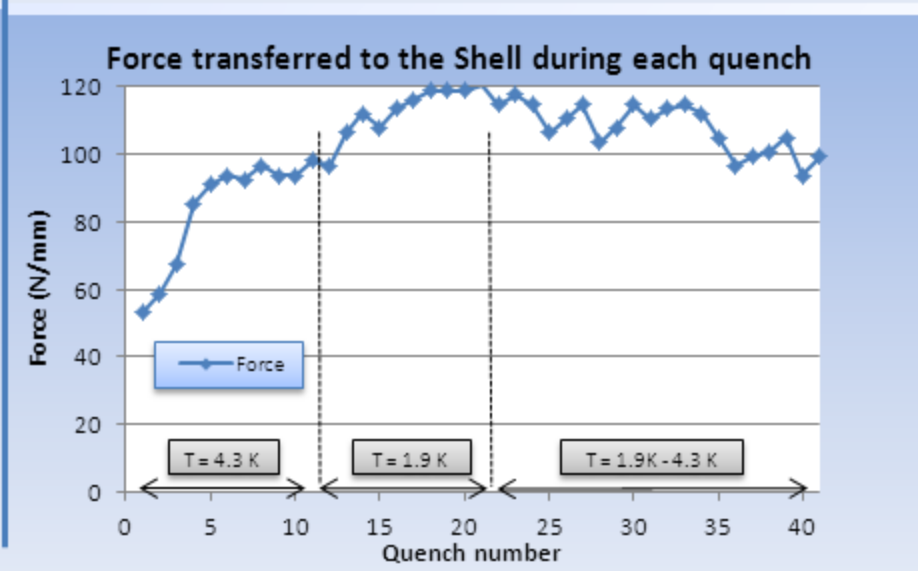
Mechanical Measurements

Training | Re-training







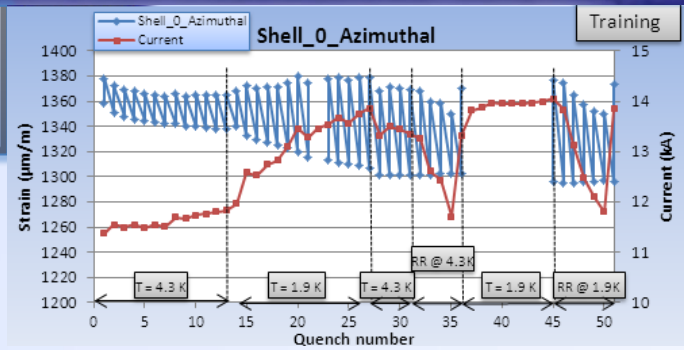


The SMC (Short Model Coil) Nb_3Sn program:

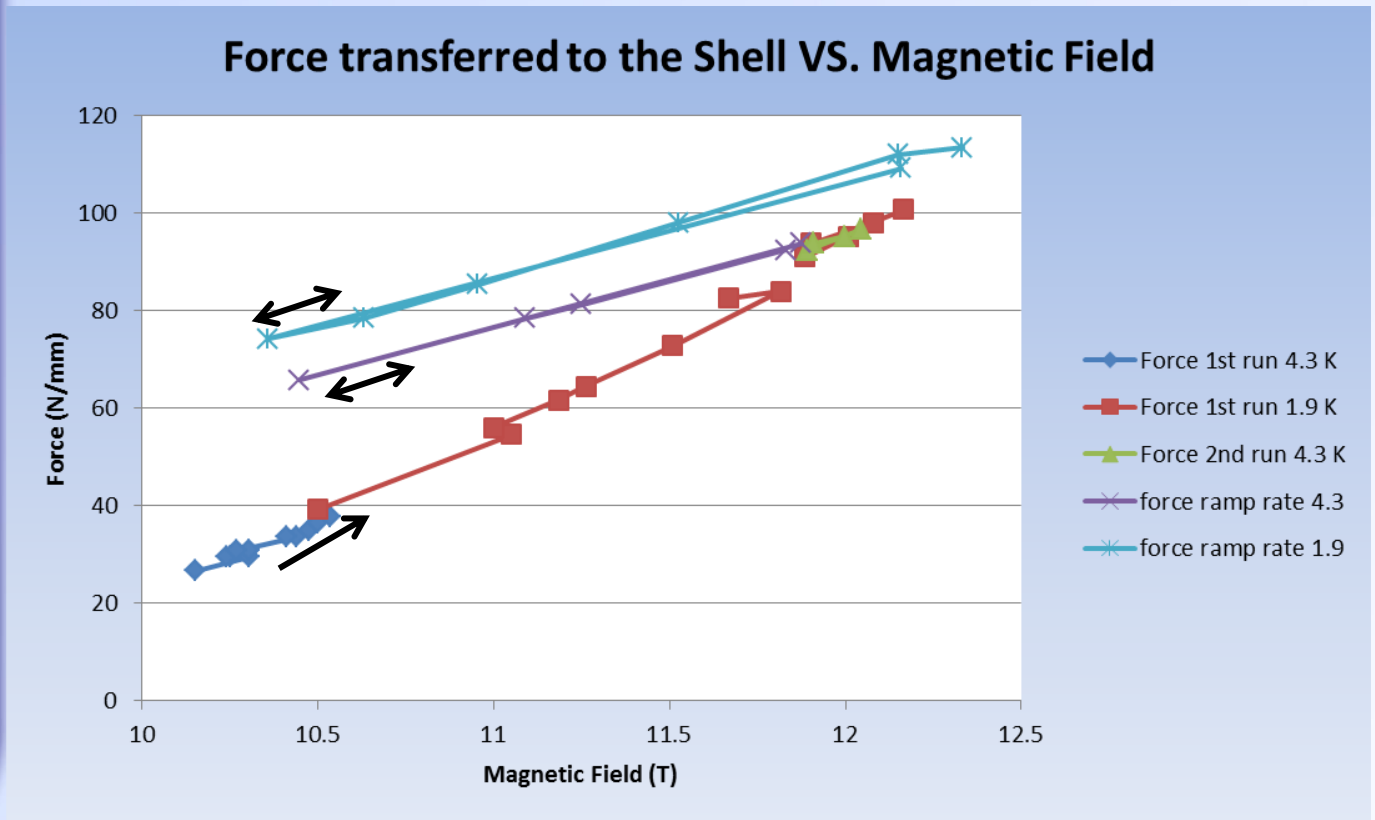
Kokkinos Charilaos
TE-MSC-MDT

Computations and comparison with strain gauges measurements

Mechanical Measurements



SMC3 Assembly
June 2011



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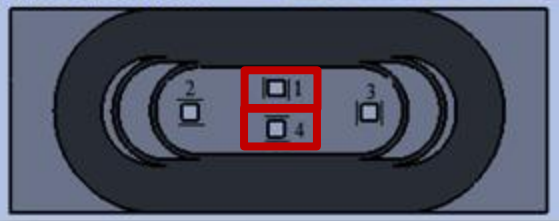
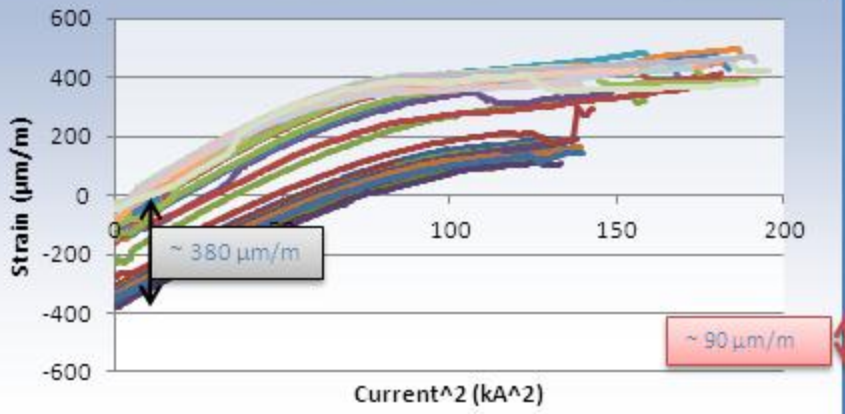
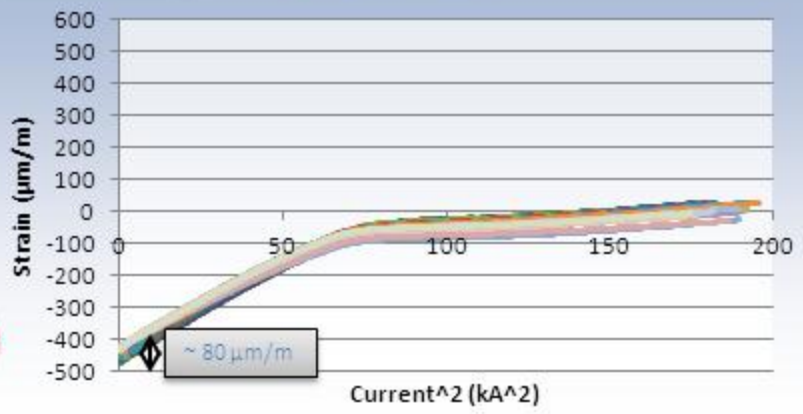
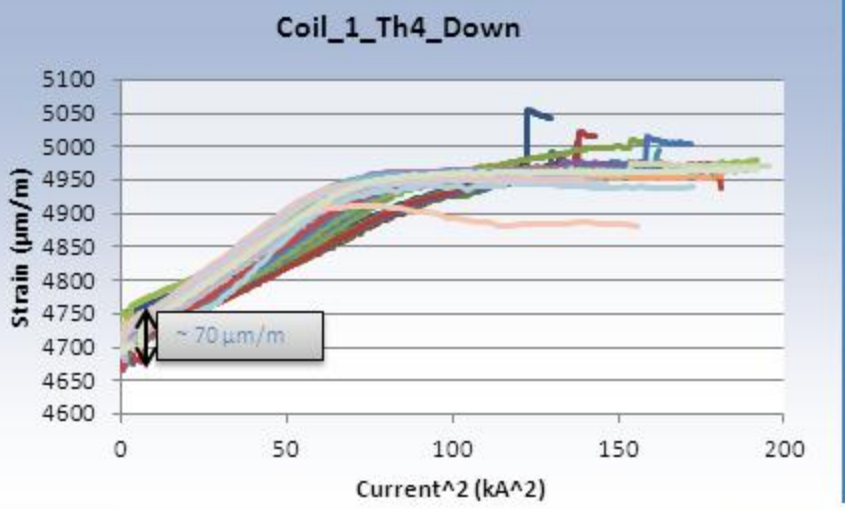


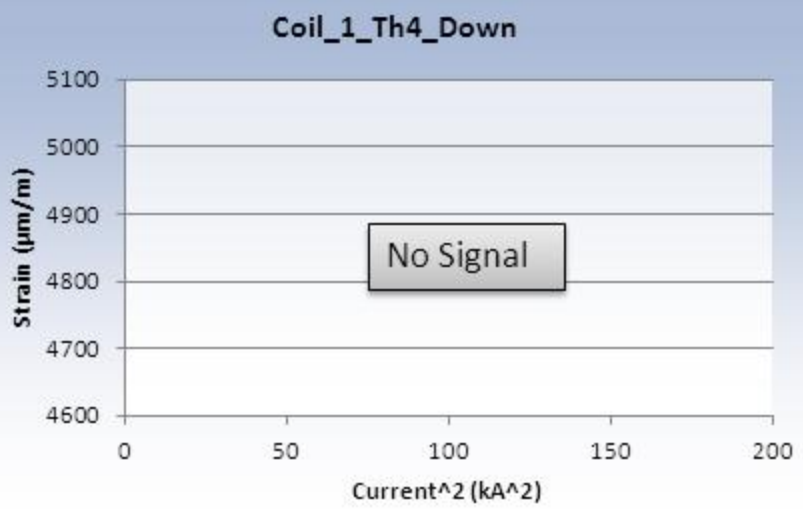
Training

Re-training









The SMC (Short Model Coil) Nb_3Sn program:

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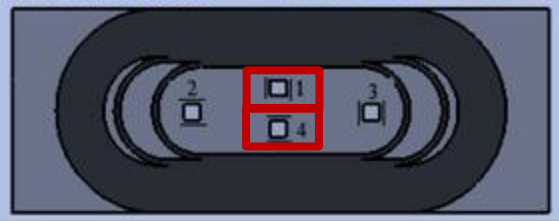
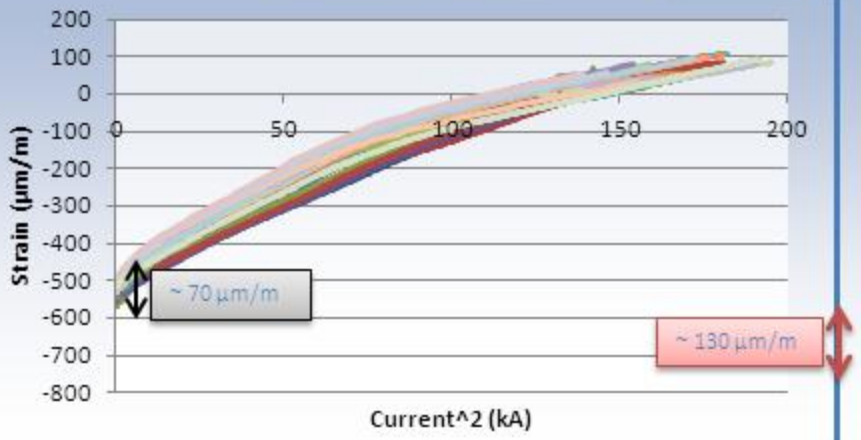
Computations and comparison with strain gauges measurements

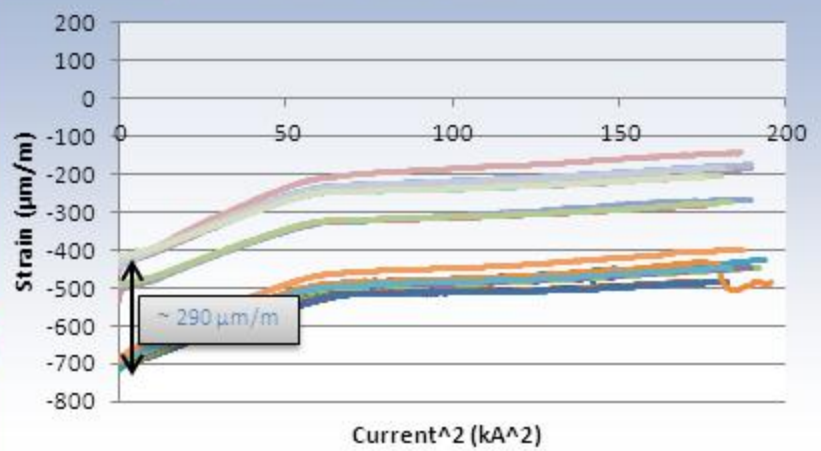
Mechanical Measurements

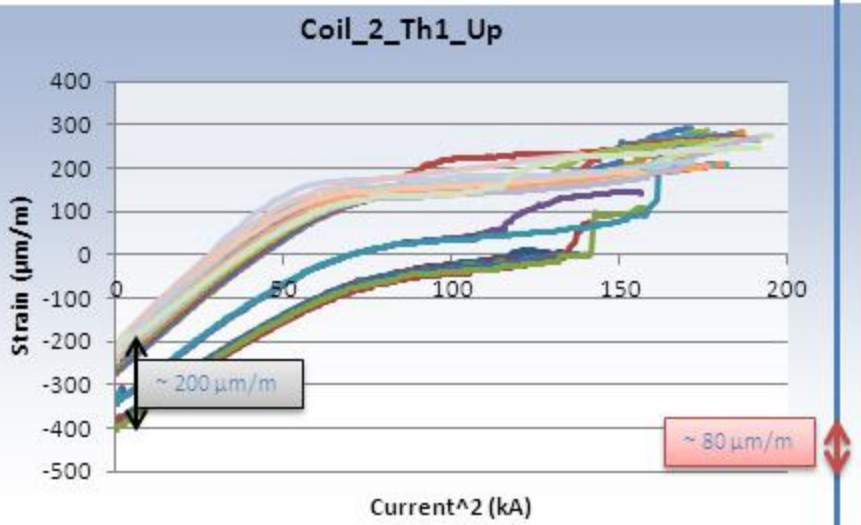


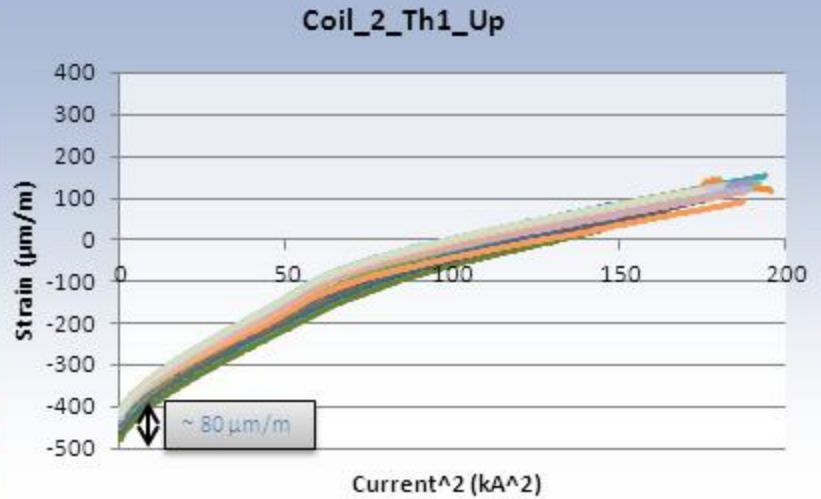
Training

Re-training





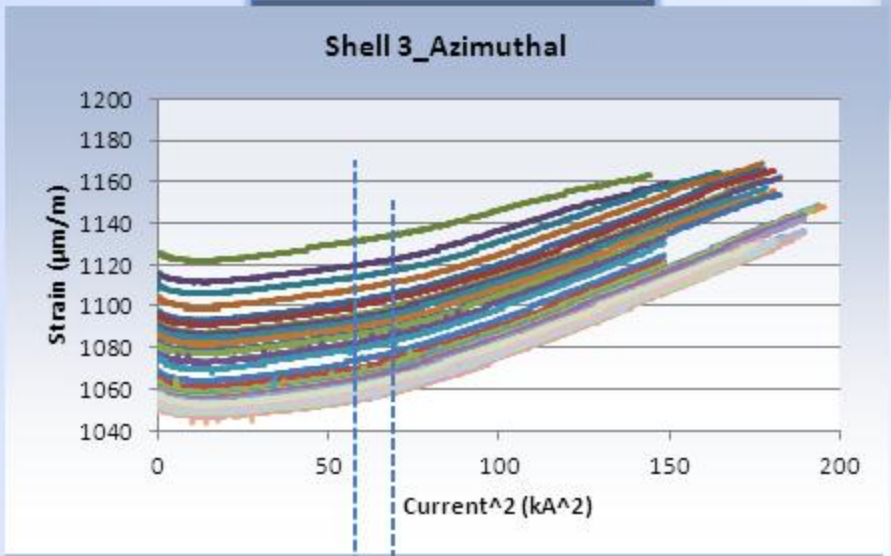


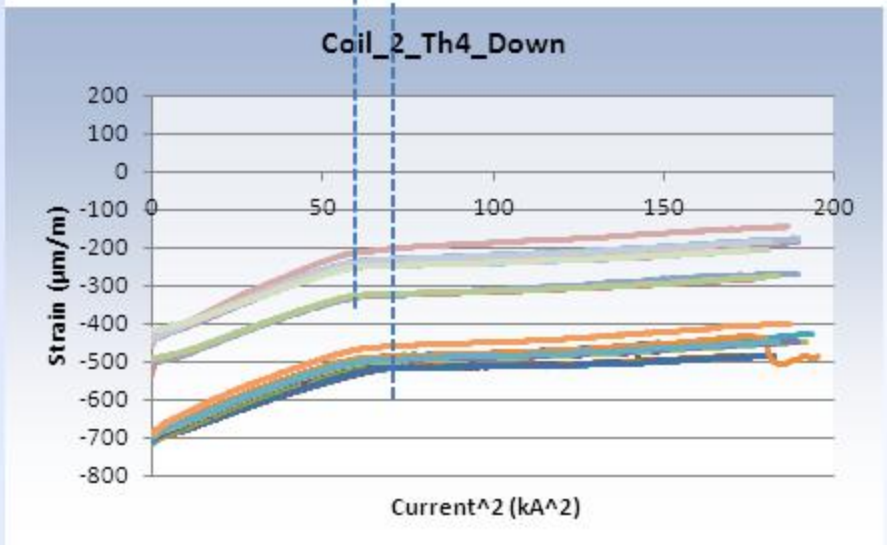


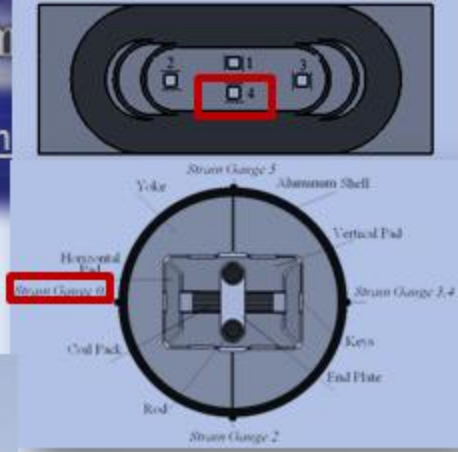
Computations and comparison with strain gauges measurem

Mechanical Measurements

SMC3 Assembly
September 2011







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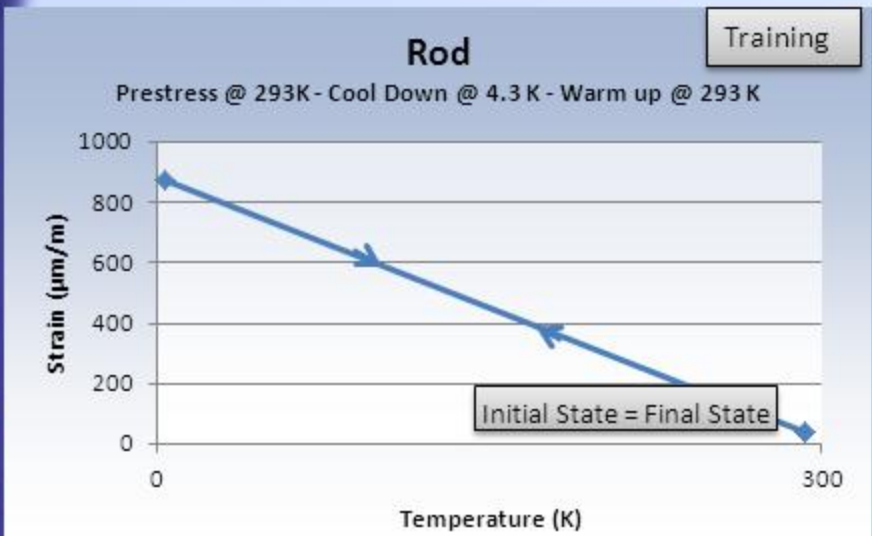
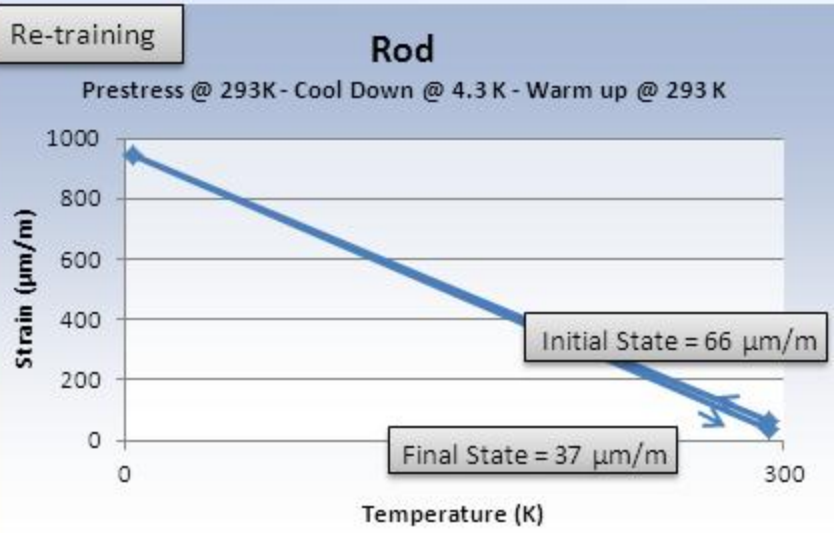
Computations and comparison with strain gauges measurements

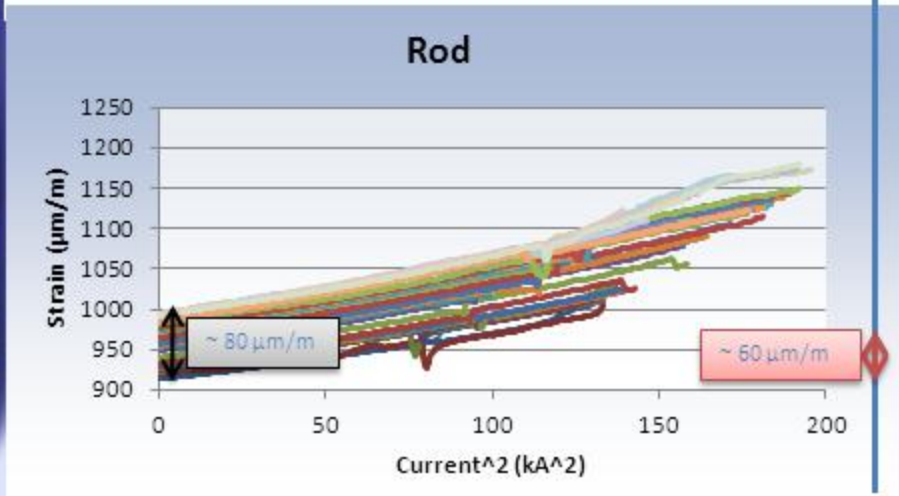
Mechanical Measurements

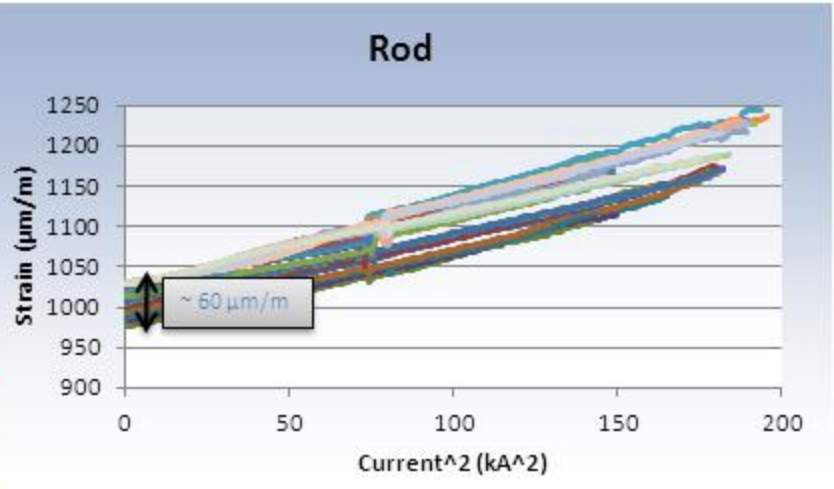
Training



Re-training







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Conclusions

- **Model:** The results between the structural analysis and the measured, from the strain gauges, values during all tests of the SMC, have been cross-checked and proved to have a good relation.
  - ***Further improvements:***
    - Include Friction
    - Non-linear material properties
- **Strain gauges:** Proved to have good sensitivity throughout the test
  - ***Further improvements:***
    - Treatment procedure
    - Number of strain gauges
    - Understand behavior at 4.3K – 1.9K (correction factor?)
- **Results:** Stress loss, possibly due to friction and creep of the coils.
  Positive effect of Pre-stress increase during the last test
  Negligible effect of axial pre-stress in the magnet's performance
- **Future tasks:** Data analysis of the latest test, in the same manner.

THANK YOU
FOR YOUR ATTENTION

KOKKINOS Charilaos
CERN
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