3MOrC1-04

Essential Design, Construction and Test Elements of ITER Axial Insulation Breaks

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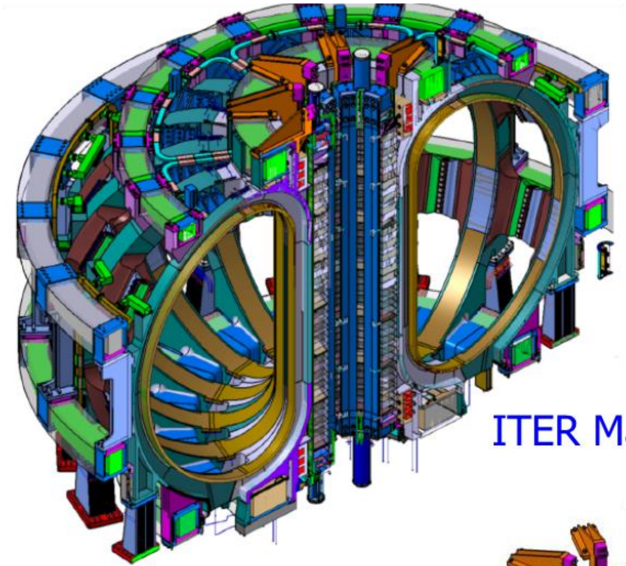
Outline

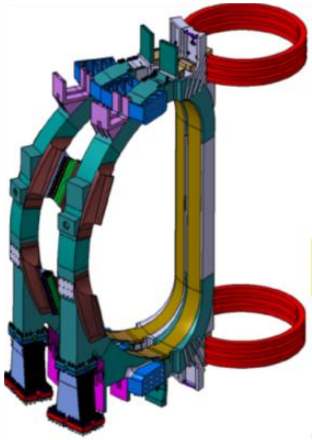
- Purpose and Need in ITER Magnets
- Conceptual design
- Specification Outline
  - Mechanical, Electrical, Leak and Pressure aspects
- Critical Design Areas and Influence of Composite Properties
  - Bonded Joints and Joint Integrity
- Realisation of concept and results
  - (with IPR limitations)
- Summary and conclusions

ITER Magnets

- The ITER magnet system is made up of
  - 18 Toroidal Field (TF) Coils,
  - a 6-module Central Solenoid (CS),
  - 6 Poloidal Field (PF) Coils,
  - 9 pairs of Correction Coils (CC's).

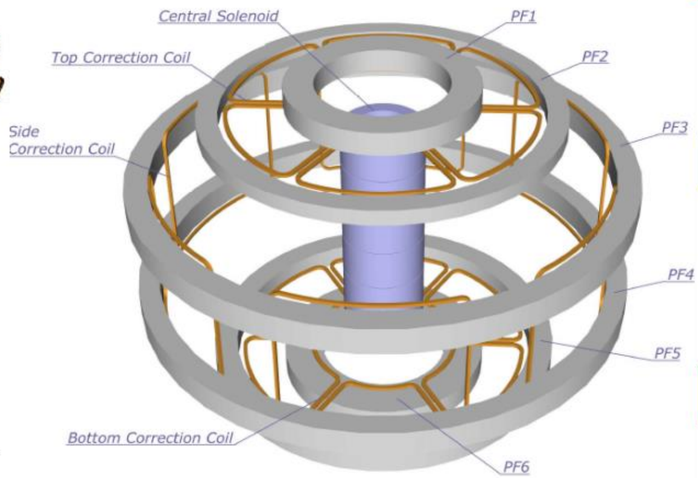


ITER Magnet System



Pair of TF Coils

CS Coil

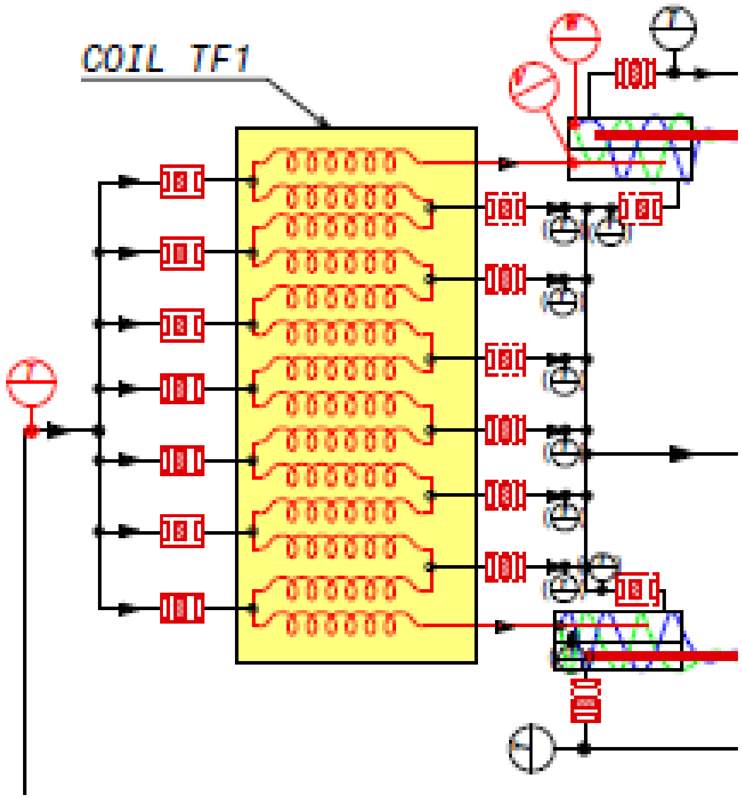


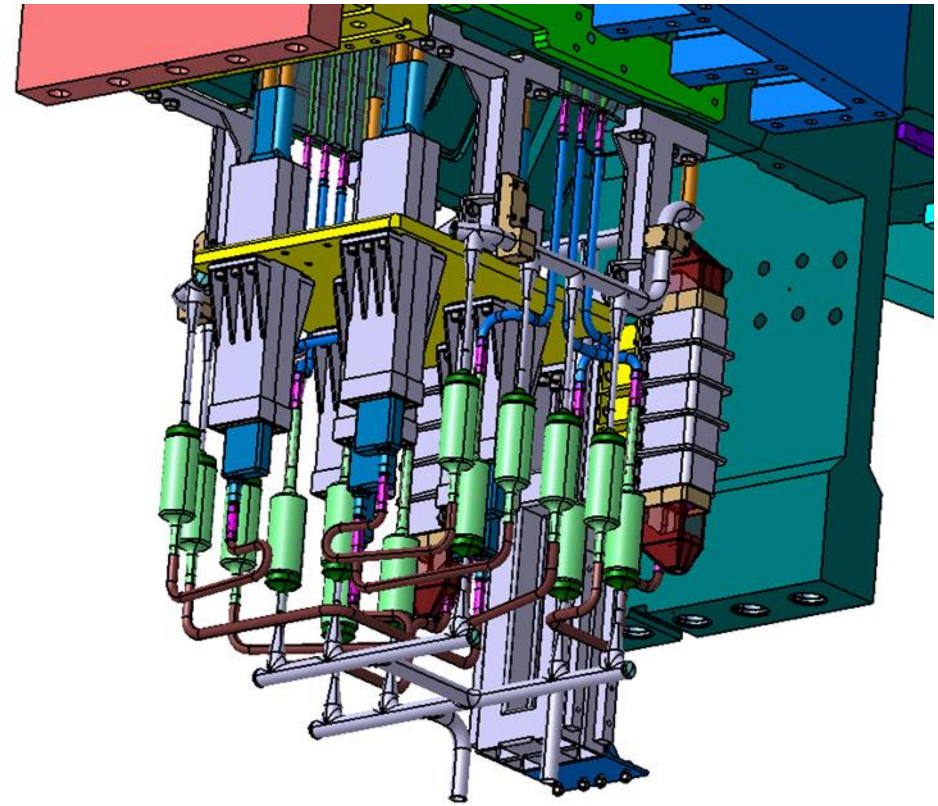
PF Coils & CC's

Purpose and Need

- Axial insulation breaks must electrically isolate the cryogenic distribution system from the high voltage of the ITER magnets and bus bars.
- Cable-in-conduit conductors and the supercritical helium distribution system are **electrically connected**
- The pulsed magnets of ITER experience a rapid rise in voltage
- Under some conditions electric potentials may rise to **28kV** in some of the magnets
- Possible high internal pressures
  - Quench pressure : 30 b

ITER Magnets and Insulation Breaks

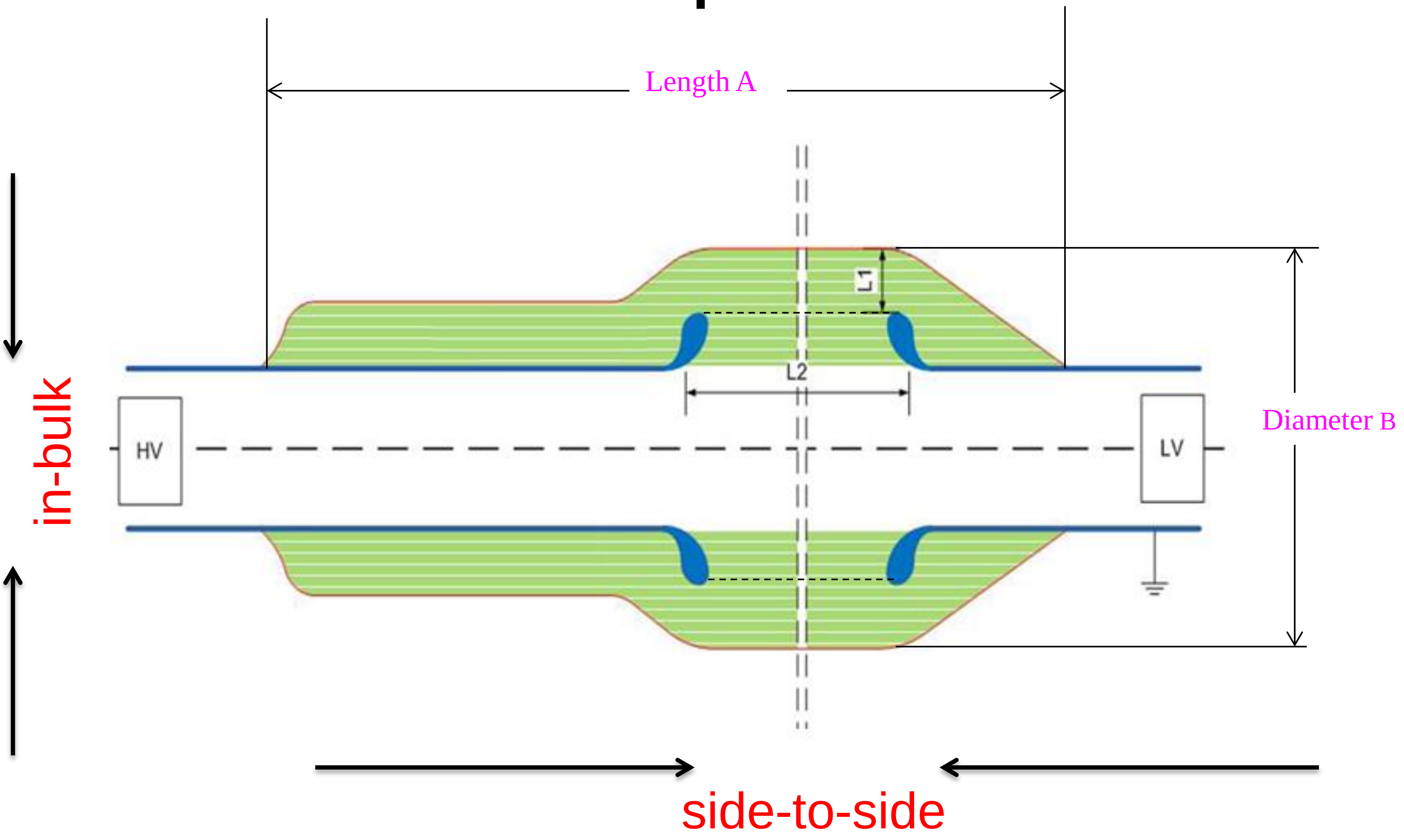




Insulation Break (IB)

About 1400 units required

A Conceptual View



Salient aspects from the specification

	Units	Value/Range	Note
Temperature of the inner fluid	[K]	4.2 - 6	Super-critical helium (^{4} He)
Pressure	[bar]	4 - 6	Absolute
Maximum pressure at quench	[bar]	30	Absolute
Maximum inner flow rate	[g/s]	20	Super-critical helium (^{4} He)
Maximum operating voltage level	[kV] DC	15	PF Coils
Worst case failure voltage	[kV] impulse	28 / 4	PF Coils/CC Coils
Outside pressure	[Pa]	$1x10^{-4}$	Presence of gaseous He in Paschen conditions

Summary of HV Levels for tests

Description	Voltage Level HV	Voltage Level LV
Type Test across L2 (‘side-to-side’, dry air)	56kV	8kV
Type Test across L1 (‘in-bulk’, dry air)	56kV	8kV
Routine Test L2 (acceptance test voltage + 20%)	35kV	6kV
Routine Test L1 (acceptance test voltage + 20%)	35kV	6kV
Acceptance Test L2 (‘side-to-side’, dry air)	29kV	5kV
Acceptance Test L1 (‘in-bulk’, dry air)	29kV	5kV

Mechanical requirements (design values)

- 2kN in tension and compression at 300K and 77K
- Bending moments of 100N.m at 300K and 77K
- Torsion 100N.m at 300K and 77K
- Fatigue resistance over 60000 cycles for +/-50% of above loads at 300K and 77K
  - The number of fatigue cycles represents a safety factor of 2
- Radiation withstand 100 kGy (10^{19} fast neutrons/m^2 and gamma)

Requirements for Thermal Cycles, Leak and Pressure (design values)

- Total of 50 thermal cycles from 300K to 77K with a predefined cooling rate
- 50 pressure cycles at 77K and at 300K, up to 39 bar
- Measurement of the leak rate at 300K and 77K after every 5 pressure cycles (<10^{-9} Pa m^3/s)
- Thermal cycles, pressure cycles and leak rate measurements alternated with mechanical tests

From Concept to Reality (and Results)

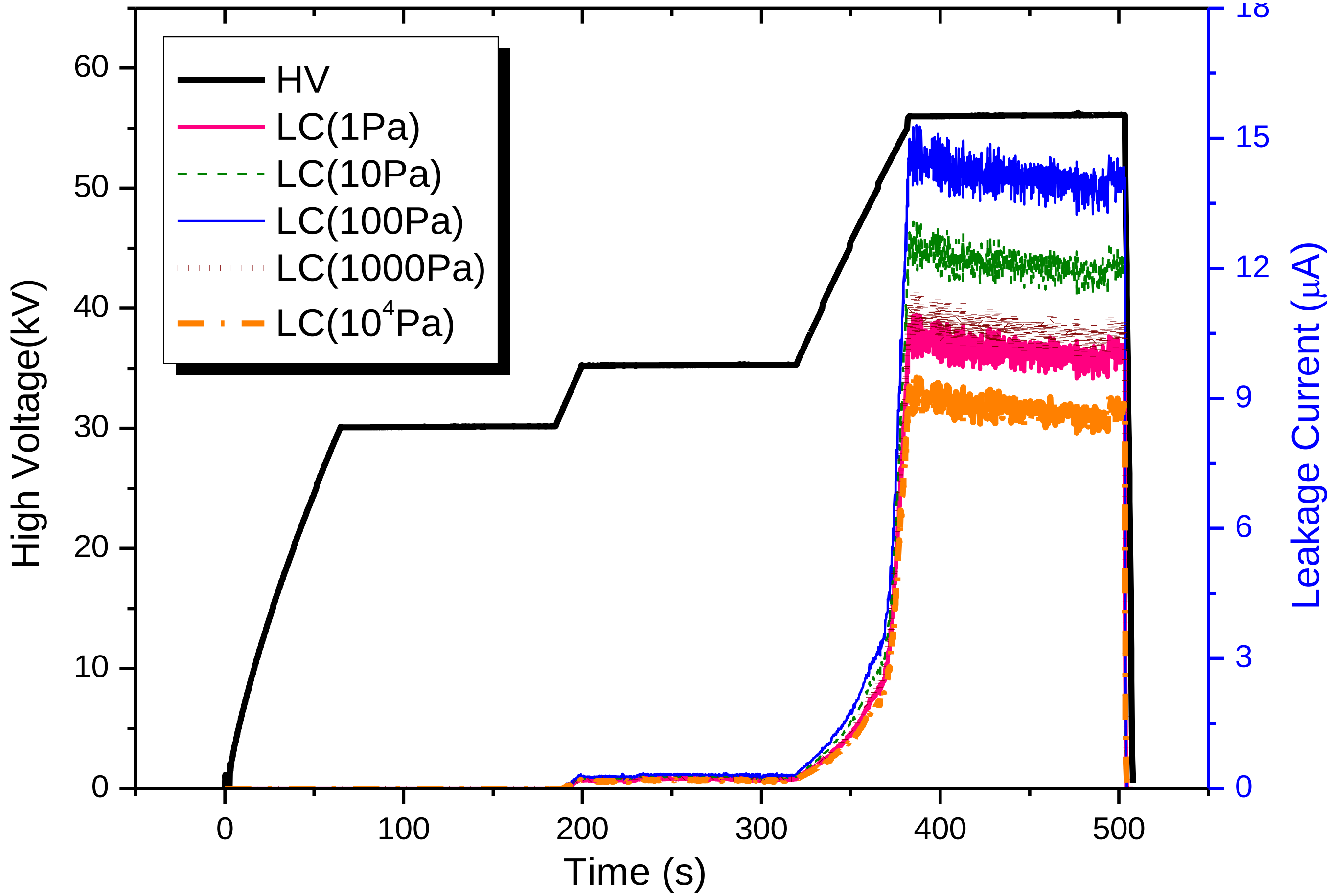
- <u>**Three contracts completed**</u> – each supplier submitted eight prototypes
- All submitted insulating breaks fully tested by supplier
- Independently tested afterwards for IO (CERN*& HVPD)
- Destructive Analysis to confirm (or other wise) compliance with design plan
- Determine from destructive analysis freedom from internal cracking (or other wise)
- Units from supplier Z showed presence of cracking in bulk

**See 1EOrF3-02 by J. Kosek et al.*

Typical Results – HV Testing

Test Condition / t=2 min	Leakage Current
29kV in bulk	0.1μA
29kV side to side in dry air	0.1μA
35kV in bulk	0.2μA
35kV side to side in dry air	0.5μA
56kV in bulk	9.2μA
56kV side to side in dry air	3.1μA

Typical Results from Paschen Test



Partial Discharge

Supplier	Length (mm) A	Length (mm) B	PDIV (kV) Internal *	PDIV (kV) Surface**
X	160	55	--	14
Y	405	65	--	16
Z	270	95	--	14

* No internal PD observed up to 56 kV
** Surface PD measured side-to-side

He Leak Test after 50 Thermal Cycles (Typical Results)

Test Condition / t= 10 min	Result
Vacuum leak at 300K, 1MPa	3.2 E-10 Pa·m^3/s
25 cycles at 1MPa, 300K	3.3 E-10 Pa·m^3/s
25 cycles at 4MPa, 77K	3.4 E-10 Pa·m^3/s
Vacuum leak at 300K and 77K (*)	3.3 E-10 Pa·m^3/s

Results after 25 mechanical cycles (tension/compression, bending and torsion) at each 300K and 77K

(*) Final verification after 60kcycles fatigue test without any measurable change in leak rate

Summary and Conclusions

- Prototypes manufactured by three potential suppliers – all prototypes delivered to IO meet specification
- Primary ‘seal’ in compression in all designs, no visible dis-bond in this joint
- Possibility that other bonds to stainless steel may be in tension – no visible dis-bonds
- Possibility of axial shear stress – no visible dis-bonds
- ‘Predictable’ failure observed in thick composite tube – longer term consequences under consideration
- Destructive analysis indicated deviations from manufacturers design plan
- Longer term ‘quality is king’ – strict adherence to QAP and Manufacturing and Inspection Plan to ensure that composite design & performance along with adhesive bond strengths are maintained
- Contract for 80% of total quantity has been already placed

ITER today ...

Thanks for your attention