Extrapolation of the W7-X magnet system to reactor size

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CONTENT

MODUCO

(MODUlar COils) by H. Wobig

Features:

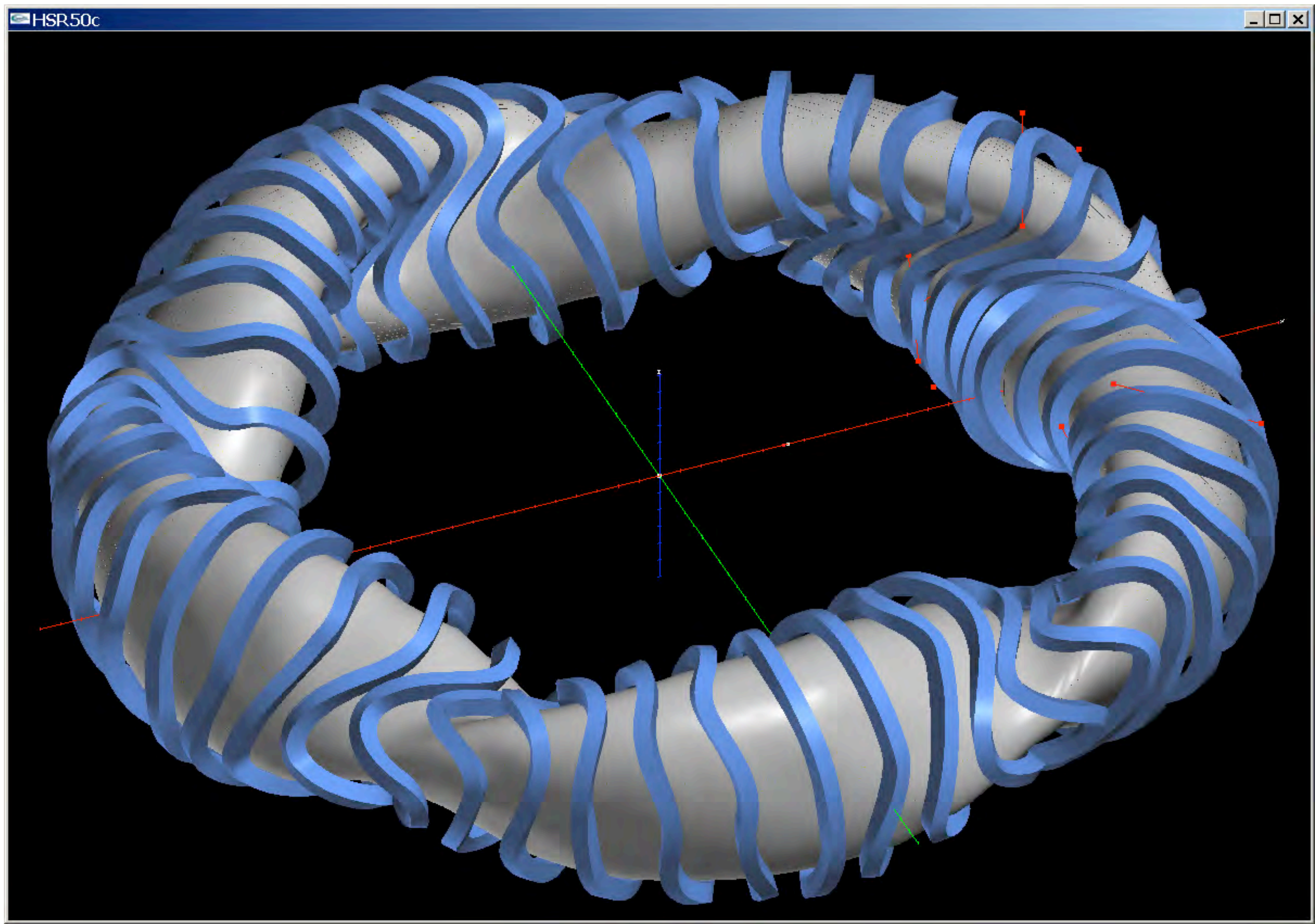
- Central coil filament (CCF) is represented by 4-6 control points with tangent vec
- CCF is interpolated by cubic Beziér curves
- Wendelstein 7-X field has been well reproduced with MODUCO
- Classical stellarator and 3, 4 and 5 period reactor configurations can be reprodu
- The code computes magnetic surfaces and particle orbits
- Magnetic field within the WP and the forces on the coils can be computed

Further features are planned:

- Computation of inductivity, magnetic energy, plasma currents, field ripple
- Modelling of vacuum vessel and blanket,
- Neutron wall load

HELIAS reactor magnet system

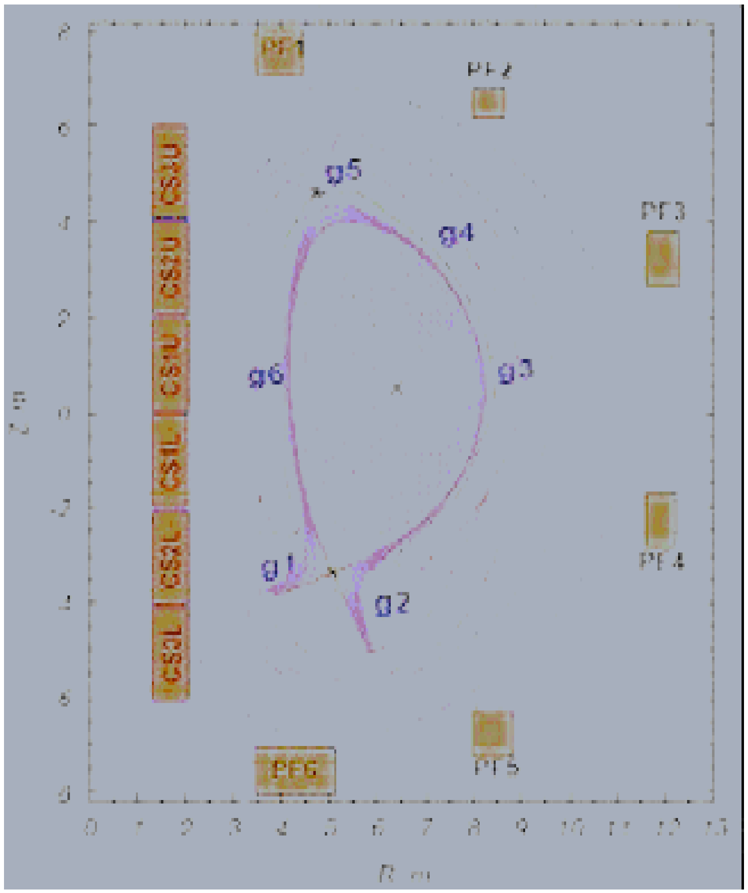
HSR50a



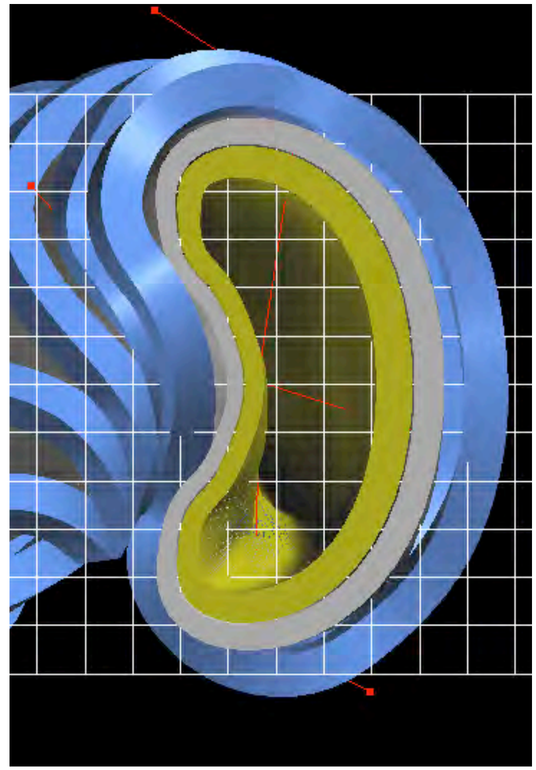
Scaling	4 x
Symmetry	5 P
Coil number	50
Major radius	22
B on axis	5.6
B on coil	12.
Magnetic energy	152

The magnetic field is isomorph to the Wendelstein 7-X field

Comparison of ITER and HSR5 coils

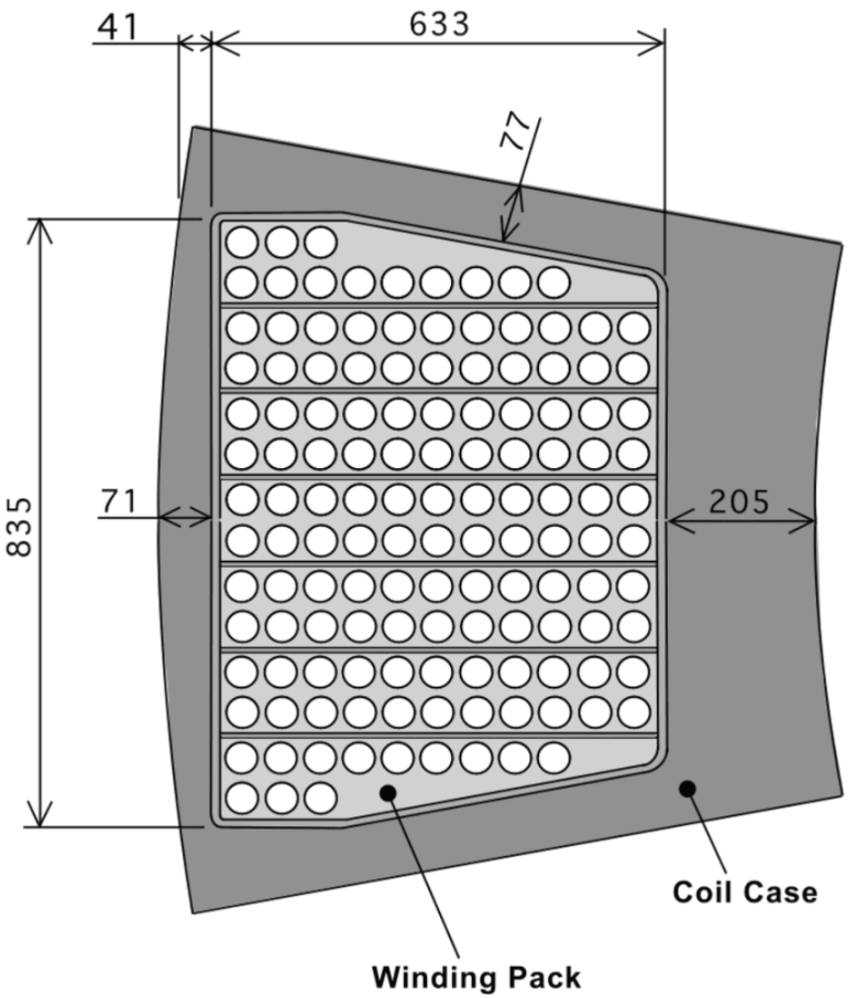


ITER toroidal field (TF) coil

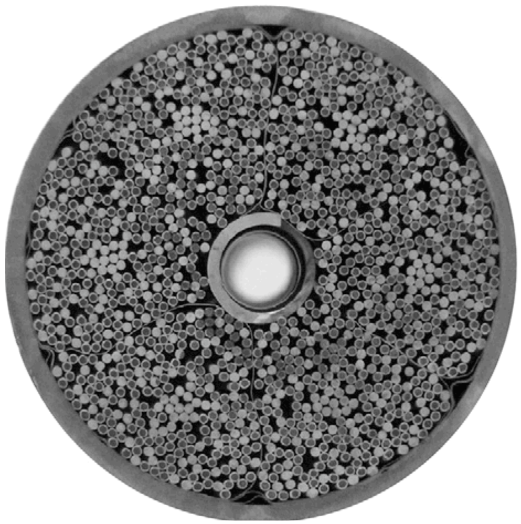


HSR50a coil #5

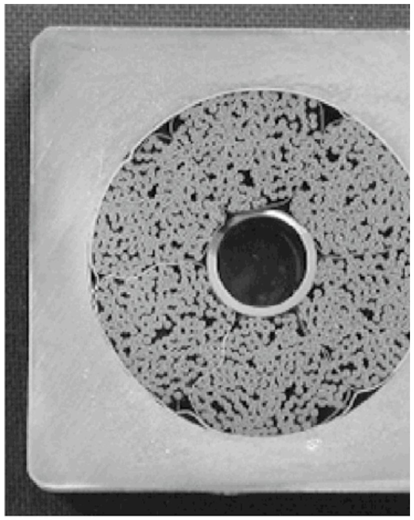
ITER coil key components



ITER TF coil inner leg section
(plasma axis is at the left side)



TF coil conductor



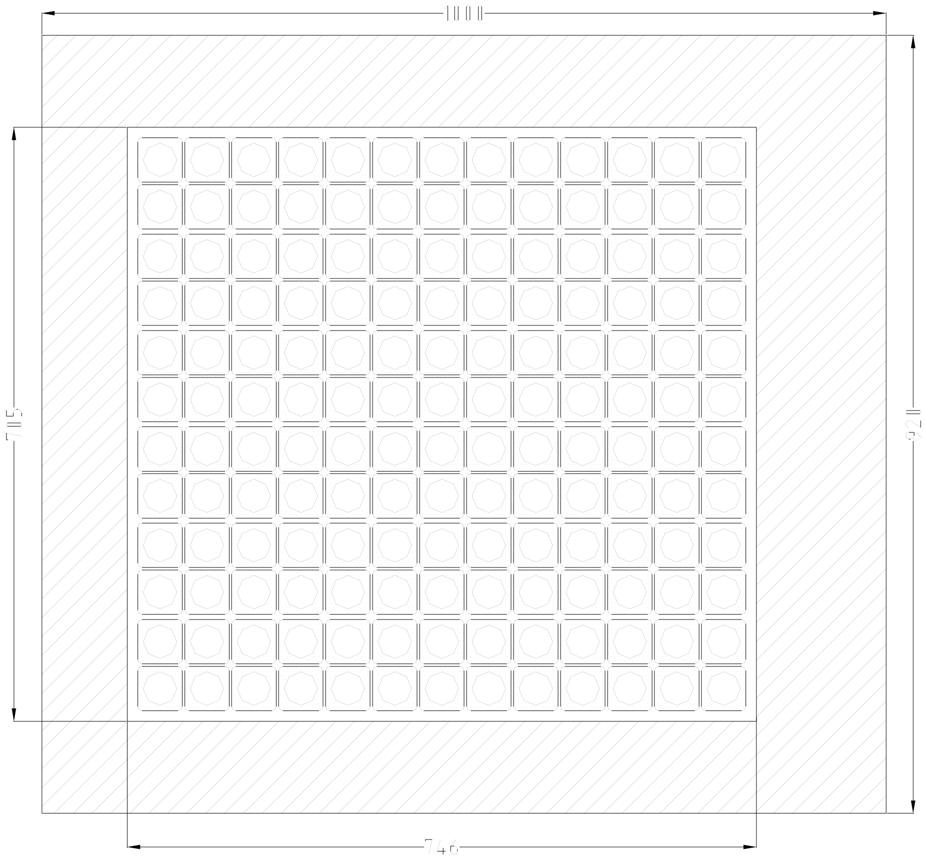
CS & PF coil conc

Comparison of ITER TF and HSR50a coils

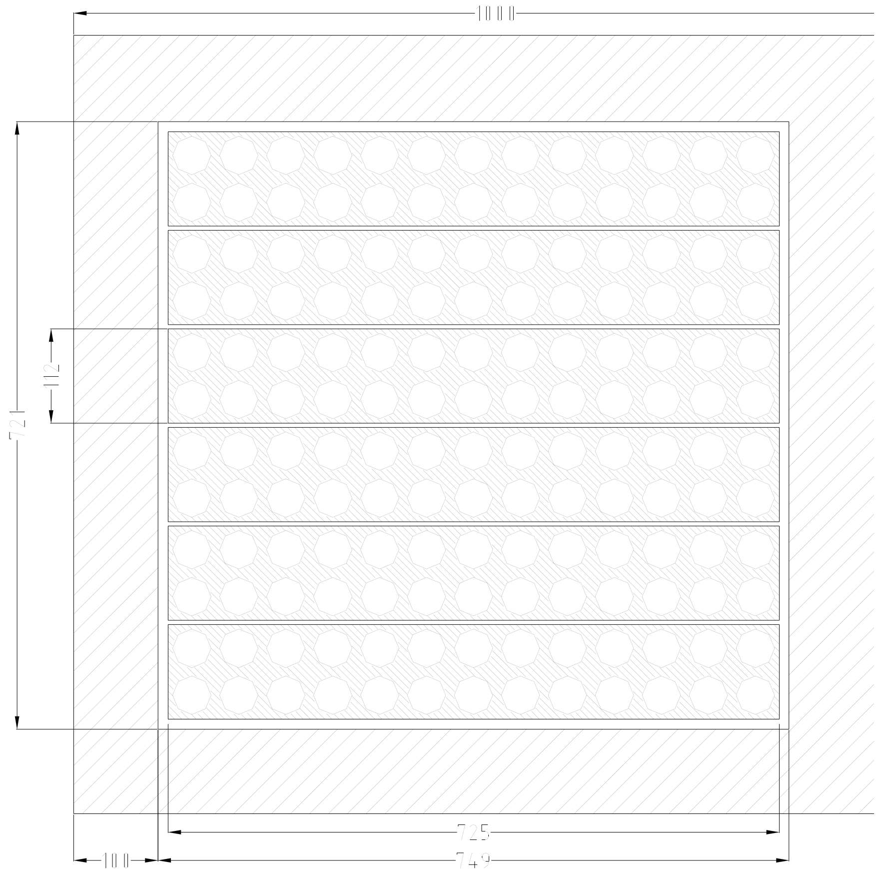
	ITER TF	HSR50a SqC*	HSR50a RP*
Cable current	68 kA	86 kA	
No. of cable turns	134	156	
Max. induct ion at	11.8 T	12.3 T	
Operation temperature	5 K		
Superconductor material	Nb_3Sn	Nb_3Al	
Strand diameter	0.82mm		
SC strand Cu:non -Cu	1		
No. of sc strands	900	630	
No. of additional Cu	522	792	
Void fraction	29 %	29 %	
Cable Cu:non -Cu ratio	2.2	3.5	
O.D. of central channel	10 mm		
O.D. of cable	40 mm		
O.D. of jacket	44 mm	53x53mm_	44 mm
Conductor insulation	1 mm	1.5 mm	1 mm
RP insulation	1 mm	-	1 mm
DP* insulation	3 mm		
Ground insulation	7 mm		
WP embedding	4 mm		

* SqC: squ are conductor , RP: radial plate , DP: double pancake

HSR50a winding pack (WP) options



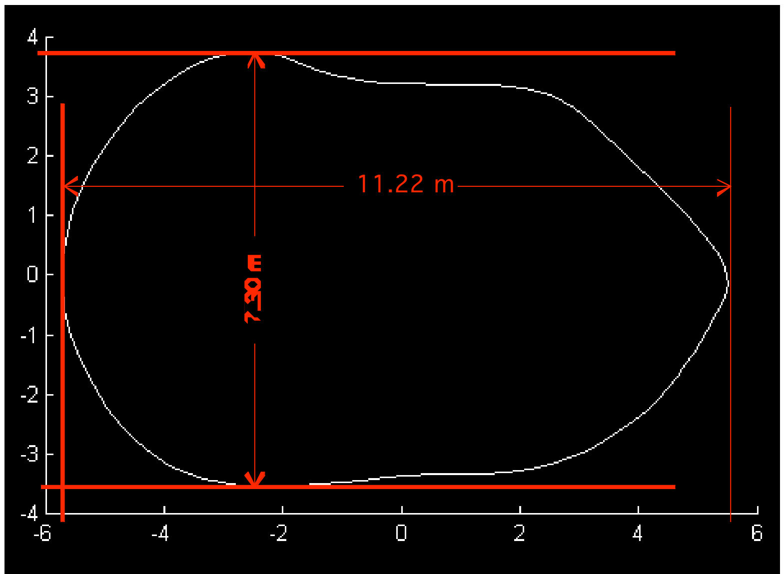
Square conductor concept
acc. to ITER CS and PF coils



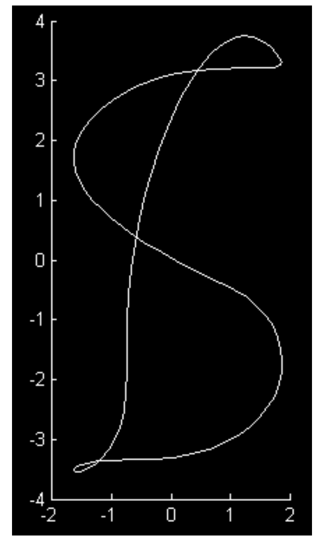
Radial plate concept
acc. to ITER TF coils

HSR50a coil 1 central current filament

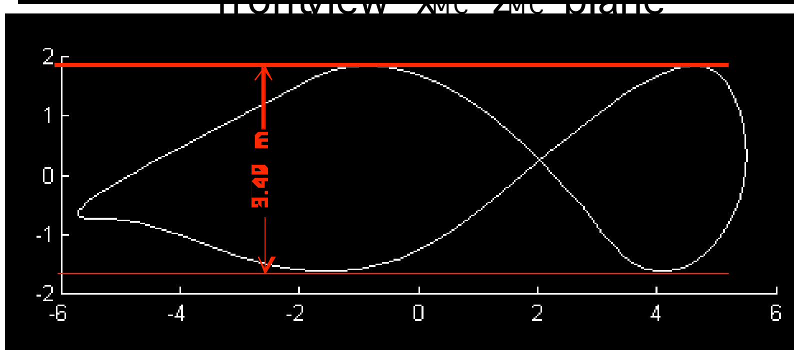
in the „minimum coordinate“ system.



frontview x_{MC}– z_{MC}-plane



sideview y_{MC}-z_{MC}



topview x_{MC}– y_{MC}-plane

HSR5 coils comparison

Dimensions of the CCF in the „minimum coordinate system“

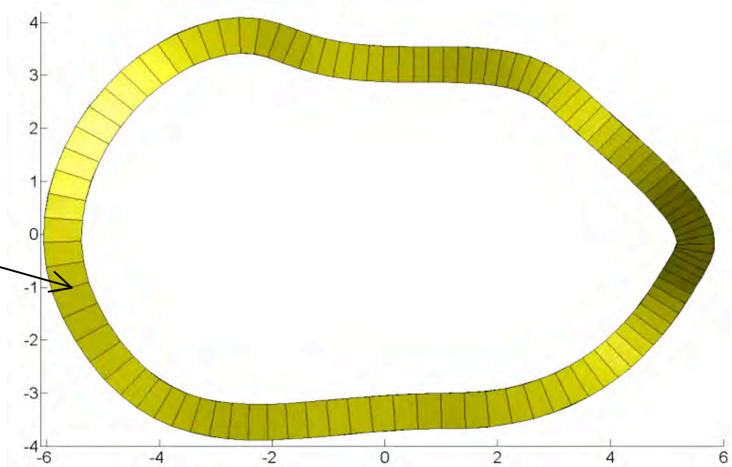
Coil type	Min. height [m]	Max. length* [m]	Width† [m]	Pos. dev.‡ [deg]	Neg. dev.‡ [deg]	CCF length [m]
1	3.49	11.22	7.30	63.8	-47.1	34.1
2	3.33	11.21	7.50	58.1	-44.3	33,8
3	2,80	11.65	7.58	49.7	-37.1	33,6
4	2.49	12.09	7.19	51.1	-31.4	34,1
5	2.22	12.02	7.57	40.5	-30.7	34,4
ITER TF	0	~12.5	~8	0	0	34.5

*) Perpendicular to minimal height
†) Perpendicular to min. height and max. length
‡) Deviations of tangent vectors from planarity

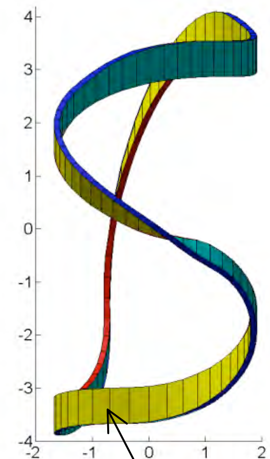
Radial plate (RP) of coil type 1

Orientation wrt. the min. coord. system

front view

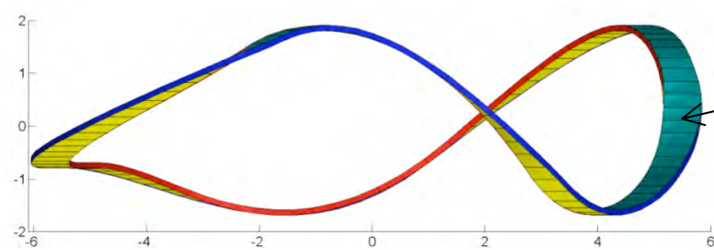


RP element long edges
in true length



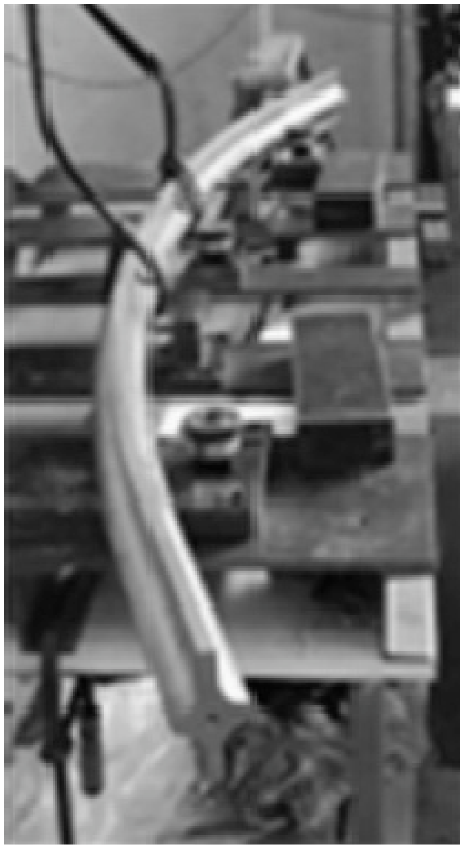
side view

top view

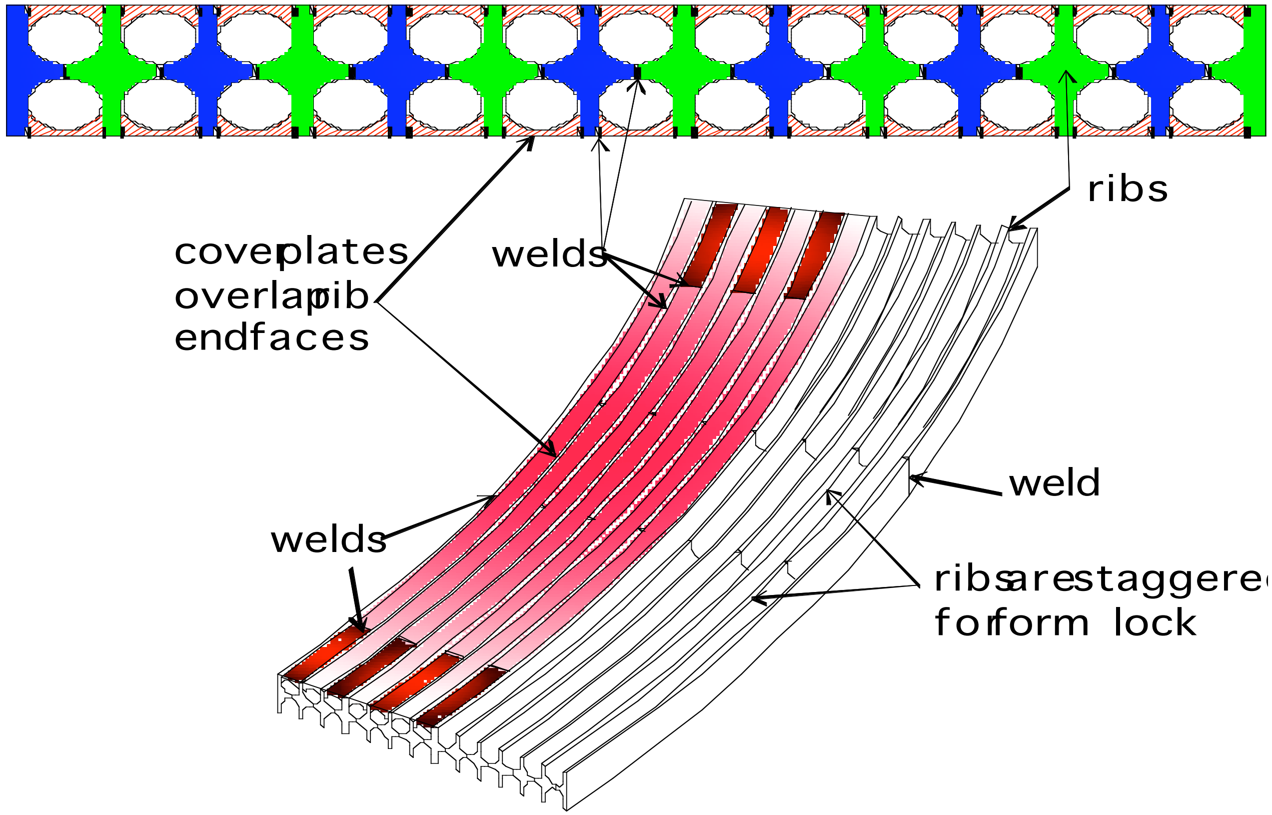


RP element long edges
are parallel the others

HSR50a radial plate concept

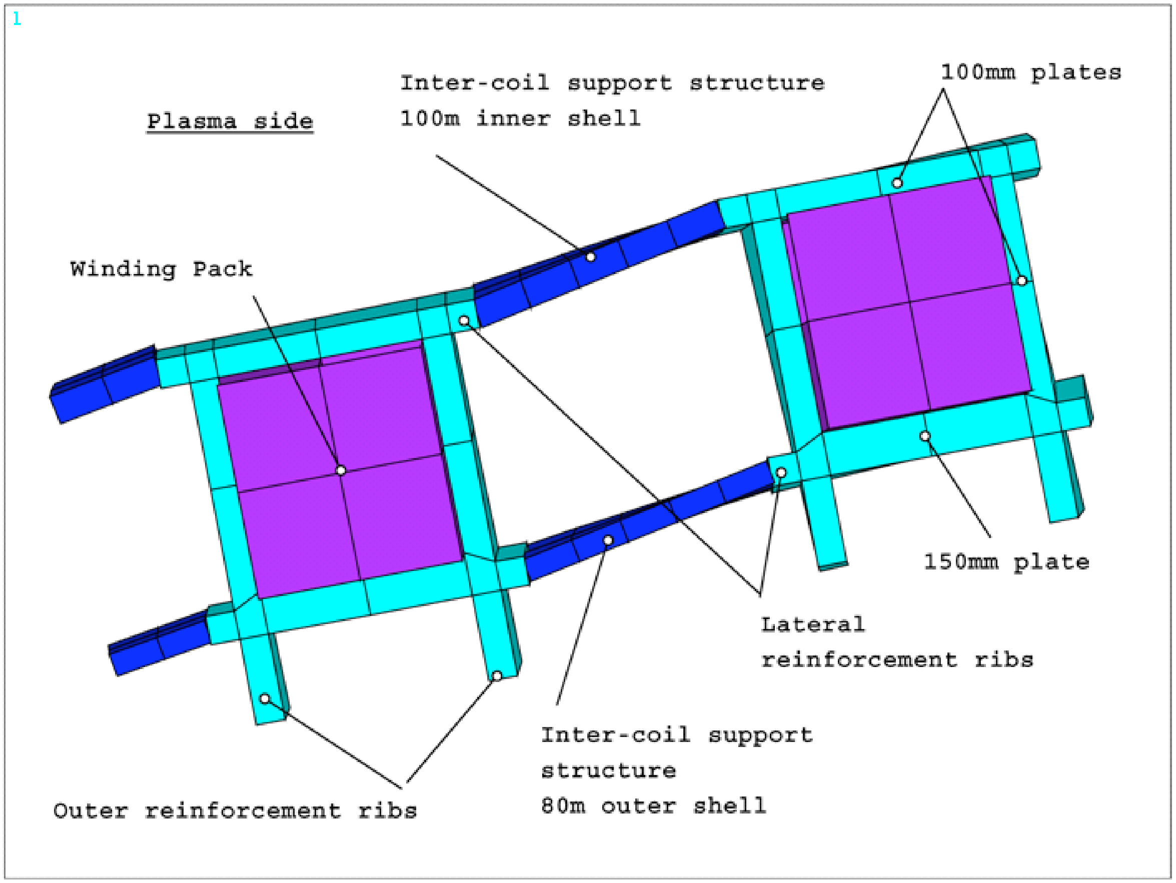


RP rib prototype for ITER



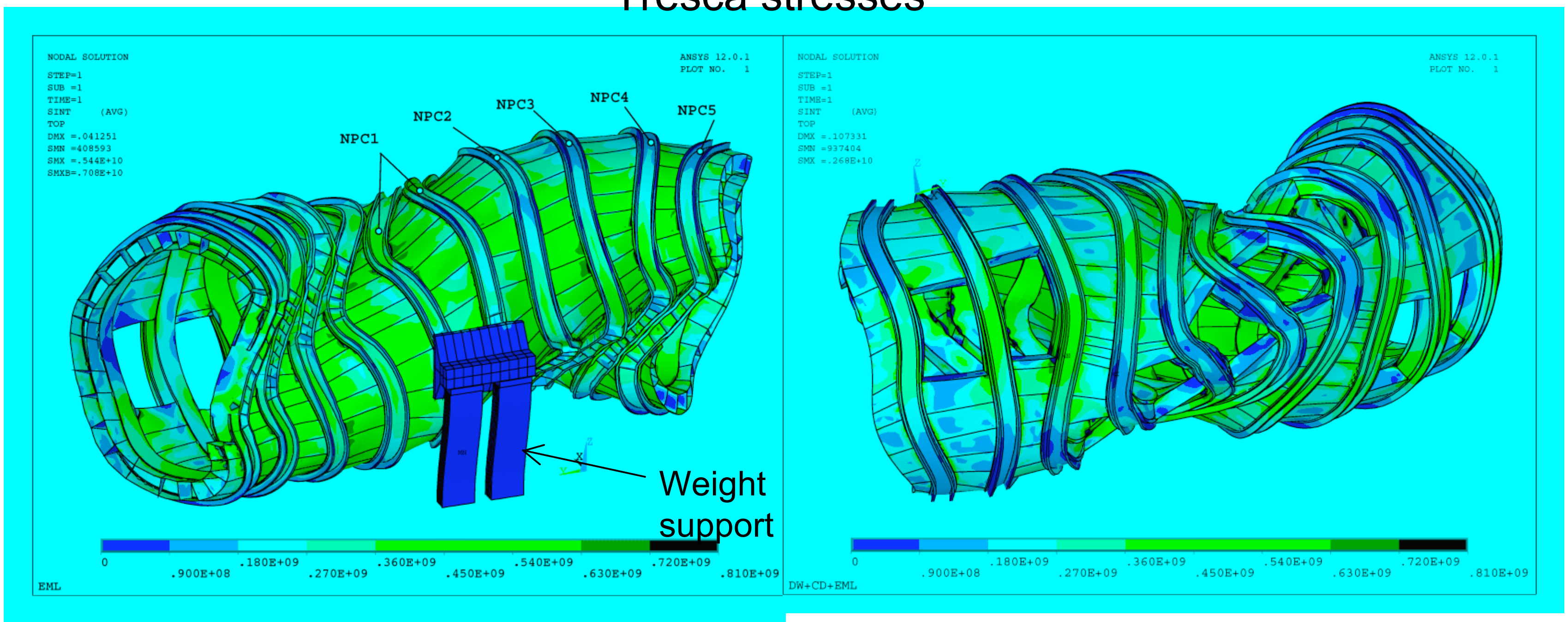
Structural analysis

Coil casing and inter-coil structure model



Structural analysis

Tresca stresses



Module inboard side

Module outboard side

- Local stress peaks are partly acceptable; partly are due to rough interface modelling
- Only a few stress peaks need to be eliminated during detail design
- Allowable limits are: 625 MPa membrane; 810 MPa membrane plus bending stresses
- Realistic material with 940 MPa yield limit assumed
- At no place a steel plate thickness >150 mm required
- Maximal deformation due to Lorentz forces is 60 mm only

Electrical design

Comparative estimates for coil fast discharge behaviour are performed with the following relations:

Discharge voltage: $U = L \cdot \frac{I}{\tau}$

Hot spot temperature: $\int_{t_0}^{t} I^2(t) \cdot \frac{\rho_{Cu(T)}}{A_{Cu}} dt = \int_{T_0}^{T} \left(\sum m_i \cdot c_i(T) \right) dT$

(τ = equivalent discharge time constant, m_i = mass per unit length)

Not considered are:

- Thermal capacities of electrical insulation and RP
- Helium flow within the conductor
- Secondary currents in RP and structure
- Capacitances between the WP components
- 3D-heat conduction within conductor and WP
- Increasing resistivity of the discharge resistors

Electrical design

simplified analysis results

	ITER	HSR50a sqare cond.	HSR50a RP
Energy, W	41 GJ	152 GJ	
W per coil	2.3 GJ	3 GJ	
Inductance, L	17.7 H	41.1 H	
Discharge time, τ	11 s	11 s	
Voltage per coil pair	12.2 kV	12.8 kV	
$T_{hot\text{-}spot}$, Δ* = 2 s	150 K	120 K	290 K
$T_{hot\text{-}spot}$, Δ = 1 s	-	85 K	220 K

*) Δ is the switch-off time delay

Electrical layout:

- All coils in series with one power supply
- Fast discharge unit after every other coil
- 25 pairs of current leads

Conclusion

- A 5-periodic HELIAS reactor with ~12 T at the coil and 5.5 T at the plasma axis can be built
- The basic physics can be directly taken over from W7-X
- Quasi existing ITER key technologies need only to be adapted to a HSR5 magnet system
- For further development work a professional full-time engineering team has to be installed
- 3- and 4-periodic HELIAS versions have to be considered too as options
- Final design decisions will be influenced by the outcome of the W7-X experiments