Status of the Concept Design of CFETR Tokamak Machine

Tokamak Machine Design Team
Presented by Songtao WU

Outline

- Guideline of the Tokamak Design
- Magnet Configuration and Preliminary Analysis
- VV Configuration
- Further Considerations
- Summary

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Guideline of the Tokamak Design

Design goal of the first option of CFETR (from "CFETR-0-00"), interpretations to Machine Design

- A good complementary to ITER
- Demonstration of full cycle of fusion energy with a minim Pf = 50 ~ 200MW；
- Long pulse or steady-state operation with duty cycle time ≥ 0.3 ~ 0.5；
- Demonstration of full cycle of T self-sustained with TBR ≥ 1.2
- Relay on the existing ITER physical（k<1.8, q>3, H~1) and technical bases (higher B_T, diagnostic, H&CD);
- Exploring options for DEMO blanket/divertor with a easy changeable core by RH；
- Exploring the technical solution for licensing DEMO fusion plant
- With power plant potential by step by step approach.

Basic Parameters of Tokamak Machine

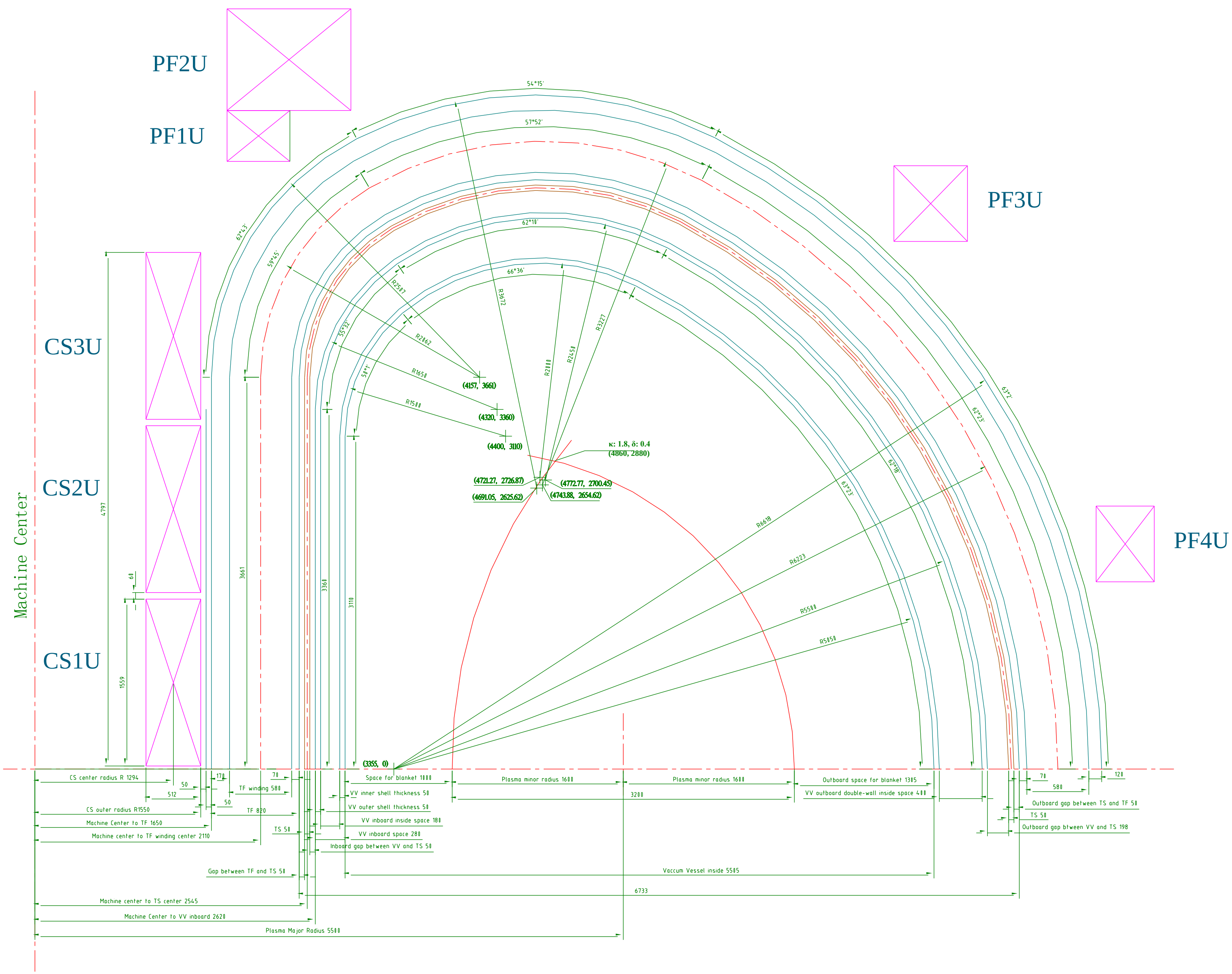
Estimated Parameters of CFETR (from "CFETR-00-00-03" and "CFETR-00-00-02")

R (m)	5.5
a (m)	1.6
Aspect ratio	3.43
Plasma volume (m^3)	500
Elongation	1.8
Triangularity	0.4
Ip (MA)	12/10/7
B_0 (T)	5.3/4.5
P_{aux} (MW)	50/80
Flux (Vs)	90
Space for Blanket (m)	1-2

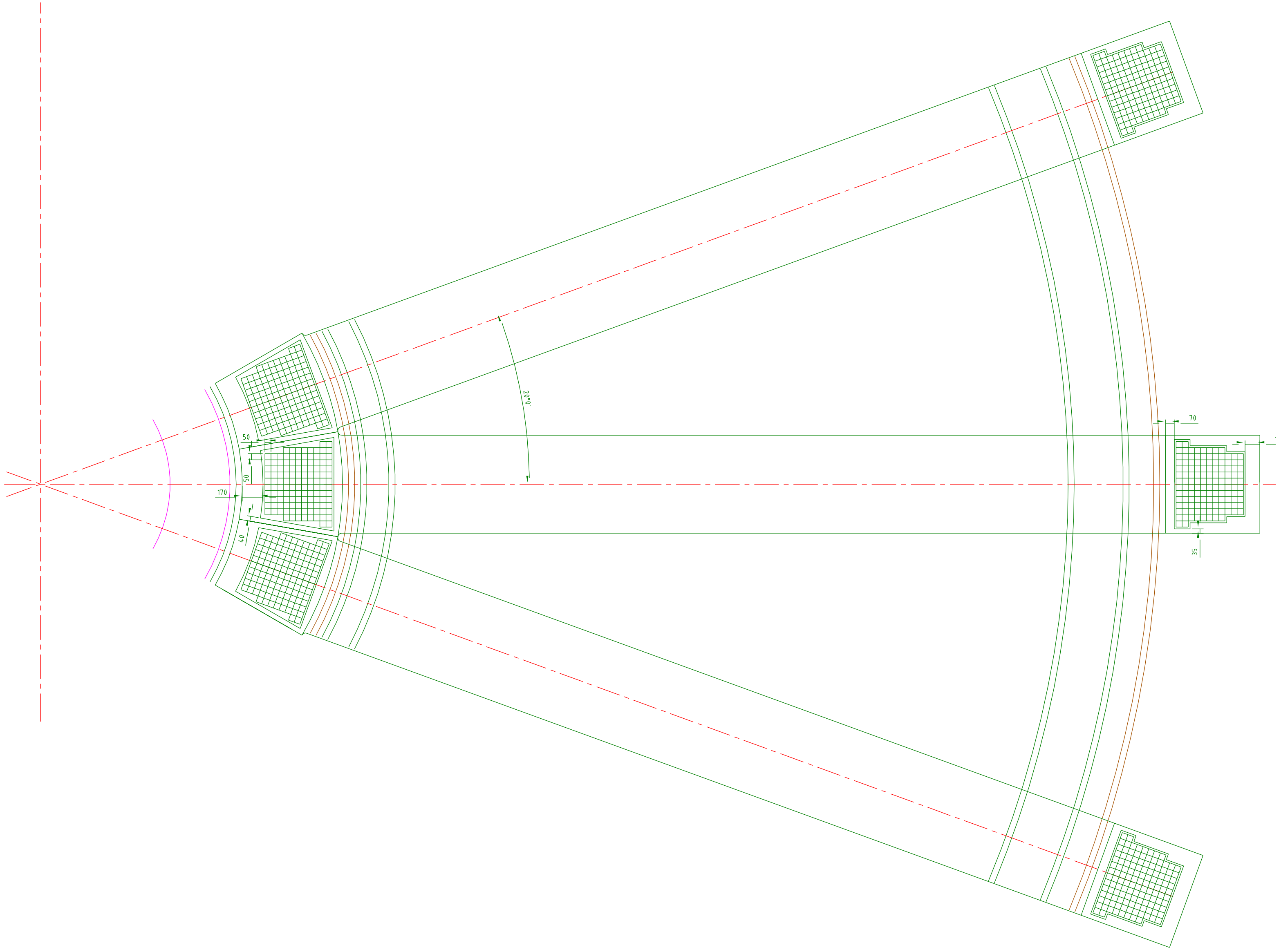
Some Integration Consideration

- To have design based on the technologies available within 5 to 10 years in China.
- To consider manufacture feasibility at early stage;
- To make sure to provide TBM space not less than 1 m;
- To use TF inboard space as much as possible to provide the VV inboard space as big as possible;
- Gaps between parts with different temperatures shall be not less than 50 mm;
- D shape consisted arcs as less as possible;
- To have enough TF winding cross-section space to ensure B_T (4.5 T/5.5 T);

Proposed Configuration (Vertical cross-section)



Proposed Configuration (Horizontal cross-section)



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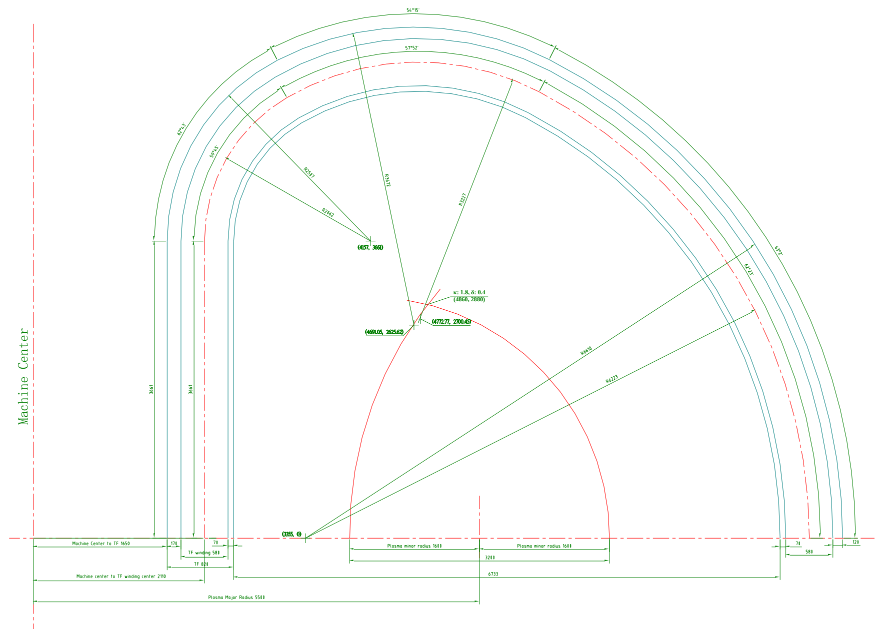
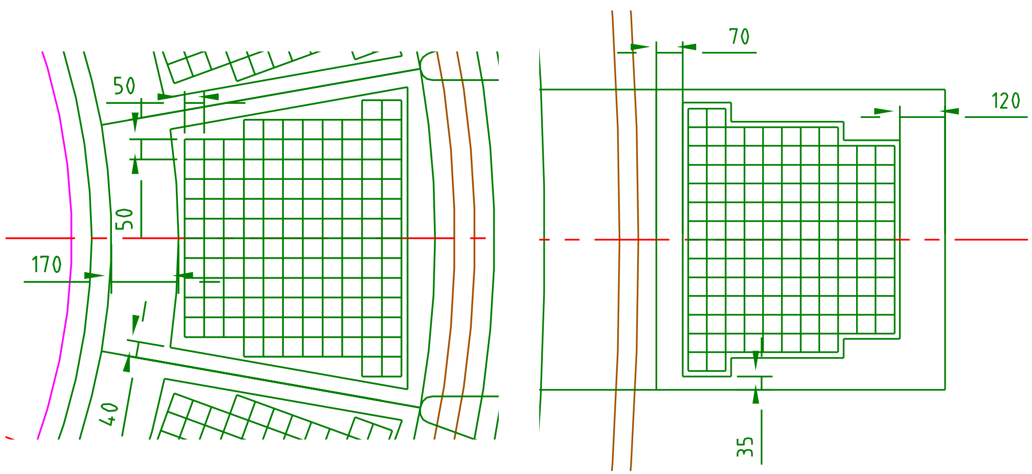
TF Design (1/5)

Main Parameters of TF:

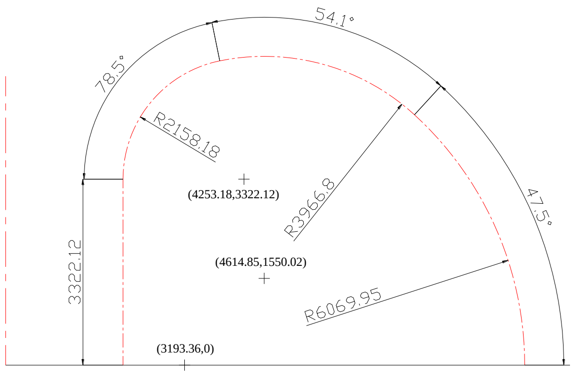
- 18 TF coils,130 turns per TF coil
- If 50-60 kA/turn, total current per TF coil about is 7800 – 9100 kA, may provide 4.5 – 5.5 T at plasma center;
- Quasi-Princeton D consisted of five arcs and one straight line;
- Conductor length of each double-pancake is about 700 m;
- Height 12 m, width 8 m.



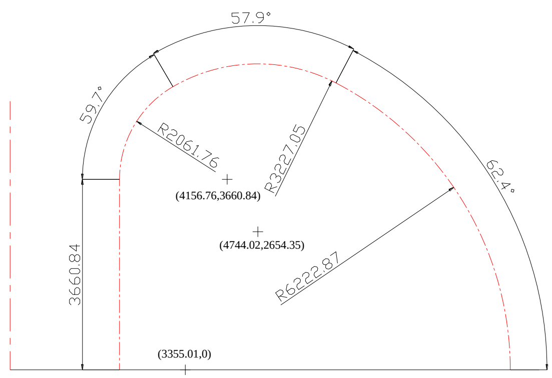


TF Design (2/5)

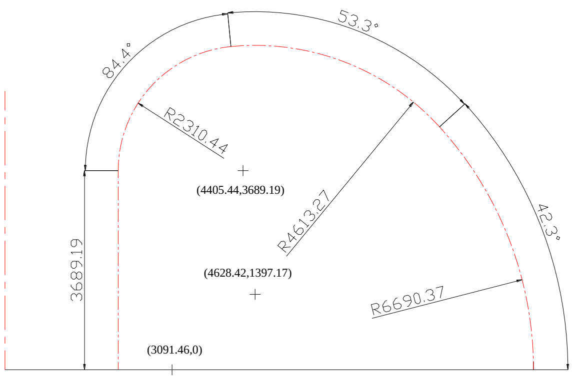
Four D optimized shapes based on Princeton-D:



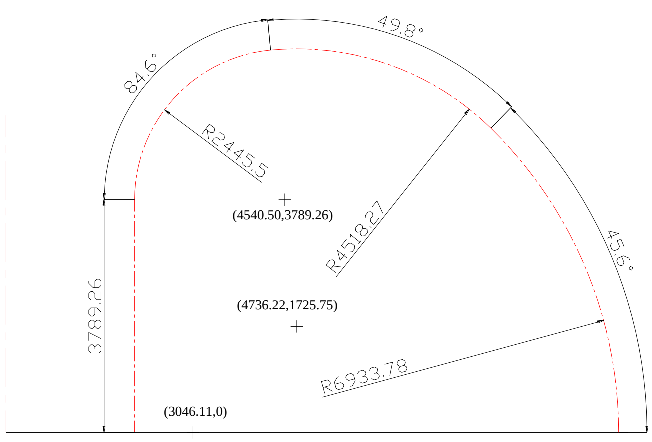
Outer arc segment immovability



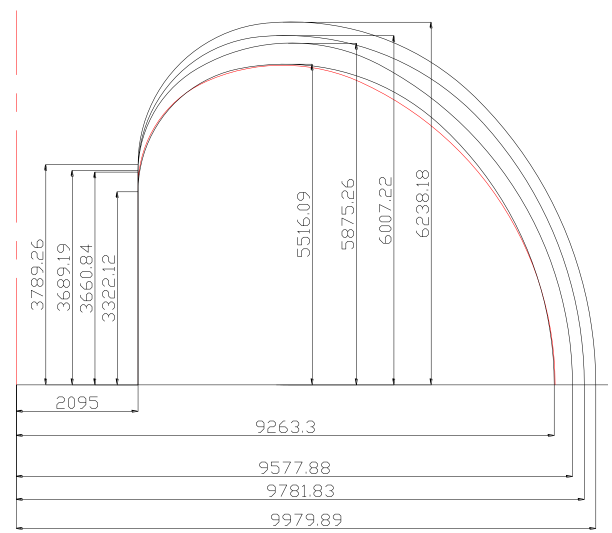
Arc segment move outward 300mm



Arc segment move outward 500mm



Arc segment move outward 700mm

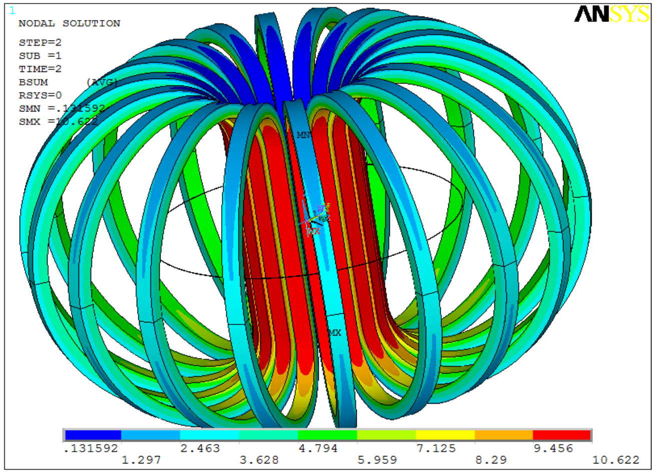


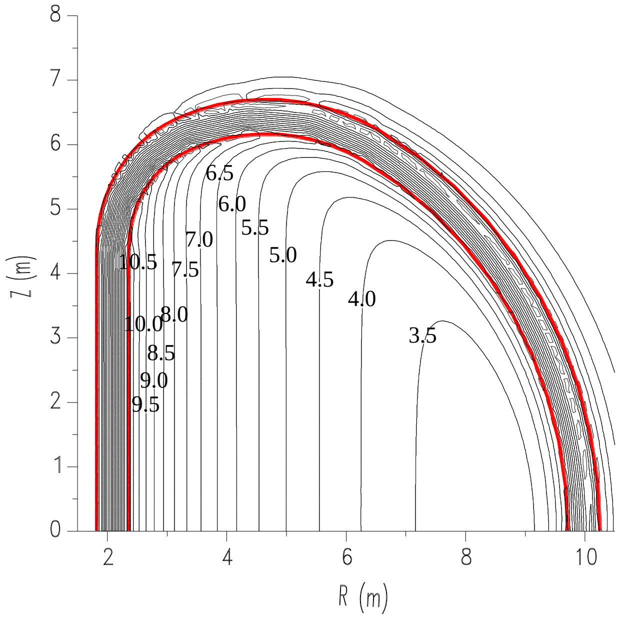
4 types curves

TF Design (3/5)

Analysis of TF:

- If the turn current is 53 kA, the magnetic field in the plasma central is 4.5 T, the maximum magnetic field is 10.6 T.
- If the turn current is up to 62.25 kA, the magnetic field in the plasma central can reach 5.3 T, but the maximum magnetic field goes up to 12.5 T.

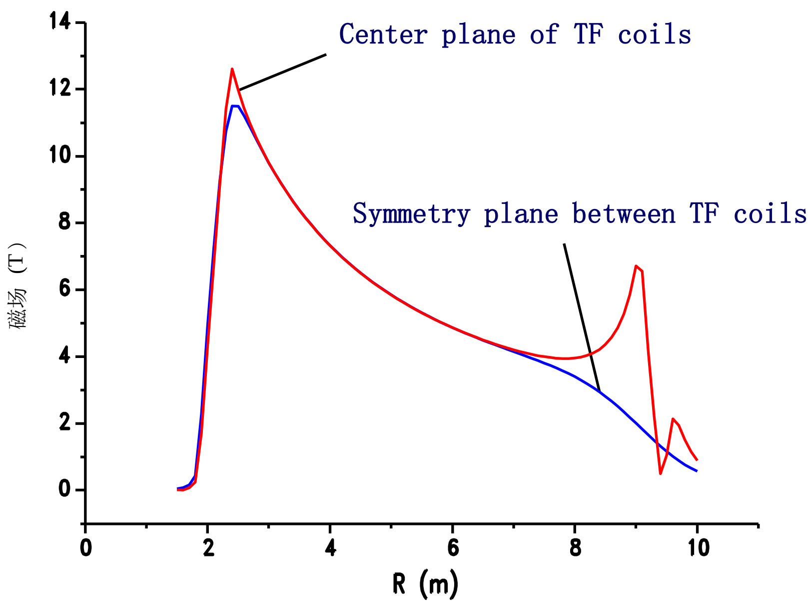


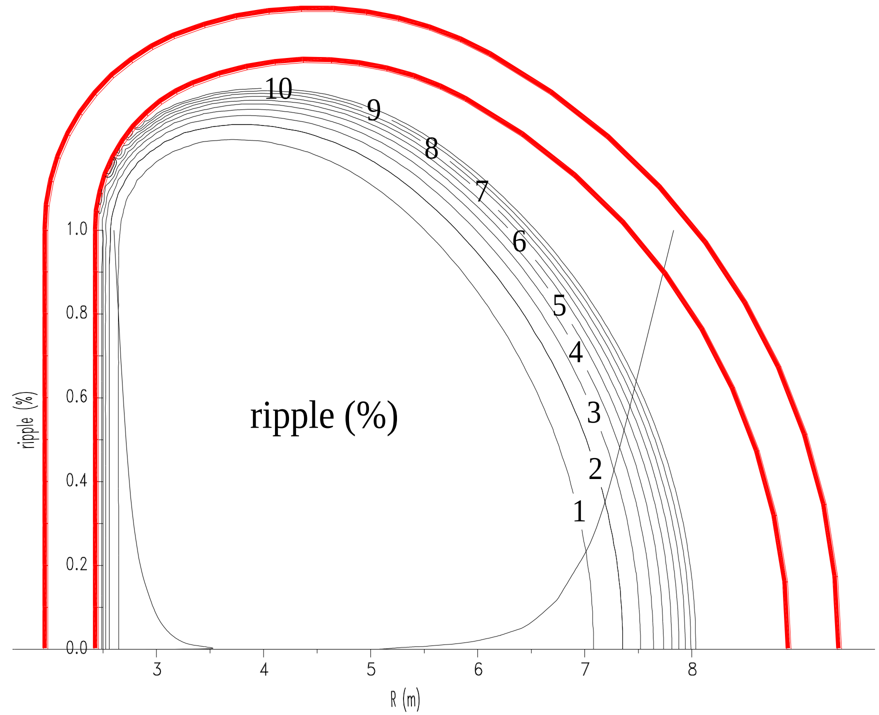


TF Design (4/5)

Analysis of TF:

$$\delta(r,z) = \frac{B_{\varphi}^{\max} - B_{\varphi}^{\min}}{B_{\varphi}^{\max} + B_{\varphi}^{\min}}$$





TF Design (5/5)

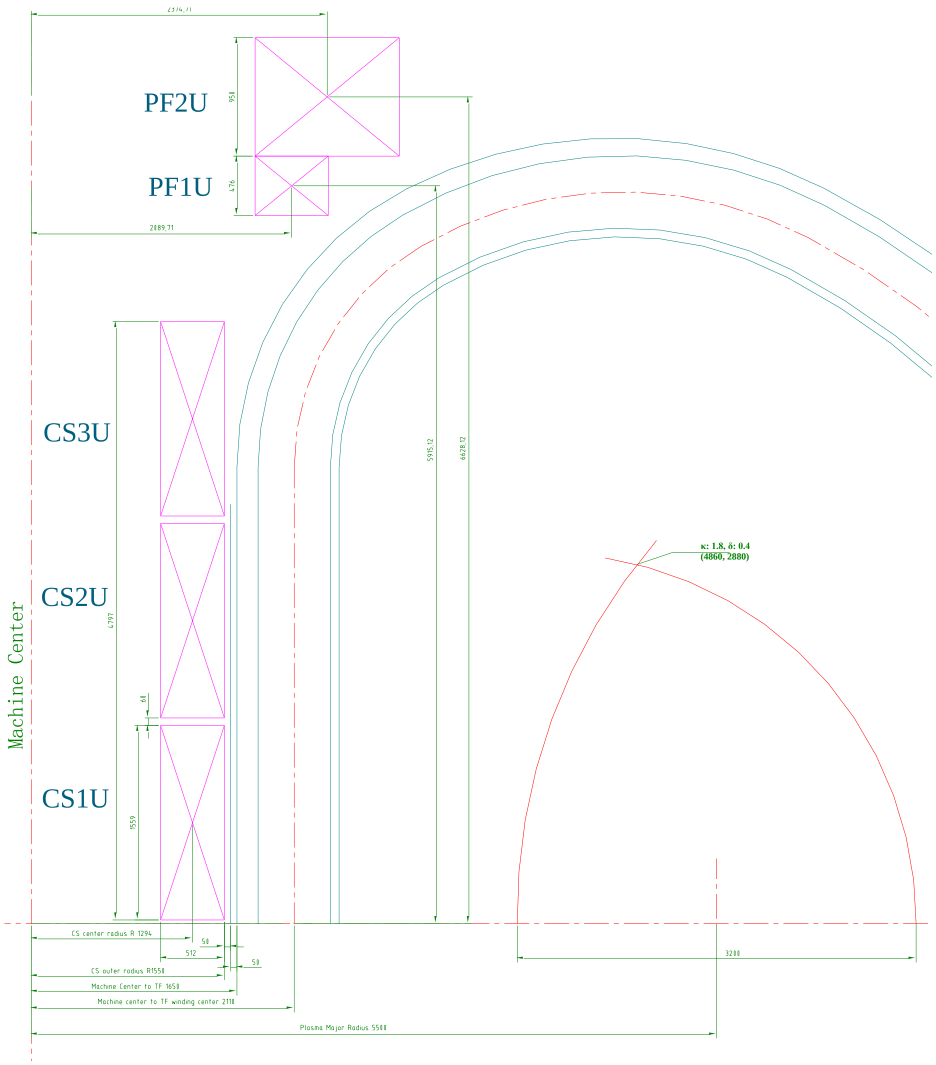
Main Parameters of TF:

	CFETR		ITER
Coil number	18		18
turns	130		134
R	5.5 m		6.2 m
Current/turn	53 kA	62.25 kA	68 kA
Center field	4.5 T	5.3 T	5.3 T
Maximum field	10.6 T	12.5 T	11.8 T
Inductance	15.78 H	15.78 H	17.7 H
Energy storage	22.2 GJ	30.6 GJ	41 GJ
Centripetal force	290 MN	367 MN	403 MN
Vertical force	128 MN	175 MN	205 MN

CS/PF Design (1/6)

CS Configuration:

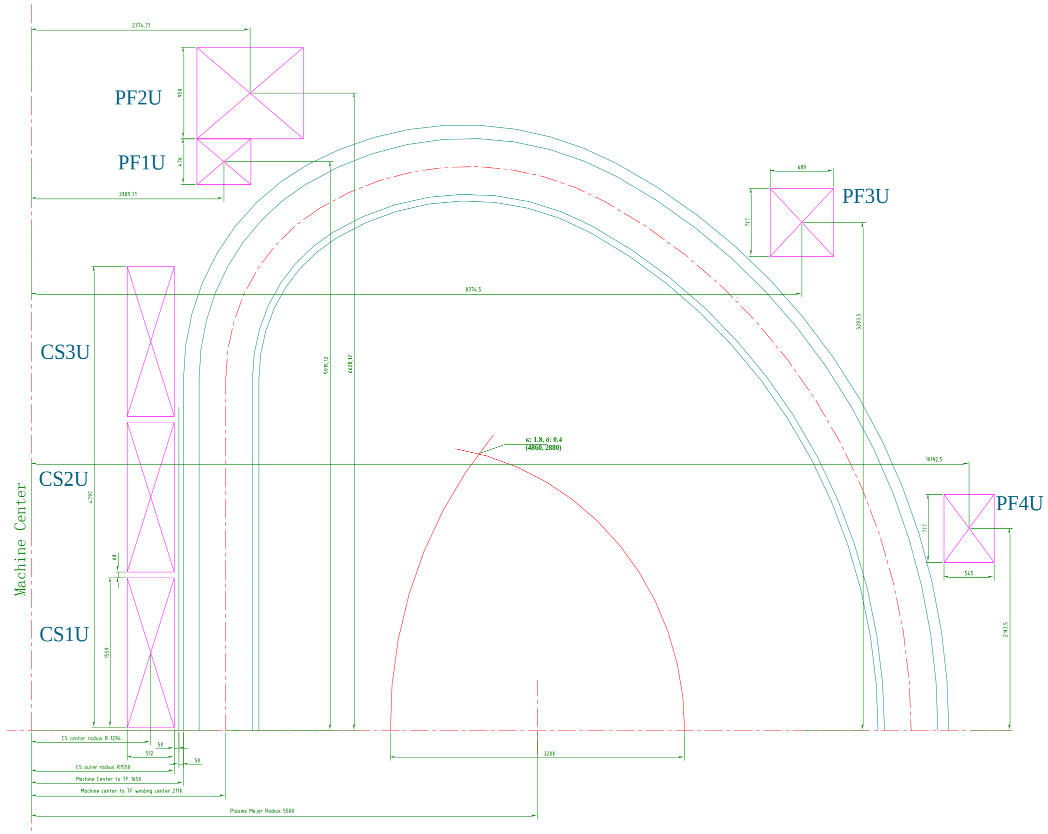
- Six windings separated with 60 mm insulated support ring structure;
- Outer diameter of CS winding: 3100 mm;
- Inner diameter: 2120 mm;
- About 260 turns, 65 A/turn provides total about 17 MA/winding for > 100 Vs;
- 1559 mm height each winding, total height 9.7 m;
- 50 mm outer support structure.



CS/PF Design (2/6)

PF Configuration:

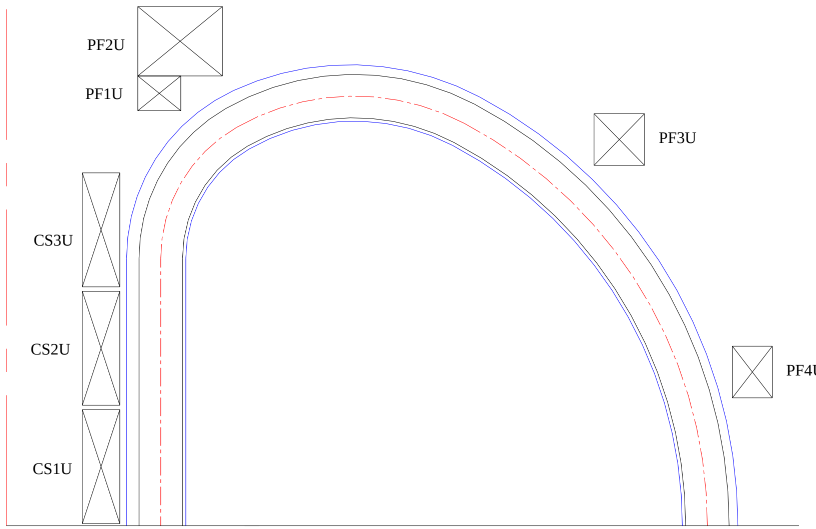
- Eight PF coils symmetrically located with mid-plan if DN is mandatory;
- Big ampere-turns of PF1U/2U for triangularity and elongation;
- CS/PF shall be design in hybrid for plasma heating and control;
- .



CS/PF Design (3/6)

Configurations of CS and PF:

Coil	R(m)	Z(m)	ΔR(m)	ΔZ(m)	Turns
CS3U	1.294	4.0475	0.512	1.559	374
CS2U	1.294	2.4285	0.512	1.559	374
CS1U	1.294	0.8095	0.512	1.559	374
CS1L	1.294	-0.8095	0.512	1.559	374
CS2L	1.294	-2.4285	0.512	1.559	374
CS3L	1.294	-4.0475	0.512	1.559	374
PF1U	2.0897	5.9151	0.587	0.476	80
PF2U	2.3747	6.6281	1.157	0.95	320
PF3U	8.3745	5.2835	0.689	0.707	196
PF4U	10.1925	2.1035	0.545	0.707	154
PF4L	10.1925	-2.1035	0.545	0.707	154
PF3L	8.3745	-5.2835	0.689	0.707	196
PF2L	2.3747	-6.6281	1.157	0.95	320
PF1L	2.0897	-5.9151	0.587	0.476	80



CS/PF Design (4/6)

PF and CS coils currents for 10/12 MA plasma (MA*turns)

		CS3U/L	CS2U/L	CS1U/L	PF1/PF6	PF2/PF5	PF3/PF4
10MA	Design1	-12.21	-11.96	-11.04	15.86	-3.52	-3.95
	Mod1	-11.27	-13.42	-13.95	15.95	-3.67	-2.98
12MA	Design1	-15.74	-15.36	-12.49	20.20	-5.02	-4.29
	Mod1	-14.49	-17.18	-16.06	20.13	-4.88	-3.32

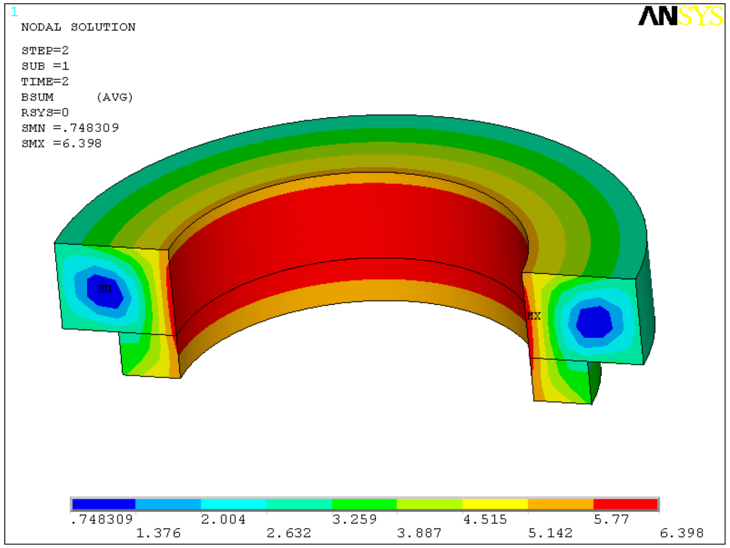
10/12 MA plasma equilibrium parameters

		R[m]	a[m]	β_p	l_i	δ_u/δ_l	k	Rxp [m]	Zxpt[m]
10MA	Design1	5.51	1.59	0.9	1.1	0.46	1.93	4.77	-3.08
	Mod1	5.51	1.59	0.9	1.1	0.51	1.95	4.70	-3.09
12MA	Design1	5.52	1.58	0.9	0.97	0.50	1.95	4.77	-3.08
	Mod1	5.52	1.58	0.9	0.98	0.52	1.96	4.70	-3.09

CS/PF Design (5/6)

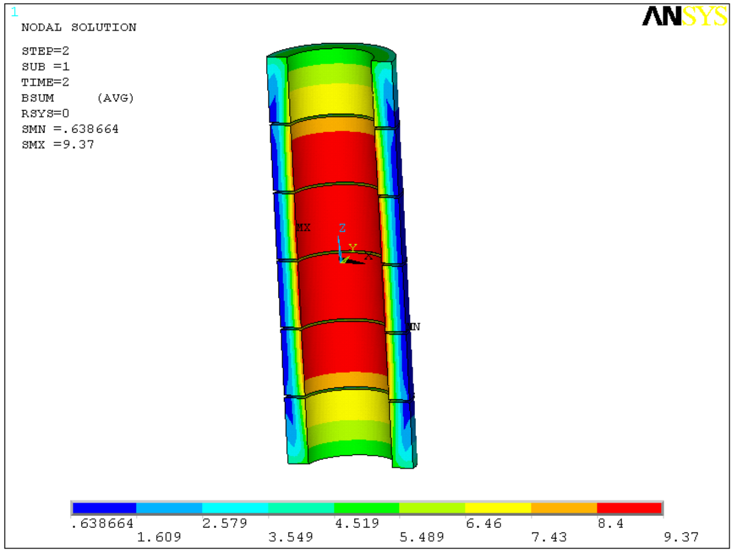
Analysis of CS/PF:

- Maximum magnetic field on PF1U/2U is 6.4 T
- Maximum magnetic field in CS is 9.4 T.



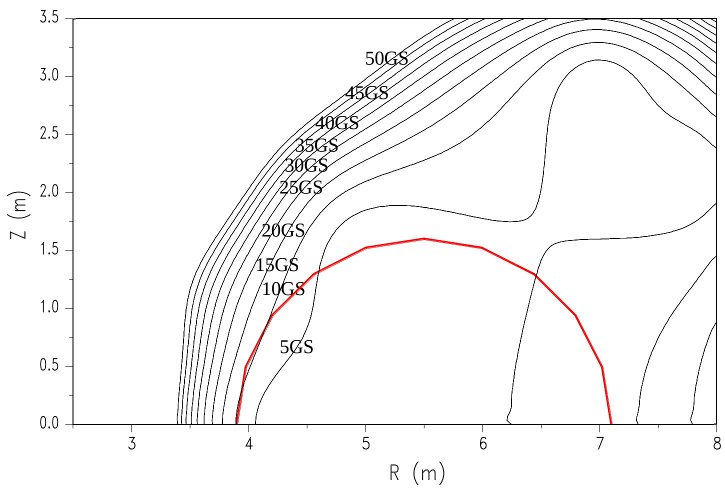
PF and CS coils EM force

Coil	MAG Fz (MN)
PF1/2U	-76.9
PF3U	25.1
PF4U	-4.52
CS3U	169.6
CS2U	54
CS1U	-9.4



CS/PF Design (6/6)

- Volt seconds of CS/PF: > 100 Vs;
- Stray magnetic field in the plasma region not beyond 10 GS;



Coil	R(m)	Z(m)	∆R(m)	∆Z(m)	turns	Current (kA)
CS3U	1.294	4.0475	0.512	1.559	374	24.037
CS2U	1.294	2.4285	0.512	1.559	374	38.262
CS1U	1.294	0.8095	0.512	1.559	374	31.615
CS1L	1.294	-0.8095	0.512	1.559	374	31.615
CS2L	1.294	-2.4285	0.512	1.559	374	38.262
CS3L	1.294	-4.0475	0.512	1.559	374	24.037
PF1U	2.0897	5.9151	0.587	0.476	80	32.391
PF2U	2.3747	6.6281	1.157	0.95	320	32.391
PF3U	8.3745	5.2835	0.689	0.707	196	1.762
PF4U	10.1925	2.1035	0.545	0.707	154	0.911
PF4L	10.1925	-2.1035	0.545	0.707	154	0.911
PF3L	8.3745	-5.2835	0.689	0.707	196	1.762
PF2L	2.3747	-6.6281	1.157	0.95	320	32.391
PF1L	2.0897	-5.9151	0.587	0.476	80	32.391

Location	Magnetic field (GS)	Magnetic flux (Wb)
(3.9,0)	9.73	50.01
(5.5,0)	3.45	50.00
(7.1,0)	8.44	49.97
(4.5,1.3)	6.51	50.02
(5.5,1.6)	3.23	50.02
(6.0,1.5)	4.37	50.01

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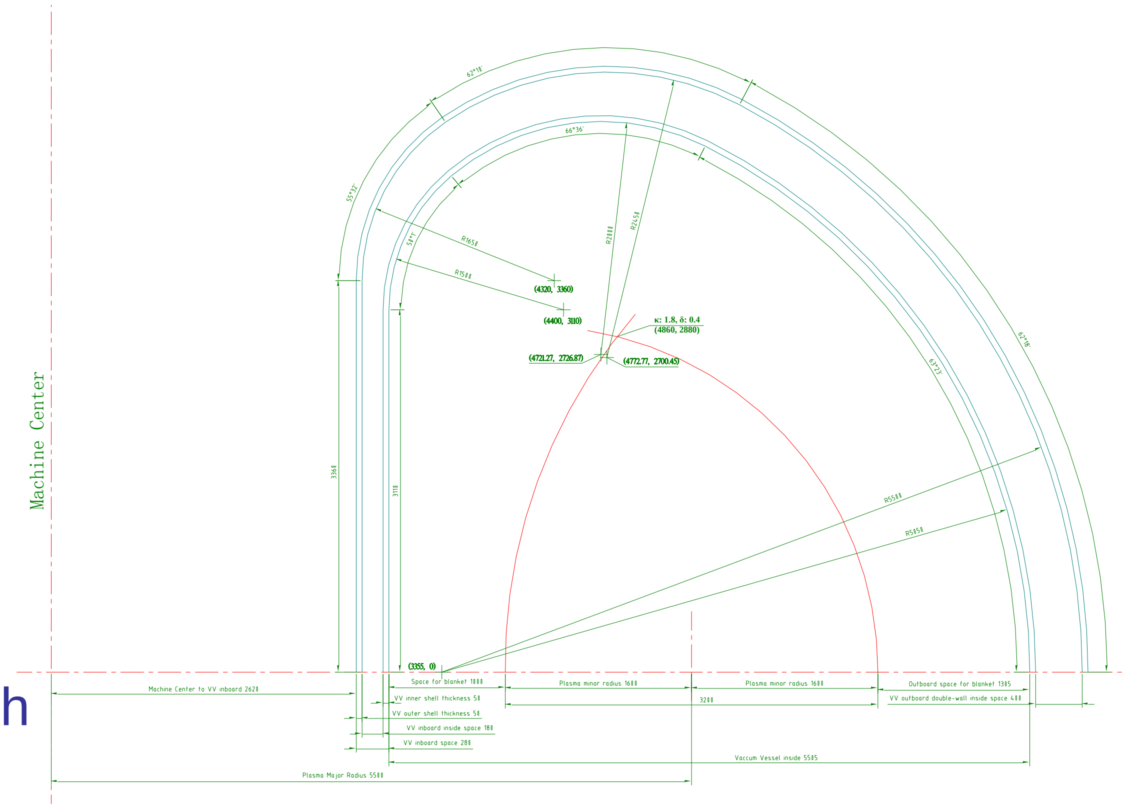
VV Configuration

- Double-shell with poloidal ribs, 50 mm of each shell;
- D shape consisted of five arcs and one straight line;
- TBM space: 1 m Inboard and 1.3 m outboard;
- Ununiformed space between double-shell from inboard to out board
- Inboard: Height 9.5 m, width 5.5 m.
- Outside: Height 10.3 m, width 6.3 m.



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Some Further Considerations (1/3)

Overall:

- Possibility to upgrade to DEMO in future?
- Necessary of DN, more important than TBM?

Magnets:

- To increase superconducting performance by: HTS or hybrid magnet with HTS?
- Or to operate at lower temperature: 3.8 K, 1.8 K superfluid He?
- Do we need standard CS?
- Replaceable TF, VV?

Some Further Considerations (2/3)

VV:

- Possibility to provide more surface for TBM by sharing big ports with maintenance ports, H/CD ports, diagnostics, …;
- To reduce neutron heating/damage of VV by neutron-sealed blanket structure?
- To reduce tritium retention of VV by differential vacuum control inside VV?
- Coating technology to reduce tritium retention;
- VV structure materials: austenitic stainless steels (easy activation, lower tritium perpeatment), Reduced-Activation Ferritic/Martensitic steel (lower activation, higher tritium perpeatment)? Vanadium Alloys?
- TBM install/alignment accuracy independent with VV manufacture accuracy.

Some Further Considerations (3/3)

R&D:

- Refer to “Key Technologies for Fusion Reactors”, presented at the 1st Workshop on MFE Development Strategy in China, Beijing, 5-6 January, 2012.

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Summary

- The configuration of Tokamak machine was drafted based on the basic requirements and plasma parameters;
- Initial analysis results show:
  - The TF system may provide B_T = 4.5 T at the center of plasma with acceptable peak filed
  - While the peak field of TF is 12.5 T if the B_T is 5.3 T
  - The peak fields are within acceptable region for CS/PF
  - The CS/PF system may provide more than 100 Vs
- The VV configuration may provide suitable spaces for TBMs;
- Further analysis of the magnet system is on-going;
- Some initial design for the VV has been performed and will be reported by the VV design team.
- Key R&D shall be addressed in the near future.

Thank you for your attention!