Design parameter and H&C for CFETR

Baonian Wan

2012-5-24

CFETR option I

CW Burning	1) P_f = 50-200MW with H mode and duty time ≧0.3-0.5 and no requirement on Q	Suitable parameters of device; Requiring enough addition P_H and P_{CD}; Requiring large amount of T consumptions;	What are the key required parameters of CFETR ?	B_t = ?	With SC or Cu coils ?
				R_0 = ?	
				b/a ~ 1.8 ?	
				a ?	
				I_P = ?	
				β_N = ?	
				P_H= ?	
				P_{CD} = ?	
	2) Duty time ≧ 0.3- 0.5	CW P_{CD} and P_H	What kind of and how high of P_{CD} and P_H are required? What kind of diverter and material could be?		
		T consumptions / year: ≧6 Kg (?)	Is it right and possible?		Assuming P_f = 200MW
	3) TBR ≧ 1.2	Produce T ≧ 6 Kg/year	Is it right and possible? What kind of blanket and the dimension are required?		Assuming P_f = 200MW
	4) Q_{eng} ≧ 1 ?	With hybrid blanket?	What kind of blanket and the dimension are required? Is it right and possible?		Should be discussed further!

Machine

- Type I ELMy H-mode as base line
- Medium betaN for stable operation

Assumption：
- Nel/nGW~0.8
- nDT/ne~0.72
- Zeff~2.1 ST=SN=1

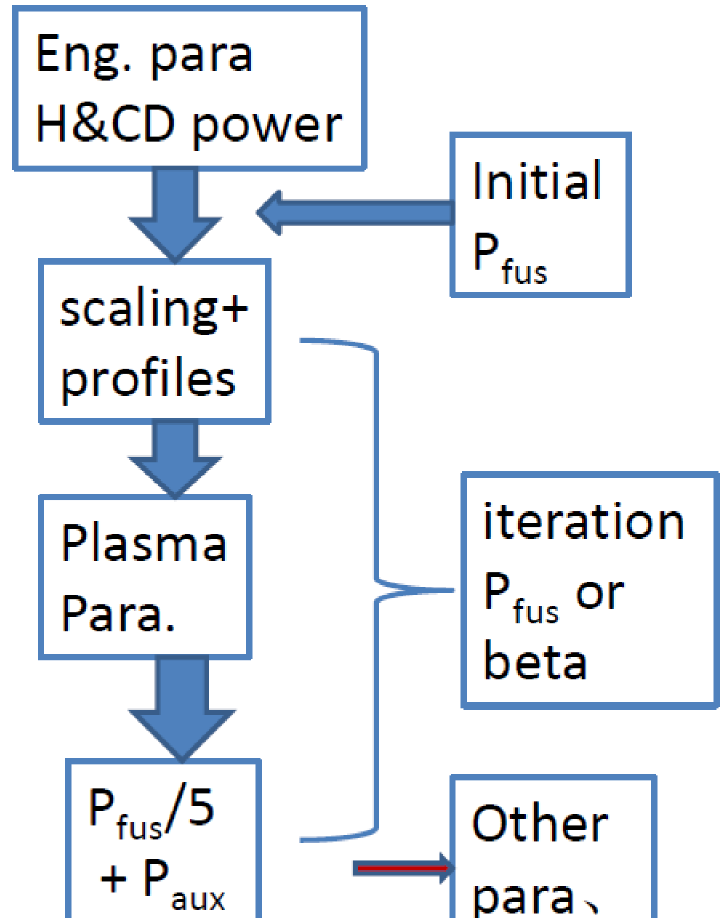
（note： peaking factor will affect the estimated fusion power. peaked profile may increase the fusion power, but not be easily realized in fusion relevant plasma）

R(m)	5.5
a(m)	1.6
A	3.43
V_Pl(m^3)	500
Elongation	1.8
B0(T)	5.3/4.5
Triangularity	0.4
Ip(MA)	12/10/7
Paux(MW)	50/80

Reasonable neutron load on blanket ~0.5MW/m^2
H&CD injection power density: 15~20MW/m^2， 4~5m^2 not available for T production！

ITER as benchmark

R(m)	6.2
a(m)	2
Plasma_volume(m^3)	832
Elongation	1.7
Triangularity	0.33
Ip(MA)	15
Paux(MW)	73
q95	3
Zeff	2.1
Fusion_power(MW)	558
Q	9.6
Ti0（keV）	17.6
nel（20/m^3)	0.95
betaN	1.54
betaP	0.53
fbs	18
taoE98Y2(s)	3.57
Resistance(ohm)	5.54E-09



Higher Bt

Ip(MA)	12	12	10	10	10	10
B0(T)	5.3	5.3	5.3	5.3	5.3	5.3
Paux(MW)	50	80	50	80	50	80
q95	3.02	3.02	3.63	3.63	3.63	3.63
F_power(MW)	337	401	169	213	451	504
Q	6.7	5	3.4	2.7	9	6.3
Ti0	14	15.4	11.8	13.3	20.8	22.6
nel	1.26	1.26	1.05	1.05	1.05	1.05
betaN	1.62	1.78	1.37	1.54	2.41	2.61
betaP	0.61	0.67	0.62	0.69	1.08	1.17
fbs	19.6	21.6	**20.0**	**22.5**	**35.1**	**38**
taoE98Y2(s)	3.27	2.64	3.23	2.49	2.27	1.9
Pn/Awall	0.62	0.8	0.34	0.42	0.9	1.0
Resistance(ohm)	1.1E-08	9.4E-09	1.4E-08	1.2E-08	6.0E-09	5.3E-09
H98					1.5	1.5

Marginal for 12MA operation, recent equilibrium calculation may request a~1.7m
It is really hard for steady-state operation, due to small fraction of bootstrap current

Lower Bt

Ip(MA)	10	10	7	7	7	7
B0(T)	4.5	4.5	4.5	4.5	4.5	4.5
Paux(MW)	50	80	50	80	50	80
q95	3.08	3.08	4.4	4.4	4.4	4.4
F_power(MW)	158	201	48	65	128	158
Q	3.2	2.52	0.96	0.82	2.56	1.97
Ti0	11.5	12.9	9.2	10.6	14.9	16.8
nel	1.05	1.05	0.74	0.74	0.74	0.74
betaN	1.56	1.76	1.25	1.44	2.03	2.29
betaP	0.6	0.67	0.68	0.79	1.1	1.25
fbs	**19.3**	**21.8**	**22.2**	**25.5**	**35.8**	**40.4**
taoE98Y2(s)	3.21	2.46	2.48	1.82	2.1	1.6
Resistance(ohm)	1.5E-08	1.2E-08	2.0E-08	1.6E-08	9.9E-09	8.3E-09
H98					1.5	1.5

Still met the mission. It is possible for fully non-inductive operation in 7MA case

Volt-seconds for burning

For ITER standard operation scenario, to build-up plasma up to 15MA needs about 90Vs. It is estimated for additional 27 Vs for 400s burning phase if no external current drive is applied.

For CFETR, to build-up plasma up to 10MA needs about 65~70Vs， if 30Vs is available for burning, then:

- **For 10MA（5.3T) ， no external CD， $T_{burning}$ >300s**
- **For 10MA（5.3T) with H98~1.5， no external ， $T_{burning}$ >750s**
- **For 10MA（4.5T)， no external CD， $T_{burning}$ ~300s**

For CFETR, to build-up plasma up to 7MA needs about 50Vs， if 45Vs is available for burning, then:

- **For 7MA（4.5T) ， no external CD， $T_{burning}$ >500s**
- **For 7MA（4.5T) with H98~1.5， external CD, $T_{burning}$ >1000s.**

Discussion for long pulse & SSO

- η_{CD} increased with T_e and decreased with n_e.
- Higher confinement (ITB) for higher f_{bs}
- ETB gives HH ~ 1 and ITB yields HH > 1, → P > P_{thr}, triggering ITB

I_{CD}/P_{CD}; $\gamma = n_{20} I_{CD\,A} R_m / P_{CD\,W}$; $\zeta = \gamma\, 33/T_{e\,keV}$

	LHCD	ECCD	FWCD	NBCD
γ [A/(Wm²)]	0.3-0.4 (indep. of T_e)	≥0.2 (ITER prediction)	0.07 (ITER prediction)	0.5 (2 MeV) (DEMO prediction)
ζ [A/(Wm² keV)]	n.a.	≥0.3	0.1-0.2	0.4-0.5
η_{CD}	0.3 (present) 0.5 (goal) (100 % coupling)	0.3 (present) 0.5 (goal)	0.5 (present) 0.7 (goal) (100 % coupling)	0.3 (present) 0.5 (goal)
$\gamma^*\eta_{CD}$ (compare to 0.25)	0.09-0.2	0.09 - 0.15	0.05-0.15	0.12-0.25

Discussion for long pulse & SSO

- P_{EC}:30~35MW, P_{LH}:20~25MW; for CD +additional heating (NBI, ICH).
- Very difficult tangential injection of NB since long port extension
- Too low driven efficiency of ICCD

Ip(MA)	10	10	7	7
B0(T)	5.3	5.3	4.5	4.5
Paux(MW)	80	80	80	80
F_power(MW)	500	330	158	120
Q	6.3	4.2	2.0	1.5
Ti0	22	26	16.8	20.
nel	1.05	0.75	0.74	0.53
betaN	2.6	2.1	2.3	1.7
fbs	38	31	40	35
Resistance(ohm)	5.3E-09	4.3E-09	8.2E-09	6.1E-09
T_burning(s)	2000	>2000	5500	SS

HH~1.3 hybrid mode, with ne ~ 0.6n_{GW}
F_{fus}~270MW for 2000 burning possible

- Assuming: HH~1.5, is it really achievable?
- Too conservative for beta?
- Reduced density to 0.6n_{GW} seems to meet mission possibly.
- Uncertainties in current drive efficiency? Particularly for LHCD
- Synergy of H&CDs
- H&CD assisting start-up

Conclusion

- betaN < 3， simplify instability control。
- With proper H&CD, assure 2000s for burning, but need higher performance.
- Additional 100s for plasma start-up and termination with ramping rate 0.2MA/s, which should met requested duty cycle>0.5。
- Potential capability for alpha-heating dominated burning plasma。

R(m)	5.5
a(m)	1.6
A	3.43
V_Pl(m^3)	500
Elongation	1.8
B0(T)	5.3/4.5
Triangularity	0.4
Ip(MA)	12/10/7
Paux(MW)	50/80
Flux(Vs)	100

Next step， checking and optimizing equilibrium and configuration; simulation based on transport models, optimization of H&CD mix