Plasma current ramp-up by the vertical field and the heating power in NSTX using the early H-mode operation

XP Meeting

by O. Mitarai

Kyushu Tokai University, Japan

March 1, 2005, at PPPL

Contents

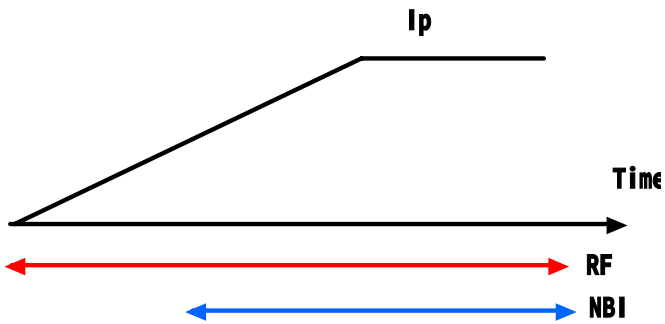
1. Why this XP re-submission?
2. Theoretical/ empirical justification:
3. Expected plasma current waveform in NSTX
4. Reference shot for this experimental

In collaboration with

Drs. C.Kessel, J.Menard, D.Gates, Y.Takase and M. Peng

1. Why this XP re-submission?

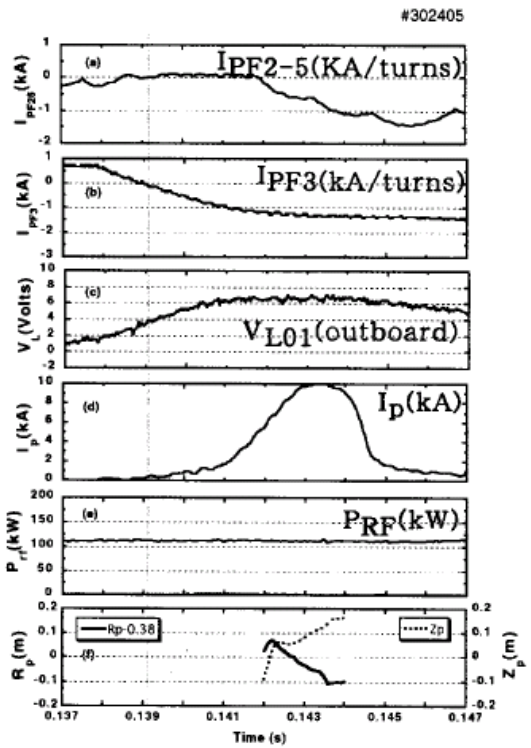
@ The plasma current ramp-up has been one of the major problems in a low aspect ratio ST.



RF can be used from the beginning, but NBI can be only used after density is increased and in the high plasma current regime to reduce the beam ion loss.

RF: C.Kessel's XP
NBI: .Mitarai's XP

@ While several methods (CHI or ECRH) for breakdown and current start-up in ST have been demonstrated without central solenoid as shown here, the plasma current ramp-up has not been demonstrated experimentally in a high plasma current regime in a ST. Actually, the plasma current breakdown and start-up to ~10 kA has been obtained in TST-2 and 20 kA in NSTX with the vertical field and RF heating power without central solenoid. To make this type of experiment, the high power ECRH system is indispensable. After future installation, it would be tried actively in NSTX.

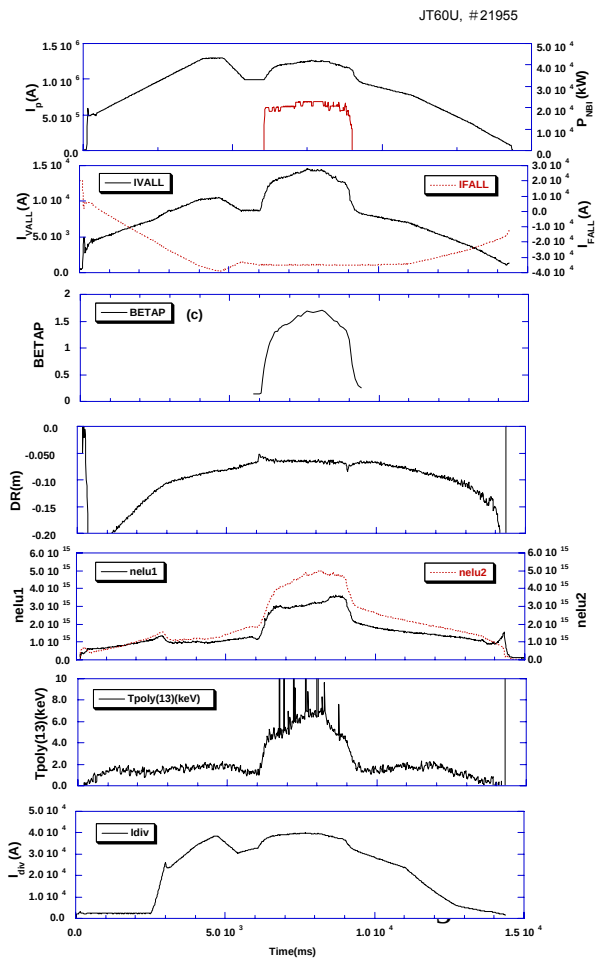


Current evolution in TST-2

@ Although I have proposed the current ramp-up experiments by the vertical field and heating power in 2001, such experiment has not been tried yet.

2. Theoretical/ empirical justification:

(1) In JT60U, the plasma current ramp-up to 250 kA has been obtained by the vertical field and heating power of 24 MW of NBI with the constant OH current.



(2) In JT60U, the plasma current increment up to 200 kA has been observed by the vertical field and heating power of NBI in the third phase without any OH current.

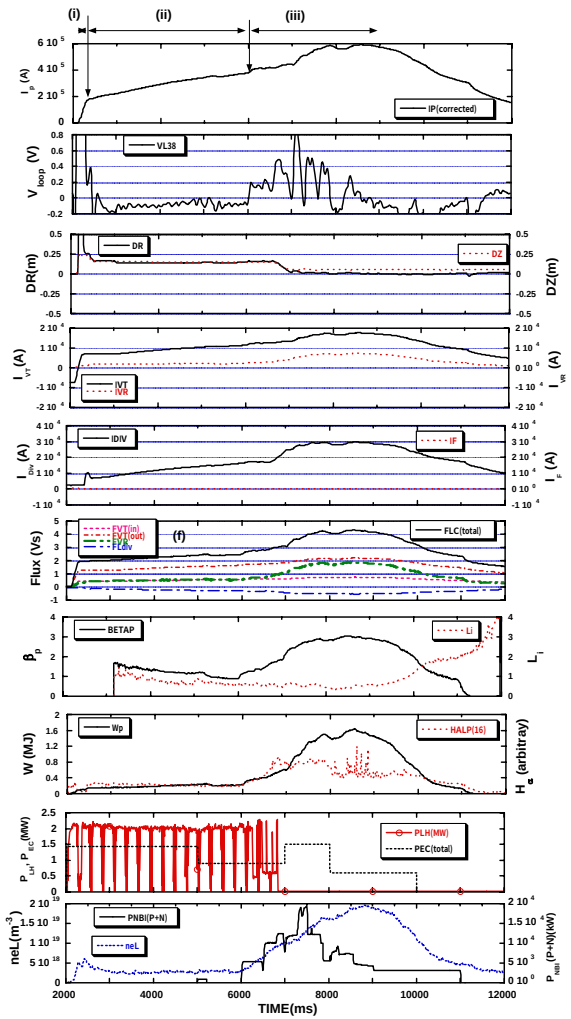


Fig.10 (41711)

The inner VT coil has been used although the flux contribution of 20 % is small. Note that <u>there are no such data in the high plasma current regime in a ST.</u>

3. Expected plasma current waveform in NSTX

Using the plasma circuit equation and zero-dimensional particle, energy balance equation.

@ **With the vertical field effect, the plasma current is dramatically ramped up to 790 kA without non-inductive drive.** ΔI_p ~330 kA (η_{CD}= 0 Am^{-2}/W) for γ_{HH} = 1

In the heating phase: $\tau_E = \tau_{IPB98y2}$
T_i/T_e=1.5 based on the experiments.
Impurity: Z_{eff} ~2.0
Density: Waveform based on Thomson scattering data
Total OH flux: 0.6 Vs
1.5, 3.0, 4.5MW NBI

Beam ion loss: ~40% at I_p=0.5 MA, ~15% at I_p=1MA $\eta_{NBI} = \left(\sqrt{\frac{I_p(t)}{1\ MA}} - 0.15\right)$

ℓ_i=0.5

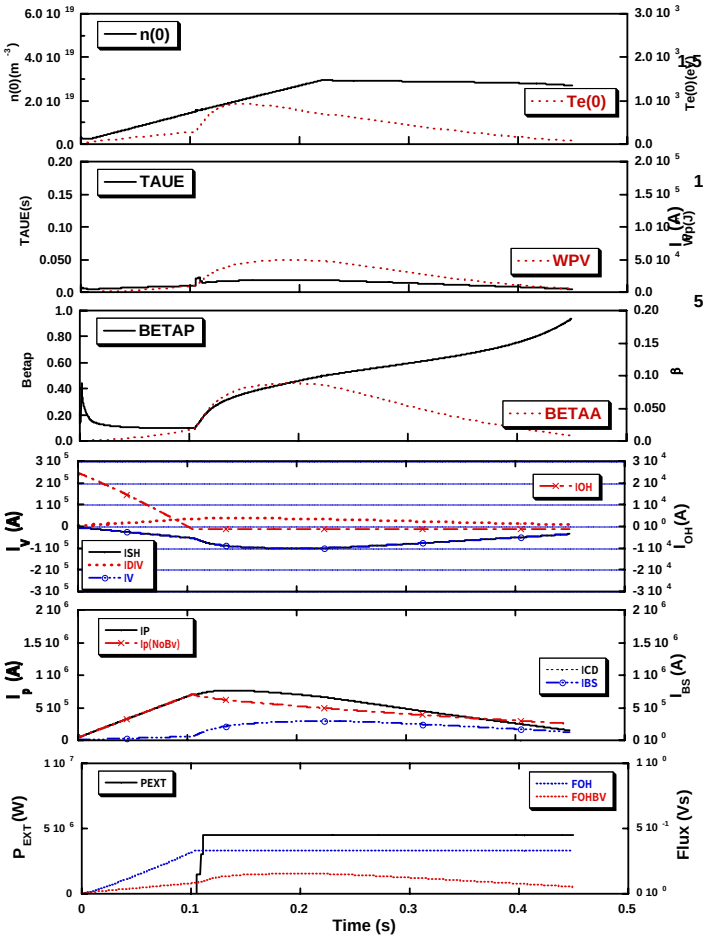
@ **When the current drive efficiency is increased to η_{CD}= 1.25x10^{18} Am^{-2}/W, the plasma currents is ramped up to 940 kA with the vertical field effect.**

@ **The larger plasma current is obtained when a higher confinement factor γ_{HH}=2.0 is achieved through the higher plasma energy.**

The smaller internal inductance ℓ_i, larger confinement γ_{HH}, large heating power P_{NBI}, and good plasma position control are important for this experiment. → Early H-mode operation provides a good target plasma.

[1] 0-dimensional analysis (O.Mitarai)

Initial OH Plasma current: I_p =700kA, γ_{HH}=1.0, ℓ_i=0.5, P_{NBI}=4.5 MW, B_t=0.3 T



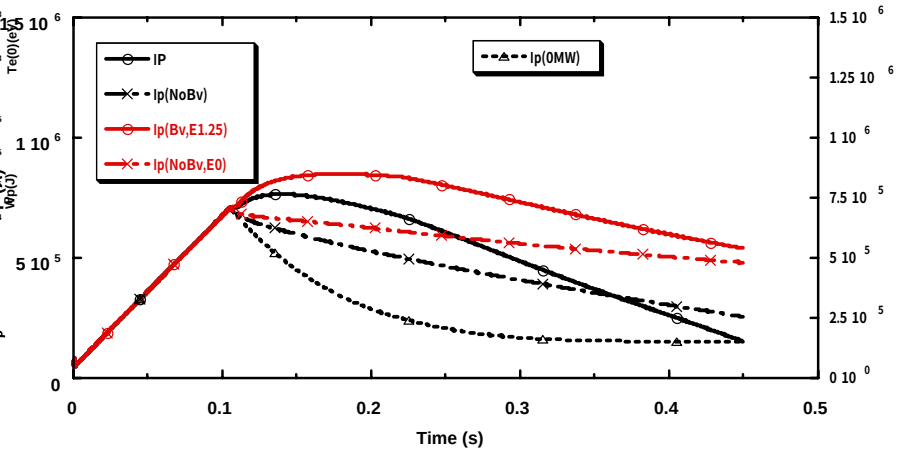


Fig. 3

[2] TSC simulation (C.Kessel)

Ohmic ramp-up to Ip = 550 kA

Try to match 109070 Te and n evolution

$\tau_E \approx 1/2\tau_{E98y,2}$

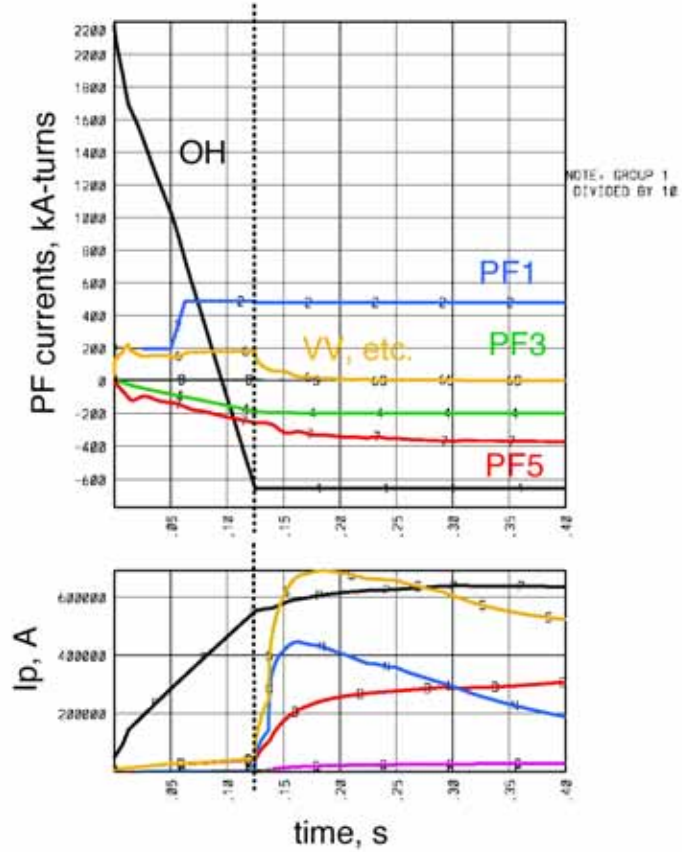
At t = 0.125 s, clamp OH current and inject 6 MW NBI

$\tau_E \approx 1.0\text{-}1.25\ \tau_{E98y,2}$

NBCD and BS drive Ip up slightly, however due to rising density, the NBCD is dropping, so Ip will also

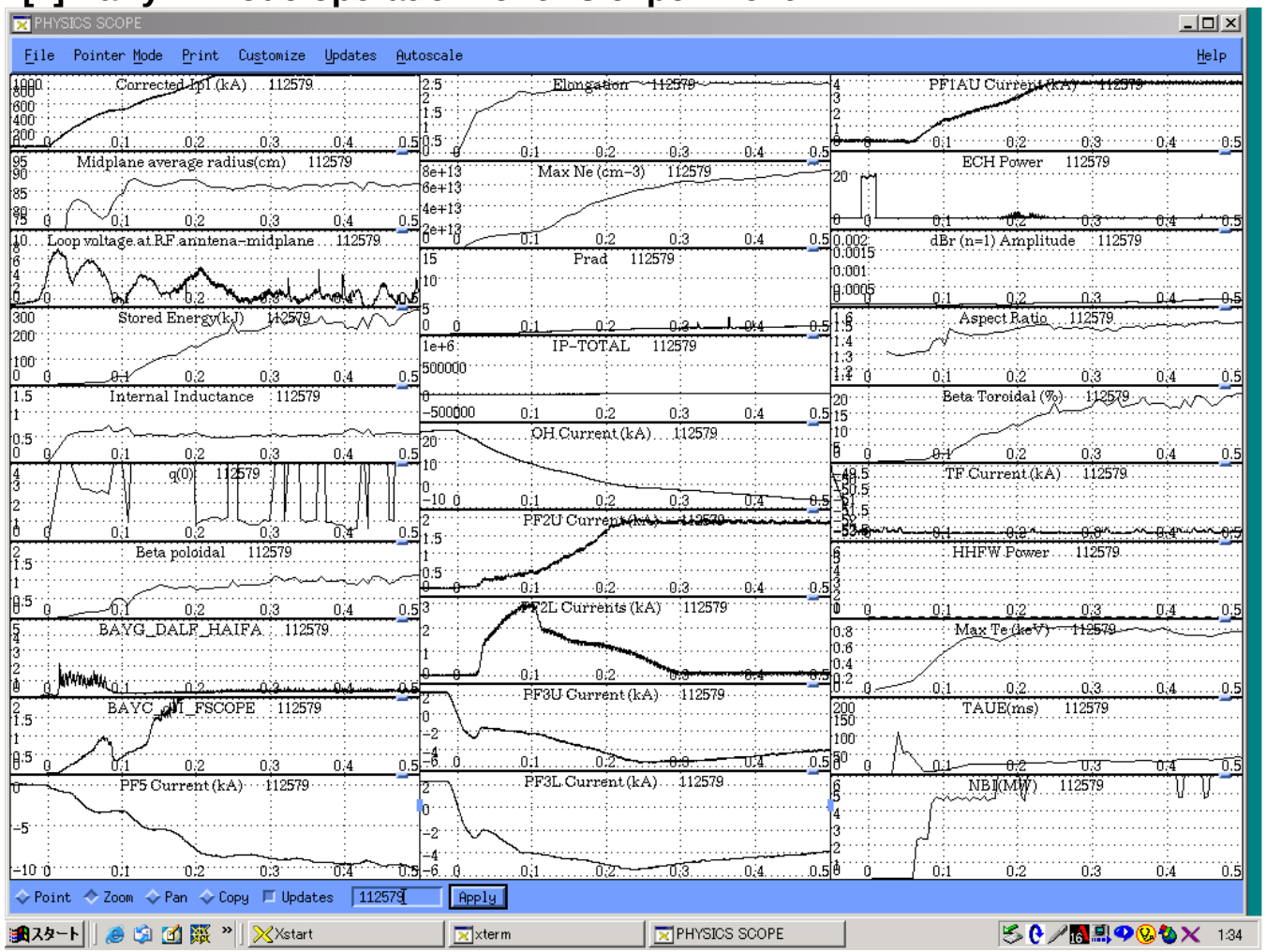
Lower Ip starting points will provide larger Ip ramps

*NB not really confined at this Ip

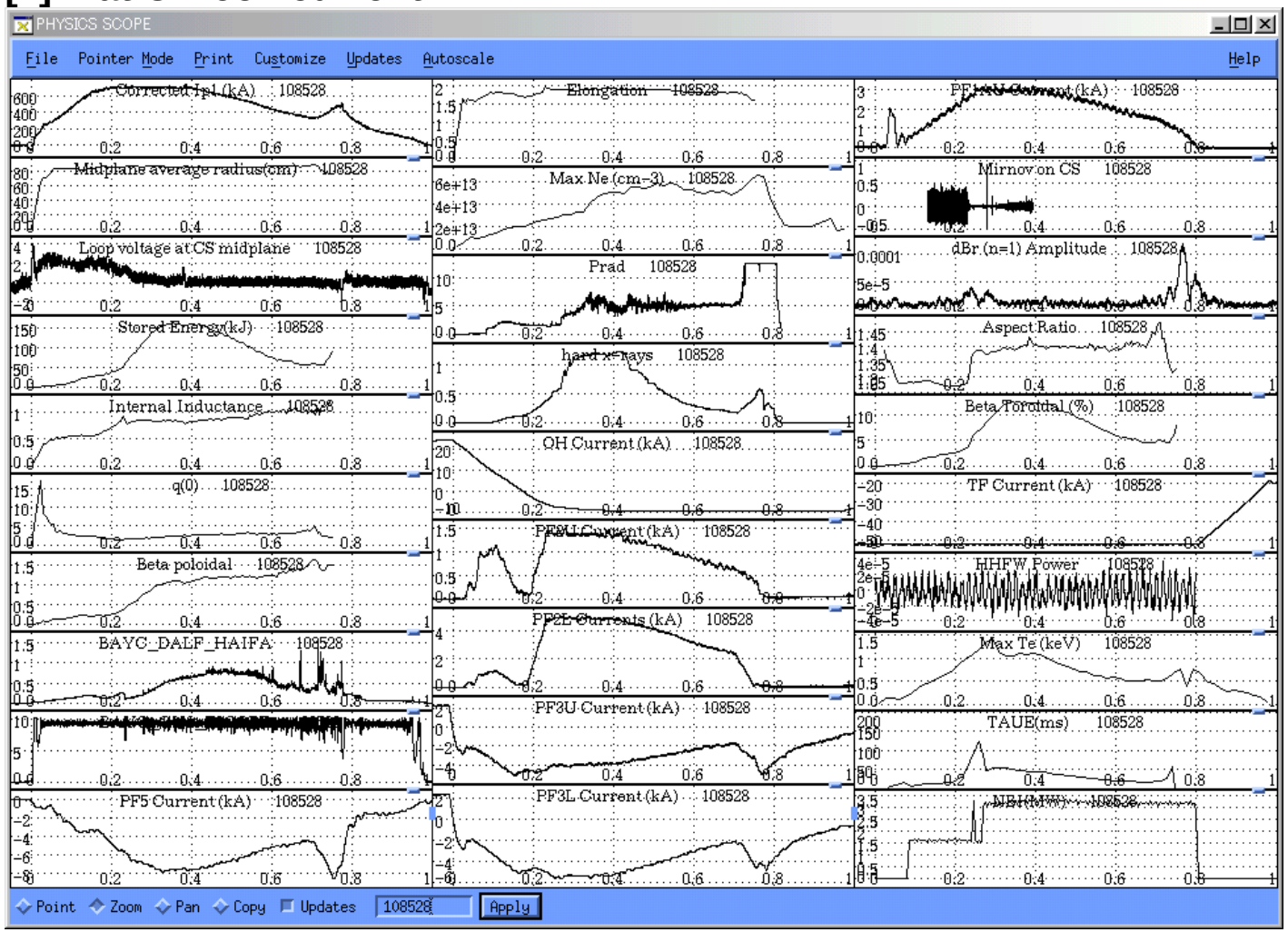


4. Example of experimental shots

[1] Early H-mode operation for this experiment



[2] Flat OH coil current



5. Experimental run plan:

To switch off the Ohmic contribution to the plasma current ramp-up, experiments are conducted during the constant OH coil current phase.

We try this experiment based on the early H-mode shot, such as #112570, recently observed in NSTX.

[1] Single null configuration with early H-mode

(1) Precock the OH coil current to the positive polarity at I_{OH}=+22 KA, and reduce it to the zero in 0.1~0.12 sec to induce the plasma current as shown in Fig. 1. Lower X-point should be controlled to get early H-mode. After the plasma current reaches 500 kA or 700 kA at around 0.1 - 0.15 sec, switch off the OH coil current or keep the same OH coil current for the subsequent phase of ~0.3 sec.

(2) Use the feedback control for :

(a) The elongation at 2.0.

(b) The radial position to keep the plasma centered near R = 85 cm. Use the EFITs to determine this condition.

(c) The vertical position to keep the plasma vertically centered.

(d) Care must be taken not to suppress the plasma current.

(3) Vary gas puff to achieve as n(0) ~$3x10^{19}$ m^{-3} or more (as high a density as possible) without density limit disruption. Adjust the time of the density increase at the beginning of the OH current free phase, if possible.

(4) The first neutral beam of ~2.3 MW is injected to make early H-mode transition, and second NBI of 5~6 MW is injected when the OH coil current starts to be clamped.

(5) Use the toroidal field of 0.45 Tesla.

Table 1

Toroidal field	Elongation	Initial plasma current	Injected NBI power				
			(1 type) NBI= 0 MW	(2 type) NBI=2.3 to 2.3 MW	(3 type) NBI=2.3 to 5.0 MW	(3 type) NBI=2.3 to 6.0 MW	(1 type) NBI= 0 MW
0.45 T	2.0	500 kA	[1]	[2]	[3]	[4]	[5]
0.45	2.0	700	[6]	[7]	[8]	[9]	[10]

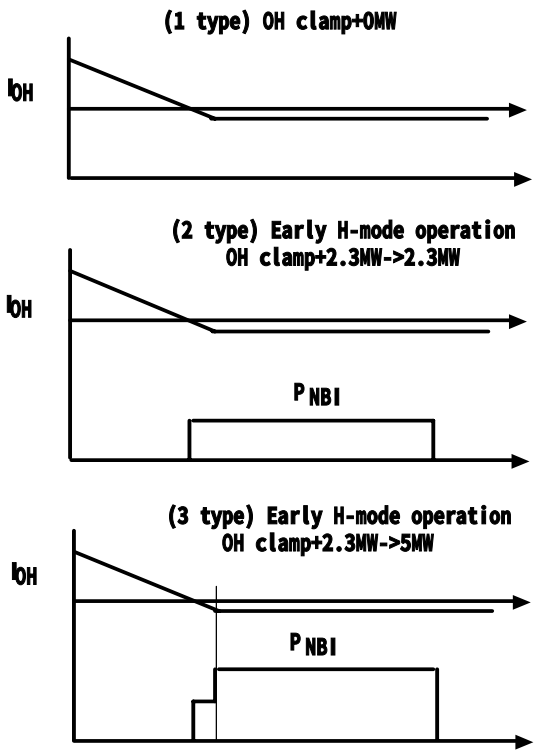


Fig. 1 Ohmic coil current and NBI power

(6) Minimum scan for 500 KA in Table 1 would require at least 5 shots.
If good results are observed, we proceed to 700 kA.

(7) If good results are observed by NBI, we proceed to this experiment.
HFFW with 0, π, 0, π phasing (no current drive mode) is applied after the NBI pulse when the OH coil current starts to be clamped. Initially 3 MW will be injected and then will be increased step by step to 6 MW.

Table 2

Toroidal field	Elongation	Initial plasma current	Injected HFFW power			
			(2 type) NBI=2.3MW long pulse +RF=0 MW	(3 type) NBI=2.3MW short pulse + RF=3 MW	(3 type) NBI=2.3MW short pulse +RF=6 MW	(1 type) NBI=0 MW +RF= 0MW
0.45 T	2.0	500 kA	[11]	[12]	[13]	[14]
0.45 T	2.0	700 kA	[15]	[16]	[17]	[18]

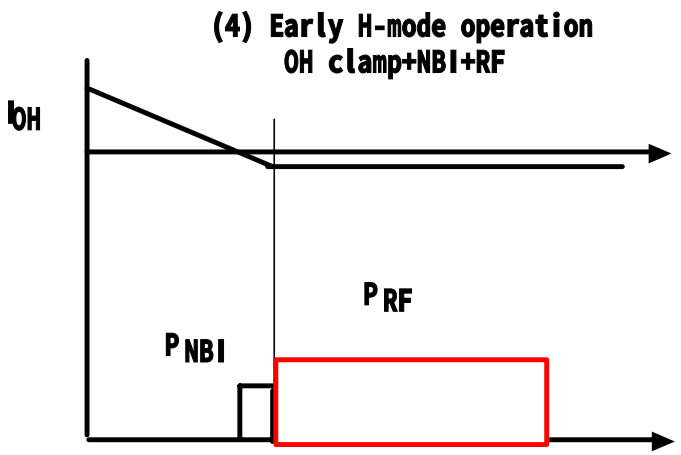


Fig. 2. NBI+RF

(8) If good results are observed, we increase the initial plasma current to 700 kA.
Entire scan for Table 1 and 2 would require at least 18 shots.

Total 18 shots +α> 1/2 run day.

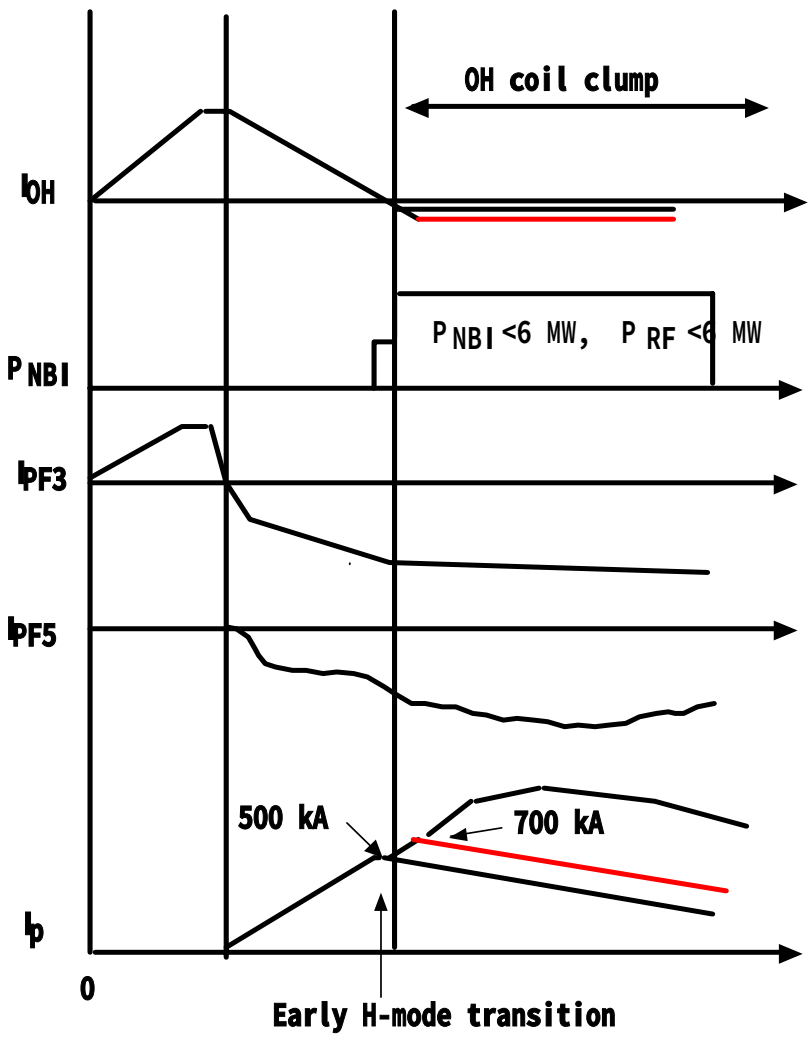


Fig. 3. The PF coil current waveforms and the timing of the heating power for proposed experiments