Study on the KSTAR 84 GHz second harmonic ECH preionization

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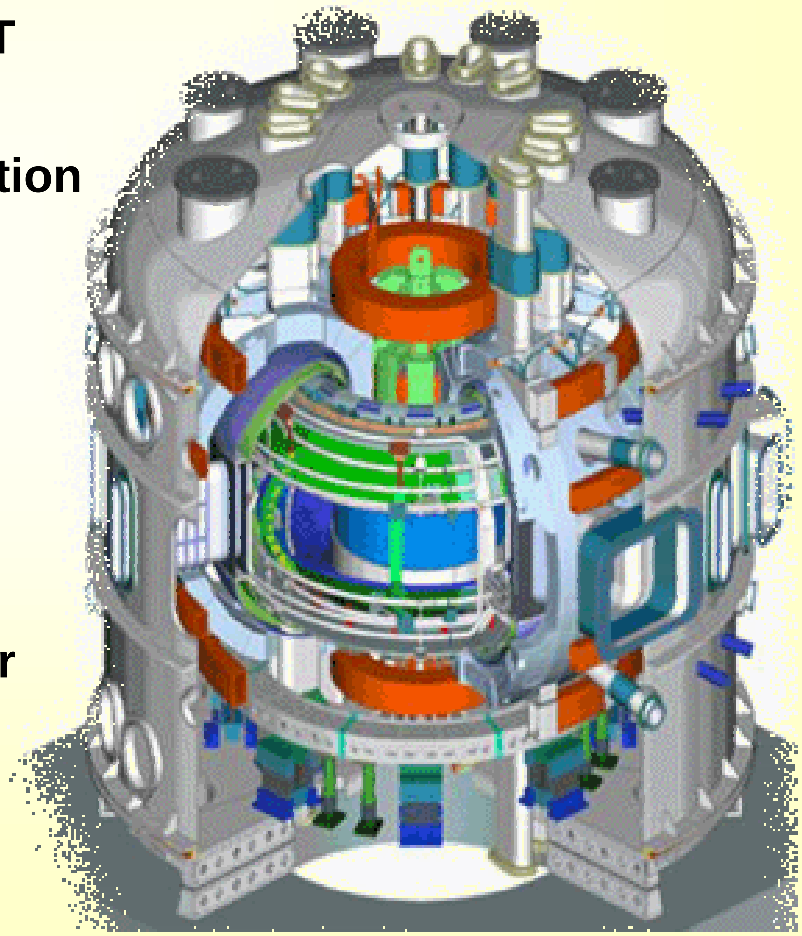
Abstract

In the KSTAR first phase operation, the toroidal magnetic field is 1.5 T which corresponds to the electron cyclotron resonance frequency of 42 GHz. However, the system for ECH preionization is under preparation for the frequency of 84 GHz for 3 T operation. Naturally, the 84 GHz ECH system becomes the second harmonic ECH preionization in the first phase operation. In this paper, we performed code calculations at various loop voltages using the KSTAR poloidal coil geometry and the coil current ramping scenarios. The results show that the present 6 V loop voltage scenario must be modified for the second harmonic ECH preionization for ramping up the plasma in millisecond with Ohmic heating. We propose the proper loop voltage and the ECH pulse duration.



Why is ECH preionization?

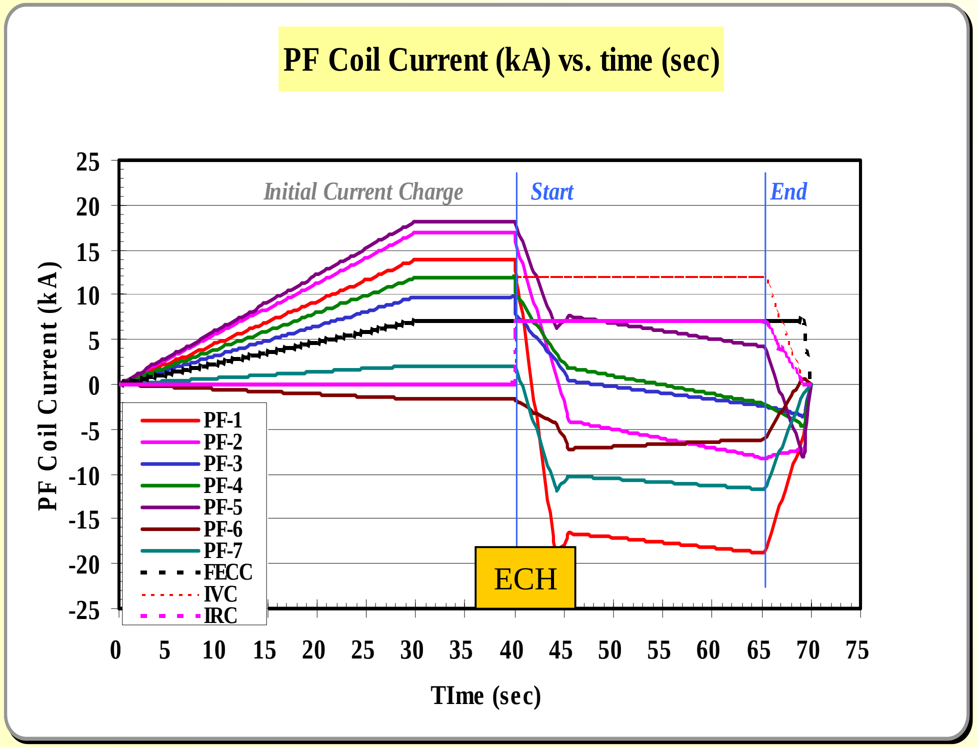
1. 루프 전압**(loop voltage)**을 낮출 수 있다**.**

   → 토카막 진공용기**(vacuum vessel)**가 두꺼워도 좋다**.**

2. **Ohmic heating** 만으로 플라즈마를 초기 절연파괴를 시킬 때 발생하는 **runaway electron**들을 줄일 수 있다**.**

3. 플라즈마 전류 상승**(ramp up)** 동안에 플라즈마 파라미터에 대해 민감한 영향을 받지 않고 초기이온화 된다**.**

ECH preionization simulation with PF coil current scenario for KSTAR



- **<u>Circuit equations</u>**

$$-\sum_{n=1}^{8} M_{n8}\frac{dI_n}{dt} - I_8 R_p = 0 \quad \Rightarrow \quad dI_8 = \frac{-\sum_{n=1}^{7} M_{n8}\frac{dI_n}{dt} - I_8 R_p}{M_{88}} \times dt$$

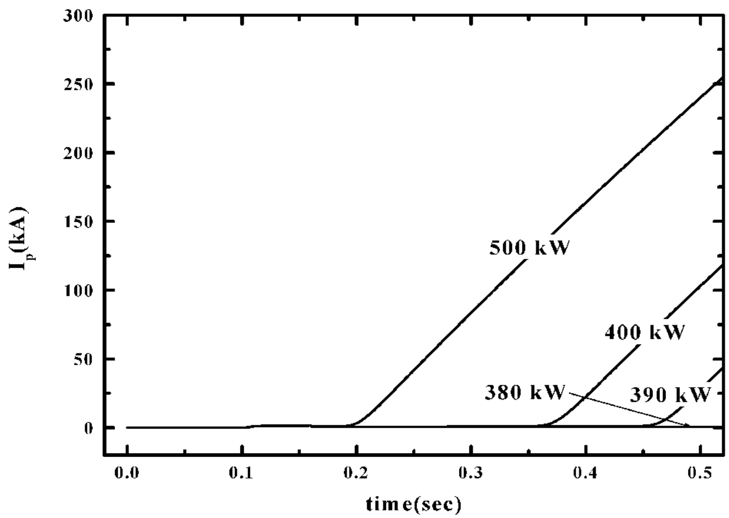
$$V_{loop}\,(\text{loop voltage}) = -\sum_{n=1}^{7} M_{n8}\frac{dI_n}{dt}, \quad V_{resis}\,(\text{resistive voltage}) = -I_8 R_p$$

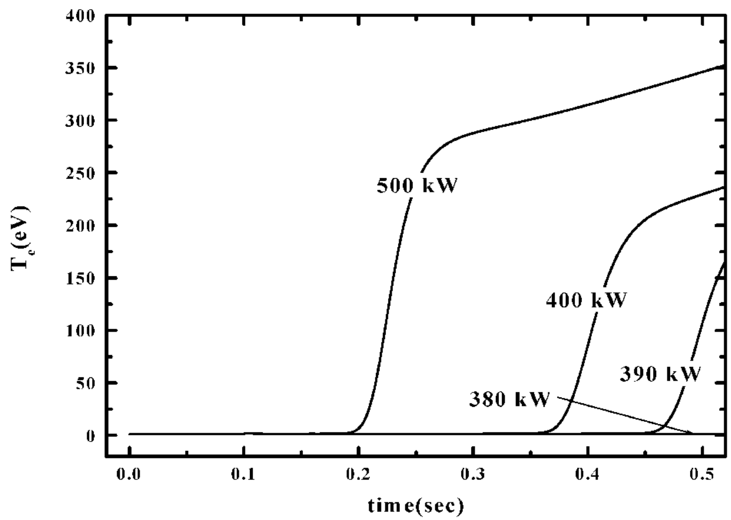
Where n = 1 – 7 for the 7 pairs of PF coil and n = 8 for the plasma, R_p is the plasma resistance, and the M_{n8} is the mutual inductances between PF coils and plasma.

Summary of parameter dependence for ECH preionization

	Fundamental harmonic	Second harmonic
RF power	$\gtrsim$ 10 kW	$\gtrsim$ 400 kW
Neutral density range for the plasma current start-up	$\lesssim 2.0\text{x}10^{13}/cm^3$	$\lesssim 0.5\text{x}10^{13}/cm^3$
Error field (B_{err}) limit	$\lesssim$ 13 mT	$\lesssim$ 0.1 mT
Carbon impurity fraction	$\lesssim$ 0.2 %	$\lesssim$ 0.07 %
Oxygen impurity fraction	$\lesssim$ 0.5 %	$\lesssim$ 0.1 %
Iron impurity fraction	$\lesssim$0.007 % for B_{err}=5 mT (sensitive)	$\lesssim$ 0. 0003 % (very sensitive)

The minimum RF power scan for second harmonic ECH



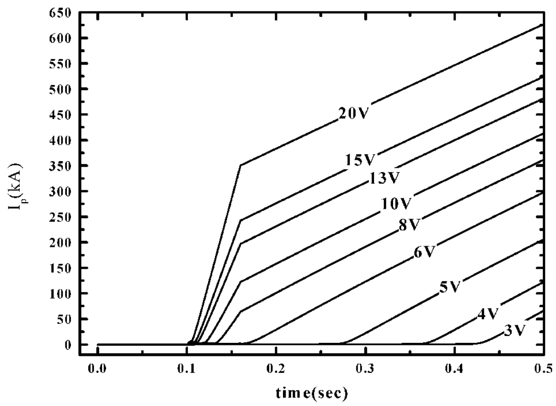


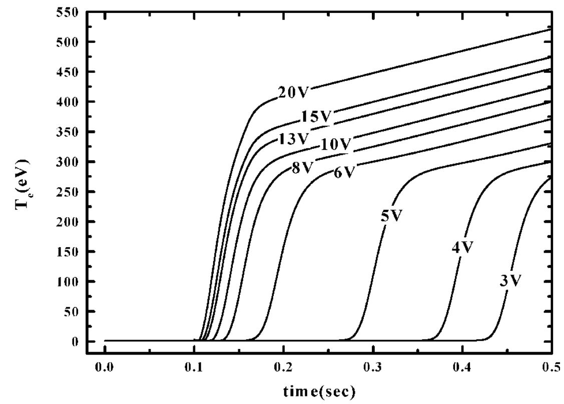
B_T = 1.5 T, R = 1.8 m, a = 0.5 m, RF power on time = 0 sec, t_{RF} = 2 sec, Ohmic heating on time = 0.1 sec, B_{err} = 1 mT, N_o = 1.0x10^{13}cm^{-3}, No impurity and all X-mode propagation

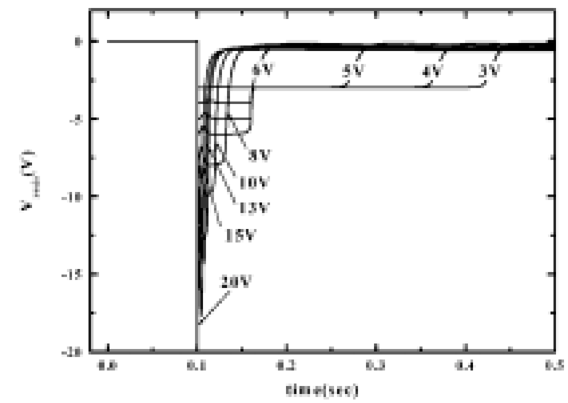
Comparison of P_{RF} = 500 kW with no RF in second harmonic ECH

B_T = 1.5 T, R = 1.8 m, a = 0.5 m, P_{RF} = 500 kW, RF power on time = 0 sec, t_{RF} = 2 sec, Ohmic heating on time = 0.1 sec, duration of applied loop voltage = 0.06 sec, B_{err} = 1 mT, N_o = 1.0x10^{13}cm^{-3}, No impurity and all X-mode propagation

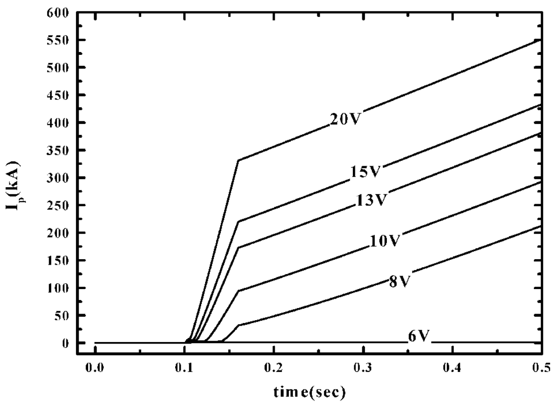
P_{RF} = 500 kW

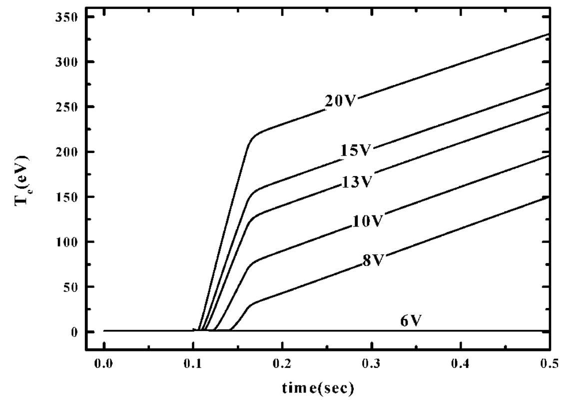


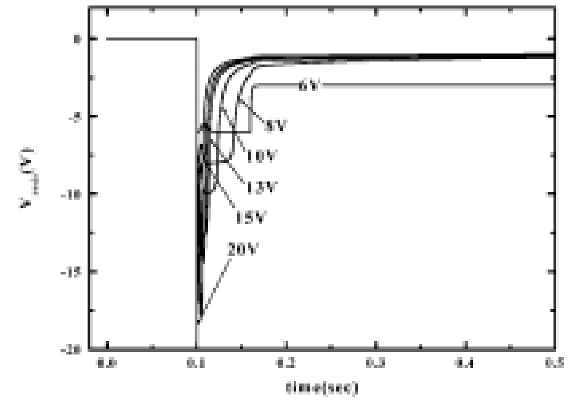




No RF power



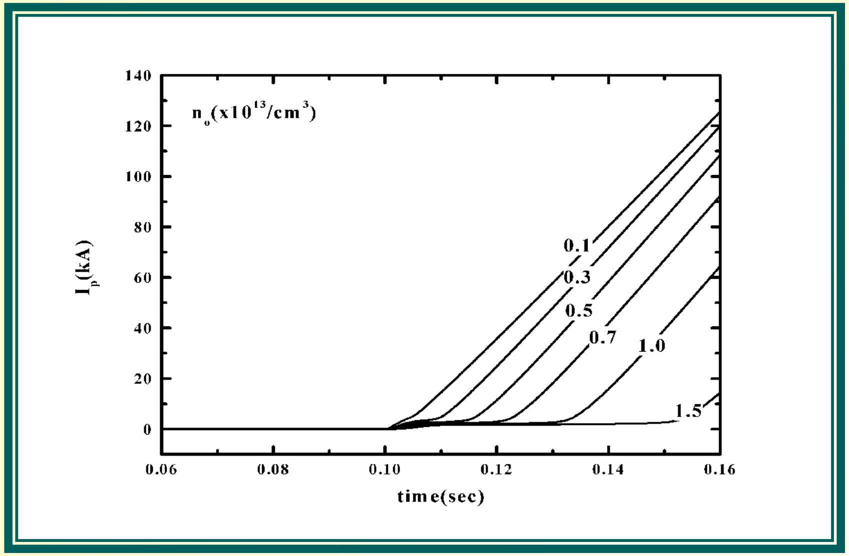


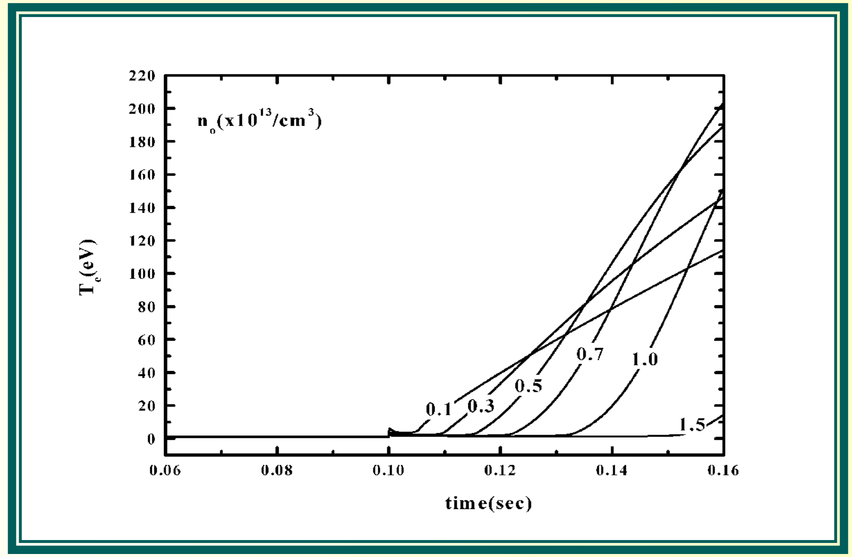


Variation of neutral density at constant loop voltage

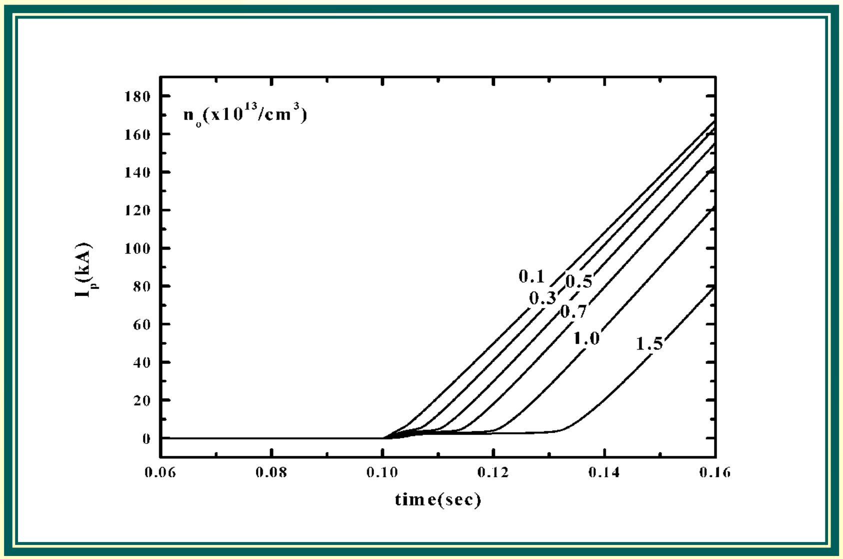
B_T = 1.5 T, R = 1.8 m, a = 0.5 m, P_{RF} = 500 kW, RF power on time = 0 sec, t_{RF} = 2 sec, Ohmic heating on time = 0.1 sec, duration of applied loop voltage = 0.06 sec, B_{err} = 1 mT, No impurity and all X-mode propagation

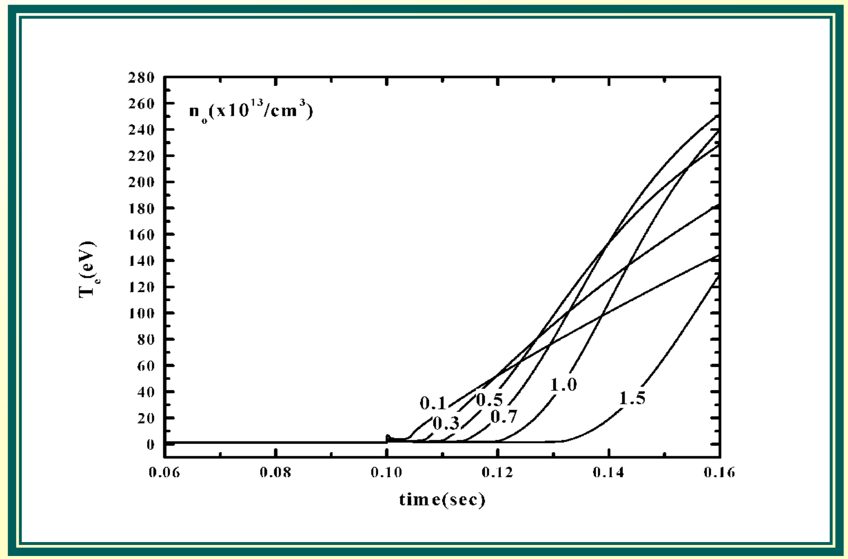
V_{loop} = 8 V



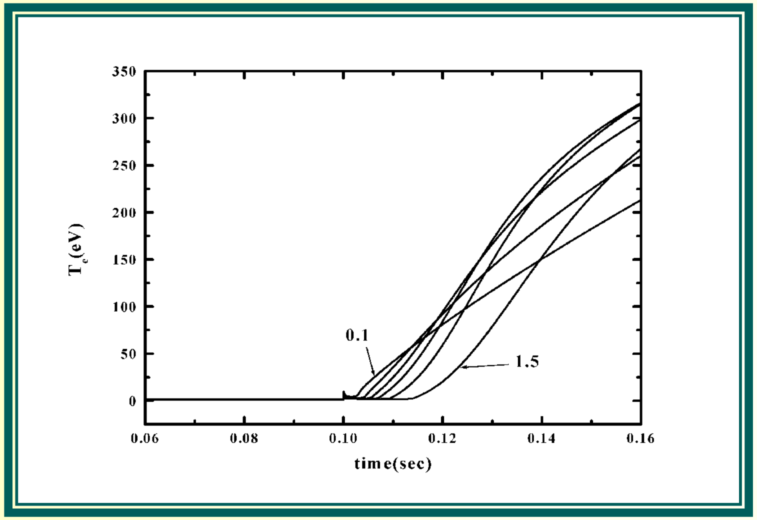


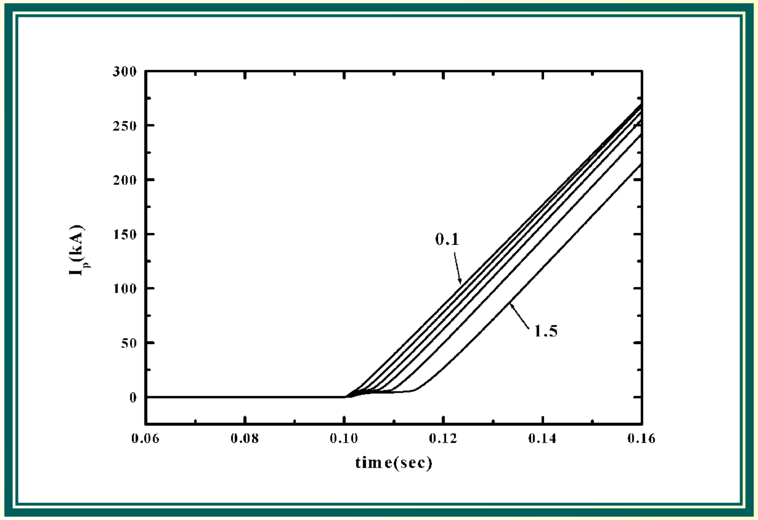
V_{loop} = 10 V





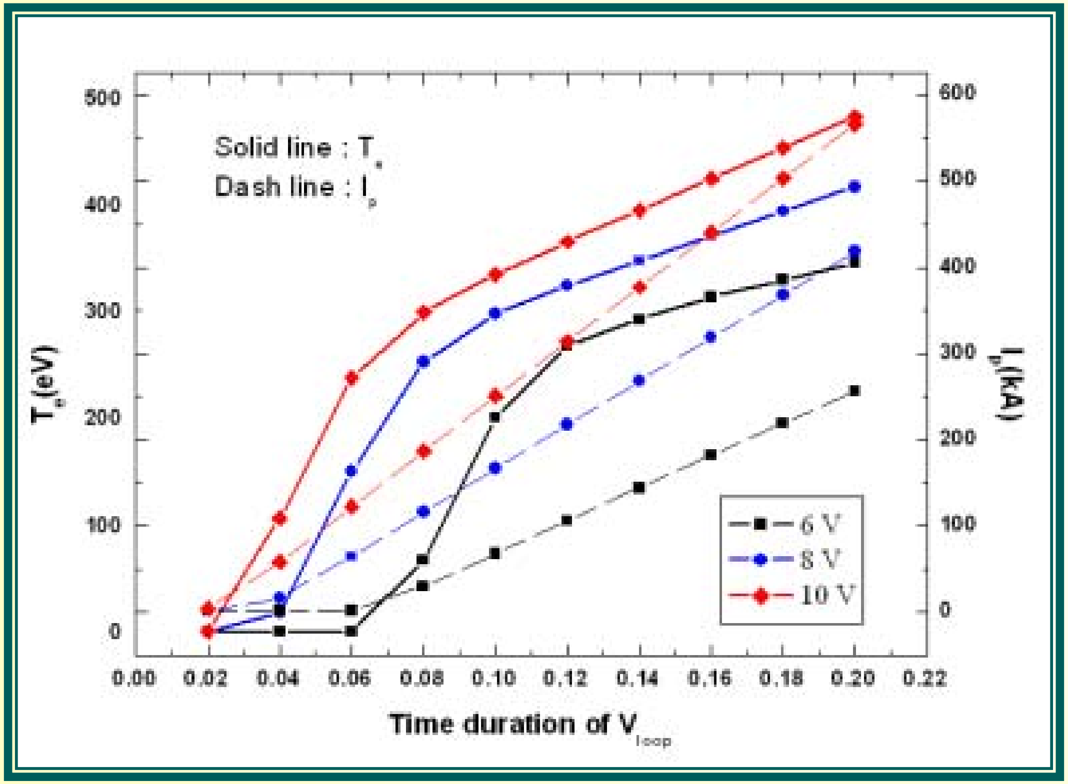
V_{loop} = 15 V





B_T = 1.5 T, R = 1.8 m, a = 0.5 m, P_{RF} = 500 kW, RF power on time = 0 sec, t_{RF} = 2 sec, Ohmic heating on time = 0.1 sec, duration of applied loop voltage = 0.06 sec, B_{err} = 1 mT, No impurity and all X-mode propagation

Variation of time duration at constant V_{loop}



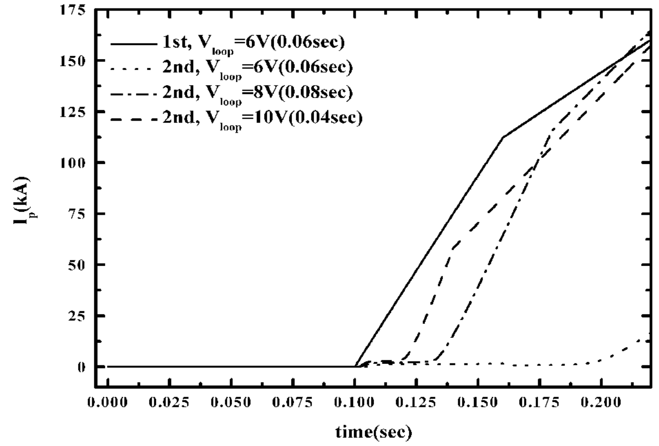
B_T = 1.5 T, R = 1.8 m, a = 0.5 m, P_{RF} = 500 kW, RF power on time = 0 sec, t_{RF} = 2 sec, Ohmic heating on time = 0.1 sec, B_{err} = 1 mT, N_o = $1.0 \times 10^{13} cm^{-3}$, No impurity and all X-mode propagation

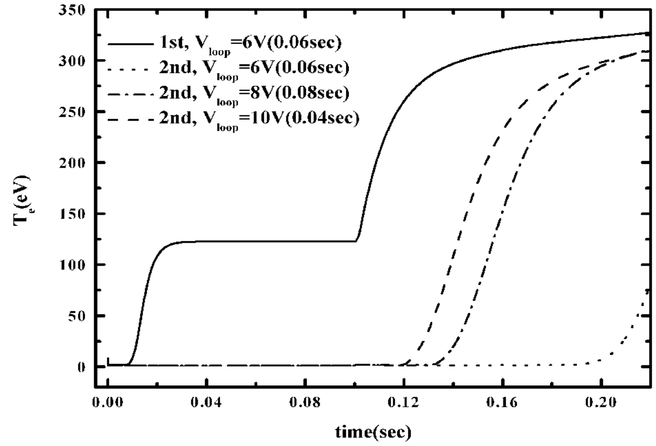
The loop voltage time duration scan for the 6 V, 8 V, and 10 V.

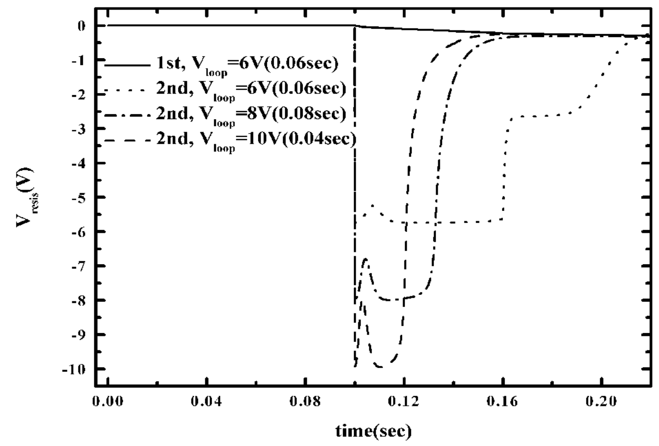
To acquire $I_p \geq 100$ kA at the end of the loop voltage applied;

1. **for V_{loop} = 6 V, 120 ms is needed.**
2. **for V_{loop} = 8 V, 80 ms is needed.**
3. **for V_{loop} = 10 V, 60 ms is needed.**

Comparison of several conditions







R = 1.8 m, a = 0.5 m, P_{RF} = 500 kW, RF power on time = 0 sec, t_{RF} = 2 sec, Ohmic heating on time = 0.1 sec, B_{err} = 1 mT, N_o = $1.0 \times 10^{13} cm^{-3}$, No impurity and all X-mode propagation

Conclusions

1. The second harmonic ECH is very sensitively dependent on tokamak parameters.
2. To initiate plasma in a few millisecond after ohmic heating, we must modify the 6 V loop voltage scenario.

→ * increase loop voltage to 8 V or 10 V

* increase the duration of the applied loop voltage

3. For the RF power of 500 kW: $V_{loop} \geq 8$ V ($E \geq 0.71$ V/m) is required for plasma initiation within 50 ms after the Ohmic heating start.