Operation and engineering research plan in KSTAR

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1. Introduction

Most of researches in the fusion devices have been concentrated to solve the physics and engineering issues at the high performance steady-state operation which are essential in the operation of ITER and in designing the future power plants. In preparing the ITER initial operation, present key issues are to achieve H-mode under the limited heating power, to suppress or mitigate type-I ELMs, to prevent disruptions, and to stabilize the MHD instabilities such as neo-classical transport mode (NTM) instability. In addition, the validation of the self-regulating high beta operation, fully-non inductive current drive under high density, and control of high heat flux at divertor are important technologies need to be solved in preparing the advanced type DEMO reactor.

Campaign	Highlights and contributions	Key parameters
2008	• First plasma at the first trial • Successful X2 ECH pre-ionization • Contribution to ITER startup	• Ip (1st plasma) > 100 kA • ECH pre-ionization (X2 84 GHz at B_T ~1.5 T)
2010	• Successful H-mode in SC tokamak • Start of proposal-based joint experiments	• Ip (H-mode) ~0.6 MA, P_{NBI}~1 MW
2011	• Successful ELM suppression at low n. • Contribution to ITER ELM control issue	• ELM suppression at n=1, 2 MP
2012	• Stationary H-mode over 16 s • Surpassing n=1 ideal no-wall limit • Showing the potential of advanced plasma research	• t (H-mode) > 16s @ 0.6 MA • β_N ~ 2.9, β_N/ li ~ 4.1
2013	• Demonstration of very low intrinsic error field and TF ripple • Uniqueness of KSTAR device	• $\delta B/B \sim 10^{-5}$

Fig. 1. The brief history of the KSTAR operation and contribution to the fusion community since the first plasma in 2008.

KSTAR project aims to explore the key physics and technologies of the high performance steady-state operation that are essential for ITER and fusion reactor utilizing the advanced superconducting tokamak device [1]. Since the first plasma in 2008 [2], KSTAR device has been operated as an international joint research device and has produced some experimental outcomes which could be contributed to the ITER initial operation. The brief history of the KSTAR operation and contribution is summarized in figure 1. KSTAR showed the successful ECH pre-ionization under the 2nd harmonic condition (f_{ECH} = 84 GHz, at B_T = 1.5 T) during the initial operation in 2008. H-mode discharges under the limited heating power (P_{NBI} ~ 1 MW) was achieved in 2010 according to the plasma shape control and wall conditioning using glow discharge and boronization [3]. In 2011, KSTAR showed a successful suppression of edge localized mode (ELM) by applying non-axisymmetric magnetic perturbation with low toroidal mode number, n=1 [4]. In the following campaigns, H-mode plasma operation range was extended up to 0.9 MA in current level and 20 s in the flattop duration and higher betaN operation up to 2.9. It showed the reliable operation surpassing the n=1 no-wall limit with betaN/li ~ 4.1. The scanning of the error field revealed a very low intrinsic error field in KSTAR compared to error field in other tokamak devices [5]. The operation results of six campaigns showed that KSTAR has lots of unique features which enable the advanced target operation and physics research such as strong shaping capability, a very low intrinsic error field, small TF ripple, and complex in-vessel control coils.

2. Highlights of the KSTAR 2013 experiments

Despite of the early termination of the 2013 experimental campaign due to an arc in the slow discharge resister (SDR) stack of toroidal field system, KSTAR was able to complete about 85 % of the scheduled experimental proposals. Due to the hardware failure, the planned H-mode discharge at 1 MA and the commissioning of newly installed motor generator system could not be conducted.

The research highlights of the KSTAR 2013 campaign could be listed as follows; (i) The improvement of plasma shaping and achieving early H-mode enabled the achievement of 20s duration H-mode as shown in figure 2. (ii) Low-n intrinsic error field is quite low ($\delta B/B$ possibly as low as $\sim 10^{-5}$) that is likely the result of good coil engineering and alignment. The calculated TF ripple is also small. (iii) The successful achievement of ELM suppression at n=1 and n=2 modes. The control of rotation and neoclassical toroidal viscosity (NTV) were conducted effectively. Those unique features of ELM control at low n-mode seem to be related to the combination of low intrinsic error field and small TF ripple. (iv) Preliminary experiments on the MHD control were conducted such as sawtooth locking experiments using EC modulation, and preliminary NTM control. The passive stabilizer showed the mechanical weakness under the large number of VDE and requires structural reinforcement to reach larger plasma current over 1 MA.

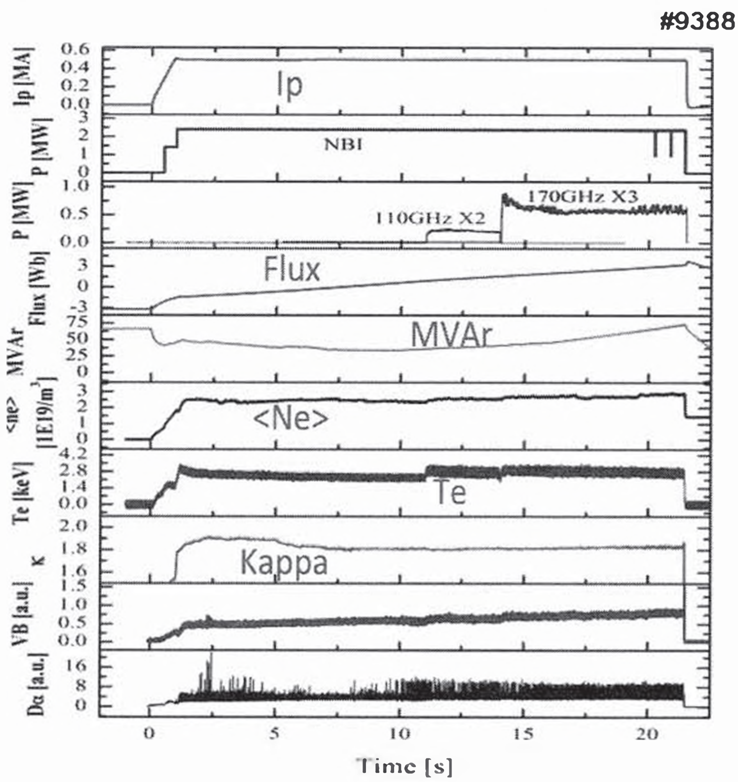

Fig. 2. H-mode discharge with 20s duration. .

3. Status of KSTAR machine upgrade

After the 2013 campaign, the device has been upgraded to enable the KSTAR operation at higher performance. The device upgrade planned to be in two steps. In the first step until 2017, hardware upgrade to support the physics research under the low density and intermediate heating power environment. The passive stabilizers has been upgraded with installing the additional vertical supporters on the lower passive stabilizer to have an mechanical rigidity against VDE and halo current occurrence as shown in figure 3. Newly installed motor generator system (200 MVA, 2 GJ) has been commissioned individually [6] and is ready for the integrated commissioning in connection with PF coils. Several sets of broadband AC power supplies are under procurement for the in-vessel control coils to give more flexibility in the ELM control, rotation control, and dynamic error field control. It could be available from 2015 campaign. NBI-1 system equipped three ion sources are under conditioning. And the control room space will be extended to absorb more participants in the KSTAR experiments. The planned heating power is about 13 MW until 2017.

After validation of the physic research under low density and intermediated power, the system will be upgraded for the experiments under the ITER or DEMO operation range. The long-term plan of hardware upgrade and research is shown in figure 4.

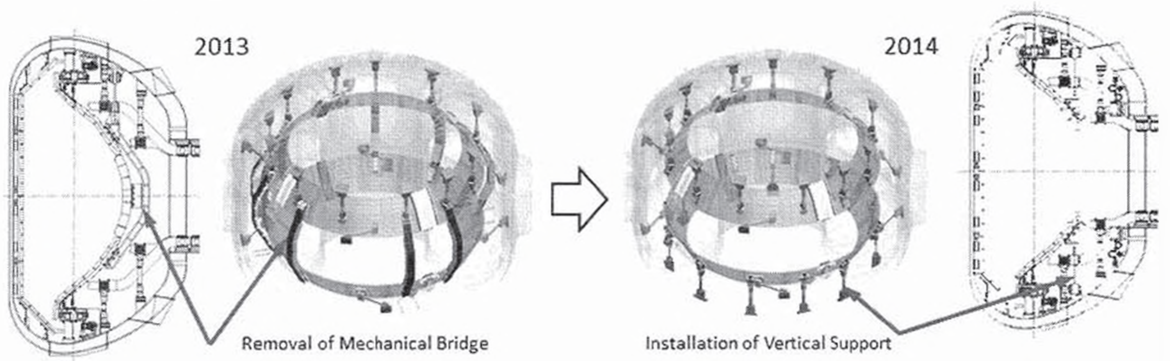

Fig. 3. The installation of the vertical supporters on the passive stabilizer.

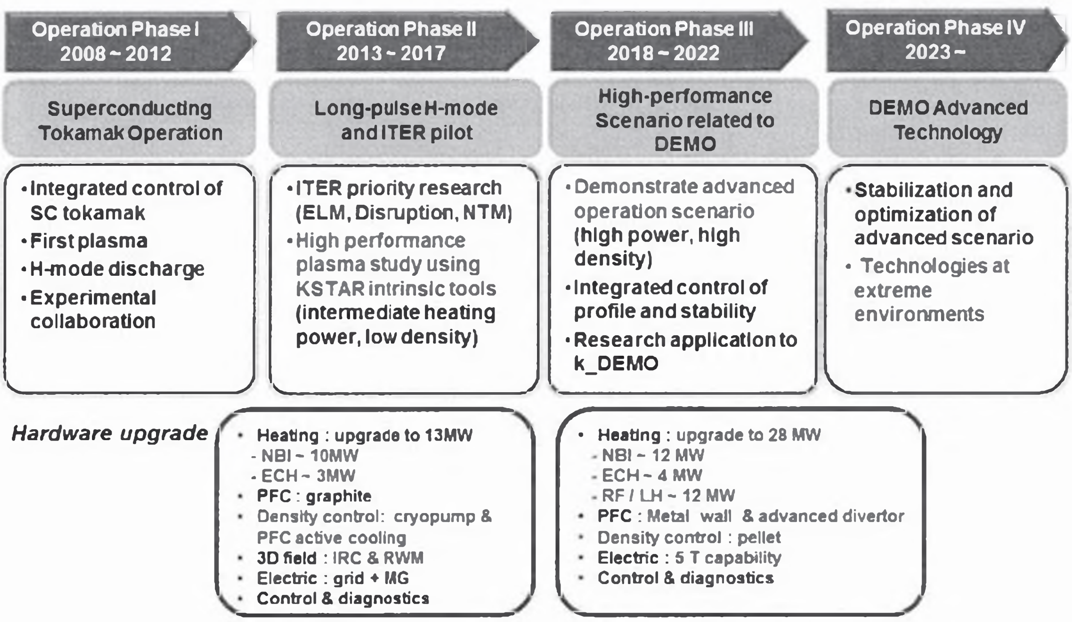

Fig. 4. The long-term research plan and expected hardware upgrade plan.

4. KSTAR operation and research plan

The 2014 campaign will be stared from the end of June and be closed at the end of December, and the plasma experiments could be available from the middle of September until the end of November as shown in figure 5. The available heating power is about 6 MW (5 MW NBI and 1 MW ECCD). Key operation targets in 2014 are (i) H-mode discharge for 30s at 0.5 MA and for about 10 s at 1 MA in plasma current, (ii) sustaining ELM suppression phase up to 10s, (iii) control of β_N using P_{NBI} ~ 5 MW and P_{ECCD} ~ 1 MW, (iv) routine measurement of profiles and fluctuations at pedestal and (iii) integrated commissioning of motor generator system.

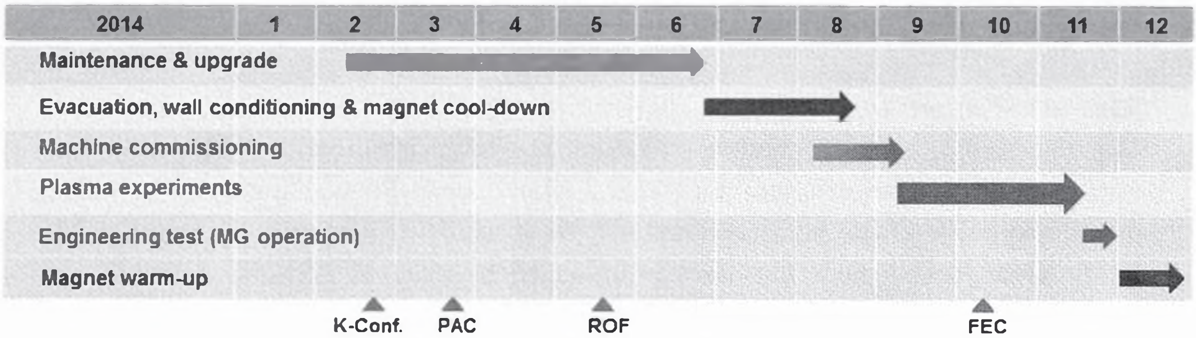

Fig. 5. The operation schedule of the KSTAR 2014 campaign.

KSTAR program has objectives to be a first mover at world fusion research solving the scientific and technical issues of fusion in demonstrating the advanced operation related to ITER and DEMO for the fusion energy commercialization. The hardware upgrade and experiments in phase II until 2017 will be will be concentrated to contribute to ITER and DEMO in several areas including the fundamental physics and innovative control techniques of the ELMs in ITER, innovative physics of L-H transition, impurity control, plasma rotation and momentum transport, understanding the influence of 3-D fields on plasma confinement and stability, and integrated operation scenarios, and runaway electron dissipation [7].

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