DEVELOPMENT OF HIGH-PERFORMANCE LONG-PULSE DISCHARGE IN KSTAR

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The mission of the KSTAR device is to sustain high-performance plasma for 300 seconds[1]. The advancement of long-pulse discharges in KSTAR aims to develop stable and sustainable high-performance scenarios and test the long-pulse operation capabilities of the device, identifying and resolving any issues that may arise during such operations from the points of view of both plasma physics and device engineering. KSTAR has been developing high-performance long-pulse discharges by applying the high β_P operation scenario, as mentioned in Ref. [2]. In the 2023 experimental campaign, KSTAR maintained H-mode plasma for 102 seconds. The operating conditions of this discharge were I_P=400 kA, B_T=1.95 T, P_{NBI}=3.9 MW, and P_{EC}=1.1 MW. The plasma characteristics of this plasma were V_{loop}~70 mV, β_P~2.5, β_N~2.1, $T_{e,core}$>6.0 keV, $T_{i,core}$~2.5 keV, and $\bar{n}_{e,core}$~3.0×10^{19} m^{-3}. The achievement of high-performance 102-second plasma as shown in Fig. 1 was based on the following factors compared to previous KSTAR experimental campaigns.

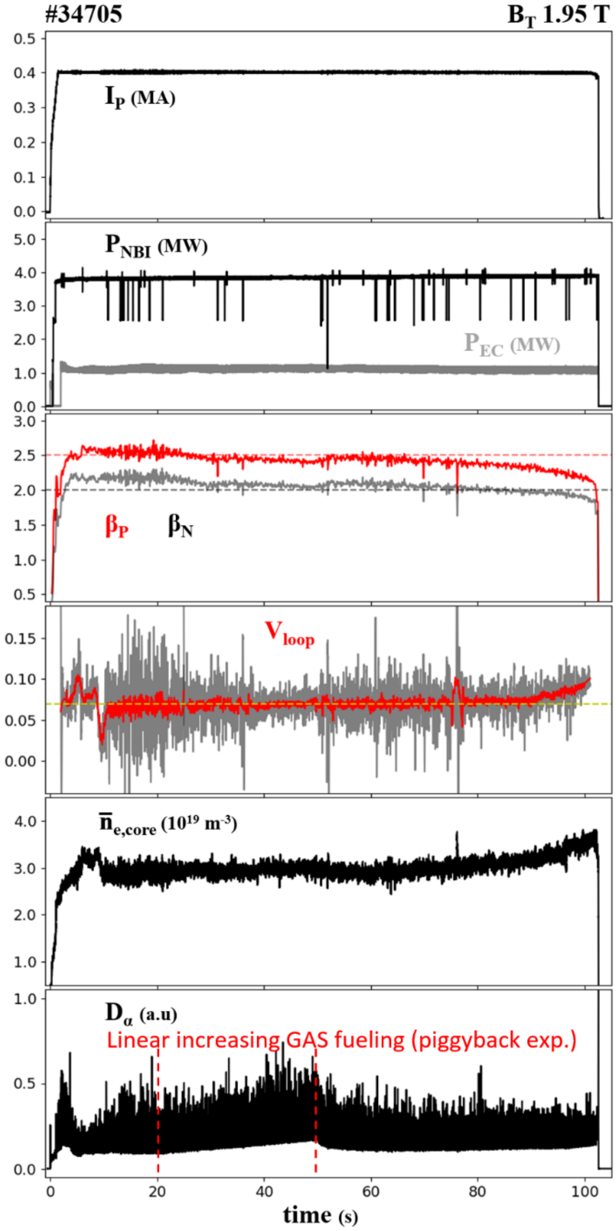

Fig. 1. Shot description of the 102-second high-performance long-pulse discharge with lower tungsten monoblock divertor in KSTAR.

Firstly, to effectively control heat flux to the divertor and protect the inner walls of the device, KSTAR installed a W-shaped tungsten divertor capable of active water-cooling. The temperature variation measured by thermocouples on the tungsten divertor during the 102-second plasma was less than 15 °C, approximately 1/25th compared to previous long-pulse discharges. However, other PFCs excluding the tungsten divertor showed temperature variations of up to 100 °C. Secondly, an algorithm was successfully developed to real-time correction of the linear signal drift of magnetic diagnostics in PCS and applied to long-pulse plasma experiments. During the 102-second long-pulse plasma, key plasma shape variables were effectively controlled within a maximum error of 2 cm. Thirdly, to maintain a relatively low line-averaged electron density for lower loop voltage, the plasma shape scenario was updated. Changes in H-mode characteristics on the tungsten divertor environment were monitored due to changes in the plasma-facing material and divertor geometry, which influenced the plasma shape and the SOL region. Consequently, H-mode characteristics in the partially covered tungsten environment appeared to be significantly different from those in the previously fully covered carbon environment. In the H-mode plasma at I_P=400-500 kA without additional gas injection, the line-averaged electron density was maintained at a higher value of ~4.0x10^{19} m^{-3} compared to previous discharges shown at ~2.0x10^{19} m^{-3}. Additionally, the tungsten divertor led to the generation and accumulation of tungsten impurities, resulting in a 3-4 times increase in total radiation power compared to before. In the case of the carbon divertor, the total power injection of ~5.0 MW resulted in the total radiation power of ~1.0 MW, whereas the tungsten divertor exhibited the total radiation power of ~3.0-4.0 MW. To enable long-pulse plasma operation, it was necessary to reduce plasma density and total radiation power by controlling the tungsten accumulation in the plasma, which was partially achieved by adjusting the plasma shape, especially the radial position of the inactive upper X-point ($R_{X,top}$). As shown in Fig. 2, it was observed that as $R_{x,top}$ decreases, plasma density, total radiation power, and tungsten intensity also decrease. We are still struggling with the detailed mechanism of this. Based on this result, the plasma shape scenario was optimized for long-pulse discharge. Fourthly, the phenomenon of gradual plasma performance degradation over time was significantly alleviated. The performance degradation that typically occurred around 20 seconds[2] was observed to be minimal up to approximately 70 seconds, where plasma performance remained almost constant. This is likely to have been influenced by changes in divertor geometry affecting the state of the SOL region and the appropriate scenario of gas injection.

The high-performance long-pulse discharges in KSTAR mostly operate in high β_P mode, with V_{loop}~70 mV, f_{NI}~0.70-0.75, and f_{BS}~0.30-0.35. Under these plasma conditions, a pulse length of ~100 seconds is expected. To achieve and sustain the high-performance plasma state for 300 seconds, which is the mission goal in KSTAR, it is necessary to reach and maintain a nearly fully non-inductive plasma state with $f_{NI}\geq$0.95. Based on collaborative research with DIII-D, we are developing a reproducible ITB (Internal Transport Barrier) formation scenario on KSTAR high β_P mode. Additionally, since q-profile control is essential for sustaining long-duration ITB formation, we are experimentally investigating the q-profile response against KSTAR H&CD system.

This work is expected to contribute to the development of scenarios aimed at maintaining consistent plasma performance over time and monitoring the temperature behavior of PFCs during long-pulse plasma operation.

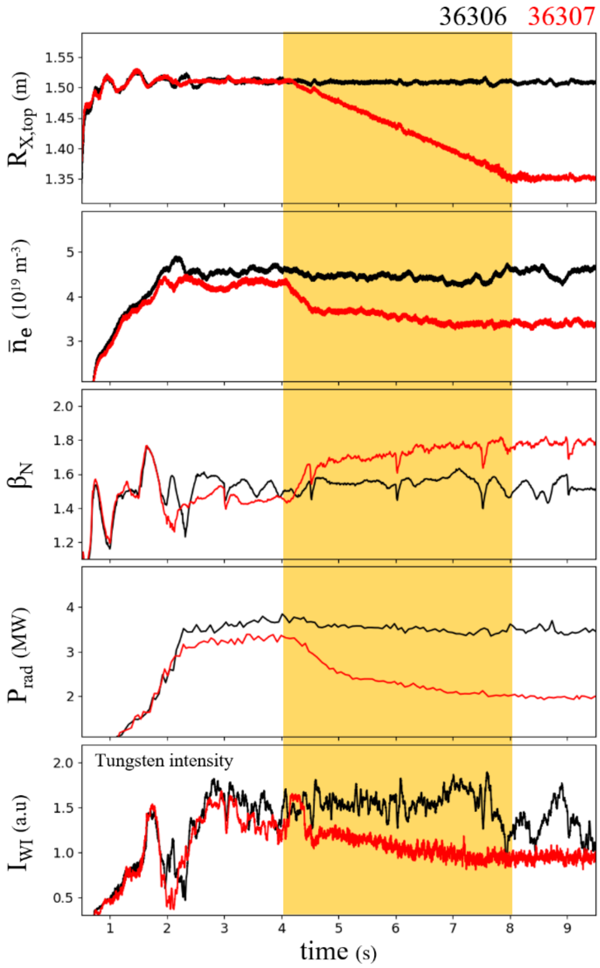

Fig. 2. Influence of $R_{X,top}$ on plasma density, radiation power, and tungsten intensity in the plasma.

ACKNOWLEDGEMENTS

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