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Achievement of 102-second High-performance Long-pulse Discharge with Lower W-shaped Tungsten Divertor in KSTAR

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The mission of the KSTAR device is to sustain high-performance plasma for 300 seconds[1]. 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, $_P$~2.5, $_N$~2.1, $T_{e,core}$>6.0 keV, $T_{i,core}$~2.5 keV, and $n_{e,core}$~3.0x10^{19} m^{-3}. The achievement of high-performance 102-second plasma was based on the following factors. 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 ℃, approximately 1/25th compared to previous long-pulse discharges. However, other PFCs excluding the tungsten divertor showed temperature variations of up to 100 ℃. 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 in the W-shaped tungsten divertor environment were monitored due to changes in the plasma-facing material and divertor geometry, which influenced the plasma shape and the state of the SOL region. Consequently, H-mode characteristics in the partially covered tungsten environment appeared to be not significantly different from those in the previously fully covered carbon environment. However, 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 ~4.0 x10^{19} m^{-3} compared to previous discharges. To enable long-pulse plasma operation, it was necessary to reduce plasma density, which was partially achieved by adjusting the plasma shape. 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. A plasma discharge lasting for 300 seconds should be pursued in conjunction with the development of a fully non-inductive plasma scenario. 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.

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References

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