Effect of inner leg configuration on detachment in MAST-U

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In this study the geometry of inner leg of the MAST-U tokamak is varied from horizontal to vertical, preliminarily showing that the evolution of plasma detachment is in agreement with predictions from analytical models.

For nuclear fusion to be viable as a power source from both economic and technical perspectives, the heat flux to plasma-facing components, and especially the divertor, must be maintained within narrow limits. In spherical tokamaks, where the target wetted area is proportionally smaller than in conventional tokamaks due to the smaller aspect ratio, this requirement is even more critical, exacerbating the power exhaust challenge. The outer divertor leg has been the focus of tokamak power exhaust studies, as it receives the majority of the heat escaping from the core in steady state conditions. However, in spherical fusion power plants (ST-FPP), significant heat will also be directed to the inner leg, potentially requiring heat flux mitigation strategies like detachment. Plasma detachment is a process where the increase of interactions of the plasma with impurities and neutral particles results in significant plasma power, momentum and particle losses. This lowers the target heat and particle flux, spreading the heat flux to a much larger area via radiation. It is therefore essential to characterize the heat flux to the inner leg and the behavior of inner leg detachment.

Previous studies on MAST-U have shown that in a conventional divertor geometry the detachment front in the inner leg separates from the target earlier than in the outer leg and exhibits a sharp transition from the target to the X-point region [1]. Such rapid movements of the detachment front towards the X-point are undesirable, as they make reliable and effective control of the target heat flux more challenging. The sensitivity of the thermal front movement can be described by the detachment location sensitivity (DLS) model [2,3]. The magnetic configuration of a leg and the front location determine the available volume for heat dissipation, and this is compared to the upstream plasma parameters. When the total magnetic field decreases from X-point to target, which is typical for the outer leg, the front is expected to move gradually. Conversely, when the magnetic field increases, which is typical for the inner leg, the movement is predicted to be more rapid. Once detached from the target, the stability of the front can also be influenced by factors such as changes in impurity concentration and plasma drifts. Previous experimental results confirmed the DLS prediction on the behavior of inner leg detachment.

The aim of this study is to investigate the impact of changing the inner leg configuration from horizontal to vertical (within the MAST-U shaping constrains) on the detachment process, both in terms of onset and further progression. We varied the inner leg geometry from horizontal to ~60 degrees while maintaining the same core shape, while making it almost vertical allowing for more significant changes. We also decreased the density from an already detached plasma, to observe if reattachment is characterized by the same transition dynamics as detachment. In these experiments the infrared video bolometer (IRVB) was the most important diagnostic employed, as it can reconstruct the total emissivity profile in the divertor with high spatial resolution. [4] Preliminary evidence suggests that the transition of the detachment front from the target to the X-point is sharper with a horizontal leg, and that even an inner leg close to vertical causes a sharp transition from target to X-point, in agreement with the DLS model. It also appears that the reattachment process is characterized by a sharp transition from X-point to target, similar to detachment. Further analysis and experiments will provide deeper insight into the physics of inner leg detachment and the factors governing its stability.

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References

[1] F. Federici, et al. Nuclear Materials and Energy, 43:101940, 2025
[2] B. Lipschultz, F. I. Parra, and I. H. Hutchinson. Nuclear Fusion, 56(5), 2016
[3] C. Cowley, B. Lipschultz, D. Moulton, and B. D. Dudson. Nuclear Fusion, 62(8), 2022
[4] F. Federici, et al. Review of Scientific Instruments, 94(3):033502, 2023