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Confinement and stability in DIII-D negative triangularity discharges and relevance for reactor devices

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In the DIII-D tokamak, negative triangularity (NT) shaped plasmas have been created and compared with matched positive triangularity (PT) plasmas, with the specific shapes shown in Fig. 1. In the NT case H-mode level confinement (H_{98y2} = 1.3) and reactor-relevant beta (β_N = 2.7) have been obtained in neutral-beam-heated discharges that have L-mode edge characteristics and are therefore inherently ELM free[1, 2]. The performance is similar to matched PT discharges that are in ELMing H-mode, thus making the H-mode performance of these L-mode edge NT discharges manifest. Figure 2 compares stored energy versus heating, showing NT achieving the same stored energy W_{th} in L-mode as PT in H-mode. Reduced turbulence levels are seen in NT compared to the PT cases and NT plasmas exhibit values of a/L_{Te} that are 15% larger in the outer regions of the plasma at matched values of current, field, density and power. Linear and non-linear gyrokinetic modeling attribute these characteristics to a weakening of TEM due to the shape; this will improve at the lower collisionality of a reactor. The good transport properties of NT discharges, with the potential of weak or non-existent ELMs and other advantages such as a divertor at large major radius for increased heat deposition area and more economical construction, make it an attractive scenario for a reactor[3]. Recent modeling with the AEGIS code has shown NT discharges having beta limits as high as β_N = 4, indicating that MHD stability is not a strongly limiting factor for the negative triangularity shape.

As the world prepares to start designing and building the next step fusion devices leading to practical fusion reactors, it is clear the issue of handling the power coming out of burning plasmas is a critical one. Current leading plasma configurations for ITER and other reactor designs tend to have high edge pressures that lead to ELM instabilities, and while mitigation measures are being investigated, there is concern these are not adequate for 100% safe operation. Also, the divertor placement in these configurations at small major radius is difficult and expensive to engineer. The recent studies of negative triangularity shaped plasmas in TCV and DIII-D offer an attractive solution. The demonstrated high confinement and low edge pressures in these experiments bode well for a reactor. And the ITER-relevant beta levels achieved in DIII-D show the configuration is MHD stable at high pressures. Further study of negative triangularity discharges is crucial for demonstrating its potential and providing confidence of this alternate path to fusion.

References
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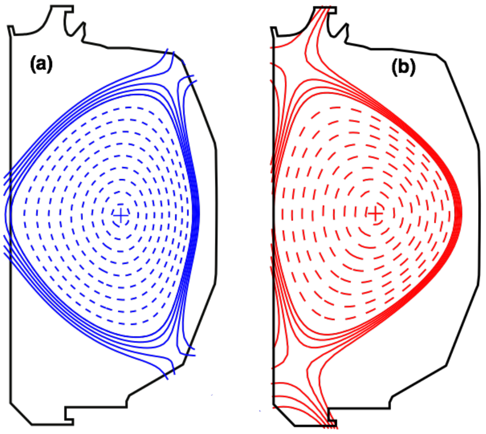

Fig. 1 Flux plots of matched plasma shapes for the DIII-D experiments; (a) negative triangularity and (b) positive triangularity, both with $|\delta|$=0.4 and κ = 1.3.

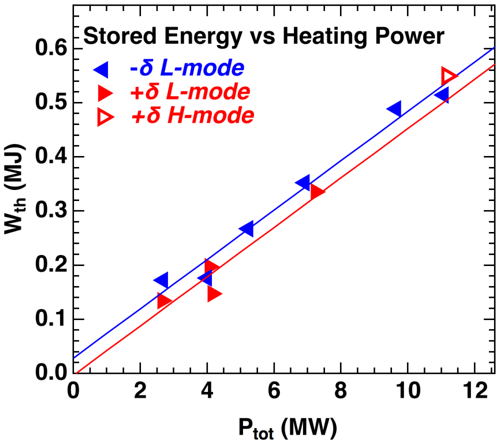

Fig. 2 Plot of stored energy versus heating power for negative (blue) and positive (red) triangularity discharges.