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Benign saturation of ideal ballooning instability in a high-performance stellarator

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The stellarator is one of the most promising concepts for future fusion reactors. The high-performance operation of the advanced Wendelstein 7-X (W7-X) stellarator has profound implications on the viability of the stellarator concept, and its success critically depends on maintaining magnetohydrodynamic (MHD) stability at high beta. To evaluate the impact of the MHD instabilities that may be triggered, we have undertaken state-of-the-art nonlinear MHD simulations of W7-X plasmas above the designed 5% beta-limit, which is enabled by the recent extension of the M3D-C1 code to stellarator geometry [1][2]. Consistent with linear analyses, ideal ballooning instabilities occur as beta exceeds 5% in the standard configuration. Nonetheless, the modes saturate nonlinearly at relatively low levels without triggering large-scale crashes, even though confinement degradation worsens modestly as beta increases [3]. This result suggests that the W7-X optimization for MHD stability is successful beyond expectation, and enhances the appeal of the stellarator approach to steady-state fusion reactors. However, more significant profile change occurs when a low-order resonance is induced by a more peaked pressure profile, and interchange modes can cause a major pressure crash in an alternative, unoptimized W7-X configuration. Therefore, MHD stability should still be treated seriously in stellarator operation and design, for which nonlinear modelling using tools like M3D-C1 can play an instrumental role.

References

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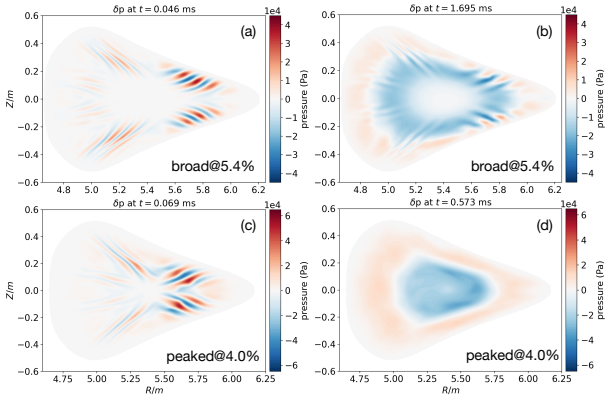

Figure 1. Snapshots of the pressure change in two EIM simulations with different pressure profiles and beta values: (a) and (c) show mode structures at the end of the linear growth phase, while (b) and (d) show saturated states at the end of the simulations. Note the different scales in the color bars.