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Self-organized stationary states of tokamaks

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We report here on a nonlinear mechanism that forms and maintains a self-organized stationary (sawtooth free) state in tokamaks. This process was discovered by way of extensive long-time simulations using the M3D-C1 3D extended MHD code in which new physics diagnostics have been added. It is well known that most high-performance modes of tokamak operation undergo "sawtooth" cycles, in which the peaking of the toroidal current density triggers a periodic core instability which redistributes the current density. However, certain modes of operation are known, such as the "hybrid" mode in DIII-D, ASDEX-U, JT-60U and JET, and the long-lived modes in NSTX and MAST, which do not experience this cycle of instability. Empirically, it is observed that these modes maintain a non-axisymmetric equilibrium which somehow limits the peaking of the toroidal current density. The physical mechanism responsible for this has not previously been understood, but is often referred to as "flux-pumping," in which poloidal flux is redistributed in order to maintain $q_0 > 1$. In this talk, we show that in long-time simulations of inductively driven plasmas, a steady-state magnetic equilibrium may be obtained in which the condition $q_0 > 1$ is maintained by a dynamo driven by a stationary marginal core interchange mode. This interchange mode, unstable because of the pressure gradient in the ultra-low shear region in the center region, causes a (1,1) perturbation in both the electrostatic potential and the magnetic field, which nonlinearly cause a (0,0) component in the loop voltage that acts to sustain the configuration. This hybrid mode may be a preferred mode of operation for ITER. We present parameter scans that indicate when this sawtooth-free operation can be expected.