The role of instabilities in helicity-injection current drive in spherical tokamaks

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Helicity injection current drive is widely used in existing and proposed spherical tokamak devices. In order to be effective, a relaxation (current drive) mechanism is required, which re-distributes the current directly driven by external electrodes to the closed flux. The detailed processes involved may vary with the device and the operating conditions, but it is likely that the existence of fluctuations, usually with dominant toroidal mode number $n = 1$, plays a key role. In order to model the onset of the $n = 1$ instabilities whose saturation leads to these fluctuations, we have developed a linear ideal MHD stability code applicable to spheromaks and spherical tokamaks which accounts for both open flux (linking the helicity injection electrodes) and closed flux. Equilibrium magnetic fields are considered with a high current on the open driven flux and a lower current on the closed flux. Earlier models used a simple 1D idealisation of the equilibrium, and predicted a stability boundary with the expectation that helicity injection is effective near to the marginal stability threshold. As the toroidal current is increased, the mode is stabilised and hence the current drive process is self-limiting. An upper limit for toroidal plasma current, for given helicity injection parameters, is thus predicted. The stability code has now been extended to deal with more realistic 2D equilibria, and has been carefully benchmarked by comparison with known results for equilibria with closed-flux only and open-flux only. The code confirms earlier results in that an instability mode centred on the open flux is unstable for sufficiently large electrode currents, but is stabilised as the plasma toroidal current increases. A new feature is that the nature of the instability mode changes with the equilibrium parameters, developing a tilt-mode character at higher closed flux currents.