Stabilization of the External Kink Instability in the ARIES Power Plant Designs

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Stabilization of the External Kink Instability

- Stabilizing the external kink instability allows higher β and higher bootstrap current fraction, leading to more economical tokamak power plants
- If the instability can not be stabilized higher toroidal fields are necessary to compensate for lower β, however, the lower bootstrap fraction would remain
- At present we don’t know if we can stabilize the external kink mode

Theoretical Predictions

- It has been shown theoretically that the external kink mode can be stabilized if a conducting shell is present and ...
  - The plasma (or shell) is rotating sufficiently fast (roughly 2-10% of Alfven speed)
  - And there is a dissipation mechanism in the plasma (sound waves, viscosity,…)
- Or
  - Using feedback coils located behind the shell and sensors in front of the shell (no rotation is required)

Experimental Observations

- DIII-D is the only experimental tokamak examining kink stabilization
- Experiments with plasma rotation (from neutral beams) showed that although the β was increased above the predicted limit with no rotation, the plasma consistently found a way to slow itself down, allowing the kink mode to become unstable
- Experiments with feedback coils show that the instability can be affected, holding off the instability temporarily, but the plasma does not appear to be stabilized indefinitely, so far

Stabilizing the Kink Instability

- The kink instability actually consists of two branches which must be stabilized simultaneously
  - Ideal plasma mode (growth time of microseconds)
  - Resistive wall mode (growth time of say milliseconds)
- The ideal plasma mode is stabilized by a conducting shell
  - Located on the outboard side
  - Located closer than a critical distance from the plasma determined by the most unstable toroidal mode number (typically 3-6) for advanced tokamak plasmas
  - The ideal plasma mode now becomes the resistive wall mode that grows on the L/R time scale of the shell

Stabilizing the Kink Instability

- The resistive wall mode is stabilized by the presence of a conducting shell in combination with
  - Plasma rotation of 2-10% of the Alfven speed
  - Conductivity and thickness of the shell roughly set by τ(wall)/τ(Alfven) > 10,000
  - The shell must be located outside of a critical distance determined by the n=1 resistive wall mode (so the wall must be located between d(resistive) < d < d(ideal))
- Or
  - Feedback coils outside the shell with sensors inside the shell (sensors measure either normal or poloidal flux)

Problems with Kink Stabilization

- Stabilization of the ideal plasma mode requires placing a shell close to the plasma, typically inside the blanket
- Stabilization of the resistive wall mode requires plasma rotation speeds 2-10% of Alfven speed
  - These speeds have only been obtained with NBI (low energy beams are OK), which is difficult to integrate into power plant designs, the RFCD does not provide sufficient speeds
- Or, stabilization of resistive wall modes requires feedback coils and sensors
  - The shell must slow the growth rate down to a timescale for a feedback system with reasonable power
  - We would need to stabilize multiple toroidal mode numbers, n=1,2,3…for advanced tokamak plasmas
  - Sensors need to be close to the plasma, between plasma and shell
  - Some plasma rotation may ease feedback requirements

ARIES-RS Kink Stabilization

- The conducting shell was a 2 cm thick layer of vanadium located at 0.095a from the plasma boundary on the outboard side
- The shell is segmented in the toroidal direction
- Only RFCD was used so the rotation required by theory was not provided
- The ideal plasma mode required a shell at 0.25a from the plasma boundary
- Resistive wall mode calculations were not performed

ARIES-AT Kink Stabilization

- The conducting shell is a 1 cm thick tungsten layer located at 0.3a from the plasma boundary on the outboard side
- This is combined with the tungsten shells for the vertical instability at the same location
- Resistive wall analysis shows that 9% of Alfven speed is required for rotation, however we again only have RFCD
- We chose to pursue feedback control, rather than rotation, with the coils located behind the sheild
- The feedback design will be modeled after DIIID system, and will only address stabilization of the n=1 kink mode

Discussion

- The external kink instability has not been stabilized experimentally with plasma rotation or feedback control, although theoretical results indicate it is possible
- Because of the above situation, we do not have a complete design approach, like we have for the vertical instability (for example)
- ARIES has attempted to introduce the perceived requirements into the power plant designs as place holders until a more complete solution emerges, and clearly indicate where the designs are deficient