Feedback Stabilization of Vertical Instabilities

Mike Kotschenreuther University of Texas

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Introduction

The conducting shell needed for vertical stability is an important design feature (and headache) in DT fusion reactors

A major impediment to achieving higher elongation is the perception that this makes the required shell too thick or too close to the plasma to be practical

A methodology has been developed by PPPL (S. Jardin) and the ARIES team (C. Kessel) to evaluate the shell thickness, coverage and power requirements

From feedback considerations, the major constraint on the shell location and thickness in ARIES designs is found to be the power needed by the feedback system

It was judged that the recirculating power from this system should not exceed ~4% => 40 MW

(The capitol cost of the power supplies from R. Miller is ~ $3 million and is not significant)

PPPL/ARIES methodology implemented into WALLCODE

The methodology to determine this uses dynamic plasma simulations with random noise in the feedback sensor loops to evaluate the feedback power

A very similar methodology has been implemented into WALLCODE

This power is maximum during the startup phase where it is assumed that plasmas with high internal inductance will arise. (However, Tony Taylor of GA recently reported that startup to AT regimes can be performed with much lower inductance and thus feedback power)

Flat current equilibria with the same li as used by the ARIES team have been generated and used in WALLCODE

When feedback power is evaluated for the ARIES RS case, WALLCODE and the ARIES team agree to with ~ 20%
(the “safety factor” has also been compared and agrees to a similar accuracy)

For the AREIS AT case, growth rates have been checked and agree to ~ 20%

For simulations of this complexity this is quite good agreement

W e therefore use WALLCODE to evaluate the shell requirements for a κ =3, 1 GW tokamak reactor with the same procedure

Such a reactor could achieve a wall loading of 8 MW/m^2 ,the APEX goal (without going to higher power level than desired by utilities)

The higher wall loading results because the higher elongation allows higher beta. This is achieved without profile optimization, and thus is more certain. With the same inboard build as ARIES RS, the major radius of a 1 GW κ =3 reactor is only 3.5 m rather than 5.5 m for ARIES RS.

(Further kink stability analysis is neeeded to justify this, but preliminary indications are positive)

Wall Parameters

We use a conducting shell of 2 cm of steel at the first wall. (Steel is one of the most pessimistic cases)

We put a .7 m hole at the top and bottom for a divertor

We put a 1 m high hole on the mid-plane for NBI, etc. (This makes very little difference)

The required feedback power vs distance from the fist wall is:

Distance (cm)	Power
0	31 MW
8.5	60 MW
17	230 MW

Alternatively, these numbers apply to a Tungsten shell 0.8 cm thick.

At 17 cm, a Tungsten shell 5 cm thick would reduce the power to 40 MW

The power is much more sensitive to distance at κ =3 than at κ = 2, but for a close fitting shell it is still acceptable

Power Minimization by Active Coil Design

The great majority of the power is reactive

Furthermore, most of the inductive back emf is *determined by the self inductance of the active coil*

The self inductance of a coil can be modified by the cross sectional shape of the coil

This has never been considered to my knowledge

This does not materially affect the coupling to the plasma and thus the stabilization capability

From E.E. - minimum inductance configuration is a strap rather than a round wire

We approximate a strap by three points- i.e., replace the active feedback wire with three wires in a line (following the shape of the shield surface)

For several different configurations, (including the κ =3 case) the power drops by a factor of 2-3

For AREIS RS if we place a strap-like active coil on the inboard side as well as a strap like coil on the outboard side (both behind the shield)- power drops by an order of magnitude

This did not work as well for the k=3 case, but I believe with some further effort I can reduce the feedback power by a factor of 4 – 10

This would allow a large reduction in the thickness of the conducting shell, or *might* allow the shell to be made from toroidally disconnects elements

Further effort is underway

Summary

Feedback power requirements for k =3 with a traditional active coil design are acceptable with a 2 cm conducting shell of steel close to the plasma

Reductions in feedback power by 2-10 appear possible by modifying the active coil design which would allow the conducting shell to be substantially thinner, further away, or perhaps made of discreet elements