REPLY

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IOP Publishing | International Atomic Energy Agency Nuclear Fusion

Nucl. Fusion **58** (2018) 018002 (2pp) https://doi.org/10.1088/1741-4326/aa8f5e

Reply

Reply to Comment on 'A new simpler way to obtain high fusion power gain in tandem mirrors'

T.K. Fowler[1], R.W. Moir[2] and T.C. Simonen[3]

[1] University of California, Berkeley, CA, United States of America
[2] Vallecitos Molten Salt Research, Livermore, CA, United States of America
[3] Lawrence Livermore National Laboratory, Berkeley, CA, United States of America

E-mail: simonen42@yahoo.com

Received 17 July 2017
Accepted for publication 27 September 2017
Published 6 November 2017

Abstract

Our response is to call attention to the possibility of utilizing pulsed ECH to stabilize trapped particle modes.

Keywords: tandem mirror, advanced fuel, mirror reactor, axi-symmetric magnetic mirror, fusion reactor concept

We thank the author for his observations about trapped particle modes observed in the TARA experiment, also cited as an issue in section 2 of our paper. His observations have prompted us to examine further our claim, in section 4.3.3 of our paper, that trapped particle modes might be stabilized by pulsing ECH in the End Plugs, following ideas in Post [1].

Post had in mind stabilizing MHD by applying pulsed ECH directly to the End Plugs as an alternative to MHD stabilization by the magnetic Expander already needed for other purposes. Why an Expander that stabilizes MHD in the End Plugs does not necessarily prevent trapped particle modes is explained in equation (14) of our paper. Why Post's pulsed ECH method of stabilization simultaneously stabilizes MHD and trapped particle modes can be seen as follows.

In Post's ECH stabilization, stability is achieved by creating stable 'sloshing electrons' bouncing between the End Plug mirrors, hence always in contact with any unstable activity near the midplane with no possibility of mirror-trapped particles isolating themselves from this stabilizing effect. Stability is achieved by ECH enhancement of the electron temperature perpendicular to **B**, at a resonance near the turning points where magnetic curvature is favorable. Post notes that sloshing ions created by angled injection of neutral beams, used in TARA to suppress the AIC ion cyclotron mode, are also stabilizing. That external quadrupole anchors were still required for MHD stability in TARA means that the sloshing ions adequate to stabilize AIC modes in TARA were insufficient to stabilize MHD, hence insufficient to stabilize trapped particle modes, also.

More precise theory, not yet carried out, could verify the qualitative argument given here, again following Berk and Pratt [2] and Berk and Lane [3] as we did in deriving our equation (14). The transient nature of pulsed ECH is essential, since otherwise off-resonance collisions would absorb the stabilizing electron pressure peaks into the average distribution, as discussed in section 3.3 of our paper. With pulsed injection, the appropriate stability theory is the well-known Matthieu equation for stability of oscillating systems (equation (2) in Post's paper). Active feedback is not required; and the average ECH power to stabilize the End Plugs would be the same as the end-plugging power given in our paper. If passing electrons connecting the End Plugs to the Center Cell do not stabilize trapped particle modes in the Center Cell, this could be accomplished directly by extending the ECH cavity in figure 4 of our paper to include both the resonance in the End Plug and the same resonance inside the Center Cell, with some additional ECH power.

The practicality of Post's idea hinges on adding pulsed power to the average ECH power required for end-plugging. Post gives an example in which creating perpendicular pressure peaks of order 9% of the midplane pressure stabilize MHD, hence also trapped particle modes by our argument above, giving as the stabilizer roughly 10% square-wave pulsed power as a modulation of the average ECH power (for example, 2 MW pulsed and 20 MW steady power for the Existing Technology reactor case in table 2 of our paper). The ECH pulsed wave train would resemble figure 4 in Post's paper. While pulsed gyrotrons exist, reproducing Post's requirements will require development. Similar pulsed RF requirements have already been met for accelerators, in kW units of GHz power but similar power densities [4]. The development required for a few megatwatts of pulsed ECH offsets developing beam injection in the Expander, no longer needed; and relieving the Expander of its stabilizing function in the KSTM concept allows designers to focus on direct conversion and power handling in the Expander.

Note added in proof. We have discovered that equation (36c) inadvertently omitted the central cell magnetic field Bc in the denominator. With tweaking of parameters after correcting this error we arrive at reactor cases substantially like those in table 2 of [1].

References

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