Issues for RMF current Drive

- Summary of Panel Discussion on Current Drive

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This session initiated with an exhaustive review on "Current drive with rotating magnetic field in FRC" by Dr. Masami Ohnishi, who has discussed the following topics:

- Current drive by rotating magnetic field
- Penetration
- Equilibrium with RMF
- Electron confinement

The session then continued with a presentation on some RMF current drive issues based on the results from TCS RMF-current drive experiment by Dr. Houyang Guo. Presently, the most critical issue for TCS is impurity contamination. While this is not intrinsic to RMF current drive, it is essential to reduce radiative losses and to increase the temperature, for the studies of the physics of RMF current drive in a more interesting regime.

Resistivities in the presently RMF formed FRCs are high. Large magnetic fluctuations have been observed by the internal magnetic probes on TCS. Some mechanisms that might be responsible for the observed high resistivities have been discussed, and are listed below:

- Drift instabilities – Dr. Steinhauer mentioned that drift LHD instabilities could be quite different in RMF formed FRCs than those observed in conventional high density FRCs
- Large ratio of B_ω/B_e
- Electromagnetic fluctuations driven by RMF

More studies are required to control the fluctuation levels and reduce the anomalous transport.

One of the concerns with RMF current drive is that RMF opens the field line, leading to energy losses and degradation of confinement. This does not seem to be an issue for the FRCs produced by the RMF with partial penetration with RMF B_r being only a few percent of axial magnetic field Bz. Based on global power balance, RMF heating power can be accounted for without additional conduction losses. Dr. Ohnishi mentioned that RMF partial penetration is preferable to the full penetration in the sense that only edge layer is opened by the RMF in this case. However, it is unclear what the consequences of open field lines are for hot FRCs. It has been proposed by Cohn that the anti-symmetric antenna system about the axial midplane could be employed to obtain closed RMF field lines configuration.

Another concern is the ion spin-up due to the frictional drag by the electrons, thus reducing current drive efficiency. It would take only about 100us for ions to be spun up to the same speed as electrons due to the high resistivity observed in the RMF formed FRCs. However, ion rotational speed, obtained from multi-channel Doppler spectroscopy, only reaches about 20% of electron rotational speed. Most probable opposition to spin-up is neutral background. However neutral density calculated necessary to result in measured spin-up fraction is much higher. Other possible mechanisms to reduce ion spin-up:

- End shorting of open field lines (Steinhauer)
- Counteract RMF torque by energetic neutral beam injection.

RMF driven FRCs are prone to rotational instabilities, which rotates in RMF direction with a frequency close to the ion rotational speed. This leads to impurity influx and increase radiative losses. It is thus essential to stabilize the rotational modes, for example, by

- Multpole coils
- Or RMF by placing the antennas close to the wall.

Both the experiments are planned for TCS.

It has been demonstrated that an inward flow is necessary to maintain current drive on the inner field lines, at least in the partial penetration case. However, it is unclear how to sustain such an inward flow. Two possible mechanisms are:

- Swirling flow around FRC ends – (3D)
- Ionization outside the field null (at edge).

Dr. Yasushi Ono has raised an issue concerning the inward flow: inward flow would lead to energy losses from the core plasma by convection to the edge open field lines, thus, degrading confinement.

Finally, some other formation technologies have been proposed in hoping to obtain hot FRCs and possibly to reduce fluctuation levels that might be originated from RMF start-up from a cold gas, as listed below:

- Starting from fully ionized plasmas
- Or preformed FRCs.