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Nanoparticle Plasma Jets (NPPJ) for Support of Fusion Research on Tokamaks

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Critical to the ultimate development of large tokamaks is the management (avoidance and mitigation) of disruptions, an area in which there has been much work and success, however, in which much remains to be accomplished – this is especially true for applications to ITER and the larger reactors envisioned for the future.

FAR-TECH, Inc. proposes that rapid and controlled injection of impurities using hyper-velocity nanoparticle plasma jets (NPPJ) be used as a runaway electron (RE) beam diagnostic and in disruption mitigation [1, 2, 3, 4]. The NPPJ has a number of unique characteristics which make it especially interesting for this application. The NPPJ prototype has demonstrated the production of a high momentum plasma jet composite of C_{60} (fullerene), carbon and hydrogen.

FAR-TECH's C_{60} nanoparticle plasma jet system

The system consists of a solid state cartridge source of C_{60} nanoparticle gas and a coaxial accelerator, each of them powered by its own capacitive driver. It utilizes pulsed power technology and produces a high momentum nanoparticle plasma jet in an extremely short time. The mass of the nanoparticle plasma jet is about two orders of magnitude larger than that of conventional gas source plasma jets from similar coaxial accelerators, while the velocity is at least an order of magnitude higher than that of a pressurized gas jet source. The high velocity contributes to rapid and deep penetration of the nanoparticle plasma jet into the tokamak plasma. The technological approach can be expanded to encompass other nanoparticles beyond C_{60}, such as boron nitride (BN) for disruption mitigation or LiD/LiT for deep fueling.

Prototype System Capability:

- Unprecedentedly large jet momentum delivery:

  First jet demonstrated a momentum of ~0.6 g·km/s, containing an estimated C_{60} mass of ~75 mg (unoptimized).

- Fast Response and Delivery Time:

  ~1 msec.

- Deep Deposition (through high B-field) due to:

  1. High Ram Pressure
  2. Large ion gyro-radius to jet width ratio

- Flexible System:
  1. Modular pulsed power system which allows tailoring of output to the mass/velocity range of interest; also allowing some control over the resulting spatial mass deposition in the plasma.
  2. Precise coordination of triggering time for multiple units.

Disruption Diagnostic:

1. Impact of early delivered impurities on disruption evolution:

   - Capability of rapidly generating and delivering the impurities allow this to be studied beginning in the thermal quench (TQ) phase.

2. C_{60} plasma jet as a diagnostic tool for runaway electron (RE) beam parameters:

   - The system can quickly inject diagnostic impurities deep in the region where REs are located, to study the effect of increased collisional drag produced by the (free and bound) electrons released/carried by impurities.

Disruption Mitigation:

1. Rapid radiative shutdown for rapid-onset disruptions (or fast off-normal events) by producing a rapid, controlled thermal quench (TQ) very fast:

   - Enabled by the system's ~1 ms response time and plasma jet high penetrability into "healthy" plasma.

2. During a TQ already triggered, to create a high density plasma before REs start to multiply:

   - The system's ~ 1 ms response time is about equal to TQ duration on DIII-D and is shorter than that on ITER (~ 3 ms).

3. Deconfine and collisionally suppress REs in early phase of 'avalanche' by triggering a secondary disruption through injection of impurity at q=2 surface (Putvinski's scheme):

   - The high velocity (few to several km/s), ram pressure, and penetrability of C_{60} plasma jet allows the rapidly inward 'moving target' q=2 to be reached.

4. Dissipation during the RE current plateau on a time scale faster than vertical instability:

   - Deep deposition and control of location of C_{60} plasma jet (by adjusting the velocity and mass through the variable driver energy).

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[1] I.N. Bogatu, J.R. Thompson, S.A. Galkin, J.S. Kim and HyperV Technologies Corp. Team. Disruption Mitigation with Plasma Jets for ITER. Proceedings of 23rd IAEA Fusion Energy Conference, October 11-16, 2010, Daejon, Korea, (Vienna: IAEA), CD-ROM EXS/P2-01, 2011.

[2] I.N. Bogatu, J.R. Thompson, S.A. Galkin, J.S. Kim and HyperV Technologies Corp. Team. Plasma Jets for Runaway Electron Beam Suppression. (selected to be presented at 24th IAEA Fusion Energy Conference, FTP/P1-31, Tuesday 09 Oct 2012).

[3] I.N. Bogatu, J.R. Thompson, S.A. Galkin, J.S. Kim, S. Brockington, A. Case, S.J Messer and F.D. Witherspoon. First Production of C_{60} Nanoparticle Plasma Jet for Study of Disruption Mitigation for ITER (to be presented at "Research in Support of ITER" session of APS DPP 2012).

[4] J.R. Thompson, I.N. Bogatu, S.A. Galkin and J.S. Kim. FAR-TECH's Nanoparticle Plasma Jet System and its Application to Disruptions, Deep Fueling, and Diagnostics (submitted for presentation at APS DPP 2012).