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PPPL physicists build diagnostic that measures plasma velocity in real time

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PPPL physicist Mario Podestà. Credit: Elle Starkman

Physicists at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) have developed a diagnostic that provides crucial real-time information about the ultrahot plasma swirling within doughnut-shaped fusion machines known as tokamaks. This device monitors four locations in a plasma, enabling the diagnostic to make rapid calculations of how the velocity profiles of ions inside the plasma evolves over time.

The results are among the first obtained from PPPL's National Spherical Torus Experiment-Upgrade (NSTX-U), the Laboratory's recently upgraded flagship machine. This research was supported by the DOE Office of Science (Fusion Energy Sciences).

In a paper in the November 2016 issue of *Plasma Physics and Controlled Fusion*, physicists Mario Podestà and Ron Bell report the successful commissioning and operation of the device, called a real time velocity (RTV) diagnostic, which could become part of a system for actively controlling the velocity of plasma rotation. "Control of rotation is critical for optimizing plasma stability against a range of instabilities," noted Stan Kaye, deputy program director for NSTX-U. Such stability is essential for fusion reactions to take place.

The diagnostic gathers information by observing what happens when a beam of neutral atoms is injected into the plasma. When these atoms interact with charged carbon ions in the plasma, the excited carbon atoms produce a photon of light that the diagnostic detects. The instrument deduces the velocity of the plasma ions by taking into account the Doppler effect—the same process that causes the pitch of sirens to sound higher when speeding toward someone and lower when rushing away.

The small number of measurements required is crucial to the calculation speed. "It's like the difference between building a road car and a race car," said Podestà. "When you build a race car, you strip out everything that's not necessary and push to increase performance. Similarly, these four measurements give the minimum amount of information to infer the plasma's velocity as the plasma discharge evolves." In fact, previous experiments on the tokamak prior to its upgrade show that four measurements—each optimized to collect the maximum amount of light—are all researchers need to control the plasma rotation, given the built-in constraints of NSTX-U.

Real-time velocity measurement is not unique. Other tokamaks, like the Joint European Torus (JET) in England and JT-60U in Japan, have diagnostics that measure velocities in real time, though at a lower sampling rate than in the RTV diagnostic. Podestà and Bell wanted a diagnostic that gave a more complete picture of the plasma's velocity profile. Producing that kind of picture meant choosing the locations of the four measurement points very carefully.

"In addition," said Podestà, "plasmas in NSTX-U can evolve on time-scales that are faster than those typically observed in JET or JT-60U. Therefore, we needed to measure at higher sampling rates to have a better idea of how the velocity changes over time during a plasma discharge."

Because of its rapid calculations, the RTV diagnostic could one day fit into a larger system that allows scientists to fine-tune a plasma's velocity profile and optimize the plasma's performance during fusion operations.

PPPL, on Princeton University's Forrestal Campus in Plainsboro, N.J., is devoted to creating new knowledge about the physics of plasmas—ultra-hot, charged gases—and to developing practical solutions for the creation of fusion energy. The Laboratory is managed by the University for the U.S. Department of Energy's Office of Science, which is the largest single supporter of basic research in the physical sciences in the United States, and is working to address some of the most pressing challenges of our time. For more information, please visit science.energy.gov.

Provided by Princeton Plasma Physics Laboratory