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Small, external magnetic perturbations can break axisymmetry of exhaust pattern in fusion device

One of the most promising fusion devices so far, the tokamak, is based on a concept of confining hot plasmas using magnetic fields generated by a set of specially designed coils. The magnetic fields normally form a donut or a ring-like shape and the plasma particles are confined inside this "magnetic container." This magnetic configuration therefore has symmetry along the direction of the plasma ring column, the so-called toroidal direction, and reduces the 3-D nature of the plasma physics to a 2-D problem. The assumption of this axisymmetry has been widely used in the tokamak plasma and greatly contributed to simplify complicated physics problems.

Recent studies, however, show that this axisymmetry can be broken in the presence of small, non-axisymmetric, i.e., 3-D, magnetic perturbations that can be introduced to the 2-D plasma equilibrium by external coils. The explicit application of small 3-D magnetic fields to the plasma boundary has been found to have a significant impact on plasma performance in tokamaks, including suppression or mitigation of a type of instability in the plasma boundary and modification of plasma exhaust patterns onto the surface of plasma facing components (PFCs) inside the tokamak. Its impact on the plasma heat and particle deposition patterns is of particular interest as the broken symmetry introduced in the plasma exhaust can impose further engineering constraint to the PFC design and affect the lifetime of a tokamak machine.

For the discharges with 3-D magnetic perturbation applied in the National Spherical Torus Experiment (NSTX) tokamak at the Princeton Plasma Physics Laboratory, the exhaust channel is split into several sub-channels to form multiple striations on the PFC surface. Spatial periodicity of the external magnetic perturbation can be chosen by arranging coil currents in an appropriate manner, out of which periodicity of 120º (n=3) and 360º (n=1) have been selected to study the impact on the exhaust pattern. Figure 1 shows the temporal evolution of the exhaust pattern observed at NSTX, showing plasma heat and particle deposition at the PFC before and after the 3-D perturbation application. A weak splitting of the exhaust channel, i.e., the striation pattern, occurs even without the application by an intrinsic error field caused by slight

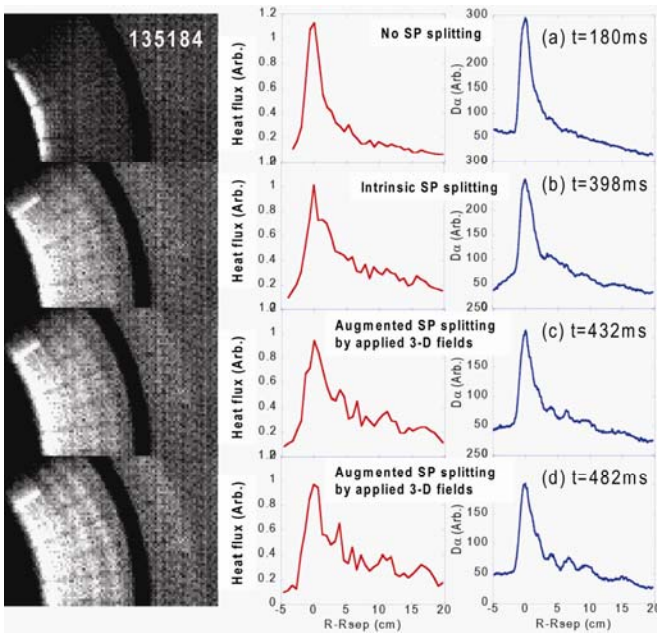

Fig.1 Raw infrared images showing heat deposition pattern at an NSTX PFC (left column), measured heat flux (middle), and particle flux (right) profiles along a radial direction, at different time slices (n=3 3-D fields applied from t=400ms), (a) no exhaust splitting at earlier stage, (b) intrinsic splitting 2ms before the 3-D field application, (c) and (d) augmented exhaust splitting by the applied 3-D fields (see the stronger striations and multiple local peaks in the profiles).

misalignment in the coil positions (2nd row of Figure 1). An additional modification to the exhaust pattern by the applied 3-D fields (3rd and 4th rows) causes higher local peak values in the profiles but does not make a significant change either in the overall peak value or in the profile width, thus the total power and particle flux stay largely unchanged across the application.

The observed exhaust splitting has been compared with a vacuum field line tracing for n=1 and n=3 cases and showed good agreement. Figure 2 shows an example of such a comparison between measured particle flux profiles and the modeled field line tracing with n=1 perturbation applied. This example includes two toroidal phase angles, at which the magnetic perturbation was applied to the plasma. It is seen that a different phase angle causes a different exhaust splitting pattern, both from the particle flux profile (represented as D_α profile) and the field line tracing, and the two results agree with each other very well. This provides direct evidence of broken axisymmetry of the exhaust pattern by the applied 3-D magnetic perturbation.

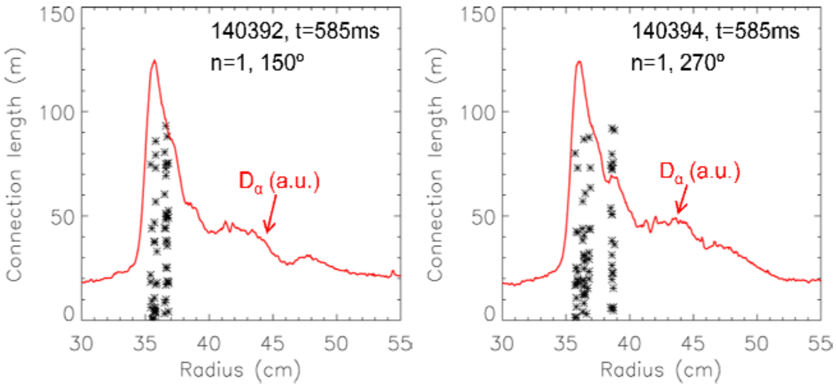

Fig. 2 Magnetic footprints on the divertor target, calculated by a vacuum field line tracing (black asterisks) and measured particle flux profile (red line) at the toroidal location of φ=255º. The applied n=1 perturbation had two different phase angles, one with 150º (left) and the other with 270º (right). Note the additional local peak at r~38.5cm in the case of 270º phase angle.

The splitting of the plasma exhaust pattern can be also affected by various plasma parameters. One example is the so-called safety factor *q*, which represents how many toroidal turns are required to make a poloidal turn when following a field line. A higher safety factor is expected to produce finer and more sub-channels for the splitting. This isconfirmed experimentally, and the agreement between the modeling and the measurement is excellent. This reconfirms the usefulness of the vacuum field line tracing to predict the change of the plasma exhaust pattern generated by the external 3-D field application, and has an important implication that the more complex phenomena inside the plasma may not need to be considered to make a 1st order prediction for this series of plasmas.

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Modification of divertor heat and particle flux profiles with 3-D fields in NSTX
4:30 PM–5:00 PM, Tuesday, November 9, 2010
Room: Grand Ballroom CD

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