Research Needs Workshop (ReNeW)

White Paper: Control of a snowflake divertor

M.A. Makowski, D.D. Ryutov, A. Hyatt, T.H. Osborne, M.V. Umansky

13 March 2009

Issue: Generic Control Issue

Background Problems of heat load handling in the DEMO may require use of new types of divertors that would allow reducing both steady-state heat fluxes and controlling episodic energetic events (ELMS, blobs). A recently proposed snowflake divertor [1] is aimed at solving all these problems by using a divertor configuration where the null of the poloidal magnetic field will be of the second order (not the first order as in a standard X-point divertor). The separatrix then acquires a characteristic hexagonal shape reminiscent of the snowflake, whence the name. The snowflake divertor has a higher flux expansion than the X-point divertor; this feature may allow the fraction of the radiated power to be increased by seeding impurities or using puff-and-pump approach. Simultaneously, by affecting the magnetic shear both inside and outside the separatrix, the snowflake configuration provides additional control over ELMs and blobs. The process of creating snowflake configuration can be considered as a process of merging of two closely separated X-points. As it turns out, exact merging is not necessary; the distance between two X-points should be simply small enough, at the level of 10% of the minor radius. As explained, control of a snowflake configuration is control of two closely-spaced X-points. This problem has not been studied before. There is therefore a need in developing robust algorithms for tracing these two nulls, relating the results to the currents in poloidal field coils, and directing the nulls to desired positions.

A gap Control of the two X-points comprising the snowflake divertor configuration is the fundamental outstanding issue that needs to be resolved in order to have the physics of this configuration fully explored.

Technical Requirements for Resolution The control problem can be reduced to two technical problems: that of identifying the locations of the two X-points, and deterministic control of the location of those X-points. [Note that snowflake configuration has been already created experimentally with the TCV device [2] and has transiently been obtained with DIII-D.] The final goal is to demonstrate that we can simultaneously control and move at our will two closely separated X-points. Of these, the first is relatively straightforward. A simple algorithm has already been developed to identify the location of the X-points. This involves forming a local expansion of the flux in the immediate vicinity of the snowflake and solving for free parameters using magnetic field values at a few locations in the same region. This algorithm has been successfully tested using a shape development shot on DIII-D and tracks the X-points to generally within 10 mm. In the time dependent case, the solution from the previous time step can be used to estimate the values at the current time and yields very good tracking of the X-points in the discharges so far examined.

The second problem, that of controlling the location of the two X-points is far more challenging, as the method must be robust under a wide variety of plasma configurations. Particularly challenging is maintaining fixed X-point location as various shape factors (such as elongation, triangularity, and squareness) are varied as these have a strong influence on pedestal physics. In order to clearly separate the effects of shape from those of the snowflake configuration, tight control of the X-point location is essential.

Control of the X-points is further complicated by the fact that the same coils needed to control shape are also needed to control the X-point locations. This control must be effective throughout the plasma discharge, including the start-up phase, flattop, and ramp-down. Further, it must treat operation in L-mode and H-mode, and the L-H/H-L transitions. During H-mode operation, edge currents flow, and these can perturb the location of the X-point locations and cause problems for the tracking algorithms, as the current version of this algorithm assumes no such currents.

A complete control system should also address the following issues: Due to the structure of the fields in the vicinity of the control coils, it is possible to have several X-points. The primary X-point is relatively easy to identify, as is the second when it is far from the coils. However, when the second X-point is close to the coils it may be difficult to identify due to the presence other, between-coil, X-points. Tests will be needed to assure that the proper X-points are tracked. Also, the snowflake configuration provides a larger flux expansion that in single X-point operation. One has therefore take measures to assure that the wetted zone does not extend to the areas that should not be exposed to plasma. One of the interesting possible configurations, the "snowflake-minus", may cause formation of the secondary separatrices (like in the imbalanced double-null configurations), and this possibility has to be addressed by a final version of a control system.

Research Thrust Elements The first step in developing a control algorithm is identifying the control parameters and actuators from the available set. The control parameters are simply defined as the location of the X-points and consist of two (R,z) locations for a total of 4 parameters. Coil currents serve as the minimum set of actuators in this case. As pointed out above, these coils are used for several purposes including determining shape and overall vertical stability of the plasma. Thus the range of variation available for x-point control can be severely limited by higher priority control protocols. Such limits must be established and will vary depending a variety of other factors. It is likely that a multiple input, multiple-output (MIMO) algorithm will be needed for control in this instance. Development of such algorithms is likely possibly, but any such algorithm must be computationally efficient. The developed system will be tested on those of the existing devices where creation of the snowflake configuration does not require significant changes of the hardware.

References

[1] D.D. Ryutov. ‘Geometrical Properties of a "Snowflake" Divertor.' Phys. Plasmas, **14**, 064502, June 2007.
[2] F. Piras, S. Coda, I. Furno, et al. “Snowflake divertor plasmas on TCV.” Plasma Phys. Contr. Fus., **51**, May 2009.