Snowflake divertor plasma studies on FAST proposal

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Introduction.

The Fusion Advanced Studies Torus (FAST) conceptual study has been proposed as possible European ITER Satellite [1]. This facility is aimed at exploring and preparing ITER operation scenarios as well as helping DEMO design and R&D. One challenging operational point is that the power exhaust handling and plasma wall interaction must be mastered to a level compatible with wall materials (for instance actively cooled W) and, at the same time, to address possible solutions for DEMO.

Different solutions [2-4] have been proposed to reduce the plasma-wall interaction optimizing the divertor region by acting on the magnetic field topology. Among these, one is the so-called snowflake (SF) divertor configuration [2, 3].

Starting from a standard single null X-point configuration, a second order null divertor (snowflake) has been preliminary studied on the present geometry of FAST proposal, by means of MAXFEA and FIXFREE codes [5, 6], with the constrains of using exactly the present poloidal system (i.e. coils and power supplies). At the moment a SF configuration of at least 4MA has been obtained. The poloidal field coils system is able to sustain this SF configuration for ~ 50s with all the coil currents compatible with the present circuits current limits.

The second-order null strongly modifies the magnetic topology in the full X point region and, consequently, it is expected to affect the edge plasma properties. In the paper the magnetic properties of this innovative configuration have been analyzed and compared with the FAST standard X-point configuration.

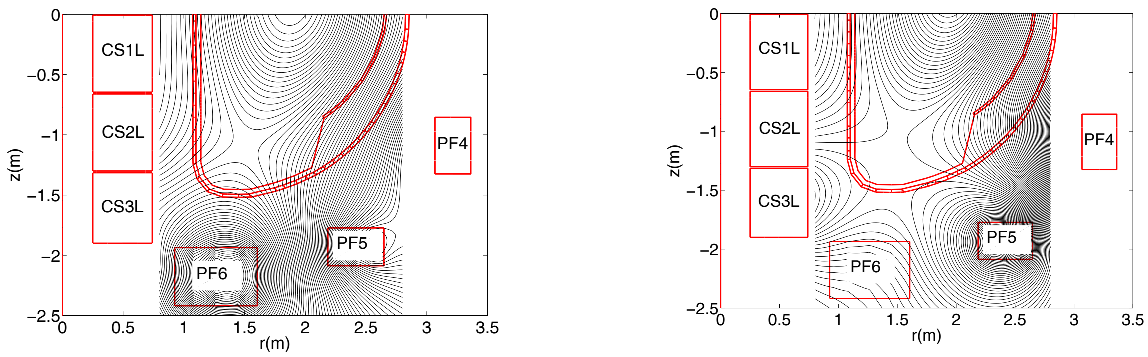
SF studies on FAST.

FAST has been designed to have the capability to approach all the ITER scenarios significantly closer than the present day experiments using deuterium plasmas. The necessity of achieving ITER relevant performance with a moderate cost has led to conceiving a compact tokamak (R = 1.82 m, a = 0.64 m) with high toroidal field (B_T up to 8.5 T) and plasma current (I_p up to 8 MA). FAST

PFCs system includes 6 coils distributed around the plasma chamber and a central solenoid (CS) made of 6 pancakes, allowing the generation of a wide range of magnetic configuration.

A preliminary 4MA (assuming both L and H mode scenarios) SF configuration (B_T=7.5T, l_i=0.9, β_P=1.12) has been obtained for FAST by iteratively adjusting the currents in CS2L, CS3L, PF3, PF5 magnetic field coils.

Poloidal magnetic flux equilibria for the reference standard single null (SN) divertor configuration and SF on are shown in Fig.1-and b.



a) b)

Figure 1. Poloidal magnetic flux FAST equilibria for: (a) reference standard single null divertor configuration; (b) snowflake configuration.

As it can be noted the magnetic topology of the magnetic flux surfaces, with a hexagonal null-point, has an appearance of a snowflake.

The time evolution of poloidal circuit currents that have been used to achieve the SF equilibrium is reported in Fig. 2. The discharge lasts ~50s and the SF configuration is sustained for ~45s. After the breakdown, the plasma current rises up to a plasma current I_p=1.5MA in Δt=1.5; during this phase the plasma evolves with circular shapes. At t=3s the X-Point configuration at low beta is achieved with I_p=3.5MA. At t=4s, the SF shape is obtained at low beta with I_p=4MA. Between t=4.5s and t=5s, full additional heating is assumed, causing an increase in the internal kinetic energy on a time scale longer than the plasma energy confinement reaching the H-mode phase. During this strong β increase the SF configuration is maintained, foreseeing to adopt a plasma control technique such as the extreme shape controller (XSC) used in JET [7].

As shown in Fig.2, the currents are compatible with the current limits in the FAST PF coils. The maximum permitted current density in poloidal field coils being 32MA/m^2.

Preliminary analysis of derivation of linear models describing the dynamics of the n=0 plasma displacements around the 4MA FAST SF configuration at flat-top, has been carried out by means of the CREATE-NL code [8].

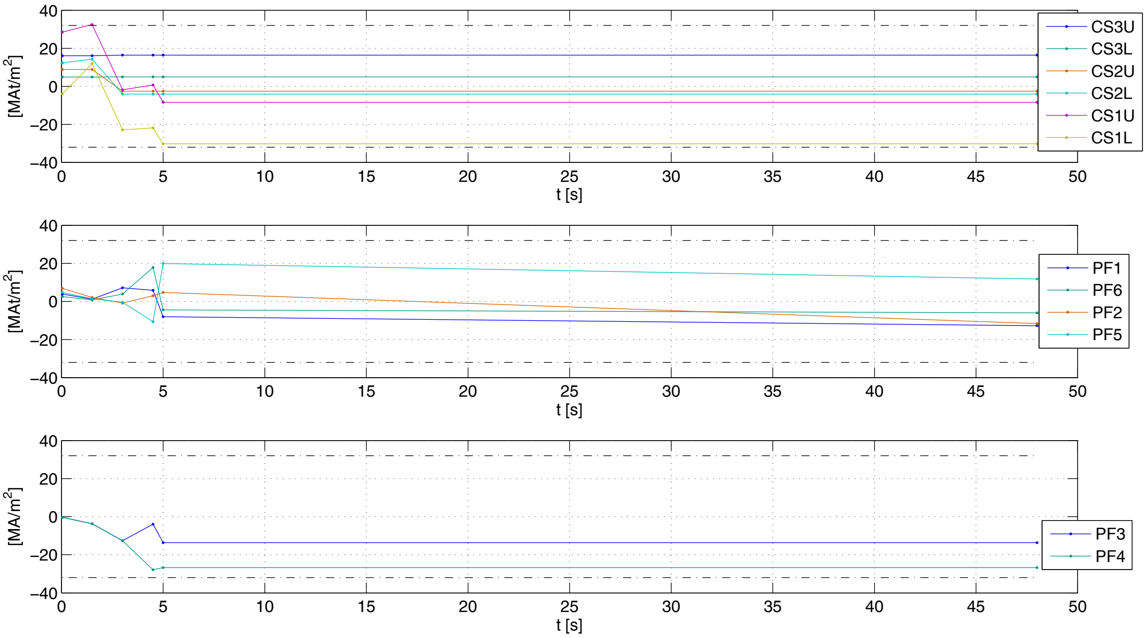


Figure 2. FAST SF configuration: PFCs currents evolution.

For the plasmas scrape-off layer (SOL), an important parameter is the flux expansion [9]:

$$f_m = \frac{(B_p / B_{tot})_{MP}}{(B_p / B_{tot})_{SP}}$$

where B_{tot} is the total magnetic field, and B_P is the poloidal magnetic field at the strike point (SP) and midplane (MP) locations. In out calculation we have computed an average of the value of B_{tot} and B_P on $3\lambda_P$ flux surfaces, with λ_P (the power flux e-folding length) assumed to be 0.005m on the outer equatorial midplane [10].

The flux expansion is related to the reduction of the poloidal magnetic field near the null point. This quantity influences the SOL thickness and the size of the radiating volume. Radial transport, and possibly formation of filaments in the edge/SOL region, may also be influenced by this magnetic topology feature. The poloidal magnetic field in this SF case is a quadratic function of the distance from the null, whereas in the standard X-point configuration it is a linear function [2, 3].

This means that the flux expansion is much larger in the vicinity of a null of a snowflake divertor, and one can try to exploit this fact for reducing the divertor heat load, as discussed in [2, 3].

Table 1. Flux expansion for FAST 4M SN and SF configurations.

	SN	SF (low beta)	SF (high beta)
f_m	~5	~15	~20

The flux expansion calculated for FAST 4MA SN and SF configurations at low and high beta are reported in Table 1. In FAST the SF flux expansion around the null point is 4 times larger than in the SN configuration and likely leading to a reduction of the local heat load to the divertor plates.

Conclusions.

In summary, the results of this preliminary work provide support for the SF divertor concept in FAST and it could be a promising solution of the plasma-wall problem for next-step high-power fusion devices as discussed in several papers. We demonstrated that a SF divertor-like configuration could be obtained with only four coils in FAS. without using ”internal” coils, and in comparison with the standard divertor, it significantly increased the flux expansion. The analysis so far performed has showed that, always within present actual currents limits, it could be possible to fuerther increase the plasma current.

A preliminary activity for studying the SOL/edge plasma snowflake main features, including heat loads on the divertor, by means of EDGE2D/EIRENE code [10] is ongoing.

References.

[1] Pizzuto, A., et al., Nucl. Fusion **50** (2010) 095005

[2] Kukushkin, A. S., et al., 2005 Nucl. Fusion **45** 608

[3] Ryutov D. D. et al 2008 Phys. Plasmas 15 092501

[4] Ryutov D. D. et al 2007 Phys. Plasmas 14 064502

[5] Barabaschi, P., 1993 “The MAXFEA code", Proceedings Plasma Control Technical Meeting, Naka, Japan, April 1993

[6] Alladio, F., Crisanti, F., 1986 Nucl. Fusion **26** 1143

[7] R. Albanese et al., (2005) Fus. Eng. Des. **74** 627

[8] R. Albanese, et al., (2003) Fus. Eng. Des. **66-68** 715-8

[9] V.A. Soukhanovskii, et al., 2011 Nucl. Fusion **51** 012001

[10] Maddaluno, G., et al., 2009 Nucl. Fusion **51** 095001

[11] R. Simonini, et al. Contrib. Plasma Phys. V. 34 (1994) 2/3, p. 368-373