*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-5.169 (2004)*

Controlling extremely shaped plasmas in the JET tokamak

F. Sartori[1,3], G.Ambrosino[3], R. Albanese[2], M. Ariola[3], G. De Tommasi[3], F. Piccolo[1], A.Pironti[3] and JET-EFDA Contributors

1. Euratom/UKAEA Fusion Ass. Culham Science Centre, Abingdon, OX14 3DB, UK.

2. Associaz. EURATOM/ENEA/CREATE, Universita' degli Studi di Reggio Calabria, Reggio Calabria, Italy.

3. Associaz. EURATOM/ENEA/CREATE, Universita' di Napoli Federico II, Napoli, Italy.

Abstract

The ITER (International Thermonuclear Experimental Reactor) reference scenario relies on the capability of obtaining high quality H mode plasmas at a plasma density close to the Greenwald density. In order to optimise the regime performances, high triangularity and elongation are of key importance. Therefore having a control system that is able to maintain the plasma shape in presence of large disturbances (e.g giant edge localised mode [ELMs] and large variations of β_p and/or l_i) is at the base of successful experiments. To achieve such performances, the eXtreme Shape Controller (XSC) system has been implemented in JET and has been successfully installed and commissioned during the last experimental campaign. Its design aims have been proven during a set of high triangularity ITBs discharges in presence of quite large variations of β_p ($\Delta\beta_p$ up to 1.5) and/or l_i (Δl_i up to 0.5). The results, which have been obtained during the commissioning phase, have demonstrated the feasibility and reliability of this control system and are the topic of this paper.

Introduction

The control of the plasma shape in JET is obtained by means of 8 Poloidal Field Coils. In order to describe the shape of the plasma, a set of geometrical descriptors (gaps), that define the distance along predefined directions of the last closed flux surface from the first wall, have been introduced. The original Shape Controller (SC) was designed to perform the feedback control on each of the 8 actuators by using as inputs to the system either the currents flowing into the Poloidal Circuits (current control) or the actual measured gaps (gap Control). When in gap control, the SC uses one gap measurement as input to the active coil that has been identified being the most influential. In this way only a limited amount of gaps (normally less then 5) are used to perform the shape control during the plasma shot. This implementation has been proved successful in most of the JET pulses but has not been able to guarantee an overall satisfying performance when highly shaped plasmas where the aim of the experiment. In order to control the overall plasma shape during a JET pulse, the XSC has been designed to implement a full gap control system in which all the active coils are used in feedback on a large set of geometrical descriptors (48). Since the number of available actuators is only 8, an optimisation process that defines the sensitivity of each gap to a variation of the current in each coil has been performed by means of a singular value decomposition (SVD) analysis.

The XSC Control Model and Design of Plasma Discharges

The XSC system has been designed on the assumption that the plasma behaviour can be described by a small number of parameters [1]. In the model used for studying the problem, the considered quantities are the currents and the voltages on each poloidal circuit, the plasma current and the β_p and l_i parameters. Since the experiments are normally carried out during flat top phases, variations of the plasma current and of the internal parameters, β_p and l_i, are considered as disturbances. The linear model used for the implementation of XSC is:

$$\begin{cases} L^* \dfrac{d(\delta I_T)}{dt} + R\delta I_T = \delta V_T - E^* \dfrac{d(\delta w)}{dt} \\ I_{Pl0}\delta G = C\delta I_T + F(I_{Pl0}\delta w) \end{cases} \qquad (1)$$

where the vectors: $I_T = (I_{P1E}\ \ I_C\ \ I_{Pl})$, $V_T = (V_{P1E}\ \ V_C\ \ 0)$, R is the resistance matrix, I_{P1E} is the current flowing in the P1E circuit (which is used for inducing the plasma current), I_C is the current flowing in the remaining active circuits, I_{Pl} is the plasma current, G is the vector of the geometrical descriptors that are used for feedback control and w are the Disturbances. Assuming that the terms (V_{T0}, I_{T0}, w_0) define an equilibrium configuration for model (1), the matrices L^*, E^*, C, F are the Jacobian matrices, that can be evaluated by using the CREATE-L code [2], and that determine the variation of the plasma shape due to a variation on the coils current. The basic step, which is needed to design a XSC controller for a JET pulse, is to define what are the actual values of the (V_{T0}, I_{T0}, w_0) parameters that characterise the desired configuration. These parameters can be identified either by using a reference pulse in which the SC had been used, where the actual poloidal currents and plasma parameters are known, or by using an equilibrium code that can identify those quantities. Once those quantities are known, they can be used into the CREATE-L code in order to compute the Jacobians matrices that are present in the linear model (1). The following step is the design of the controller for that configuration by means of the XSC-Generator Tool. This tool uses the Jacobians matrixes computed by the CREATE-L to design the controller, compelling to some basic decisions that the designer specifies. The usual design choices specify what are the gaps that the designer is most interested in and what are the coils that have to be used most in order to have those gaps kept constant. As result a controller configuration is produced and used, together with the Jacobian matrixes, by another tool, namely E-Generator, which defines a set of slightly different configurations that can be used to adjust the plasma shape to fit the aim of the experiment. The scientist, that designs the plasma experiment (at JET known as session leader), can decides to modify the actual shape request by using a set of sliders that are integrated into the program interface used to load the plant settings and waveforms into the systems (namely "Level1" system). The E-Generator tool produces the final configuration file that defines the controller parameters and the plasma shape configurations that can be used in the experiments. Figure 1 summarises the pulse generation process for the XSC.

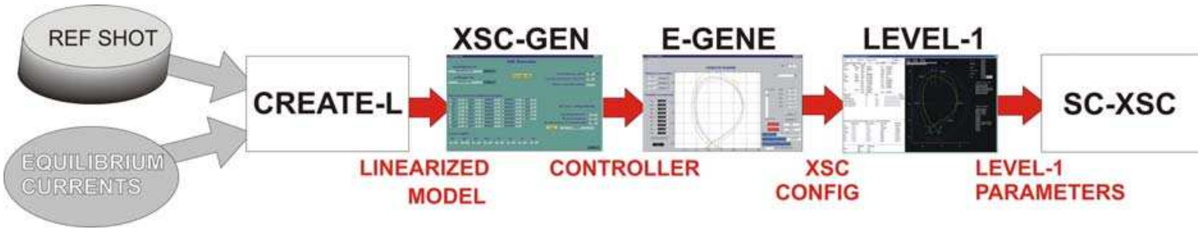

Figure 1 Schematic of the JET Pulse Design for the XSC

Experimental results obtained with XSC

The XSC has been used to control a set of different plasma configurations in which the controller robustness and flexibility have been tested. This set of configurations consists of plasma discharges in which the internal parameters, β_p and l_i, present considerable variations and of plasma discharges in which the elongation and triangularity are quite high. For what concerns the internal parameters variations, particular attention has been given to the high triangularity ITB discharges and to the high β poloidal experiments. The high elongation and triangularity experiments, that have been used for testing the XSC, are mainly related to pulses designed to explore Vertical Displacement Events (VDE) but have also been used in other different types of plasma configurations. In these pulses the plasma elongation and triangularity have been slowly increased by means of the sliders integrated in the Level1 interface to study the dependence of the plasma vertical growth rate from the plasma shape or to adjust the plasma shape during the pulse. Whilst the former set of pulses is aimed at testing the XSC reliability and robustness to the actual disturbances, the latter aims at proving the extreme flexibility that this tool is capable of. Figure 2 and 3 show a sequence of plasma shapes that have been obtained with the XSC; the yellow area defines the difference between the requested shape and the obtained one for that particular snapshot. More precisely, Figure 2 shows an example of shape evolution during a high β_p experiment; the shape is kept constant during the whole experiment length even if there are considerable variations of β_p and l_i. It has to be said that some problems have been experienced when extreme variations took place. More precisely, an oscillation on the upper plasma shape has been observed and is currently under investigation; the main cause of this oscillation is thought to be the presence of a particular ELM frequency that triggers a conflict between the Vertical Stabilisation and the XSC.

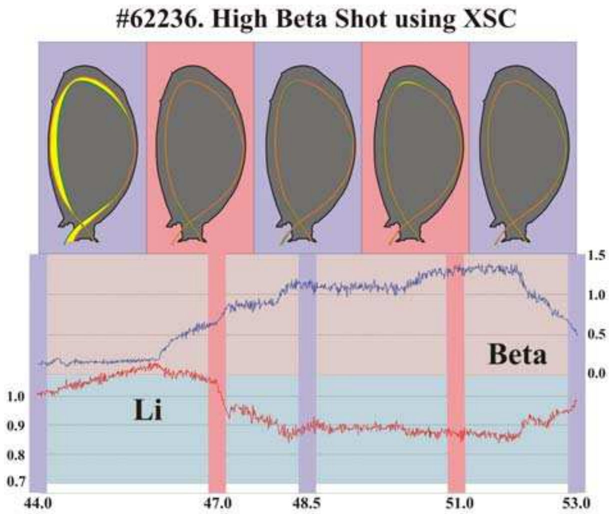

Figure 3. High β_p Experiment with XSC.

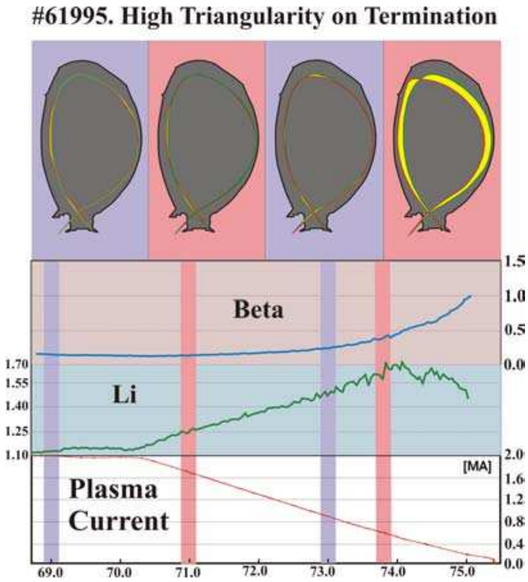

Figure 4. High Triangularity Experiment (δ_{up}=0.340, δ_{low}=0.330, elongation=1.63)

Figure 3 shows an example of high triangularity shape used during the termination phase of a JET pulse to test the XSC flexibility and robustness to variation of internal parameters β and l_i and to a drastic change in plasma current. This configuration is not normally used during the termination phase with SC since it is extremely difficult to predict how the plasma shape will behave in response to such large excursions of β_p and l_i. As Fig. 3 shows, this task is successfully accomplished by the XSC till 73.8 seconds, when a current limit on the divertor circuit (D1) is hit. It has to be said that the controller was not designed to address this kind of experiments and, the obtained results have proven the extreme versatility and robustness of the design approach that has been used. The XSC will prove to be a very powerful tool for keeping the plasma shape constant as internal parameters change.

References:

[1] G. Ambrosino, M.Ariola, A. Pironti, F. Sartori, A new shape controller for extremely shaped plasmas in JET, Fusion Engineering and Design 66-68 (2003) 797-802

[2] R. Albanese, F. Villone, The linearized CREATE-L plasma response model for the control of current, position and shape in tokamaks, Nucl. Fusion 38 (5) (1998) 723-738

Acknowledgements: Work performed under the European Fusion Development Agreement and partly funded by Euratom and UK Engineering and Physical Sciences Research Council.