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** See annex of M.L. Watkins et al, "Overview of JET Results ",*
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INTRODUCTION

The exhaust particles collected by the divertor structures cause a localized thermal load around the strike points (the intersections of the separatrix with the divertor). To spread on a larger region this thermal load it is convenient to resort to a sweeping, i.e. a periodical movement, of the strike points. This technique has been already applied to JET by applying 4 Hz triangular waveforms on the divertor D2 and D3 coil currents. This strategy is implemented in the architecture of the JET Shape Controller (SC), and has been validated in a number of experiments. However, it suffers from the inconvenience that the movement of the strike points causes, to a certain amount, 4 Hz oscillation of the overall shape. These problems are further exacerbated with the JET eXtreme Shape Controller (XSC) [1], which reacts to the strike point movements, since the sweeping frequency is within its bandwidth. This paper introduces an alternative sweeping strategy which address these difficulties. The proposed algorithm has been implemented within the XSC architecture, and has been validated recently at JET [2].

THE SWEEPING ALGORITHM

The sweeping problem concerns how to let oscillate the plasma boundary between two different configurations named A and B, following a given waveform at a given frequency. As far as the strike points sweeping problem is concerned, the configurations A and B differ significantly only in the bottom part of the plasma. In principle the sweeping could be obtained by using the XSC controller [1], and choosing the shape references according to the desired waveforms. Unfortunately at JET this approach cannot be pursued, because the required sweeping frequency (typically 4 Hz) is just outside the closed loop system bandwidth guaranteed by the XSC. The closed loop frequency behavior of the XSC is limited by the speed of the slowest power supply of the poloidal field (PF) coils system. Therefore to solve the sweeping problem the XSC architecture has been modified has shown in Fig. 1. In particular the XSC is composed by two subsystems: the *Plasma Shape Controller* and the *PF Currents Controller*. The former, whose input is the plasma shape tracking error, computes the current references, which are tracked by the latter, which computes the voltages to be applied to the PF circuits. The PF Currents Controller performs the tracking of the PF currents as fast as possible according to the PF circuit power supplies characteristics. The modification needed to perform the strike points sweeping with the XSC consist in the addition of two feedforward signals at the input of both subsystems. The current feedforward signal I_{FF} is computed to obtain the desired sweeping movement, while the feedforward signal added at the input of the Plasma Shape Controller is chosen so as to blind the XSC w.r.t. sweeping movement.

FEEDFORWARD WAVEFORMS CALCULATION

Given the desired periodic waveforms describing the time behavior of the strike point positions, the current feedforwards have to be evaluated so as to: **i)** the strike point positions follow as close as possible the desired waveforms; **ii)** the other gaps remain as close as possible to their nominal values. Using the modelling approach of [3], the nominal configuration can be characterized by the currents flowing in the PF coil circuits I_{PF}, the plasma current I_p, the plasma poloidal beta β_p, the internal inductance l_i, and the plasma boundary geometrical descriptors g (a number of gaps, the X-point position, and the strike points). The variations around the nominal configuration $(I_{PF_N}, I_{p_N}, \beta_{p_N}, l_{i_N}, g_N)$ can be described by the following linearized model:

$$\delta g = C \delta I_{PF} + F_1 \delta \beta_p + F_2 \delta l_i \,. \tag{1}$$

The evaluation of I_{FF} is performed finding the PF current variations δI_{PF_A} and δI_{PF_B} which moves the plasma from the nominal shape N, to the desired *sweeped* configurations A and B (see Fig. 2). If δg_A and δg_B are the gap variations that corresponds to the configurations A and B, then δI_{PF_A} and δI_{PF_B} are computed via a static optimization procedure based on the singular value decomposition (SVD) of the C matrix in (1). I_{FF} is obtained by varying the PF circuit currents between $I_{PF_N} + \delta I_{PF_A}$ and $I_{PF_N} + \delta I_{PF_B}$, with the prescribed waveform (typically triangular), and it is then added to the output of the Plasma Shape Controller, to have a gaps variation between $g_N + \delta g_A$ and $g_N + \delta g_B$. Unfortunately the Plasma Shape Controller counteracts these variations, which are seen as disturbances. To avoid this behavior the Plasma Shape Controller is blind w.r.t. the sweeping movement, computing on line a feedforward which is added to the plasma shape references.

EXPERIMENTAL RESULTS

The sweeping algorithm has been validated at JET during the C-17 experimental campaign in the hybrid scenario sessions (see [2]). The requirement was to spread as much as possible the heating load on the divertor region, moving the strike points on the tiles between the two extreme configurations shown in Fig. 3(b). Fig. 3(a) shows the experimental waveforms of the strike points (ZSI and RSO)for the JET pulse 68414. The sweeping has been performed at 4 Hz, using only the currents in the divertor coils. Fig. 4 shows the effects of the sweeping on the temperature of the divertor tiles. In this figure two similar pulses, one without the sweeping (the pulse 68409), and one with the sweeping (the pulse 68414) are considered. The measurements coming from the new infrared camera [4], show that the sweeping allows to reduce the temperature in the region where the two separatrix baffles intersect the divertors.

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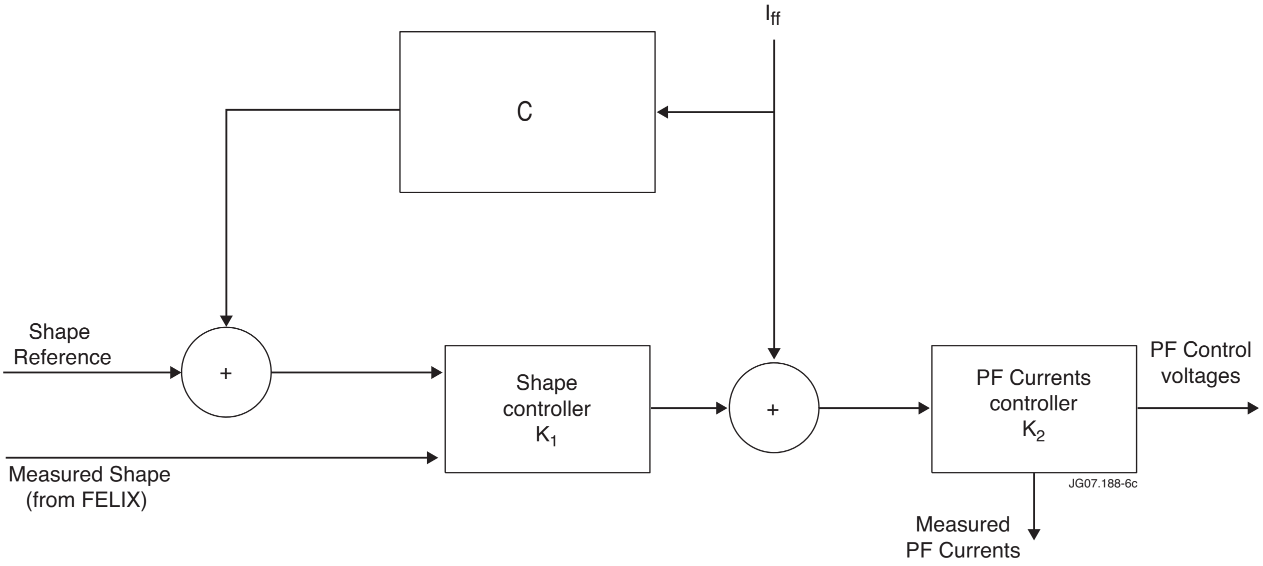

Figure 1: The scheme used to perform the strike points sweeping at JET

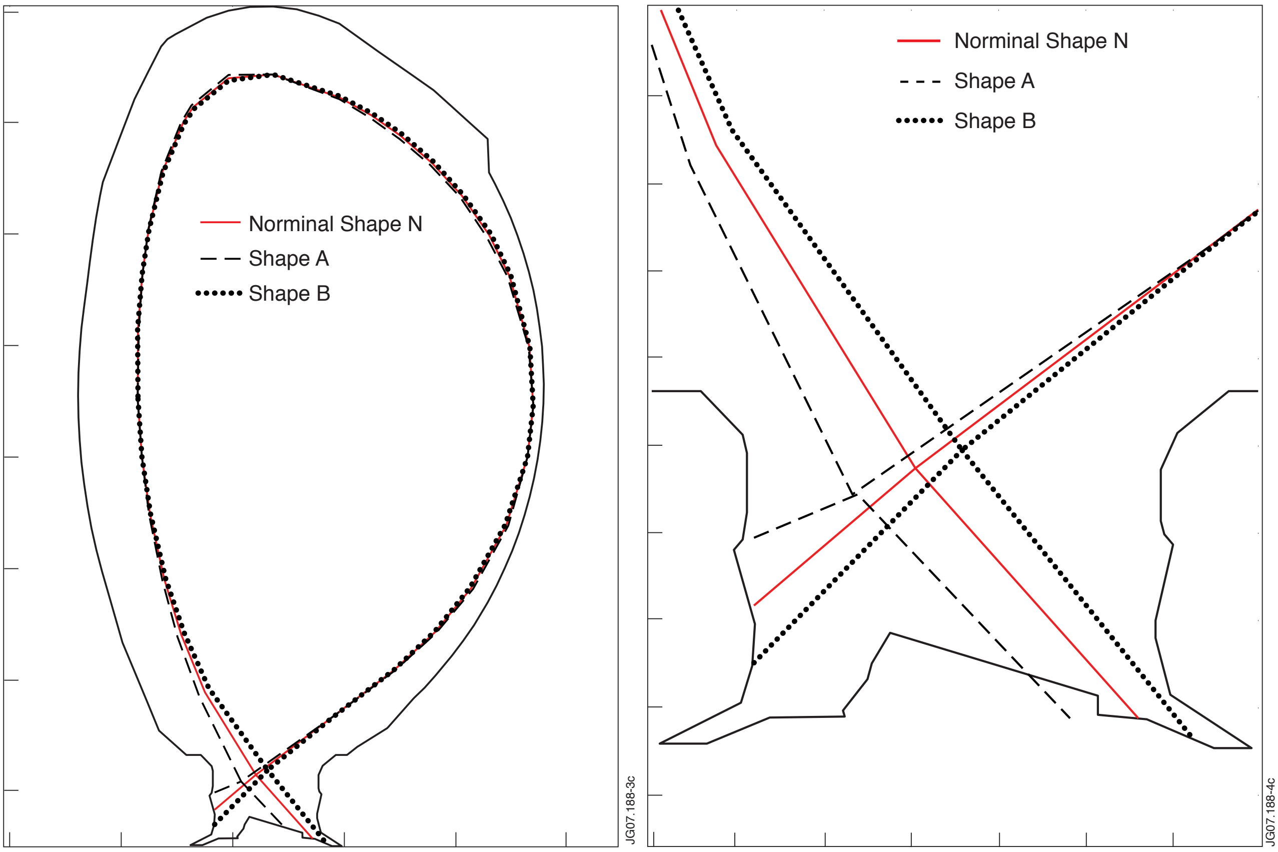

Figure 2: An example of sweeping design. Fig. 2(a) shows the nominal shape (N) and the two varied configurations A and B. Fig. 2(b) shows the details in the divertor region.

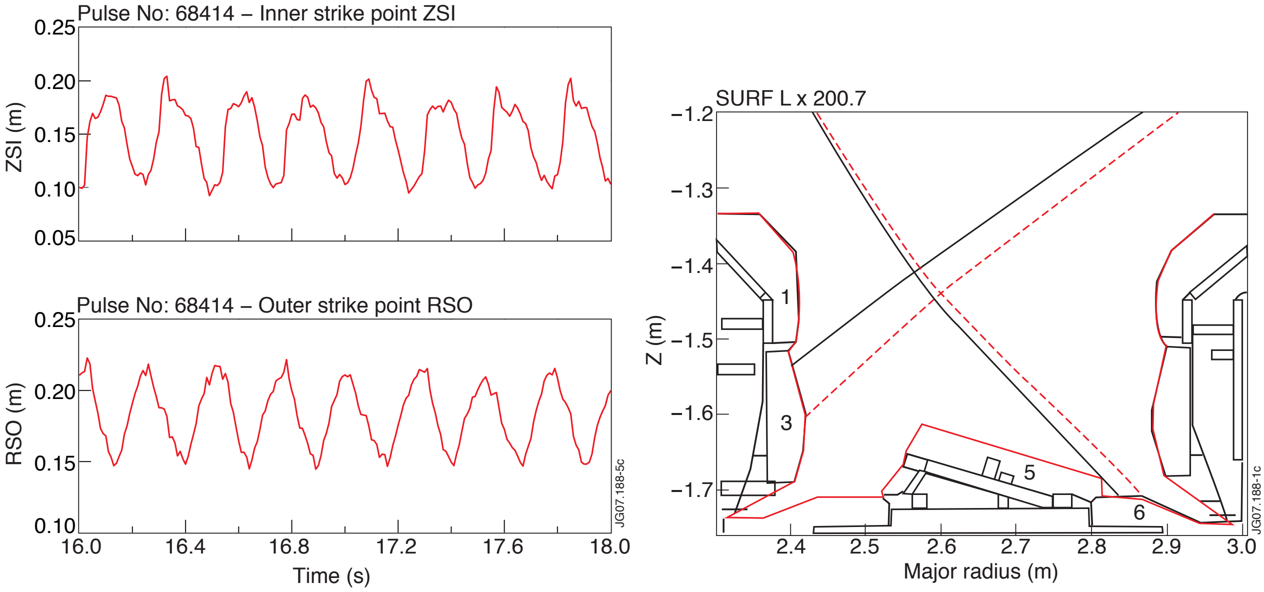

Figure 3: Sweeping experimental results for the JET Pulse No: 68414. (a) Time behavior of two strike points (b) Shapes at t = 17.1s and t = 17.2s.

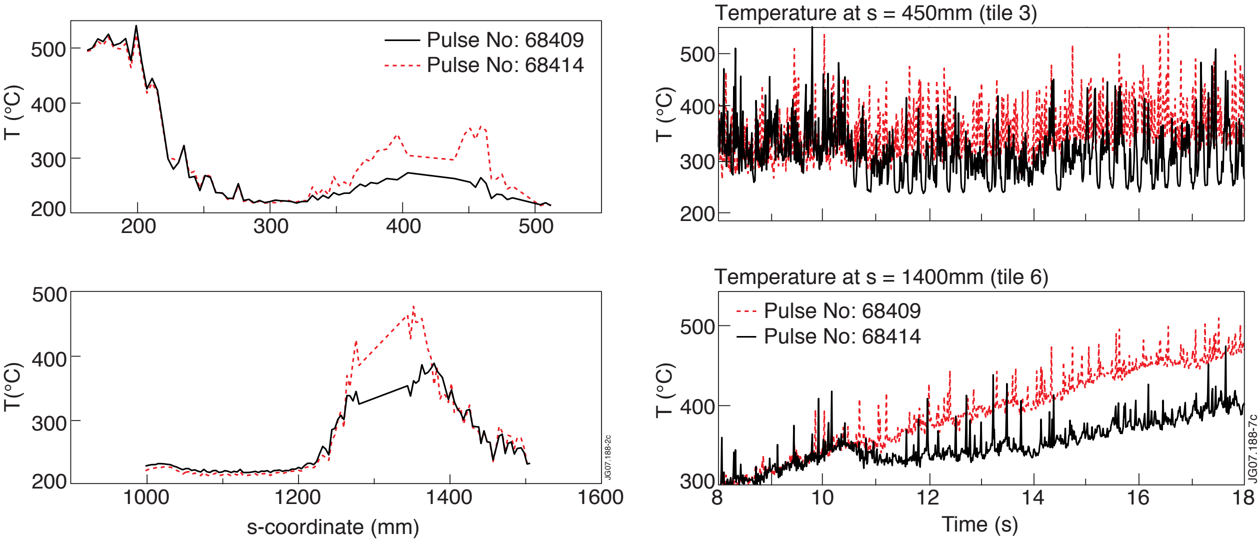

Figure 4: Divertor temperatures with (Pulse No: 68414), and without (Pulse No: 68409), the sweeping. The s-coordinate is a poloidal coordinate defined along the divertor surface, its value is given by the distance from the innermost point on the divertor.