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Exploitation of modularity in the JET tokamak vertical stabilization system

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ABSTRACT

The vertical stabilization system of the JET tokamak has been recently upgraded. This new system enables a more sensitive control of the plasma geometry and can withstand larger perturbations, enabling to push the plasma performance to its limits without risking a severe control loss, which might endanger the machine integrity. The project was successfully delivered in the course of 2009. This paper introduces the architecture of the new JET vertical stabilization system, discussing how its modularity enabled the system to provide different experimental features in several operational environments. Furthermore, some of the major achievements of the commissioning activity and of the regular operation during the 2008/2009 experimental campaigns are presented.

1. Introduction

The research in the nuclear fusion field aims at providing a complementary source for alternative energy. In particular, tokamak devices have been proved to be the most promising devices to achieve magnetic confinement of plasma (Wesson, 2004).

In a tokamak reactor, plasma is formed in a vacuum chamber (the *vessel*), and several magnetic fields are applied to confine the plasma. The dominant one, the toroidal magnetic field, is generated by a set of coils named toroidal field coils. However, a plasma placed in such a field cannot come to an equilibrium force balance (Freidberg, 2007). For this reason an additional poloidal magnetic field component should be added to confine the plasma. In the tokamak configuration this difficulty is overcome by passing a toroidal current through the plasma itself.

The combined (toroidal and poloidal) magnetic field is helical. Another component is added to the plasma generated poloidal field by means of the poloidal field (PF) coils (see Fig. 1(a)). This additional component is used to achieve the desired plasma configuration, defined by a shape and a position.

The need for achieving always better performance in the present and future tokamak devices has leveraged plasma control importance in tokamak engineering. The interested readers can refer to Pironti and Walker (2005) in Special Issue on Control of Tokamak Plasmas (2005), to Walker et al. (2006) and Lister, Portone, and Gribov (2006) in Special Issue on Control of Tokamak Plasmas—Part II (2006), to Gribov et al. (2007) in Special Issue on ITER (2007), and to the book Ariola and Pironti (2008).

In order to increase the energy confinement time, which is a vital criterion for realizing sustained fusion, modern tokamak designs favor vertically elongated plasma shapes. The downside is that these configurations are vertically unstable (De Tommasi et al., 2011a; Walker & Humphreys, 2009), requiring an active feedback system, called a vertical stabilization (VS) system.

Different solutions have been proposed for plasma vertical stabilization in tokamaks: simple SISO controllers (Jardin & Larrabee, 1982; Lennholm et al., 1997), optimal linear-quadratic control (Moriyama, Nakamura, Nakamura, & Itoh, 1985), predictive control (Gossner, Vyas, Kouvaritakis, & Morris, 1999), nonlinear adaptive control (Scibile & Kouvaritakis, 2001), and robust control (Al-Husari et al., 1991; Vyas, Morris, & Mustafa, 1998). In Schuster, Walker, Humphreys, and Krstić, (2005) an anti-windup synthesis is proposed to allow operation of the vertical controller in the presence of saturation. Furthermore, thermal constraints limiting the current into the actuator have

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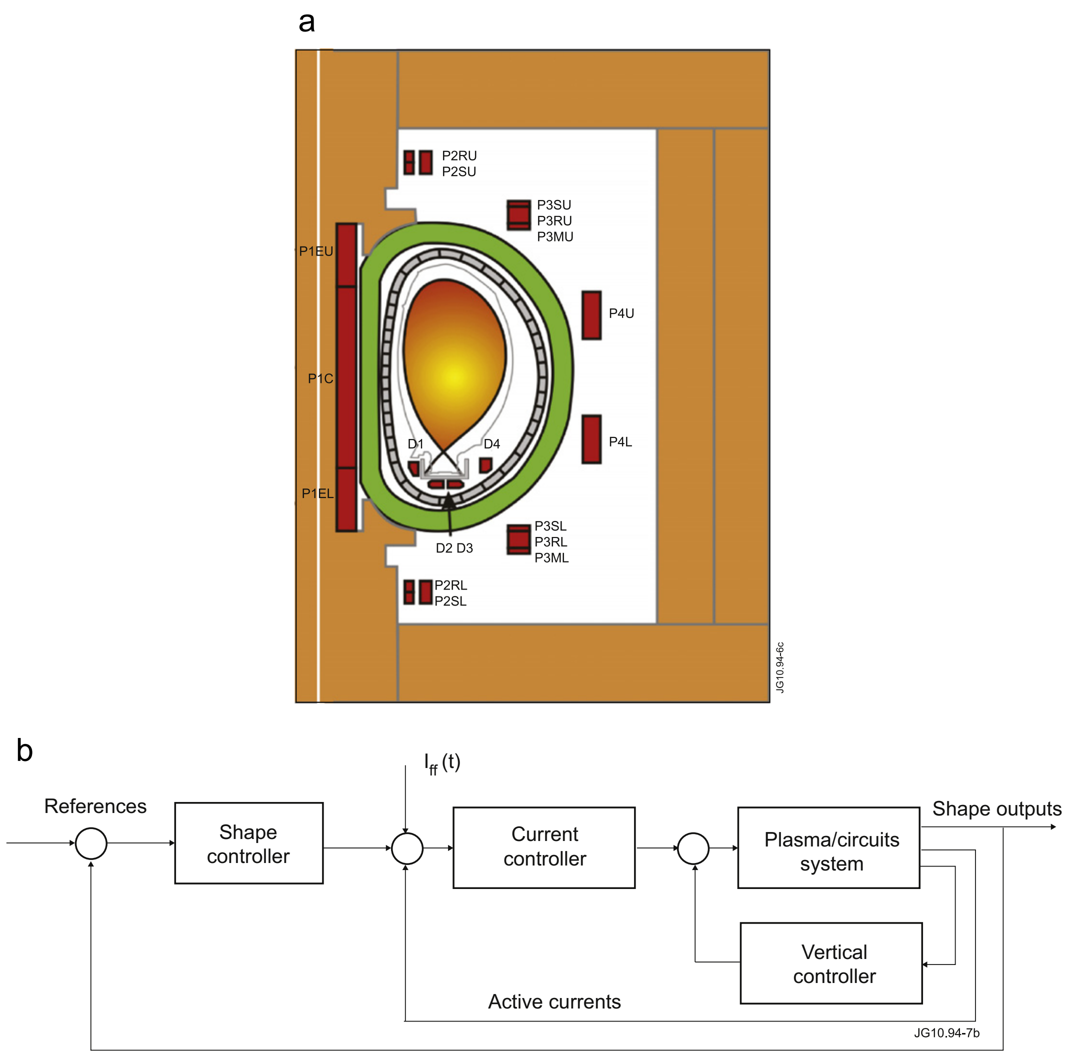

Fig. 1. The magnetic control system of the JET tokamak. (a) The JET poloidal field coils system. The radial field circuit, termed *RFA*, connects the P2RU, P3RU, P2RL, and P3RL, and is used by the VS system. The *P*1 circuit includes the elements of the central solenoid P1EU, P1C, P1EL, as well as P3MU and P3ML. The series circuit of P4U and P4L is named *P*4, while the circuit that creates an imbalance current between the two coils is referred to as *IMB*. *SHA* is made of the series circuit of P2SU, P3SU, P2SL, and P3SL. The central part of the central solenoid contains an additional circuit named *PFX*. Finally the four divertor coils (*D*1–*D*4) are driven separately each by one power supply. (b) Architecture of the JET magnetic control system, where the VS system has a dedicated control system. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

been considered in Ambrosino, Ariola, De Tommasi, and Pironti, (2011).

The VS system of the Joint European Torus (JET, Special Issue on JET, 2008) has been recently upgraded as part of the *Plasma Control Upgrade* (PCU) project (Sartori et al., 2010). This project has increased the capabilities of the JET VS system so as to meet the requirements for operations with the *ITER-Like-Wall* (ILW, Matthews et al., 2007; Paméla, Matthews, Philipps, & Kamendje, 2007). The VS upgrade has included

- the design and the deployment of a new power supply (Toigo et al., 2007);
- the deployment of a new hardware and software architecture for the VS system.

The new VS system (Bellizio et al., 2010) has replaced the old DSP based control system that was deployed during the first operation with the divertor at JET (Garriba et al., 1994; Sartori, De Tommasi, & Piccolo, 2006). The new VS enables more sensitive control of the plasma geometry, and can withstand larger perturbations, e.g. larger Edge Localized Modes (ELMs, Bécoulet et al., 2003), enabling to push the plasma performance to its limits without risking a severe control loss, which might endanger the machine integrity.

Plasma disruptions are characterized by an abrupt termination of the plasma current and a consequent transferring of high heat loads into the plasma facing components. The system upgrade became necessary as JET prepares for experiments with its ILW, where the number of disruptions must be kept to an absolute minimum, since these may lead to the melting of the beryllium surface. The system's response time was improved by increasing the amplifier's maximum voltage and current (Toigo et al., 2007), while the hardware was replaced to increase the signal to noise ratio. Processing capabilities have also been increased to two gigaflops (Neto et al., 2011a), giving the possibility to implement more complex control algorithms. In particular the system was upgraded giving the option of easily implementing different control algorithms which can be applied to the different phases of the plasma discharge.

This paper presents the system architecture of the new JET VS and discusses the first results attained during the last experimental campaign. It is structured as follows: Section 2 gives an overview of the JET magnetic control infrastructure, while Section 3 focuses on