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Bangbang controller design and implementation for EAST vertical instability control

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HIGHLIGHTS

- The linearized plasma vertical response model is designed and analysed.
- The Bangbang controller for EAST vertical displacement is designed.
- The Bangbang controller is optimized for time delay of control system.
- We investigate efficacy of Bangbang controller with simulations.
- Performance of the controller is roughly given by experiments.

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ABSTRACT

In the EAST 2014 campaign, a new internal coil (IC) power supply was used in order to enhance the control over the plasma's vertical instabilities. The IC power supply now allows for current and voltage working modes with much higher peak voltages and currents and faster response time. In comparison the previous power supply only allowed for the current mode. A Bangbang and PID composite controller has been designed for the voltage mode based on optimal control theory and the RZIP rigid plasma response model. This paper will demonstrate that faster and enhanced controllability are realized with the combination of Bangbang and PID controller. For the large z position drift, the Bangbang controller will export the maximum voltage to achieve much faster power supply response and slow the vertical displacement events (VDEs). The PID controller is used for the small z drifts which will finally stabilize the VDEs with minimum z position oscillation. Furthermore, to evaluate the time latency of this control system and power supply, the stability and performance of the closed loop were simulated and analysed. This controller was finally implementation and test on EAST using the Quasi-snowflake shape which achieved growth rates of 500 s^{-1}. This paper shows that the new power supply using the bangbang + PID controller can significantly enhance the control over vertical instabilities.

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1. Introduction

Some advanced plasma configurations, such as the Quasi-snowflake shape, which have high growth rates of vertical instability, were implemented in the EAST 2014 experimental campaign. The growth rate of the EAST Quasi-snowflake equilibria is higher than 500 s^{-1}. The vertical instability controllability of older EAST vertical displacement control system is shown in Fig. 1, which is smaller than 1.2 cm with a growth rate higher than 200 s^{-1} [3]. However, the increasing vertical displacement growth rate increases the risk of the vertical displacement event [10,11]. So the vertical displacement control system is required to be upgraded for safe and robust control.

In 2014, the Internal Coil (IC) power supply system was upgraded. In Fig. 2 is a comparison between new IC power supply and old IC power supply which could only use a current control mode, the voltage mode of the new IC power supply has been able to respond much faster. The communication time of the vertical control system has been upgraded from 1.0 ms to 0.5 ms. And the current rising time in voltage mode from 0 to 5.4 kA is 0.6 ms whereas before when using the current mode the rise time was more than 1.0 ms. Finally, more active control schemes are now available with the upgrade of the IC power supply system.

The scheme of vertical instability control is important and extensively studied in the fusion community. A summary of the

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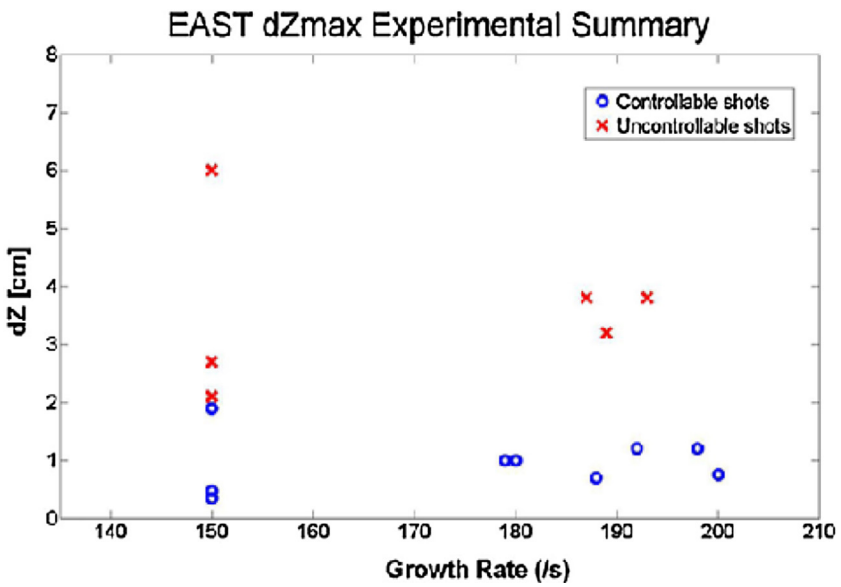

Fig. 1. Summary of EAST experiment measuring dZmax in 2012.

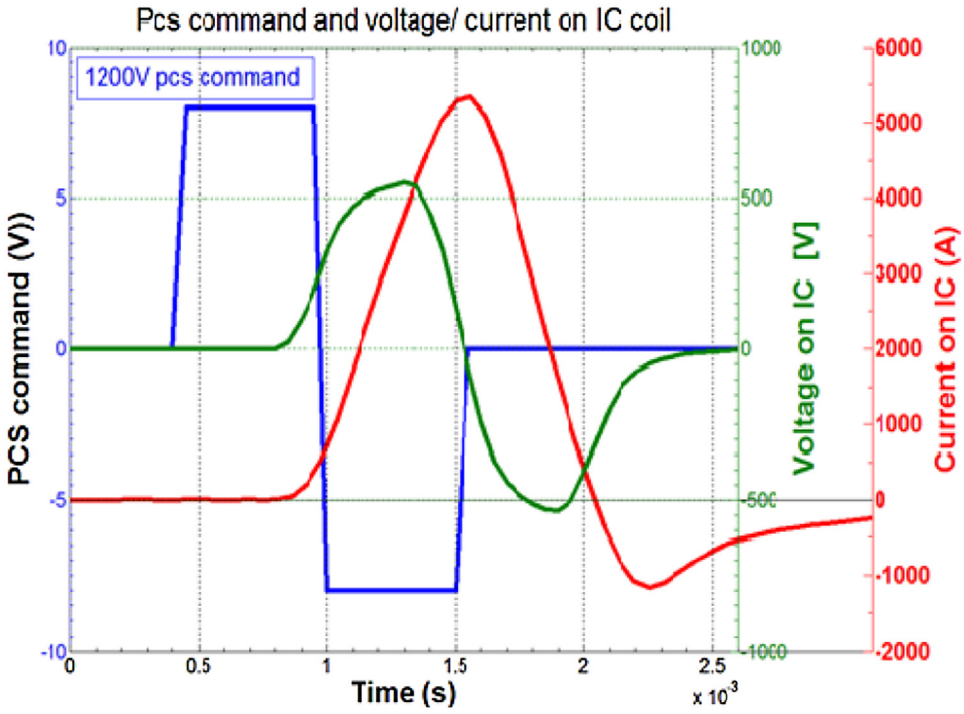

Fig. 2. IC voltage and current response for control command.

existing work with normal control method can be found in [4]. Some of the recent works begin to consider the saturation of coil currents and voltages. There were efforts to minimize the control demand for vertical control as in [5]. In [6,7] the authors have designed a new scheme of vertical control called the anti-windup controller to optimize the influence of saturation on the control system.

The goal of the Bangbang controller is to maximize the performance of the control system while subject to the constraints of the coil voltage saturation and the time delay of the control system in this paper. In Section 2, based on the plasma response model a time optimal controller for the ideal model was designed. Section 3 introduces the optimization results for the time delay of the control system. Section 4 shows the simulation results of the controller. Section 5 discusses the experimental results of the Bangbang controller. Finally, Section 6 presents the summary and conclusions.

2. Bangbang controller design with ideal model

2.1. Plasma model

The RZIP rigid plasma response model [2] has been widely used in tokamak plasma shape and displacement control. It can be expressed in the standard state-space model form.

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \tag{1}$$

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