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# Plasma vertical position control simulation of EAST Tokamak

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**Abstract**: EAST Superconducting Tokamak is a non-circular advanced steady-state plasma experimental device, which will be build at ASIPP in next year. Tokamak plasmas with highly elongated cross sections are subject to a vertical displacement event (VDE). For long duration steady state operation of EAST, it would be very crucial to maintain the plasma radial and vertical positions accurately. For designing the position controller in EAST we have adopted 1.5D equilibrim evolve control model. While the vertical position instability is slowed down by a set of passive stabilizers placed closed to the plasma edge, a pair of in- vessel active feedback coils can adequately control vertical position perturbations of up to 2 cm. The parameters of both vertical and radial position control coils and their power supplies are determined based on the simulations.

## 1. Introduction

Vertical instability in elongated tokamak is a critical design issue, for careful analysis is required to understand the trade-off between increasing elongation and maintaining a reliable vertical control system. High elongation plasma shape can improve idea MHD stability limits. However, it is well known the higher elongation lead to more vertically unstable plasmas, requiring more powerful feedback control systems.

The EAST superconducting tokamak is a proposed experimental device, which is intended to develop a steady-state-capable superconduct tokamak to establish the scientific and technological basses for an attractive magnetic fusion rector[1]. It will address advanced physics issues such as extension of present stability and performance boundaries of tokamak operation and develop methods to achieve steady state operation of tokamak fusion reactors using non-inductive current drive. Major parameters of EAST are shown in Table 1. In order to accomplish the mission and research objective of EAST, it is necessary to posses strong control capabilities. Among the various control issues, control of plasma vertical stability is of fundamental importance. Large amount of work has been done for this issue[2][3].

Here, we use a numerical code that is able to model the behavior of a free-boundary axisymmetric tokamak plasma interacting with a conducting wall and a set of axisymmetric conductors that obey circuit equations with active feedback amplifiers included. Modified magnet hydrodynamic equilibrium is solved inside a computational domain that includes a plasma region, a vacuum region, a specified number of solid conductors and a wall. The interaction of the plasma with passive conducting structures as treated in a self-consistent manner. This method has been applied to many problems in tokamak design and has been used to simulate experiments on various toroidal fusion devices[4][5].

Tab 1 Major parameters of the EAST device

| | |
|---|---|
| Toroidal field Bt (T) | 3.5 |
| Plasma current Ip (MA) | 1.5 |
| Major radius R0 (m) | 1.78 |
| Minor radius a (m) | 0.4~0.7 |
| Elongation | 2.0 |
| Triangularity | 0.7 |

In the present work, we report the results of control simulations of vertical stability of EAST. We first compute the linear growth time of vertical instability as a function of plasma internal inductance to offer a base line plasma condition for the vertical control simulations in Section 2. In Section 3, we discuss the control of vertical motions in EAST. A summary is given in Section 4.

## 2. Vertical stability analysis for EAST

In this section, we calculate the linear growth time of the vertical instability for EAST plasma. The plasma vertical growth time depends on the geometry and resistivity of the conducting structure, the plasma current profile $l_l$ and the pressure $\beta_p$ . The purpose of the growth time calculations is to identify the $li$ and $\beta_p$ corresponding to the most unstable plasma and present a base line for vertical control simulation.

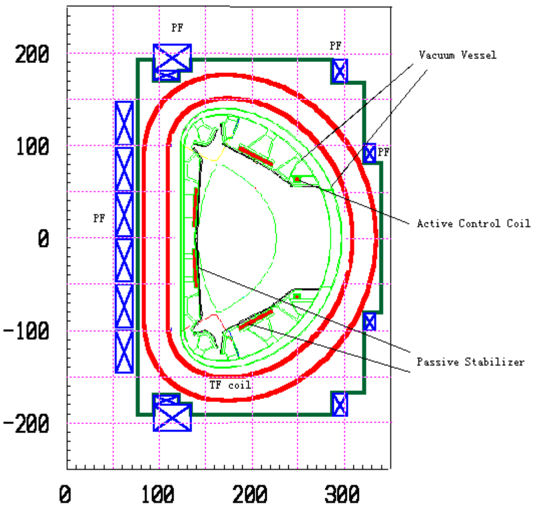


Fig 1

Fig. 1 shows the locations of external PF coils, passive structures and internal control coils being used in the calculation of linear vertical growth time and vertical control simulation for EAST. The passive structures of EAST consist of a double-walled vacuum vessel and two pair of a passive stabilizer.

Once the surrounding passive structures are defined, the vertical growth time depends on the plasma shape, pressure and current profile. We examine the vertical stability for $\beta_p$=0.1 and 0.6<$l_i$<1.4 with other major plasma parameters given in table 1.

These plasma conditions correspond to expected conditions at the start of current flat to (SOFT), which is characterized by full plasma current, full shape, and ohmic β. The low β SOFT plasmas are expected to be the most unstable ones for the axisymmetric mode during the current flat top stage. For the growth time calculations, we do not include the interactions between the plasma and PF and active control coils.

A reference double null equilibrium is calculated using up-down symmetric coil currents in the seven PF coils external to the vacuum vessel. The equilibrium is the given a small displacement by introducing antisymmetric coil currents in the internal control coils. For the time dependent vertical stability calculations, the coil currents in PF coils are maintained constant in time. In this way, the double null plasma is perturbed from its equilibrium field location, and a vertical instability is induced.

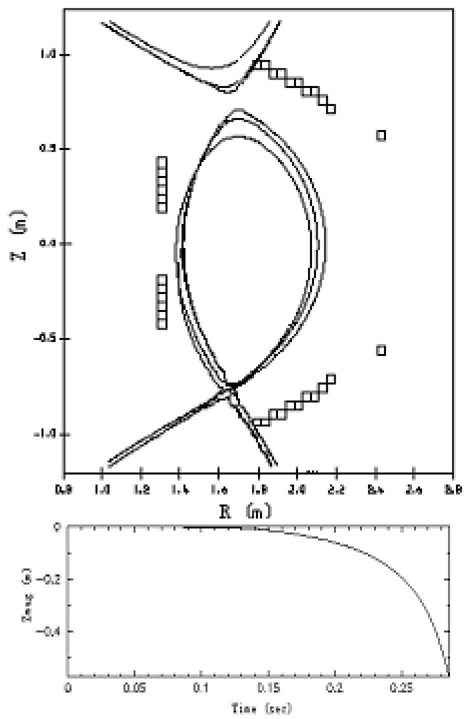


Fig 2

Fig 2 shows a typical time history of the last closed flux surface and magnetic axis evolution during a vertical instability. The plasma drifts vertically and eventually shows an exponential dependence of $Z_{mag}$ with time. In this linear phase when $Z_{mag} \sim \exp(-t/\tau_z)$, the growth time, $\tau_z$ is independent of time.

Fig 3 shows the vertical growth time as a function of $l_i$ for $\beta_p$ = 0.1 and plasma parameters given in Table 1. The plasma is the most stable when $l_i$ = 0.8 . It is found than the plasma is more unstable when $l_i$ is either small or larger.

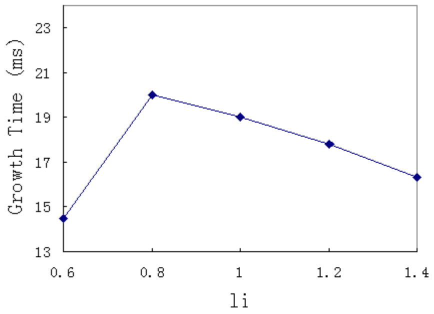


Fig 3

## 3. Vertical position feedback control analysis

The vertical position control simulation is done with the 1.5D code, with three specific disturbances: a 2 cm step response, a 1 cm random disturbance and a 2 cm drift and recovery.

**Step response simulation**

The step response simulations provide a simple and direct way of examining the feedback characteristics of the control system. The simulations determine the optimum feedback system gains, which minimize power, supply consumption.

The present design requirements of the EAST vertical feedback control system are that is provides a 2cm offset in vertical position and that is stabilizes a random disturbance characterized by $\Delta Z_{rms}$ = 1 cm with a power spectral bandwidth $\omega=1/\tau_z$, where $\tau_z$ is the plasma growth time, for all the anticipated plasmas in EAST. The random simulation will be described in next section. As a base line plasma, we chose a plasma with $\beta_p$=0.1 and $l_i$=1.4. Such plasma will require the largest power consumption among all the expected plasmas.

For the feedback system law, we use proportional and derivative (PD) gain control given by $I_f = g_p(Z_{mag} - Z_0) + g_d \frac{d}{dt}(Z_{mag} - Z_0)$ where $Z_{mag}$ represents the vertical position of the plasma magnetic axis, $Z_0$ is the desired value of $Z_{mag}$ (in this case $Z_0$=2cm) , $g_p$ and $g_d$ are the proportional and derivative gains, respectively. Here, it is assumed that the vertical position of the plasma magnetic axis can be measured and used for vertical feedback.

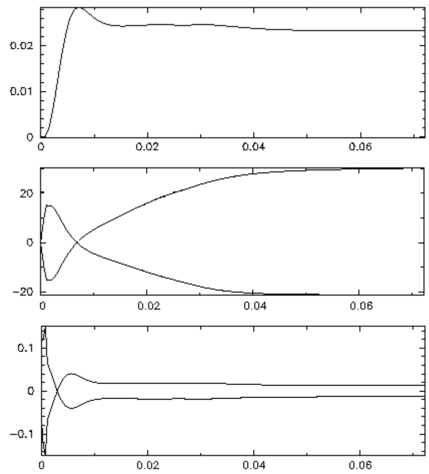


Fig 4

**Random disturbance simulation**

Random disturbance simulation is simulated by feeding the control coils a random signal to move the plasma from position to position. The random disturbance in magnetic axis is given by:

$$Z_0(t) = 2Z_0\left[\frac{\pi\tau}{T}\right]^{1/2}\sum_{n=1}^{\infty}\exp\left(-\frac{\omega_n^2 T_n^2}{8}\right)\cos(\omega_n t - \phi_n)$$

where $Z_0$ is the amplitude, $\tau$ is the autocorrect time and T is the period of the random disturbance, Also, $\omega_n$=2n/T and $\phi_n$ is a uniform random phase ($-\pi \le \phi_n \le \pi$), the root-mean-square disturbance of $Z_{mag}$ is fixed to be 1 cm.

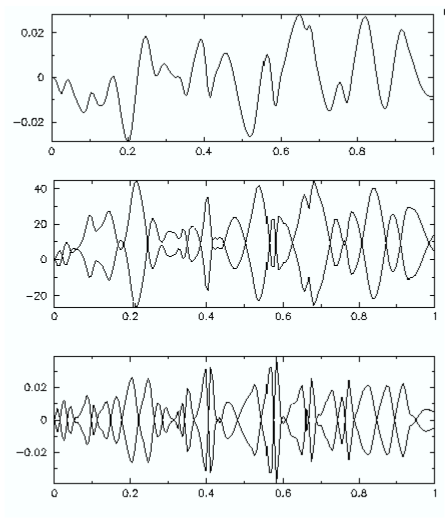


Fig 5

Fig 5 represents the time histories of plasma vertical position and coil currents and voltages during a random disturbance simulation. We do not limit the power supply voltage. The maximum excursion of $Z_{mag}$ is about 2 cm . The maximum current and voltage are found to be 43 kA-turns and 39 V/turn. These are similar as those in The TPX design[4].

**Drift and recover simulation**

Drift and recover simulation is simulated by first turn off feedback system for a while to move the plasma to new position, then turn on feedback system to pull the drifted plasma back to original position. Fig 6 represents the time histories of plasma vertical position and coil currents and voltages during a drift and recovers simulation.

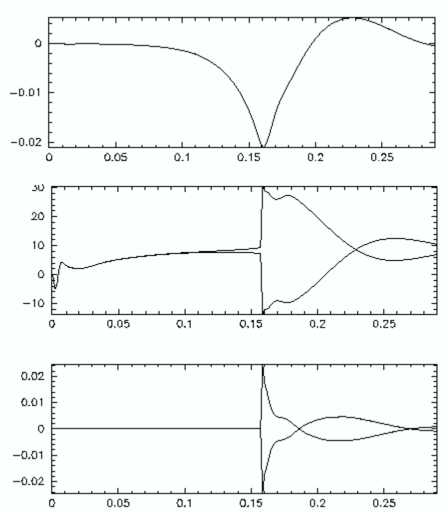

Fig 6

## 4. Conclusion

In this paper, we have investigated the vertical control issues for EAST tokamak plasma. 1.5D code was used as a simulation tool. We have examined the vertical stability for reference EAST plasmas including the presently defined conduction structures, passive stabilizer plates and the double-walled vacuum vessel. It has been shown that the plasma is most stable near li=0.8 and becomes unstable as li increases or decreases. Three specific disturbances has been exam by simulation. The power supply requirement has been evaluated from random disturbance simulations. The analyses adopted in the present work will also be helpful for the design study of future tokamak.

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