Numerical study on feedback stabilization of neoclassical tearing modes via minimum growth rate seeking method

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1. Introduction

The feedback control of EC launcher angle is essential to reduce the misalignment between the location of the ECCD deposition and the island O-point for efficient NTM stabilization. Successful control using the extremum seeking methods have been reported which minimize the width by tuning the misalignment [1, 2]. However, when the control loop time is smaller than the island saturation time, this minimum relation between width and misalignment becomes somewhat unclear as shown in figure 1 (a). If the growth rate is minimized, the controller can find a right solution as shown in figure 1 (b) since generally the growth rate decreases as the misalignment decreases assuming the time interval is small. Consequently, the minimum 'growth rate' seeking control can be a more accurate and efficient for stabilization of NTM than the minimum 'width' seeking control.

Therefore, here the concept of the minimum growth rate seeking method is proposed and investigated by time-dependent predictive feedback control simulations with two types of minimum seeking controller and compared with the minimum width seeking control method.

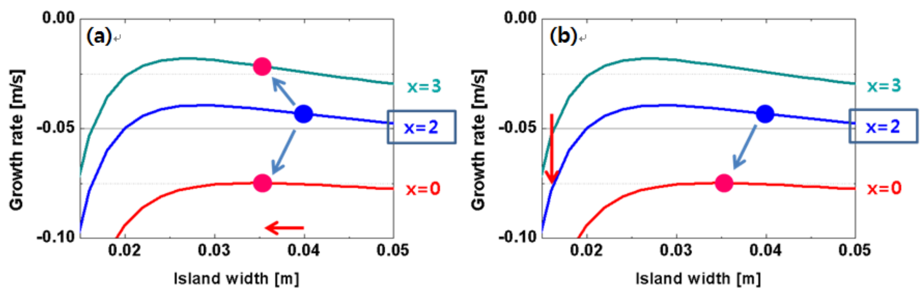

Figure 1 Example of a heuristic misalignment control depicted in the growth rate and the island width space; a control path starting from the blue point to the red point using the minimum 'width' seeking method (a) and using minimum 'growth rate' seeking method (b) where x is the magnitude of misalignment.

2. Numerical methodology for NTM feedback control simulations using the minimum seeking methods

2.1. Minimum growth rate seeking controller

Two types of the minimum seeking controller are employed. One is the finite difference method (FDM) based minimum seeking controller which estimates the sign of the gradient between the input and the output [3]. The adaptive gain is optimized by simulations of gain scan. This is also modified by the gain adjusting method according to the island width [1]. Secondly, the sinusoidal perturbation based minimum seeking controller is employed [1,2]. This introduces a perturbation signal to the output to get a measure of the gradient. The adaptive gain is also selected in gain scanning simulations.

2.2. Integrated numerical modeling of NTM

An integrated numerical system has been established in a self-consistent way to perform feedback control simulations [4,5]. For the time evolution of plasma, ASTRA [6] is employed. Resulting island is described by the modified Rutherford equation (MRE) [4,5,7-10].

$$\frac{\tau_R}{r_s}\frac{dW}{dt} = r_s\Delta_0' + r_s\delta\Delta_0' + a_2\frac{j_{bs}}{j_p}\frac{L_q}{W}\left[1 - \frac{W_{marg}^2}{3W^2} - K_1\frac{j_{EC}}{j_{bs}} - \alpha_H F_H\frac{W}{W_{dep}}\frac{P_{EC}\eta_{EC}}{I_{EC}}\right]. \quad (1)$$

The diagnostic which provides the measurement of island width to the controller is selected as the Mirnov coil. A ‘Mirnov diagnostic’ module is coupled with ASTRA to convert a simulated island width to $\left|\tilde{B}_\theta\right|_{wall}$ of the Mirnov coil measurement affected by the plasma conditions [11]. This ‘measured’ width, $\left|\tilde{B}_\theta\right|_{wall}$ is used for obtaining the ‘measured’ growth rate to mimic the real experiment. The feedback controller loads this and deduces the poloidal EC angle in every control time steps. TORAY [12] is used to calculate the ECH/CD.

3. NTM stabilization simulation results with minimum seeking feedback controllers

An imaginary KSTAR plasma is assumed to obtain 2/1 mode NTM suitable for 170 GHz EC. The NTM is assumed to appear at 0.5 s with 4 cm. The controller turns on 100 ms later. The initial EC beam is assumed to be aligned close to the island. Two initial angles are tested; 62 degree and 61 degree. The adaptive gain is scanned and optimized with the 62 degree. The control loop time is set as 20 ms.

3.1 Results of minimum growth rate seeking control simulations

Stabilization of the NTM is simulated using the FDM based minimum growth rate seeking controller for the two cases of the initial poloidal angle. Although the target angle is not assigned, the poloidal angle is controlled to move to the direction of decreasing the growth rate. The controller regulates around the zero misalignment point as designed. The sinusoidal perturbation based minimum growth rate seeking controller also succeeds to fully stabilize the mode for the two cases of the initial poloidal angle. The controller works well so that the averaged angle gradually approaches to the angle of the zero misalignment.

3.2. Comparison with the minimum width seeking control

The stabilization simulations of the mode using minimum width seeking method are compared with that of minimum growth rate seeking control. The initial poloidal angle is assumed as 62 degree.

The FDM based minimum width seeking controller is found to fail to stabilize the mode without island width saturation. The controller overshoots the zero point of the misalignment and increases the misalignment since the width keep on decreasing regardless of misalignment. The controller is improved to avoid this by adding an island saturation checking step and stabilizes the mode successfully. However, the controller has to wait for the saturation and the reducing the misalignment takes longer than the minimum growth rate seeking controller.

Secondly, the sinusoidal perturbation based minimum width seeking controller is tested and succeeds to fully stabilize the mode. The reason is conjectured as the controller can extract the responsive signal as the perturbation induces that of the misalignment and subsequent that of the growth rate through MRE. However the controller cannot achieve the zero misalignment easily than minimum growth rate seeking controller and time for stabilization is increased. This is thought that the responsive island width is obtained from the growth rate and this can cause the phase shift and complexity of the signal to filter out the proper value.

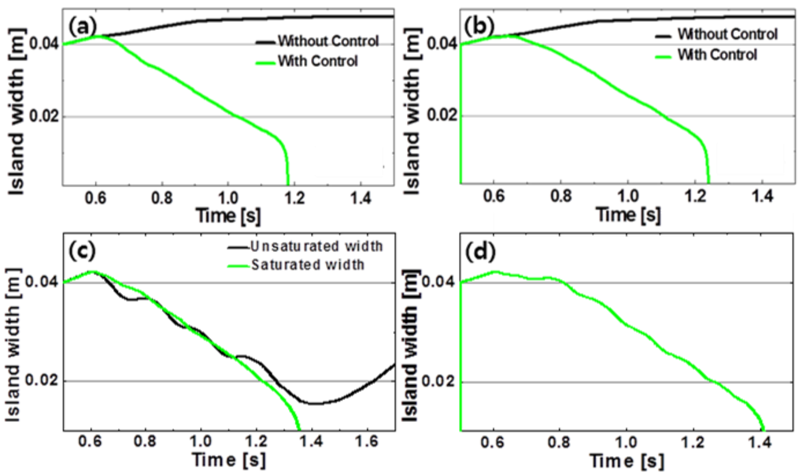

Figure 2 The simulated island width behavior for initial angle of 62 degree using the FDM based minimum growth rate seeking controller (a), using the sinusoidal perturbation based growth rate seeking

controller (b), using the FDM based minimum width seeking controller (c) and using the sinusoidal perturbation based minimum width seeking controller

4. Conclusion

The minimum seeking control of the island growth rate is proposed. Using an integrated numerical system, simulations of the NTM stabilization are performed with FDM based and sinusoidal perturbation based minimum seeking controller. The simulation results exhibit that full stabilization of the NTM is successfully achieved for the both types. Then, these are compared with that of the minimum width seeking controller. The minimum 'growth rate' seeking method is more effective in terms of the stabilization speed and robustness and also less affected by selection of the seeking controller type.

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