The nonlinear phenomena in the unstable region of a single heated channel natural circulation loop with supercritical water

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Abstract. In this study, the nonlinear dynamic model of a supercritical natural circulation loop (NCL) is developed, and supercritical water is selected as the working fluid for analysis. Based on the design parameters of a next-generation supercritical water nuclear reactor, this study conducts nonlinear dynamic analysis of the system after the occurrence of instability. The results indicate that complex nonlinear phenomena could exist in the system, such as subcritical Hopf bifurcations, supercritical Hopf bifurcations and period doubling bifurcations. A distinct route from periodic oscillations to chaotic oscillations is identified through period doubling bifurcations. The analysis of fast Fourier spectral transform further confirms the existence of chaotic oscillation.

Introduction

The advanced applications with supercritical fluids are implemented in various aspects, e.g. the new type of thermal power plants and the next-generation nuclear power plants. The supercritical heated system is inherently a nonlinear system. Since the instabilities, especially density-wave instability, may deteriorate the operation and safety of a supercritical heated system, it is essential to clarify the nonlinear phenomena of them. However, the nonlinear dynamic models for supercritical heated systems are quite sparse in the literatures. Some subcritical system codes or CFD tools [1-2] were amended to investigate the nonlinear characteristics in the supercritical heated systems. At present, such large system codes are generally inappropriate for analyzing the nonlinear phenomena in detail due to their complexity and time-consuming. Therefore, the objective of this study is to develop a simple nonlinear dynamic model of a single heated channel NCL at a supercritical pressure, which can conduct nonlinear stability analysis for the system.

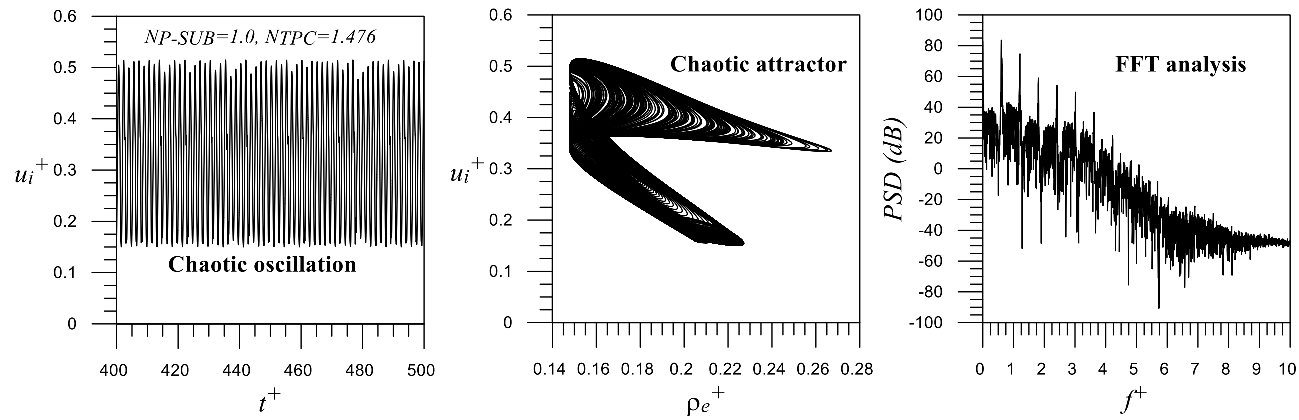

Figure 1: Chaotic oscillation, the corresponding attractor and Fast Fourier Transform (FFT) analysis.

Results and discussion

Employing three-region polynomial approximation [3], the nonlinear dynamic model of a supercritical heated channel NCL can be derived by the boundary condition: the summation of pressure drops through this closed NCL equals to zero. Through the nonlinear analysis, this study finds that outlet loss coefficient of the heated channel has a great influence on the nonlinear behaviors of the system. With a small outlet loss coefficient (i.e. ke=1), the nonlinear types in the unstable region are mainly subcritical Hopf bifurcation and supercritical Hopf bifurcation. If the system with a large outlet loss coefficient (i.e. ke=8), the complex nonlinear phenomena exist in the unstable region, particularly in the area of high inlet temperature. A route from limit cycle oscillations, periodic oscillations and eventually to chaotic oscillations (Fig. 1) is identified through period doubling bifurcations. The existence of chaotic oscillation is also verified through the analysis of fast Fourier spectral transform, as revealed in Fig. 1. It indeed illustrates an interesting chaotic attractor like butterfly wings.

References

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