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論文内容要旨

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学位論文題目	A Numerical Investigation of Self-Excited Combustion Instability (自励燃焼不安定性に関する数値解析に関する研究)		

内容要旨

Nowadays, combustion provides more than 80% of the worldwide energy sources. However, practical combustion systems are often susceptible to combustion instabilities characterized by large-amplitude and low-frequency pressure oscillations. This dissertation presents a nonlinear analysis and a Computational Fluid Dynamics (CFD) simulation of those self-excited combustion instabilities with a Rijke tube combustor. It is necessary to learn the mechanisms of combustion instabilities in-depth to prevent combustion instabilities or control them at acceptable levels.

The nonlinear analysis of the combustion is implemented first. A model of a one-dimensional (1D) Rijke tube burner with both ends opened is built. The nondimensional momentum equation and energy equation of the acoustic perturbation are derived and solved in the time domain by using the Galerkin technique. A saturated n-τ model is proposed to descript the nonlinear flame heat release rate. The time evolution of the combustion instability is calculated. The stabilities of the systems under given conditions are determined by calculating the eigenvalues. Next, the bifurcation analysis of the dynamics behavior for the Rijke burner is performed for the variation of flame location, flame heat release intensity, and the time lag between heat release and flow velocity perturbation. Nonlinear phenomena, including hysterical, critical bifurcation, and stability switching, were observed, verifying the nonlinear characteristic of the Rijke tube burner. Further, the phase diagram and Poincaré map of the limit cycle oscillations are given, showing the oscillations' periodic character. The growth rates of the onset for the exciting case and decay for the stable case are calculated too. This nonlinear analytical method helps to understand the nature of combustion instability.

Second, the self-excited combustion instability in a two-dimensional (2D) Rijke tube burner with a center-stabilized premixed methane-air flame is numerically studied. The simulation considers the reacting flow, flame dynamics, and radiation model to investigate the essential physical processes. A finite volume-based approach is used to simulate reacting flows. Chemical reaction modeling is conducted via the species transport model with one-step reaction mechanisms, and the radiation heat flux is determined by using the P-1 model. The steady-state reacting flow is first simulated for model verification. Then, the dynamic pressure, velocity, and reaction heat evolutions are determined to show the onset and growth rate of self-excited instability in the burner. The growth rate of the acoustic disturbances at the onset stage are calculated by curve fitting. Using the fast Fourier transform (FFT) method, the limit cycle oscillation frequency is obtained, which agrees well with the theoretical prediction. The dynamic pressure and velocity along the tube axis provide the acoustic oscillation mode and amplitude, agreeing well with the

prediction. Finally, the unsteady flow field at different times in a limit cycle shows that flame-induced vortices occur inside the combustor. The temperature distribution indicates that the back-and-forth velocity changes in the tube vary the distance between the flame and honeycomb in turn, forming a forward feedback loop in the tube. The results reveal the route of flame-induced thermoacoustic instability and indicate periodical vortex formation and breakdown in the Rijke burner.

In summary, the combustion instability in a Rijke type burner is numerically investigated from the nonlinear dynamics analysis and CFD simulation. The nonlinear analysis results show that combustion instability is a nonlinear system. There are bifurcation, stability switching phenomenon that exist, and the systems may have stable and unstable results for a given state. The CFD results verify the predictions of 1D analytical results and reveal details of the dynamics flow field, showing that even in very low Reynold numbers, the coupling of flow perturbation and heat release may induce vortices. These results provide people new perspective in studying the mechanisms of combustion.