Nonlinear dynamics of cross-flow heat exchanger tube conveying fluid

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Abstract. For the efficiency and durability of heat exchanger, its flow-induced vibration analysis is essential. The present work is to study the dynamics of a cross-flow heat exchanger tube conveying steady/pulsatile flow. The motion of tube is modelled using Euler-Bernoulli beam theory while the internal and cross-flows are modelled with plug-flow and quasi-steady-flow model, respectively. Galerkin discretization and Runge-Kutta time integration were used to solve the governing delay-differential equation of motion. Results revealed that the internal steady flow amplifies the periodic oscillations of cross-flow induced flutter of tube but reduces the critical cross-flow velocity and flutter frequency. These variants are negligible for the rise in internal flow velocity. For the supercritical cross-flow velocities, the internal flow pulsation induces quasi-periodic oscillations. For other velocities, the time delay effect eliminates the parametric instability due to internal pulsatile flow.

Introduction

In the heat exchanger (HE), the external cross-flow induces the fluidelastic instability (FEI) in tube array beyond a critical flow velocity resulting in flutter of tubes. For a low mass damping parameter, the array dynamics can be equivalently modelled by considering the time delay between single flexible tube motion and fluid forces acting on it [1]. In addition to the vast amount of literature on FEI of HE tubes [2], there exists a substantial literature on the flow-induced vibrations of the tubes conveying fluid where the internal steady flow induces static instability while the pulsatile flow induces parametric resonance/instability [3]. To the best of authors' knowledge, the existing studies on the FEI of HE tubes omitted the internal flow. A recent experimental study considering the cross-flow turbulence excitation and internal steady flow [4] revealed a rise in amplitude of vibration of tube due to the increased mass of system. Thus, it may be important for the design of HE array to consider the effect of internal flow as the dynamics may significantly vary due to the presence of aforesaid kinds of instability. Therefore, it is intended to study the effect of internal steady/pulsatile flow of the fluid on the nonlinear dynamics of HE inline square array tube under FEI. The governing equation of motion is derived by modifying the governing equation of tube conveying fluid to include the effect of cross-flow through the distributed force along its length.

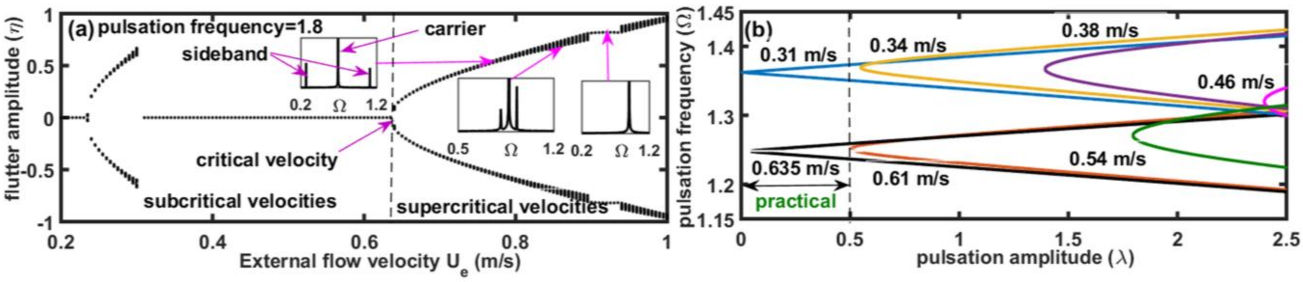

Figure 1: (a) bifurcation diagram of HE tube, (b) parametric instability regions for different external flow velocities.

Results and discussion

An investigation on the effect of internal steady flow revealed an increase in amplitude of periodic oscillations of the flutter of tube but the reduction of critical cross-flow velocity and flutter frequency. Whereas these variants are very low for an increase in internal flow velocity. However, for the supercritical cross-flow velocities, the internal flow pulsation along with FEI induces two-period quasi-periodic oscillations (Fig. 1(a)) of the tube instead of periodic oscillations while having insignificant change in the amplitude of oscillations. Here, the flutter frequency appears as its carrier frequency. Near the pulsation frequency equal to the twice of flutter frequency, the side-band frequencies gradually converge towards the carrier frequency and results in parametric resonance with period-2 oscillations. Whereas for the subcritical cross-flow velocities, an interesting damping phenomena due to the time lag effect is observed that eliminates the parametric instability completely (Fig. 1(b)). Thus, this study reveals the importance of the consideration of internal flow in the dynamic analysis of HE array.

References

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