Analysis for flow induced vibration of slender tubes of a shell-and-tube heat exchanger

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Abstract

Shell-and-tube heat exchangers play important roles in cooling/heating process gases in petrochemical production lines. Structurally, a heat exchanger of this type is a sealed metal shell with capped ends which contains hundreds of slender, thin-walled tubes supported by multiple baffle plates. The shell is filled with a coolant/heating fluid that flows externally over the tubes, thus cools/heats the other fluid that runs inside the tubes. The transverse part of the external flow is generally unsteady and, in many occasions, turbulent during the heat exchange. Unstable vortices can be found downstream that creates pulsating fluidal force on the walls of tubes. With higher Mach numbers, the vortex shedding can be encountered with a frequency that is close to one of the natural frequencies of the tube structure. As a result, the tubes experience large amplitude of transverse vibration. In this study, the flow induced vibration is analyzed for a shell-and-tube heat exchanger that has experienced strong tube vibration. Both three- and two dimensional computational fluid analyses are conducted using ANSYS-CFX with different inlet velocity. It is found that the flow is highly turbulent for some tubes near the contour of the shell. The fast Fourier transform shows that not one or two, but a family of vortex shedding frequencies in the dynamic pressure of flow. These frequencies are identified as fractional and multiple folds of the theoretically predicted vortex shedding frequency involving with velocity, tube diameter and the Strouhal number. The flow induced vibration is excited by one of these vortex frequencies close enough to the tubes' first structural frequency. To further the study, a two dimensional oscillator is established to adopt the coupling between the tube movement and the unsteady external flow field. The fluid-solid interaction between the two fields is achieved as the elastic deformation of the tube and the transverse flow of the shell fluid are obtained with an integrate model. It is confirmed that the resonance is indeed caused by the downstream vortex shedding. Finally, a strengthening plan is proposed to stiffen the heat exchange tubes to eliminate their harmful structural vibration.