Simulation of flow past an oscillating triangular cylinder using Finite Element Method

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Abstract

This paper is related to the characteristics and the development of a particular fluid-structure interaction phenomenon –the continuous oscillation of an equilateral triangular cylinder in the uniform incoming flow. We propose the explanation of this oscillation. Preliminary analysis indicates that the cylinder could oscillate incessantly by initial positional perturbation or incoming flow fluctuation. It is the unbalance force acting on the cylinder's side faces that causes such movement. On one side, the flow will be flow-past-flat-plate like, whereas the other side will be flow-past-sharp-edge like. Due to the unbalanced pressure exerting on the two sides, the cylinder rotates. When the cylinder moves, these mechanisms switch side interchangeably, and bring the cylinder to continuous oscillation.

Prior experiments had been conducted to investigate such behaviour by means of Food coloring dye and Laser Induced Fluorescence flow visualization. The oscillating frequencies appeared to be governed by Strouhal numbers, which fell within limited range of $0.13 < Str < 0.18$. Beyond this range, the cylinder was either stationary or rotates only in one direction

Due to measurement difficulties in experimental study of the unsteady flow pattern in the water tunnel, only qualitative results were obtained. Alternatively, computational fluid dynamics (CFD) simulation presents a viable approach. Recently, the quasi-steady two-dimensional flow study using CFD was conducted recently to get quantitative results and presented in this paper. The uniform incoming flow was implemented for CFD simulation.

The CFD simulation was carried out using Finite Element Method solver, so-called "FEMLAB" running on Origin 3400 Silicon Graphics (SGI) supercomputer. To optimize the number of cell distribution, body-fitted coordinates (BFC) grid distribution was applied over a quarter of the valve flow channel. Approximately, there were 20,000 elements in the entire flow domain. Element distribution was particularly dense within the hinge region where flow structure development was of interest and importance.

The uniform flow shows that, on the windward side of the cylinder, a vortex was formed at the sharp edges of the cylinder during the initial phase, whereas on the leeward side, the flow stayed attached. The size of the separated vortex increased with the inlet velocity. Toward the rear of the cylinder on the leeward side, the sharp edge behind the cylinder created another vortex –of the opposite sign to the windward one, and causes reverse flow. Behind the cylinder, the pair of windward and leeward vortices interacted each other and were shed downstream by the main flow. The shedding pattern was, however, different from the common circular cylinder case.

As time went on, due the unbalance pressure forces acting on the lateral sides, we calculated the movement and move the cylinder and its accompanying grid. We found out that the overall flow pattern remained the same in every phase motion. Under inviscid flow, the cylinder would not return to equilibrium position, due to its own polar moment of inertia. Therefore, the motion took place in periodic manner, and the oscillation could continue indefinitely.

The present study of a simplified quasi-steady flow past an oscillating triangular cylinder discovered an interesting vortical flow pattern that was not observed in previous experimental investigation. The simulation also provided quantitative measurement of the pressures and the rolling moment. Under the simple uniform incoming flow, the vortex shedding pattern, at certain flow velocity, was observed. The results appeared to agree with the proposed underlying physical explanation of the phenomena, as mentioned above. This study of the flow past an oscillating triangular cylinder could be further enhanced by considering more definite fluid-solid interaction, incoming flow fluctuation, non-Newtonian effect.

Keyword: *fluid-structure interaction, oscillation, triangular cylinder, vortex shedding, Strouhal number, Finite-element method*