A New Model of the Lift Force on Oscillating Cylinder in Uniform Current

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ABSTRACT

A spectrum model for the lift force on an oscillating cylinder in uniform stream is presented in this paper. The model is based on VIV experiments and accounts for fluid-structure interaction. The formula is derived as a function of the natural frequency of the cylinder using a Weibull probability density function. The response of a cylinder with a 20mm diameter was calculated with the lift force model and compared with the response obtained by experiment.

KEY WORDS: lift force; vortex induced vibration (VIV); hydrodynamics; Strouhal frequency; cylinder oscillation; fluid force; fluid-structure interaction

INTRODUCTION

Vortex-induced vibration (VIV) of a circular cylinder is one of the fundamental problems in flow induced vibration. Flow separation and vortex streets are formed in the wake of a cylinder in a cross flow when the Reynolds number, based on the cylinder diameter and flow velocity, exceeds a critical value. The vortices are alternately shed from either side of the cylinder. This induces an approximately periodic excitation on the cylinder that causes it to vibrate. The structural vibration modifies the flow, which in turn alters the induced force acting on the cylinder. The resulting fluid–structure interaction is a non-linear process giving rise to structural vibration with multiple frequencies.

Many studies of VIV on circular cylinders have been documented (Gabbai, 2005). Most have focused on the mathematical models to characterize oscillation patterns such as wake-oscillators, single-degree-of-freedom models, force-decomposition models et al. Lesser attention has been given to lift force models. Sarpkaya (1978) proposed an empirical model for the time-dependent force acting on a rigid circular cylinder undergoing forced transverse oscillations in a uniform flow. Wang (2003) developed a model of non-linear fluid force acting on a freely vibrating cylinder in cross flow based on an iterative process and modal analysis. Blevins (1999)’ model is composed of the harmonic lift components of in-of-phase and out-of-phase. Sallet (1975) developed a fluid dynamic model of the lift and drag forces on oscillating cylinder based on a simplified hypothetical two-dimensional wake model. Fluid-structure interaction is therefore taken into account in some way in all of these models. Also, the measurements of hydrodynamic forces on oscillating cylinder have been conducted in some of experimental studies (Bidde, 1971; Griffin, 1977; Bearman, 1979 and 1989, Chung, 1994).

The oscillation of the cylinder in cross flow has a significant effect on both of drag and lift force because the oscillation disturbs vortex shedding. Thus, the cylinder natural frequency is a key parameter in evaluating drag and lift forces. The natural frequency, in turn, is dependent on size (diameter) and Young’s modulus.

A spectrum expression of the lift force acting on an oscillation circular cylinder is presented in this paper based on the measurements of hydrodynamic pressure on the cylinders undergoing a uniform current. The proposed lift force model is a function of the natural frequency of the cylinder as well as diameter (D) and cross flow velocity (U). This model can be used to predict vortex-induced vibration of a circular cylinder.

TEST SETUP

Two arrangements were used in the tests.

The first arrangement was used to measure hydrodynamic pressure on an oscillating cylinder. Four pressure sensors were located at the mid span of a UPVC pipe with a diameter of 110mm, 3.2mm wall thickness and 1.5m in length. Two sensors were located in line with the current (on either side of the pipe) to record drag force. The second pair of sensors were located at right angles to record transverse lift force. All sensors were therefore positioned at right angles to each other on the cylinder circumference, as shown in Fig. 1.