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The Prediction of Lockin Vibration on Flexible Cylinders in a Sheared Flow

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Abstract

A method is proposed for the prediction of the flow induced vibration response of flexible cylinders such as cables, pipes, and risers, in a sheared flow. The significance of material and hydrodynamic sources of damping is discussed. The reduced damping or response parameter plays a key role in response prediction. However, the dependence of the response parameter and therefore the response amplitude on the ratio of cylinder mass per unit length to the displaced fluid mass per unit length is shown to be widely misunderstood. Under lockin conditions, damping is important in determining response amplitude, but cylinder mass per unit length is not.

Introduction

Flexible cylinders, such as cables, drill pipe, and marine risers, often exhibit an harmonic flow induced vibration response known as lockin. Under uniform flow conditions, lockin has been extensively studied and empirical response prediction techniques are often adequate. However, real ocean applications often require response prediction under non-uniform (sheared) flow conditions. Very long cylinders with closely spaced natural frequencies rarely exhibit lockin behavior and frequently behave as infinite strings (1). For shorter cylinders, with well separated natural frequencies, lockin with one mode is possible, even in the presence of shear. However, in such cases, response amplitude is very difficult to predict and it is often difficult to determine which mode, if any, will dominate the response. In this paper, a method for predicting lockin in a sheared flow is proposed. The method makes extensive use of the concept of the response parameter or reduced damping, as it is sometimes called.

A very common misconception regarding the response parameter is pointed out. The response parameter is shown to be primarily a function of damping and is specifically not a function of the cylinder mass per unit length.

References and figures at end of paper.

Normal Mode Model of Lockin Vibrations

A pipe or cable under tension has, from an analytical view, an infinity of natural modes. When the cylinder is deployed with its longitudinal axis normal to an incident uniform flow, vibration is caused by the shedding of vortices in the wake of the cylinder. The vortex shedding process generates both fluctuating lift and drag forces on the cylinder. Under the correct circumstances, described extensively in the literature, (2,3) a phenomena known as lockin may occur. Lockin is characterized by the synchronization of the wake with either the cross-flow (lift direction) oscillations or with the in-line (drag direction) vibrations. This paper focuses on cross-flow lockin only, in which one cross flow mode dominates the response. At lockin in a uniform flow the lift forces are coherent over the entire length of the cylinder. A normal mode solution to the partial differential equation of motion may be obtained, and is briefly reviewed below.

Consider a beam or string under tension with fixed ends as defined in Figure 1. Let the vortex-induced cross-flow displacement be given by

$$y(x,t) = \sum_i q_i(t)\Psi_i(x) \tag{1}$$

where the $\Psi_i(x)$ are the mode shapes and the $q_i(t)$ are the modal amplitudes. Using the method of normal mode superposition, and assuming insignificant damping related intermodal coupling, a set of independent equations of motion are obtained, one for each mode. These equations are of the form:

$$M_i\ddot{q}_i + R_i\dot{q}_i + K_iq_i = N_i(t) \tag{2}$$

This equation is simply that of a linear, single degree of freedom mass-spring-dashpot system excited by a force $N_i(t)$, known as the modal exciting force for mode i. There exists one such