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Study on dynamic behavior analysis of towed line array sensor

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ABSTRACT: *A set of equations of motion is derived for vibratory motions of an underwater cable connected to a moving vehicle at one end and with drogues at the other end. From the static analysis, cable configurations are obtained for different vehicle speeds and towing pretensions are determined by fluid resistance of drogues. Also the dynamic analysis is required to predict its vibratory motion. Nonlinear fluid drag forces greatly influence the dynamic tension. In this study, a numerical analysis program was developed to find out the characteristic of cable behaviour. The motion is described in terms of space and time coordinates based on Chebyshev polynomial expansions. For the spatial integration the collocation method is employed and the Newmark method is applied for the time integration. Dynamic tensions, displacements, velocities, accelerations were predicted in the time domain while natural frequencies and transfer functions were obtained in the frequency domain.*

KEY WORDS: Underwater vehicle; Towed cable; Cable dynamics; Towed Array Sonar System (TASS).

INTRODUCTION

The cable used for marine applications includes mooring lines for ship berthing, deep sea mooring systems for floating offshore structures (Triantafyllou, et al., 1986) and tether cables for remotely operated vehicles (Grosenbaugh, 1991), etc.. Recently, underwater vehicles operate towed array sensor systems to expand detection range. This system can be regarded as a combined cable in about a thousand meters long (Hover, 1993). At this point, cable configuration and towing tension are very important for efficient operation. So, static and dynamic analyses are required to understand this system's behavior.

In this study, a nonlinear equation of motion was derived for cables (Shin, 1987). Nonlinear higher-order terms are eliminated to simplify the equations, however, important nonlinear terms such as nonlinear fluid drag and large dynamic tension were considered (Tse, et al., 1978; Shin, 1985). Numerical technique is used for the spectral analysis method which can obtain displacement, velocity and tension through time-domain analysis (Gottlieb and Orszag, 1977). Spectral analysis method is free from complicated processes such as determination of eigenmodes by using the orthogonal func-tions (Hildebrand, 1976) and can calculate the unknown variables accurately. The time-domain analysis has the advan-tages which do not need any nonlinearity equivalent replacement. It would rather use the Collocation method than the Galerkin method due to nonlinearity (Shin, 1987). Also, the Newmark's method was used for the time derivative.

GOVERNING EQUATION

Newton's second law can be written for an element with unstretched length *ds* and stretched length *dp* as

$$m_0 \frac{Dv}{Dt} ds = \sum_{i=0}^{n} \vec{F}_i dp \tag{1}$$

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where m_0 is mass per unit length in the unstretched coordinate, $\vec{v} = v_1\vec{t} + v_2\vec{n} + v_3\vec{b}$ is cable velocity, *s* is unstretched distance of a material point from the origin, $\vec{F}_i$ is external force per unit stretched length of cable and *p* is stretched distance of a same point from the origin.

The equation is rewritten as

$$m_0\left[\frac{\partial \vec{v}}{\partial t} + \vec{w}\times\vec{v}\right] = \sum_{i=0}^{n} \vec{F}_i(1+e) \tag{2}$$

Explicitly this is written as

$$m_0\left[\frac{\partial v_1}{\partial t} - v_2 w_3 + v_3 w_2\right] = \sum_{i=0}^{n} F_{ti}(1+e)$$

$$m_0\left[\frac{\partial v_2}{\partial t} - v_3 w_1 + v_1 w_3\right] = \sum_{i=0}^{n} F_{ni}(1+e) \tag{3}$$

$$m_0\left[\frac{\partial v_3}{\partial t} - v_1 w_2 + v_2 w_1\right] = \sum_{i=0}^{n} F_{bi}(1+e)$$

Eq. (3) is the equation of motion for a cable expressed in the natural coordinate system. Subscript 1 is Tangential direction, subscript 2 is Normal direction. And subscript 3 is Bi-normal direction. Compatibility relation can be derived using displacements.

$$\frac{D\vec{v}}{Ds} = \frac{\partial e}{\partial t}\vec{t} + (1+e)(\vec{w}\times\vec{t}) \tag{4}$$

where *s* is arc length coordinate. These are the compatibility relations in term of velocities. Explicitly this can be written as

$$\frac{\partial v_1}{\partial s} - v_2\Omega_3 = \frac{\partial e}{\partial t}$$

$$\frac{\partial v_2}{\partial s} - v_1\Omega_3 - v_3\Omega_1 = (1+e)w_3 \tag{5}$$

$$\frac{\partial v_3}{\partial s} + v_2\Omega_1 = -(1+e)w_2$$

Where $\mathbf{\Omega}$ is Darboux vector.

The vertical unit vector in terms of the natural vector can be expressed.

$$\vec{k} = \sin\phi\vec{t} + \cos\psi\cos\phi\vec{n} - \cos\phi\sin\psi\vec{b} \tag{6}$$