International Journal of Offshore and Polar Engineering
Vol. 3, No. 3, September 1993 (ISSN 1053-5381)

Simulating the Dynamics of Underwater Vehicles with Low-Tension Tethers

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ABSTRACT

A numerical technique for calculating the two-dimensional motions of a tethered underwater vehicle is presented. The method is unique because of its ability to simulate accurately the dynamics of cables that are under low tensions. This is accomplished by incorporating bending stiffness into the cable equations and thus removing the singularity that occurs when the cable tension becomes zero. Numerical results for several tether-vehicle maneuvers are presented.

INTRODUCTION

The use of tethered, remotely operated underwater vehicles (ROV) by the offshore industry and the oceanographic research community has increased in recent years. This has created the need for computer programs that can simulate vehicle and tether dynamics. Such programs are needed for designing the vehicles and, subsequently, for operating the vehicles in an automatic or semi-automatic mode.

In this paper, a technique is presented for simulating the two-dimensional planar motion of an ROV and its tether. The principal attraction of the method is its ability to simulate the dynamics even when the tension in the tether is nearly zero.

The term "low tension" is defined for situations in which the cable's static tension is much smaller than its dynamic tension. Under these circumstances, the basic mechanism that serves to propagate energy is dramatically altered. Transverse disturbances of taut cables are propagated at a speed proportional to the square root of the tension. When the tension is low, very little energy is transferred in this fashion. Instead, the disturbance is propagated by bending stiffness at speeds independent of the cable tension (Rao, 1986).

Previous numerical techniques for solving the equations that govern the dynamics of tethers can only be used for situations where the static tension is *large* compared to the dynamic tension (e.g. Webster, 1975; Sanders, 1982; Ablow and Schechter, 1983; Delmer et al., 1983; Bliek, 1984; Kamman and Huston, 1985). All of these algorithms become singular when the cable tension vanishes anywhere along the interior of the cable, a situation that is likely to occur in low-tension applications. For example, this would prevent the study of neutrally buoyant systems under zero initial tension.

The failure of these computer methods stems from two sources. First, the numerical approximation techniques mentioned above result in dynamical equations that are singular for zero tension. Second, in the absence of tension, the cable may form a discontinuous slope, thereby violating the compatibility relations. In reality, the bending stiffness of the cable ensures that the cable shape is smooth even when the tension is low or zero.

The algorithm developed by Howell (1992) incorporates bending stiffness into the equations of motion. By including bending stiffness, the zero tension singularity is removed. Dowling (1988) has shown using advanced analytic techniques that when the cable tension is balanced by a fluid loading term, a critical point develops. She found that in order to obtain solutions beyond the critical point, bending stiffness must be incorporated in the boundary layer near this singularity.

In this paper, Howell's (1992) algorithm for low-tension cables has been incorporated with a dynamic model of an ROV. Other researchers have developed vehicle-tether simulations (Lewis et al., 1984; Hover et al., 1991; Kalske and Happonen, 1992), but these models greatly simplified the implementation of the cable dynamics. The present simulation provides a comprehensive treatment of both vehicle and tether dynamics and, in particular, is capable of analyzing low-tension behavior.

EQUATIONS OF MOTION

The equations of motion of the tether and the vehicle are derived in the vertical plane. The equations include terms that represent gravitational forces, but these can be set equal to zero to simulate motion in a horizontal plane.

The first step in the derivation is to set up separate body-fixed coordinate systems, one corresponding to the tether and one corresponding to the vehicle (Fig. 1). For the tether, a tangential unit vector $\hat{t}$ directed along the axis of the cable and a normal unit vector $\hat{n}$ directed perpendicular to $\hat{t}$ are defined. The orientation of $\hat{t}$ and $\hat{n}$ varies along the tether's length.

For the vehicle, it is assumed that it is a rigid body and that the origin of its coordinate system is at the center of gravity. The x-axis of the coordinate system defines the direction of the vehicle's *surge* motion and the y-axis defines the direction of the vehicle's *heave* motion.

The vehicle operates in a spatially uniform current of magni-

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Received January 9, 1993: revised manuscript received by the editors June 21, 1993. The original version (prior to the final revised manuscript) was submitted directly to the editors.
KEY WORDS: Low-tension cable, underwater vehicle, dynamics.