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Formulation and Validation of a Lumped Mass Model for Low-Tension ROV Tethers

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ABSTRACT

This paper presents the development and validation of a mathematical model and computer simulation of an ROV tether operating in low-tension situations. The model uses a lumped mass approach in which the ROV tether is considered to be a system of point masses connected by viscoelastic springs. Although this formulation is stable when the tension in the tether disappears, it is necessary to include bending effects in order to generate realistic results for low-tension manoeuvres. Assuming that all sections of the tether have negligible rotational inertia, we demonstrate that the curvature at any point in the tether can be related to internal bending forces. This continuous relationship is discretized using the Galerkin method of weighted residuals, to allow calculation of the bending forces at the node points. The mathematical model was implemented in C/C++ and was used to model several tether manoeuvres, producing good agreement with the expected tether behaviour. Experiments performed in a controlled aquatic environment with a section of tether have produced video footage of submerged tether motion. Comparison of the experimental and simulated results showed good agreement between the real and simulated tether motions.

INTRODUCTION

The ability of an underwater, remotely operated vehicle (ROV) to move equally well in longitudinal and lateral directions makes it a proficient tool in a wide variety of underwater tasks. The tether which supplies power and telemetry to the ROV is designed such that the forces it exerts on the ROV during operation are minimal. To this end, the tether is generally neutrally buoyant and quite flexible in comparison to armoured towing cables. Such tether design, and the omnidirectional capability of ROVs, leads to slack, or low-tension, sections of tether developing during operation. However, it has been documented that the hydrodynamic and gravitational forces acting over the tether do create, in many circumstances, internal forces within the tether that significantly disturb the motion of the ROV (McLain and Rock, 1992). Thus, to accurately simulate the motion of an ROV, an ROV simulation must accurately model the tether dynamics, including a capability to realistically simulate slack tether. By accurately modelling these low-tension instances, the subsequent onset of high-tension situations, and the resulting ROV motion, will be accurately modelled.

Ablow and Schechter (1983) presented a numerical model of an underwater cable that uses a finite difference method to discretize the motion of a marine cable in space and time. The technique is implicit in that it solves for the tensions, positions and orientations of the tether segments simultaneously, using Newton's method. A consequence of the model development is that the solution scheme is subject to a singularity when the tension in the tether goes to zero. Grosenbaugh et al. (1993) suggested this is due to a violation of the compatibility relations which are a foundation of this algorithm. To eliminate this problem, Burgess (1992) introduced 3 additional rotational equations of motion, and defined additional internal forces generated by the cable curvature. Howell (1992) and Burgess (1993) showed that, by assuming negligible rotational inertia for the tether, these additional forces could be included in the translational equations, thus simplifying a low-tension cable model. In this manner, the finite difference scheme could be extended to model the 2-dimensional motion of an ROV tether in slack instances (Grosenbaugh et al., 1993).

An alternative to finite difference methods, the finite element approach defines the governing equations of motion over an element, or segment, of the tether. Applying a technique, such as a method of weighted residuals, these element equations are discretized, producing a linear system of coupled ordinary differential equations that govern the motion of the elements. Driscoll et al. (2000) presented a 1-dimensional model of a marine cable composed of linear viscoelastic elements based on this approach. A simple and effective tether model, consistent with the linear finite element approach, is the lumped-mass tether model that was first presented by Walton and Polacheck (1960) and, recently, by Huang (1994). This model introduces the spatial discretization in the initial formulation of the governing motion equations by considering the tether to be a series of point masses, or nodes, connected by linear, massless, viscoelastic elements. As shown by Huang (1994), the lumped-mass model reduces to a continuous tether in the case of infinitesimal element size.

To account for the elasticity of the tether, the tension within an element at any time step is calculated directly from the position of the element nodes using a constitutive relationship. As the element tensions are calculated explicitly, the onset of zero tension does not affect the stability of the lumped-mass method. However, the model results are highly unrealistic in slack or low-tension situations, and thus a motivation for the inclusion of bending effects in lumped-mass type models also exists. This paper extends a 3-dimensional lumped-mass cable model, previously developed for the modelling of towed marine vehicles (Buckham et al., 1999), to modelling of a slack ROV tether.

To validate the performance of the slack tether model, data are needed that allow for a direct comparison between the motions and internal forces of real and simulated tethers undergoing a slack

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