International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 15, No. 1, March 2005, pp. 40–45

Wave Energy Absorption by a Submerged Sphere of Variable Radius with a Swinging Single Point Moored Tension Line

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This paper follows the work of Sarmento and Cruz (2003) where the absorption of energy by a submerged pulsating sphere fixed at a generic surface position was optimized considering sway, surge and heave. It concerns the same sphere now connected to the seabed by a tension line (single point moored) that oscillates with respect to the vertical direction in the plane of wave propagation. Linear theory is applied throughout the paper. The hydrodynamic coefficients presented in Linton (1991) and Lopes and Sarmento (2002) for a submerged sphere are used. The equations of motion are presented for several directions, and the results include, as in Sarmento and Cruz (2003), the influence of the sphere's radius and mass on the capture width, external damping, external spring constant and amplitude of oscillation as a function of the wave number.

INTRODUCTION

The scientific world has seen in recent times a growing interest in the renewable energy issue. The need to find a solution to the energy problem that is friendly to the environment is now a given fact, which can be enhanced with the legal obligations provided by agreements such as the Kyoto Protocol. It is only natural then that the largest natural resource of all, the sea, emerges in this scope. Since Salter (1974), the development of ideas and devices to extract energy from ocean waves has not been continuous, but presently some prototypes have evolved into an advanced stage. As examples of this renewed interest in wave energy we have the OPD Pelamis (Yemm et al., 2003), the Wave Dragon (Sorensen et al., 2003) and the AWS (Rademakers et al., 1998). The model studied in this paper can be described as a variable volume submerged sphere with a single fixed point where a tension line connects it to the seabed. This tension line oscillates due to the incident wave.

From the hydrodynamic point of view, the change of volume and the motion in 2 perpendicular axes of the sphere's center of gravity (surge and heave; sway is not considered in this paper) cannot be considered separately. These motions are intrinsically connected to another: The swinging motion of the tension line (assumed to be rigid), caused by the incident wave.

The sphere is hollow and filled with air and can be considered a pressurized membrane whose radius and volume depend on the external pressure. Hence, and as a consequence of the resulting external hydrodynamic pressure change due to the incident wave, the sphere changes its volume as well as its radius: In the wave crest, the excess of external pressure causes the sphere to shrink, opposite to what occurs in a through wave. In still water, the internal air pressure plus the elastic force due to the sphere's shell balance the radial force due to the external pressure.

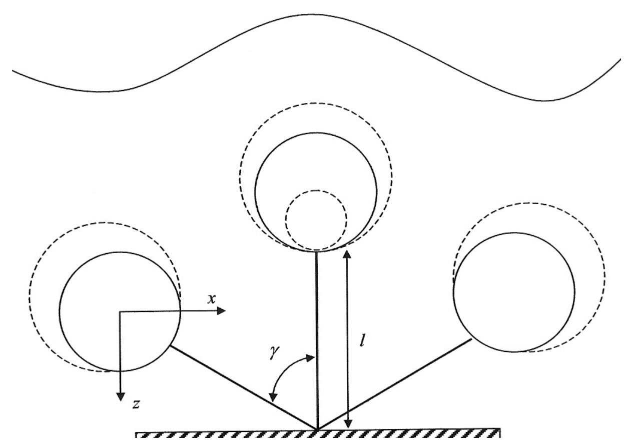

Fig. 1 Schematics of system under study

This relative motion between the surface of the sphere and its center is the basic physical phenomenon that allows the absorption of energy by, for instance, a system of dampers that connects the sphere's center to its surface. The purpose of this paper is to show the influence of some parameters on the efficiency of the sphere as a wave energy absorber, considering especially the influence of small angular displacements around the vertical position (angle γ).

The analysis is based on the linear theory of surface waves. Hence viscous effects such as shear stresses and flow separation are not considered. The equations of motion (dynamic equations) are deduced for the radial, surge and heave directions. The radiation and diffraction problems are solved following Linton (1991) and Luís et al. (1998). The wave energy absorption analysis follows the work of Evans (1976). The paper extends the work presented in Sarmento et al. (1998) and Luís et al. (1998), and it follows the work of Sarmento and Cruz (2003).

MATHEMATICAL ANALYSIS

Cartesian coordinates (x, y, z) are used with $z = 0$ at the undisturbed free surface and z increasing with depth. A spherical coordinate system (r, θ, α) is also used with its origin placed at the

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Received April 12, 2004; revised manuscript received by the editors October 22, 2004. The original version (prior to the final revised manuscript) was presented at the 14th International Offshore and Polar Engineering Conference (ISOPE-2004), Toulon, France, May 23–28, 2004.
KEY WORDS: Linear theory, pulsating sphere, submerged sphere, swinging moored tension line, wave energy absorption, frequency domain.