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Self-Adaptive Control of a Piston Wave Absorber

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ABSTRACT

The paper presents recent progress in the control of active wave absorbers. A simple theoretical model of an ideal piston wave absorber is derived in the framework of 2D linearized potential theory. Due to a lack of causality, this optimal device cannot be physically realized in the time-domain, but sub-optimal realizable approximations were derived. Because they work better when the incident wave frequency is known, a self-adaptive *tuner* is developed. It is based on a frequency tracking extended Kalman filter algorithm. The absorption properties of such a self-tuning system are shown to equal those of sub-optimal frequency adapted systems.

KEYWORDS

gravity waves, wave absorption, adaptive control, causality, perfect fluid, free surface.

INTRODUCTION

The principle of active absorption of free-surface waves lies in the generation of waves in counterphase with regard to the waves they are intended to cancel (Milgram 1970). Thus, an active wave absorber, also referred to as : dynamic wave absorber, is nothing but a wave generator driven in close reaction to the incident wave. The problem to be solved is to determine the reaction law giving the best absorption coefficient whatever the incident waves may be.

In the present study, the wave absorber consists in a simple piston at the end of a two-dimensional wave tank. The single degree of freedom of the device is the horizontal translation, but the method could be extended straightforwardly to hinged paddle wave absorbers. Systems with more than one degree of freedom were investigated in our first studies (Clément and Chapuis 1985), but we concluded at that time that the associated mechanical constraints were not sufficiently balanced by the gain in hydrodynamic (absorption) efficiency.

The theoretical modelling of the piston wave-absorber is based on free-surface potential flow theory. A perfect absorption may easily be achieved in the linear frequency domain approach by determining the piston motion from either the hydrodynamic force signal or the water wave elevation (Skourup 1996). In both cases, it is well known (Naito & Nakamura 1985, Perdigao & Sarmento 1989-1993, Clément & Maisondieu 1993, Falnes 1995) that the transposition of this ideal transfer function to the time-domain leads to an anti-causal relation between the controller input and output. In a previous study (Clément & Maisondieu 1993), it was shown how a realizable sub-optimal control may be deduced from this non-realizable optimal solution. This control includes a feed-forward loop which may be tuned to the incident wave frequency in order to increase absorption performance.

In the present study this tuning of the feed-forward loop is automatically achieved by an on-line estimation of a pseudo-frequency by means of an extended Kalman filter. Unlike usual algorithms, this bounded error estimator (Gouraud et al. 1995) can easily take into account time variation in the process parameters (frequency and amplitude). This new self-adaptive feature of the controller allows the system, working blindly in time-domain, to reach an absorption level very close to the performances it had when it was manually tuned to the known incident wave frequency. This promising technique will be applied not only to wave absorbers for laboratory basins, but also to optimize the performances of wave energy devices.

THE OPTIMAL CONTROLLER

Let us first consider the problem in the frequency domain. The usual assumptions of potential flow theory are made, and the problem is restricted to two dimensions; the space variables will be non-dimensionalized with respect to the water depth h, the time variable with respect to $(h/g)^{1/2}$.

An incident leftgoing wave (→ velocity potential Φ_I) is totally reflected by the vertical end wall ($X = 0$) of a semi-infinite basin (→ velocity potential Φ_D). On the other hand, the piston motion

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