ENE 302 – Energy Conversion Processes II

WEEK 10: TIDAL ENERGY

INTRODUCTION

Oceans and seas contain a vast quantity of mechanical energy in form of surface waves and tides. The high density of oscillating water results in high energy densities, making it a favorable form of hydro power. Ocean and sea wave energy is a concentrated form of solar energy [1]. The sun produces temperature differences across the earth, causing winds that blow over the ocean or sea surface. These cause ripples, which grow into swells. Such waves can then travel thousands of miles with no loss of energy. The power density is much higher than for wind or solar power. These deep-water waves should not be confused with the waves that are seen breaking on the beach. When a wave reaches shallow water (roughly when the water depth is less than half a wavelength), it slows down, its wavelength decreases and it grows in height, which leads to breaking. A wave carries both kinetic and gravitational potential energy. The total energy of a wave depends roughly on two factors: its height, H and its period, T. The power carried by the wave is proportional to H^2 and to T, and is usually given in Watt per metre of incident wave front. In view of yearlong ocean wave condition, it's known from the research on this subject that ocean wave provide a mean power density of 1 kW/m^2 [2]. Yoshio Masuda may be regarded as the father of modern wave energy technology, with studies in Japan since the 1940s. He developed a navigation buoy powered by wave energy, equipped with an air turbine, which was in fact what was later named as a (floating) oscillating water column (OWC). These buoys were commercialized in Japan since 1965 (and later in USA) [3]. Later, in Japan, Masuda promoted the construction, in 1976, of a much larger device: a barge (80 m - 12 m), named Kaimei, used as a floating testing platform housing several OWCs equipped with different types of air turbines [4].

About converting wave energy into usable energy, more than one thousand patents had been registered by 1980 [5] and the number has increased markedly since then. The earliest such patent was filed in France in 1799 by Girard [6].

There is a wide variety of wave energy technologies, resulting from the different ways in which energy can be absorbed from the waves, and also depending on the water depth and on the location (shoreline, near-shore, offshore) [7]. Several methods have been proposed to classify wave energy systems, according to location, to working principle and to size (‘‘point absorbers’’ versus ‘‘large’’ absorbers) [1] and vertical or horizontal type Savonius hydraulic turbines are among the ones which propose a simple solution for harnessing energy from the ocean waves under low wind speeds [8] through a hydrodynamic rather than aerodynamic mechanism [9]. Savonius rotors are simple, semi-circular in shape with a combination of blades that rotate on the differential drag created by moving fluid across the rotor and usually inexpensive to construct [10].

THEORY

- ***Wave Modeling Theory***

The mathematical equations for describing of linear wave theory are outlined and are extended to derive Stokes 2nd Order theory. Later, this derived equation is used to define and calculate a marine energy converter.

- Real waves propagate in a viscous fluid over an irregular seabed of varying permeability [11]. Viscous effects are usually concentrated in a thin “boundary layer” near the surface and the seabed and the main body of fluid motion is nearly irrotational. As water can also be considered to be effectively incompressible, a velocity potential and a stream function should exist for waves.

- To illustrate some of the theoretical considerations it is convenient to initially discuss a simplified small amplitude water wave problem with the following assumptions:

i) Flow is incompressible and inviscid

ii) Flow is irrotational

iii) Uniform density

iv) Waves are two-dimensional

v) Monochromatic waves

- **Small amplitude theory**: the small amplitude theory can be developed by the introduction of a velocity potential, $\varphi(x,z,t)$.

  Horizontal and vertical particle velocities are defined in the fluid as $u=\frac{d\varphi}{dx}$ and $w=\frac{d\varphi}{dz}$. By combining the velocity potential, Laplace's equation, Bernoulli's equation and appropriate boundary conditions, the small amplitude formulas can be developed due to Dean and Dalrymple (1966). The elevation of wave surface is then given by:

$$\eta(x,t)=\frac{H}{2}Cos\left(\frac{2\pi x}{L}-\frac{2\pi t}{T}\right) \qquad (1.1)$$

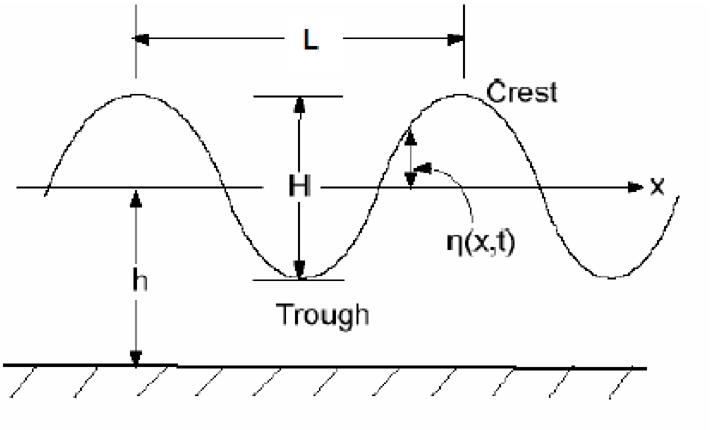

Figure 1. Sinusoidal wave

Eqn. 1 can be rewritten as follows:

$$\eta(x,t)=ACos(kx-\omega t) \qquad (1.2)$$

where *k* is referred to as wave number, ω is the angular frequency (s^{-1}), $t$is the time (s). The wave number can be given as $k\frac{2\pi}{L}$.

The dispersion relationship relates the wavelength to frequency as follows:

$$\omega^2=gk\tanh kh \qquad (1.3)$$

Using the known form of the free surface and velocity potential, expressions for horizontal, $u(x,z,t)$ and vertical $w(x,z,t)$ velocities can be given by the following equations:

$$u(x,z,t)=\frac{\partial\varphi}{\partial x}=\frac{gAk}{\omega}\frac{Cosh k(z+h)}{Cosh\, kh}Cos(kx-\omega t) \qquad (1.4)$$

$$w(x,z,t)=\frac{\partial\varphi}{\partial z}=\frac{gAk}{\omega}\frac{Sinh k(z+h)}{Cosh\, kh}Sin(kx-\omega t) \qquad (1.5)$$

- **Stokes 2nd Order waves:**

  During derivation of linear wave theory, small quantities such as the higher order expansion values within the Taylor expansion of the free surface elevation are neglected to simplify the calculations. Stokes 2nd theory is a well-known variation to Linear theory and includes an additional “higher order” component in the formulation:

$$\eta=\frac{H}{2}\cos(kx-\omega t)+\frac{H^2k}{16}\frac{\cosh(kh)}{\sinh^3(kh)}(2+Cosh\,2kh)\cos 2(kx-\omega t) \qquad (1.6)$$

where η is the surface profile. The velocity components in the x-direction and z-direction can be represented by the following formulas:

$$u=\frac{H}{2}\frac{gk}{\omega}\frac{\cosh k(h+z)}{\cosh kh}\cos(kx-\omega t)+\frac{3H^2\omega k}{16}\frac{\cosh 2k(h+z)}{\sinh^4(kh)}\cos 2(kx-\omega t) \qquad (1.7)$$

$$w=\frac{H}{2}\frac{gk}{\omega}\frac{\sinh k(h+z)}{\cosh kh}\sin(kx-\omega t)+\frac{3H^2\omega k}{16}\frac{\sinh 2k(h+z)}{\sinh^4(kh)}\sin 2(kx-\omega t) \qquad (1.8)$$

Where H is the wave height, ω is the wave frequency, k is the wave number, and h is the mean wave depth.

PROBLEM SETS

Problem 1: Define hydrodynamic poser of an Oscillating water column (OWC).

Solution 1: Assume that the inner surface of the OWC behaves as a piston the hydrodynamic power, P_{hyd} absorbed by the PWC can be computed from the simple formulation power:

$$Power = Force.\frac{Displacement}{Time} \quad \text{(w)}$$

Re-arranging this formulation and substituting *Force = Pressure x Area* and assuming that the hydrodynamic power is transferred to the air column, this can be written as:

$$P_{hyd} = \mathrm{Pr}essure.Area.\frac{dS}{dt} \quad \text{(W)}$$

That is for the OWC wave energy converter:

Pressure: The pressure inside the chamber (Pa)

Area: surface area of the water surface inside the chamber (m^2/m width)

$\frac{dS}{dt}$: differentiated position of the water surface inside the chamber or velocity of the OWC piston (m/s)

Thereby, given knowledge of the pressure developed inside the cahmber and the surface oscillation inside the chamber, the hydrodynamic power transmitted to the OWC can be determined.

References:

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