Förnyelsebar elproduktion och eltransporter (DAT460)

Wave Energy Assignment

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Submission deadline: TBD

1. Introduction

Through this assignment, students are expected to learn how to estimate wave energy potential and to understand the working principles of a buoy wave energy conversion device.

2. Wave power theory

The time average wave power per unit of wave crest length is given by:

$$P_{wave} = \frac{1}{32\pi} \rho g^2 T H^2 \tag{1}$$

where

P_{wave} is the time averaged wave power per unit of wave crest length [W/m]
ρ is the sea water density $[kg/m^3]$
g is the gravitational acceleration $[m/s^2]$
T is the wave period $[s]$
H is the wave height $[m]$ (from crest to trough, i.e. twice of the wave amplitude)

Task 1: A community living in an isolated island has electricity demands of 80 MWh per year. Now the electricity is supplied from a diesel generator. They want to reduce the diesel fuel consumption by 50% by installing a wave energy converter unit. Wave data and plant parameters have been given as follows:

Wave height:	1.75 meters
Wave period:	5.25 seconds
Wave plant type:	buoy-type
Mechanical conversion efficiency:	30%
Electrical generator efficiency:	90%
Wave plant availability:	80%

Calculate power rating of the wave energy plant in order to fullfil the demand.

Calculate rough estimation for the width of the wave converter.

3. Buoy wave energy conversion

A buoy is a floating mass that moves vertically following sea waves. The sea wave can be modelled as sinusoidal wave. The buoy is connected to a linear generator located in the bottom of the sea using a stiff rope. The physical structure of a buoy wave energy converter is shown in Figure 1.

In the following tasks, equations describing dynamic behaviours of a buoy wave converter will be given. You will not need to use these equations to do calculation, but you'll need to understand the meanings of different force and their relationship.

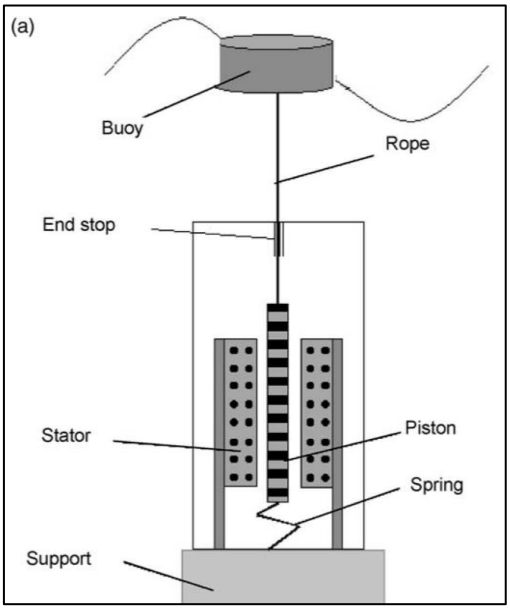

Figure 1: Buoy wave energy converter (Ivanova, 2005)

Note that the rope is modelled as a stiff mass-less piston in this exercise. Therefore, only the forces acting on the buoy are considered (Figure 2).

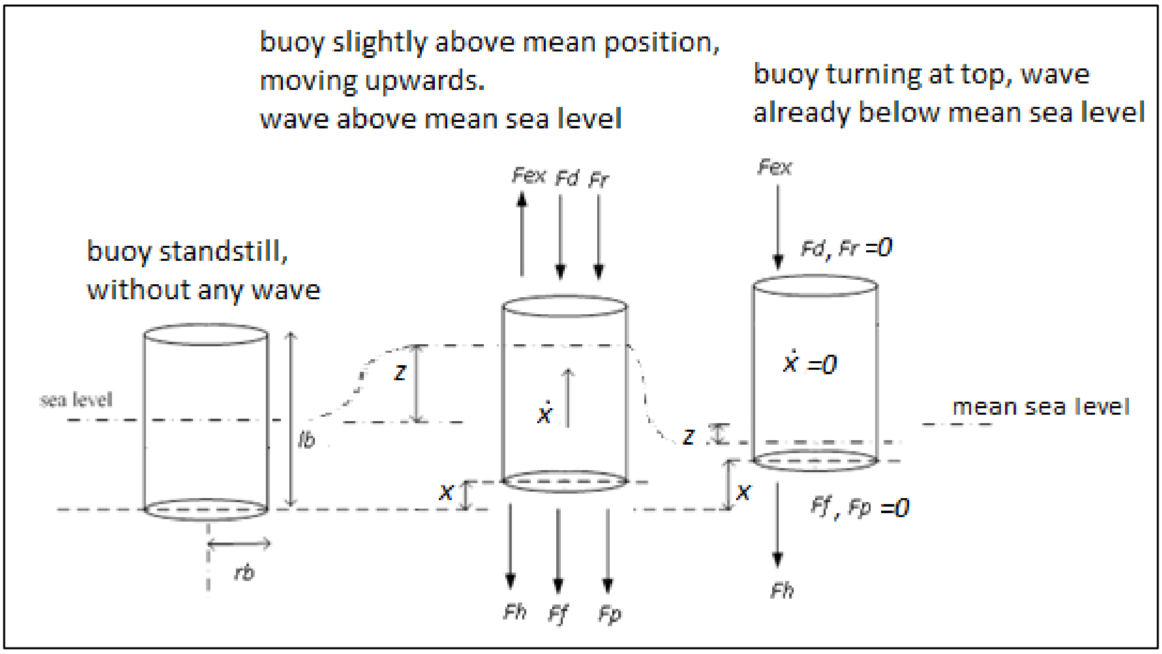

Figure 2: Schematic of buoy geometry. Mean floating position without any wave (left). Forces acting on the buoy, in two different instants of the oscillation cycle (middle and right).

Figure 2 illustrates different forces involved in the buoy motion equation. $\boldsymbol{F_{ex}}$ is the **excitation force**, which is the force caused by the incoming waves. This force will strive to lift the buoy when the wave level, z, rises (i.e. make the buoy follow the wave). $\boldsymbol{F_h}$ is the **hydrostatic force**, which will strive to return the buoy to the static equilibrium position. The combination of the excitation force and the hydrostatic force make up the net buoyancy force, or Archimedes force. The remaining forces, $\boldsymbol{F_d}$ **(drag force),** $\boldsymbol{F_r}$ **(radiation force),** $\boldsymbol{F_f}$ **(mechanic friction force) and** $\boldsymbol{F_p}$ **(force due to generator power extraction)** are all damping forces. The damping forces strive to slow down the motion of the buoy, and are therefore always in opposite direction to the buoy velocity.

The **motion equation** is given as follows

$$F_{total} = F_{ex} + F_h + F_r + F_p + F_f + F_d = m_{total} \frac{d^2x}{dt^2} \tag{2}$$

where

m_{total} is the total moving mass [kg].

x is the buoy displacement from equilibrium position [m].

F_r is the radiation force [N].

F_d is the drag force [N].

F_{ex} is the excitation force on the buoy, due to the wave elevation [N].

F_h is the hydrostatic force [N].

F_p is the power extraction force due to the electric generator [N].

F_f is the mechanical friction force [N].

The **electric power** is calculated using

$$P_e = F_p \frac{dx}{dt} \tag{3}$$

The expression of the **excitation force** and the **radiation force** are:

$$F_{ex} = c_{ex}(\omega) e^{j\theta_{ex}(\omega)} z \tag{4}$$

$$F_r = -R_r(\omega) \frac{dx}{dt} \tag{5}$$

where

x is the buoy displacement from equilibrium position [m].

z is the wave elevation [m].

c_{ex}, θ_{ex} are excitation force coefficients (frequency dependent) [N/m, rad].

R_r is the radiation damping coefficient (frequency dependent) [Ns/m].

In the case of the **hydrostatic force**, it is calculated as:

$$F_h = -k_h x \tag{6}$$

where

k_h is the hydrostatic stiffness [N/m].

For a cylindrical buoy shape, the hydrostatic stiffness is given as:

$$k_h = \rho g \pi r_b^2 \tag{7}$$

Where

r_b is the buoy body radius.

The **power extraction force** due to the electric generator is calculated as:

$$F_p = -R_p \frac{dx}{dt} \tag{8}$$

where

R_p is the electromagnetic constant.

The **mechanical friction force** is calculated as:

$$F_f = -R_f \frac{dx}{dt} \tag{9}$$

where

R_f is the friction constant.

Task 2: In this task, the wave specifications in task 1 are used, and the buoy wave energy converter has the following specifications:

ρ = 1025 [kg/m^3]	r_b = 2 [m]
g = 9.81 [m/s^2]	l_b = 10 [m]
R_f = 0	R_p = 50212

Simulation has already been done, and result curves have been shown below.

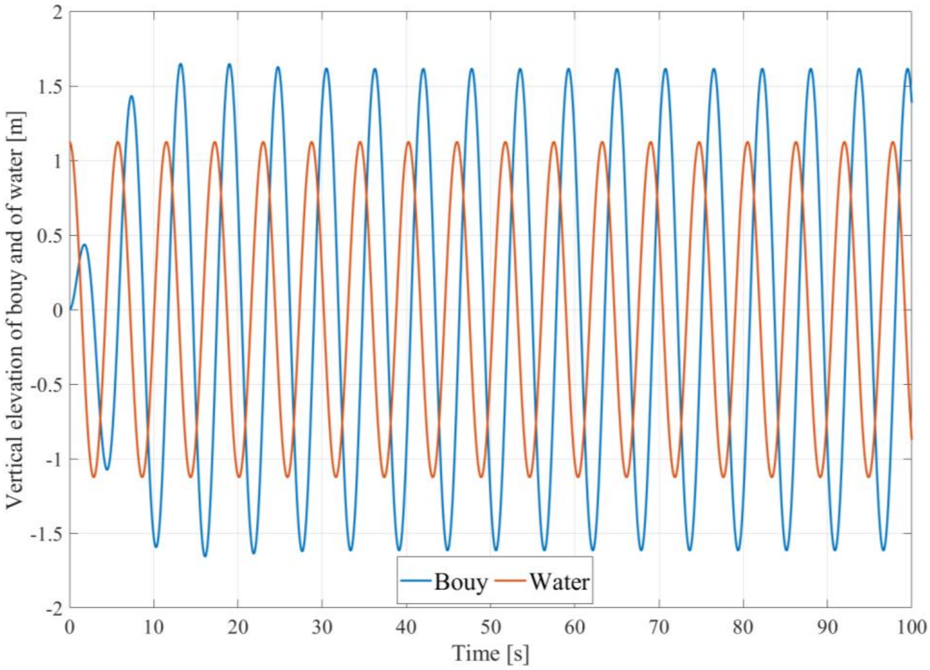

Figure 3: Simulation results, sea surface and buoy position

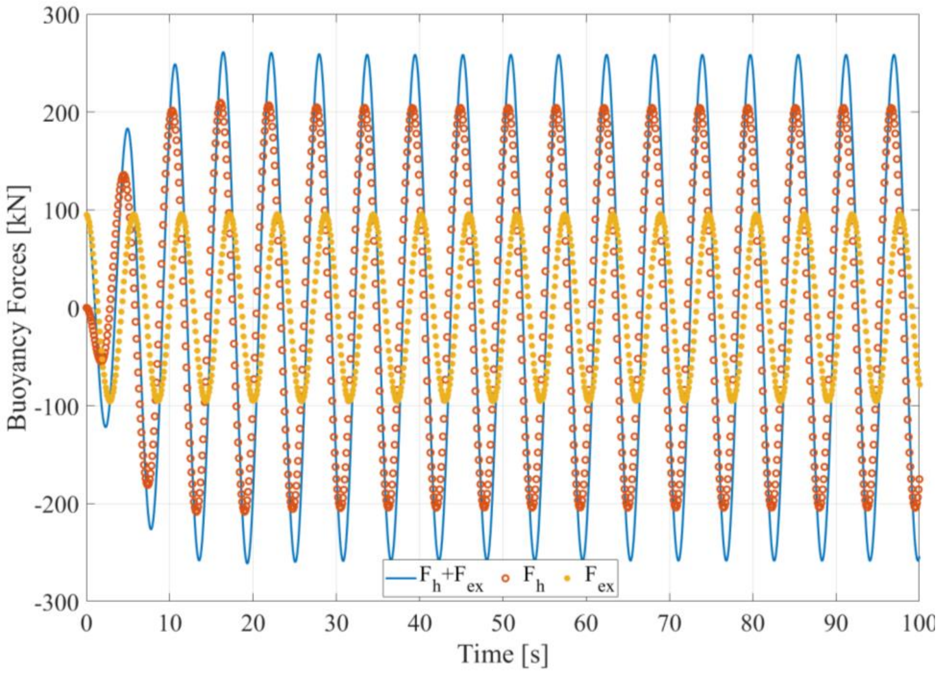

Figure 4: Simulation results, excitation forces and hydrostatic forces

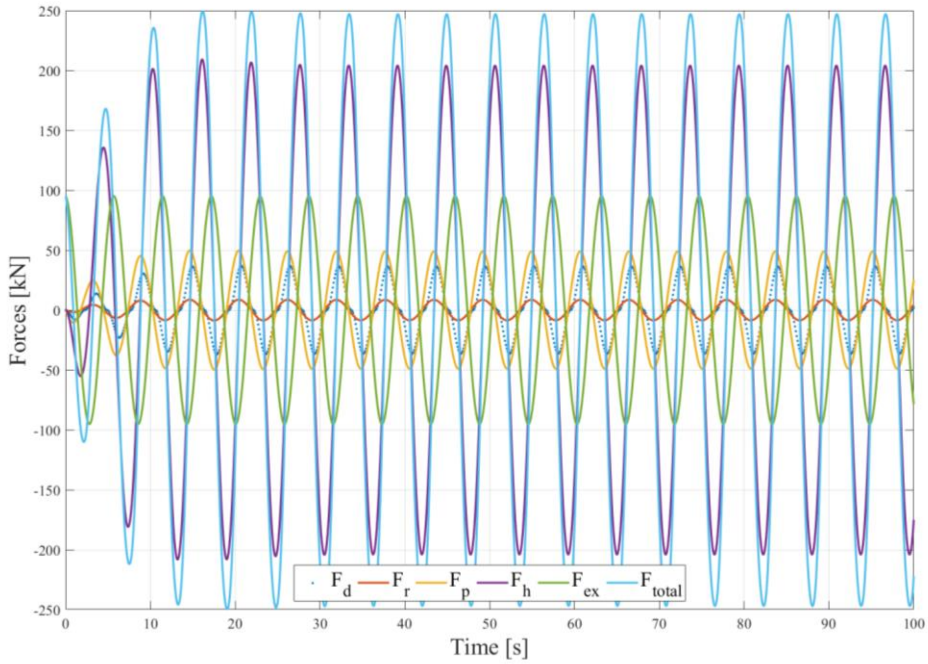

Figure 5: Simulation results, all forces acting on the buoy

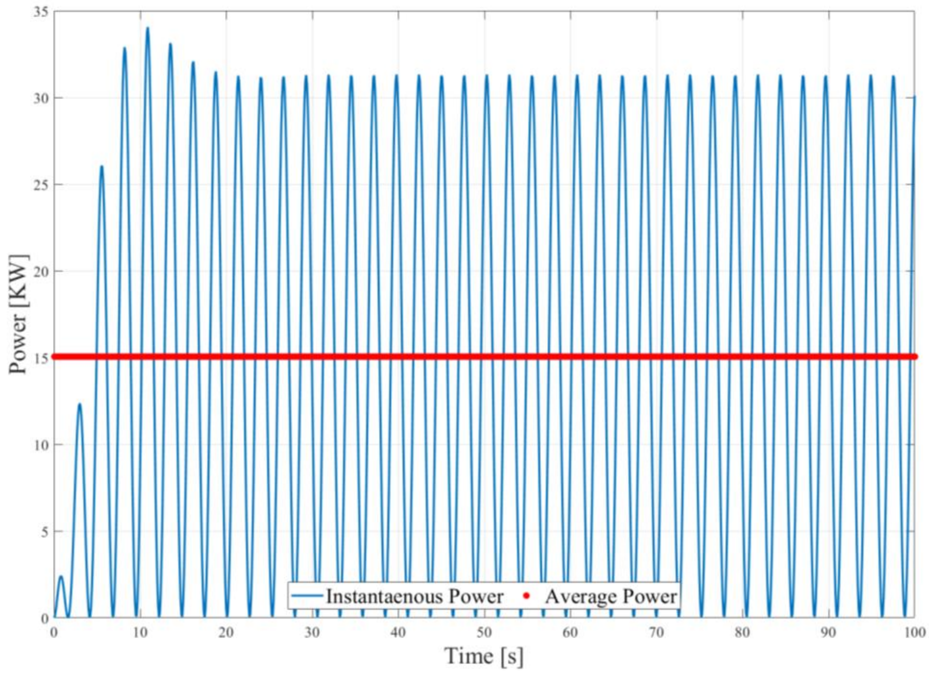

Figure 6: Simulation results, instantaneous and average electrical power

After observing the above four plots, answer the following questions:

- When the buoy is above the equilibrium position, which direction is the hydrostatic force (F_h)?
- When the buoy is moving up, which direction are the radiation force (F_r) and mechanical friction force (F_f)?
- When the buoy is moving down, which direction is the power extraction force (F_p)?
- What is the maximum and average electric power of this buoy wave energy converter?