

Modelling of submerged oscillating water columns with mass transfer for wave energy extraction

In the past decades, the global demand for energy has increased. The aim to reduce has led to an increase in the production of renewable energy sources, such as wind and solar energy. However, there are more major energy resources available in the oceans, such as wave and tidal power. The estimated potential global energy resource in waves is around 2 Terra Watt. Over the years, many different technologies have been developed to harvest this high-density energy source. Yet, the harsh weather conditions are challenging the survival of the energy converters.

A potential device that avoids the risk of high environmental impacts and has a reduced vulnerability is the Neptune: The Neptune is a fully submerged wave energy converter. Inside the structure, a weir and internal air pocket separate two water columns. One column acts as an oscillating water column to pressures of the incident waves. During its oscillations, the inner free surface level exceeds the weir and spills water into the second column. This column acts as a reservoir, and the overflow water is drawn off through an exit pipe, including a turbine. From the net flow through the columns, energy can be extracted. This design has the advantage of being fully submerged and has a single moving part, namely the turbine.

The objective of this thesis is to form a more scientific base concerning this device. A numerical model is made to predict the dynamic behaviour of the system. The equations of motion of the water columns are derived from the equations of conservation of mass and momentum. The excitation forces are obtained from the linear wave theory for regular undisturbed waves. The hydrodynamic coefficients are determined from associated literature. The dynamics of the internal air pressure is derived from the conservation of mass and the pressure density relation for an adiabatic and reversible thermodynamic process. The pressure oscillation of the air chamber is coupled to the flow of the columns. The mass transfer between the columns is assumed instantaneous and modelled for the different conditions of the free surface displacement with respect to the weir level. The weir discharge is included in the expressions for the convective acceleration and momentum associated with the change of mass in the columns. An impact pressure is derived for the falling water from the weir on the column. The response of the turbine was modelled assuming a linear relationship between the flow through the turbine and the regression relation of stationary hydraulic turbines.

Using the developed model, the time series of the response is obtained by solving the non-linear differential equations in the Matlab ODE45 solver. The model is solved for a full-scale structure with a natural period of 8.5 seconds. The results are found for different periods of regular incident waves and various weir levels. From the results, an increase of resonance periods was identified, caused by the transfer of potential energy from the resonating column to the other column. Due to the weir discharge, a uni-directional flow is obtained in the second column. The uni-directional flow is desired for the extraction of energy.

Furthermore, an increase in the mean displacement in the first column is found, caused by the damping in the second column. The increased damping, from pressure losses or the turbine, resulted in a decrease of weir discharge. An optimal turbine diameter was found to be dependent on the relation between the dynamic flow and the damping induced by the turbine. This relation also results in a maximum power take-off efficiency of 7 to 12% depending on the weir level and the incident wave height. These are low efficiencies compared to other wave energy converters. It is likely caused by the inefficient energy transfer between the columns. Further research and optimizations are required to assess the feasibility of this wave energy converter.

