# Laboratory Tests Of A Submerged Wave Energy Device

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# Content

# 1.0 Introduction

## 1.1 Project Background

Energy is the most important resource for human survival and development. With the continuous progress of society, energy consumption increasing has become a very serious problem. It is estimated that global energy consumption in 2040 will be 30 percent higher than that in 2010, 40 percent of which is electricity generation (Lópeza et. al., 2013). At the same time, the exploration and utilization of energy has also been widely paid attention to. Figure 1-1 (World Energy Council, 2013) shows the contents of different kinds of energy resource supplying in 1993, 2011 and the estimated value in 2020.

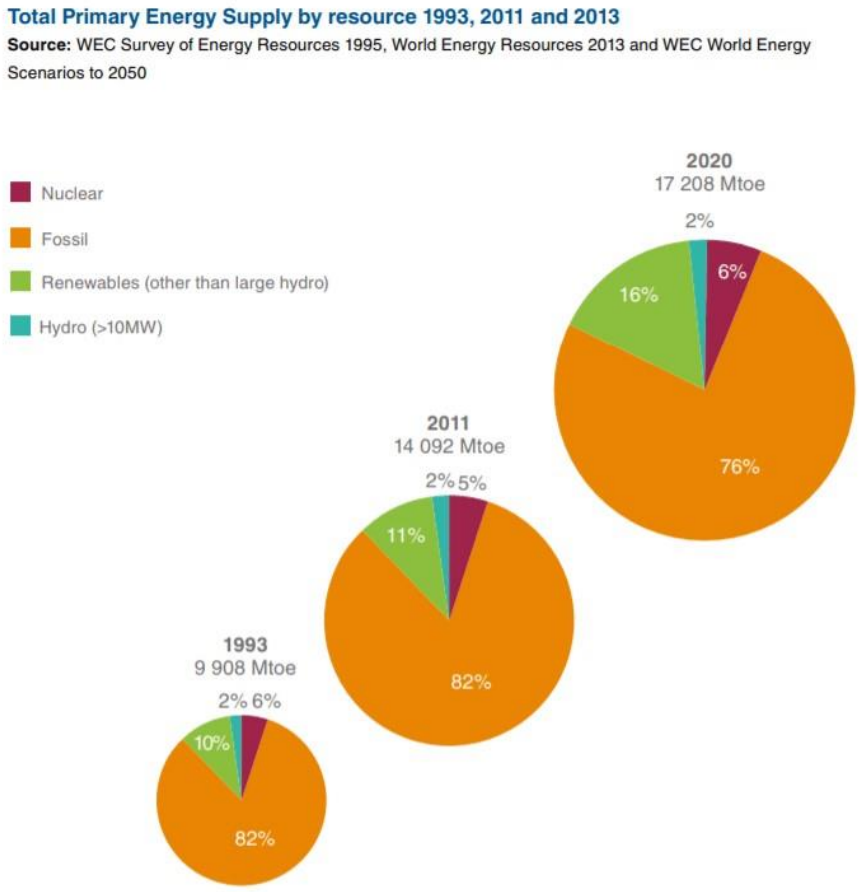


Figure1.1 World Energy Demand in Different Periods (1993, 2011. 2020) (World Energy Council, 2013)

As can be seen from the pie charts, fossil fuels are a major part of global energy consumption. There is also another figure 1-2 (Vernon, 2006) showing the mean production of indigenous primary fuels.

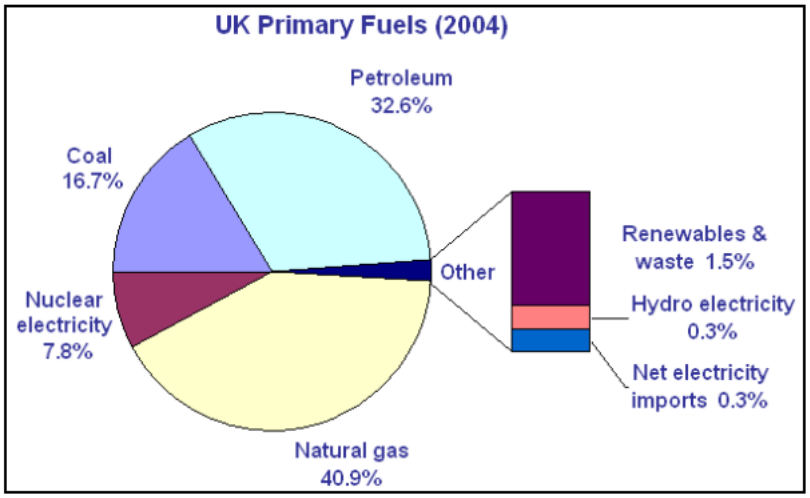


Figure 1.2 Production of indigenous primary fuels of UK in 2004 (Vernon, 2006)

Fossil energy not only brings civilization to mankind but also brings a lot of contradictions and problems. With the development of the society, the contradiction between the limited nature of fossil fuels and the infinite nature of human energy consumption is growing obviously. How long it will last for using fossil energy is still unknown. Although there is no conclusion, with this situation continuing, there will be energy shortages in the near future.

Over the past decade or so, environmental pollution and destruction have gradually attracted worldwide attention. Environmental issues hidden behind the economic development of energy consumption have become increasingly prominent, directly or indirectly affecting the scale and speed of economic development. Environmental pollution and destruction are particularly prominent in developing countries. The initial stage of economic development mainly depends on a large amount of energy input, and the low-tech basic industries are usually combines not only high energy consumption but also low efficiency and low output, which also have little spare capacity to effectively control the pollution problems. However, the limited environmental capacity and self-limiting makes it limit the capacity of pollutants within a certain range, meanwhile, most

environmental pollution and destruction are irreversible. Specifically, environmental pollution is mainly due to the combustion of fossil fuels which releases carbon dioxide, sulfur dioxide and nitrogen oxides, also including the pollution caused by mining and transportation. In 2015, the British magazine Nature published a heavy theme of climate change. From its calculations, Nature's article found that by 2015, the world was expected to emit 35.7 billion tons of carbon dioxide. Extensively using coal as energy source, China, for example, in 2014, sulfur dioxide and soot emissions causing by coal-fired accounted for 90% and 70% of the total national emissions (Zheng, et. al., 2012). The heavy emission of all those acid gas makes the acid rain problem worse over time.

Under the grim situation of the above problems, the demand for the development and utilization of new energy is increasing daily. New energy sources include a variety of renewable energies and nuclear energy (IRENA, 2014). Compared with traditional energy sources, new energy sources generally have the characteristics of less pollution and large reserves, which are of great significance for solving the serious environmental pollution problems and depletion of resources (especially fossil fuels) in the world today.

## 1.2 Renewable Energy

Renewable energy is relatively conventional energy terms, referring to the energy that can be continuously regenerated and used continuously in nature, and has inexhaustible features such as solar energy, wind energy, water energy, biomass energy, geothermal energy and ocean energy (Liu, et. al., 2010). Renewable energy is harmless or minimally harmful to the environment, and its resources are widely distributed and suitable for current needs of development and utilization. Renewable energy can be recycled in nature relative to the potentially exhaustible fossil fuels. The large-scale exploitation and utilization of fossil fuels such as coal, petroleum and natural gas in modern society has been formed and stored by the earth during the evolution of ancient times. Once they have been exhausted, we cannot recover and regenerate the fuels anymore.

In addition to the above points, renewable energy has the following features (World energy council, 2013) :

1) Not yet on a large scale using, and some even in the initial stage of research and development;
2) Storage conditions and physic characteristics have a significant difference other than those of normal energy;
3) Complexity of development and utilization of technical, high cost;
4) Environmental protection, can achieve low even zero emissions of carbon dioxide and other pollutants;
5) Large amount of storage, widely distributed, but low energy density.

## 1.3 Marine Renewable Energy

The vast sea not only contains rich mineral resources but also more inexhaustible ocean energy. As a significant part of earth, the ocean contains a wide variety of energy sources. Renewable natural energy in the oceans includes wave energy, tidal energy, ocean current energy, thermal energy and osmotic energy, which are shown directly in figure1-3(IRENA, 2014). It is estimated that the total amount of ocean energy reserves up to 4000TW, which can be taken as great potential for development.

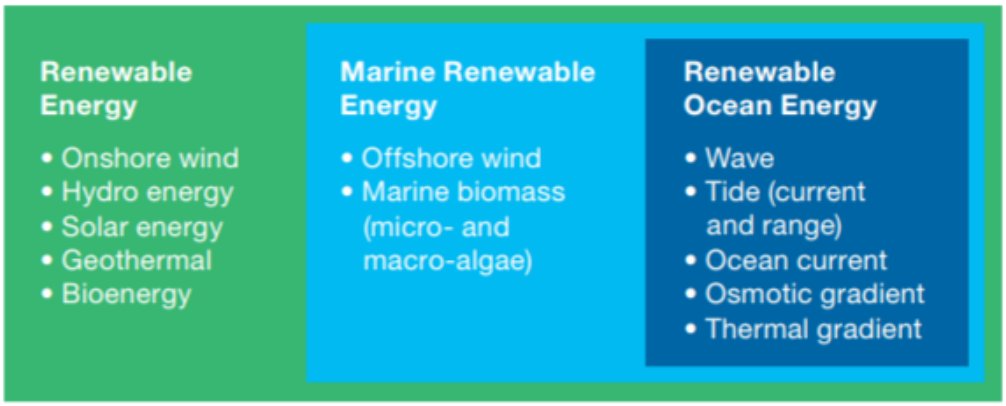


Figure 1.3 Renewable Energy resources and categories (IRENA, 2014)

Tidal energy is a kind of the ocean energy in the form of potential energy. It refers to the potential energy and kinetic energy of water formed by tide rise and ebb. Although only a few ports in the world have the ideal conditions for developing tidal energy, the

research on tidal energy power generation equipment has been very extensive. In particular, the United Kingdom is at the leading position in the field of tidal energy development in the world. Recently, the report of the Sustainable Development Board (SDE) pointed out that tidal power generation is expected to meet 10% of the UK's energy demand based on the geographical factors of the United Kingdom. This report will further promote Britain's tidal energy development process.

Ocean current energy refers to the kinetic energy of the flow in the seawater and mainly refers to the relatively stable flow in the subsea channel and the strait, and the regular seawater flow due to tides as well. Compared with other ocean power generation technology, the use of ocean current power generation technology research is still in its initial stage. The potential of ocean current energy generation technology is enormous, but there are also a number of issues that involve complex and costly maintenance projects and potential damage to vulnerable marine ecosystems (Li et. al., 2010).

Osmotic energy means the chemical potential difference between seawater and freshwater or between two kinds of salt water with different salt concentrations. Osmotic power generation is to use the chemical potential difference energy of two different concentrations of salt water, to convert it into effective power. It is estimated that the osmotic energy between seawater and freshwater contents up to 3.5 billion kW, 2.6 TW of which is available (Falnes, 2007).

Marine thermal energy is generated by the temperature difference between deep and surface seawater. The estimated theoretical reserves of ocean thermal energy worldwide are 10 billion kW. It is calculated that the oceanic surface from 20 degrees south latitude to 20 degrees north latitude, if half of which is used to generate electricity and the average sea water temperature dropped 1 ℃, 600 billion kW of electricity can be gained, which is equivalent to the current generation of electricity all over the world. Therefore, this kind of renewable marine energy is recognized by the international community as the most exploitable and potential marine energy (Li et. al., 2010).

Although the cost of marine power generation is 10 times that of traditional power generation methods, and the technical risks are high, besides, there are still many technical problems in the development and utilization of ocean energy and the impact on

the environment is uncertain, the research and development of marine energy have become the general worldwide trend.

## 1.4 Wave Energy

When the wind passes over the sea, the waves are generated. Wave energy is characterized by high energy density and wide distribution. It is an inexhaustible and cleanest renewable resource. Its development and utilization will greatly ease the crisis caused by the gradual depletion of mineral energy and improve the environmental damage caused by burning mineral energy.

There are many differences between tide energy and wave energy. Firstly, tidal movement involves the entire body of water, while wave movement involves only surface water; tides are mere water movements while waves act as a carrier of energy. In addition, the geographical environment requirements to develop wave energy are much lower than the tidal energy (Li et. al., 2010).

The power generation process is through the wave energy device: the wave energy is first converted to hydraulic energy, and then converted into electricity. This type of technology emerged in the early 1980s. All these wave power generation devices have their own advantages and disadvantages; however, a common problem is that there are many intermediate links in which wave energy is converted into electric energy, which is inefficient and has large power output waste. This is also one of the main reasons that affect the large-scale development and utilization of wave power generation. With decentralized, low-density, unstable wave energy, how to effectively and economically transfer the energy into electricity and to avoid the damage of the energy generation devices are the problems and directions for the development of wave energy nowadays (Pelc, and Rod, 2002).

Although wave energy has lots of problems about the complex technology, high cost and long payback period, various countries in the world have still devoted a great deal of effort to unremitting exploration and research in the past 200 years.

## 1.5 Submerged Wave Energy Device

Through the understanding of wave energy, a new submerged wave energy device(SWED) is designed to improve the existing wave power generation devices. This structure basically consists of three parts: the supporting part, the moving part and the generating part. The moving part is a desk designed to be different shape and size in order to fit different type of waves. The generating part consists magnets and metal part. The moving desk connects to the generating metal part with a rod. All these two parts are settled by the supporting structure to stay steady on the seabed. More details can be found in figure 1-4 (Li, 2017).

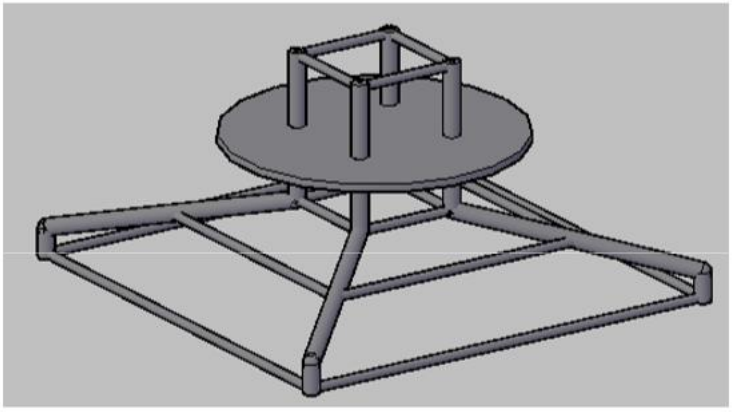

Figure 1.4 3D rendering of the wave energy converter (WEC) (Li, 2017)

The working mechanism of the device is that the flat plate moves up and down along the fixed rod under the action of waves, and drives the metal part to move then cut the magnetic induction line to generate electric current. Specific principles and situation analysis will be given in another chapter later.

## 1.6 Project Aim

The purpose of this thesis is to discuss the optimal design of the device in different situations.

Experiments will be conducted by designing different types of waves to test and recording the production results of different shapes and sizes of the desks. Then the

comparison will be made between the results of plate movements and the effects on the results. Based on the experimental results, the feasibility and future development of the device will be discussed.

# 2.0 Literature Review

## 2.1 Wave Energy Devices

Wave power is the main method of wave energy utilization. Waves can be used in a wide variety of devices, with more than 1,000 invention patents on wave energy conversion devices. These devices are mainly based on the following basic mechanisms: the oscillation and swing motion of objects under wave action; the change of wave pressure; the wave can be converted to the potential energy of water by using the coastal climbing of the wave (António, 2010).

The wave power technology has been gradually approaching the practical level through the laboratory study of various wave energy devices in the 1970s and the sea condition test and application demonstration in the 1980s. The research is focused on several kinds of device that is supposed to be a commercial value, including oscillating water column device, tilting device, oscillating float type wave energy conversion device and contraction channel type wave energy conversion device.

## 2.2 Types of WED

There are various forms of wave energy conversion devices, which totally can be divided into three levels and will be analyzed separately.

The first stage transformation is directly in contact with the wave, whose function is to convert the wave energy into the energy held by the entity, which is characterized by the mechanical energy of the undulating motion with the wave. Third stage conversion, or the final transformation, is to transfer to mechanical energy into electrical energy device, usually in the form of generators, such as passing out after a certain transformation directly into electricity grid, used for end users.

In addition to the first and final conversion, intermediate transitions are not essential. It mainly plays a stable direction in the wave conversion device, increasing the conversion speed and keeping conversion speed steady. In other cases, the first and final conversion

devices may have a certain distance, so the intermediate switching device is required to transmit energy.

The wave energy conversion device can be divided into three parts: the energy receiver, the energy converter and the fixed body. The energy receiver and the fixed body are two essential parts of the wave energy conversion apparatus, and their combination realizes the transformation of the wave energy.

### 2.2.1 Oscillating water column wave energy conversion device

According to mooring ways can be divided into floating type and fixed type (Yao, et. al., 2016).

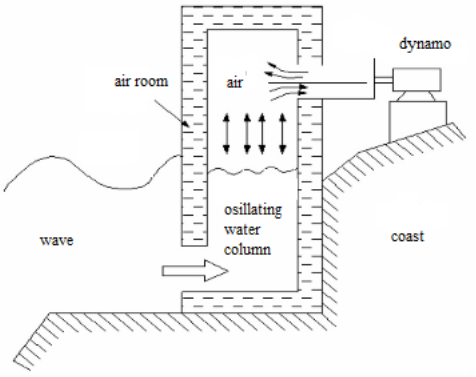


Figure 2.1 Oscillating water column wave energy conversion device (Yao, et. al., 2016)

Floating type namely conversion device by massive mooring floating on the sea surface, and stationary (fixed by shore) wave approach generally built in the shore side, which on shore construction is more convenient, and the interconnection and transmission is simpler. Its main principle is to use air medium, conversion of energy acquisition through the air chamber, air chamber of the underwater with sea water in the lower and the upper portion of the air chamber (nozzle) and atmospheric connected. Under the action of wave force, the water column in the lower part of the air chamber is forced to vibrate, and the compressed air in the air chamber is reciprocated through the nozzle to transform the wave into the pressure potential energy and kinetic energy of the air. An impeller is installed at the nozzle and the impeller shaft is connected to the generator, which can be used to drive the impeller and drive the generator to generate

electricity. Currently, the wave power devices have been improved in this way, and the world's commercial wave power devices are basically based on this principle. In addition, such devices use air to deliver energy, which avoids the direct impact of waves on the generation system. There are two main current problems of the oscillating water column wave energy conversion device. One is how to design the air chamber to improve the pressure of the internal oscillating water column. The second is how to determine the location of the device on the sea surface. If these two aspects can be better solved, then the power generation device will be more widely used.

### 2.2.2 Oscillating body wave energy conversion device

Oscillating body wave energy conversion device is mainly floating on the surface of the sea. It contains a few parts, such as oscillating body, hinges between the body parts and energy conversion device, which is almost the most important part. The design of this kind of wave energy conversion device mainly follows wave energy - mechanical energy - electric energy. In the first place, a floating body directly exposed to the waves can transform a wave into a mechanical energy held by a suspension. Secondly, the motion of the floating body is transferred to the energy conversion device. The energy conversion device not only collects the mechanical energy, but also transfers the multi-directional movement to a single direction. Finally, the energy conversion device converts the collected mechanical energy into electrical energy (Falnes, & Perlin, 2003).

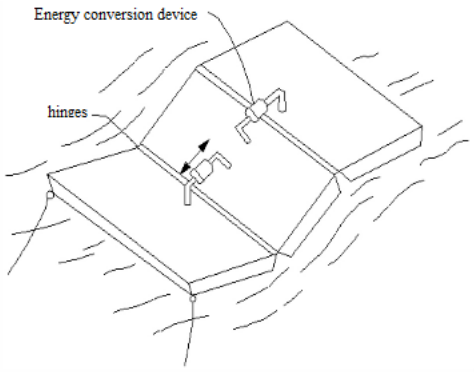


Figure 2.3 Oscillating body wave energy conversion device (Yao, et. al., 2016)

According to the fixed mode and position, the oscillating body wave energy conversion device can be divided into fixed and floating types; along shore and offshore types.

### 2.2.3 Overtopping wave energy conversion devices

The overtopping wave energy conversion device is to use the water channel to lead the wave into the high reservoir to form the water level (water head) difference, and the water head difference is directly driven by the water head to generate power. This kind device comparing other forms of wave energy conversion device has its obvious advantages: sea surface and the reservoir provides the stability of the water head, which can help the unstable wave energy be converted into a smooth and continuous output power, therefore, can overcome output power instability problems in the process of wave energy power generation. At the same time, the device can be developed jointly with marine engineering buildings such as breakwater, which can greatly reduce the input cost. The wave power generation device has become a research hotspot in the world (Henderson, 2006).

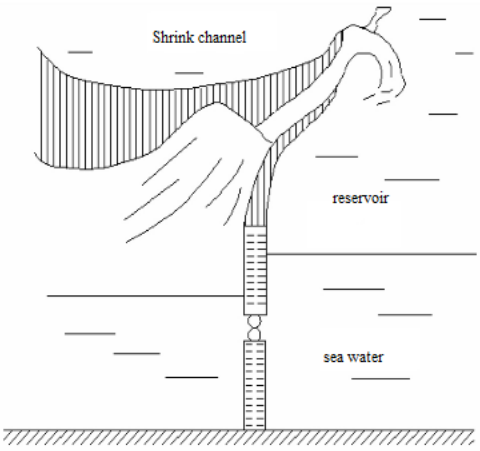


Figure 2.3 Overtopping wave power technologies (Yao, et. al., 2016)

## 2.3 Current Challenges

The wave energy conversion device technology has been developing for a long time and some have become commercialized, but there should be some problems in practical operation.

### 2.3.1 Total power generation efficiency

During the conversion process, due to the multistage transformation, the loss of energy is large. In some actual situation, the wave is unstable and irregular. This is a very high requirement for energy conversion devices and energy storage devices, and the complexity of the device is greatly increased (Jarocki, 2010). The instability of waves makes the conversion of electrical energy also unstable. The ultimate purpose of wave energy transformation is to convert into electricity. Due to the limitation of power grid, the cost of wave power generation is much higher than that of general resources, and the low efficiency of power generation of wave energy is also a problem to be solved.

### 2.3.2 Construction requirements

#### 2.3.2.1 Construction material requirements

The corrosive nature of seawater is a difficult problem for marine resources technology. At the same time, as the basic principle of wave conversion device is absorbing wave energy, this means that the energy conversion device is directly or indirectly under the effect of wave force, and in some cases the waves can cause inconsiderable damage. Therefore, the corrosion resistance and durability of the wave energy conversion device are very important (McCormick, 2007).

#### 2.3.2.2 The complexity of the device

Since the wave energy conversion device is set in the ocean, repair and maintenance become more difficult. If the device is more complex, the difficulty of maintenance and maintenance will be greatly increased.

### 2.3.3 Cost

The cost of wave energy generation has been a barrier to the widespread adoption of wave energy. At this stage, the cost of wave energy generation is much higher than that of ordinary energy generation. Only by constantly innovating and improving the wave power generation technology can people truly benefit from this clean energy (Vowles, 2010).

### 2.3.4 Environmental problems

The energy conversion device set on the surface or fixed on the shore will affect the beauty of the natural scenery. And the devices that are set in the ocean can also cause damage to marine life and impact on marine ecosystems. Due to occupying a larger sea surface area, it may also affect normal shipping work. So the location of the wave energy generating device is particularly important.

# 3.0 SWED: Submerged Wave Energy Device

For most European countries, the wave condition is good, which is suitable for large devices such as oscillating water column wave energy conversion devices. This kind of wave energy conversion device can avoid the contact between the wave and the electromechanical part, and effectively prolong the service life of the device. However, the construction cost of this device is expensive; the construction difficulty is high; the total conversion efficiency is low, and the impact on the natural landscape is great. Therefore, this thesis will discuss another small submerged wave energy conversion device, short for SWED.

SWED consists mainly of the following parts: a floating plate which contacts with the electromechanical part; a fixed frame; an energy conversion and an energy output device that follows the wave motion and connects the generator. The details are shown in the figure as followed:

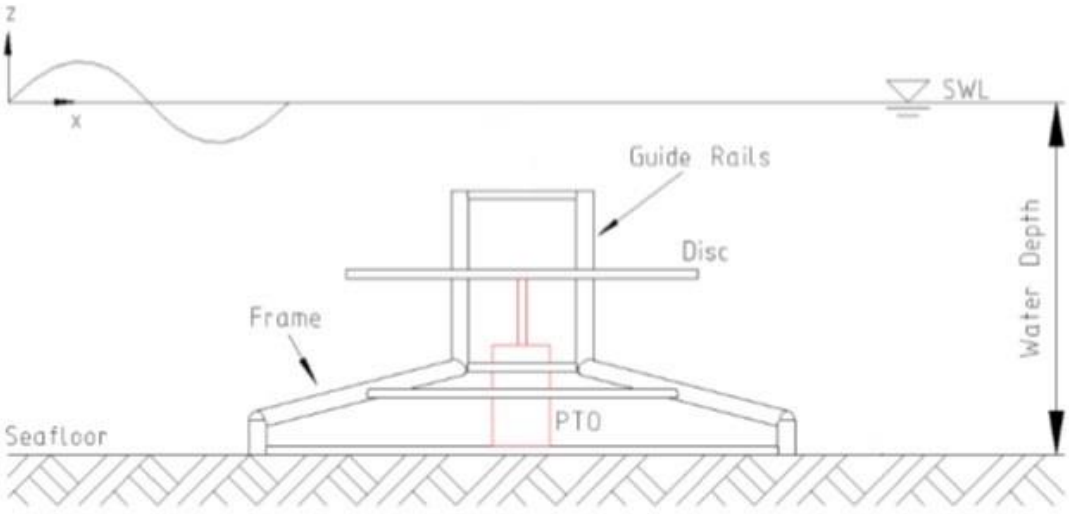


Figure 3.1 Scheamtic Diagram of the SWED (Li, 2017)

Submerged wave energy conversion device is to use a plate fixed on the frame, which can move up and down under the action of wave as carrier wave energy absorption, and then the gears is driven through the plate's up and down movement, connecting with the energy conversion device, finally drives the generator to produce electricity. Now, the assumption of the power generation unit of the submerged wave energy conversion

device is mainly that the metal parts moves with the floating plate up and down to cut the magnetic induction line of the magnet in the electromechanical device to generate electricity. This kind of power generation method is simple, theoretically as long as the cutting of the magnetic induction line occurs that can generate electric energy, thus improving the absorption efficiency of the device to the wave energy. Compared with the large-volume wave energy conversion devices, the submerged device can effectively collect the wave energy, the energy loss during the transmission process is small and the energy conversion efficiency is high. The equipment is convenient for maintenance and mobility. It can collect various waves and adapt to a variety of seabed topography.

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