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# Design and configuration of an energy harvesting device from ambient vibration on sea waves

Bachelor Thesis



Vietnamese-German University

Binh duong 2022

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# Design and configuration of an energy harvesting device from ambient vibration on sea waves

A thesis presented

by

Vũ Hoàng Quân



Vietnamese-German University

Submitted to the department of Mechanical Engineering of the  
RUHR-UNIVERSITÄT BOCHUM and VIETNAMESE-GERMAN UNIVERSITY

in partial fulfilment

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## Affirmation in lieu of oath

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Title of Thesis: Design and configuration of an energy harvesting device from ambient vibration on sea waves

I hereby declare in lieu of oath that I have produced the aforementioned thesis independently and without using any other means except the aids listed. Any thoughts directly or indirectly taken from somebody else's sources are made discernible as such.

To date, the thesis has not been submitted to any other board of examiners in the same or a similar format and has not been published yet.

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# ABSTRACT

The purpose of this thesis is to design a wave energy converter (WEC) that can transform the linear energy from the sea wave into rotary energy which can drive generator. The design is based on existing model of WEC which have develop for decades. The design focus on the Power-Take-Off system of a WEC and is shaped to be a point absorber type of WEC. The engineering design process is applied to the thesis which is conducted over three phase: Gathering information; Concept generation and Detail design. In first phase of the process, a literature review has been done; design parameters have been decided and PDS has been made to make a foundation for the whole design process. Second phase show a creation of 7 new concept based on the data gathered from the initial phase, then a concept selection of one promising idea is made using the Weighted Rating Method. After recruiting the favorable candidate concept, an 3D model of the device is detail made, showing working principle, assembly overview, parts and components, material design, dimension, etc., resulting in a new PTO design for a WEC. Further development is needed such as control solution and testing analysis.



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# CHAPTER 1: Introduction

## 1.1 An overview of Wave Energy Converter

With the problem of rising level of CO<sub>2</sub> in a global scale, the demand for renewable energy source has never been so high.[1] An high density and availability energy source on Earth is known as wave energy. There has been many research concerning how to harvest this kind of energy all around the world. The first person to informally developed the technology is Yoshio Masuda (1940s).[2] Up until now, there are more than 1000 concept of WEC device, which locate mostly in Europe, Japan, North America

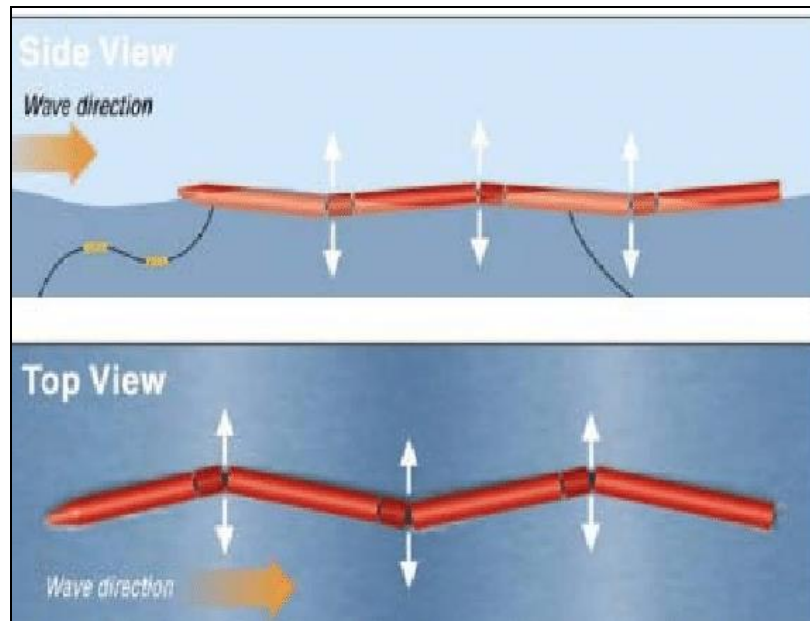
Despite the numerous concept have been proposed, WECs are divided into three main types.[3]

### 1.1.1 Attenuator

Attenuators floats on the wave, parallel with the wave direction. The device can be seen as ‘riding’ the wave. Pelamis is a clearest example for Attenuator type WEC, shown in Figure 1



Figure 1 Pelamis WEC[4]



**Figure 2 Pelamis' working principle[5]**

The Pelamis is built as a 3.5 m in diameter steel tube, which is fill with air inside to make it float, they are linked together by hinged joints as show in Fig. 2. In-between each tube, there are power conversion system. The up and down or side-to-side motion is both capture by hydraulic piston. These cylinder pumps fluid through hydraulic motor, which then power the generator to produce electricity. Accumulators are used to separate the pumps with the motor, and act as damper to smoothen the flow, create stable generation. Each Pelamis have 3 joint which have 3 PTO system and can have the length up to 120m, each produced 250 kW. [3]

### **1.1.2 Point absorber**

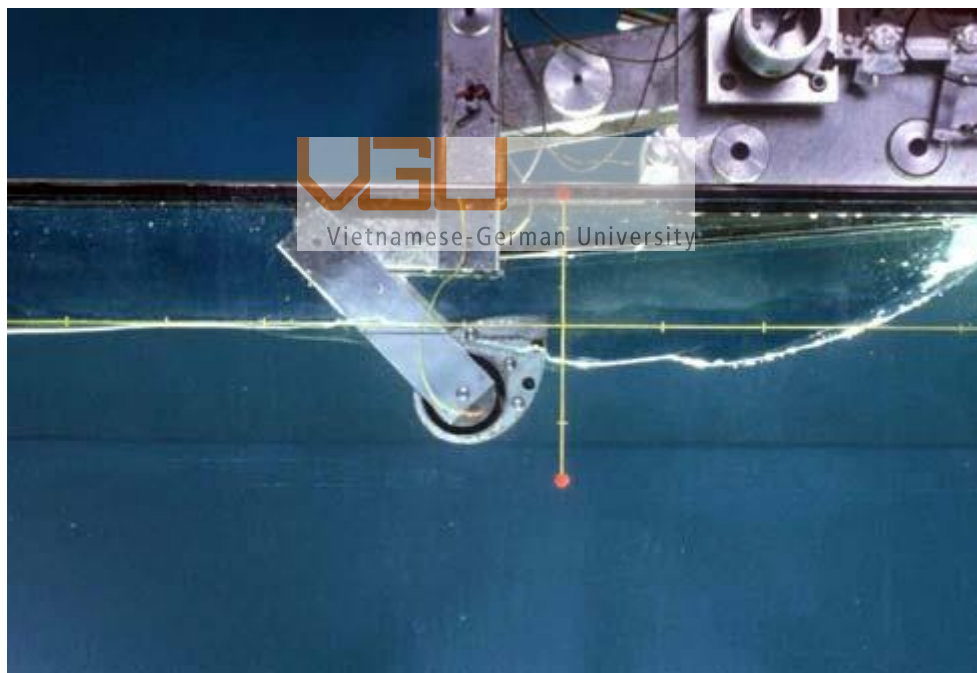
A point absorber (PA) is very small device compare to the wavelength. Floating buoy on water surface or stay inside the ocean which rely on the change of pressure between depth of sea level can be described as PA device. Wave direction is not play a part in these devices as for the size is too small. A vast number of example for PA devices, an example is the Ocean Power Technology's Powerbuoy.



**Figure 3 Point absorber device: OPT Powerbuoy[3]**

### **1.1.3 Terminator**

Terminator devices working direction is perpendicular to the wave direction and physically intercept waves. One example is the Salter's Duck, which is being improved at the Edinburgh University, illustrated Fig. 4



**Figure 4 Salter's Duck[3]**



## 1.2 Power take-off system

The power take-off (PTO) of a wave energy converter is the mechanism which have the job of absorb wave energy, and turn it to electricity energy. The PTO system is utmost important as it decide how fully the wave energy is converted; how the device is weighted, dimensioned.[6]

Up until now, many different types of PTO system exist that is using different type of mechanism. Fig. 5 shows an overview of all existing method of energy transfer through PTO system. Five most commonly used PTO system is:

- Direct mechanical drive system
- Hydro turbine transfer system
- Hydraulic motor system
- Pneumatic air turbine transfer system
- Direct linear electrical drive systems



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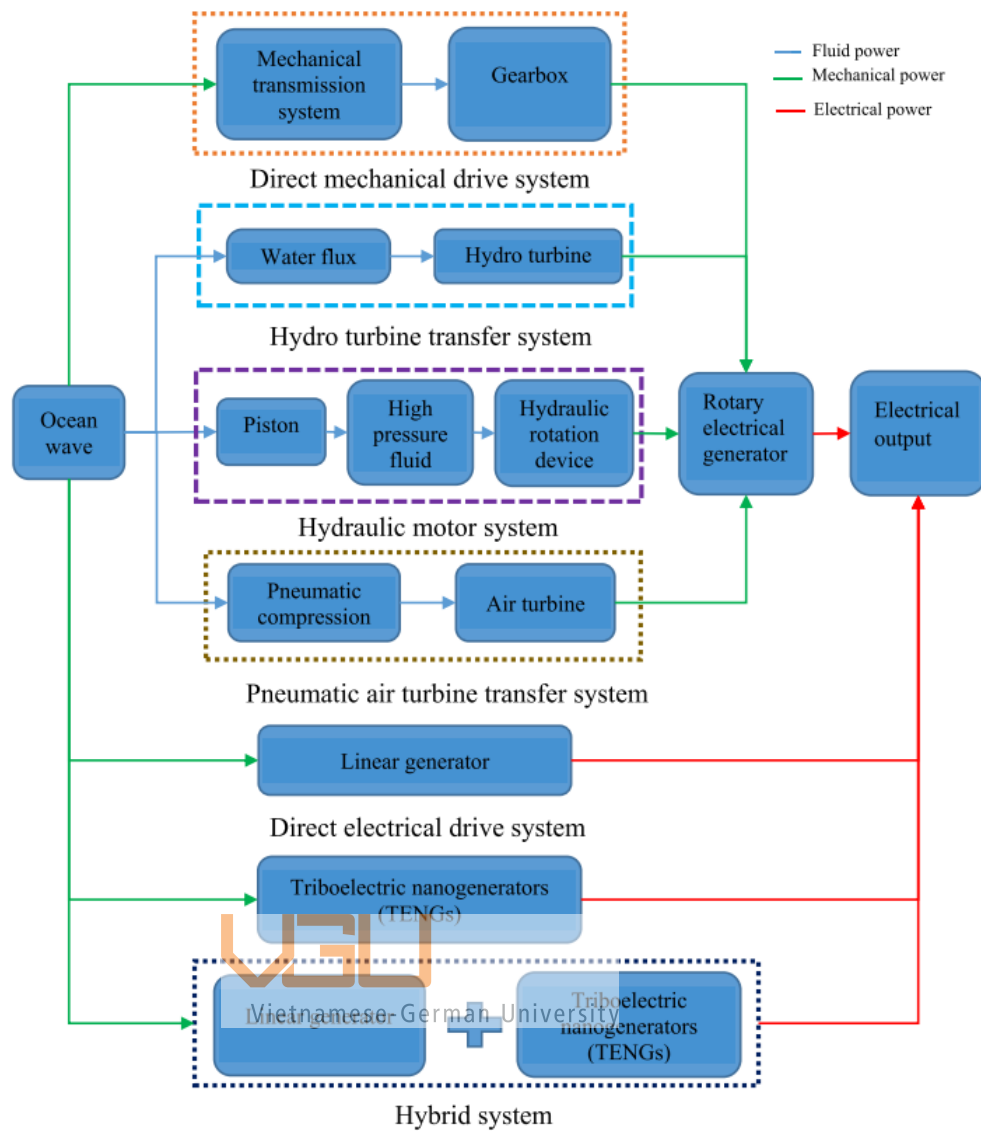
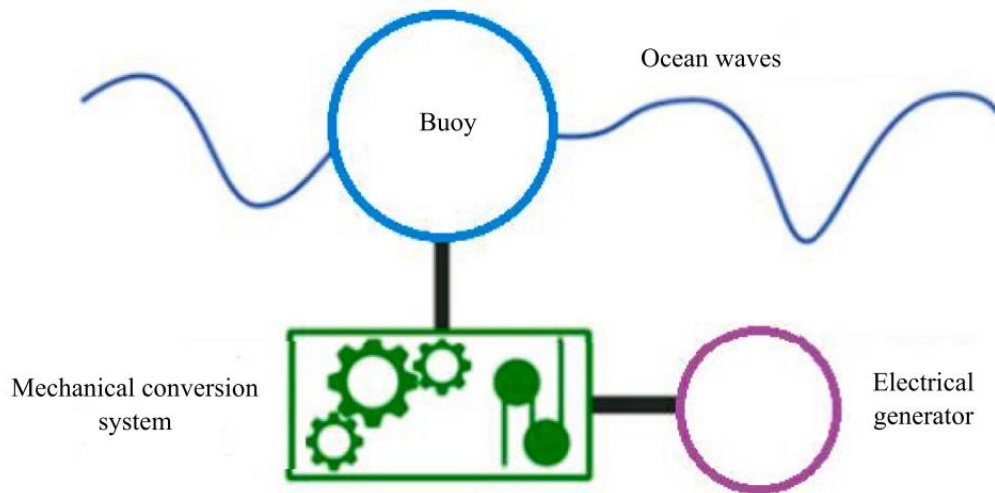


Figure 5 The working principle of PTO systems[1]

### 1.2.1 Direct mechanical drive system

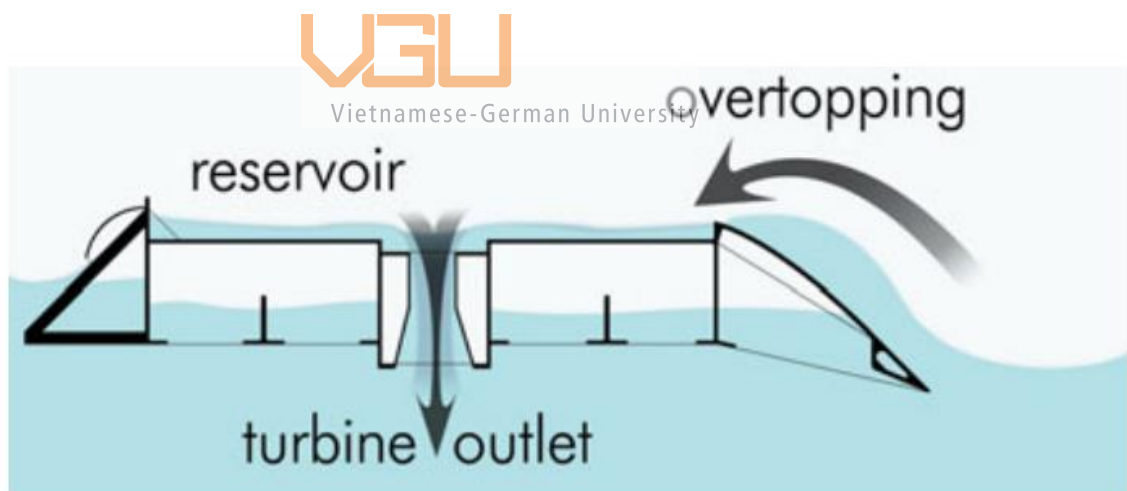
A direct mechanical drive PTO system uses an extra mechanical system to convert the energy absorbed from the wave to rotary energy which can drive an electrical generator. Illustration is shown in Fig. 13. For example, Gear box, pulley and cable can be comprised inside a mechanical conversion system. To smooth out power variations, a flywheel can be installed in the rotary shaft.[6]



**Figure 6 Mechanical drive system's scheme**

### 1.2.2 Hydro turbine system

Hydro turbines can be seen in overtopping WECs or sea water based hydraulic pump systems. The wave would create momentum to push the water over the ram, into a basin. Water would fall back through an channel back to the ocean which drive the turbine outlet to create electricity (see Fig. 7).[7]



**Figure 7 Overtopping WEC's principle[7]**

### 1.2.3 Hydraulic motor system

“Waves apply large forces at slow speeds”[3]. The design of a hydraulic motor systems is suitable for absorbing energy in these situations. Figure 9 shows the working principle of the mentioned device. The buoy connected to the piston is forced to move up and down[3]. The liquid inside push the hydraulic motor to move, driving the electrical generator. As the generator moving at constants speed, check valves and accumulator is used to rectify the flow[3]

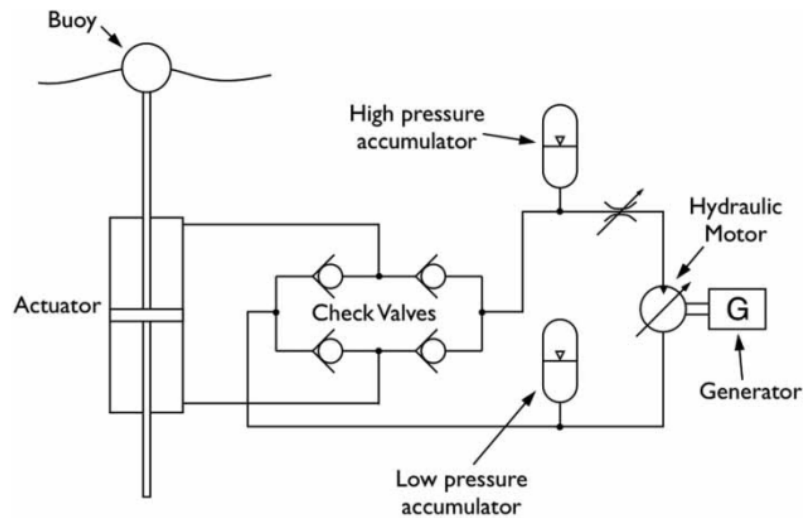


Figure 8 Typical hydraulic circuit for WEC[3]

#### 1.2.4 Pneumatic air turbine transfer system

With the air turbine is the main idea, a way to deliver an air flow by ocean wave is introduced. An air chamber is used to create flow. The incoming wave generates an oscillating water column that pushes the air out of the chamber and pulls it back in. The propeller is placed to capture the air flow at the nozzle. [7] The schematic is shown in Fig. 9.

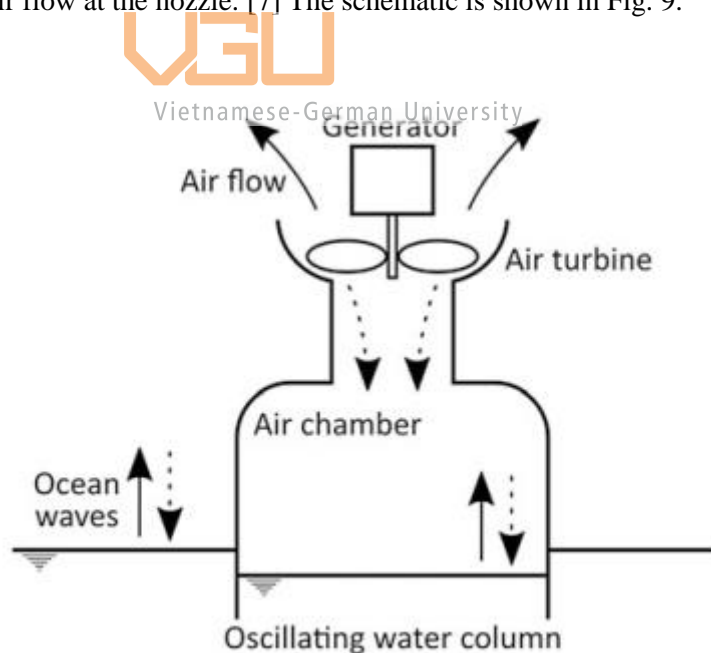
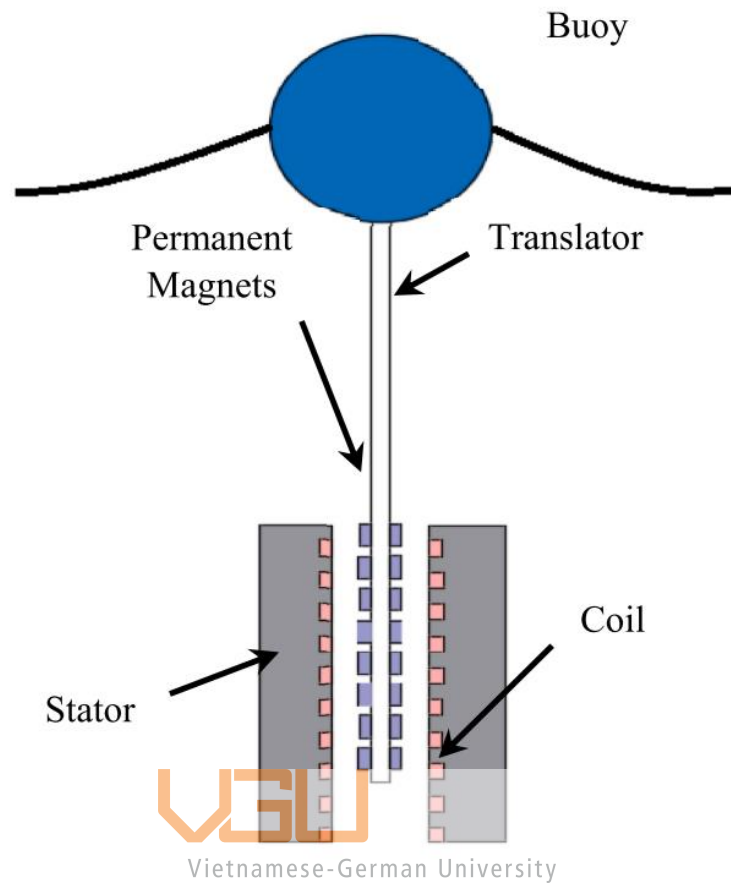


Figure 9 Air turbine working principle[7]

#### 1.2.5 Direct drive linear systems

The concept of a permanent magnet moving inside a coil will create electricity is very well-known. The linear generator uses the very same idea. The magnet is installed on a buoy, which provides movement. The coil is attached down the base of the WEC. With the effect of the buoy

when it is excited by the wave, the magnet moves inside the coil will create electricity. The schematic is shown in fig. 10



**Figure 10 The direct electrical drive system[3]**

### 1.3 Introduction to the problem

To produce electricity, generator is an unavoidable piece of the WEC. They commonly are rotatory generators. The up-down movement or back and forward of the wave is not going to make the generator spin. Therefore, a transfer mechanism is needed to connect these two pieces together. This is the main purpose, to create a linear-to-rotary PTO system.

The benefit of WEC is clearly to be seen but there are some other challenges that need to be conquered in order to maximize the efficiency and its place in the renewable energy market. As waves height and period change over time, their power levels change accordingly.[3]

### 1.4 Objective

The main aim of the thesis is to design new concepts about the PTO system based on existing solution. This is solely focusing on the mechanism that transfer the linear motion of the sea wave to rotary motion which powered the generator. Because the vast variety of design for WEC, this project will only narrow down to point absorber type of wave energy converter only. Applying the engineering design process, the thesis follows three phases shown if fig. Design requirements and parameters are identified to generate concepts. The most suitable solution is then selected from these concepts by using criteria that focus on having a Linear-to-rotary mechanism. The design can be brand new or a combination of existing solution. The operating environment has to be taken into account is the Vietnamese coastline.

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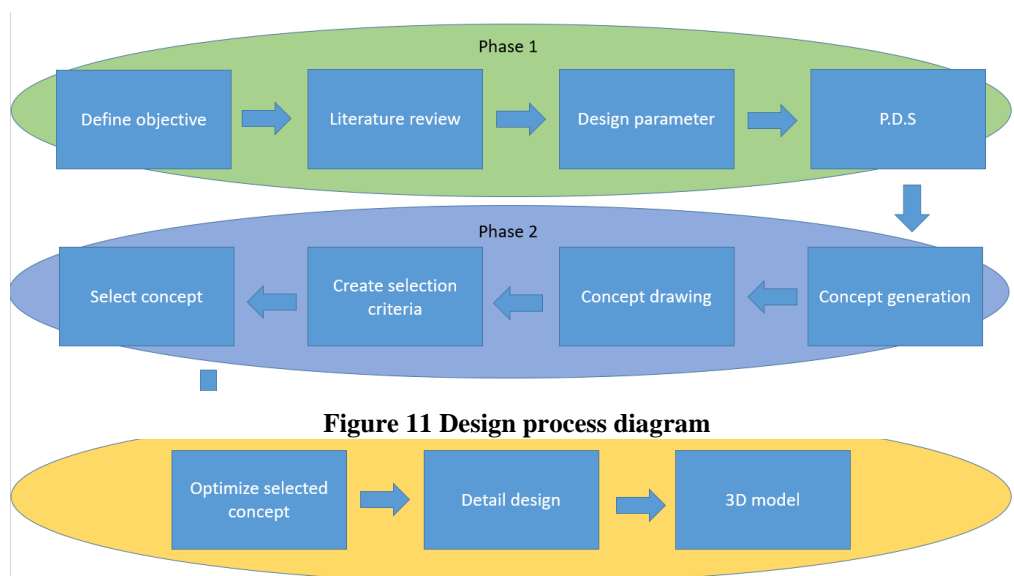


Figure 11 Design process diagram

# CHAPTER 2: Literature review

## 2.1 Summary for Literature review:

### 2.1.1 Wave Characteristic:

- Benefits of wave energy[3]:
  - ✓ Sea waves have the highest energy density
  - ✓ Less environmental impact.
  - ✓ Seasonally, the change of wave matches the demand of energy
  - ✓ Little loss of energy when the wave travels
  - ✓ It is reported that 90% of the time, WEC can produce energy, compare to wind and solar which is only 20-30%
- Main dimension of wave includes:
  - ✓ Wave height: Distance of H in the illustration
  - ✓ Wave length: distance of L
  - ✓ Wave period: time for the wave to travel a distance of L

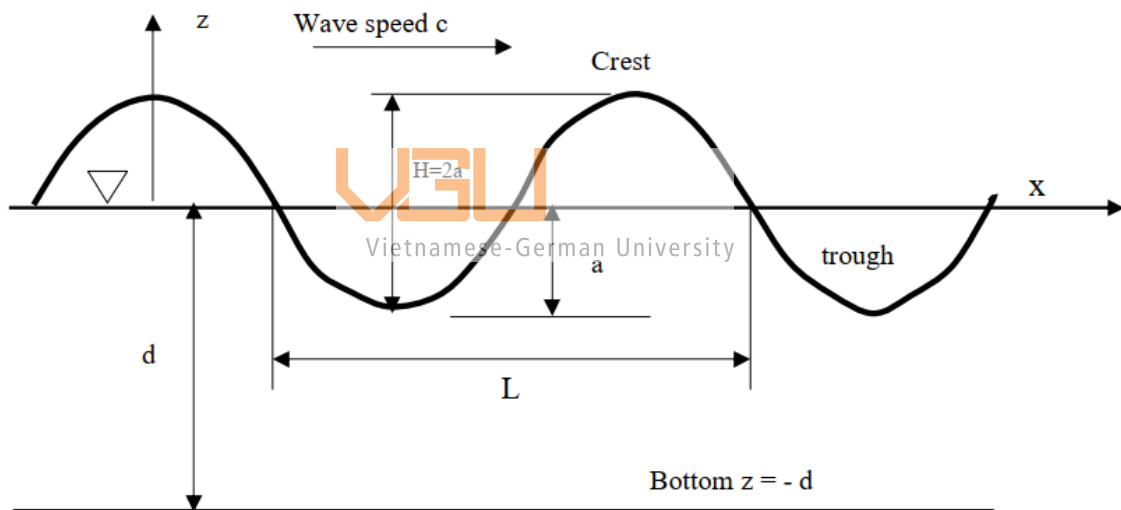


Figure 12 Wave schematic

- Distance between crests (wavelength,  $\lambda$ ) and time between crests (period, T) is related to each other by equation (1)[8]

$$\lambda = \frac{gT^2}{2\pi} \quad (1)$$

- Energy from wave can be determine in respect to wave height and wave period. Formulate in equation (2) below[9]:

$$P = \frac{1}{32\pi} \rho g^2 H^2 \quad (2)$$

With: P = Energy flux (Watt/m)  
 ρ = Density of sea water (1025 kg / m<sup>3</sup>)  
 H = Wave height  
 T = Wave period

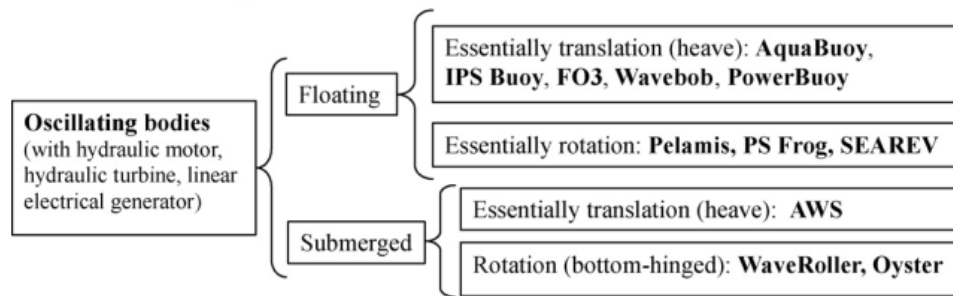
- **The bigger value of wave height and wave period, the higher energy is produced by the wave (especially wave height)**

### 2.1.2 Existing WEC technology:

- Three main types of WEC[3]:
  - ✓ Point absorber
  - ✓ Attenuator
  - ✓ Terminator
- These types of WEC use three types converter technology[10]:
  - ✓ Oscillating water column
  - ✓ Oscillating bodies (can be fixed to seabed or floating or submerged)
  - ✓ Overtopping (can be fixed to seabed or floating)
- Power take-off technology is the mechanism inside the WEC that have one sole purpose is to convert wave energy to useable electricity. There are 5 major groups that exist and commonly use. Four of them are the mechanism that transfer the linear motion of wave to rotary motion of the generator. The other one using the linear generator that can directly convert wave motion to electricity[1].
 

<ul style="list-style-type: none"> <li>✓ Hydraulic motor system</li> <li>✓ Direct mechanical drive systems</li> <li>✓ Hydro turbine transfer system</li> <li>✓ Pneumatic air turbine system</li> </ul>	}	Linear-to-rotary mechanism
<ul style="list-style-type: none"> <li>✓ Linear generator</li> </ul>	→	Direct transfer mechanism
- The thesis concentrates in designing oscillating bodies system, further classify in five other types of system[2]
  - ✓ Single body buoys[2]
  - ✓ Two-body buoys[2]
  - ✓ Fully submerged heaving systems[2]
  - ✓ Pitching devices[2]
  - ✓ Bottom-hinged systems[2]
- Fully develop product exist on the market which classified as Oscillating bodies:





**Figure 13 List of WEC base on Oscillating bodies[2]**

- **Pelamis** is a Attenuator WEC using Hydraulic motor system[11]
- **SEAREV** is a Point absorber WEC using both hydraulic and direct-drive PTO[12]
- **AquaBuOY** is an upgrade version of **IPS Buoy**. They both are Point absorber WEC using hydro turbine transfer PTO[13]
- **WaveRoller** and **Oyster** a Point absorber WEC using Hydraulic motor system[14]
- Ten linear-to-rotary mechanism is commonly use on WEC system[15]:
  - ✓ Track tire/ wheel
  - ✓ Windlass spindle
  - ✓ Slider-crank
  - ✓ PM Helical
  - ✓ Belt or chain
  - ✓ Roller screw or ball screw
  - ✓ Hydraulic system
  - ✓ Hose pump system
  - ✓ Rack and pinion (single)
  - ✓ Rack and Pinion (double)

### 2.1.3 Recent new idea of WEC:

- A two body floating WEC[16] by Youming Dai, Yangzhi C-hen, Longhan Xie

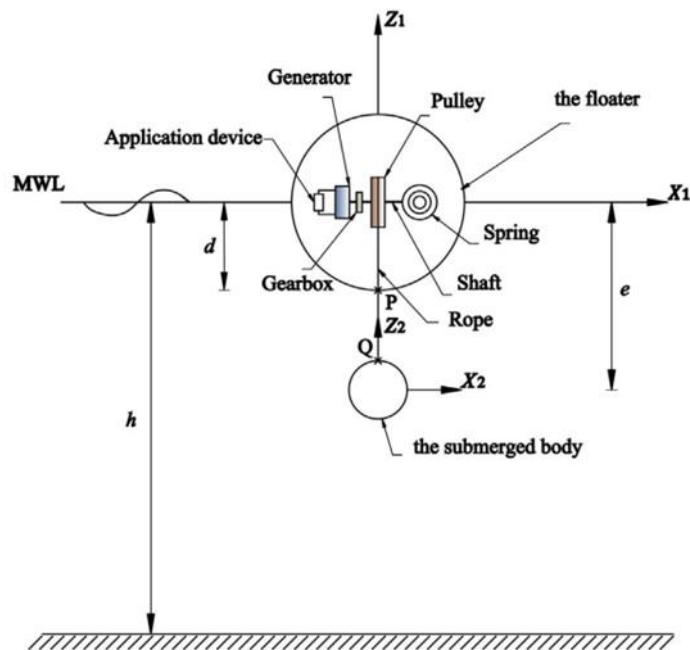
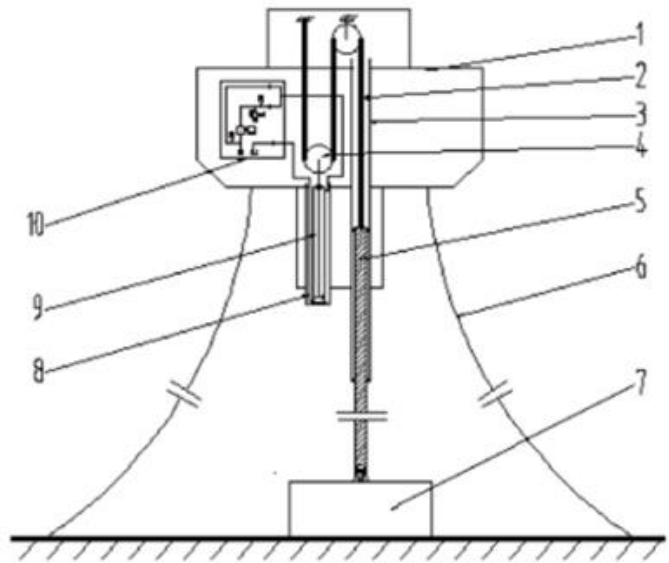


Figure 14 Sketch if the two-body WEC



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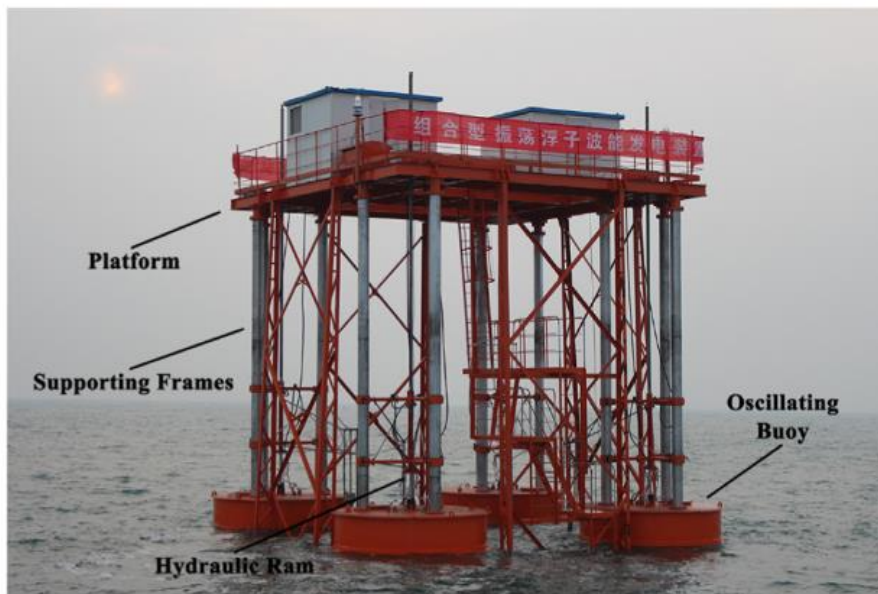
- Buoy-chain-sprocket wave energy capture device by Fangdong Ji, Defeng Wu, Yajun Li, Zhilin Zhu, Linsen Zhu[17]



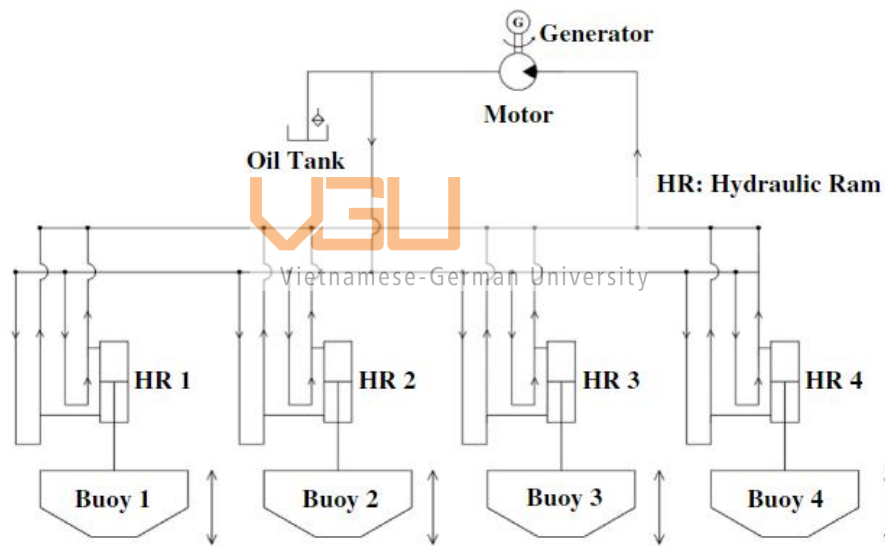
1: Floating body; 2: Chain; 3: Duct; 4: Sprocket  
5: Guide rod; 6: Anchor chain; 7: Gravity anchor;  
8: Protection tube; 9: Hydraulic cylinder; 10: Power system.

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Figure 15 Schematic of the WEC device[17]

- An oscillating-buoys-array WEC[18]



(a) WEC on-site



(b) Schematic of HPS

Figure 16 Oscillating-buoy-array WEC[18]

- Water Mass Gravity Force WEC by Masjono Muchtar

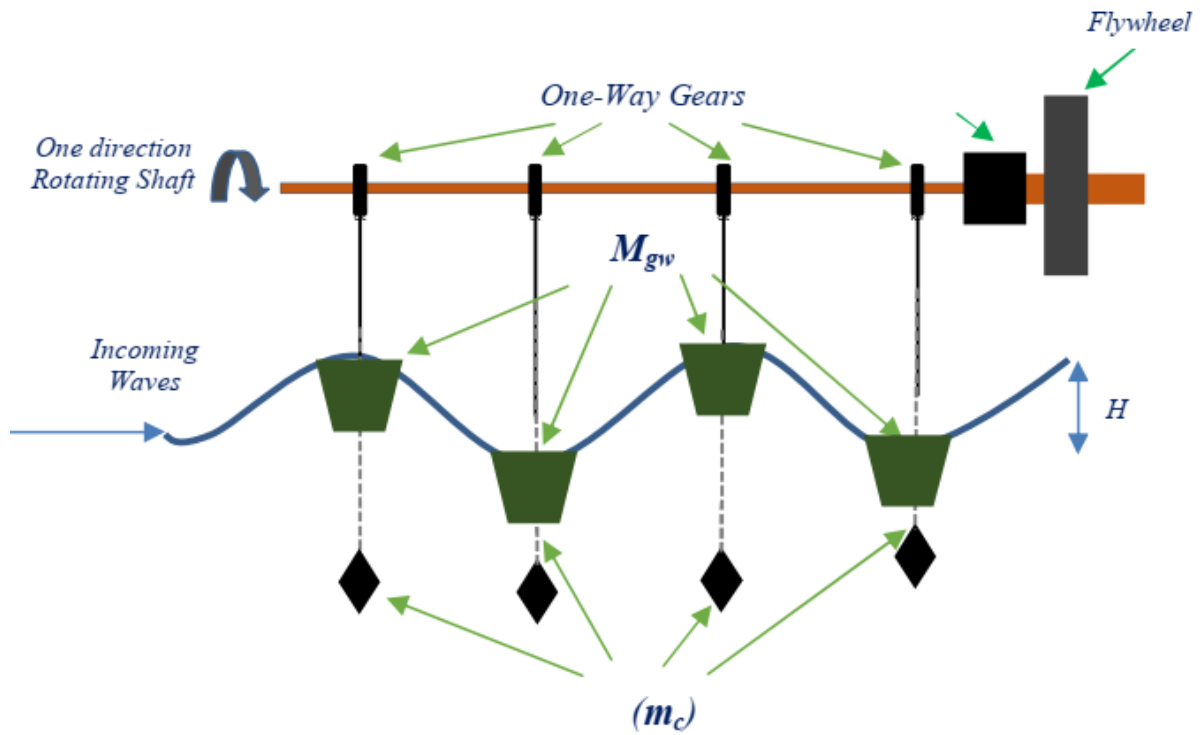


Figure 17 Schematic of mechanism[9]

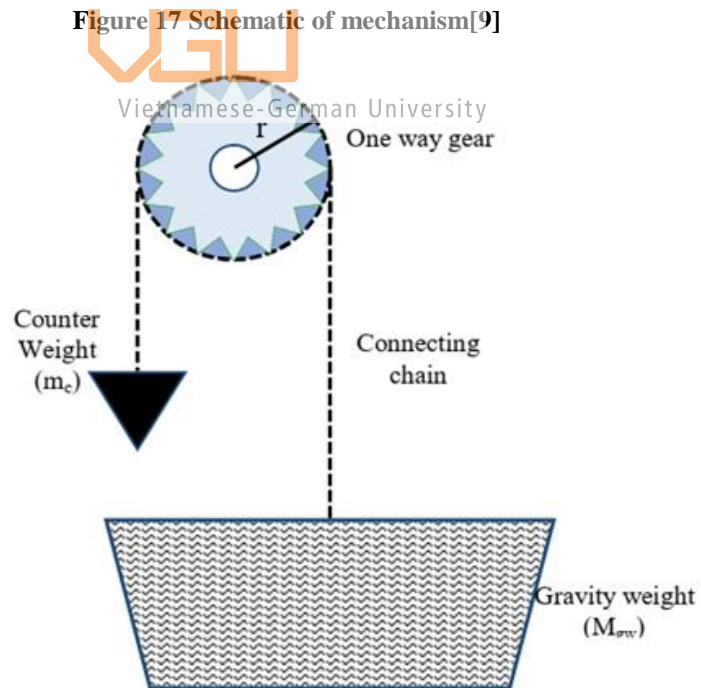


Figure 18 One-way gear gravity-weight[9]

## CHAPTER 3: Design parameters[19]

“Parameters are a set of physical properties whose values determine the form and behavior of a design. Parameters include the features of a design that can be set by designers and the values used to describe the performance of a design.”[19] After researching, a set of design parameter is decided.

Design parameters (DP)	
Linear-to-rotary Power take-off (PTO) mechanism	Focus design on a mechanism that harvest the motion of sea wave, which is the linear movement in to rotary motion that can drive generator
Point Absorber type of WEC	The design will focus on this type of WEC only. These type of design work best at deep water (>40m in depth)
Deploy offshore	Deep water provides more strong wave. The potential site for deployment is locate around 50-100km offshore central Vietnam with depth vary from 50m - 200m
Sea wave condition of East Sea	Peak wave height is around 2.3m, extreme wave height is 8m, Wave period range from 8s-18s Sea pressure at 40m depth is 0.405 Mpa Extreme weather like storm happen more than 10 time a year
Dimension	The height of the WEC device cannot exceed 40m as it is deploy in water region of 50 m minimum depth.

**Table 1 Design parameters**

# CHAPTER 4: P.D.S

## (Product Design Specification)

When gather enough information, the product is then decided if it is worth investing or not. That is the goal of design process planning. And it is documented as the product design specifications (PDS). This document will provide source for the product's design and manufacturing[19]. It should not force the design to end up in a certain concept or "see the future", but it should also consider all the real life constraints.[19]

Below is the PDS of WEC that have developed over the whole design process. Some of the headline in the PDS is to be determined since the thesis does not cover a deep area of wave energy study.

### Product Identification

- A device absorbs the power from sea wave and convert to usable electricity.
- Device applies linear-to-rotary mechanism.

### Key performance

- Absorb the heaving motion OR pitching motion of sea wave
- The mechanism convert linear motion of sea wave into rotational motion which drives the generator to produce usable electricity

### Special feature

- Having a mechanism that can absorb potential energy of the crest and trough with respect to calm sea level at the same time
- A mechanism that can increase productivity of the WEC without increasing the input (wave absorber)

**Target production cost** To be determined (TBD)

**Quantity** One final detail concept

**Manufacturing facilities** TBD

### Product life span

- Renewable energy device will be key to energy industry from now on
- Estimation: Now to 30 year later
- End of life strategy: Housing frame and component will be all recyclable

### Customer

- Target customer will be EVN, electricity exclusive distributor in Vietnam.
- Renewable energy company I.e. Ocean Power Technologies(US), NEMOS (German) or AMOG Consulting(Australia)

### Competition

- Product should not use expensive sensors to increase efficiency
- The mechanism should harvest maximum potential or kinetic energy and or both at same time

### Service life

- Useful life time is 5 years and more.
- Reliability (mean time failure): 5 year

### Environment

- The device should be able to harvest the energy the following sea parameter
  - o Deploy in open sea at water depth vary from 50m to 100m
  - o Wave height vary from 1 - 2.3 meters
  - o Wave period is ranged from 8 secs to 18 secs.
- The WEC should withstand:
  - o Sea pressure: 0.405 MPa
  - o Usually encounter harsh weather: storm, hurricane
  - o Temperature: 10°C to 40°C
  - o Humidity: up to 100%
  - o Corrosive salty sea water

### **Size**

- Height of the WEC submerged to the water do not exceed 40m since it is deployed in the 50m water depth. The 10 meter different is for working movement such as heaving down so that the device does not make contact with seabed
- Internal volume: TBD
- The size of the WEC buoy is generally less than a tenth of the wavelength which is 1 - 5 meters for the diameter of the buoy

### **Material TBD**

### **Weight TBD**

### **Maintenance**

- Maintenance schedule: Every 6 months
- Replacing worn part should be easy and fast
- Parts should not be replaced after 1 year
- 

### **Manufacturing**



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- All framing and support components will be manufactured in house.
- Others will be Commercial off-the-shelf (COTS)
- Supplier: TBD

### **Appearance**

- The WEC is designed to be a point absorber device
- The design can also be mooring station which installed point absorber type devices

### **Technology apply**

- Hydraulic transfer system
- Hydro flux transfer system
- Pneumatic air turbine system
- Direct-drive mechanical system

### **Reliability**

- Internal space for electrical parts should be seal to prevent water leakage
- Hydraulic component should be well manufacturing to ensure no oil leakage to the ocean
- Design feature that reduce stress on connectors, components should be added on the whole concept



# CHAPTER 5: Concepts generation

A very few number of computational tools that can assist designers on concept design.[20] Using the previous information gathered from Phase 1, the DP and the PDS, the designer is able to come up with some conceptual design. Ideas can come, popping in your head at any time. They can be while working, resting, eating, moving from place to place or even showering. It is very important to always keeping notes and sketch down ideas whenever new one come up. An example of the rough sketch is show in figure 19.

Base on others ideas that have been published on the accessible sources, the designer has formed 7 concepts which also taking account of the PDS. As mention before, the pure concentration of the design is the mechanism of the device where main focus is to convert the linear motion of the wave and transform it to rotary motion to power the generator. Each concept is detail explained from section 5.1 to 5.7

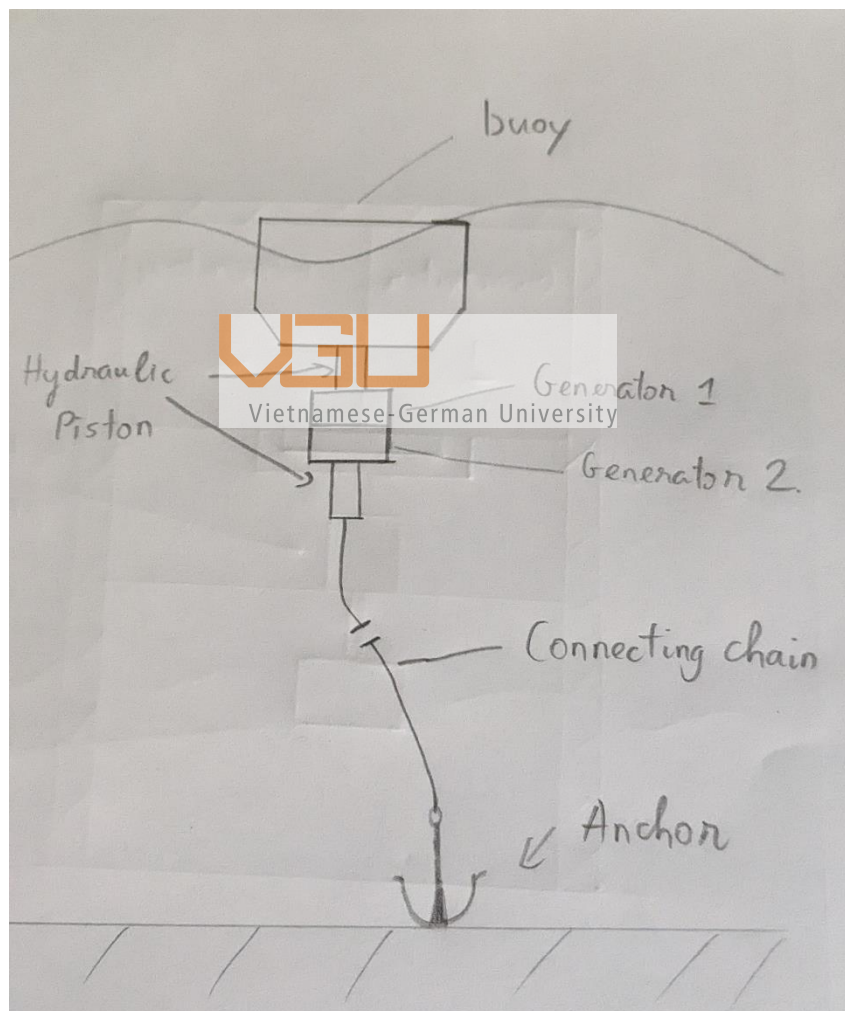


Figure 19 Rough sketch for WEC concept

# 5.1 Schematic of 1<sup>st</sup> concept

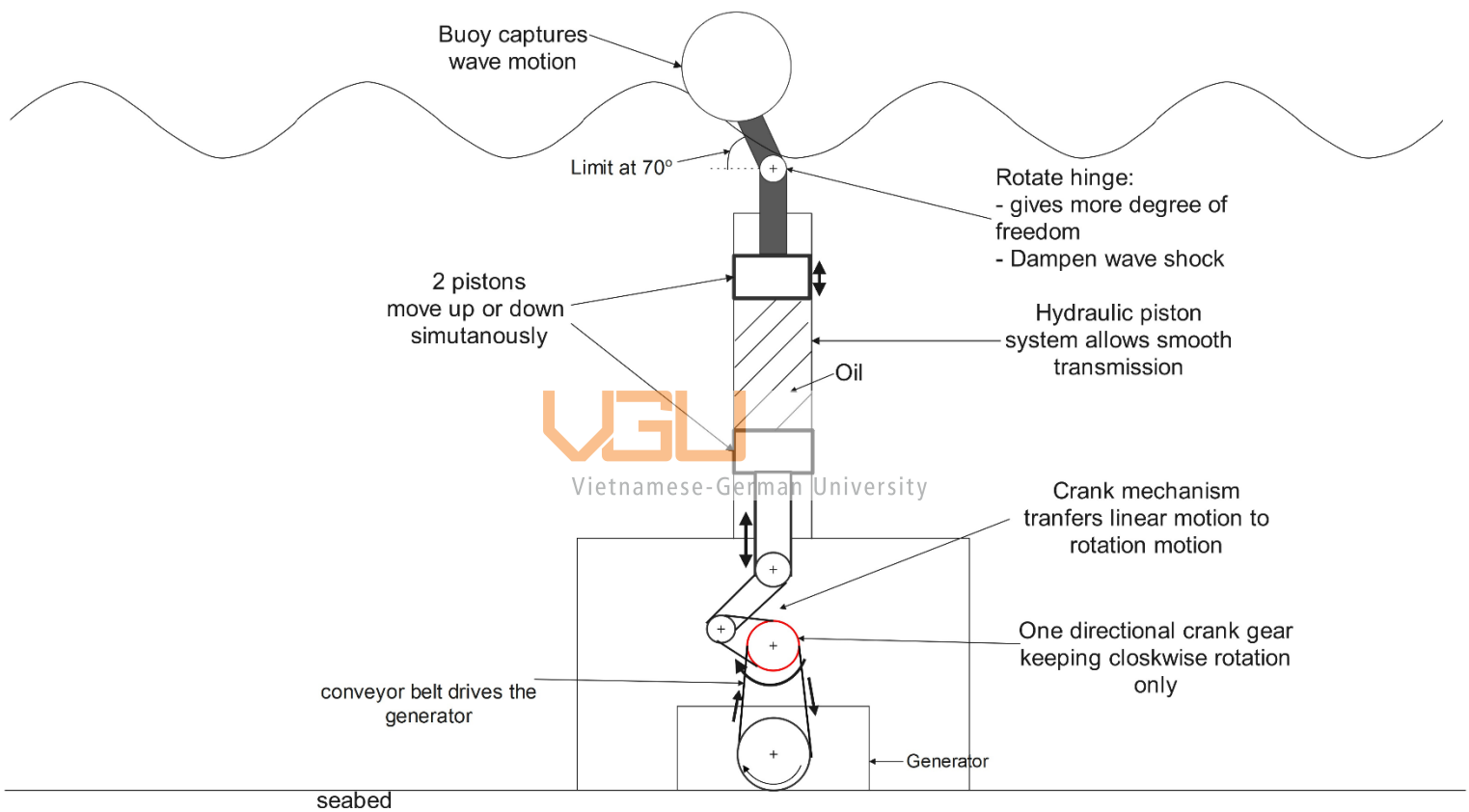


Figure 20 Concept 1

## 5.2 Schematic of 2<sup>nd</sup> concept

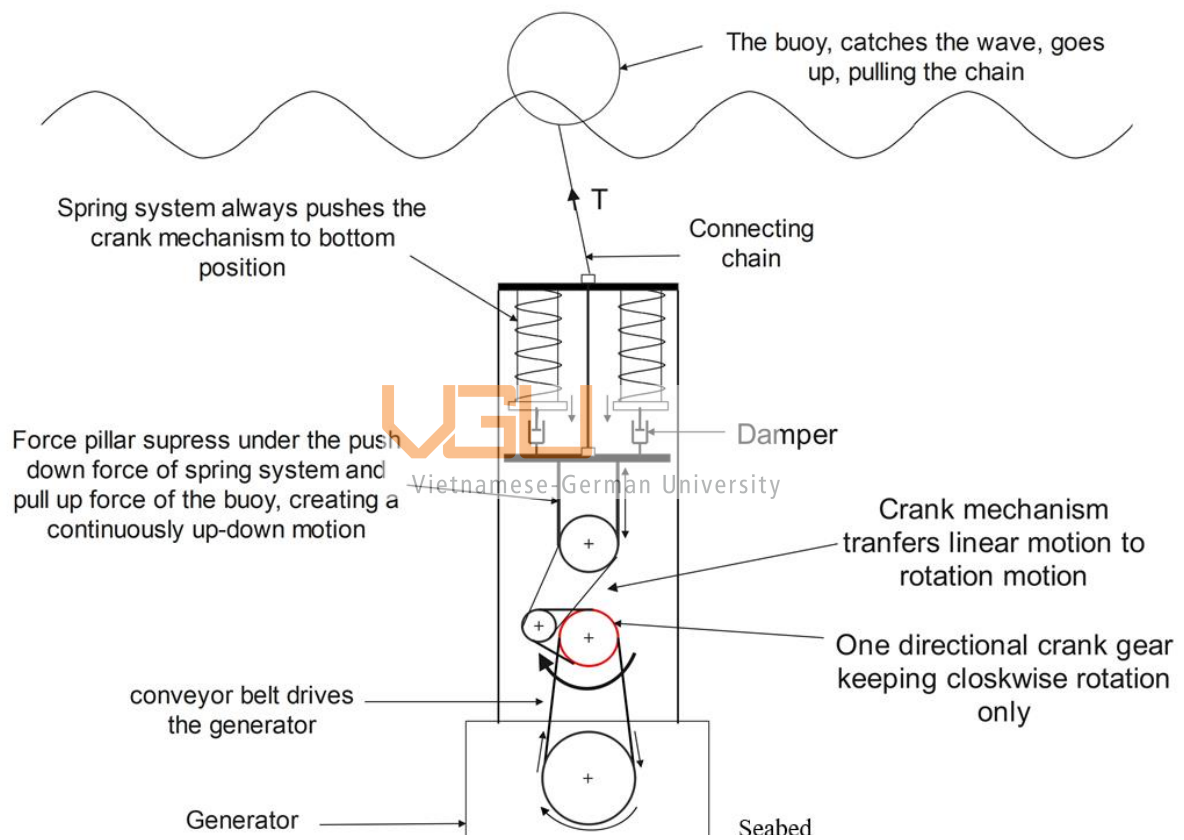


Figure 21 Concept 2

### 5.3 Schematic of 3<sup>rd</sup> concept

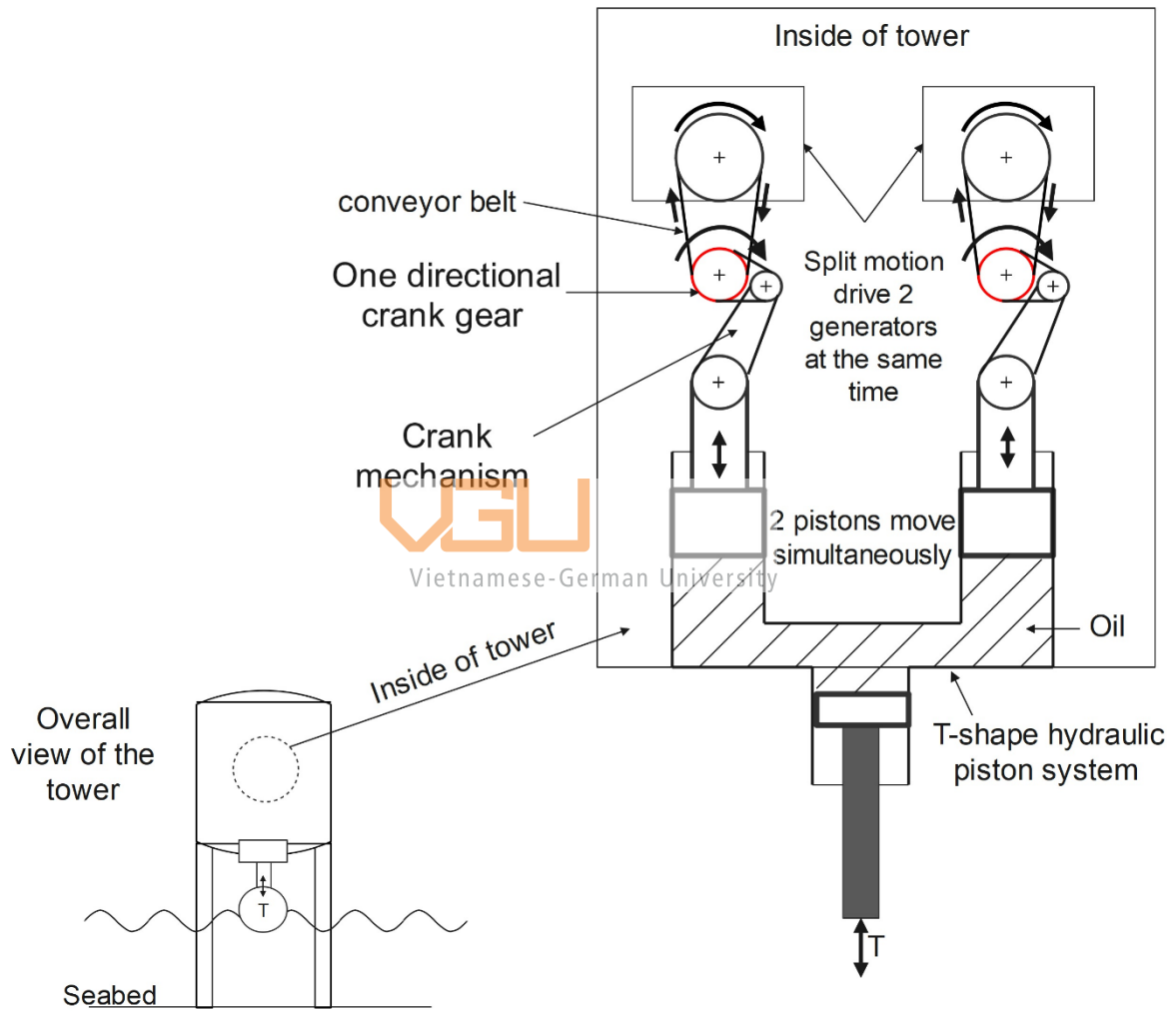


Figure 22 Concept 3

## 5.4 Schematic of 4<sup>th</sup> concept

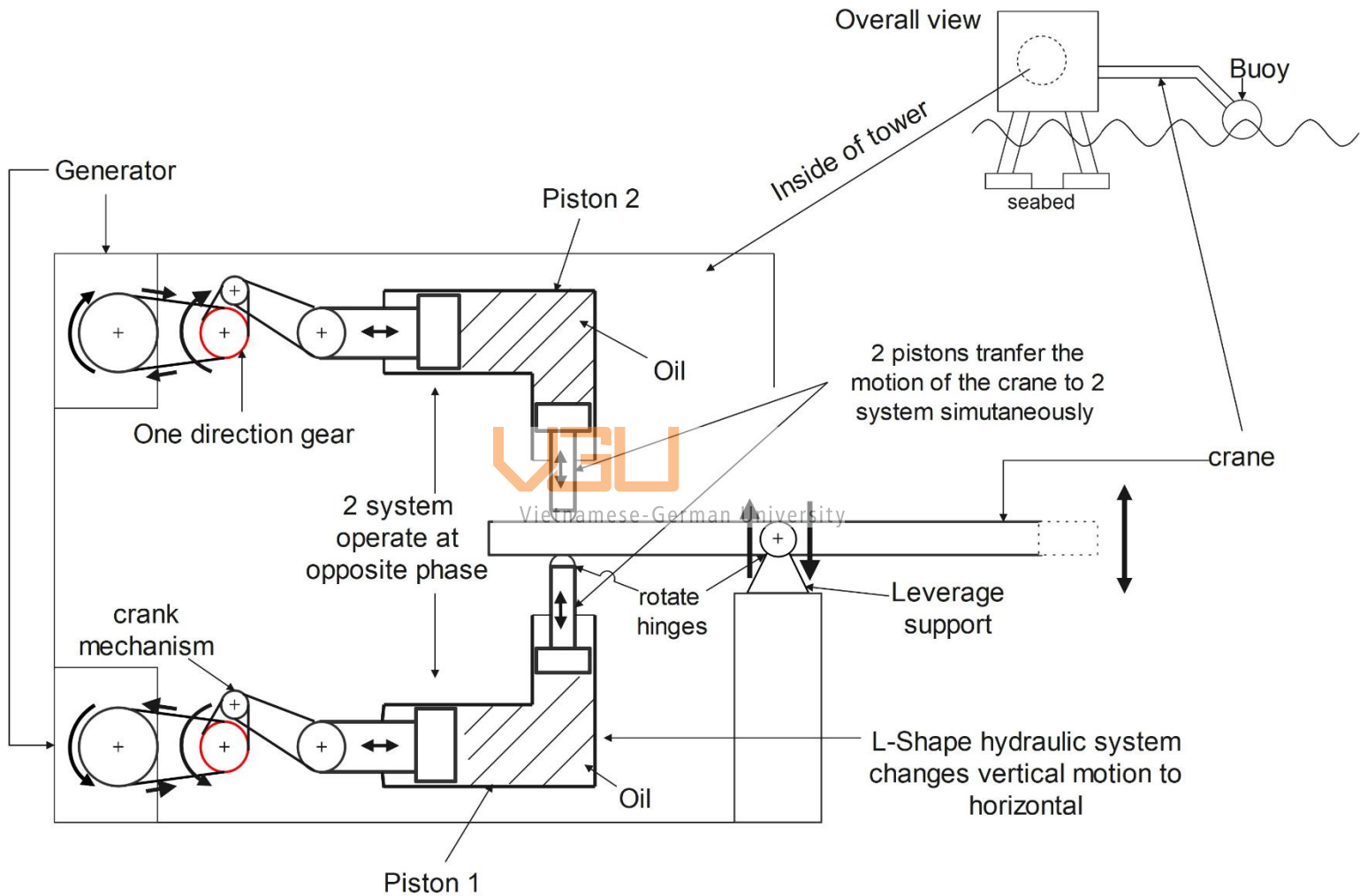


Figure 23 Concept 4

## 5.5 Schematic of 5<sup>th</sup> concept

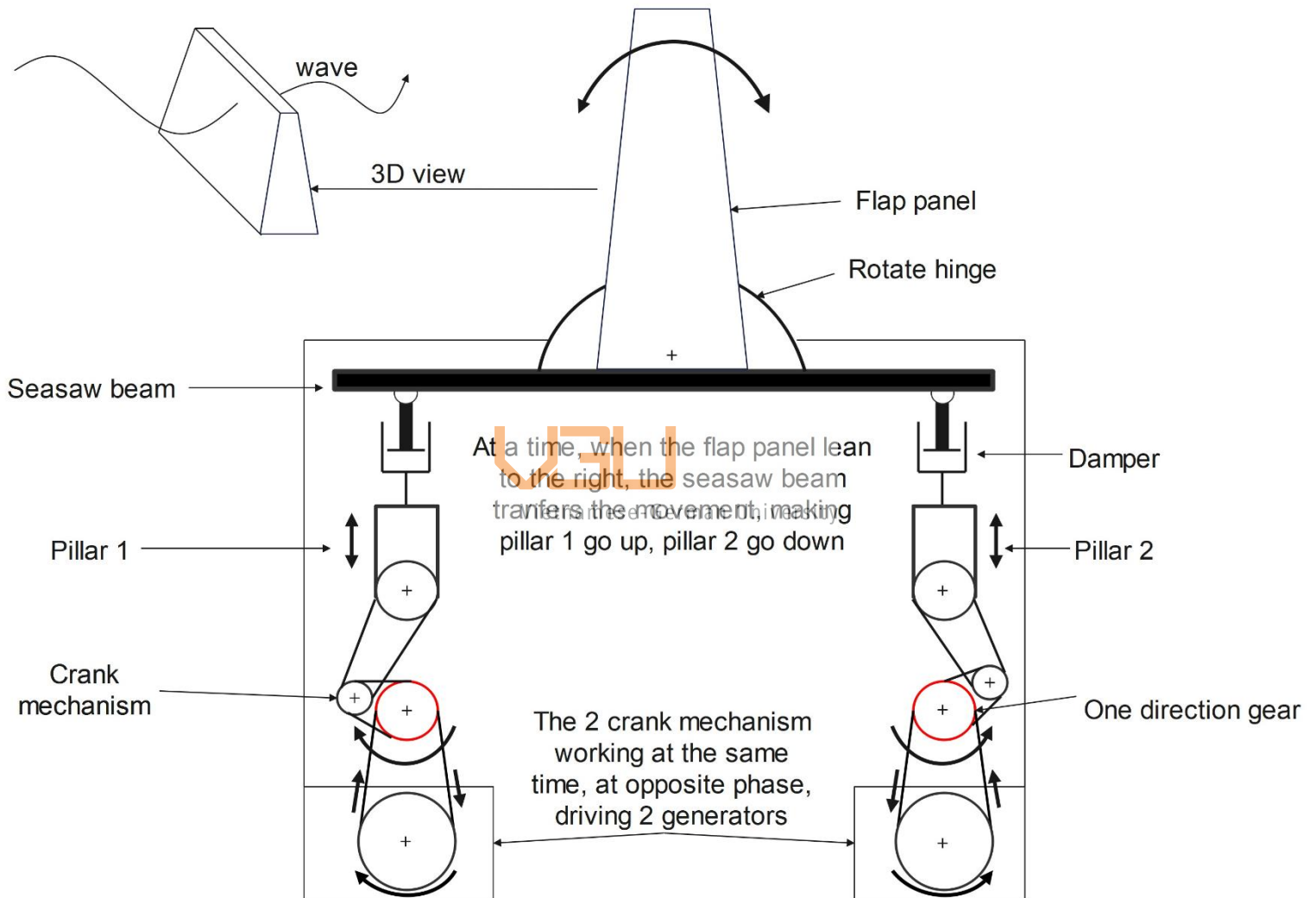


Figure 24 Concept 5

## 5.6 Schematic of 6<sup>th</sup> concept

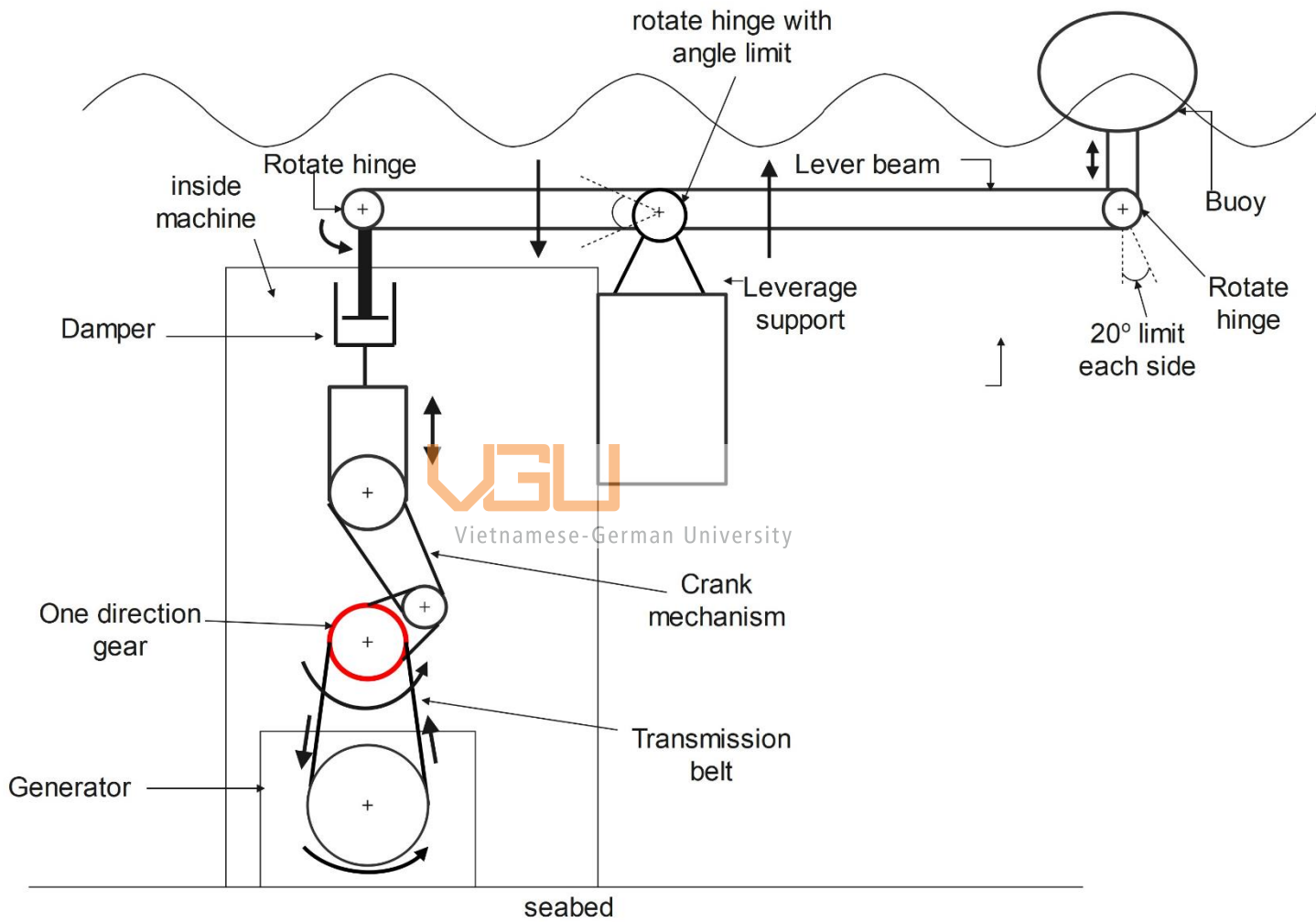


Figure 25 Concept 6

## 5.7 Schematic of 7<sup>th</sup> concept

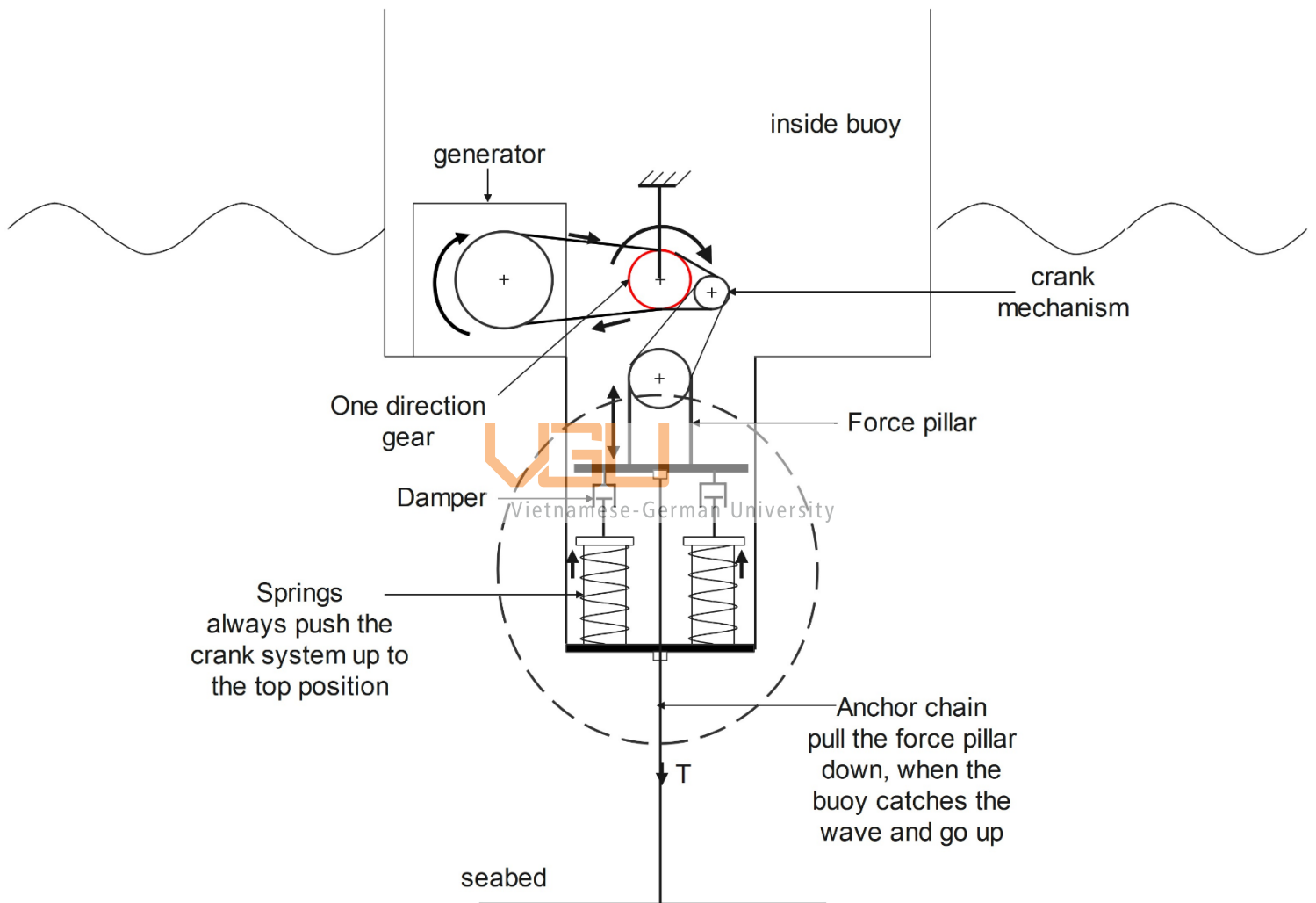


Figure 26 Concept 7



# CHAPTER 6: Selection criteria

A lot of concept can be created from the previous part. So to know which concept is right for the design purpose is very difficult. In order for a designer to choose the best concept, the following questions must be answered

- How to select the most promising concept?
- How to report the process in paper?
- How to combine concepts into a stronger version?

By using Weighted rating method, the best concept can be selected, the document is recorded in form of a matrix and stand out attribute can be shown in the process.

To create the weighted rating matrix, 6 steps must be taken:

- I. Team selects criteria of selection
- II. Prepare a table with the criteria in the 1<sup>st</sup> column
- III. Give percentage to each criteria so that they sum up to 100
- IV. List concepts in columns
- V. Score each concept with 0, 1, 2, 3 respect to not satisfy, tolerable, adequate, good
- VI. Multiply each concept rating by weight and summed then up to create ultimate rating for that concept

**Table 2 Selection criteria**

1	Use Linear-to-rotary PTO
2	Absorb fully potential or kinetic wave energy
3	A point absorber type of WEC
4	Have a productive mechanism
5	Use hybrid PTO mechanism
6	Apply exist PTO technology
7	Reliable mechanism
8	Have stress reduce feature
9	No sea water leakage
10	Easy for maintenance
11	Easy for installation
12	Easy for manufacturing

## 6.1 Weighted rating matrix

No.	Selection Criteria	Weight	Concepts													
			1 Multi-direction buoy system		2 Anchor system		3 Flap panel design		4 Lever buoy design		5 Buoy crane tower		6 Buoy tower		7 All-fused buoy	
Rating scale			Rating	Rated Score	Rating	Rated Score	Rating	Rated Score	Rating	Rated Score	Rating	Rated Score	Rating	Rated Score	Rating	Rated Score
			0	Unsatisfactory												
			1	Tolerable												
			2	Adequate												
			3	Good												
1	Use Linear-to-rotary PTO	16%	3	0.48	3	0.48	3	0.48	3	0.48	3	0.48	3	0.48	3	0.48
2	Absorb fully potential or kinetic wave energy	13%	3	0.39	3	0.39	3	0.39	3	0.39	3	0.39	3	0.39	3	0.39
3	A point absorber type of WEC	10%	3	0.3	2	0.2	3	0.3	3	0.3	3	0.3	3	0.3	2	0.2
4	Have a productive mechanism	10%	1	0.1	1	0.1	3	0.3	2	0.2	3	0.3	3	0.3	1	0.1
5	Use hybrid PTO mechanism	10%	3	0.3	0	0	0	0	0	0	3	0.3	3	0.3	0	0
6	Apply exist PTO technology	7%	3	0.21	3	0.21	3	0.21	3	0.21	3	0.21	3	0.21	3	0.21
7	Reliable mechanism	6%	2	0.12	2	0.12	1	0.06	3	0.18	2	0.12	2	0.12	2	0.12
8	Have stress reduce feature	6%	3	0.18	1	0.06	1	0.06	3	0.18	2	0.12	2	0.12	1	0.06
9	No sea water leakage	6%	3	0.18	3	0.18	3	0.18	2	0.12	1	0.06	3	0.18	3	0.18
10	Easy for maintenance	6%	1	0.06	1	0.06	1	0.06	2	0.12	3	0.18	3	0.18	3	0.18
11	Easy for installation	5%	1	0.05	1	0.05	1	0.05	1	0.05	1	0.05	1	0.05	3	0.15
12	Easy for manufacturing	5%	2	0.1	2	0.1	2	0.1	2	0.1	1	0.05	1	0.05	3	0.15
	<b>Total Score</b>			2.47		1.95		2.19		2.33		2.56		2.68		2.22
		100%														


Table 3 Weighted rating matrix

### Rating

- 0 The design does not reach the requirement of the criteria
- 1 Some small aspect of the design is acceptable to the criteria.
- 2 Enough in quantity, or good enough in quality for the criteria to be reached
- 3 The design meet the criterial completely or even exceed expectation

**Concept 6 are selected**

## 6.2 Selection criteria explanation

1. Use Linear-to-rotary PTO: The mechanism of the design must be a linear to rotary mechanism
2. Point absorber: Follow the PDS, the design of the WEC device must be a point absorber which have small dimension relative to incident wavelength.
3. Absorb fully potential or kinetic wave energy: An important feature for designing the mechanism whether it can take up all the potential energy created by the wave from the crest to the trough, Or the kinetic of an incoming wave and return wave. If the device can only absorb a half of wave cycle, then the point given to that concept will not reach maximum
4. Have a productive mechanism: The design mechanism produces more output rotary energy without increasing the number of input. If one absorber component transfers the energy to run double or triple the amount of linear-to-rotary PTO, then the whole system is considered productive.
5. Use hybrid PTO mechanism: If the design mechanism can apply multiple type of existing PTO, not only the new PTO can have all the advantages of the applied PTO, but also eliminating the weakness of each PTO by supporting each other
6. Apply exist PTO technology: When reviewing existing PTO of WEC, they show a good amount of advantage for transfer linear motion to rotary motion, increase productivity, increase reliability. Applying these technologies is also inheriting these good characteristic of each type of PTO.
7. Reliable mechanism:  The design needs to work reliably; the mechanism should be able to work well even in testing conditions with more loads and stress than real world situations. Vietnamese-German University
8. Have stress reduce feature: The design can have connection, joint that work under stress. Having a feature that can reduce stress at these point will increase the reliability of the whole system
9. No sea water leakage: The designed PTO mechanism need to put inside a seal compartment where corrosive sea water cannot leak through in order to not damage electrical parts or mechanical components
10. Easy for maintenance: The device should be easy to access for maintenance. Worn part should be easy to replace
11. Easy for installation: As the design environment is the sea, at 50m and more depth, the installation of the device will be challenging. The design should promote a simplest way to deploy in the open sea
12. Easy for manufacturing: The schematic of the device is recommended to be simple, easy to understand. The mechanism of the machine must be simple so that it is easy to manufacturing.

### 6.3 Weighting explanation

	Selection Criteria	Weight	Explanation
1	Use Linear-to-rotary PTO	16%	The main purpose of the design is to create a linear-to-rotary PTO, so this must have the most weight
2	A point absorber type of WEC	13%	The PDS narrow the design down to point absorber WEC so to design a linear-to-rotary PTO that can fit to working principle of point absorber device is also important but rank after Criteria 1
3	Absorb fully potential or kinetic wave energy	10%	These have the same weighting as they all address the increasing productivity of the mechanism.
4	Have a productive mechanism	10%	
5	Use hybrid PTO mechanism	10%	
6	Apply exist PTO technology	7%	This criteria is about inheriting the strong point of existing PTO so it is ranked after productivity criteria
7	Reliable mechanism	6%	These criteria generally focus on a reliable system so they have the same weighting.
8	Have stress reduce feature	6%	
9	No sea water leakage	6%	
10	Easy for maintenance	6%	
11	Easy for installation	5%	The main purpose of the project is the PTO mechanism designing, so the focus for installation and manufacturing is not vital, but cannot be left ignore, so this has the least weighting
12	Easy for manufacturing	5%	

Table 4 Weighting explanation

# CHAPTER 7: Detail design

As the wave distribute not evenly on the water surface, their energy also fluctuates over time. To effectively harvest energy that change magnitude over time require a ‘control solution’ which adjust the mechanism to actively response to change in wave height, wave period is challenging and deviate from the main aim of the thesis.

As for that reason, the condition of the sea wave is remaining constants. The wave height and wave length is chosen from the result number of Dastgheib A [21] where the height of the wave is 1.2m and wave’s period is 5 sec. As shown in fig. 11,  $H= 1.2\text{m}$  so the length from the crest or trough to the water surface (a) is 0.6 m.

## 7.1 Assembly of PTO mechanism for the Buoy Tower

It has been decided that concept number 6 is to put in to detail design.

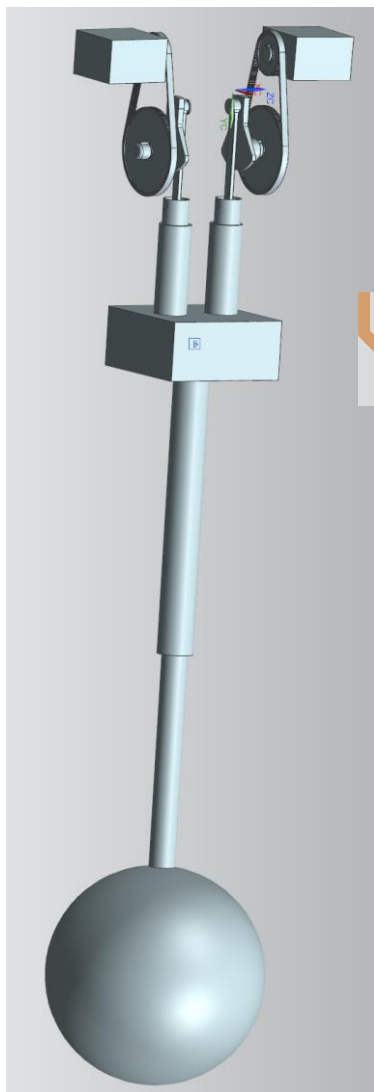


Figure 28 Assembly of WEC Front View

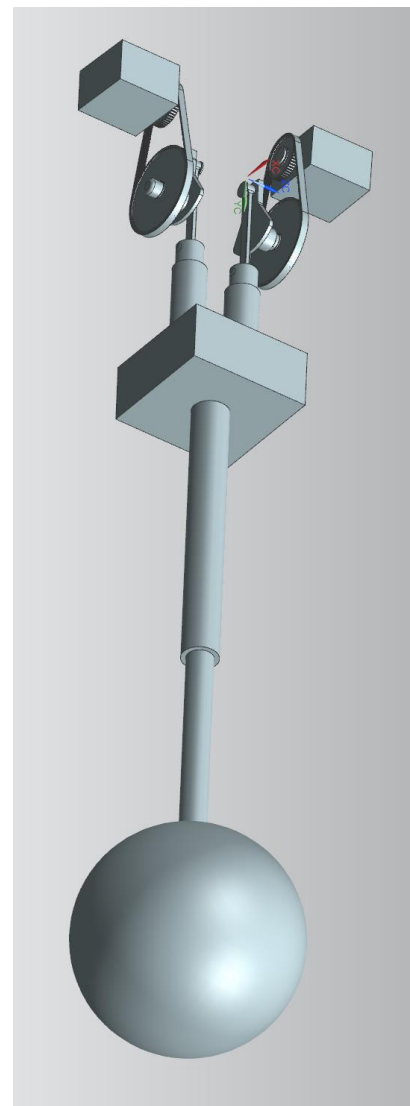


Figure 27 Assembly of WEC bottom view

No.	Part name	Quantity
1	Buoy piston	1
2	Large hydraulic piston tube	1
3	Oil container	1
4	Small hydraulic piston tube	2
5	Piston head	2
6	Connecting rod	2
7	Small timing pulley	2
8	Big timing pulley	2
9	Crank shaft	2
10	Generator	2

**Table 5 List of parts**

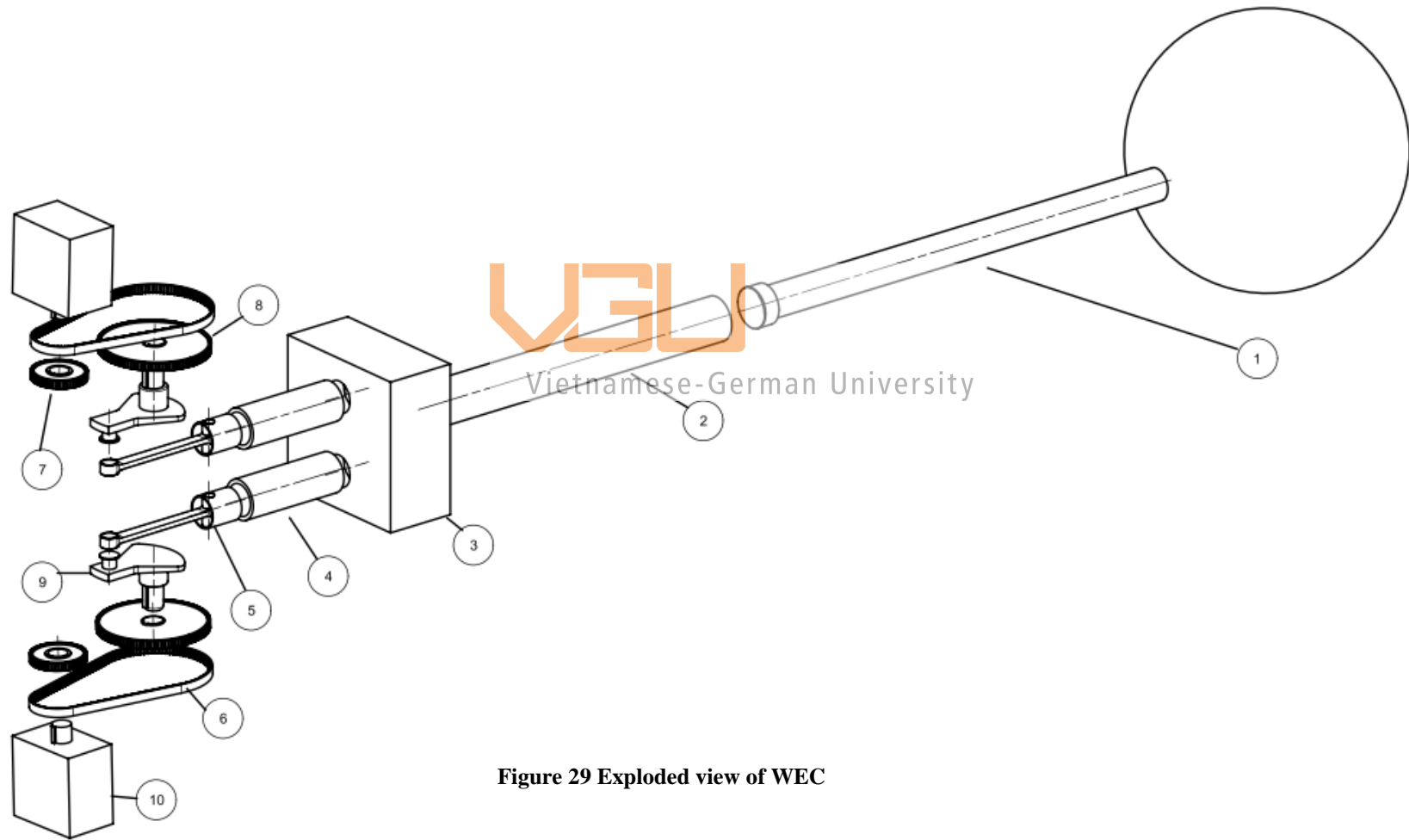


Figure 29 Exploded view of WEC



The design of the Buoy Tower (BT) is 3D designed to be focus on the mechanism inside only. Each part of the assembly is belonged to three stage of the conversion stage for a Wave energy device. They are absorption stage, transmission stage, generation stage. The 1<sup>st</sup> stage's duty is to convert the wave motion into moving motion of the WEC. This absorbed energy is transmitted into a different kind of energy called the rotary energy in the 2<sup>nd</sup> and transfer into electrical energy in the 3<sup>rd</sup> stage.[22]

In the absorption stage, the buoy piston is the sole component. The generator belongs to the generation stage. And every other component in table 3 is a part of the transmission stage.

The working principle of the system is based on how to transfer the linear motion of the wave to oscillating motion and then convert it to rotary motion that can drive the generator. The buoy will capture the up and down motion of the wave, making the piston (1) attach to it move inside the hydraulic cylinder. Within the cylinders and the oil container (3) are fill with oil. The oil acts as a transferring medium to transfer the energy to make the piston located inside the small hydraulic tube move. The movement is then transform in to rotary motion by the connecting rod and the crankshaft which are well-known for their usage in combustion engine. Finally, the crankshaft is connected with the generator with a timing pulley system. Bigger radius pulley is mounted into the shaft; the smaller radius pulley is mounted to the generator shaft. These two pulley is connected with each other by a belt. So when the crankshaft spin, the pulley system will transfer that spinning energy to the generator. But on the oil container there are two holes which is to multiply the system by two from then on. At one stroke of the buoy piston, the oil deliver energy to two mechanisms, increasing the productivity by two. Two crankshaft spin at them same time, driving two generators simultaneously.

General dimension

Length: 1290mm

Width: 1000 mm

Height:4808.8 mm



In the design, the big hydraulic tube, the two smaller hydraulic tube and the oil container is welded together to create a uniform body with hollow volume inside that hold a constant amount of oil. The amount of oil is 33,080,200 mm<sup>3</sup>. That include the volume of the big cylinder when the buoy piston positioned at the middle of the tube (1) + the volume of the hollow space inside the oil container (2) + the volume of the two small cylinder when the piston also positioned at the middle of the tube (3) – the different between (1) and (3). This amount of oil will create an air space inside the oil container. As the buoy piston pushes the (1) amount of oil up in the oil container, the air will be replaced by the oil and escape through an air hole tube with small diameter. The piston of the crank mechanism is designed to move a 400 mm distance. Because the amount of (1) is bigger than (3), so if the is no free space inside the oil container, the buoy piston cannot move up to maximum height (600 mm) but only 400 mm instead.

## 7.2 Parts and components

### 7.2.1 Buoy piston

Function: The Buoy is made hollow inside so that it can float on water, the hydraulic cylinder is attach to the buoy. As the buoy absorb the wave motion, the piston will push the oil to go up or pull it back down.

Material: Stainless steel

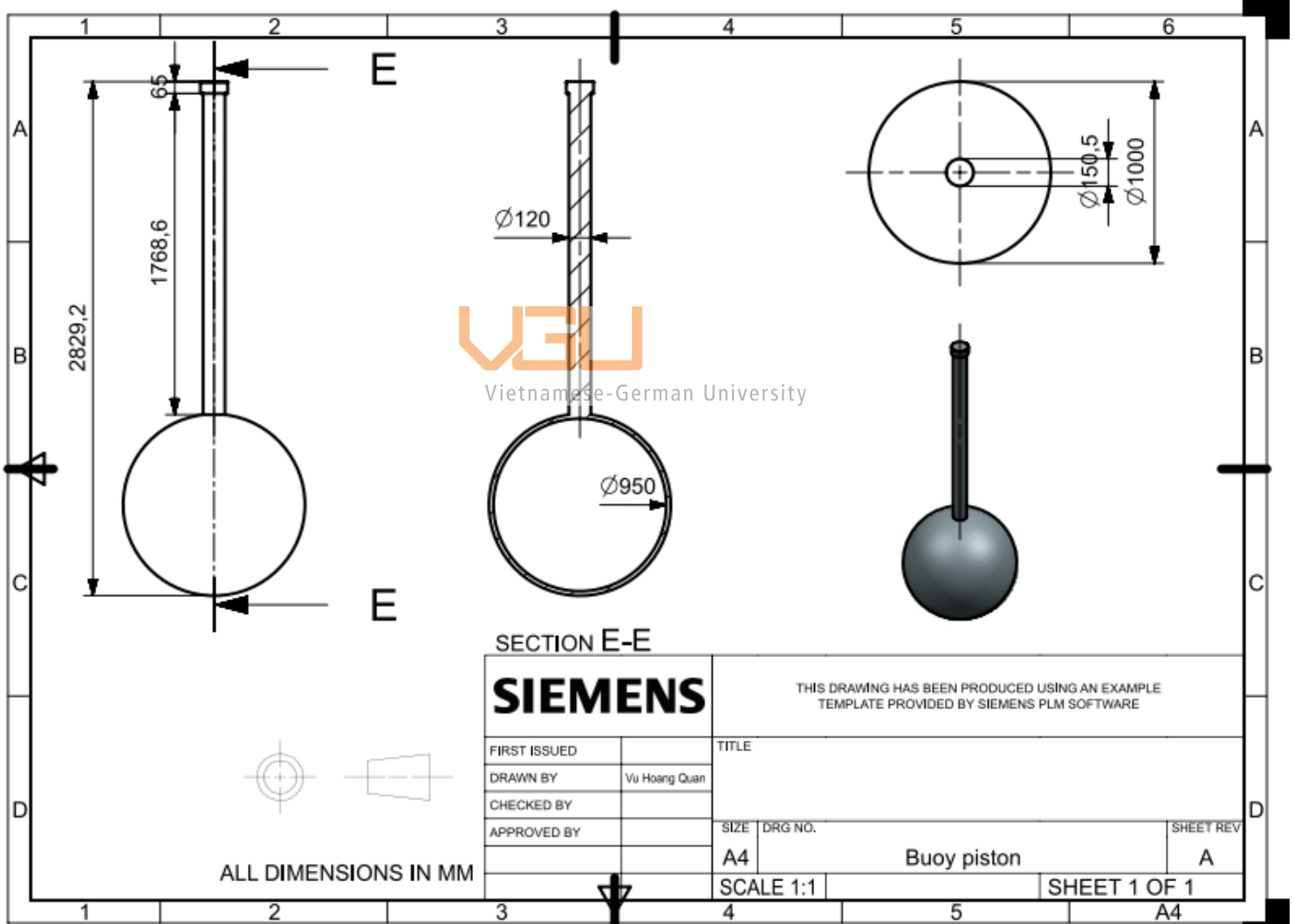


Figure 30 2D sketch of buoy piston

### 7.2.2 Hydraulic piston tube

Function: The tube acts as a guiding slide for the piston to move. It also restricts the piston from moving other direction other than vertical motion. Also the tube is made to be fit with the piston head of the piston buoy so that there will be no oil leakage.

Material: Stainless steel

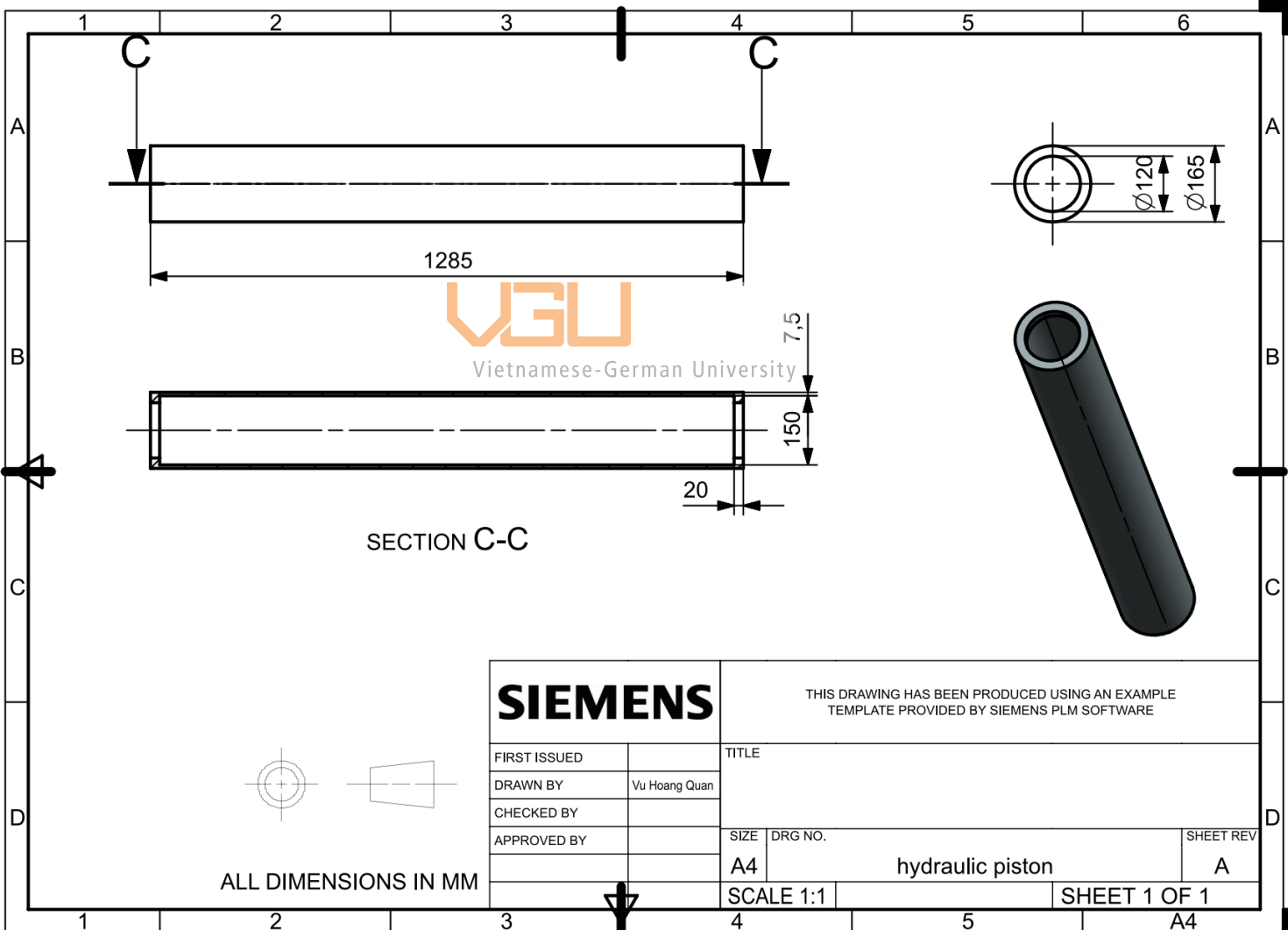


Figure 31 2D sketch of Hydraulic piston

### 7.2.3 Oil container

**Function:** The oil container is designed to split the oil flow into two directions. Its design has one input for the buoy piston and two output for the two hydraulic piston that power the crankshaft. The design for oil also acts as a damper, smoothing the abrupt motion of the wave, increase the reliability of the system

**Material:** Stainless steel

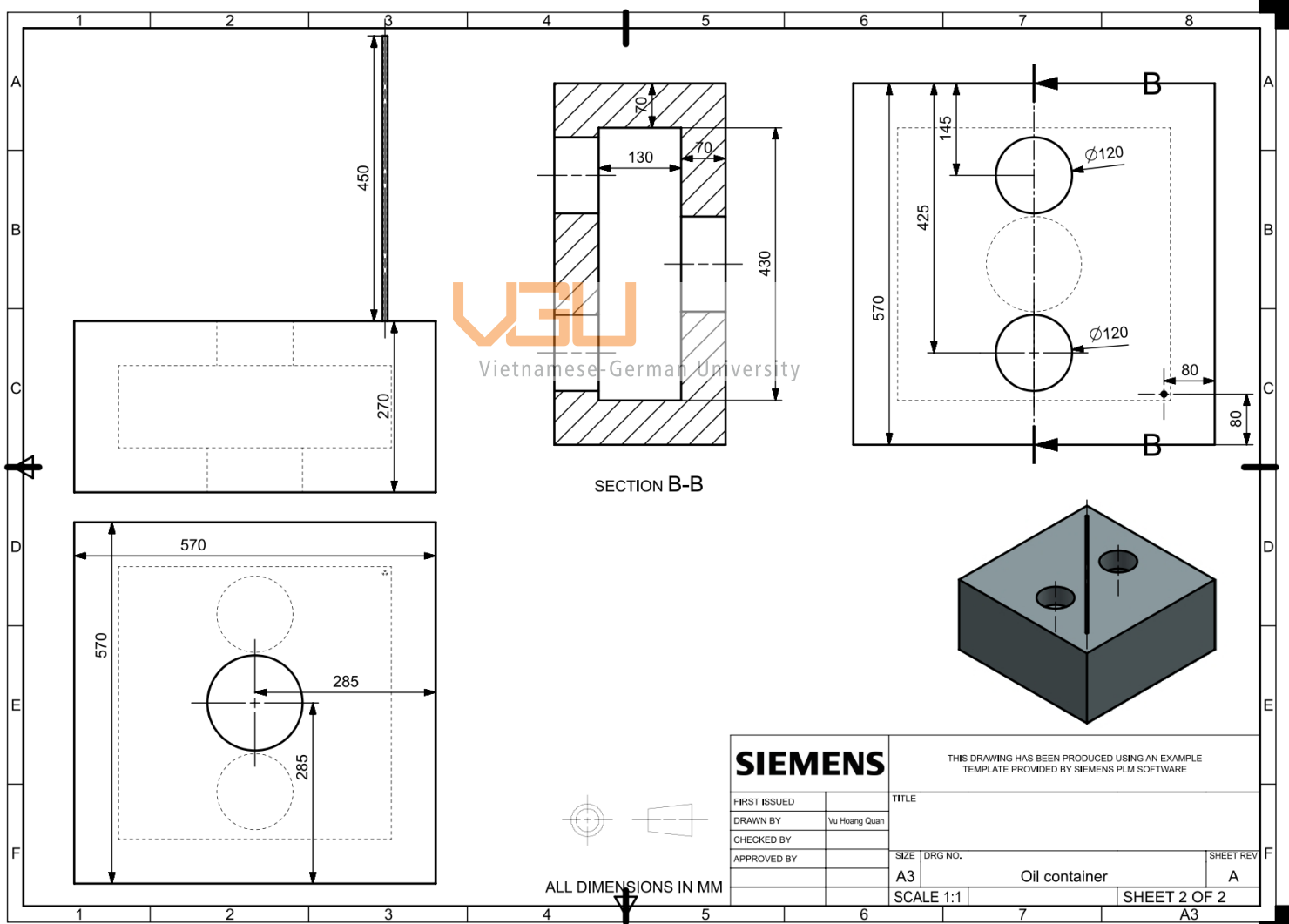


Figure 32 2D sketch of oil container

### 7.2.4 Small hydraulic tube

**Function:** The tube acts as a housing for the oil and the piston. As the oil raise up inside, the tube will guide the piston to move in vertical movement only and also prevent oil leakage as it inner diameter is designed to fit with the piston head inside.

**Material:** Stainless steel

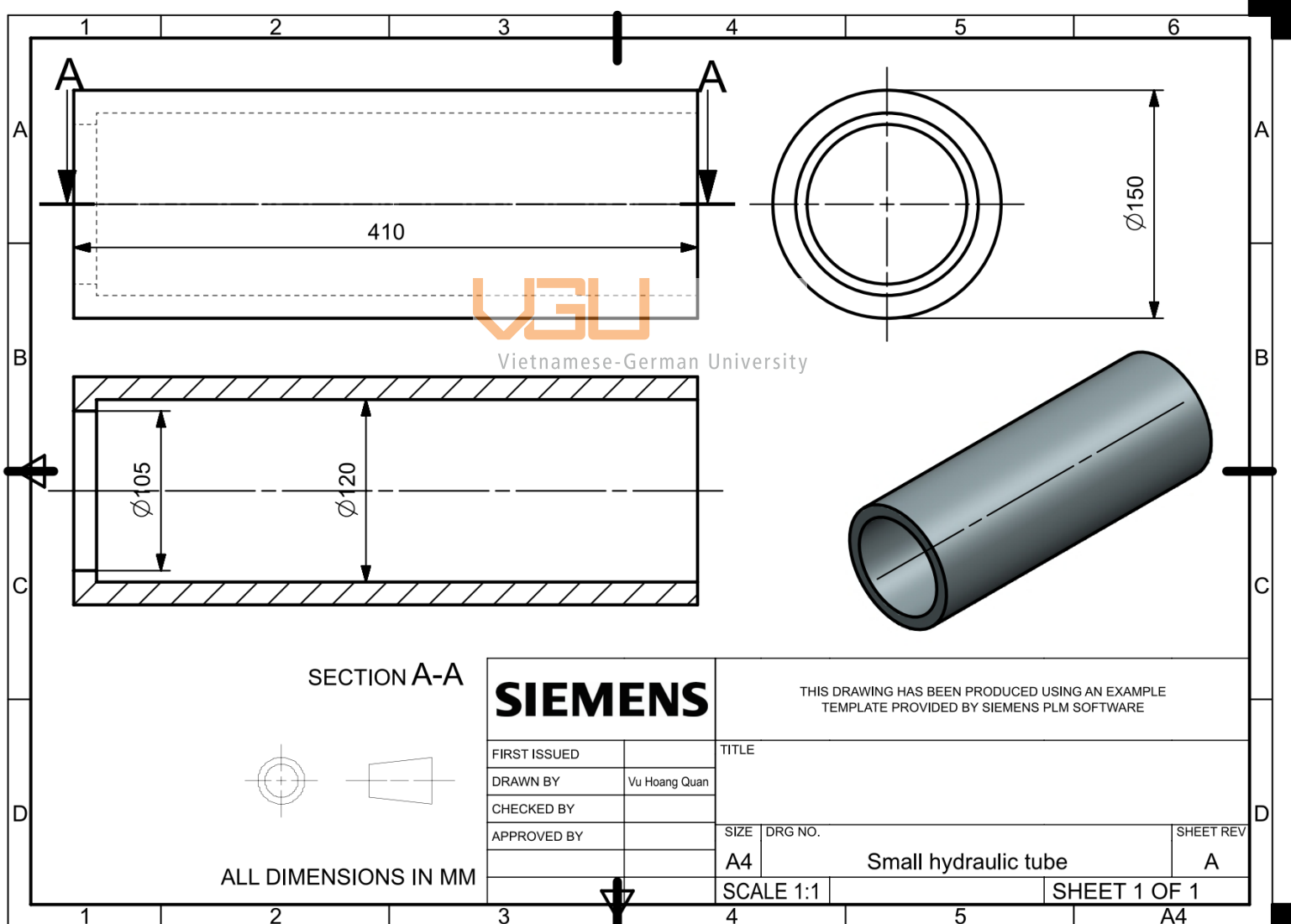


Figure 33 2D sketch for small hydraulic tube

### 7.2.5 Connecting rod

**Function:** The rod is design to connect the piston to the crankshaft. Together with the crank, the connecting rod transfers the reciprocating motion of the piston into the rotation of the crankshaft. The connecting rod is very important as it can transmit the compressive and tensile forces from the piston.

**Material:** Steel

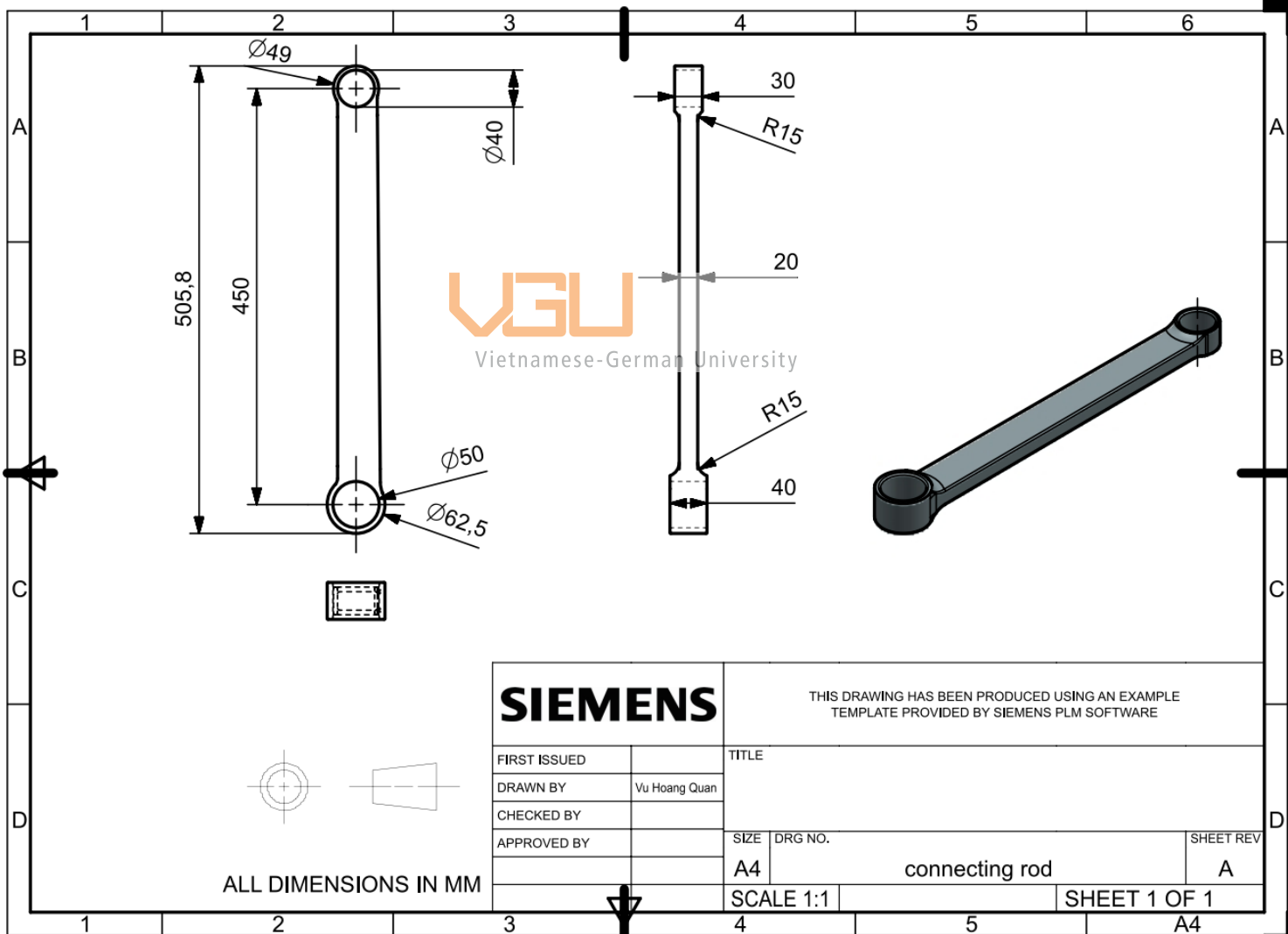


Figure 34 2D sketch of connecting rod

### 7.2.6 Piston head

**Function:** This moving component inside the cylinder that can push or pull the liquid contain by the whole hydraulic system. It is supposed to receive the force from the oil and transfer it to the crankshaft via the rod

**Material:** Steel

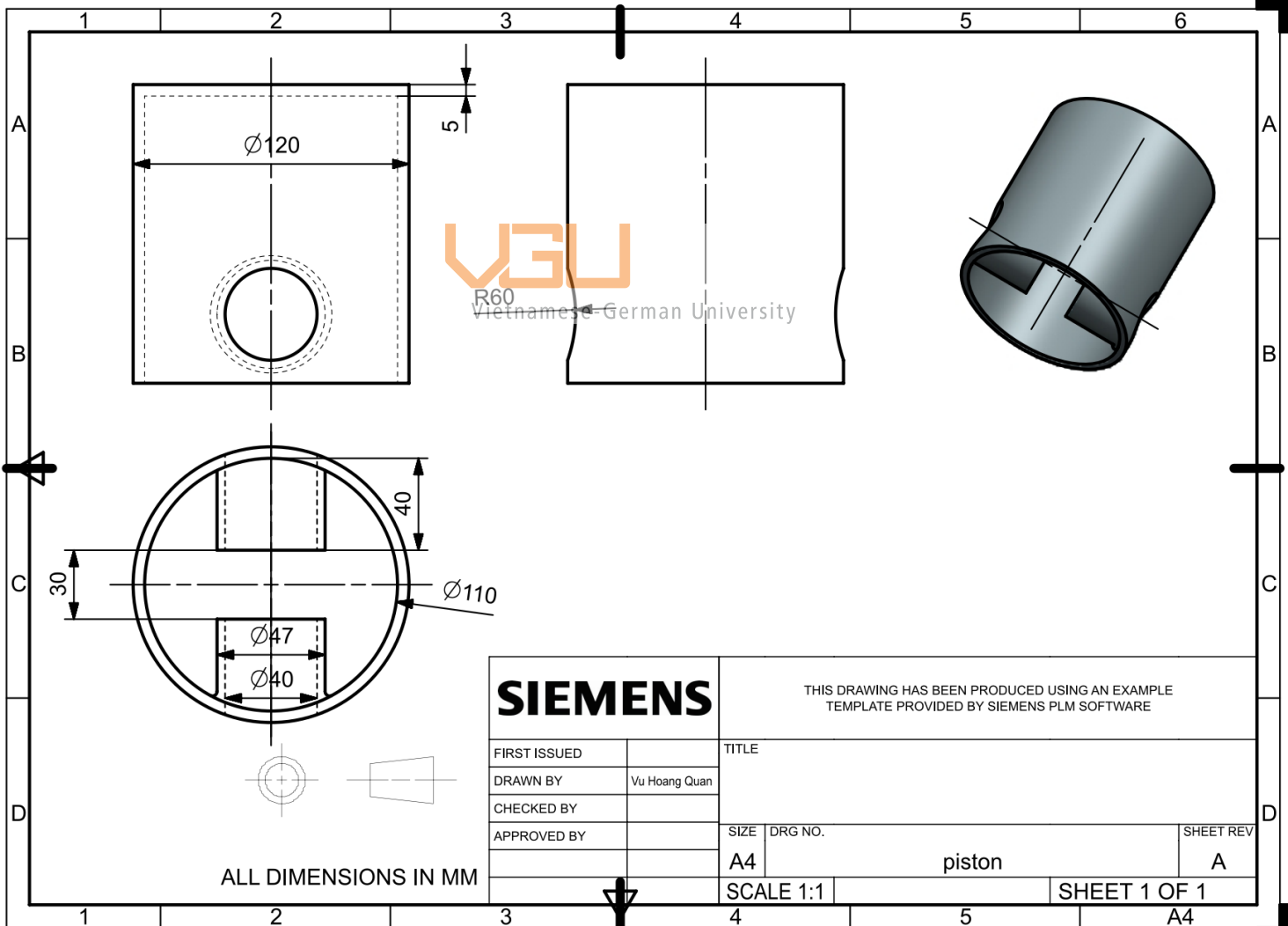


Figure 35 2D sketch of Piston head

### 7.2.7 Timing pulley small

Function: This pulley is fix to the generator. Together with the belt and the other timing pulley, it transfers the rotary motion from the crankshaft to the generator

Material: Aluminum

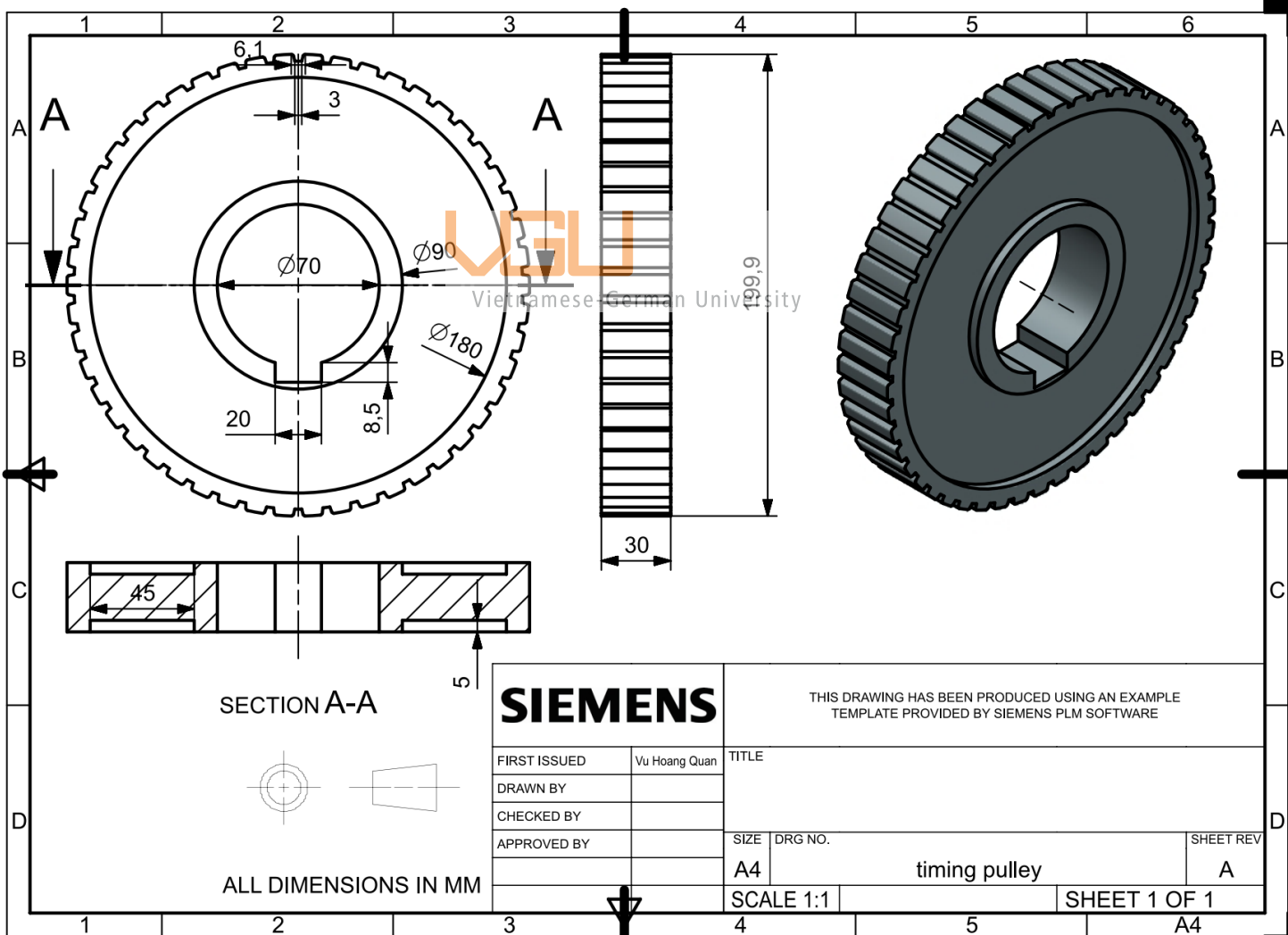


Figure 36 2D sketch of timing pulley small



### 7.2.8 Timing pulley big

Function: This pulley is fix to the crankshaft. Together with the belt and the other timing pulley, it transfers the rotary motion from the crankshaft to the generator

Material: Aluminum

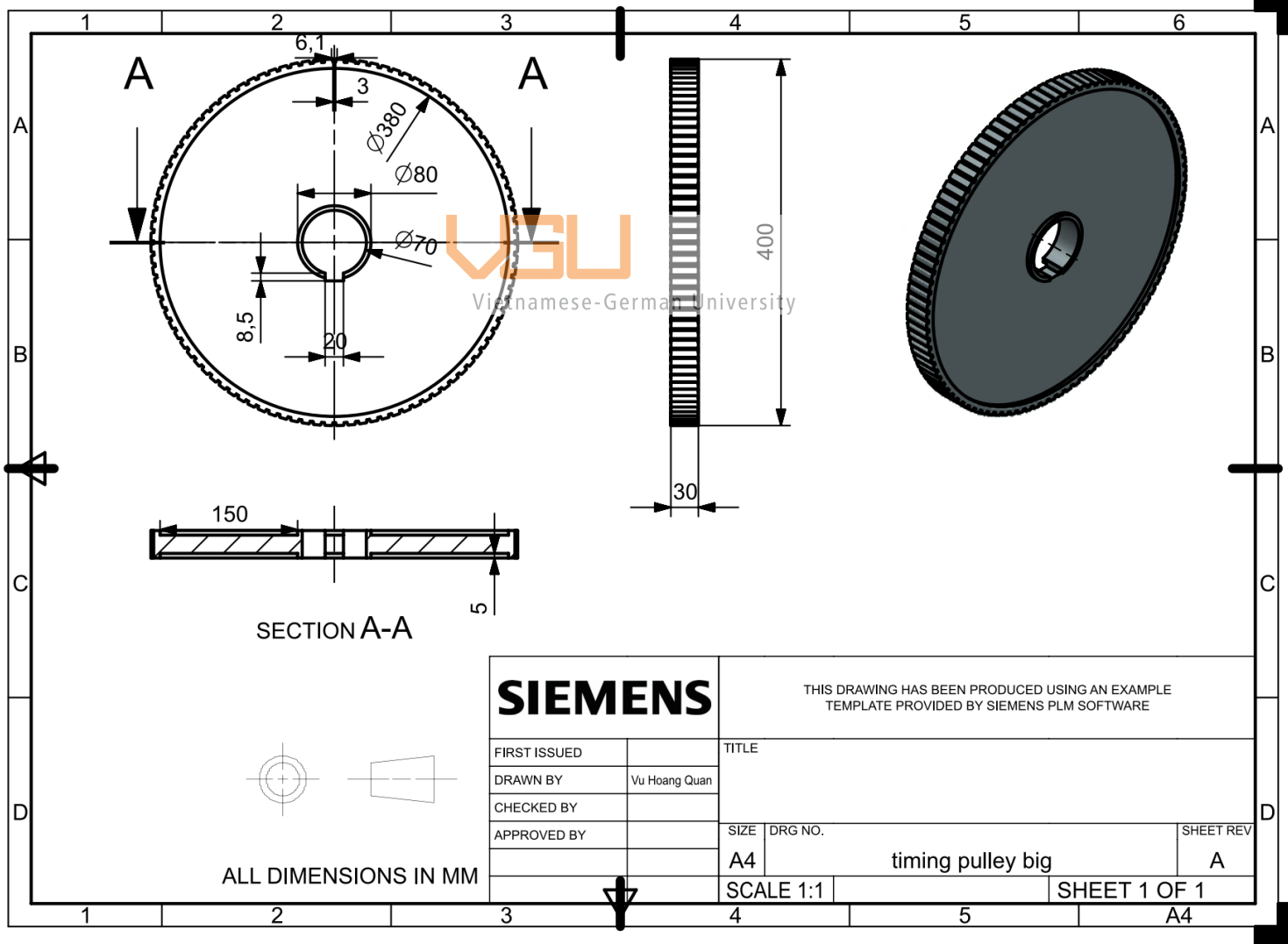


Figure 37 2D sketch of the timing pulley big

### 7.2.9 Crankshaft

Function: It transforms reciprocating motion of the piston into rotational motion which make the timing pulley spin.

Material: Forged steel

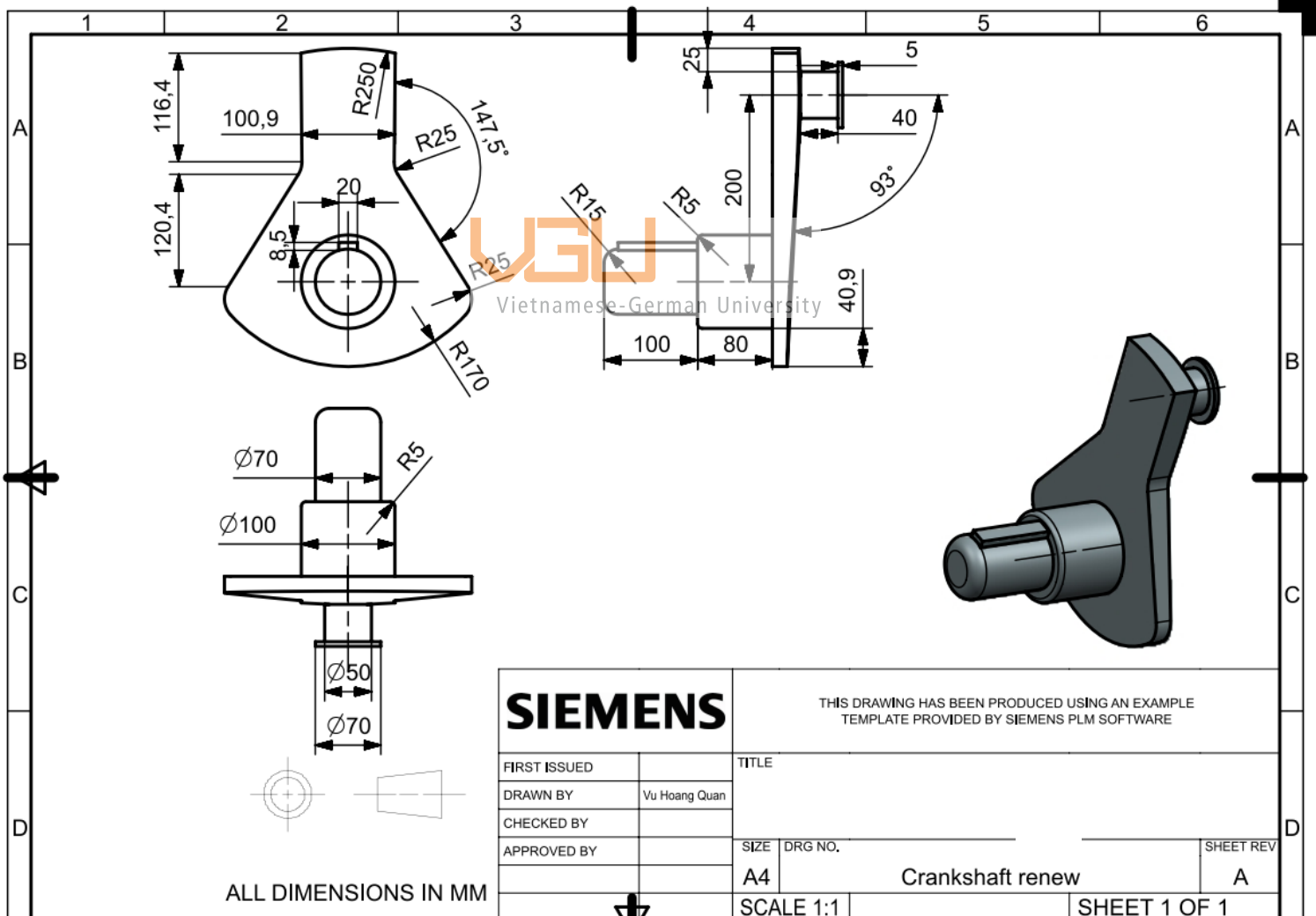


Figure 38 2D sketch of the crankshaft

# CHAPTER 8: Conclusion

## 8.1 Conclusion

The demand on new renewable source of energy has been increasing since the care for environment raised importantly. Wave energy show a promising future for electricity production. The thesis focuses on a new design for an WEC device that possesses a linear-to-rotary PTO. The thesis has been done by applying the engineering design process, including three phase: Gathering information; Concept generation; Detail design. After selecting from 7 concepts, a final idea is detail designed. 3D model is made with the help of computer-aid-design software, NX 12.

The problems encountered during the work are shortage of information, especially the data for Vietnam coast, sea condition which is crucial for designing. Also the calculation for the dimension of the detail model is another time-consuming task.

## 8.2 Future work

The thesis excludes from the unstable feature of wave energy, uncertain variation of wave overtime. Further development need to be made in order to increase energy absorption efficiency. A control scheme need to be investigate and more testing analysis must be considered if the design wants to be developed further such as commercial model.



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