OCEAN ENERGY MLS SVALBARD PROJECT

REPORT

Technical Design Report

CONFIDENTIAL

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CHAPTER 1

INTRODUCTION

This technical report serves the purpose of describing the different findings in the Svalbard OCE project. The main goal of the project is to develop a WEC system with similar technology as the OCE light buoy project. Whic consist of a linear to rotary magnetic gear and rotary generator for converting the mechanical motion into electricity, which should be used for charging of Electric Vehicles (EV's) at Svalbard. In this chapter the energy demand for charging three EV's is calculated, and the WEC topology is presented.

1.1 Energy demand

In order to design an appropriate Wave Energy Converter (WEC) for EV charging, it is necessary to calculate the energy demands for such charging station. It is assumed that the EV which should be charged at the facility is a Tesla Model S, which is claimed to have a consumption of 170 Wh/km based on the NEDC (New European Drive Cycle) [1]. However, to account for charging efficiency and weather conditions the consumption is set to 249 Wh/km [2, 3].

If the EV is to travel 7000 km per year, the energy demands for one year can be calculated:

$$7000km * 249Wh/km = 1743kWh \tag{1.1}$$

Calculating the average power production needed to have the EV running for one year, assuming that the WEC will produce power at 5000 hours per year:

$$1743kWh/5000hours = 350W \tag{1.2}$$

Following the above calculations, the WEC should be designed to deliver 350 W in mean power production per EV. The WEC should be able to deliver enough power to charge three EV's, why the total amount of power for the full WEC system is set to a mean power of 1050 W. In order to accommodate this power demand, the following simulations are performed for the WEC, in order to size the WEC.

1.2 WEC Topology Analysis

This section describes the analysis of different WEC topologies for the Svalbard OCE project. However it has been decided to construct the Power Take Off (PTO) system of the WEC using the linear to rotary magnetic gear (MLS) connected to a rotary electric generator in order to convert the mechanical output into electric power. The topology for the WEC is chosen based on simulations of different WEC topologies and an analysis of the mechanical structure together with complexity and robustness. Two different topologies has been analysed, which is depicted in 1.1.

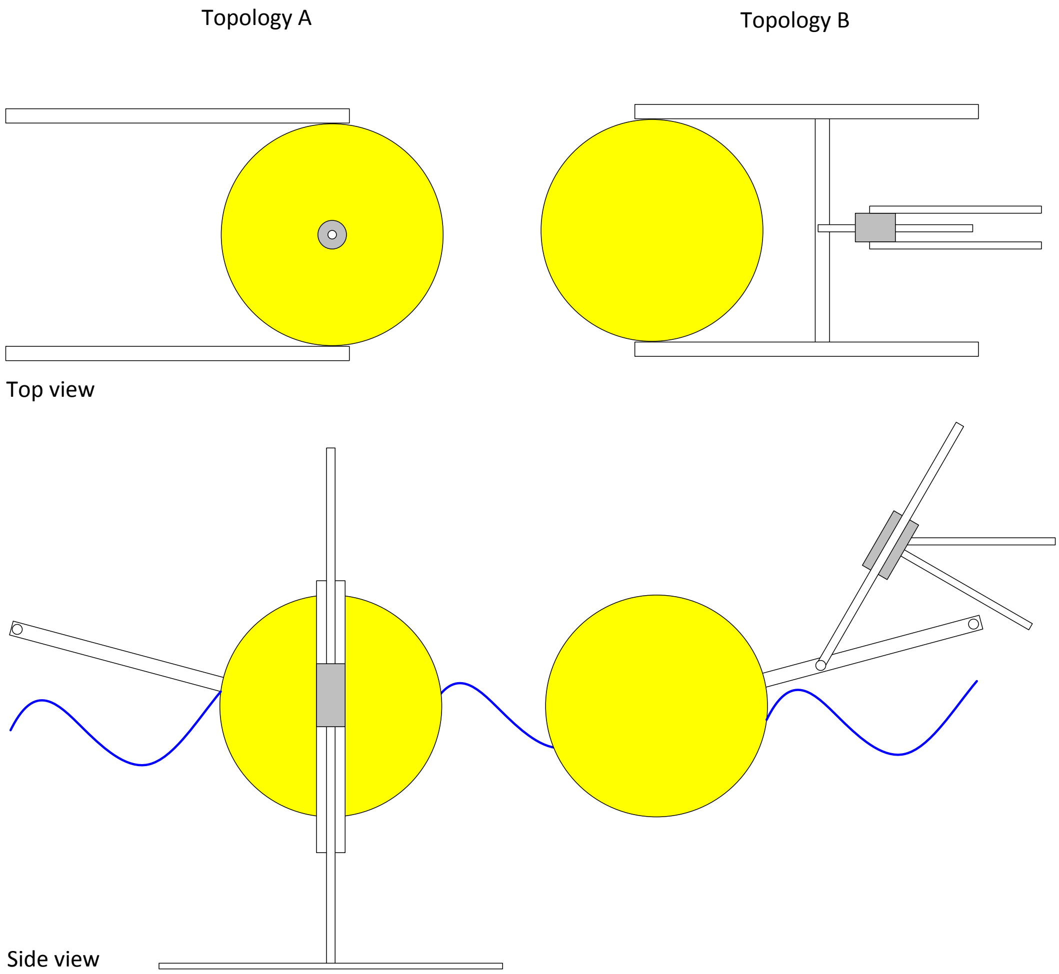

Figure 1.1: Topology for Svalbard project

Topology A is similar to the design of the OCE light buoy and topology B is based on anchored motion. Topology A utilize a dragplate submerged in the water beneath the float for increased relative movement between the generator (gray) and the translator. Topology B, has the translator fixed to the float, while the generator is fixed to the same stationary point as the hinges of the float. Topology A has the advantage that the movement of the float is not limited as the drag plate follows the movement of the float if the translator reaches its maximum stroke. The generator unit in topology A is however situated close to the water surface, why it is necessary to have a high degree of protection (min. IP68) against seepage of water into the electric generator. Topology B is situated above the water surface why a lower degree of protection is used (IP67). Topology B has a direct connection from the float to the translator of the MLS generator, this makes it possible to increase the damping force of the generator at low velocity, compared to topology A, where the drag force of the plate is dependent on the velocity of the plate itself. To choose the desired topology, a simulation of both topologies featuring almost the same MLS generator is performed. The MLS generator is for topology A designed with 30 mm/rev and for topology B with 15 mm/rev. The mean harvested power for the two topologies can be found in Table 2.1.

Parameter	**Topology A**	**Topology B**
Stall force	5600 N	5600 N
Generator power	6.8 kW	6.8 kW
MLS lead	30 mm/rev	15 mm/rev
MLS generator IP class	min. IP68	IP67
Max. stroke	1800 mm	1800 mm
Float diameter	1.8	1.8
Dragplate diameter	1.8 m	-
Mean generated power	77 W	259 W

Table 1.1: Performance of topology A and B

In Table 2.1 the difference between topology A and B in terms of mean generated power is a factor of 3 in favour of topology B. Therefore topology B is chosen for the WEC, event though topology A has some advantages compared with topology B.

CHAPTER 2

WEC SIMULATION

This chapter introduce the modelling of the WEC, which consist of a model of the float and wave interaction, the mechanical and magnetic system and finally the electric generator. By using this model, it is possible to estimate the harvested energy of one year for different parameters of the design, thereby optimizing the power production for the particular wave data.

2.1 WEC model and parameters

The WEC is modelled using Simulink from Matlab, where a linear wave theory model with the mechanical and electrical model of the MLS generator has been developed. The linear wave theory model is formulated, and the hydrodynamic diffraction coefficients are calculated using ANSYS AQWA. The float has a 1.8 m rectangular shape with a draft of 1 m, see Figure 2.1. The float has a buoyancy of 2200 kg and a weight of 280 kg and a volume of 2500 litres. The result from ANSYS AQWA is depicted in Figure 2.2 to 2.4.

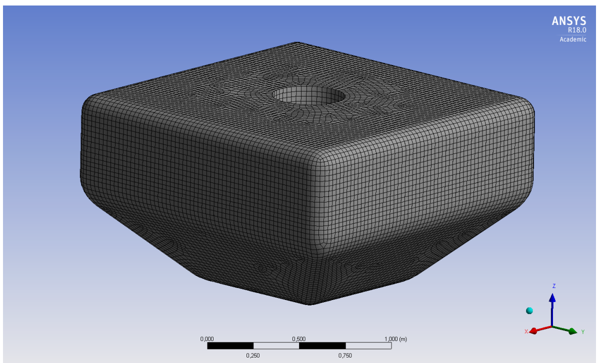

Figure 2.1: Mesh of 1.8 m float (ANSYS AQWA) for FEM calculations

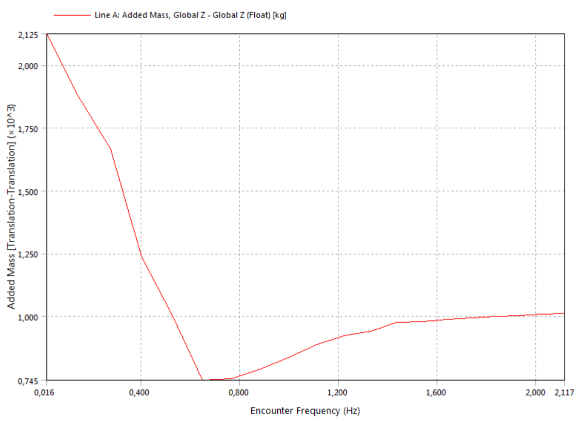

Figure 2.2: Added mass of 1.8 m float at different wave frequencies ($m_{add\infty} = 1010 kg$)

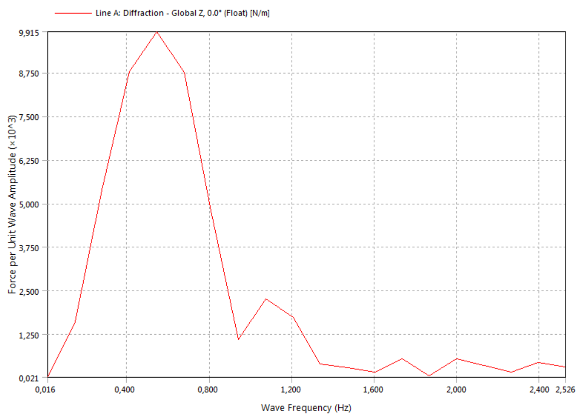

Figure 2.3: Restoring force from diffraction

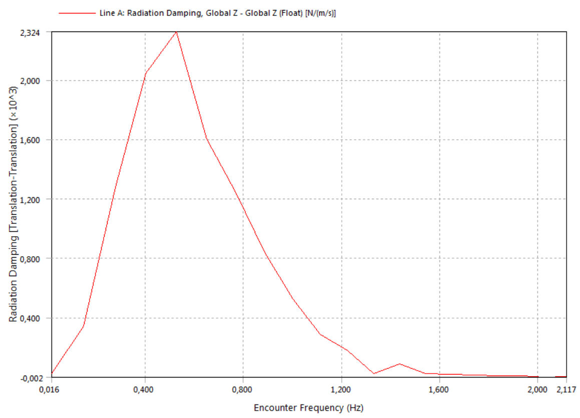

Figure 2.4: Radiation damping of 1.8 m float at different wave frequencies

These figures show an added mass of 1010 kg, which is the mass of the water which is moved when a wave hits the float with the frequency at infinite found in Figure 2.2. The hydrodynamic float parameters are then used in the simulation model in order to get the correct movement of the float, when an incoming wave hits the float. For the simulation of power production of the WEC, the parameters listed in Table 2.1 are used. These parameters are found on behalf of the chosen motor described in section 3.1 and the physically parameters of the float.

Parameter	**Value**
Stall force	3000-7000 N
Hybrid gain	1 and 2.2
Generator power	6.0 kW
MLS lead	15-30 mm/rev
Max. stroke	1800 mm
Float diameter	1.8 m
Generator resistance	0.4 ohm
Generator peak torque	16 Nm
Generator peak velocity	450 rad/s
Generator kt	1.2 Nm/A
Inverter peak phase current	13.5 A

Table 2.1: Performance of topology A and B

By using these parameters in the simulation model, it is possible to calculate the harvested power of the MLS WEC as a function of stall force and lead of the magnetic lead screw. Parts of the cost of the MLS for the WEC is dependent on the stall force of the MLS, why the stall force is seen as a important parameter, and why the power per stall force is depicted. The lead of the MLS however, do not have a direct impact on the cost of the MLS device, why this can be chosen arbitrary.

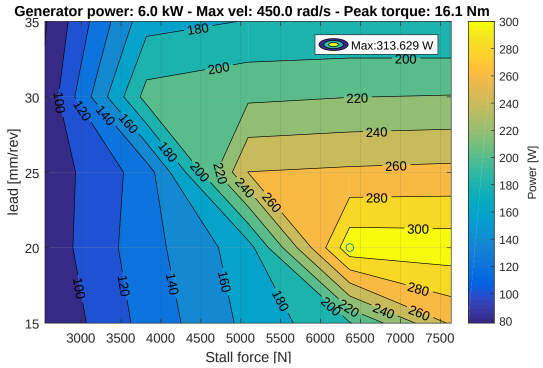

Figure 2.5: Mean power production as a function of lead and stall force (Hybrid gain = 1)

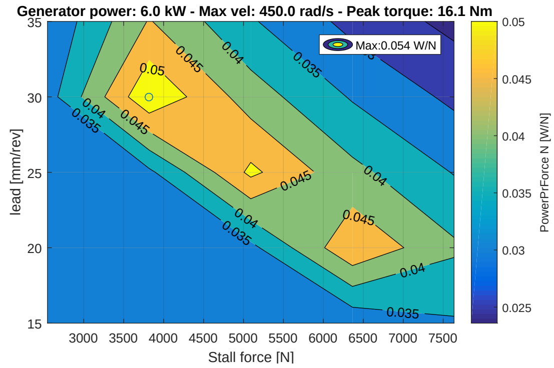

Figure 2.6: Utilization of magnets - power per force (Hybrid gain = 1)

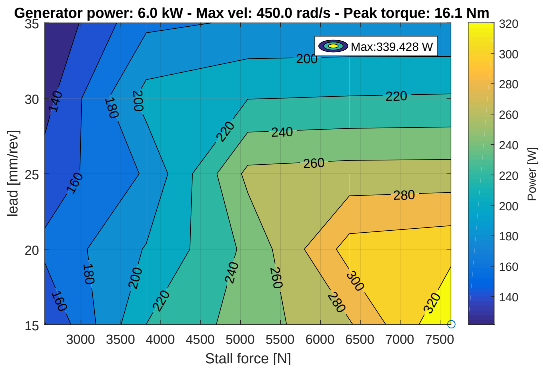

Figure 2.7: Mean power production as a function of lead and stall force (Hybrid gain = 2.2

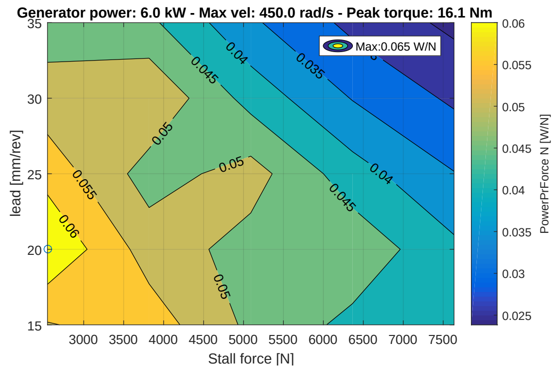

Figure 2.8: Utilization of magnets - power per force (Hybrid gain = 2.2)

As seen in Figure 2.7, the lead of the MLS should have a value lower than 25 mm/rev in order not to decrease the harvested power for the hybrid version. However for the pure reluctance based MLS, Figure 2.5, the lead should be increased if the stall force is decreased. Additionally concerns regarding the mechanical construction, limits the length of the MLS rotor, which therefore limits the stall force of the MLS unit. The rotor diameter could have been increased in order to achieve a higher stall force, however this would require the rotor diameter of the rotary generator to be increased, which is not possible as the generator has been chosen to be standard sized. This leads to a optimal stall force of 5500 N and a lead of 25 mm/rev, which thereby minimizes the need for a hybrid solution using magnets on the translator.

CHAPTER 3

MLS GENERATOR DESIGN

This chapter describes the design of the MLS generator unit. The chapter is divided into three sections, where the first section describes the std. generator chosen, the second section the magnetic design of the MLS and last the mechanical design of the MLS generator unit.

3.1 Rotary Generator

The generator used for the MLS WEC is a standard PMSM motor supplied by LeroySomer with the designation LSRPM90SL.

Figure 3.1: LeroySomer LSRPM90SL stator

Figure 3.2: Name plate: LeroySomer LSRPM90SL

In order for the standard generator to fit with the MLS rotor unit, the inner stator diameter should be as large as possible for a 6 kW generator. The LeroySomer generator was found to be a good match for the MLS rotor unit, as the inner diameter was found to be 101.5 mm.

3.2 Magnetic Lead Screw - magnetic

The magnetic design of the MLS unit, is based on a halbach array on the rotor part of the MLS and a reluctance based translator. However as the simulation of the yearly energy productions stated that using the hybrid solution with magnets between the iron teeth of the translator, was not beneficial for the cost of energy, calculations will still be presented in this chapter, as the conclusion is heavily affected by the size of the generator stall torque compared with the MLS stall torque. Therefore for a larger rotary generator the hybrid solution could potentially decrease the overall cost per energy. For the magnetic design of the pure reluctance based version, two parameters is of interest, the width of the iron teeth and the height.

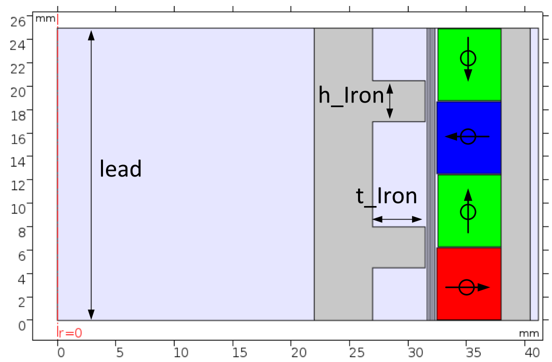

Figure 3.3: COMSOL model parameters

The dimensions of the magnets for the Halbach array is held at a fixed dimension which is set according to a maximum force per magnet mass, and minimization of inertia of the MLS rotor. In Figure 3.4 the stall force as a function of translator teeth dimensions is depicted, where a clear optimum is present at $h_{iron} = 3.5$ mm and $t_{iron} = 5$ mm with 5527 N and 1.95 kg magnets (2.8 kN/kg). In Figure 3.5 the force per kg magnet for the hybrid solution is depicted, it show another optimum at $h_{iron} = 2.25$ mm and $t_{iron} = 3.4$ mm with 1414 N/kg which is only half the force per magnet mass compared with the pure reluctance based version.

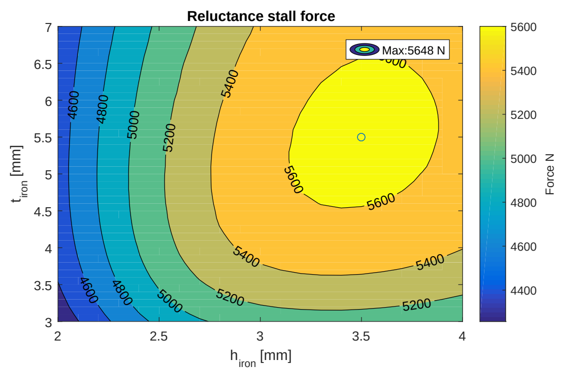

Figure 3.4: Stall force as a function of translator teeth dimension for pure reluctance based MLS version

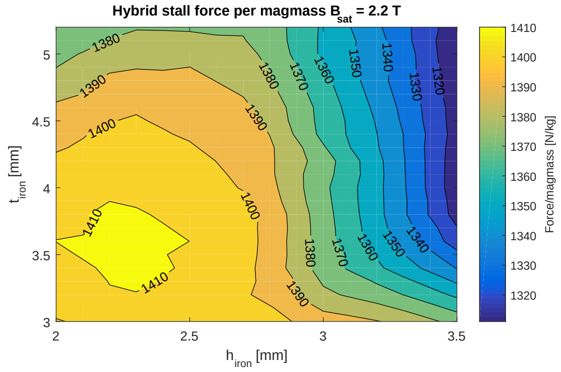

Figure 3.5: Force per magnet mass for hybrid version with 2.2 T iron saturation, and hybrid stroke of 600 mm

Considering the hybrid solution, the saturation of the iron translator is of outer most importance as this has a direct impact on the produced stall force. The magnetic saturation of the steel is however difficult to measure and is not part of the standard properties supplied by the steel industry. As seen in Figure 3.6 and 3.7 the stall force decreases with 2000 N at some points when the saturation of the steel is reduced from 2.4 T to 2.2 T. This show the importance of measuring the saturation of the supplied steel before production.

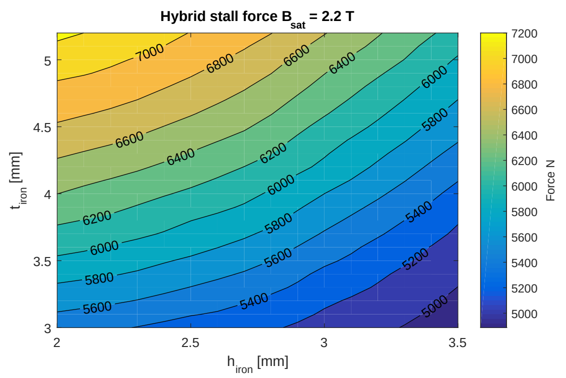

Figure 3.6: Stall force as a function of teeth dimension with iron saturation of 2.2 T for hybrid version

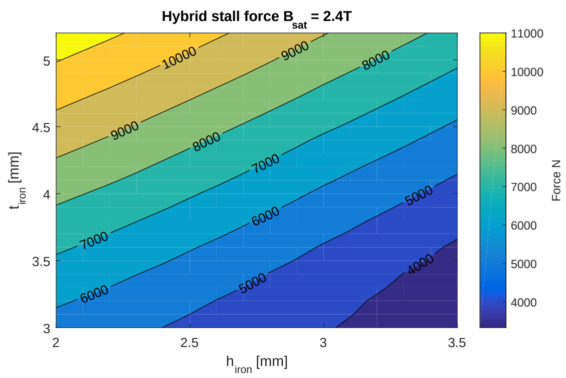

Figure 3.7: Stall force as a function of teeth dimension with iron saturation of 2.4 T for hybrid version

Considering these results it has been chosen to use the parameters listed in Table 3.1 for the MLS WEC unit.

Parameter	**Value**
Stall force	5500 N
Hybrid gain	1
MLS lead	25 mm/rev
MLS translator diameter	Ø 63 mm
MLS active rotor length	220 mm
Number of threads	1
Total MLS magnet mass	1.95 kg

Table 3.1: Final MLS parameters

The flux density plot for the designed MLS unit is depicted in Figure 3.8 with the mesh layout from COMSOL in Figure 3.9.

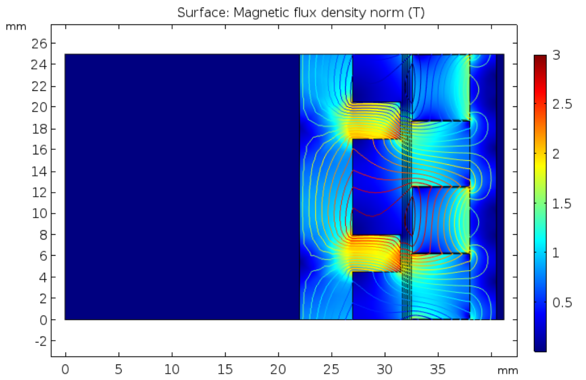

Figure 3.8: Flux density of MLS with final parameters

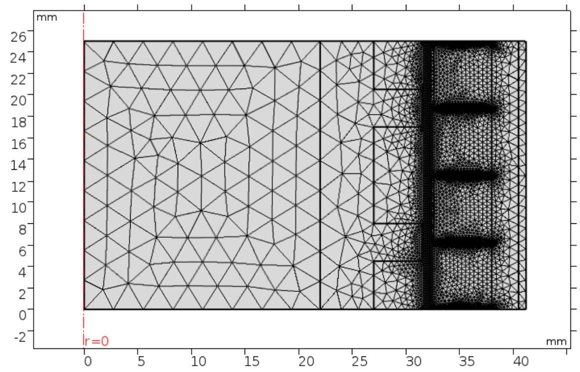

Figure 3.9: Mesh of COMSOL model using the final MLS parameters

3.3 Mechanical Design

In this chapter the mechanical design of the MLS generator unit is described briefly. The MLS generator is suspended by four steel profiles, which secure the distance from the MLS stator to the float steel profiles. The orientation and position of the steel profiles is designed for maximum gearing from the float linear movement to the linear movement of the translator. Additionally, the position has been chosen such that the float has almost unlimited upwards travel, which thereby enables a storm protection mode.

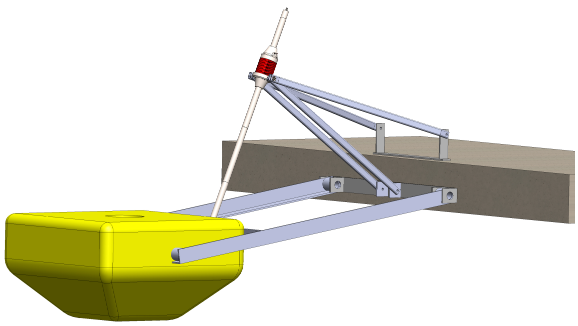

Figure 3.10: MLS WEC

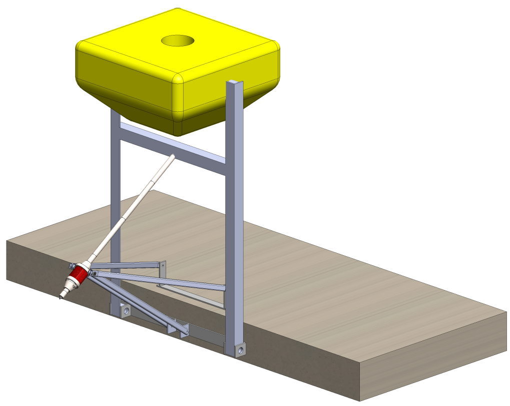

Figure 3.11: MLS WEC (storm protection)

In Figure 3.12 the dimensions of the proposed WEC is presented, the dimensions correspond to a stroke of 1800 mm for the MLS generator unit.

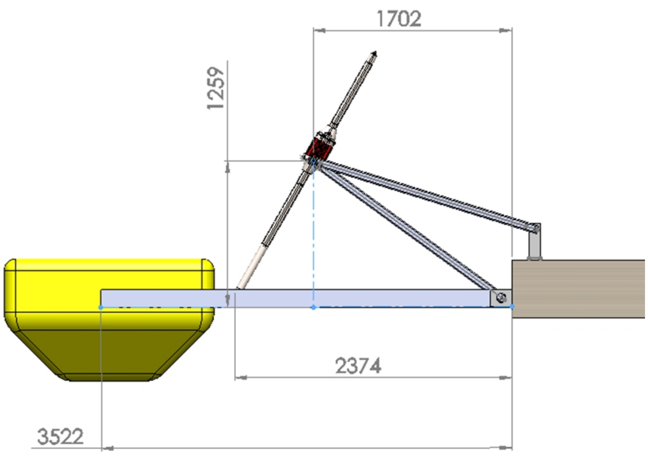

Figure 3.12: Dimension of WEC

The core component of the design is the LeroySomer stator which is the red part depicted in Figure 3.14. In each end of the Leroy Somer, two roller bearing houses are attached to the stator frame. In the end of the bearing housing, the linear bearing house is mounted, which guides the MLS translator. Inside the Leroy Somer housing, the MLS rotor is located, where a 125 mm Zettlex Incoder (INC-3-125-141001-ABZ5-AFL3-24-AN) is mounted at the end of the rotor in order to achieve rotary position feedback from the generator unit. In one of the bearing housings the axial lock pins are mounted, which restrain the MLS stator from moving in the X-Y plane, however the pins allow for rotation through a sliding bearing in the steel profiles.

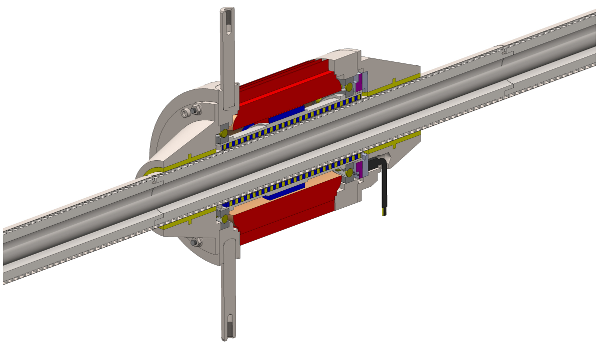

Figure 3.13: MLS WEC cut through

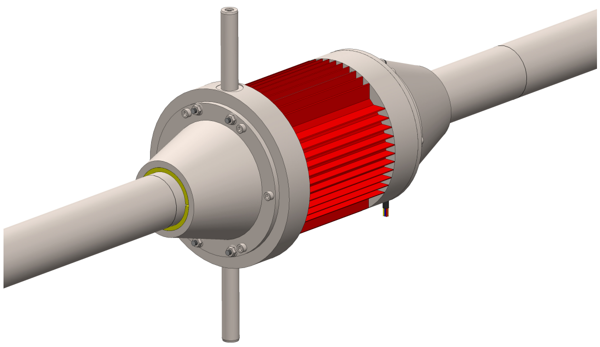

Figure 3.14: MLS WEC

The full length of translator of the MLS WEC is depicted in Figure 3.15. The active part of the translator is divided into three parts, each 600 mm in length in order to minimize production cost. The three active parts of the translator is mounted to a bottom and top part which connect the translator to the steel profiles connected to the float. In the top mount, a steel threaded rod connects all parts of the translator in pressure like connection, minimizing possible fatigue loads of the translator as the load will not be fluctuating around zero, but at the pre-tension load of the rod.

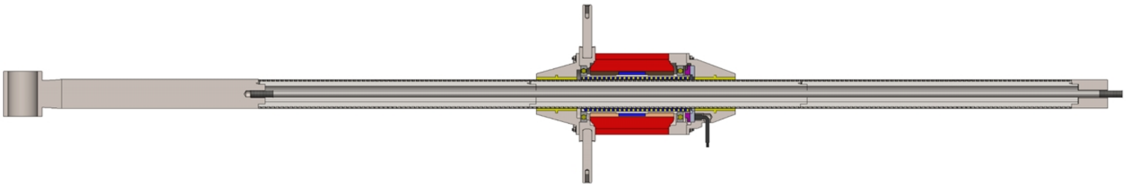

Figure 3.15: MLS generator unit

CHAPTER 4

SUMMARY

The MLS WEC for the Svalbard project has been designed, and the harvested energy has been estimated. The data for the estimated energy production is based upon wave data from Hanstholm in DK, as wavedata from the Svalbard location was not supplied by OCE. Therefore any changes in wavedata will affect the estimated harvested energy, and the estimated energy is only valid to a certain degree if the WEC was installed at the coast of Hanstholm. However it is believed that the wave climate at Svalbard is similar to Hanstholm. The aim of this project is to develop parts of the MLS generator, in order to test the stall force of the pure reluctance type MLS. This implies construction/production of the following parts:

Part	Part number	pieces	Manufacture
Translator1by1	3301	3	AAU
Rotor sleeve	3107	1	RMF
Rotor motor	3101	1	AAU
Resolver Ring	3108	1	AAU
Motor magnet IN	3604	6	MagSound
Motor magnet OUT	3605	6	MagSound
MLS magnet IN	3607	120	MagSound
MLS magnet OUT	3608	120	MagSound
MLS magnet AXIAL	3609	240	MagSound
BearingHouse FREE	3205	1	AAU
BearingHouse LOCK	3203	1	AAU
LinBearingHouse FREE	3207	1	AAU
LinBearingHouse LOCK	3204	1	AAU
SKF Roller bearing	16016	2	SKF
Incoder	INC-3-125	1	Zettlex
LeroySomer	LSRPM90SL	1	Nidec

Table 4.1: Parts to be manufactured

When the parts are delivered the prototype is partly build and the stall force is tested, which concludes the project period.

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