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Design of electrical powertrain to a submersible hoist for efficient launching and lifting boats on slipways

From diesel to electric

Bachelor Thesis in Electrical engineering

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Bachelor Thesis 2022

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Abstract

Swede Ship Sublift AB is a Swedish company that develops a uniquely designed submersible hoist vehicle for launching and lifting boats on slipways. The product has been on the market for around 40 years and started with the name “The Mudskipper”. To this day, about 200 vehicles have been sold all over the world. The vehicle that now is referred to as a Sublift can transport both sail- and motorboats. With its adjustable frame width as well as lifting arms the Sublift is a very flexible vehicle.

This project report covers two concept designs for a possible electric powered Sublift. The two different concepts presented as the result of this project are Concept one: hydraulic and electric hybrid powertrain, and Concept two: fully electric powertrain. Both concepts is designed with a split battery pack of two consisting of 1690 lithium-ion cells each, producing 32 kWh at nominal voltage of 400 V. Concept one is designed with a 22 kW permanent magnet synchronous motor driving a hydraulic transmission pump which is driving two parallel hydraulic motors. As for Concept two, it is designed with a gearbox with a ratio of 1:10 direct mounted on the rear shaft to a 10kW motor on each rear wheel pair.

Keywords: Electric powertain, Driveline, Lithium-ion cells, PMSM, Battery, Hybrid, Marine Technology.

Sammanfattning

Swede Ship Sublift AB är ett svenskt företag som utvecklat en kompakt, självgående submarin båtvagn för att sjösätta och lyfta båtar på ramper. Produkten har funnits på marknaden i cirka 40 år och började med namnet "Slamkrypare". Hittills har cirka 200 fordon sålts över hela världen. Det fordon som numera kallas Sublift kan transportera både segel- och motorbåtar. Med sin justerbara rambredd samt lyftarmar är Sublift ett mycket flexibelt fordon.

Det här projektet omfattar två konceptutformningar för en möjlig eldriven Sublift. De två olika koncepten som presenteras som resultat av detta projekt är följande, koncept ett: hydraulisk och elektrisk hybriddrift och koncept två: helt elektrisk drift. Båda koncepten är utformade med ett uppdelat batteripaket med två batterier bestående av 1690 litiumjonceller vardera, vilket ger en kapacitet på 32kWh och en nominell spänning på 400V. Koncept ett är konstruerat med en synkronmotor med permanentmagnet på 22 kW som driver en hydraulisk transmissionspump som i sin tur driver två parallella hydrauliska motorer. Koncept två är konstruerat med en växellåda med en utväxling på 1:10 som är direktmonterad på den bakre axeln till en 10 kW-motor på varje bakhjulspar.

Acknowledgements

This project was carried out at the Department of Electrical Engineering at Chalmers University of Technology together with Swede Ship Sublift AB and is our bachelor's thesis, consisting of 15 credits in total.

We would like to thank our supervisor at Swede Ship Sublift AB, Peter Hartzell, for this opportunity and for the enthusiasm. Also, we would like to thank our examiner Yujing Liu for the interesting discussions and help along the way. Lastly, a special thanks to Öckerö Marina for letting us visit and examine one of their private Sublifts.

Gustav Tydén, Gothenburg, June 2022
Emil Callerfjord, Gothenburg, June 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BLDC	Burshless DC Machine
BMS	Battery Management System
EM	Electrical Machine
EMF	Electromotive Force
EV	Electrical Vehicle
HEV	Hybrid Electrical Vehicle
IM	Induction Machine
Li-I	Lithium-Ion
MMF	Magnetomotive Force
PMSM	Permanent Magnet Synchronous Machine
RPM	Revolutions per Minute
PWM	Pulse-Width Modulation
REE	Rare Earth Element
SM	Synchronous Machine
SOC	State of Charge
SOH	State of Health
TOC	Total Cost of Ownership

Nomenclature

Below is the nomenclature of variables that have been used throughout this thesis.

Parameters

g	Gravitational acceleration $[9.82m/s^2]$
r_w	Radius on wheel $[m]$
r_R	Radius on Robson axle $[m]$
m	Mass of Sublift and load $[kg]$
h	Height $[m]$
$\eta_{Htransmission}$	Efficiency of hydraulic transmission system [%]
η_{Hpump}	Efficiency of hydraulic pump [%]
η_{Hmotor}	Efficiency of hydraulic motor [%]
$V_{battery}$	Battery voltage $[V]$
$Wh_{battery}$	Battery capacity $[kWh]$
V_{cell}	Cell voltage $[V]$
Ah_{cell}	Cell capacity $[Ah]$
D_{cell}	Cell diameter $[m]$
d_{gap}	Cell gap distance $[m]$
m_{cell}	Cell weight $[kg]$
nr_{series}	Cells in series $[units]$
$nr_{parallel}$	Cells in parallel $[units]$
μ	Friction Coefficient $[units]$
α	Slope angle [°]

Variables

n	Rotational speed $[rpm]$
η	Efficiency [%]
p	Pressure in $[Bar]$
Q	Flow rate $[L/min]$
D	Displacement factor $[cm^3/rev]$
T_h	Torque produced by hydraulic motor $[Nm]$
T_w	Torque on wheel $[Nm]$
T_R	Torque on Robson axle $[Nm]$
F_{flat}	Force on flat surface $[N]$
$F_{acceleration}$	Accelerating force of Sublift $[N]$
F_{total}	Total amount of needed force $[N]$
E_{total}	Total amount of needed energy $[kWh]$
E_{lift}	Energy needed to lift an object $[J]$
P_{lift}	Power needed to lift an object $[kW]$
$P_{L-motor}$	Power of motor for the lifting system $[kW]$
P_{motor}	Power of electric motor $[kW]$
P_{flat}	Power required on flat surface $[kW]$
P_{slope}	Power required in slope $[kW]$
$P_{motor\_concept\_1}$	Power of electric motor addressed to concept 1 $[kW]$
$P_{motor\_concept\_2}$	Power of electric motor addressed to concept 2 $[kW]$
v_i	Initial speed$[m/s]$
v_f	Final speed$[m/s]$
$V_{battery-min}$	Minimum voltage for battery pack $[V]$
$V_{cell-min}$	Minimum voltage for battery cell $[V]$

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Introduction

As the global temperature rises, the world wide demand for a change is evident. No longer is living in denial an option. According to the statistics from Oxford universities *Our World In Data* the transport sector stands for 16.2% of the total global emissions of the year 2020 [1]. Each year the demand of electrical vehicles intensifies. As the demand for better batteries constantly increases, the development and production also evolve.

In Sweden, there where as much as 53% rechargeable cars sold out of every sold car in January 2022. Out of these 53%, a total of 26% were fully electric which is an increase of 367% from January 2021[2]. As the technology advances batteries are getting smaller with increased energy density, electrical components are getting more efficient, and vehicles are getting smarter. As of the year 2022, owning vehicles with electric transmission are not only positive for the environment but also for the economy. Electric vehicles (EVs) generate a lower total cost of ownership (TOC), since there are significantly less maintenance needed due to less moving parts, much less heat waste and less friction. Also, quality difference between, among other things, electric machines and combustion engines, simply the electrical powertrain is more robust [3].

The technological advances generated within the automotive industry can undoubtedly be applied to many industries. Especially to the marine industry, and somewhere in between the automotive and marine industries the Sublifte operates.

1.1 Background

Swede Ship Sublift AB is a Swedish company that develops a uniquely designed submersible hoist vehicle for launching and lifting boats on slipways. The product has been on the market for around 40 years and started with the name "The Mudskipper". To this day, about 200 vehicles have been sold all over the world. The vehicle that now is referred to as a Sublift can transport both sail- and motorboats. With its adjustable frame width as well as lifting arms the Sublift is a very flexible vehicle.

In marinas, one single Sublift can replace a tractor, a crane, and a trolley, making it economically advantageous. The vehicle is controlled by a hand controller and is produced in four different models where the smallest can lift boats up to 12 tons, and the biggest can lift boats up to 90 tons. The two middle sized models can lift

25 and 40 tons. All Sublift models are diesel powered. However, with an increasing demand of electrical vehicles around the world and other aspects as noise and air pollution, an electrical Sublift is right in time.

1.2 Objective

The purpose of this project is to evaluate the possibilities of replacing the diesel engine with an electrical motor. And to come up with two concepts, one with an electrical powertrain for the driving system, as well as a hybrid concept using both hydraulic and electrical components for the driving system. With the overall aim to lower the emissions from the Sublift.

1.3 Delimitations

The project will strictly focus on the technical and environmental aspects of replacing a diesel engine with an electrical motor. As the technical references only will include the aspects of electronics with high voltage components and some aspects of the mechanics of hydraulics. An economical evaluation will not be included. The project will only focus on the 12T Model of the Sublift.

1.4 Clarification of the question

- How much battery capacity is needed?
- What type of motor is best?
- How will the environmental impact change?

1.5 Outline

- Introduction
  - Background and description of project
- Theory
  - Detailed description of current Sublift model 12T
  - Relevant theory needed to evaluate calculations and concept design
- Method
  - The methods and tools that have been used to achieve the objective of the project
- Dimensioning
  - Calculations and validations to enable the right dimensions for each concept
  - Battery Capacity
  - Battery sizing and placing
  - Motor
  - Wiring
- Environmental evaluation

    - Social impact
    - Ecological impact
- Results
    - Presenting the resulting outline and components for each concept
    - Environmental evaluation
- Conclusion
    - Conclusion of the project
    - Short discussion about future advancements

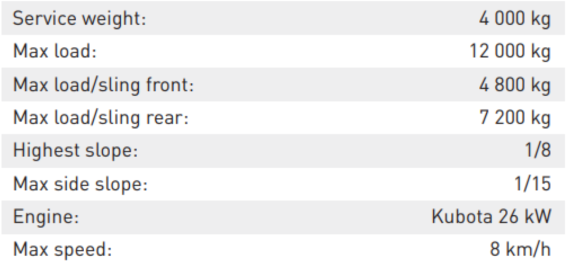
2

Theory

In the following sections, the physical and technical functions of the Sublift, as well as, the technology in the components for an electric powertrain is described in detail with theories and figures.

2.1 Sublift - 12T

The dynamic vehicle is steered by a hand controller. The operator positions the vehicle at the bottom of the sea, below the boat intended to relocate. Subsequently, the lifting arms catch the boats with the straps attached at each arm tip. Then the operator drives the Sublift with the boat up the slipway to the intended location. Widening the body of the Sublift up to one meter is possible to maneuver in tight areas. Lastly, the vehicle lowers its lifting arms to place the boat. The parameters of the 12 ton Sublift model are presented in Fig 2.1.



Service weight:	4 000 kg
Max load:	12 000 kg
Max load/sling front:	4 800 kg
Max load/sling rear:	7 200 kg
Highest slope:	1/8
Max side slope:	1/15
Engine:	Kubota 26 kW
Max speed:	8 km/h

Figure 2.1: Sublift 12T parameters.

Figure 2.2: Sublift 12T model lifting a boat.

2.2 Powertrain

The Sublift is real wheel driven with four rear wheels powered by a Robson drive. The basic of a Robson drive can be described as the mechanical power is transferred to the rear wheel pair by a drive roll mounted in between the wheels on each side, see figure 2.2. A top speed of 8 km/h can be reached when unladen.

Figure 2.3: Robson drive roll mounted in between the rear wheel pair.

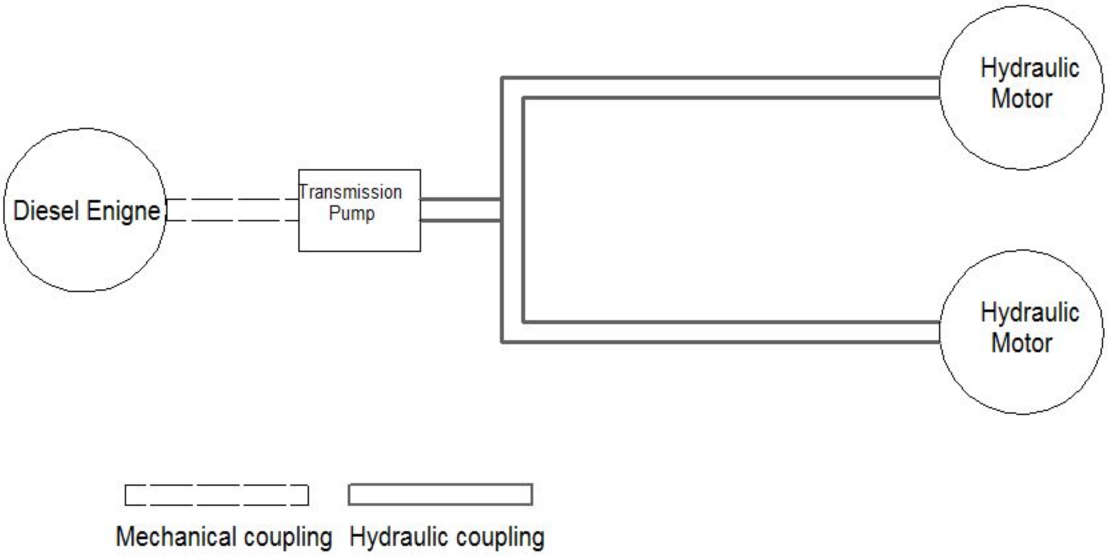


Figure 2.4: Schematic of current diesel-hydraulic hybrid powertrain.

2.2.1 Hydraulics

Hydraulic systems are often used in heavy-duty applications because of their capability to produce significantly high torque at low speeds. Also, hydraulics are robust and inexpensive when considering per unit of force. Yet, in comparison with electronic systems, hydraulics are not as adaptable in movement capabilities [4].

The Sublift is designed with a two-part hydraulic system powered by a diesel engine. In the hydraulic system, two parts are divided into transmission and lifting.

2.2.1.1 Transmission system

An axial piston pump is directly mounted on the shaft of the diesel engine and works within a closed hydraulic system. On the other end of the transmission system, there are two parallel-connected hydraulic radial piston motors, one on each real wheel pair. The two motors are identical and consist of two gears. One for low speed and the other one for higher speed. By changing gear in the radial piston motor the internal displacement changes, low gear equals greater displacement, and higher gear decreases the displacement volume. The effect on the speed of the different displacement volumes is shown in equation (2.1).

$$n_{rpm} = \frac{Q \cdot 1000}{D} \tag{2.1}$$

However, decreasing the displacement volume to increase maximum speed will decrease the maximum torque according as well (2.2).

$$T_h = \frac{D \cdot p}{20\pi} \tag{2.2}$$

2.2.1.2 Lift and steering system

An external gear pump is, as well as the axial piston pump, directly mounted on the shaft of the diesel engine. This part of the hydraulic system is working within an open system with an oil tank of 150L. The gear pump is connected to a flow divider that is controlled by the driver. When a lift command is requested by the driver, the flow divider is making the oil flow in the desired way to create pressure in the four lifting cylinders placed one on each lifting arm. Otherwise, the oil in the system will flow proportional to the speed of the diesel engine but create no pressure on the lifting cylinders. The power needed to lift can be calculated by multiplying the time it takes to lift the object by the potential energy the object will obtain at a certain height h, equations (2.3) and (2.4). The total efficiency of the lifting system is needed to calculate the needed energy output of the motor, equation (2.5).

$$E_{lift} = m \cdot g \cdot h \tag{2.3}$$

$$P_{lift} = \frac{E_{lift}}{t} \tag{2.4}$$

$$P_{L-motor} = \frac{P_{lift}}{\eta_{lift}} \tag{2.5}$$

Furthermore, there are two extended functions that the axial piston pump is operating. Steering as well as widening of the body. There are two hydraulic cylinders for the steering and one for the widening.

2.2.2 Diesel Engine

Diesel engines are commonly used in heavy-duty vehicles due to their capability to produce high torque at low speeds. The efficiency of a diesel engine is normally no higher than 40%. However, Mercedes presented a combustion engine suitable for Formula 1 cars with an efficiency of 50%. Despite progress in the development of more efficient engines, the diesel ones are far from the efficiency of electrical machines which can reach 95% [5].

In the current Sublift 12T model, the motor is a vertical, water-cooled 4-cycle diesel engine with a 3-cylinder from Kubota with a peak power of 28kW at 2700rpm. Peak torque is around 115.8Nm at 1600rpm, and fuel consumption reaches 240g/kWh at peak power output.

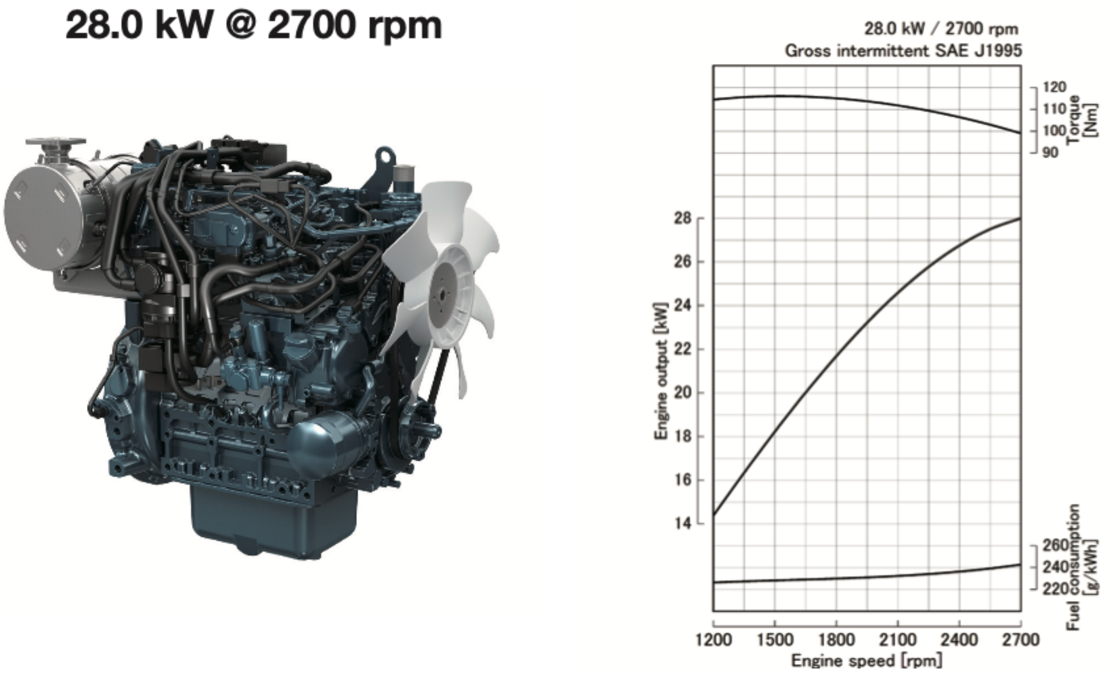


Figure 2.5: Kubota diesel engine with graph of characteristics.

2.2.3 Force and Torque

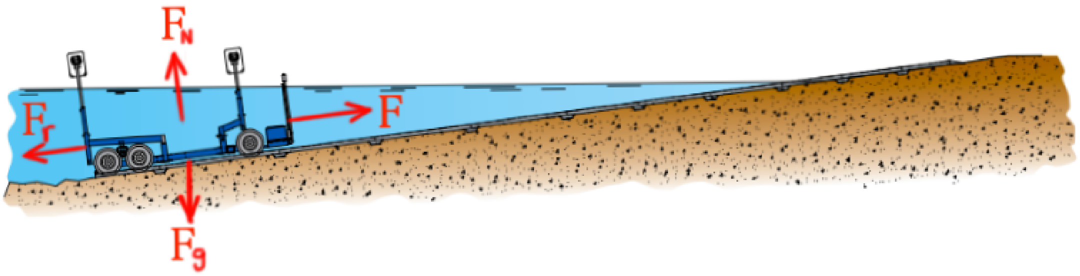


Figure 2.6: Forces acting on the Sublift.

To properly dimension the motor, determining how much power and torque the Sublift requires to be able to operate is mandatory. The 12T Sublift needs to be able to handle a load of 12 000 kg at a maximum slope angle of 7°. There are three different operation points the Sublift operates. Up/down a slope, flat surface driving and raise/lower boats. The instance where the Sublift is driving up a slope requires the most amount of torque and power, hence will the design of the motor be based on this operating point. The following equation determines the amount of force necessary to move the Sublift up a slope.

2.2.3.1 Slope

$$F_{total} = mg \cdot (\mu \cos \alpha + \sin \alpha) \tag{2.6}$$

When the total force required is calculated. The following equation is used to calculate the torque on the tyre.

$$T_w = F_{total} \cdot r_w \tag{2.7}$$

There is also a robson wheel connected with the tyre. The following equation determines the torque on the robson wheel.

$$T_R = \frac{r_R}{r_w} \cdot T_w \tag{2.8}$$

And to calculate the total power required to move the Sublift at a certain speed during operation in a slope. The following equation can be used.

$$P_{slope} = F_{total} \cdot v_{slope} \tag{2.9}$$

2.2.3.2 Flat surface

When the Sublift is operating on a flat surface, the maximum speed is higher than what the Sublift performs on a slope. The force required to accelerate the Sublift is determined by the following equation.

$$F_{acceleration} = m \cdot \frac{v_f - v_0}{t} \tag{2.10}$$

The total force on flat surface can then be calculated.

$$F_{flat} = \mu \cdot m \cdot g \tag{2.11}$$

$$F_{Tot-flat} = F_{flat} + F_{acceleration} \tag{2.12}$$

To calculate power required multiply the total force with the operating speed.

$$P_{flat} = F_{Tot-flat} \cdot v \tag{2.13}$$

2.3 Electric Powertrain

Electrical powertrains consist of a battery bank where the energy is stored. The battery is replacing a gasoline or diesel tank in a combustion powertrain configuration. Moreover, the battery is connected to the electrical machine via power electronics. The power electronic block, which is the brain of the system may vary depending on the application however, a motor controller together with a battery management system (BMS) are needed in a pure transmission application [6].

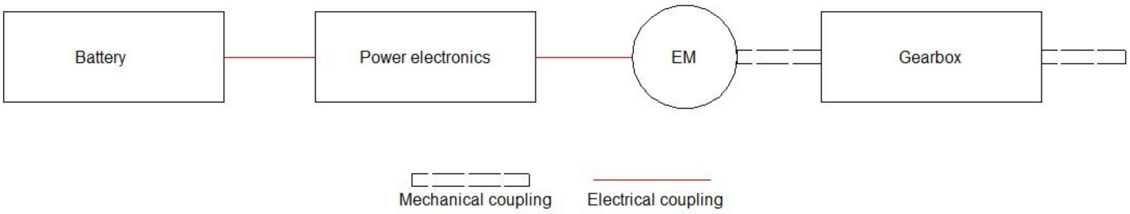


Figure 2.7: Simplified schematic of electrical powertrain.

2.3.1 Electromagnetics

The theory of electromagnetic is a fundamental block in electrical engineering. It is describing the relationship between electric and magnetic fields interacting and depending on each other. A current flowing in a conductor creates an external magnetic field, and a magnet moving through a closed-circuit creates a current in the circuit, see figure 2.8.

The current created within the circuit induces a voltage, called electromotive force (EMF). This was discovered by Michael Faraday in 1831, known as Faraday's law, and can be described by the following equation (2.14) [7].

$$emf = -\frac{d\phi}{dt} \tag{2.14}$$

Moreover, Faraday realized that by looping the circuit in the same position the EMF increased by a factor of a number of loops, (2.15).

$$emf = -N\frac{d\phi}{dt} = -\frac{d\psi}{dt} \tag{2.15}$$

By expressing the discoveries of Faraday in combination with Maxwell's equations, we can say that a time-fluctuation magnetic field always carries a space varying non-conservative electric field, equation (2.16) [7].

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{2.16}$$

Electromagnetism is often described using Maxwell's four equations composed by Oliver Heavyside in 1884. Where Faraday's law, equation (2.16) is referred to as equation number three. The other three equations are described below.

$$\nabla \bullet D = \rho \tag{2.17}$$

$$\nabla \bullet B = 0 \tag{2.18}$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \tag{2.19}$$

Where (2.17) is Gauss law, explaining how electric fields are caused by electrical charges. Equation (2.18), known as Gauss law for magnetism described how the magnetic field through a closed surface is zero, which indicates that there can not be a magnetic mono-pole. The magnetic field always flows from one pole to another. Lastly, equation (2.19) is a mathematical description of Ampère's law that entails how magnetic fields occur from variations in electric fields [7].

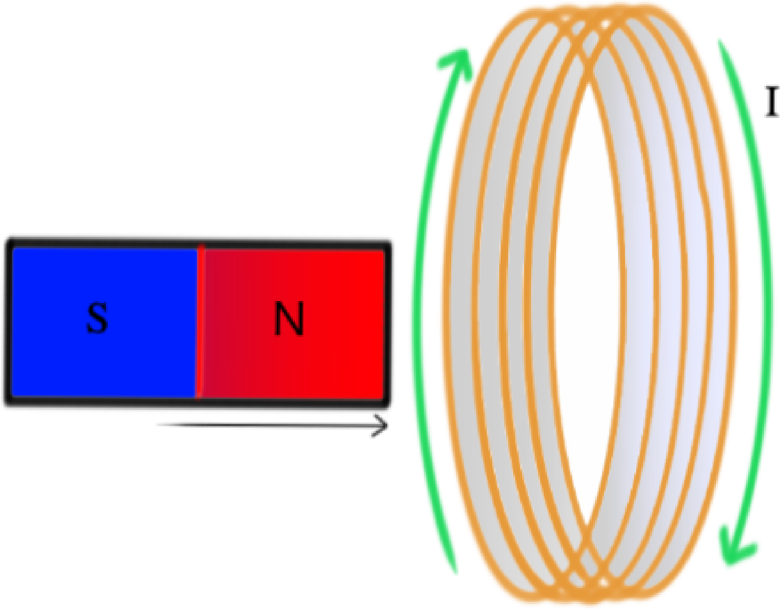


Figure 2.8: Induced current caused by an external time-vary magnetic field.

2.3.2 Electrical Machines

The design of electrical machines (EM) enables the property of working both as a motor and a generator. Electrical machines produce zero-emission and have the advantage of having low noise compared to combustion engines. However, the greatest advantage of electrical machines compared to traditional combustion engines is the energy conversion efficiency [8].

An EM consists of a stator surrounding a rotor where the rotor is, as the name suggests, the rotational part, and the stator is the stationary part, see figure 2.9. EMs are built with laminated steel to reduce the circulation of eddy currents [9]. The stator features three-phase winding from the motor controller which creates an electromagnetic field rotating in the direction depending on the current phase-shifting in the windings. Similarly, the rotor consists of either windings or magnets.

The reason is that the magnetic field in the rotor is created by the current induced in the rotor windings and the speed of the rotor must be less than the speed of the rotational magnetic flux produced in the stator, otherwise, no currents would be induced in the rotor windings resulting in no magnetic field. Thus, there will be a distance between the rotational magnetic field of the stator and the physical speed of the rotor, which is called slip. These types of machines are known as induction machines (IM). However, if the rotor consists of magnets, the created magnetic field formed by the magnets of the rotor will stay in sync with the rotational magnetic field created by the stator windings. These types of machines are called synchronous machines (SM). The torque of the EM is simply the interaction in the air-gap between the electromagnetic field formed in the stator and the separate one formed in the rotor [9].

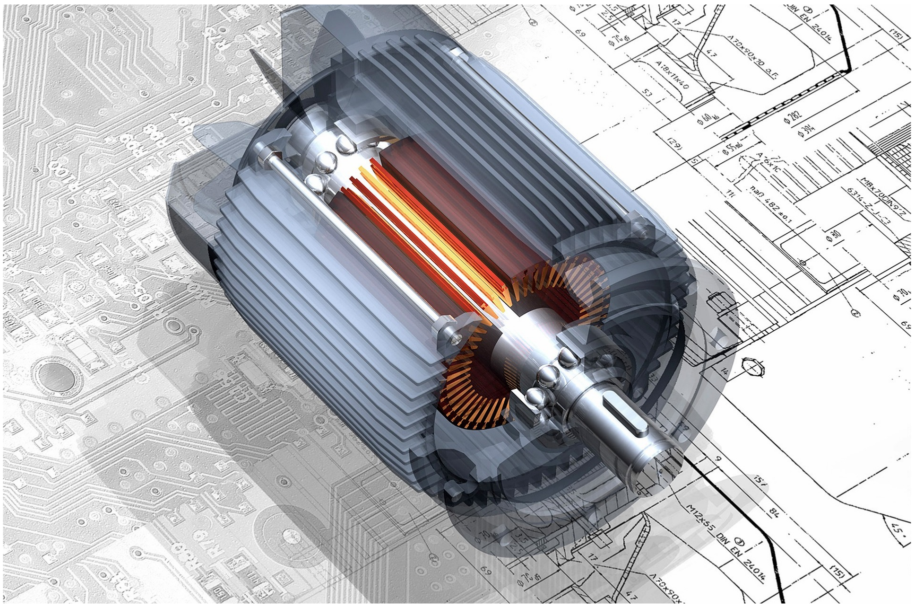


Figure 2.9: Motor showing stator and rotor [10].

2.3.2.1 Permanent Magnet Synchronous Motor

Permanent magnet synchronous motors (PMSM) are the most commonly used electric motors in electric vehicles [9]. The PMSM is, as the name implies, a synchronous AC motor whose field excitation is provided by permanent magnets that has a sinusoidal back EMF. The magnets allow the PMSM to generate a high starting torque since no currents are needed to excite a magnetic field in the rotor. The rotor magnets that do not provide magnetization current are allowing the PMSM to operate with a higher power factor and offer a higher torque density compared to IM, having a smaller size for the same power output. Hence the PMSM is more efficient than an IM because of the magnetization current losses developed in the rotor windings inside an IM.

There are two main configurations of rotor magnet placement in PMSM design, insert and surface mounted. Insert mounted magnets are most common in high-speed applications like electric cars since it is a more stable configuration than the surface mounted [9].

Figure 2.10 is showing the typical characteristics of a PMSM, including the working point (point of field weakening), where the high-speed section begins. This is possible due to the decrement in torque output. As the name implies, the magnetic field in the air gap, generated by the permanent magnets in the rotor is weakened, not due to the weakening of the magnets but due to the phase adjustment of the drive current, which allows the motor to run at a lower voltage than the back EMF voltage of the motor.

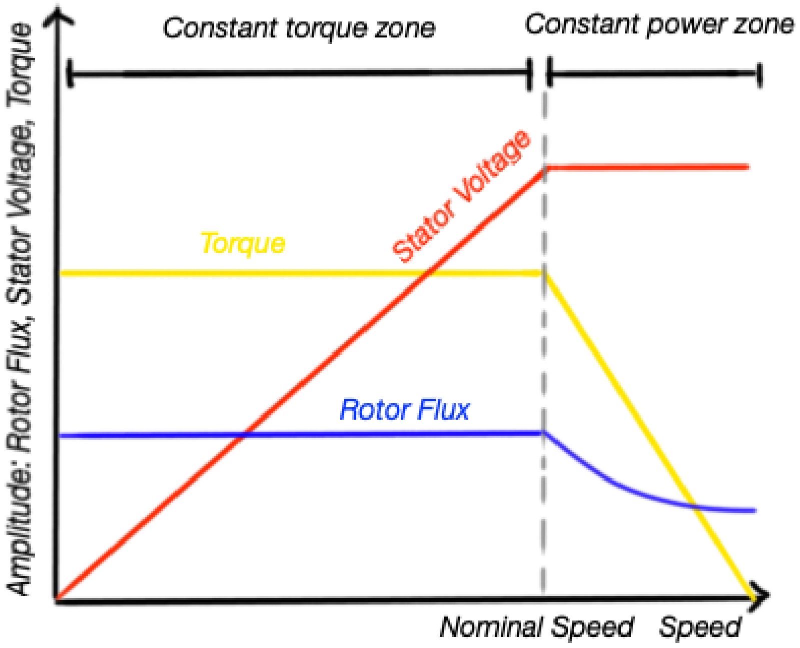


Figure 2.10: PMSM speed, torque and power characteristics

2.3.2.2 Hub Motor

As mentioned, the PMSM comes in many different shapes and forms. A less common design is the inverted PMSM, known as the Hub motor. As the name entails in the inverted PMSM, the position of the stator and rotor are swapped. The rotor with mounted magnets is rotating on the outside of the stator, often inside a wheel, see figure 2.11.

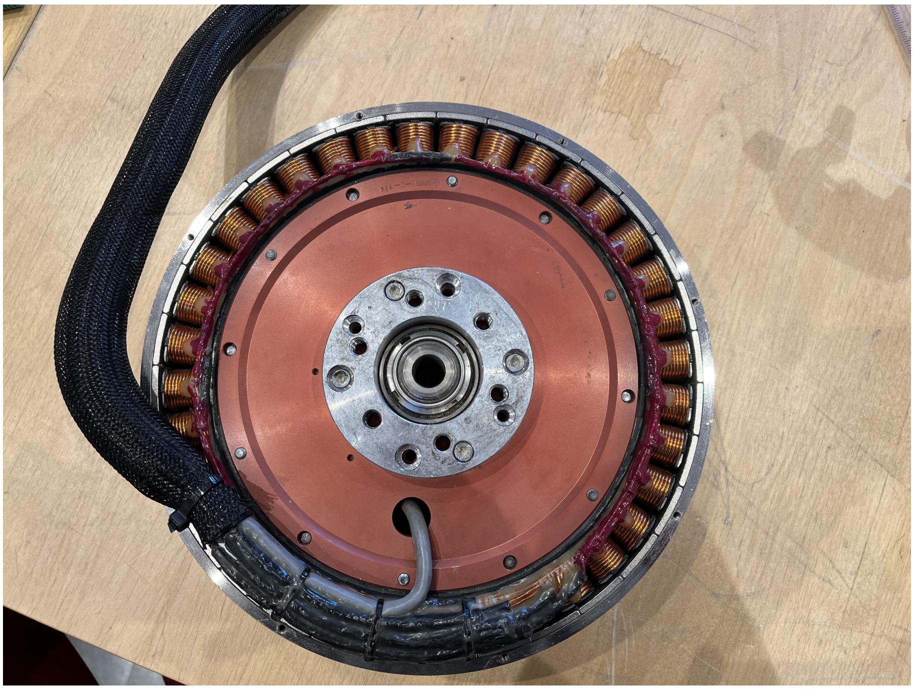


Figure 2.11: Mitsuba M2096D-III, used in Chalmers solar car.

Hub motors are often referred to as high-torque and low-speed motors since there can be no external gears. However, there are hub motors with internal gears to enable higher top speed. In an internal gear configuration, the coils in the stator are moved, reducing the coupling between stator and rotor. The magnetomotive force (MMF) is the force required to drive the magnetic flux through the circuit, (2.20).

$$MMF = \phi \cdot \Re \tag{2.20}$$

MMF can also be described as the produced magnetic force from the current in a N series turns coil, (2.21).

$$MMF = N \cdot I \tag{2.21}$$

Therefore, reducing the number of coils, by moving the stator, will reduce the MMF, and decreases the amplitude of the magnetic flux, since (2.22).

$$\phi \cdot \Re = N \cdot I \tag{2.22}$$

By reducing the number of coils, the magnetic flux will decrease causing the back EMF to decrease, equation (2.15), enabling the rotational speed to increase since the back EMF will be significantly less than the applied voltage. Furthermore, by reducing the coupling, the torque reduces but the amount of power will still be maintained, simply because the power is a product of the torque and revolutions per minute (RPM), (2.23) [9].

$$P \, \alpha \, T \cdot n_{rpm} \tag{2.23}$$

2.3.2.3 Permanent Magnets

There are four major types of permanent magnets used in electrical applications. Ferrite, Alnico, Samarium Cobalt, and Neodymium Iron Boron (NdFeB). The primary differences between the permanent magnets are cost, maximum energy product per size, and operating temperature [10]. As an example, NdFeB has a very high energy product per size but is not as tolerant to high temperatures making it great for motor applications where cooling is achievable, electric vehicles among other things.

With an exception of Ferrite, all of the listed permanent magnets are assembled with rare earth elements (REE) making them expensive and leaving a larger environmental impact.

2.3.3 Cooling of motor

The current Sublift has a water cooling system, a very efficient way of cooling a combustion engine.

In many cases, an electrical motor does not have the same need for such a comprehensive system. An electrical motor have a much higher efficiency ($\sim$ 90%) than a normal combustion engine ($\sim$ 40%). A more efficient system leads to fewer losses in terms of power converted to heat. A combustion engine requires more cooling than an electric motor does because of the preceding information.

2.3.4 Motor controller

To enable the control of electrical machines in the same way traditional combustion engines are controlled by interacting with a gas pedal and a gear-shifter a motor controller is needed. A motor controller regulates the speed and direction of the electrical machine by adjusting the current input to the machine. Also, a motor controller protects the machine from overloading and can limit the torque.

The design of a controller is an assembly of multiple devices. Fundamentally, an inverter is used to convert the DC voltage from the battery into suitable three-phase AC voltage for the motor, followed up by a speed regulator. Speed regulators are designed differently depending on the motor. IMs use variable frequency drives, DC motors use pulse-width modulation signals (PWM), and PMSMs use a more complex model of variable frequency drive with a digital feedback system to monitor the position of the rotor in relation to the stator [12].

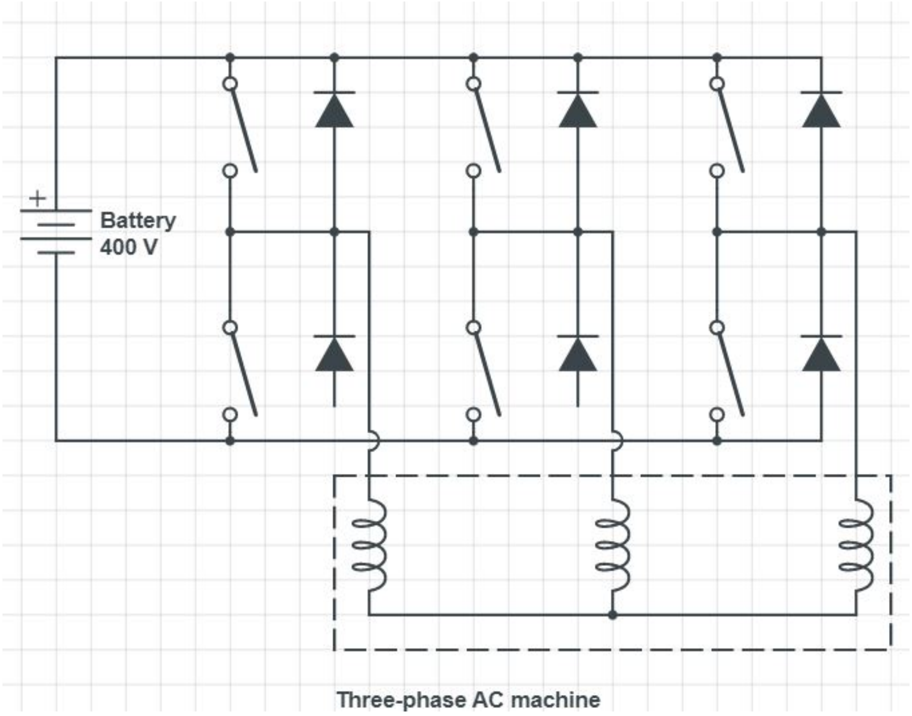


Figure 2.12: Inverter schematic with inductive Ac motor load.

2.3.5 Battery

Batteries are used in many different applications. However, lately, with the expansion of electric vehicles, the demand for better capacity and lifetime is increasing. In vehicle applications, electrochemical batteries are used, converting chemical energy into electrical energy when discharging and electrical energy into chemical when charging. A battery pack is built with battery cells stacked together in series and parallel.

In EVs and HEVs there are three major cell groups used, lead-acid, Nickle-based, and lithium-based. Where the last mentioned is the most discussed one, more specific lithium–polymer (Li–P) and lithium-ion (Li-I). A high electrode potential results in significantly high energy density which is the reason why the interest in lithium-ion cells has increased rapidly [13]. However, these batteries must be operated within voltage and temperature limitations, since lithium-based batteries are more sensitive to exceeding limitations than both lead-acid and Nickle-based batteries [14]. This is the greatest disadvantage of using lithium-based batteries.

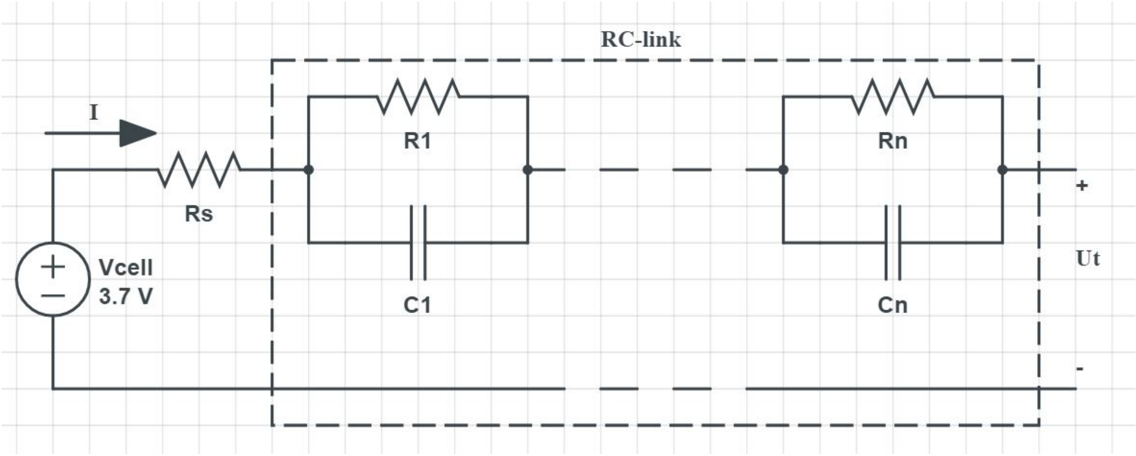


Figure 2.13: Thevenin equivalent circuit for Li-I cells in series.

Table 2.1: Battery cell parameters [15]

Battery cell type	Life cycles	Nominal voltage V	Energy density Wh/kg
Lithium-Ion	600-3000	3.2-3.7	100-270
Lead-acid	200-300	2.0	30-50
Nickel-cadium	1000	1.2	50-80
Nickel-metal hydride	300-600	1.2	60-120

Along with table 2.1, it is clear that Li-I cells are out-preforming the other alternatives, and have the quantities needed for composing a battery pack for vehicle application, where high voltage is prioritized to minimize current according to Ohm's Law, equation 2.24, leading to smaller wire-size, making the application cheaper.

$$V = R \cdot I \tag{2.24}$$

Automotive standard voltage in batteries is $400V$. However, recently automotive manufacturers like Koenigsegg where extreme cars are built, have increased the rated voltage of the entire high voltage system to $800V$ to further push the limits to use smaller cable sizes for the reasons of cost as well as weight [16].

2.3.5.1 Capacity

To be able to dimension the correct size of a battery. Some calculations are needed to be able to make an estimation of how much energy is consumed in the diesel-driven Sublift.
When the power is calculated for the different instances in section 2.1.4 it is now easy to determine the total energy needed with the following equation.

$$E = P \cdot t \tag{2.25}$$

The sublift on average launches 12 boats a day. The sum of the energy for the three different instances multiplied by 12 will determine the energy needed for a full day of operating.

$$E_{total} = (E_{slope} + E_{flat} + E_{raise/lower}) \cdot 12 \tag{2.26}$$

2.3.6 Battery management system

A BMS is necessary for achieving sustainable and safe operations of batteries in electric vehicles. The BMS has many functions when controlling the operational state of the battery. Among other things are real-time monitoring of temperature, state of charge (SOC), charging limitations, and state of health (SOH).

Furthermore, in today's society, the demand for fast charging has increased by the rate of increase in every sold EVs and HEVs. However, fast charging can lead to quick temperature variations inside the battery, in which case a BMS will detect and adjust for. Therefore, a BMS contributes to a more safe battery system.

The BMS is providing its work with the use of current and voltage sensors. To ensure a wider application, considering temperature, SOC and SOH the BMS is using control units to calculate these parameters. Consequently, a deep understanding of battery characteristics and configurations is needed to provide the right data to operate as accurately as possible, to evaluate battery cells to determine the characteristics testing is also needed since realistic parameters are hard to evaluate using only simulations. This is in terms of safety in which accuracy is very important [15].

2.3.7 Charging

The most common way of charging an EV is with a wall-mounted electric charger that is connected to the house's electrical system. This way, charging an EV becomes very simple. The electric charger is mounted close to where the EV is usually parked. It also exists charging stations in public places. These charging stations usually are able to deliver very high power to reduce the charging time. These chargers are usually installed outside supermarkets, restaurants, or other large crowded areas.

There are a few different types of charging which are categorized by how much power they are able to deliver.

Type 1

A type 1 charging cable is used to power the car's charger with 1-phase AC and can charge up to 7.4 kW (230V / 32A). It is mainly on Asian car models using this standard. Charging cables with type 1 are characterized by a small locking mechanism. When you press the locking mechanism, a microswitch is activated which signals to the car. As a result, the resistance value of the signal pin changes, which means that the car ends the charging process before the charging cable is connected to the car.

Type 2

Type 2 is a more flexible variant. It supports both direct -and alternating current. It is also able to charge with 1-phase or 3-phase. Type 2 is constructed for the European earthing system (TN-S) and has a charging power of up to 43 kW. The type 2 standard charging cable has two conductors (1 phase) or 4 conductors (3 phases). A type 2 charging cable with 4 conductors can charge the car with triple capacity (3 phases). The charging capacity is 3.7 kW (16A) and 7.4 kW (32A) at 1-phase, and 11 kW (16A) and 22 kW (32A) at 3 phase. The charging connector on the charging cable itself is characterized by a short and a long signal pin, which guarantees safety. When disconnecting the charging cable from the charging station or the car, the short signal pin disconnects the voltage before disconnecting the cable. In this way, sparks that can damage the charging sockets are avoided and the service life of both sockets and charging cable is extended [17].

Most cars produced in Europe are supplied with type 2 sockets, including Tesla's cars on the European market. Cars with type 2 charging cables usually have the option of fast charging. Most public charging stations are equipped with type 2 sockets [17].

2.3.7.1 Inductive charging

Inductive charging is carried out via a charging plate that is mounted on the ground in, for example, a garage or in a parking lot. There is a coil in the charging plate and when the car is parked exactly above the plate, a magnetic field is created from the coil to the secondary coil on the car. This solution requires no cables and can be very beneficial for a Sublift that frequently is in contact with water. Charging with a normal cable charger when the socket is wet can lead to corrosion and fires due to water being a very conductive liquid [18].

2.3.8 Gearbox

The Sublift requires large amounts of torque to be able to operate under heavy loads. This is where a hydraulic system becomes very attractive, a high torque, low RPM system which is easy to maintain. Although a hydraulic system has many benefits, the disadvantages include low nominal speed and low efficiency.

This chapter covers how a Sublift could be designed without the use of hydraulic motors. And, instead, using electrical motors driving the robson wheels. The torque needed to set the Sublift in motion is marginally higher than a PMSM without gears is able to produce. To achieve the required torque external gearboxes are needed to be mounted between the shaft of the Robson wheel and the PMSM. According to C. Schlage, A. Hösl, and S. Diel [19], manual gearboxes in-vehicle applications have an efficiency of around 92-97%, whereas automatic gearboxes are less efficient with an efficiency of 90-95%.

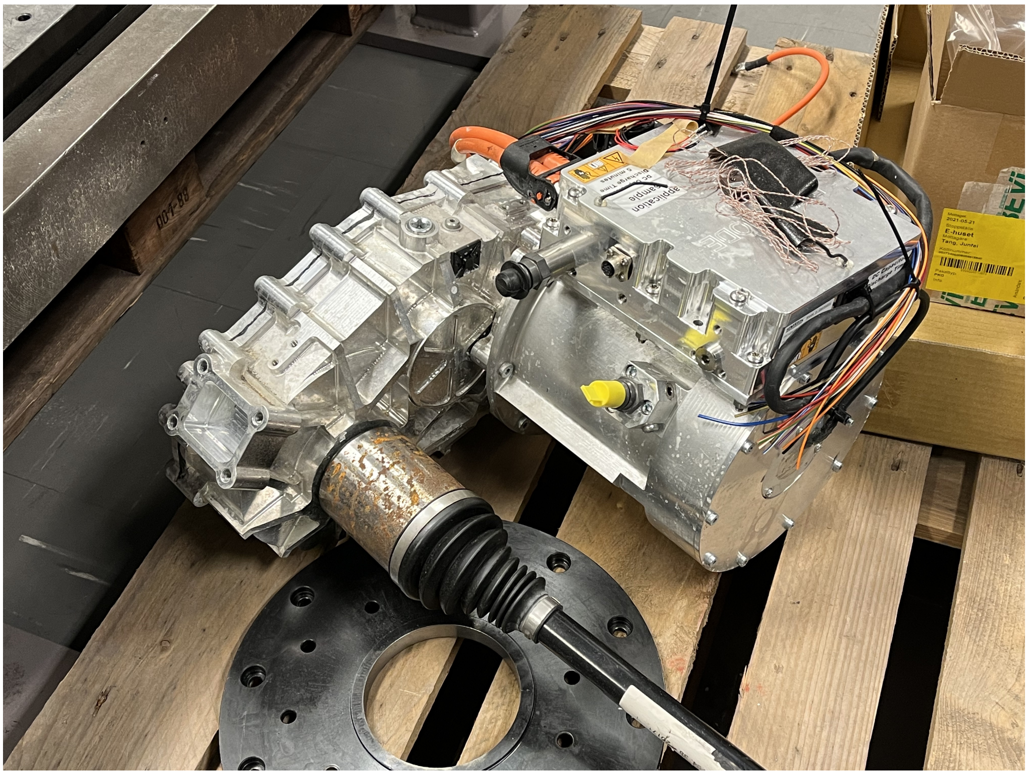


Figure 2.14: Gearbox with 1:14 ratio with an attached 60kW PMSM

3

Methods

This chapter explains the methods and tools that have been used to achieve the objectives of the project.

3.1 Work process

In preparation for the project, prestudies were made to enhance the understanding of hydraulics as well as the understanding of diesel powertrains. Also, a planning report was made with timelines, as well as an outline of the thesis report.

Then, the first visit to Öckrö marina took place at the same time as a meeting with the supervisor, Peter Hartzell at Swede ship Sublift AB, to initiate the project. Subsequently, different types of data were collected and used to analyze the parameters needed to calculate the total energy consumption and power requirements. A second visit to Öckerö marina took place where hydraulics and electronics were analyzed and alternative concepts were discussed.

Lastly, the environmental impacts were reviewed.

3.2 Application of theory

To determine the parameters needed to convert a Sublift powertrain from diesel to electric it is needed to adapt and apply the theories presented in chapter 2.

3.2.1 Collection of data

To collect the needed data two study visits to Öckerö marina were done. At Öckerö marina several Sublifts are in operation. The first visit included a quick walk-through and in-action maneuvering together with Peter Hartzell, whereas the second visit was a technical review of the hydraulic and electrical system led by Peter Pålsson. The visits to Öckerö marina contributed to a better understanding of the practical operation of a Sublift as well as the understanding of the data needed to apply the theories to calculate the right power consumption in the different states of operation.

However, the data for the different operational time cycles were collected in collaboration with Trälhavets marina located in Stockholm where an estimation of the operational time cycles has been made. The time-cycle data was assumed to be a general estimation for every 12T Sublift model in operation.

Furthermore, technical data of the Sublift including the current component setup was collected from datasheets provided by Swede Ship Sublift AB in order to analyze and calculate the needed torque and power requirements.

In addition, Chalmers digital library and google scholar were used as a platform for information search.

3.2.2 Calculation and design methods

Calculations were done using Matlab. For the creation of all self-made illustrations, SketchBook was used. Model design for the layout in both concepts one and two were done using EasyEl. Lastly, an electrical schematic was created using CircuitLab.

4

Dimensioning

This chapter evaluates the parameters to further calculate the necessary elements needed to dimension the Sublift 12T model with precision. Moreover, the term *cycle* is used to describe one full pathway of the Sublift, including the time frame in the following order: Lift, then slope, followed by the flat surface, ending with a lift.

4.1 Lifting system

It takes 60 seconds for the Sublift to raise its lifting cylinders from the lowest to the highest state, which is a distance of 1m. According to the datasheet, the external gear pump has a total efficiency η_{lift} of 80% [20].

Using (2.3) the required energy to lift results in $122.75kJ$. With (2.4), and (2.5) the required motor size is calculated to $2.56kW$.

4.2 Transmission system

According to the datasheet, the hydraulic motors have a working efficiency of about 90%, figure 4.1 [21]. Moreover, the transmission pump is assumed to have a efficiency of also 90%. Neglecting the leakage in the tubes and connections the total efficiency of the transmission system is resulting in 81%, see equation (4.1).

$$\eta_{Htransmission} = \eta_{Hpump} \cdot \eta_{Hmotor} = 0.81 \tag{4.1}$$

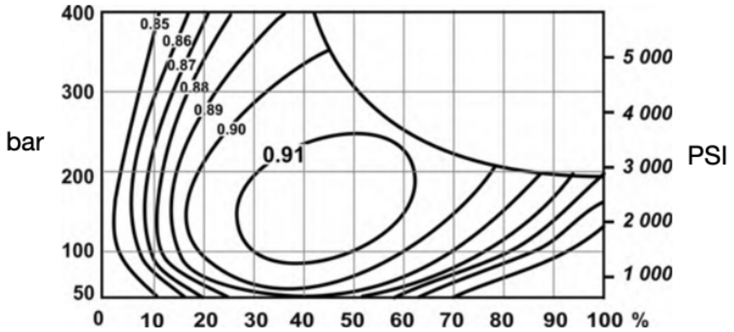


Figure 4.1: Efficiency chart of the hydraulic motor [21]

4.3 Battery

In this section, the battery capacity will be calculated. It is sectioned into three different parts. The energy required for the lifting system, driving on a slope and on a flat surface.

It is not necessary to dimension the battery for launching 12 boats weighing 12 tonnes each day. An average boat weighs somewhere around four to five tonnes. But, boats are becoming heavier and heavier each year. The Sublift is in operation for many years. And to meet the requirements for the future, the following calculations are made with an average boat weighing 6000 kg.

4.3.1 Slope

Using equation (2.6) the total force is calculated to be 13.4kN. The speed of the Sublift going up a 7° slope is around 3 km/h. Converting the speed to SI-units and using equation (2.9) the total power is calculated to be 11.2 kW

Multiplying the power with the Sublifts operation time in the slope, the energy can be calculated to be 0.65 kWh using equation (2.24).

4.3.2 Flat surface

When the Sublift goes from operating in a slope to the flat surface. The following equations assumes the Sublift has a speed of $3km/h$ at the top of the slope. And accelerates from $3km/h$ to $6km/h$ in a span of 4 seconds. Using these numbers in equation (2.10) the force is calculated to 1.5 kN to accelerate the Sublift. Adding equation (2.10) with equation (2.11) the total force on a flat surface is calculated to 3.55 kN.

The same procedure to calculate the power is done by equation (2.9) now using $v = 6km/h$ which give a result of 6 kW.

The energy is calculated using (2.24) and the result is 1.48 kWh.

Table 4.1: Total energy

Operating mode	Time(minutes)	Power(kW)	Repetitions	Total energy(kWh)
Slope	3.5	11	12	8
Flat surface	15	6	12	18
Lift	1	2.56	24	1

According to Table 4.1, a full day of operating the Sublift will require around 27 kWh of energy. To reduce the degradation speed of the cells. It is recommended to operate between 10% - 90% or 20% - 80% of the battery's total capacity to maximize the lifespan of the battery. If the battery discharge is set to a maximum of 80% of the total capacity. The total battery capacity will have to increase by 20% to make sure that the battery's capacity in normal conditions is within the set threshold. Using equation (2.26) multiplied by 1.2 gives a total capacity of 32 kWh.

4.3.3 Size and placement

To determine the size of the battery, some reference is needed. Hence, Li-I 18650 cells are used as a reference in the following segment. The reason for this is discussed further in section 6.2. Battery and cell parameters are presented in table 4.2.

Table 4.2: Specific battery and cell parameters

Parameter	Variable name	Value
Battery voltage	$V_{battery}$	400V
Battery capacity	$Wh_{battery}$	32kWh
Cell voltage	V_{cell}	3.7V
Cell capacity	Ah_{cell}	2.6Ah
Cell diameter	D_{cell}	0.0189m
Cell gap distance	d_{gap}	0.001m
Cell weight	m_{cell}	0.045kg
Cells in series	nr_{series}	109
Cells in parallel	$nr_{parallel}$	31

$$Ah_{battery} = \frac{Wh_{battery}}{V_{battery}} = 80Ah \tag{4.2}$$

$$nr_{parallel} = \frac{Ah_{battery}}{Ah_{cell}} = 31 \tag{4.3}$$

$$nr_{series} = \frac{V_{battery}}{V_{cell}} = 109 \tag{4.4}$$

$$nr_{cells} = nr_{parallel} \cdot nr_{series} = 3380 \tag{4.5}$$

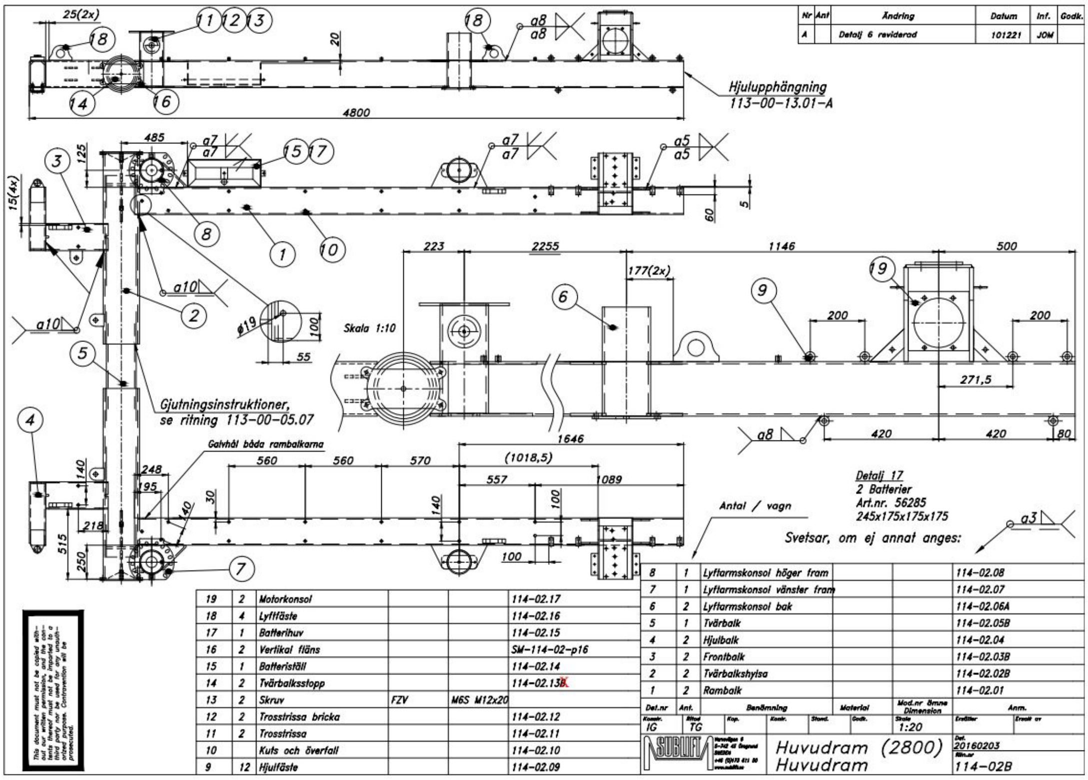
$$d_{total} = D_{cell} + d_{gap} = 0.0199m \tag{4.6}$$

$$L_{battery} = d_{total} \cdot nr_{series} = 2.17m \tag{4.7}$$

$$Wh_{battery} = d_{total} \cdot nr_{parallel} = 0.617m \tag{4.8}$$

$$m_{battery} = nr_{cells} \cdot m_{cell} = 151.92kg \tag{4.9}$$

The Li-I 18650 cell has a diameter of 18.9mm and a height of 70mm. Placing of battery depending on weight and transferred power. Therefore, one battery pack with 1mm cell cap will have the dimensions, without housing, 2.15m length and 0.617m width, according to equations (4.6) to (4.9). Since the weight of the battery, excluding the housing, is calculated to be approximately 150kg it can be divided into two separate packs to disperse the weight. Each battery pack would have an approximate weight of 75kg.



Nr	Ant	Ändring	Datum	Inf.	Godk.
A		Detalj 6 reviderad	101221	JOM	

Det.nr	Ant.	Benämning	Material	Mod.nr Ämne Dimension	Anm.
19	2	Motorkonsol			114-02.17
18	4	Lyftfäste			114-02.16
17	1	Batterihuv			114-02.15
16	2	Vertikal fläns			SM-114-02-p16
15	1	Batteriställ			114-02.14
14	2	Tvärbalksstopp			114-02.13B
13	2	Skruv	FZV	M6S M12x20	
12	2	Trosstrissa bricka			114-02.12
11	2	Trosstrissa			114-02.11
10		Kuts och överfall			114-02.10
9	12	Hjulfäste			114-02.09
8	1	Lyftarmskonsol höger fram			114-02.08
7	1	Lyftarmskonsol vänster fram			114-02.07
6	2	Lyftarmskonsol bak			114-02.06A
5	1	Tvärbalk			114-02.05B
4	2	Hjulbalk			114-02.04
3	2	Frontbalk			114-02.03B
2	2	Tvärbalkshylsa			114-02.02B
1	2	Rambalk			114-02.01

Figure 4.2: Explosion drawing of Sublift 12T

According to the explosion drawing of the Sublift 12T, figure 4.2, the most suitable position is the distance between the lifting arms, since there will be no disturbances for boats. Resulting in a distance of approximately 2.075m by subtracting the diameter of the lifting arms. Considering the length and width needed to achieve the required characteristics, the battery needs to be divided into two packs with a parallel connection. As a result, 0.309m will be the width of each battery pack, without housing. Subsequently, the length must be taken into consideration since the battery packs are longer without housing than the distance between the lifting arms. After all, the voltage is determined by the number of cells in series. However, the solution simply is to package the cells vertically. By doing so the length reaches only 1.075m making a generous room for the housing. The height of the battery would result in, with a one-centimeter safety distance between the layers of cells, approximately 0.24m without housing.

Furthermore, the voltage drop in the Li-I cells is approximately 1V during discharge, fully charged the voltage peaks at 3.7V, and reaches 2.7V when discharge with around 10% capacity left [13]. The voltage drop in the cells during discharge will result in a voltage drop in the battery pack resulting in a voltage of 294.3 V, equation (4.10).

$$V_{battery-min} = nr_{series} \cdot V_{cell-min} = 109 \cdot 2.7 = 294.3V \tag{4.10}$$

4.4 Battery housing

The best material for the battery housing, for this purpose, is steel, because of the thermal conductivity of steel which is very low compared to other metals. The thermal conductivity of a material describes its capability to transport thermal energy through itself [22]. As the Sublift often is situated in water, the steel housing of the battery will be cooled by the surrounding water. Since the Sublift is placed under water for several minutes, the steel housing will be cooled and will retain a cooler temperature due to its low thermal conductivity.

4.5 Motor

In this section, the electric motor parameters are calculated for each concept.

4.5.1 Concept one

To determine the power rating of the PMSM replacing the diesel engine and the required torque are calculated through equations 2.6-2.9. The rated speed is set to $3km/h$ on the slipway. Concept one is designed with a Robson wheel, like the current Sublift 12T model. To calculate the torque needed to drive the Robson wheel a ratio between the traction wheel and Robson wheel is calculated, as the radius of the wheels is $r_w = 0.2225\,m$ for the traction wheel and respectively $r_r = 0.115\,m$ for the Robson wheel.

Using (2.6) with mass $m = 16000kg$ results in a total force of $21.5kN$. When F_{total} is calculated, equation (2.7) is used to determine the torque on the wheels $T_w = 4.7kNm$. Then, it is simple to calculate the torque on the Robson wheels with (2.8), $T_r = 2.4kNm$.

When it comes to the shaft power, using (2.9) the total power needed at the shaft is calculated to $18kW$.

Furthermore, to calculate the power rating of the motor the total efficiency of the hydraulic transmission system is taken into consideration, in equation 4.1 the efficiency is calculated to 81%. With the power at the shaft of the hydraulic motors as well as the efficiency of the system, the rated power of the PMSM can be calculated according to equation 4.11.

$$P_{motor\_concept\_1} = \frac{P_{shaft}}{\eta_{Htransmission}} = 22.22kW \tag{4.11}$$

4.5.2 Concept two

Concept two is also designed with a robson drive configuration although powered by two electric motors instead of one, one motor for each robson wheel. The result in power at the Robson drive-shaft is the same as in concept one, equation **??**. Since there are no hydraulic transmission losses, the losses from the hydraulic system will be replaced with the losses from the gearbox. As mentioned in chapter 2.3.6 the efficiency of an automatic gearbox is around 90-95%.

$$P_{total} = \frac{P_{shaft}}{\eta_{gearbox}} = \frac{18}{0.9} = 20kW \tag{4.12}$$

In the Sublift application, an automatic gearbox is required which is discussed in chapter 2.3.6. By using the same power rating as on the shaft in Concept 1, each electric motor placed on the rear wheels have a needed power rating according to equation 4.13.

$$P_{motor\_concept\_2} = \frac{P_{total}}{2} = 10kW \tag{4.13}$$

The required gearbox ratio is determined based on the torque ratio. The PMSMs have a continuous peak torque from very low rpm until the point of field weakening. In this concept, the PMSMs are assumed to have a constant torque output of 125Nm. According to equation 4.14, a gearbox ratio of 1:10 is required to achieve 1250Nm of torque output per set of the rear wheel.

$$GearRatio = \frac{125}{1250} = 0.1 \Rightarrow 1:10 \tag{4.14}$$

4.6 Wiring

When the motor parameters are determined. It is of great importance to dimension the cable size correctly. Underdimensioned cables are more prone to becoming overheated. Overheated cables can melt, increasing the risk of a fire and an increased risk of short-circuiting components.

On the other hand, over-dimensioned cables are more costly. While also having increased losses due to the resistance increasing with the length of the cable as seen in equation (4.22).

$$R = \rho \cdot \frac{l}{r^2 \cdot \pi} \tag{4.15}$$

Using equation (4.23) the maximum current drawn from the motor can be calculated.

$$P = \sqrt(3) \cdot U_{nominal} \cdot I_{max} \cdot cos\phi \cdot eff \rightarrow I_{max} = \frac{P}{\sqrt(3) \cdot U_{nominal} \cdot cos\phi \cdot eff} = 31\ A \tag{4.16}$$

A minimum safety factor of 1.25 of the wires ampacity is a common requirement by many countries. Multiplying I_{max} with 1.25 determines the current able to flow through the cable in normal conditions. The voltage drop, in this case, is negligible because of the short length of the cables.

$$I_{max} \cdot 1.25 = 31 \cdot 1.25 = 39A \tag{4.17}$$

Cross Section (mm2)	Approximate Overall Diameter (mm)	Current Rating	
		Single Phase (Amps)	Three Phase (Amps)
1.5	2.9	17.5	15.5
2.5	3.53	24	21
4	4.4	32	28
6	4.68	41	36
10	5.98	57	50
16	6.95	76	68
25	8.7	101	89
35	10.08	125	110
50	11.8	151	134
70	13.5	192	171
95	15.7	232	207

Figure 4.3: Datasheet for wire sizing.

According to *Figure* 4.3. A three-phase current of 36 Ampere requires a minimum cross-section of 6 mm^2. I_{max} previously calculated is rated at 39 Ampere. For safety reasons a cross section of 10 mm^2 rated for 50 Ampere will be used.

Losses in the cables can easily be calculated by using equation (4.18). The equation shows the importance of the current in cable systems. The impact of the current will affect the losses in the system exponentially.

$$P = R \cdot I^2 \tag{4.18}$$

5

Environmental Evaluation

Internal combustion engine vehicles and automobiles have made a significant impact on the development of the modern world. Automobiles have contributed to society with large mobility advancements and this has led to an industrial and highly modern world. The automobile industry and other industries serving it directly or indirectly have the largest numbers of employers in the world's working population.

However, there are not only good things that have originated from the industrial combustion engine. Global problems regarding environmental impacts and effects on humans can be traced back to the combustion engine. Major problems have arisen such as air pollution, global warming and the extraction of petroleum might have reached a rate where it starts to permanently decrease have engaged the majority of the world to together find solutions to minimize these challenges.

In recent decades, research and development of alternatives to the combustion engine have been made to increase efficiency and reduce pollution of the planet. Among these developments, electric vehicles and hybrid electric vehicles have been created to replace conventional vehicles in the near future. This chapter will review the social and ecological aspects of replacing a combustion engine with an electrical motor and drivetrain in the Sublift [6].

5.1 Social

The Sublift is working in marinas, as for the 12T model it is mostly marinas with private boats located close to houses, workplaces, and other social areas. Considering the working hours of a Sublift, it can be very early in the morning, late in the evenings, and also on the weekends. Hence, an electric motor will drastically decrease the noise level of the vehicle.

In Öckerö marina, the workers who operate the Sublifts are using hearing protection to avoid the continuous loud noise a diesel engine produces. An electric motor as a replacement to the loud diesel engine would make it possible to operate the Sublift without hearing protection, enabling the operator to maneuver the vehicle more safely, since hearing will increase the chances of detecting risks.

5.2 Ecological

As previously stated, the combustion engine causes many different environmental impacts on the planet. Such as air pollution caused by different gasses released such as nitrogen oxides, carbon monoxide, and unburned hydrocarbon [6]. A report from Volvo [23] came to the conclusion that a fully electric vehicle only using green electricity to charge needs to drive around 400 00 km to cover up the emissions from a combustion engine. Most vehicles will reach this number in their lifespan. The first Sublift that was built around 40 years ago is still in operation. A study from the US Department of Energy [24] shows that the average car consumes around 1800 liters of gasoline per year. A Sublift consumes at least this amount each year if the daily consumption during operating days is 10 liters as previously mentioned in the report.

Although changing from a combustion engine to an electric one will most likely reduce the total air pollution, mining rare earth elements pose mounting toxic risks. Rare earth elements are used in almost every electrical and electronic component, this includes batteries and electrical motors. Rare earth elements are mined using acids that are used to wash the metals out of the boreholes. The poisoned mud remains behind. In addition, there are large amounts of residues containing toxic waste (thorium, uranium, heavy metals, acids, fluorides). The sludge is stored in artificial ponds, which are by no means safe, especially in China due to the lack of environmental regulations. In addition to this danger to groundwater, there is a permanent risk of radioactivity leakage, since many rare earth ores contain radioactive substances [25].

6

Results

In this chapter the concept models are presented as Concept one, and Concept two. Concept one is a hydraulic and electrical hybrid version for the driving powertrain. Where the electrical motor is swapped with the diesel engine in today's version. Concept 2 is a pure electric version for the drivetrain with two electric motors driving the robson wheel with external gears. The layout, meaning the placement of the batteries is the same for both concepts, accordingly, figure 6.1.

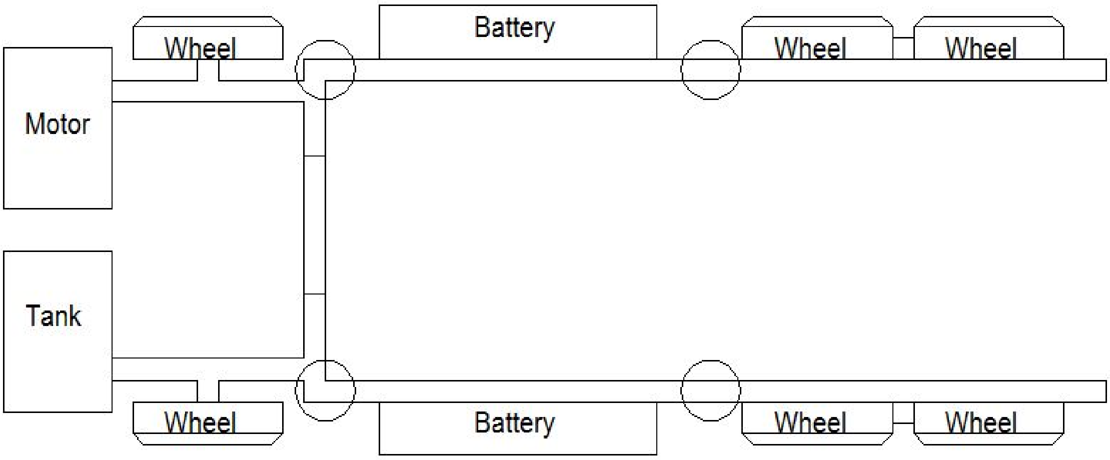


Figure 6.1: Placement of battery drawing.

6.1 Battery

The batteries are divided into two separate packs, calculated to be around 75kg per pack without housing. Each pack has a width of $0.308m$, a length of $1.075m$, and a height of $0.24m$. Consisting of a total of 3380 cells, making 1690 cells per pack. The battery total voltage reaches $400V$ however, the voltage drop approximately $1V$ per cell during discharge, making the battery voltage around $294.3V$ during 10% capacity.

As for the capacity, it is strictly based on the usage of the Sublift. The capacity is depending on how many cycles a Sublift will perform during one work day, resulting in figure 6.2 presenting the capacity based on how many cycles the Sublift is needed to manage during one work day.

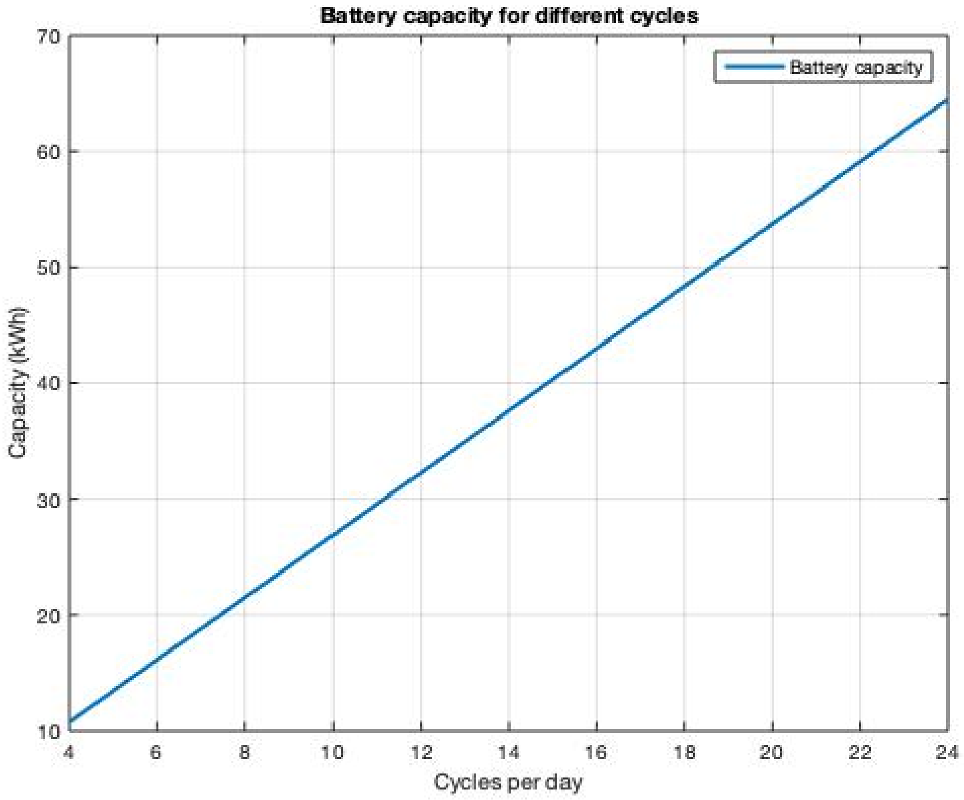


Figure 6.2: Capacity of battery pack depending on usage.

6.2 Cooling

The Sublifts housing of the motor will be submerged under water for some time during each launch. This will cool the entire housing and so, also the air inside the housing, which will happen from operating the Sublift. This also applies to the cooling of the battery. The steel housing will ensure a low temperature due to its low thermal conductivity.

From these points, it is not necessary to have an additional cooling system in terms of water-jacketed bearing housing, fans, or any other type of cooling system.

6.3 Lifting system

The lifting system is not a part of the power train, it is divided into a separate system with the same layout for both concepts consisting of the equivalent hydraulic parts in the existing 12 Sublift version. The system requires approximately 2kW to lift the maximum weight. With an estimated efficiency of 80% based on the datasheets of the external gear pump, the system is designed to require 2.56kW at full load.

6.4 Concept one: Hybrid

Concept one is designed with an electrical and hydraulic hybrid powertrain, like the existing 12T Sublift version the hydraulic system is powered by an external motor. The motor is a three-phase PMSM with a power rating of 22kW. Both hydraulic pumps, transmission as well as external gear are directly mounted on the PMSM. The 22kW PMSM is considered to have a continuous torque output of 125 to match the current diesel engine.

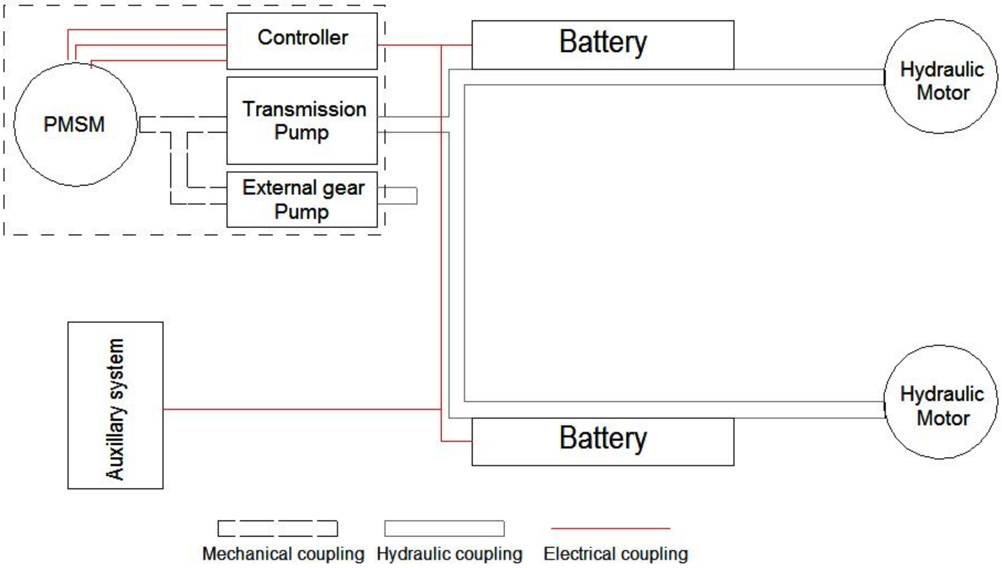


Figure 6.3: Schematic of components in Concept one

6.5 Concept two: Full electric

The architecture of Concept two is similar to Concept one. However, the layout of Concept two is fully electric. As a result, there are two three-phase PMSMs instead of hydraulic in the robson drive configuration. To ensure the right amount of torque is available a gearbox with a ratio of 1:10 is mounted between the electric motor and robson drive roll. Each electric motor has a peak power of 10kW. Moreover, in Concept two there is a separate motor driving the external gear pump The motor is a servomotor with a power rating of 3kW.

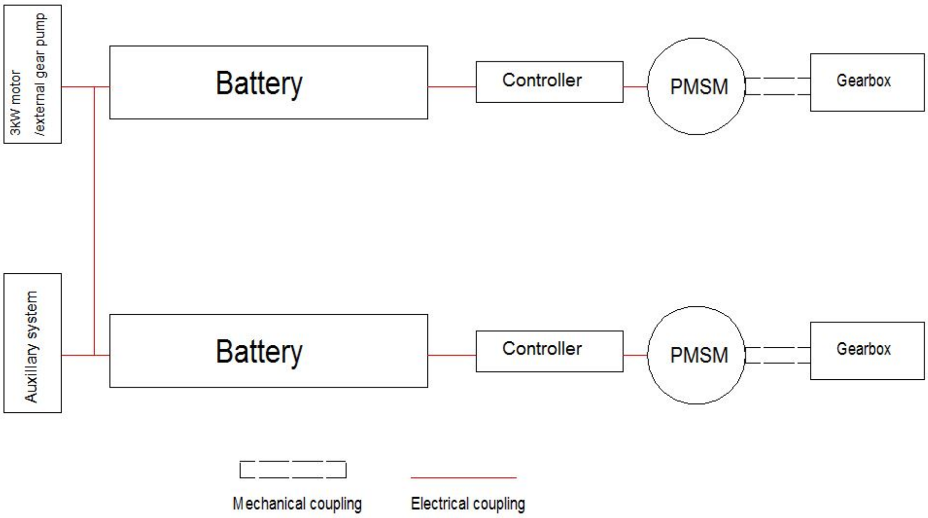


Figure 6.4: Schematic of components in Concept two

7

Conclusion

The amount of torque needed to move the vehicle up the slipway is more than a hub motor can deliver, even though the hub motor often is referred to as a high-torque, low-speed motor, producing approximately 1200 Nm will not be possible. Therefore, a gearbox is needed. However, a gearbox cannot practically be mounted to a hub motor, instead, a PMSM is used.

PMSMs are used in both concepts because the magnets are producing a high starting torque since no currents are needed to excite a magnetic flux in the rotor. Making it more similar to a diesel engine than for example an induction machine. Both concepts, one and two, are high torque applications, where the hydraulic in Concept one is in need of high torque to maintain pressure at all times, and Concept two demands as small a gearbox as possible to occupy less space.

The system voltage is set to $400V$ to reduce the magnitude of the currents. Because, the currents are the main contributor to losses in systems, since the resistance of the system times the current squared equals the losses, see equation 4.18. Keeping a low current in the cable network will therefore have a large impact on the efficiency. 400 voltage systems are automotive standards. However, as mentioned, the automotive standard voltage is as high as $400V$, and there are indications in the automotive industry that the standard voltage will increase to lower the losses and wiring size even more.

Considering the pathway and time frame of a Sublift there is no need for water cooling of either the motor or the battery. First, the placement of the PMSM in Concept one is inside the same container as the diesel engine currently is placed. The motor and battery containers are underwater whenever the PMSM is delivering maximum power output, making the containers surrounded by water and also likely an amount of the inside of the motor container as well, cooling down the entirety of the system very efficiently. The thermal conductivity of the material forming the housing of a PMSM is relatively low, meaning it is moderately resistant to temperature changes over shorter periods of time. Likewise, this can be applied in Concept two, as the housing of the motors and gearboxes will be underwater at the highest temperature fluctuations. The option of air-cooled motors is indeed suitable for this purpose.

The Li-I cells are the best option for this application, as shown in table 2.1. However, the report only focuses on cylindrical cells yet, pouch cells may be an option worth taking into consideration. The 18650 Li-I cells are commonly used in automotive battery composition. Hence, it is used in this project to enable the further design of both concepts.

7.1 The future of the Sublift electric concepts

This is a project that takes time. This report is just a model of the start of the project, and how it can be evaluated, considering two concepts. To further evaluate the concepts, finding and manufacturing the right components are the next steps. Followed by testing and evaluation.

Moreover, the subject of inductive charging is an up-and-coming technique in both the automotive and marine industries. This is slightly touched on in section 2. Inductive charging would simplify the practical process of charging. With the increasing efficiency of this charging technique, it may be suitable for the Sublift.

Also, a further interesting topic is the replacement of the hydraulic lifting system with electric cylinders. The actual implementation of electrical cylinders is possible. The downside with hydraulic cylinders is the oil, which obviously is not environmentally friendly. With approximately 130 litres of oil in the Sublift 12T model, a leakage would cause horrendous local disturbances in the environment. Since the Sublift often is situated in the ocean, a leakage may happen in the water, making it even harder to clean up. On the one hand, the oil in the hydraulic cylinder is viscous, providing robustness to the cylinder and making it resistible to rapid and unpredicted movement. On the other hand, the Sublift, in its normal working routine, is very slow and does not create any rapid movements in the lifting process, making the electric cylinder a very good replacer for the hydraulic cylinder. With the same aim as in this project, considering the direction towards electrification and a more pleasant environment, electrical lifting cylinders are worth considering.

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