February 20th, 2017

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

Re: ENSC 405W/440 Requirements Specification for *Zyklus by Müve* - a portable self-sustaining rechargeable Battery Pack for Bicyclists

Dear Dr. Rawicz,

The purpose of this document is to outline our the project requirements and specifications for our *Zyklus*, *Müve*'s portable battery pack, apropos to ENSC 405W/440 (Engineering Capstone Design). This requirements specs will delve into further detail on the materials needed for the initial prototype of this self-sustaining bicycle module. Furthermore, this document will elaborate on the technicalities for the proposed idea, and how it will fit into its respective market.

An in-depth analysis of the problem and justification for the chosen requirements will be provided, and a discussion on the differences on the requirements between the current project version, and future iterations of the prototype. The process details will also include a comprehensive discussion on the appropriate constraints for the proof-of-concepts and current/future product versions. Finally, this document will conclude with an analysis of relevant engineering standards, existing sustainability issues and the safety of the device. Major considerations for future product versions will also be discussed.

*Müve*'s four chief executive officers, Bob Jiu, Melissa Mah, Michael Fujiwara and Pooja Mahesh Kumar, would be happy to answer any further questions you may have about our project requirement specifications document. Please direct inquiries to 778-846-2399 or msm16@sfu.ca.

Kind Regards,

*Melissa Mah*

Melissa Mah
Chief Risk Officer
*Müve*

# A Portable Self-Sustaining Rechargeable Battery Pack for Bicyclists

February 20, 2017

Bob Jiu
Melissa Mah
Michael Fujiwara
Pooja Mahesh Kumar

## ABSTRACT

We live in a fast-paced world, carrying most of our lives around with us on our electronic devices. With all the rush and excitement of our daily lives, most of us forget to charge our electronic devices - in fact, we're so busy exerting energy that we don't get much of it back. *Müve* has created *Zyklus*, a self-sustaining, rechargeable and removable battery pack that can be stored on bicycles, enabling users to generate and store energy as they go about their day. The need for portable chargers is on the rise, and increase in bicycle usage due to new bike lanes within the lower mainland proves that *Zyklus* can be a hit amongst urban dwellers. This document outlines the functional specifications needed for *Zyklus*, as it moves from the proof-of-concept stage to the initial prototype, and finally to the end-product. With thorough research into bike design, battery types and charge times, *Müve* has chosen initial design parameters and have justified the chosen parts below. Lastly, relevant engineering standards and sustainability/safety of the requirements are discussed in detail within this document.

# CONTENTS

ABSTRACT ........ 1

Glossary ........ 3

Introduction ........ 4

REQUIREMENTS ........ 4

- Classification ........ 5
- General Requirements of Zyklus module (see figure 1) ........ 5
- Lithium Ion Battery ........ 6
  - Physical Requirements ........ 6
  - Hardware Requirements ........ 6
  - Reliability Requirements ........ 7
  - Performance Requirements ........ 7
  - Standard requirements ........ 7
- Dynamo ........ 8
  - General Requirements ........ 8
  - Physical Requirements ........ 8
  - Mechanical Requirements ........ 8
  - Firmware Requirements ........ 8
  - Sustainability/safety requirements ........ 8
  - Performance Requirements ........ 8
  - Standard Requirements ........ 9
- Arduino ........ 9
  - General Requirements ........ 9
  - Physical Requirements ........ 9
  - Firmware Requirements ........ 9
  - Reliability Requirements ........ 9
  - Sustainability/Safety Requirements ........ 9
  - Performance Requirements ........ 9
- Bicycle & Phone Holder ........ 10
  - General Requirements ........ 10
  - Software Requirements ........ 10
  - Physical Requirements ........ 10

Process Details & Problem Analysis ........ 10
Sustainability/Safety ........ 13
Conclusion ........ 16
References ........ 17

## LIST OF FIGURES

Figure 1 – Sketch Of *Zyklus* Module ........ 6
Figure 2 – Charging Stages of A Li-Ion Battery ........ 7
Figure 3 – Types of Dynamos Available On The Market ........ 9
Figure 4 – Flowchart of Process Design ........ 11
Figure 5 – Preliminary Test Results, Relating Cycling Speeds To Battery Power Stored ........ 12
Figure 6 – List of Parameters ........ 12
Figure 7 – Sketch of *Zyklus* Module ........ 12

## GLOSSARY

| | |
|---|---|
| IP | International Protection Marking |
| EIU | Electromagnetic Induction Unit |
| App | Android Application |
| MTTF | MTTF |
| MPH | MPH |
| Li-Ion | Lithium Ion |

## INTRODUCTION

Technology today grows at an exponentially rapid rate and in turn, our dependencies on it grow linearly. There isn't enough battery power in any handheld device to support all the tasks we run on our cellphones. This is where our company, *Müve*, has a solution that not only allows you seamless charging on the go but also, encourages a healthy lifestyle.

In large metropolitan cities, more people turn to cycling as a primary method of transportation and *Müve* aims to create a detachable bicycle module, *Zyklus,* which is a self-sustaining portable rechargeable battery pack powered by the bicycle. As of now, our vision is to have *Zyklus* draw energy from movement of the bicycle by mounting it on the handlebars or on the down tube. Additionally, we plan to incorporate fitness tracking abilities into the final product that will track the calories burned, distance covered, effort exerted while going between different terrains and the route traveled. Finally, we plan to turn this into a social experience for the user. *Zyklus* would communicate with a phone application that would not only display the rider's statistics but also, consists of a rewards program where you can gain credit based upon your mileage and earn coupons towards participating retailers.

Our target market is within Canada, specifically major urban hubs like Vancouver, Calgary and Toronto. Furthermore, this lies with Mayor Robertson's vision of Vancouver being the greenest city by 2020 (Vancouver, 2016). The overall goal is to create an affordable and socially inviting product that appeal to not only seasoned cyclists but also encourages new cycling enthusiasts to continue on their path of a greener tomorrow.

## REQUIREMENTS

The purpose of this document is to outline and maintain a record of the functional requirements each design phase of the detachable bicycle module *Zyklus*. The specifications will be used by the entire *Müve* team and ensure seamless transitioning between phases. Requirements are classified based on types, and listed under each main, critical component used in this entire project.

## CLASSIFICATION

In this document, the following convention is used to reference the functional requirement specification,

**[ZC-#]**

Where **'Z'** is the product name, *Zyklus*, **'C'** is the category which is denoted by **H, F, S, M, PH, ST, R, PE or G** to describe the type of requirement: Hardware, Firmware, Software, Mechanical, Physical, Standards, Reliability, Performance and General respectively, and **'#'** is the priority of the requirement which is given by,

**I** This requirement applies to proof-of-concept system only

**II** This requirement applies to prototype system only

**III** This requirement applies to final product only

## GENERAL REQUIREMENTS OF *ZYKLUS* MODULE (SEE FIGURE 1)

[ZG - I, II, III] *Zyklus* is compact and light enough to be mounted onto bike.

[ZG - I, II, III] *Zyklus* is removable, and can be used to charge external devices.

[ZG - I, II, III] *Zyklus* is designed to be used outdoors.

[ZG - I, II, III] Dynamo unit should weigh around 2 lbs.

[ZG - I, II, III] *Zyklus* is ergonomic and easy to attach to bicycle.

[ZG - I, II, III] *Zyklus* is sturdy and stable; won't fall off when bicycle is in motion.

[ZG - II, III] Product is compatible with both fixed and variable gear bicycles.

[ZG - III] *Zyklus* will retail at around $180 per unit.

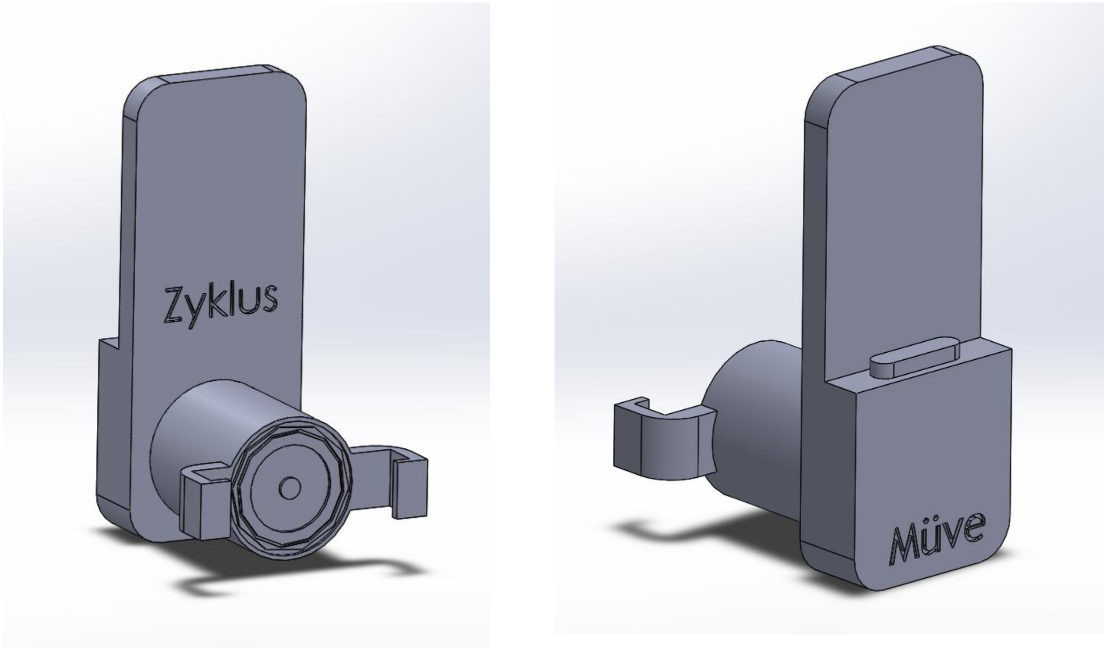


Figure 1 – Sketch of *Zyklus* module

## LITHIUM ION BATTERY

### PHYSICAL REQUIREMENTS

[ZM - I, II, III] Lithium ion battery should weigh around 5 lbs.

[ZH - I, II, III] Lithium ion battery should have a charging time of approximately 4.20V/cell, as seen in Figure 1.

[ZH - I, II] All circuitry is wired neatly and contained in a electrically sound box.

[ZH - I, II] Hardware is on soldered protoboard

[ZH - III] Hardware is contained in weatherproof housing.

[ZH - III] Hardware is printed onto custom PCB to eliminate loose wiring.

[ZH - III] PCB supports bluetooth, accelerometer, gyroscope and torque sensors.

### HARDWARE REQUIREMENTS

[ZH - I, II] Hardware contains basic rectifier circuit.

[ZH - II, III] Charge counting circuit to track amount of charge stored in battery.

[ZH - I, II] Hardware controls power management circuit which controls voltage going into battery pack.

[ZH - I, II] Hardware incorporates torque sensors.

muve

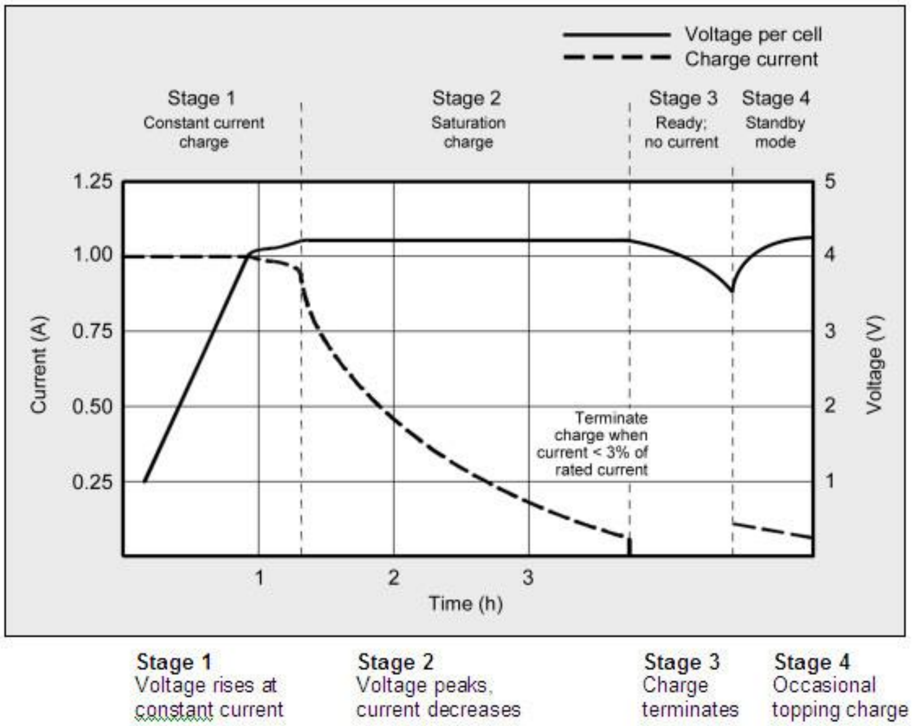


Figure 2 - Charging stages of a Li-ion battery (Buchmann, 2017).

## RELIABILITY REQUIREMENTS

[ZH - I, II, III] Lithium ion battery to have a MTTF of 1024 charge/discharge cycles.

## PERFORMANCE REQUIREMENTS

[ZH - II, III] Battery power of at least 2800 mAH.

## STANDARD REQUIREMENTS

[ZST - II] The battery will be in compliance with **IEC/TR 62914:2014**

[ZST - II] The battery will be in compliance with **CAN/CSA E62133:2013**

[ZST - II] The battery will be in compliance with **IEC 62133-2:2017**

[ZST – II, III] The device will be in compliance with **UL 1642**

[ZST - III] The battery will be in compliance with **WEEE Standards Directive 2012/19/EU** for electrical and electronic waste.

[ZST - III] The battery and surrounding electrical circuit will be in compliance with **SPE-1000:2013** for Canadian Electrical Code.

[ZST - III] The battery will be in compliance with **UN 38.3** for dangerous goods transportation.

[ZST - III] The battery will be in compliance with **IEEE 1625:2008** *for* rechargeable batteries for multi-cell mobile computing devices.

[ZST - III] The device will be in compliance with **UL 2054**

## DYNAMO

### GENERAL REQUIREMENTS

[ZM - I, II] Dynamo is purchased within Canada, off-the-shelf, as seen in Figure 3.

[ZM - II] Dynamo is able to charge battery.

[ZM - III] Build custom Dynamo.

### PHYSICAL REQUIREMENTS

[ZM - I, II, III] Weight of dynamo should not exceed 5 lbs.

[ZM - II, III] Dynamo attaches to the front gear hub of the bicycle wheel.

### MECHANICAL REQUIREMENTS

[ZM - I] Dynamo produces tappable energy by external rotation.

[ZM - III] Custom Dynamo unit compensates for natural external forces (friction, gravity, drag).

### FIRMWARE REQUIREMENTS

[ZM - II, III] Dynamo communicates with firmware through specialized filter circuit.

### SUSTAINABILITY/SAFETY REQUIREMENTS

[ZM – I, II, III] Dynamo is protected from external factors in a weatherproof box.

### PERFORMANCE REQUIREMENTS

[ZM - III] Dynamo is able to charge battery to capacity of at least 2800 mAH.

[ZM - I, II, III] Dynamo must be able to generate electrical power at low cycling speeds of 5 - 10 MPH.

[ZM - I, II, III] Dynamo behaves like an ideal electric generator unit.

### STANDARD REQUIREMENTS

[ZST - III] The dynamo will be in compliance with **WEEE Standards Directive 2012/19/EU** for electrical and electronic waste.


Figure 3 - Types of dynamos available on the market (Phillips, 2015).

## ARDUINO

### GENERAL REQUIREMENTS

[ZG - I, II] The type of firmware is Arduino 101.

[ZG - I, II] Arduino should be reprogrammable.

### PHYSICAL REQUIREMENTS

[ZPH - I, II] Arduino receives and processes values sent from sensors.

### FIRMWARE REQUIREMENTS

[ZF - I, II] Arduino sends the signal to mobile application.

[ZF - III] Microcontroller chip runs on custom PCB.

### RELIABILITY REQUIREMENTS

[ZR - I, II] Internal components of the Arduino (accelerometer, gyroscope etc.) work properly.

### SUSTAINABILITY/SAFETY REQUIREMENTS

[ZSS - I, II] Arduino is protected within a weatherproof box.

### PERFORMANCE REQUIREMENTS

[ZPE - III] Arduino will be powered by *Zyklus*.

[ZPE - III] Microcontroller chip has minimal power consumption.

[ZPE -  III] Microcontroller chip is compatible with Android.

[ZPE - I, II] Microcontroller chip will be powered by external batteries.

## BICYCLE & PHONE HOLDER

### GENERAL REQUIREMENTS

[ZG - I, II, III] Bicycle will feature a bike phone holder for cell phone to display software app.

[ZG - I] Testing on standard fixed gear bicycle.

### SOFTWARE REQUIREMENTS

[ZS - I] App contains skeleton pages for future functionality.

[ZS - I, II] App communicates with Arduino via Bluetooth.

[ZS - III] App has a reward systems page allowing users to track progress quantitatively.

[ZS - II, III] App tracks daily distance covered graphically on a homepage widget.

[ZS - III] App tracks past progress in separate tab allowing user to view weekly/monthly/yearly progress.

[ZS - II, III] App has a user profile page allowing them to customize their goals.

### PHYSICAL REQUIREMENTS

[ZPH - I, II, III] Phone holder should be small and easily attachable to bicycle handles.

## PROCESS DETAILS & PROBLEM ANALYSIS

Our initial proposal detailed our usage of an EIU that would attach to the bicycle in order to generate electrical energy. Upon further consideration and research, we propose a different solution; the use of a Dynamo. A dynamo is quite similar to our original idea, however, it is a more compact, small electric generator. This electric generator makes direct current electric power using electromagnetism. This idea is an upgrade from our original idea, as our initial thoughts were to have the magnet attached to either the spokes of the wheel, or inserted into the handlebars of the bicycle. This would have been a major constraint to the prototype, as having the magnet and coils in separate locations on the bike, and thus would hinder the consistency in power generation. Another major constraint would be harnessing power at average speeds of a bicycle, which could range anywhere from 5 MPH - 55 MPH (Arzten, 2013). Moreover, it would be critical to capture the power at slow speeds between 5 - 10 MPH, a range that most bicyclists would be travelling at within a city hub. Figure 4 shows an overview of the system process.

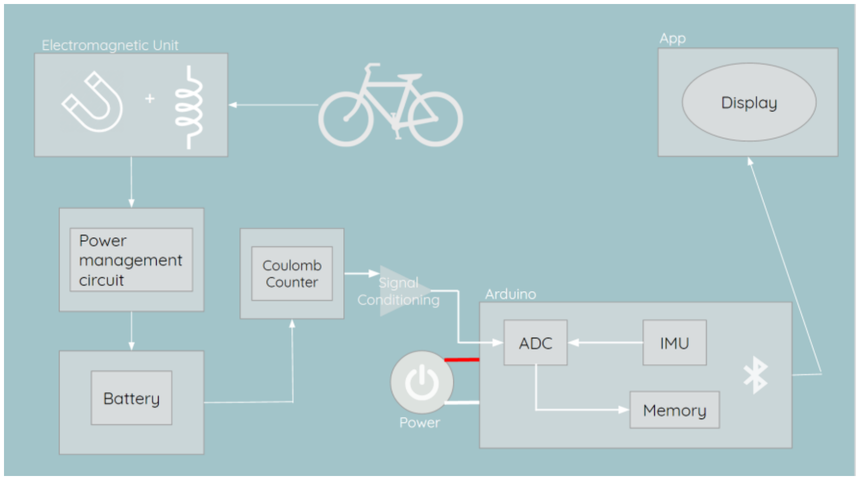


Figure 4 – Flowchart of process design

To solve this issue, our current project version has shifted to the use of a bicycle dynamo. A bicycle dynamo is a type of generator, usually attached to the front wheel of the bicycle, and touches the tire's rim that spins when the bicycle moves. Usually, a bicycle dynamo has more than one magnet with coils of wire spinning inside their poles. Very similar to a typical electrical generator, the dynamo consists of a stationary module, the stator, and the rotating armature (Publishing, 2017b). Generally, bicycle dynamos are rated at 6 Volts, 3 Watts (Arzten, 2013). The only constraint to using the dynamo is ensuring the device is compatible with the bicycle used in both our prototype, and the final product.

The major hurdle to this project would be choosing a dynamo that generates power from the bicycle and efficiently capturing said power. A past thesis report details the road cycling power and it's relevant parameters in Figure 6 and 7. The output power of the dynamo hub needs to be between 2.5W (5V at 500mA) and 5W (5V at 1A) of power to charge a common iPhone 5. From test results performed in a past thesis report (as seen in Figure 5) (Arzten, 2013) - while taking into account characterizations of the dynamo hub such as electrical frequency, voltage and power - shows the typical DC power stored within the battery, depending on the speed (MPH) of the bicycle.

| Speed (MPH) | Freq. (Hz) | Vin Peak (V) | Current in (mA) | Power In (W) | Efficency (%) | Power Out (W) | Vout (V) | Iout max (mA) | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 14.7 | 1.66 | 500 | 1.15 | 75 | 0.87 | 4.2 | 206 | |
| **7** | **20.4** | **4.54** | **500** | **2.17** | **75** | **1.63** | **4.2** | **388** | |
| **9** | **26.2** | **7.42** | **500** | **3.19** | **75** | **2.39** | **5.0** | **478** | |
| 10 | 29.0 | 8.86 | 500 | 3.70 | 75 | 2.77 | 5.0 | 555 | |
| **15** | **43.4** | **16.05** | **500** | **6.24** | **75** | **4.68** | **5.0** | **936** | |
| **20** | **57.8** | **23.24** | **500** | **8.78** | **75** | **6.59** | **5.0** | **1000** | |
| 25 | 72.2 | 30.43 | 500 | 11.33 | 75 | 8.49 | 5.0 | 1000 | |
| 30 | 86.6 | 37.63 | 500 | 13.87 | 75 | 10.40 | 5.0 | 1000 | |
| 35 | 100.9 | 44.82 | 500 | 16.41 | 75 | 12.31 | 5.0 | 1000 | |
| 40 | 115.3 | 52.01 | 500 | 18.95 | 75 | 14.22 | 5.0 | 1000 | |
| 45 | 129.7 | 59.20 | 500 | 21.50 | 75 | 16.12 | 5.0 | 1000 | |
| 50 | 144.1 | 66.40 | 500 | 24.04 | 75 | 18.03 | 5.0 | 1000 | |
| 55 | 158.5 | 73.59 | 500 | 26.58 | 75 | 19.94 | 5.0 | 1000 | |
| **Battery** | **DC** | **3.05** | **1400** | **4.27** | **75** | **3.20** | **5.0** | **641** | ***Discharged at 2C** |
| **Battery** | **DC** | **3.05** | **1050** | **3.20** | **75** | **2.40** | **5.0** | **480** | ***Discharged at 1.5C** |

Figure 5 - Preliminary test results, relating cycling speeds to battery power stored (Arzten, 2013)

$$\mathbf{P} = \left[ \begin{array}{c} V_a^2 V_G \frac{1}{2} \rho (C_D A + F_W) + V_G C_{RR} m_T g \cos(\tan^{-1}(G_R)) + V_G (91 + 8.7 V_G) 10^{-3} \\ + V_G m_T g \sin(\tan^{-1}(G_R)) + \frac{1}{2} \left( m_T + \frac{I}{r^2} \right) \left[ \frac{(V_{Gf}^2 - V_{Gi}^2)}{(t_i - t_f)} \right] \end{array} \right] / E_C$$

Figure 6 - Equation for Road Cycling Power, where $E_c$ represents the chain efficiency (Arzten, 2013)

| Value (Units) | Variable | Parameter |
|---|---|---|
| (m/s) | $V_a$ | Air velocity tangent to the direction of travel |
| (m/s) | $V_G$ | Ground velocity |
| 1.2234 (kg/m³) | $\rho$ | Air density |
| 0.2565 (m²) | $C_D$ | Coefficient of drag |
| | $A$ | Frontal area |
| 0.0044 (m²) | $F_W$ | Drag area of the spokes |
| 0.0032 | $C_{RR}$ | Coefficient of rolling resistance |
| (kg) | $m_T$ | Total mass of bike and rider |
| 9.81 (m/s²) | $g$ | Acceleration of gravity |
| | $G_R$ | Road gradient (rise/run) |
| 0.14 (kg*m²) | $I$ | Moment of inertia of the two wheels |
| 0.311 (m) | $r$ | Outside radius of the tire |
| (m/s) | $V_{Gf}$ | Final ground velocity |
| (m/s) | $V_{Gi}$ | Initial ground velocity |
| (s) | $t_i$ | Initial time |
| (s) | $t_f$ | Final time |
| 0.97698 | $E_C$ | Chain Efficiency |

Figure 7 - List of parameters (Arzten, 2013)

Dynamo usually outputs 5V-6V AC. Most phones take in a regulated DC level of 5V, while batteries take in a regulated 3.6 - 4.2V. The differences between lithium ion vs. lithium polymer batteries are outlined in further detail below.

**Prototype vs. Final End Product**

For the short-term vision, the compatibility of the *Zyklus* prototype will be based solely on the bicycle used. Our goal in the long run is to have our product work for consumers with varying bike types. Our prototype will make use of the Arduino 101 microprocessor due to the built in accelerometer, a gyroscope Bluetooth capabilities. However, running this 3.3V microprocessor (Arduino) on our battery pack would not be ideal - instead, our end product will utilize a microprocessor that doesn't draw as much power, and will be made into a compact PCB along with optimal circuitry. Another difference between the *Zyklus* prototype and the end product would be in the software suite offering. Given the time constraint, *Müve* expects to develop a test application featuring the most important app components, such as the home screen. In the future, *Müve* will make a full software suite available, i.e. adding in a competitions page, and having personal profiles link to other social media accounts (like Facebook). Lastly, also due to the time constraint, *Müve* will be purchasing our own dynamo unit. In the future, our goal would be to create an ideal dynamo that would be highly compatible with the lithium ion battery used, and that would control and maximize power generation.

## SUSTAINABILITY/SAFETY

A company's number one priority when releasing a product is always the safety of its users, followed by the usability and sustainability of the product. Products are researched and tested prior to release to ensure that all risks are minimized, and that all hazards are labeled. One major component of our product is the rechargeable battery that the device will be charging. Especially with the recent rise in the number of battery-related accidents and injuries, our company has decided to focus on the quality and safety precautions of installing a battery. We will also take a look at the life expectancy and risks of other components such as the wiring, motors, and weather-proofing methods.

We had two different types of batteries that we could potentially incorporate into our design: Lithium ion, and Lithium Polymer batteries. The difference between these two, and its feasibility is as follows. The use of Lithium ion batteries is optimal for including in our product, Zyklus, as it is low maintenance, have low self discharge, and high energy density, which means that it is much more sustainable and long-lasting than nickel cadmium based batteries. Another advantage of these batteries is the fact that it can be made thin and compact. The use of Lithium Polymer batteries was also considered for our product as well, and it was discovered that these batteries can be even more thin, compact, and lightweight compared to lithium ion batteries ("Lithiumpolymer psds," 2015). It was also discovered that lithium polymer batteries have improved safety over other types of batteries. However, it provides a decreased cycle count, lower energy density, and is expensive to produce. The safety considerations for this type of battery is very like that of the lithium ions listed above. As per usual, the battery will need to be charged within its specified voltage range to ensure the safety and sustainability of the product.

The only safety concern regarding this battery is the different risks of overcharging the battery, and its durability in different environmental conditions that the bike may be exposed to. ("Lithiumion psds," 2015). Several different things must be considered - first, the battery charger itself must be sustainable, in the way that it would not get damaged from the movement of the bike. Manufacturers of lithium ion batteries warn that exposure of the battery to excessive physical shock or vibration should be avoided, which is not entirely possible when mounting onto a bike. We will be required to create a mechanism that would minimize or absorb as much of the movement and shock as possible to reduce the risk of battery failure. Furthermore, we must ensure that the casing of the battery charger is strong enough to protect it from the movement and the external environmental conditions; charging the battery with a broken charger increases the risk of battery failure.

Rechargeable batteries are designed to be charged many times. However, the life of the batteries can quickly diminish when it is continuously charged for more than 180 minutes without discharging. A backup circuitry to cut off the power from the generator to the battery will be required to avoid the risk of overcharging. Batteries often include an internal protection circuit that prevent it from exceeding its charging voltage limitations.

The temperature at which it is used in is also a concern, as the product will be used in different weather conditions – on both a cold winter morning, or a hot summer afternoon. The charging temperature will need to be kept between 0°C and 50°C, which means that a protective casing is required to ensure that the temperature stays within this range. Furthermore, waterproofing will be necessary to avoid risks such as short circuiting. In the case that the battery becomes damaged or ruptured, it must be ensured that that no water enters the battery. Prolonged short circuiting of the battery will increase the temperature of the battery, and may become a fire hazard.

To maximize the performance of the recharging components, and to extend the lifetime, the battery and its recharging circuit must be stored in an appropriate protective casing. The lifetime of the battery will vary with its different manufacturers and its build quality; however, looking at a reliable brand such as Energizer, the battery is expected to have a lifetime of approximately 5 years under ideal conditions. The protective casing of the circuity should at least have an Ingress Protection code of IP64. IP64 means that the device is totally protected against dust, which is necessary when biking in the outdoors, and protected against water sprayed from all directions, which will protect against mist and other weather conditions that the biker may ride through.

The life expectancy of copper wiring is extremely long – in the upwards of 30 to40 years, although this all depends on the insulation of the wiring. For instance, temperature often has a large impact on its durability (Solutions, 2010). Exposing the wires to areas with a high temperature, or packing too many wires in a small area can increase its temperature and degrade its quality. In the case of our product, there is the risk of exposing the circuit wiring to a wide range of temperatures – from extremely cold winter conditions, to hot summer temperatures – which may cause the insulation to become brittle. To maximize the lifespan and the efficiency of the circuit, we must ensure that all components are kept in a weather and temperature-protected casing that doesn't expose the circuitry to external variables and cause it to lose power.

Another consideration of extending the lifespan of the components is to manage the amount of current going through the DC dynamo motor ("What are the factors that significantly affect the life span of a DC motor?," 2017). If an excessive amount of current is produced from cycling, a power management circuit will be required to be installed to ensure that the amount of current will not heat up the motor too much. Excessive voltage in the motor will also shorten its life, as the motor will be rotating faster than it should be. When the motor is in operation, it produces some heat. It is important to make sure that the heat produced through the operation of the DC motor combined with the external temperature does not exceed its maximum heat tolerance. Most motors can stand an external temperature of 40°C. Exceeding this temperature will overtime damage the insulation, bearings, and the brushes of the motor, decreasing its lifespan. As our motor, will be used in outdoor weather conditions, the motor will be required to be completely sealed. The motor should be protected against moisture, corrosion, and metal rust. This is possible using water-proof sealed bearings, waterproof wire exits, and O-rings in openings to keep water out.

## CONCLUSION

We, at *Müve,* are incredibly excited at the prospect of building *Zyklus* and have reinvented our approach toward the product. The functional requirements outlined in this document allow us to move forward with clear-cut goals ahead of us. As elaborated within the specifications, our end system will be held in a weatherproof casing and will not only generate energy but also fun the firmware chip. We move toward this in two steps, the proof of concept model wherein we use standard off the shelf parts followed by the prototype stage during which, our team will specialize each element to reach our final product. With the combined expertise of our core team, this should be an attainable goal.

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