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Technical Concept Study of an Electric Motorcycle Model

From Idea to Prototype, with Focus on Material and Process

Master's thesis in Production Engineering & Materials Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
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Cover: Illustration of a covered RGNT motorcycle.

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Abstract

Larger cities are beginning to phase out vehicles with combustion engines[14] and the sales of electric motorcycles is simultaneously increasing[5]. Electric motorcycles can be a more competitive alternative in urban areas since it often is cheaper than other electrical vehicles. RGNT Motorcycles is a company making electric motorcycles and are starting to investigating a new motorcycle model.

This project aims towards giving RGNT a good technical concept study to base the development of this new model on. The aim is to produce the best conceivable concepts of different sub-systems where there are significant performance gains to be had. The focus will lie on developing concepts where effort has been put into having reasonable materials and processes to be able to reduce the cost of the end product. The concepts will be developed with a data driven product development process following the methods described by G.Gustafsson [11]. Once concepts for the different subsystems like frame, batteries and tyres have been developed, a prototype will be designed and manufactured in order to test the performance of these subsystems.

The project has produced results in some major investigation areas and they are as follows. An evaluation of the current state of the latest model from RGNT which helped in developing the problem definition. A frame and suspension geometry together with a set of tyres to begin the practical testing with. It also resulted in a battery pack enclosure design which would help keeping the cost of the swappable battery packs low. A model for estimating the required energy storage capacity was developed in order to make informed decisions about how to design a battery pack in theory and for the prototype.

It could be concluded that the requirement specification set together with RGNT in the beginning of the project might need to be adjusted slightly to be closer to the wanted end result of this concept. The current requirement of a 100 km range together with 100 km/h top speed makes the battery system unnecessarily large and compromises the wanted packaging. Lowering the range and top speed requirement slightly would decrease this effect. It was also concluded that a pressed steel frame could lead to great cost saving but that there are plenty of work left before this concept can be implemented.

Keywords: Electric Motorcycle, Prototype, Swappable Battery Pack, Sheet Pressed Formed Frame

Acknowledgements

This project is a masters thesis that has been carried out by two students with backgrounds in production engineering and materials engineering. The project had a duration of 20 weeks, starting in early January 2021 at Chalmers University of Technology and in collaboration with RGNT Motorcycles.

We would like to begin by thanking RGNT Motorcycles for giving us the opportunity to be a part of such a big development project. Every single one of you have in some way, small or large, helped us with this project. Alexander Lewandowski have been helpful with questions related to the design and the overall image of the model concept.

We are grateful to have had Niels Jonsson at RGNT as our supervisor and even though everyone's time has been scarce during this spring, Niels always made sure to take time to help us.

A special thanks goes to our examiner Göran Gustafsson who has help us navigate through and learn about the field of product development. He helped us to focus on what was important and he always helped where possible.

Thank you.

Ludvig Brodén & Filip Jonsson, Gothenburg, June 2021

Contents

1
Introduction

1.1 Background

There is a global trend of phasing out vehicles powered solely by internal combustion engines and even in some places only allow fully electric vehicles to be sold after a certain year [17]. Several larger cities around the world are also introducing zero emission zones in the most urban areas and London is one of them, with a clear goal of zero emissions from transportation as early as 2025 in some areas [14].

The sales of electric motorcycles has increased several years in a row in Europe [5] and this trend might be accelerated if larger cities keep straining the regulations for emissions since electric motorcycles can be a cheaper alternative to other electric vehicles.

RGNT Motorcycles is a Swedish manufacturer of mid-sized electric motorcycles. Their latest model is today built to order in a functional workshop layout, the coming models are to be of a higher production volume and therefore the processes and designs must be adapted thereafter.

One of many concept ideas which RGNT has is to make a smaller size electric motorcycle made for inner city travelling where focus lies in ease of use and simplicity, this while also getting the benefits of having a highly modern electric vehicle. This motorcycle would be cheaper to reach a larger portion of the market. This model concept will hereafter be called model x and this project aims towards clarifying what this model could be.

1.2 Purpose and Goals

The purpose of the project is to perform a technical concept study of the model x concept that can act as a pre-study for the company when they begin their development process for it. It will include recommendations for the major subsystems regarding materials and processes to lay the base for future development. The challenge lies in making the motorcycle have a feeling of quality while keeping costs low. It is also important to include the manufacturability aspect early on since it can have a large effect on the overall profitability.

1.3 Scope

This project will consider the mechanical and electromechanical design aspects of the product focusing on materials and processes. RGNT will do most of the market analysis work and with the results from that develop the requirement specifications together with the thesis workers. The business case for the model concept as well as surface design and general style of the motorcycle is done by RGNT. The initial goal is to investigate the following research questions during the project.

- How a suitable frame and suspension geometry could look for a motorcycle of this size and with the desired properties.

- How a suitable frame would be manufactured. The design and shape of the desired look determines largely what kinds of processes and materials can be used.

- What kind of rims would be suitable for this motorcycle? How does the cost of spoked rims differ from cast ones for example?

- How an energy storage design could look which meets the requirements, fits in with the overall packaging and has the potential of being easily swappable.

2

Theory

2.1 Glossary

- BMS - Battery Management System
- BoM - Bill of Material
- CAD - Computer Aided Design
- CCS - Combined Charging System, a standard for electric vehicle chargers
- CoF - Coefficient of Friction
- CoM - Center of Mass
- DFMA - Design For Manufacturing and Assembly
- EV - Electric Vehicle
- R&D - Research and Development
- VCU - Vehicle Control Unit

2.2 S-curves in Innovation

Product innovation usually follows s-shaped curves where new technologies needs more engineering effort in the beginning and in the end of their development [10] for performance gain. Performance can in this case be anything from cost to CO_2-emissions or customer satisfaction. In order to improve a mature products performance, increasingly more engineering effort needs to be put into it. At some point it costs more to develop it than what is gained from doing so. This is usually when a leap to a new technology is made out of necessity solving the same problem but with higher performance. Making a leap to a new technology is however also highly demanding with regards to the engineering effort needed. This is visualized in Figure 2.1.

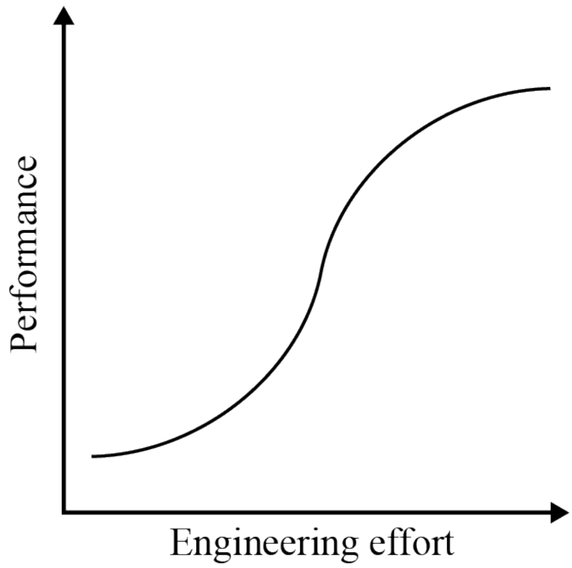


Figure 2.1: A diagram of the required engineering effort and performance gains

A motorcycle usually consists to a large part of highly matured parts sourced from a supplier which mass produces them. Some examples of mature products that usually comes on a motorcycle which is hard to make performance gains with are as follows.

- Handle bars - Usually a steel tube with some kind of surface treatment. The end result is both good looking and cheap if the process is automated.
- Brake levers - Usually one cast and machined part which has looked similar for a long time.
- Electric horn - Modern electric horn models are usually sold to several different vehicle models and brands and most of them look similar.

You would need to take a leap to something completely new in order to save cost on the functions these sub-systems allow for. Electric motorcycles as a whole system is not a mature product yet and therefore the engineering effort is better spent on sub-systems and components which are in the beginning or in the middle of their s-curves from an economical perspective.

2.3 Interview with Experienced Product Development Engineers

The opportunity to talk to two experienced product developers was given and individual interviews were held with them. The goal was to get a better understanding of how the product development process can look in other automotive related companies and the main take-aways are documented in this section.

2.3.1 Dantar P. Oosterwal

Dantar has a passion for vehicles of all sorts and has worked in the automotive industry for many years in companies such as General Motors, Harley-Davidson and Buell Motorcycle where he mostly worked with product development inn some form or another. He is now a consultant within the field of lean product development. Getting his input to this project helped guiding it in the right direction and to focus on the right things. The main areas of discussion during the interview were as follows.

Idea to market and learning from earlier projects - Buell Motorcycles aimed for 1 year of time from when they got an idea of and motorcycle to when the first motorcycle was sold. Depending on the complexity of the project and amount of carry-over, Harley-Davidson aimed for somewhere between 12 and 18 months of development for their new models. Dantar stated that in order for the development of a new motorcycle model to be this quick, it is necessary to be a learning organization and take advantage of what was discovered from previous projects. Only then can the projects resources be spent on what really makes a difference.

If you already know the limits of the system you are designing within, then the design process will take less effort. It is necessary to figure out in early stages what works and not by creating a set of prototypes and testing it when working within new design limits. It is not enough to see if one thing works or not, then you might be missing out on advantageous possibilities. Another way of finding out what works and not is to get competitors products and analysing them. For example, if a new frame is being designed and it is needed to know how stiff it must be, then you can find competitors with similar set-ups and measure their stiffness instead of making wild guesses. In short, as much information as possible with minimal resources spent and early in a development project is important.

2.3.2 Norbert Majerus

Norbert worked at Goodyear for many years with product development and seemed to know everything worth knowing about tyres. He had at some point worked with motorcycle tyres when Goodyear owned Dunlop and had some pointers to keep in mind when doing a project such as this. Norbert was also experienced with mechanical design and vehicles in general so this subject was also discussed. He is now retired but still works with lean product development as a consultant.

As stated by Tony Foale [8], the tyres is a major part of what makes the suspension and roadholding of any vehicle perform as wanted. Therefore most of the questions to Norbert was regarding this, since he is experienced in the field. It was agreed after having discussed with Norbert that the intricate behaviour of tyres and investigating the performance of different variants is out of scope for this project. Development of tyres for new vehicles is usually best left to a tyre manufacturing company once a fairly mature prototype has been developed. It was also concluded that as long as you start with a set of road legal tyres from a name brand company which are intended for the same category of motorcycle then you probably have a fairly good starting point and can work with that brand to develop more suitable tyres. It was also learned that making custom tyres for new vehicle models is common and that the extra development and tooling cost does not have to be economically detrimental even for relatively small production volumes.

Another topic that was briefly discussed with Norbert was design for manufacturing. He had come in contact with companies that had research and development departments that were completely separated from the manufacturing side of the company and in some cases set up as two completely different companies. Some high performance, spare-no-cost type of companies can manage to have it separated like that but in almost every company that is not the case. The design for manufacturing starts the same day you start a new design process, otherwise the company risks missing out on benefits later on and might end up spending unnecessary resources at trying to shoe horn a product with low manufacturability through a manufacturing process instead of focusing on making a better product.

2.4 Global Coordinate System

To refer to orientations and dimensions of and on the motorcycle a global coordinate system is defined. Here the positive Y is in the forward direction of the motorcycle. The positive Z is normal to the ground. The positive X is thereby rightwards of the forward direction of the motorcycle and the origin is in the center of the front wheel. The axis of the coordinate system can be seen in Figure 2.2.

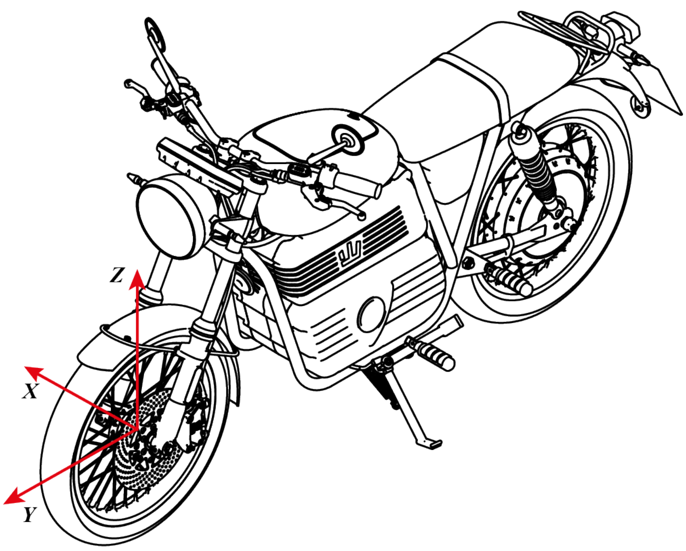


Figure 2.2: Vehicle coordinate system definition

2.5 Motorcycle Geometry Nomenclature

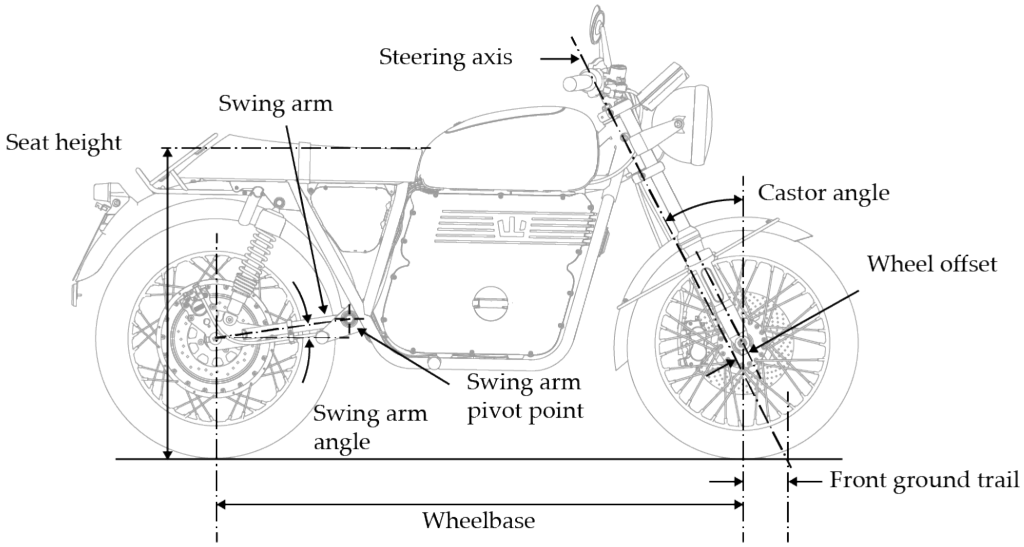


Figure 2.3: Definition of motorcycle geometries

- Seat height - Seats usually does not have a parallel surface to the ground and they compress when the user is seated. An approximation of where the driver will end up is used.
- Steering axis - This measurement is defined by the axis which the front suspension is rotating around. This axis is usually parallel with the forks of the front suspension.
- Castor angle - The castor angle is also commonly referred to as rake angle and it is synonymous. It is the angle between the front forks and the z-axis and is usually measured without any steering angle, at stand-still and without the driver on the motorcycle.
- Wheel offset - This is the perpendicular offset from the steering axis to the to the center of the front wheel.
- Front ground trail - This is the distance in the y-direction from the center of the front wheel to the point where the steering axis intersects the ground plane.
- Wheelbase - This is the distance in y-direction from the center of the rear wheel to the center of the front wheel.
- Swinging arm - This is a mechanical part which is commonly used in rear suspension designs in motorcycles. It connects the rear wheel to a pivot parallel to the x-axis in the frame of the motorcycle.
- Swinging arm angle - This is the angle in the yz-plane between a line through the center of the rear wheel and the swinging arm pivot point together with the y-axis.
- Rolling radius - This is the radius which the wheels has under loaded conditions.

2.6 Swappable Batteries

Range anxiety is a phenomenon where users and potential users of electric vehicles (EVs) are anxious about not getting where they want to go with the range available. This can lead to them avoiding to use their EVs or not buying them at all [20]. Companies are investigating how to speed up the charging process of their vehicles in order to avoid this phenomenon and one way of doing so is to replace the entire battery pack with a charged one. This is usually referred to as swappable batteries. Several motorcycle manufacturers has agreed on a standard which their swappable batteries will follow in order to have common charging stations and similar.

One example of a successful implementation of swappable batteries in electric motorcycles is the company gogoro which already have an expanding network of charging stations in Asia [21]. The customers park their motorcycles close to the charging station and it then recognize the customer and shows where to place the discharged battery packs. The customer proceeds to take new battery packs once the old ones has been put into the charging station and leaves with a fully charged motorcycle.

There have been critics of the swappable batteries concept. One example is the article by L. Ulrich [25] where he questions the feasibility of swappable batteries. The arguments in the article are sound but the critique is mainly aim towards electric cars and not EVs in general. The main concern in the article is the mechanical size of the machinery needed to swap battery packs of several hundred kilograms.

Separating the battery from an EV by introducing swappable batteries could lead to companies selling vehicles as one product and batteries as the "fuel" for them. This would mean that the cost of a new EV could be separated from the cost of the batteries which in some cases is the most expensive part of an EV. [9] Some people are reluctant towards buying EVs because they are worried about the aging of the batteries and the re-sale value. This concern could also be reduced by having the batteries and vehicle as separate units.

3

Methods

This chapter describes the methods that have been utilized in order to perform this project. The problem definition and concept development work is based on the process described by Ulrich & Eppinger [24].

3.1 Problem Definition

By working through the following parts of the problem definition, the project becomes more clear for everyone involved and it is easier to take decisions that bring the project closer to the wanted end result.

3.1.1 Technology and Stakeholder Analysis

A technology and stakeholder analysis is one of the first steps in the product development process. This step is performed by RGNT resulting in their understanding of the market and the product gap covered by the model concept considered in this project.

From the market analysis done by RGNT, a product specification document is formed. This will include background information about the typical user and eventually result in functions to be fulfilled by the product. This was delivered to this project in the form of a presentation covering the topic.

3.1.2 Requirement Specification

It is important to translate what RGNT wants this model concept to be able to do into measurable functions. This is to be able to make a requirement specification where it will be possible to determine if a requirement is met or not.

A requirement specification was set from discussions held with RGNT and what customer needs they see. The requirement specification is used in order to be able to weight different solutions against each other and remove alternatives that are worse than other ones.

3.2 Evaluation and Benchmark of the Latest Model from RGNT

An investigation of how the latest motorcycle model from RGNT performs within the new set of requirements for model x to get a better understanding of what changes needs to be done is performed. As discussed with D. Oosterwal, it is important to learn from previous projects in order to increase the engineering effort efficiency.

3.3 Concept Development

Concepts forming and evaluations are done by using the methods described by Ulrich & Eppinger [24]. After benchmark and pre-study of solutions on the market, solution ideas were created using structured and unstructured methods. The goal is to develop concepts and solutions covering the whole design space and eventually eliminate the least suitable alternatives finally resulting in only one remaining concept [11]. New concepts are incorporated by combining solutions from different concepts or new ideas. An illustration of the concept development process can be seen in Figure 3.1. The concept evaluation will focus on material and process aspects.

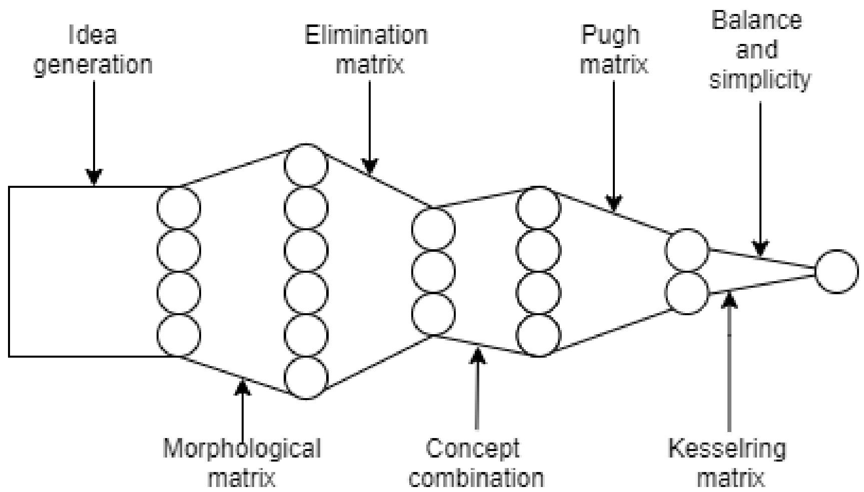


Figure 3.1: Schematic on the concept development process

3.3.1 Concept Generation

For each of the work areas the design space is defined. The goal is to have a design space as open as possible while boundaries are required to limit solutions not matching the product idea or scope. The product generation is done using structured and unstructured methods.

3.3.1.1 Brainstorming

Solutions for the functions are generated using brainstorming, which is an unstructured concept forming method. Brainstorming encourages participants to be creative and generate concepts for the functions even if they are unrealistic or hard to achieve [24]. Solutions not otherwise thought of could occur by having no restrictions on the created ideas in this stage. This stage can also utilize the findings from the benchmark as inspiration.

3.3.1.2 Morphological Matrix

Ideas found from the brainstorming are categorised into function groups. Complete concepts are then created by combining solutions from all function categories. All possible combinations are not considered since it would be unreasonably many to work through. A handful of randomly selected combinations are instead picked and evaluated in the next step of the process.

3.3.2 Concept Evaluation

The most suitable concept from the concept generation is to be found and this is done by a concept evaluation where the least suitable solutions gradually is eliminated until only one remains.

3.3.2.1 Elimination Matrix

Concepts are evaluated on the requirements from the requirements specification in the elimination matrix. Concepts not fulfilling the requirements for the system is eliminated. Concepts which are impossible to realize within the time frame or budget are eliminated.

3.3.2.2 Pugh Matrix

The concepts are ranked in relation to a reference and evaluated over a series of criteria, a relative comparison. Each criterion can be weighted to differentiate the importance of them. The ranking is done on the resulting value for each concept, highest value gives the highest rank. The concept with lowest rank is eliminated if a clear value difference is observed. Before the concept is eliminated the major benefits for the solution is noted to later be used in forming of new concepts. The matrix can be used again to further eliminate concepts by changing the reference solution. The process is stopped when the result converges and the ranking is independent on the reference.

3.3.2.3 Kesselring Matrix

The Kesselring matrix is an absolute comparison method. Each criterion is weighted against the others to form a relative sum of importance. For each criterion a scale of grading is formed, this is used to translate concept solutions into a normalized value. The products of the relative sum of importance and the grade are summed up to a total value used for ranking. The concept with the lowest rank is eliminated if a clear value difference is observed. The scale of grading used can be linear or non-linear to the quantities depending on the character of the criterion. Some criteria can be difficult to grade by values or quantities and in these cases a subjective grading can be done by a selected group of people or stakeholders.

3.3.2.4 Solution Balance and Simplicity

A solution balance is performed if more than one concept is remaining after the Kesselring matrix. Concepts including large variances of grades create an unbalanced product and can give the impression of an unfinished design. Concepts with an even level of development is preferred. The concepts are also graded based on their simplicity which can be described as a complexity number $K = (N_p \cdot N_{op} \cdot N_c)^{1/3}$ where N_p = the number of parts, N_{op} = the number of unique parts and N_c = the number of interfaces [11]. A lower value indicates a simpler design which is preferred.

3.4 Subsystem Design

Semi-detailed construction for some of the final concepts will be made in CAD to see if the overall packaging and way of manufacturing would work. The goal during this stage is to find problems with the subsystem that affects the analysis of the manufacturing process.

3.5 Material and Process Determination

GRANTA EduPack is a software which allows the user to compare materials and processes in a data driven way. It will be used while evaluating materials and processes for different components of the motorcycle. Parameters used and data extracted from the software are often based on general cases and will therefore need to be considered as guidelines.

3.6 Prototype

A prototype will be made to further evaluate if the customer needs are fulfilled with the concepts from the development process. New things that have not been thought of and missed in the design process can be discovered while making prototypes. The design department at RGNT wants to have a real life prototype to get a better understanding for how this model concept could feel in the end. A full size prototype will be used to test the major concept ideas in this project. Therefore the main thing to test with the prototype is the size and proportions of the motorcycle, the extraction of swappable batteries and if there is time for it, the frame type and shape.

4

Implementations

This chapter describes what was done during the project and how the method was implemented.

4.1 Evaluation of the Latest Model

The performance of the latest models was evaluated in regards to the new requirements in order to gain knowledge for model x.

4.1.1 Material Cost Analysis

The items with the highest cost in the latest model and have high potential of being reduced in cost by re-design are listed below.

- Frame assembly
- Rims and tyres
- Fuel tank
- Battery box
- Mudguards

Items that are expensive because of lower order volumes are disregarded from this list since the solution to their cost issue is mainly other than re-design.

Parts that are common for many motorcycle models which are sourced from a large supplier like lamps, handlebars and similar are disregarded as well since a re-design of these components would likely increase the cost of them instead of decreasing it.

Items that are designed by RGNT and are mature in their development process and in other words late in their s-curves are also disregarded.

All of the items in the list are in some way considered in this project which indicates that focus is put on the right parts of since cost reduction is one of the main challenges for this motorcycle model concept.

4.2 Problem Definition

4.2.1 Business Case

The business case for this motorcycle model concept is determined and described by RGNT as follows.

This motorcycle model concept is to be a smaller capacity, lighter and cheaper vehicle. Its mission is to attract an audience which are looking for an affordable but high quality motorcycle. The model will be a vehicle for frictionless urban intracity traveling and with the possibility of highway travel.

4.2.2 Wanted Features

To be a competitive product the vehicle must have a minimum range of 100 km and a top speed of 100 km/h. It must be an easy ownership with minimal maintenance. It must also be compatible with the connectivity functions RGNT supplies and support charging at regular charging stations.

4.2.3 Environmental Aspects

Even though most selling points of electric motorcycles are convenience and performance, one important aspect is the sustainability impact of them. A goal is therefore to make this motorcycle concept as environmentally friendly as possible while fulfilling all other requirements. There are several ways of minimizing the environmental footprint of electric motorcycles and some of them are described below.

- Considering the expected life span while designing sub-systems is important. The first sub-system that breaks and which the user wont fix is the one determining the overall life span of the entire motorcycle. This means that care has to be put into designing parts that will last for at least the expected life span.

- Making the re-use and re-manufacturing of battery packs easier by considering it during design. One way of doing this is to avoid permanent fastening methods like gluing battery cells together. Having components screwed together instead allows for easier disassembly and repairs.

- The energy efficiency of the motorcycle together with the capacity of the battery pack determines the range capability but it also determines how much energy is consumed in total over the motorcycles life cycle. The energy efficiency of an electric motorcycle is mainly determined by designing an efficient drive line, an exterior with low aerodynamic drag and lowering the vehicle mass. This can be seen in a later chapter about range estimations. The range could also be greatly affected by helping the user drive in a more efficient way with, for example providing information for a more planned driving and allowing the driver to use energy saving mode settings if they would like.

These aspects will be taken into account while developing the motorcycle model concept where possible.

4.2.4 Ethical Aspects

There are several ethical issues which can be discussed about manufacturing vehicles and especially about motorcycles and electrical ones. One example that affects the users experience significantly is honesty with the range of the motorcycle which is important in order to give the customer what they pay for. There are ways of showing results from range tests and calculations that indicates that the vehicle will travel longer than it actually will. This could for example be calculating the range instead of doing real tests. Calculating the range naturally leads to some error and the questions is what assumptions are made and what parameters are disregarded. It could also be that manufacturers choose to do range tests other than what is used during homologation. This could lead to a more accurate estimation but it could also give a skewed picture of what range the vehicle has.

4.2.5 Competing Products

A benchmark in terms of exploring competing products was done to understand the market. Price, range, power and battery capacity data was gathered for the competing products which are listed in Table 4.1.

It is important to note that the range stated by manufacturers necessarily is not tested in the same way. Even though there are standardized drive cycles for determining range of motorcycles, many manufacturers choose to use their own drive cycles which in some cases lead to longer range. Seen in the last column of Table 4.1 the energy consumption for the listed vehicles differs. Since different kinds of motorcycles are compared it is expected that the numbers will vary but one can also see that models of similar size and battery capacity show significant differences in energy consumption.

Table 4.1: Competitors to the model x

Brand - Model	Price [SEK]	Range [km]	Power [kW]	Capacity [kWh]	Consumption Wh/km
Fatscooter - Premium 3000W	18.988	80	-	1,3	16,3
Gogoro - Smartscooter 2	20.385	170	7,6	2,6	15,3
WK - E-colt	20.500	60	1,5	-	-
Vässla - 2	23.495	50	1,8	1,2	20
Super Soco - CUX Ducati	27.900	75	2,8	1,8	24
Super Soco - TS	29.900	80	2,4	1,56	19,5
Super Soco - TC	32.900	80	3	1,8	22,5
Super Soco - TSX	34.900	75	3	1,8	24
Fonzarelli - NKD	45.000	200	12	-	-
Husqvarna - EE5	49.900	-	5	1	-
Peugeot - E-Ludix	49.990	50	2,5	1,6	32
Super Soco - TC Max	54.900	110	3	3,4	29,5
Horwin - CR6	63.000	120	6,2	4	29,5
Vespa - Elettrica	79.900	100	4	4,3	43
Fuell - Fllow	92.000	241	35	10	24,1
Cake - Kalk INK&	105.000	83	10	2,6	31,3
Cezeta - Type 506 / 02	105.000	150	11	6	40
Cake - Kalk&	140.000	83	10	2,6	31,3
Zero - SR/S	166.060	198	82	12,6	63,6
Tarform -	200.000	193	41	10	19,3
Harley-Davidson - LiveWire	350.000	158	78	15,5	98,1

4.2.6 Overall Requirement Specification

The information gathered in this section was compiled into a requirements specification found in Appendix A. This document includes information for the overall vehicle and more specific requirement specifications for subsystems are done where needed.

4.3 Frame and Suspension Geometry

The reason for developing the frame and suspension geometry is to be able to better visualize and test different concepts. It will also act as a base for when the prototype is constructed. Some considerations will therefore be taken for practical limitations like available parts.

The first step in making a motorcycle frame is determining the coordinates of joints in the suspension, also called hard-points. Where these joints are placed in the suspension system largely determines the dynamics of the vehicle together with components like springs and dampers. This topic is covered in John Bradley's book *The racing motorcycle: a technical guide for constructors* [4]. The suspension system on any vehicle affects the experience of it while driving.

The overall geometry and dimensions of the motorcycle is the base of all other decisions for the suspension and packaging. Wheelbase, wheel size, seat height are the main parameters needed to be able to start the rest of the hard-point development. The latest model from RGNT and competitors models which are similar to the wanted end result are analyzed and used as benchmark.

The same type of suspension as is on the latest model from RGNT is likely to be used since there are no obvious performance gains seen in changing it. The latest model has telescopic forks and twin shock suspension. The spring rates and damping coefficients will be chosen once the final mass and layout of the motorcycle has been set and is therefore not a necessary part of this project. The manufacturer of the forks and dampers can usually help with choosing the right hardware to get the wanted damping properties.

4.3.1 The Wanted Properties of Model X

The idea of how the model x concept could feel while riding and using it was discussed together with the R&D department at RGNT and the following was concluded.

- The model x should give an agile feeling when riding in inner cities while still being stable at highway speeds (or top speed).
- The wanted handling could be compared to one of the newer Honda Cubs. The 2019 Honda Super Cub C125 is used as a reference.

4.3.2 Properties of the Latest Model from RGNT

An overview of the overall sizes and properties of the latest model from RGNT is summarized below with information found on RGNT's webpage [15].

Table 4.2: Dimensions of the latest model from RGNT

Feature	**Value**	**Unit**
Wheelbase	1408	mm
Castor and trail	27 - 118,6	degrees and mm
Suspension	Telescopic fork and swinging arm	N/A
Front tyre size	90/90 - 18	mm, %, inch
Rear tyre size	110/80 - 18	mm, %, inch
Mass	160	kg
Seat height	828	mm

The CoM for the latest model is determined in Appendix **??** by measuring the mass distribution of the front and rear tyre at different angles of the motorcycle. The CoM of the motorcycle and the driver is found to be placed 703,4 mm above the ground and 836,1 mm behind the front wheel center meaning the the mass distribution is 41/59, i.e. rear heavy. As found in Appendix **??** a good estimation of the wanted CoM position to get good grip in dry situations, according to John Bradley [4] is half the wheelbase from ground in vertical direction and half the wheelbase in the longitudinal direction. This means that the goal is to have the CoM on the model x slightly more towards the front than what the current model from RGNT has. This needs to be kept in mind while developing the packaging concept of the motorcycle model concept.

4.3.3 Properties of 2019 Honda Super Cub C125

This version of the Honda Super cub is chosen as a reference because it has plenty of reviews and information online. Following are the general properties of it.

Table 4.3: Dimensions of the 2019 Honda Super Cub C125 [12]

Feature	**Value**	**Unit**
Wheelbase	1243	mm
Castor and trail	26,5 - 71,12	degrees and mm
Suspension	Telescopic fork and swinging arm	N/A
Front tyre size	70/90-17	mm, %, inch
Rear tyre size	80/90-17	mm, %, inch
Mass	107	kg
Seat height	780	mm

4.3.4 Wheelbase

Following is a list of examples on how the behaviour of a motorcycle changes with the wheelbase. The list is based on the dynamic behaviours described in [4].

- Shorter wheelbase leads to the ability of doing smaller turning radii without reaching the maximum steering angle. This allows the motorcycle to be more maneuverable at lower speeds, while pushing and parking for example.

- Shorter wheelbase leads to less steering effort required while cornering. This can make the motorcycle feel more nimble but can lead to less high speed stability.
- Shorter wheelbase leads to more pitch while braking and accelerating if the CoM-height is assumed to be constant. For model x, the positive acceleration will likely not be a problem since the power to weight ratio will be relatively low. If the same size brakes is used as from the latest model for model x and the wheelbase is shorter, then the tendency of the motorcycles rear wheel to lift during heavy braking will increase.

This means that a more agile but less stable behaving motorcycle is achieved from decreasing the wheelbase and which is the right direction of change for model x.

As stated by J.Bradley [4], there are lengths of wheelbases which when exceeded gives a motorcycle distinct new characteristics, Bradley states that if a 125 CC exceeds about 1310 mm of wheelbase it starts to feel like a bigger motorcycle. Somewhere around 20 kW power output is common in 125 cc racing engines while the Honda cub has 7,1 kW.

Following is a list of wheelbases of motorcycles with similar user cases.

- The latest model from RGNT - 1408 mm.
- The 2019 Honda cub C125 - 1243 mm.
- Cake Ösa+ - 1340 mm.
- Sondors metacycle - 1320 mm.

A wheelbase of 1300 mm is chosen for model x in order to not exceed the 1310 mm mark while still having as much as possible in order to maximize the stability and still having the nimble feeling. A wheelbase of 1300 mm seems reasonable when comparing to similar motorcycles.

4.3.5 Castor Angle and Trail

As explained by J.Bradley [4], what castor angle and trail needed is dependant on what tyres are used and the values chosen in this section will only be a starting point from which a better geometry can be further developed on.

The amount of ground trail is what mainly affects the dynamic properties of the front end of a motorcycle so it is set first. The rake angle mainly effects how loads are distributed through the suspension and to the frame. Since changing the castor angle causes the trail to change it will need to be adapted to what trail is chosen.

The wanted amount of trail is somewhere between what the 2019 Honda Super Cub C125 and the latest model from RGNT has. A trail of 90 mm would be slightly below the mean value of the two, which seemed reasonable when comparing to what the smaller sized road motorcycles have in J.Bradley's compilation of motorcycle front suspension properties [4].

The wheel offset on the latest model from RGNT is around 35 mm. Since the front wheel center does not have any offset to the forks, all of the offset comes from the forks offset to the steering axis. These properties are kept for model x, partially because there is no obvious performance gain to be had from changing it and also to be able to use the same hardware for the prototype as is used in the latest model.

The castor angle has been determined by having set the trail, wheel offset and rolling radius. The castor angle could then be measured to 22,6 degrees by constraining these angles, the hard points and the tyres to each other in CAD .

A castor angle of 22,6 degrees is quite aggressive and mostly seen in sportier motorcycles. It is within an acceptable range but might lead to chatter while braking if the forks are not stiff enough. This will be tested in the prototype.

4.3.6 Swinging Arm Geometry

The swinging arm geometry is kept identical from the latest model since no issues had been seen with it. Since the front suspension has been moved closer to the rear, the interactions between the wheels will not be identical as to the latest model. The anti-squat will be slightly different but this is also something that would be fine tuned once a more developed prototype can be tested.

4.3.7 Seat Position

The seat height of the motorcycle is of importance both for the motorcycle to be comfortable to drive but also to allow for a safe handling at stand still. From the geometry comparison in Appendix C it was concluded that a 5^{th} percentile female may struggle to achieve a good driving position on the current model by RGNT and at standstill she may have problems balancing the motorcycle with a fully stretched leg and flexure. The 5^{th} percentile female will have better balancing possibilities on the model x with a slightly lower seat height of 800 mm, but the leg still needs to be fully stretched. The shorter wheelbase allows for a better driving position for the shorter drivers while still being reasonable for the longer ones. On the Honda Cub the 5^{th} percentile female reaches the ground without fully stretching the leg and can have it less flexured. The seat height of 800 mm is used as a starting point for model x since both shorter and taller people seems to be able to use it comfortably.

4.3.8 Model X Properties

Following is a table showing the dimensions and properties discussed in this chapter of the model x.

Table 4.4: Dimensions of the model x

Feature	**Value**	**Unit**
Wheelbase	1300	mm
Castor and trail	22,6 - 90	degrees and mm
Suspension	Telescopic fork and swinging arm	N/A
Front tyre size	3,25-17	-
Rear tyre size	3,25-17	-
Mass	110	kg
Seat height	800	mm

4.4 Frame

The frame of the motorcycle will be a big part of the look of the vehicle. It is out of the project scope to determine the wanted look of the motorcycle. Instead suggestions and sketches are gathered and potential manufacturing processes are investigated.

4.4.1 Type of Frame

Design sketches which are showing a frame style similar to vintage mopeds with pressed steel frames were made by RGNT. The decision to go for a frame of this style was taken together with RGNT. A few varieties of the design was received and the style found to be most interesting is seen in Figure 4.1 and therefore the overall shape and features from this is considered.

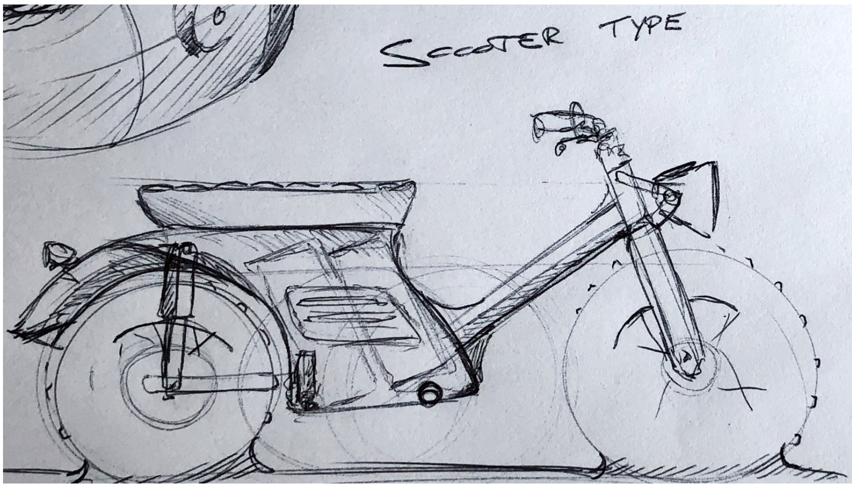


Figure 4.1: Concept drawing by RGNT

Besides the double curved surface shape of the component this style of frame includes features as mounting points for the rear suspension system, the front steering head, foot pegs, inspection openings and lids, various holes for mounting of accessories and more.

4.4.2 Material and Manufacturing Method

GRANTA Edupack 2020 [2] was used to browse and eliminate non suitable manufacturing processes and materials for the frame. To suit the vintage style and feel of the component only metals were considered. Complex geometries needs to be possible to form with the manufacturing process. The criteria for processes to pass the first stage was as follows.

- Be compatible with metals.
- Form components with a mass range of 5-10 kg which is an estimate of half the frame mass based on existing frame masses.
- Can create parts with a wall thickness less than 3 mm.

- Create double curved surfaces

.
The process groups found to fulfill these criteria are shown in Figure 4.2.

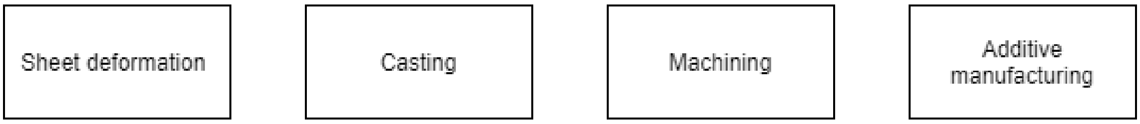


Figure 4.2: Surviving shaping processes from selection

The part to be made is large and thin and since a pressed frame acts as body panels and load bearing unit the part will have complex geometries and mounting points for other systems. The surface finish and the formability will be used to evaluate how suitable the process is for forming the body panel. The frame also needs to withstand the different loads acting on the motorcycle and hence a good mechanical performance is required. To meet the planned production volume the process time is included in the comparison. The criteria for the process is used in a Pugh matrix where the found process groups are compared to eliminate non suitable and unrealistic alternatives, the matrix can be seen in Appendix D.1.

From the four processing groups castings was found to be the least suitable option with no benefits compared to sheet forming. Machining and Additive manufacturing have better formability and mounting point position freedom compared to sheet forming but at significantly higher cost and longer process time. The level of material utilization is also lower with machining. The mechanical performance of the component is best from the sheet forming process. Processes of sheet forming is further investigated and three methods from the software are found to fulfill the criteria. These are Press Forming, Sheet Hydroforming and Superplastic Forming.

4.4.2.1 Press Forming

Press forming includes a range of sheet forming processes utilizing sets of dies and pressure [2]. The process can be drawing, blanking, bending, shearing etc. and may be used consecutively if needed. The tools are dedicated to the specific component meaning that the tooling costs are high. The process is most commonly used with steels but other metals can be processed and are commonly used for automotive body panels. Common features with this process are holes, cavities, tabs and raised sections.

4.4.2.2 Sheet Hydroforming

Hydroforming is a sheet forming process using only one die [2]. Pressurized fluid is used to form the material as seen in Figure 4.3 driving the blank sheet into the die. Complex shapes are possible and can be done in one step compared to press forming where multiple forming steps might be required. Tooling cost is low due to the requirement of one die lowering the required batch size before the cost per manufactured part converges. The process is suitable for ductile materials as stainless steel, aluminum and copper. The method is used in automotive and aerospace applications.

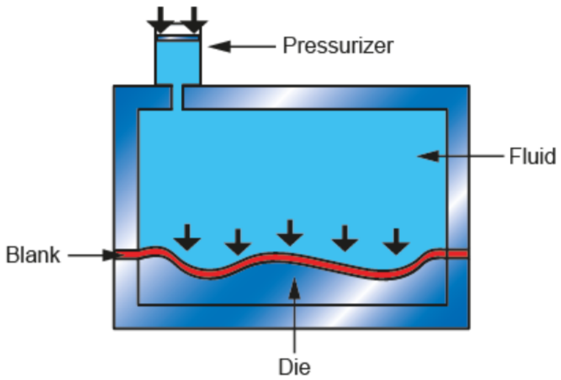


Figure 4.3: Principle sketch of sheet hydroforming [2]

4.4.2.3 Superplastic Forming

Superplastic forming is also a sheet forming process using only one die [2]. As for hydroforming the material is pressed against the die using a pressurized medium, in this case air as seen in Figure 4.4. The material is formed under controlled temperatures and strain rates to ensure superplastic conditions allowing strains 100 - 1500% at relatively low stresses. Limited to materials with stable superplastic microstructures such as Ti-6AL-4V and aluminum 7475. The method commonly is used in aerospace applications.

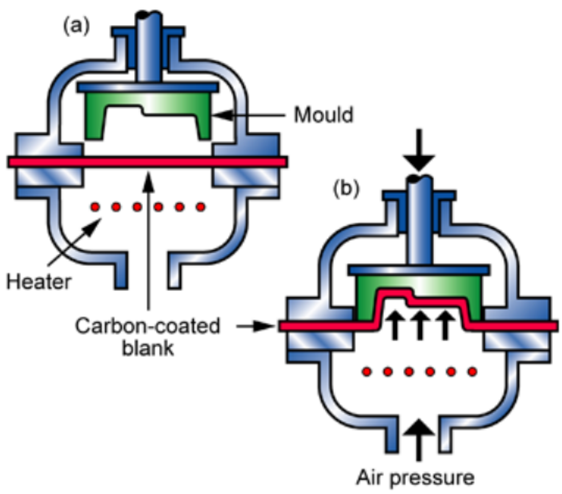


Figure 4.4: Principle sketch of superplastic forming [2]

4.4.2.4 Frame Materials

For each of the three processes GRANTA EduPack provides information about materials suited for it as shown below. Hydroforming and Superplastic forming have a limited number of materials suited for the processes while Press forming can be used to shape almost all metals.

- Hydroforming - Stainless steels, aluminum and copper.
- Superplastic forming - Stainless steels, aluminum, beryllium, cobalt and titanium
- Press forming - Steels (alloy, carbon, iron, high strength low alloy), stainless steel, aluminium, titanium, copper, magnesium and more.

4.4.2.5 Historical Material in Sheet Deformation Frames

Motorcycle frames are usually made from steel and aluminum. Plastic covers are commonly used to create the body on modern motorcycles. Pressed frames from classic mopeds are commonly made from steel as the classic Piaggio Vespa in Figure 4.5a or the moped models by Puch in Figure 4.5b. Both of these are made from formed steel sheet metal which are welded and bolted together.

(a) Piaggio Vespa [22]

(b) Puch Alabama [6]

Figure 4.5: Motorcycles with sheet metal body panels

4.4.3 Cost Analysis of Sheet Deformed Frames

A cost estimation of the remaining processes for the frame is done to eliminate costly alternatives. Material groups normally used in motorcycle frames and seen to be suitable for the manufacturing methods is used in the estimation. Material groups considered as rare earth materials are directly excluded. The frame is assumed to be made from two parts mirrored along the YZ-plane resulting in a component area of approximately 0,5 m^2 per half. The thickness is dependent on the material and in this comparison the thickness of steel and stainless steel is 1 mm. To keep the same relative stiffness the aluminum is 3 mm based on the Young's modulus of the materials.

The cost estimation in GRANTA EduPack gives a relative cost index for a given batch size considering a set of input data. The indices are compared at a batch size of 10.000 units with the parameters *Component length*, *Component mass*, *Material* *cost*, *Overhead rate*, *Discount rate*, *Capital write-off time* and *Load factor*. The component length is taken from early sketches of the design, the mass is given by the thickness and density of the component and the material cost is variable and taken from the software for the respective material which can be seen in Table 4.5. The overhead rate, discount rate, capital write off time and load factor is left at default values.

Table 4.5: Input data for cost estimation using GRANTA EduPack

Material group	**Thickness** [mm]	**Density** [kg/m^3]	**Mass** [kg]	**Price** [SEK/kg]
Steel	1	7850	3,925	7,07-7,82
Stainless steel	1	7800	3,90	28,6-31,6
Aluminum	3	2700	4,05	39,4-41,7

Table 4.6 shows the relative cost indices for combinations of materials and processes. It was found that the superplastic forming is considerably more expensive and therefore eliminated.

Table 4.6: Relative cost index for shaping one frame half

	Sheet Hydroforming	**Superplastic forming**	**Press forming**
Steel	-	-	95-590 SEK
Stainless steel	180-380 SEK	500-3200 SEK	210-700 SEK
Aluminum	220-400 SEK	620-3300 SEK	280-760 SEK

The cost of the components to be manufactured is to be minimized while fulfilling all requirements and hence the cost and process time of the frame halves is of interest. Welding is to be used for joining components on the frame and therefore the weldability of the material is of interest. The total mass of the motorcycle is the be no more than 110 kg and since the frame is one of the largest components, the mass of it is important to keep at minimum. To serve through the lifetime of the vehicle the fatigue and corrosion resistance is to be maximized from the material and manufacturing process. A Pugh matrix of the remaining alternatives is made based on the criteria: cost estimate, processing time, component mass, weldability, corrosion resistance and fatigue resistance. The Pugh matrix is found in Appendix D.2 where sheet hydroforming of aluminum and press forming of aluminum shows considerably lower values for cost, weldability, corrosion- and fatigue resistance. Alternatives where aluminum is used are eliminated.

Sheet hydroforming is only possible on stainless steels by the two remaining options [2]. The process requires ductile materials. Small concave sections may be difficult to manufacture and this is needed in the mounting points on the frame for example. The fluid used in the process might leave residues which needs to be removed before joining or surface treating the frame.

The properties where stainless steel out-performs ordinary steel alloys provides no benefits to the frame. The often higher ductility [2] may be useful when forming but the process indicates no limitations on formability of steels. The better corrosion resistance of stainless steel brings a higher cost and since the frame likely is going to be painted, the additional corrosion resistance becomes unnecessary.

The material and manufacturing alternative remaining after this is press forming of steel. The specific alloy to be used and how to split the frame into sections for high manufacturability is to be decided when there is a surface model of the frame.

4.4.4 Design Considerations for Pressed Steel Frame

The aim is to have the final component in the desired geometry within the set tolerances and with minimal thinning of the sheet [1] when press forming. Process parameters are developed to avoid scratches, wrinkles and orange peel effects. Enough deformation hardening from the process to enhance the performance of the component while still remain some of the plasticity is desirable. Features which can cause the part to be difficult to manufacture needs to be considered while designing in order to avoid the previously mentioned defects.

Small radii of the tool or die can cause excessive thinning or thickening of the workpiece, resulting in wrinkles due to compression or fracture due to the thinning of the material. Another limitation in press forming is according to Meelis Pohlak et al. [18] geometries including steep walls with draft angles close to 0°. The steep walls with draft angles approaching 0° results in strain states above the forming limit curve causing the material to fail. For the design limitations of the frame this means that a draft angle large enough to cause strain states under the forming limit curve is required.

Meelis Pohlak et al. also states that shallow extrusions with large radius of curvatures can lead to accuracy problems due to spring back of the material. This can be problematic if holes for mounting or other mating components is to be aligned with it. The elastic spring back can be reduced if the tool design is done carefully with a accurate gap between the tool and die and forming of the component is performed with support. If the tool design is not carefully designed then the component can contain high residual stresses causing the it to warp when flanges are trimmed off. A thermal treatment to remove the residual stresses may be required before trimming.

Fracture or material failure is often a fatal defect and is to be avoided in sheet metal forming. It is possible to make the process predictably fail on a specific location if designed correctly in order to enhance the formability in other sections of the component [7]. This is only usable if the sacrificed section is to be removed from the final component.

4.5 Rims and Tyres

The product development process of the tyres and rims are described in this section.

4.5.1 Tyre Requirements

The following requirements of the tyres are extrapolated from the overall requirements of the motorcycle.

- Requirements
  - The tyres must follow the European regulations for road worthiness.
  - Be safe enough in combination with the suspension setup.
  - The size of the tyres should fit together with the rest of the motorcycle. They must be somewhere between the latest model from RGNT and the 2019 Honda Super Cub C125.
  - Vintage style look to fit the overall style of the motorcycle.
- Wants
  - Made by Tyre company x. RGNT currently has a deal with Tyre company x where if they exclusively use their tyres, they will get a good discount on the listing price. If a tyre from Tyre company x can be used it is therefore an advantage.
  - Low cost. The price of the tyres is important since they make up a significant part of the total price of the motorcycle
  - If a tyre is tubeless or not. Tubeless is an advantage since you could put a tube in a tubeless tyre but not the other way around. (It can be dangerous to put a tube in a tubeless tyre).
  - If the same tyre can be used both as a rear and a front tyre it would makes the BoM shorter and could perhaps give an advantage when discussing the price with retailers.
  - Optimal mix of grip and reduced rolling resistance.

4.5.2 Tyre Data set and elimination

Start with all tyres listed in Component supplier X's catalogue. It gives a good picture of what tyres are commercially available. Only name-brand quality tyres are listed in this catalogue, which is an advantage since the choice of tyre reflects on the overall quality feeling of the motorcycle.

It was found that one of the more important aspects for RGNT regarding the tyres was the style and tread pattern. Hence the selection of tyres are more subjective and the first stage was to remove all tyres which did not have a retro tread pattern.

Next, the tyres were sorted on size. All tyres with sizes only available outside the determined limits were eliminated. The Honda Cub was used as a reference since RGNT stated that a suitable wheel size would be between the Honda Cub and their latest model. The Honda cub has had 17" rims both front and rear on most variants throughout the years. To make sure there is a distinct difference between the current model and model x it was chosen to go with 17” rims. The 2019 Honda Super Cub C125 70 mm wide in the front and 80 mm in the rear, this is therefore the lowest allowed width. The tyres would probably look too tiny if they were narrower. Since the current model is fairly narrow as it is, with 90 in the front and 100 in the rear) the upper limit is slightly above that, 100 and 110.

Tyres that are not rated for the speeds and loads the model X will have are then removed. The speed rating needs to be at least M - 130 km/h. The current model is capable of top speeds of 125 km/h. The new model will be able to output as much or less power than the current model; around 8 kW. The top speed is mainly determined by the aerodynamic drag force and the power output. The aerodynamic drag force will be similar to that of the current model. This means that the top speed will be equal or less than the current model. The load rating needs to be around 44 in the front and around 52 in the rear. This is based on the values from the measurements from the mass distribution of the current model.

The initial elimination of alternatives left six sets of tyres. These six are compared in a Pugh matrix, see Figure 4.6, examining the criteria discussed in the beginning of this chapter. In this case each criteria have a weight factor to amplify the importance of selected criterion. Each tyre is then compared to a reference graded with a (+) if better than the reference, (0) if equal to the reference or (-) if reference is better. The grads are them summed up, taking the weight factor to account, creating a total value for each tyre. The alternatives are ranked from high to low based on this value where the alternatives with lowest rank is eliminated if a significant difference is observed.

Pugh matrix Criterion	Weight	Model A	Model B	Model C	Model D	Model E	Model F
Made by Avon	2	Reference	0	0	-	-	-
Price	2		+	0	+	+	+
Tube and Tubeless	1		0	0	0	-	0
Look	3		0	+	+	0	0
Sum +			2	3	5	2	2
Sum -			0	0	-2	-3	-2
Value		0	2	3	3	-1	0
Rank		4	3	1	1	6	4

Figure 4.6: Pugh matrix for tyres

Model E, A and F was found to have low rankings and are eliminated. The Model E tyre showed a better price than the reference but the option to run it as both tube and tubeless is not possible. Neither is it made by Tyre company x. Model F showed a better price but the rest of the criteria was the same or similar to the reference.

Of the two tyres with highest ranking one was made by Tyre company x and one by Tyre company y. The Model D tyre showed good results in the evaluation but the production of them was found to be stopped and therefore this alternative was removed. By the two remaining alternatives the Model C had the most appealing tread pattern and was selected for the prototype.

4.5.3 Rim Requirements

The rims have some requirements they need to fulfill which are stated in the following list.

- The rims must be compatible with the surviving tyre concept. They therefore need to be 17 inches in diameter and between 1,85 and 2,50 inches wide.
- The look of the rims needs to fit in with the rest of the motorcycle. This means that a more classic look is necessary.
- The cost of manufacturing needs to be as low as possible since the rims make up a significant part of the total manufacturing cost.
- The rims must be able to at least handle the loads that the tyres are rated for.
- The rims must be corrosion resistant since they are likely to be highly visible and effect the overall look of the motorcycle. It might effect the overall quality impression of the motorcycle if parts corrode prematurely.
- The design must have the ability to accommodate for a hub-motor. The current model from RGNT has a hub motor which is laced into the rear rim.

Rims are a sub-system that usually are decoupled from most other sub-systems. They have dependencies with the tyres and the wheel hubs and often nothing else. This makes them suitable easier than other sub-systems to change late in a design phase even though they are a key part of the overall performance of the motorcycle.

Since a lot of engineering effort has been put into motorcycle rims and that they have looked quite similar for many years it indicates that motorcycle rims have reached the later plateau of a s-curve. Instead of trying to develop a new way of making rims, a comparison of existing ones and how they perform in regards to the requirements of model x is made.

4.5.4 Comparison of Rim Manufacturing Methods

All common manufacturing methods of motorcycle wheels that could be found is documented in the following list.

- Cast rims - Usually made with an aluminum alloy and the wheel hub is integrated in cast. It is machined to finish.
- Laced spokes rims - The rim trace is made with either extruded aluminum or steel and then rolled and welded together. The spokes are threaded and bent and the hubs can be cast and milled or only milled.

- Stamped rims - Metal sheet spokes are stamped out of a blank and usually riveted to a rim trace which is manufactured similarly to once made for laced spokes rims.
- Machined rims - These rims are made by machining a billet workpiece into a one-piece rim or by making several small parts and fastening them together.
- Composite rims - A laminate of dry or pre-impregnated fibers are put in the a mould before curing. Once this has cured the part can be de-moulded and finished by grinding, sanding and polishing.

Composites rims are unreasonably expensive in comparison to other kinds and are therefore disregarded. A set of carbon fiber rims in sizes suitable for the model x retails for between 16.500-24.000 SEK [16].

Stamped rims are disregarded after having discussed with the design department at RGNT. They do not fit into the more classic look of rims they look for.

The estimated cost per wheel with the different remaining manufacturing methods is listed below.

- The estimated cost of cast rims in aluminum is 350-800 SEK in aluminium. This number was taken from the price estimate calculation in GRANTA Edu-Pack. This was done with a calculated production volume of 10.000 units. This is not including the machining cost of making the bearing seats and potentially other finishing operations. The resulting cost could therefore end up above 1.000 SEK.
- Laced spokes rims have an estimated cost of 2.500 SEK. This is based on what could be found online when looking for similar rims.
- Machined rims of this size would cost about 5.000 SEK. This is based on previous experience when rims of about the right size was machined for another project. These rims were 16 inch aluminum rims which were machined for Chalmers Solar Team in 2019. A batch of 4 were made but the manufacturer stated that the price was as good as in a higher volume order.

4.6 Estimated Energy Need for Wanted Range

This section describes the process of how an standardized drive cycle was used to determine the energy needed for model x to get the wanted range specified in the requirements.

4.6.1 Drive Cycle and Homologation

A standardized drive cycle is used by the homologation office while determining the range of new motorcycles. This drive cycle is called WMTC, World Motorcycle Test Cycle[23]. All European motorcycle manufacturers have had to use the WMTC set of drive cycle since 2017 and it is recognized globally. Which part of the driving cycle is used is determined by the speed the motorcycle is able to reach and what type it is being homologated into. The model x will end up going through the WMTC part II with the current specifications it has and Figure 4.7 shows the vehicle speed during this drive cycle. The driving cycle has an average speed of 55 km/h including lots of speed variations and a top speed close to 100 km/h.

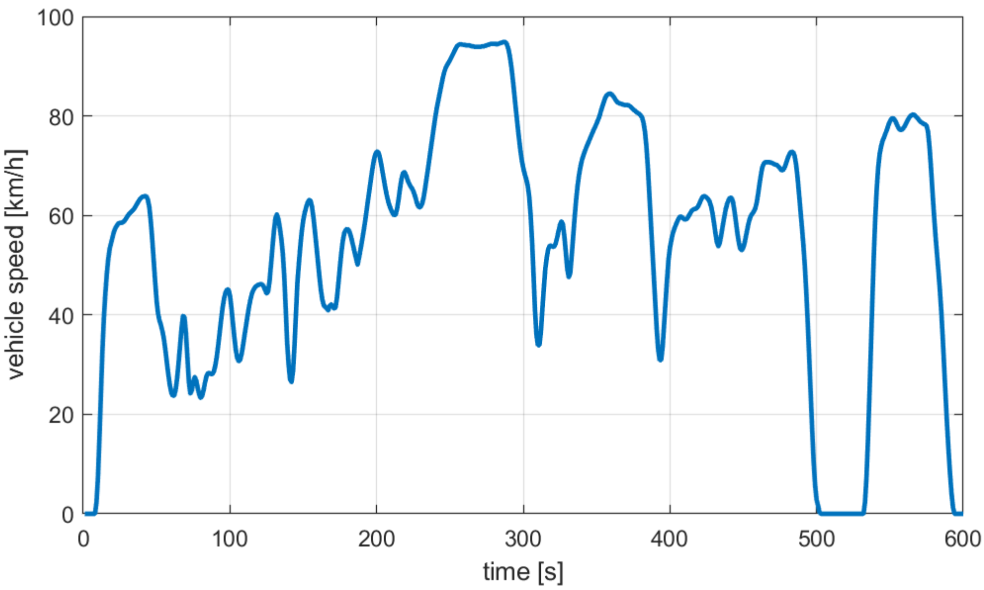


Figure 4.7: A graphical representation of the WMTC-II drive cycle

4.6.2 Input to Estimation Model

All energy that is used for anything other than mechanical energy from the battery cells to the ground is seen as losses when estimating the range. The following diagram shows where the main losses in the motorcycle comes from.

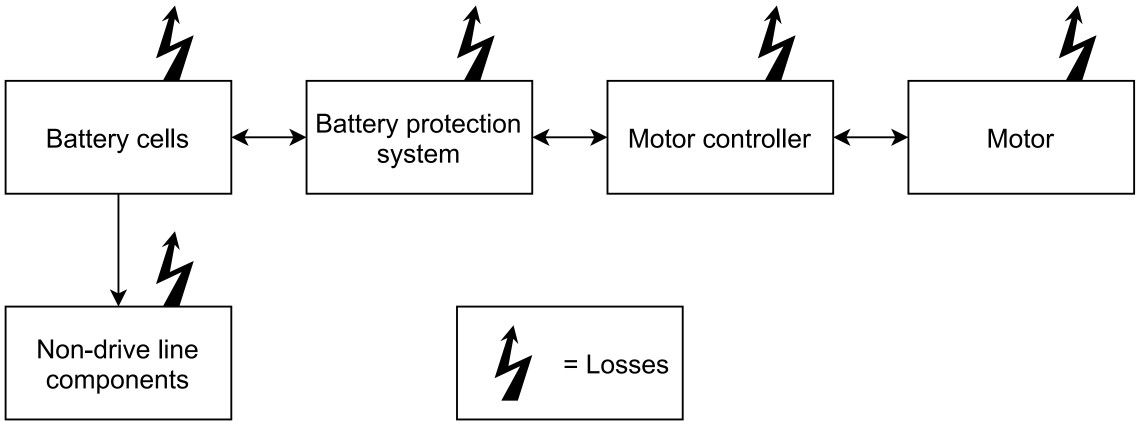


Figure 4.8: Map of considered losses

Following are descriptions of the input parameters to the energy estimation model and some parameters which are disregarded.

- The internal impedance of the battery cells causes heat energy loss when current is drawn through them. The datasheet of the battery cells used in the latest model specifies a maximum internal impedance which is used to calculate the losses. The internal resistance is not constant for different temperatures but for this estimation it is good enough to assume it is. Calculations for the maximum power loss for the battery pack is described below. When calculating the current, the total power draw of the motorcycle is divided by the lowest possible battery pack voltage, this results in the worst case possible current.

$$P_{max} = I_{max}^2 \cdot R_{internal,tot}$$

  The power loss is calculated from the cut-off voltage to get a worst case estimation. The power losses in the drive train varies as the battery voltage drops during discharge. The voltage drops during dynamic loads are not being taken into account.

- The non-driveline components and the battery protection unit has some constant power draw and is a part of the power consumption model.

- The efficiency of the motor controller to the motor can be described approximately with the a function that was fitted to data gathered from benching the motor controller and motor.

- The aerodynamic drag is assumed to be equal or less to the latest model. For the purpose of the model, the same coefficient is used. The constant frictional losses from bearings and such is assumed to be linear with the fully laden mass of the motorcycle. These two factors are taken from the homologation documentation from the latest model and the frictional force factor is adapted to the wanted mass of the model x.

- The losses in conductors such as wires and bus bars are disregarded.

- A maximum amount of regenerative braking is set. This is based on the maximum current the batteries can be charged with and the average voltage of the battery cells.

4.6.3 Results from the Latest Model and Model X

In order to determine whether or not the results are close to what they would have been in a real test with this drive cycle, the results were compared to the ones from the homologation of the latest model where this drive cycle was used. It was seen that the estimated range was within 4 % of the range value received from the homologation process of the latest model. It was decided from this that the model was accurate enough to be able to estimate the needed energy for model x. The results gotten from the estimation model when using the parameters of model x was that about 5,0 kWh is needed to be able to have a range of 100 km.

Figure 4.9 shows how much energy is consumed by different effects during the drive cycle.

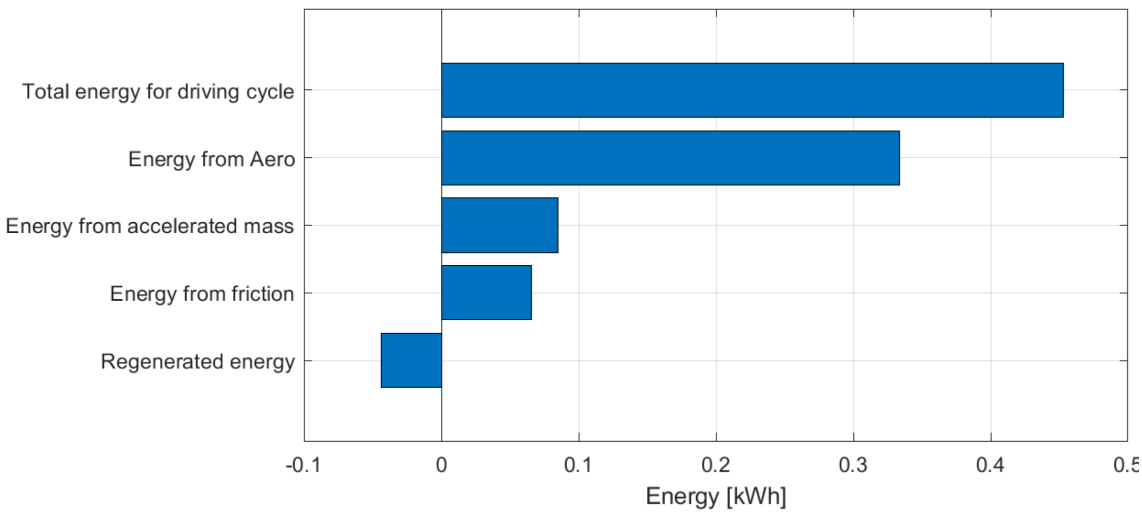


Figure 4.9: Energy distribution

4.7 Top Speed

Another requirement is to be able to reach 100 km/h. An estimation of the power output needed to reach that speed is made. This is to be able to design a battery pack that can handle the maximum power output.

Li-ion battery packs has a lower power output capability as its state of charge decreases. This is because such batteries usually has a rated maximum current or discharge rate which is independent of its state of charge and therefore voltage. The maximum power output of a battery pack is defined as the maximum current output times the voltage of it. This means that the absolute top speed of the motorcycle will be when it has a full charge. The top speed is therefore defined as the highest speed the user will be able to reach at full charge in this project.

The following is taken into account in the model for estimating the top speed of the motorcycle.

- The coefficient of drag is assumed to be the same as the latest model from RGNT. This is reasonable since the frontal area and coefficient of drag is likely not increased for model x.
- The frictional losses are also assumed to be the same as in the latest model from RGNT since the wheel assemblies and brakes are likely too look similar.
- The efficiency of the motor is estimated to be the same.

The formula for determining the estimated power drawn by the motorcycle at different speeds is based on the following.

$$P_{battery-output}(V) \approx \frac{P_{friction}(V) + P_{aero}(V)}{\mu_{motor}(V)}$$

A function for the total power consumption at different speeds was then plotted and it could be seen that at 100 km/h the motorcycle would consume around 7,9 kW.

4.8 Charging and Battery Pack

The charging method affects the user experience to a large extent and basically defines how popular the motorcycle can be. The best suited charging concept will have to determine what battery configuration is to be used, what battery cells and how the battery pack will look. The requirements for the charging system that can be extrapolated from the general requirement specification are as follows.

- Requirements
  - Allow for the use of both regular outlets in homes and at charging stations.
  - Fit in with the overall look of the motorcycle if it is visible from outside the motorcycle.
  - Charging time below 3 hours.
- Wants
  - Charging time below 1 hour.

4.8.1 Charging Concept Generation

The lowest DC charging voltage that Combined Charging Systems (CCS) usually can accommodate for is 200 V DC [19]. It will therefore not be possible to use DC fast charging directly onto the battery pack terminals since one of the requirements for this project is to keep the system voltage which is lower.

There are no common sources for charging voltage at the exact system voltage so there has to be a voltage converter (charger) involved somewhere in the charging process. It has to be decided weather this charger will be permanently built into the motorcycle or not. The charger could also be semi-permanent where it is easy to upgrade it and service it if it breaks but that the user is not supposed to take it out of the motorcycle on a daily basis.

It also has to be decided what sources of charging the motorcycle should be compatible with. Some electric motorcycles are only compatible with regular single phase outlets usually found in homes while others also have compatibility with charging stations.

By combining these factors the following alternatives are generated.

- On-board charger - single phase
- On-board charger - charging station
- On-board charger - single phase and charging station
- External charger - single phase
- External charger - charging station
- External charger - single phase and charging station

Important factors to take into account while deciding how to place the charger and what charging source to use are described below.

- Charging time - No matter where you place the charging unit, the charging time will remain the same as long as you are able to fit the electronics needed inside the motorcycle. It might be hard to fit a standardized charging station connector and charger in a small motorcycle.

- Ease of use - It can be practical to know that the charger is with the motorcycle all the time when it is on-board. The time it takes to connect the charger to a power source and the motorcycle might be a bit longer for the external version since you might need to move the charger itself and not only the cables.

- Mass of the motorcycle - If a charger is permanently mounted on the motorcycle, then the mass of it is increased which in turn decreases the range of the motorcycle. A combination charger is probably slightly heavier than an on-board charger since it needs to have a box in the motorcycle and an encapsulation to be isolated as it is by itself. An external charger doesn't add any mass to the vehicle compared to the other concepts. The combination charger has the benefit that it can be detached if the driver wants to use the storage for something else or ride a lighter motorcycle.

- Packaging - An external charger does not need any packaging consideration in the motorcycle itself.
- R&D cost and manufacturability - The on-board charger will probably have the highest R&D cost since more research needs to go into it because it is not a separate system from the motorcycle. The R&D-cost is probably lowest in the completely external charger since it has less design constraints. The combination type charger is likely somewhere in between.

The combination type charger is best in all aspects except adding slightly more mass when loaded and might cost more than the completely external charger to develop.

Single phase together with single phase charging station is the most accessible way of charging so that is what is most suitable for model x.

4.8.2 Battery Pack Requirements

The electrical system of the battery pack is not to be considered in this thesis and therefore is work only done to give the required input for the enclosure of the battery pack. Following are the requirements of the battery pack.

- 5 kWh of total energy capacity in the battery pack.
- The total pack must not have a mass more than 15 kg so most people are able to lift them. The maximum recommended mass to lift repeatedly stated by the Swedish Work Environment Authority is 15 kg [3].

The energy density of the of the battery pack of the latest model by RGNT is 0,235 kWh/kg [15]. This energy density will be used for estimations. It is assumed that

3,5 kg is needed for other components than the cells themselves.
With the required energy capacity with the energy density just mentioned the the mass of the cells would be 5 kWh/0,235 kWh/kg = 21,3 kg which is more than the acceptable 15 kg of the whole battery pack. Many users would probably find it too heavy if the required amount of battery cells were to be put into one battery pack.

To be able to achieve an acceptable mass, the battery needs to be split up into several smaller packs. The allowed cell mass per pack would be 15 - 3,5 = 11,5 kg. The number of battery packs then needs to be 21,3/11,5 = 1,85. The motorcycle needs 2 battery packs in order to have the required range and mass.

4.8.3 Battery Cells

Choosing battery cells and designing a battery pack with new cells is a complex matter and was decided to be out of scope for this project. It is mainly because of the lack of a good database from which cells could be selected from. A prototype pack will however be made based on the battery cells from the latest model and protective circuits.

4.9 Battery Pack Enclosure

The battery pack is put inside an enclosure to protect the battery cells. This enclosure is what the user and connections will be interfacing with. The enclosure and especially the features interfacing with the cells is dependent on the specific cells used and therefore modifications related to this may be adjusted. This chapter will consider features required for the interface between the enclosure, the motorcycle and user.

4.9.1 Requirements

The battery pack enclosure will protect the battery cells and internal electronics from weather and damages during handling and usage. Hence it needs to be securely seated in the motorcycle and stable outside the vehicle. The user should not be required to operate multiple functions at the same time while putting the battery pack in or out of the motorcycle and the user should be able to use both hands to lift the battery pack. It should not take more than one minute to disconnect, lift out and put in a new pack.

A total of 10.000 vehicles is to be made and assuming 2,5 battery packs are sold per motorcycle a production volume of 25.000 units and 6250 units annually has to be made. The complete battery pack can have a maximum mass of 15 kg. The internal electronics, cells and cell holder has a combined mass of 13 kg leaving 2 kg for the enclosure including electrical connector. All subsystem requirements are gathered in a requirements sheet which is found in Appendix E.1.

4.9.2 Benchmark

A benchmark on already existing battery packs was done as a market analysis and idea generation. From the benchmark, different enclosures were found and the most common options are moulded plastic, extruded aluminum housings with plastic ends, sheet metal boxes and cast aluminum enclosures as on the latest model by RGNT.

The enclosures are secured in the motorcycles in different ways and options found are screws, snap lock, none, blocked by a fence bar or physically blocked by other locked components.

To connect the battery pack to the electrical system in the vehicle, different options are used, the most common way is to have a top mounted manual connector, some manufactures have systems which are more automatic and the connection is done as the battery is placed in the vehicle.

4.9.3 Enclosure Concept Generation

From the requirements list for the subsystem an idea generation was done by sketching and listing possible solutions for the corresponding functions. To keep the solution concepts to a minimum the individual ideas were examined before the morphological matrix. The ideas and the elimination of solutions not fulfilling the requirements sheet is found in Appendix E.2.

The ideas was sorted to avoid concepts which are hard to realize or do not follow the requirements. From this, the solution ideas were put in a morphological matrix, see Appendix E.3, to generate concepts of the whole subsystem. Five initial concept groups were put together which are presented below.

Concept 1: An injection molded plastic enclosure with integrated handle. Locked in place by an actuated pin. Automatic electrical connection when battery is mounted with inaccessible connection pins.

Concept 2: An extruded aluminum profile with plastic ends. Lifted in a strap and locked in place by an actuated pin. Electrical connection using a 2 pined EV connector protected by a lid.

Concept 3: Bent sheet metal enclosure made from steel. Moved as a trolley mounted low in the vehicle to not require lifting and held in place by other blocking components. Type 2 AC connector protected with a lid.

Concept 4: Cast aluminum casing with integrated handles. Locked in place with a butterfly latch. Electrical connection using a 2 pined EV connector with female end in enclosure.

Concept 5: Plastic enclosure made using additive manufacturing. Locked in place with a leather strap and have no handles. Electrical connection using a 2 pined EV connector with female end in enclosure.

To determine the feasibility of manufacturing processes and materials the wall thickness for the different combinations was determined using process information from GRANTA EduPack. The internal electronics in the enclosure has a known cell configuration and therefore also size. The mass of the enclosure can be estimated to find combinations exceeding the mass requirement. This shows that the cast aluminum and possibly the steel sheet metal casing is likely to exceed the mass requirement as seen in Table 4.7.

Table 4.7: Battery enclosure material and process mass estimates

Material	Process	Wall thickness [mm] (Process limitation)	Mass estimate [kg]
Aluminum	Cast	3-5 (3-999)	2,9-4,8
Aluminum	Extruded profile	1-4 (1-900)	0,97-3,88
Aluminum	Sheet metal	1-4 (0,2-5)	0,97-3,88
Steel	Sheet metal	0.7-2 (0.2-5)	1,97-5,64
Plastics	Injection moulded	1-4 (0,4-6,3)	0,36-1,44
Plastics	Additive manufacturing	1,2-4 (1,2-100)	0,43-1,44

The first five concepts are evaluated using Pugh matrices which are found in Appendix E.4.1. Concept 3 and 5 eliminated after two rounds due to the lower quality feel and robustness of the concepts. Both concepts include deficient solutions of handling the battery enclosure with either low gripping areas or complex systems for it. Combinations of solutions from the remaining concepts were used to form new concepts. Main benefits from concept 1, automatic battery connection and locking mechanism ease of use. Main benefits from concept 2, quality feel and manufacturing simplicity. Main benefits from concept 4, manufacturing simplicity, integrated handle.

Concept 6: Automatic battery connection, inaccessible connector pins, locking pin mechanism, an extruded aluminum profile with plastic ends, integrated handles.

A third Pugh matrix found in Appendix E.4.3 was done finding concept 4, cast aluminum, to be eliminated due to design and manufacturing complexity with casting and the found risk of high mass of the enclosure. The three remaining concepts were concept 1, 2 and 6 which are further developed and modelled in CAD to increase the level of details to evaluate in the following Kesselring matrix. Before the Kesselring matrix evaluation, the criteria are determined and compared to each other to form a relative sum of importance. The comparison showed that robustness, ease of use, charging time and quality feel are the four most important criteria which are seen in E.1. The grading matrices are found in Appendix E.2. The matrix showed lower values on robustness, ease of use, cost and manufacturing simplicity for concept 2 than the two other concepts. Concept 1 and concept 6 showed similar total values, seen in Appendix E.3.

The two remaining concepts are further evaluated by its simplicity and balance of solutions. For the balance the variance of the grades is compared finding concept 1 to have a variance of 0,5277 and concept 6 to have a variance of 0,5 meaning that concept 6 is slightly better but the difference is not substantial. The simplicity can be described as a complexity number. For concept 1 this index is $K_1 = (2 \cdot 2 \cdot 1)^{1/3} =$ 1,587 and for concept 6 it is $K_6 = (3 \cdot 3 \cdot 2)^{1/3} =$ 2,621. The complexity number shows a substantial lower value on concept 1 giving it a clear benefit allowing concept 6 to be eliminated.

4.9.4 Concept refinement

The remaining concept is further developed considering geometry of the enclosure and placement possibilities. The ergonomic handling is considered along with the geometry to be stable outside the motorcycle. The enclosure should have at least one flat side to stand on with the internals with high mass placed low in the enclosure, preferably the cells under possible electronics place in the battery pack. Cables or connectors attached to the pack should be placed so the risk of tipping the pack over is minimized.

The complete battery pack is considered to be mounted to the motorcycle in three different ways, from the top, side or bottom. A top mounted pack will provide high control of the lift without sudden load additions for the user. It provides freedom in placement to adapt for the wanted CoM. A top mounted battery can require high lifting depending on the size of the battery enclosure and the incorporation in the motorcycle. A side mounted pack will allow for better lifting heights but sudden load variations may occur when the battery comes out of the motorcycle resulting in lower control of the lift. It provides freedom in placement to adapt for the wanted CoM. The bottom mounted battery pack will require lifting near ground if the incorporation is not done in a way to allow the user to mount the battery without lifting it. There is less freedom in positioning since it is restricted to the underside of the motorcycle. To have a good control of the lift and allow for placement freedom during design a top mounted battery is considered to be the most flexible alternative.

5

Prototype

A prototype was made to evaluate ideas and concepts found in chapter 4. A physical model of selected subsystems will allow for a better understanding and possibly give valuable insights to the design and help in further development. The major systems to test are the size and feel of the vehicle, how it is to ride and the swappable battery system. The geometrical shape of the body was outside the time scope of the build.

By making a prototype in full scale, RGNT will have a platform to experiment with and continue to work on before determining what they potentially can bring from the tested concepts.

The goal of the prototype is to make a motorcycle as close to the concept as possible and at the same time being possible to drive. This requires the prototype to be safe enough to let people ride it. Mechanical systems as brakes, suspension, steering lock etc. needs to be implemented and functioning. Electrical systems protecting the high-voltage systems needs to be in place to make sure the prototype is electrically safe to use.

To get the designed driving experience from the prototype the suspension setup and mass of the prototype needs to be as close to the concept as possible. While having a prototype as close to the concept as possible a model where rapid changes can be done may come in handy in an early stage of prototyping. This would allow for changes of size or geometry of the motorcycle or relocation of components by moving brackets or attachment points.

5.1 Digital Models

To be able to early on in the project play around with different concepts and see if some solutions for sub-system works together with the other parts of the motorcycle, a CAD model was created. A snap-shot of an early version of the CAD model can be seen in Figure 5.1.

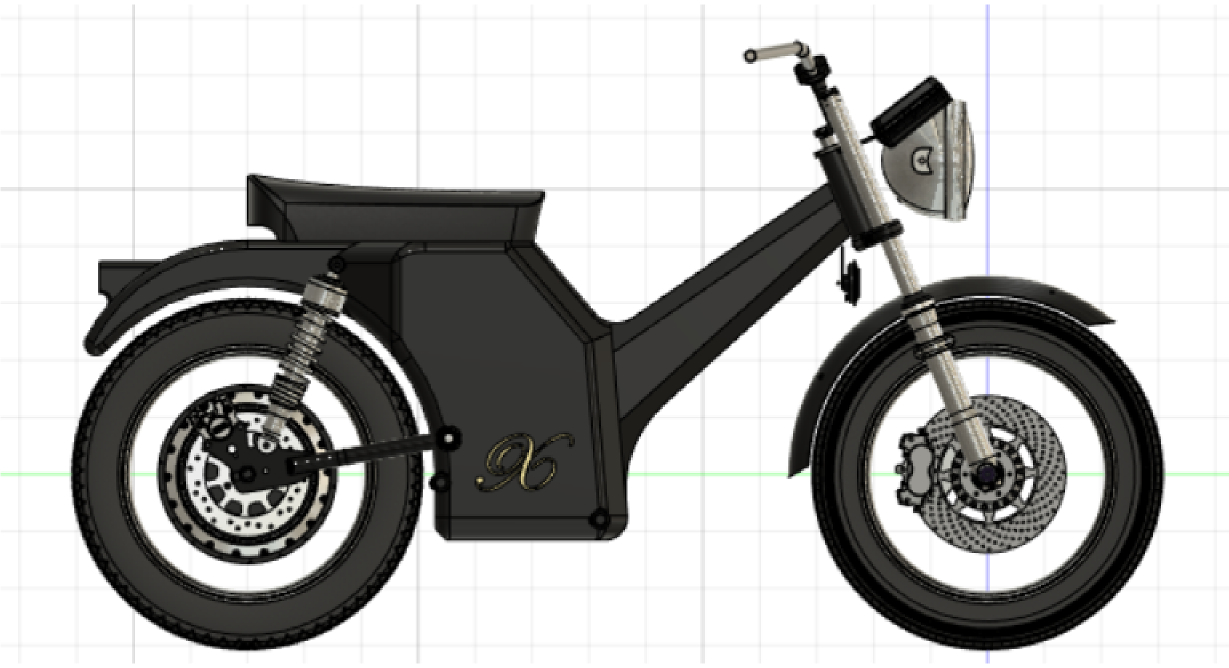


Figure 5.1: A capture from the full assembly of the prototype

The CAD model can be used as a testing platform for the theoretical findings to see how they could be applied in reality while also acting as base for the manufacturing drawings and models.

5.2 Electrical systems

The electrical system design and manufacturing for the prototype is described in this section.

5.2.1 Overall System Design

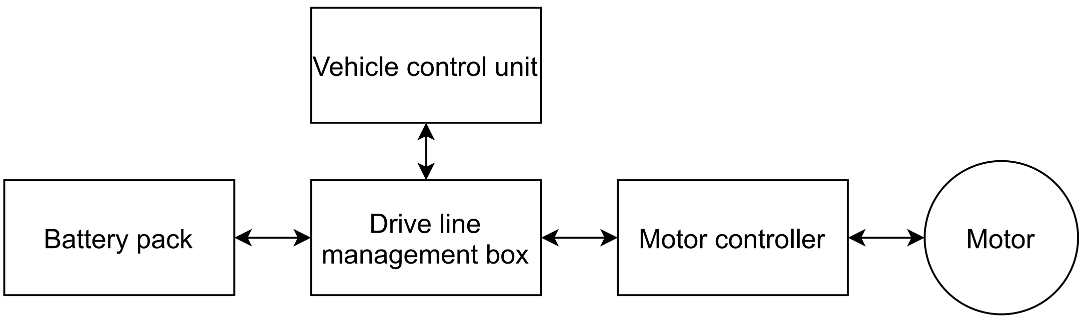


Figure 5.2: A schematic overview of the drive line of the prototype

- Battery pack - The battery pack contains the battery cells, voltage sensors and temperature sensors. The battery terminals and sensor wires are connected to the drive line management box with quick connect type connectors. This is to be able to remove the battery pack reasonably quick and emulate how a swappable battery would feel.

- Drive line management box - This box contains electronics which is used for keeping the driveline within safe limits.

- Vehicle Control Unit (VCU) - The function of the VCU is to communicate with different electrical sub-systems and control the start-up and shut-off of the motorcycle. It also handles functions like turn- and brake signals.

- Motor controller and motor - The motor controller ensures the proper functioning of the motor and it is energized by the battery pack through the drive line management box.

5.2.2 Dimensioning of Battery Pack

Requirements for the prototype battery pack are as follows.

- Keep the same number of battery cells in series to be able to use the rest of the HV system with some software changes.
- Be able to deliver at least 5 kW nominally at any state of charge.
- Have close to 2,5 kWh energy capacity.
- Optimize for having as few cells as possible to make an overall lighter pack.

One of the dimensions of the battery pack layout is set by the nominal voltage of the latest model from RGNT. The power output is determined by the maximum rated current through one series which is the same as what one cell is rated for. The maximum rated current for one cell is 12 A. The lowest possible voltage for one cell is 2,75 V and with 24 in series that is 66 V. The rated power for the pack will therefore be as follows.

$$I_{max} \times N_{cells} \times V_{low} = P_{max}$$

The number of cells that must be in parallel is therefore as follows.

$$N_{cells} = \text{Rounded up } (\frac{P_{max}}{V_{low} \times I_{max}}) = (\frac{5000}{66 \times 12}) = 7$$

Each cell has nominall energy capacity of 4000 mAh and a nominal voltage of 3,7 V. Each cell therefore has $4 \times 3,7 = 14,8$Wh of energy.

The total energy in the pack would therefore be 24 x 7 x 14,8 = 2,49 kWh which is around 2,5 kWh. No cells needs to be added to get enough energy.

5.2.3 Battery Enclosure

It was desired to make something as close as possible in feeling and look as a injection moulded battery enclosure. 3D printed PLA was used to create the outer shape. Each half was printed in sections glued together. Filler was used on gaps and layer mark from the printing before it was sanded and painted. The prototype enclosure serves the purpose of an injection moulded component.

The component itself was made of an constant thickness shell with ribs as reinforcement. A gasket grove was included in the splitline of the two halves to allow a rubber gasket to get some water resistance.

PLA plastic is a brittle plastic and therefore the prototype enclosure needs to be handled carefully. Cracks and layer delamination was encountered during the post processing of the halves.

5.2.4 The Size of the Battery Pack

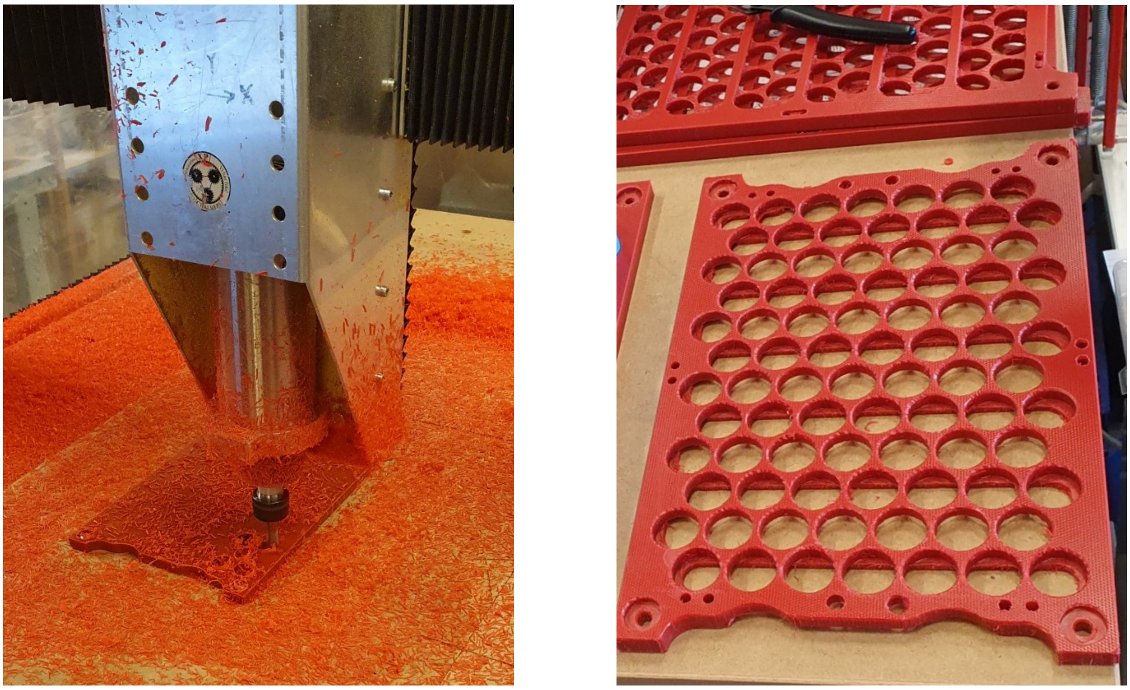
Once the battery pack prototype was shown to the rest of the R&D department, it was agreed that it was too big for some potential users of the motorcycle. It was therefore decided to only use one of these battery packs in the prototype. This means that the range is reduced to about 50 km instead of 100 km and that the total weight is about 14 kg less than what the original concept would have.

The motorcycle frame designed was not finished at this point so the change was welcome and a better design with more freedom with space could be done.

5.2.5 Cell Holders

To position and support the battery cells inside the battery pack, cell holders were made. They were made from milled plastic with pockets for the cells milled from one side and pockets for busbars milled on the opposite side. To support the cells without play or risk of movement the holes for the cells needed to be a tight clearance fit. Hence a test piece was made first and potential compensation was done before the cell holder was milled as seen in Figure 5.3a. Additional holes for bolts, zip ties and cable management was added into the design as seen on the final cell holder in Figure 5.3b.

HDPE plastic was used since it is a electrically insulating, ductile and not very stiff material, allowing the cell holder to absorb some of the vibrations and potential shocks to the battery pack. Polyethylene plastics are also oily to the touch easing the process of cell assembly.



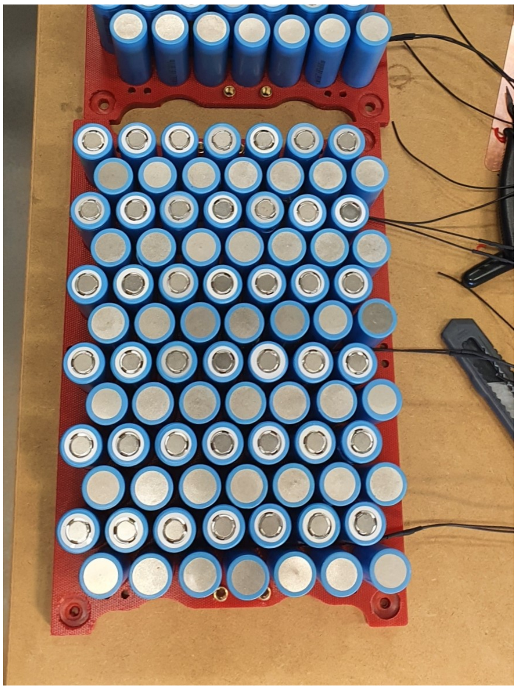
(a) Cell holder milling (b) Complete cell holder

Figure 5.3: Cell holder manufacturing

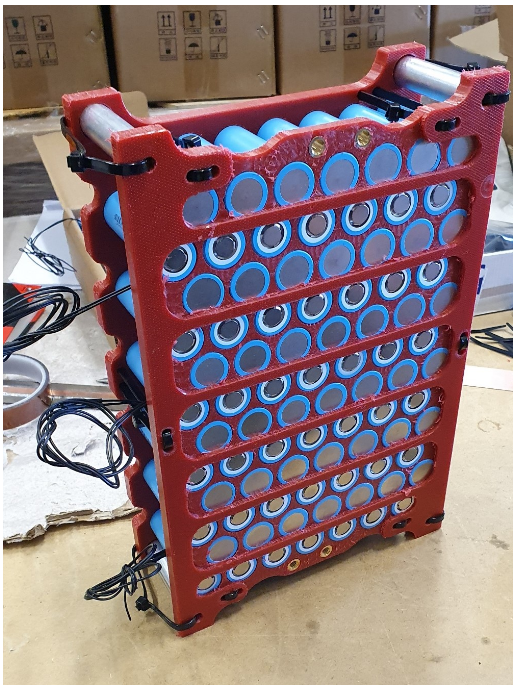
5.2.6 Assembling Battery Modules

First step of the battery cell assembling was to match the voltages of the cells to reduce the unbalance in the pack making the balancing quicker and also finding potential cells of critical voltages. Cells were then put in the pockets according to the selected configuration as seen in Figure 5.4a. In each module three temperature sensors were placed to track the temperatures in the battery pack.

The top cell holder is then mounted and kept in place with zip ties ready for welding busbars, strips of copper sheets connecting the rows of battery cells. The welding was done by hand using a micro arc welding torch. On each busbar a wire is attached to allow for voltage measurements and balancing of the pack. After welding, each module is wrapped in Kapton tape to protect against short circuits and ease handling.



(a) Cell assembly

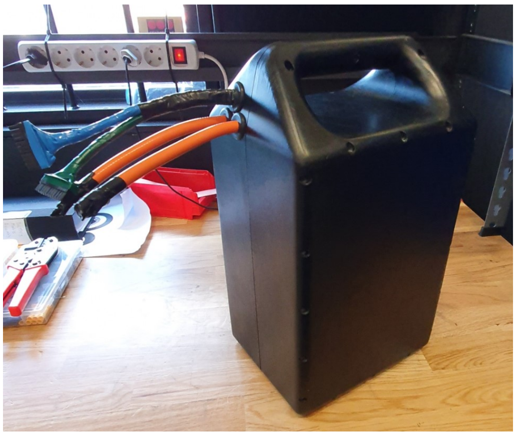


(b) Pre-assembled battery module

Figure 5.4: Battery module assembly

Two battery modules are screwed together and placed in the enclosure as shown in Figure 5.5a. The final wiring is done by mounting the aluminum busbar connecting the two modules, routing the high voltage cables and the sensor harness. The top half of the enclosure is then added and screwed into place resulting in the final prototype battery pack seen in Figure 5.5b.

(a) Complete modules placed in enclosure



(b) Complete battery

Figure 5.5: Final battery assembly

5.2.7 Drive line management box

The high voltage electronics box is described in this section. Its main function is to let the VCU control and guarantee a safe flow of energy from the battery pack to the motor controller. The contents of the high voltage electronics box will not be covered in this report. The function of the box will instead be described at system level and can be seen in Figure 5.6.

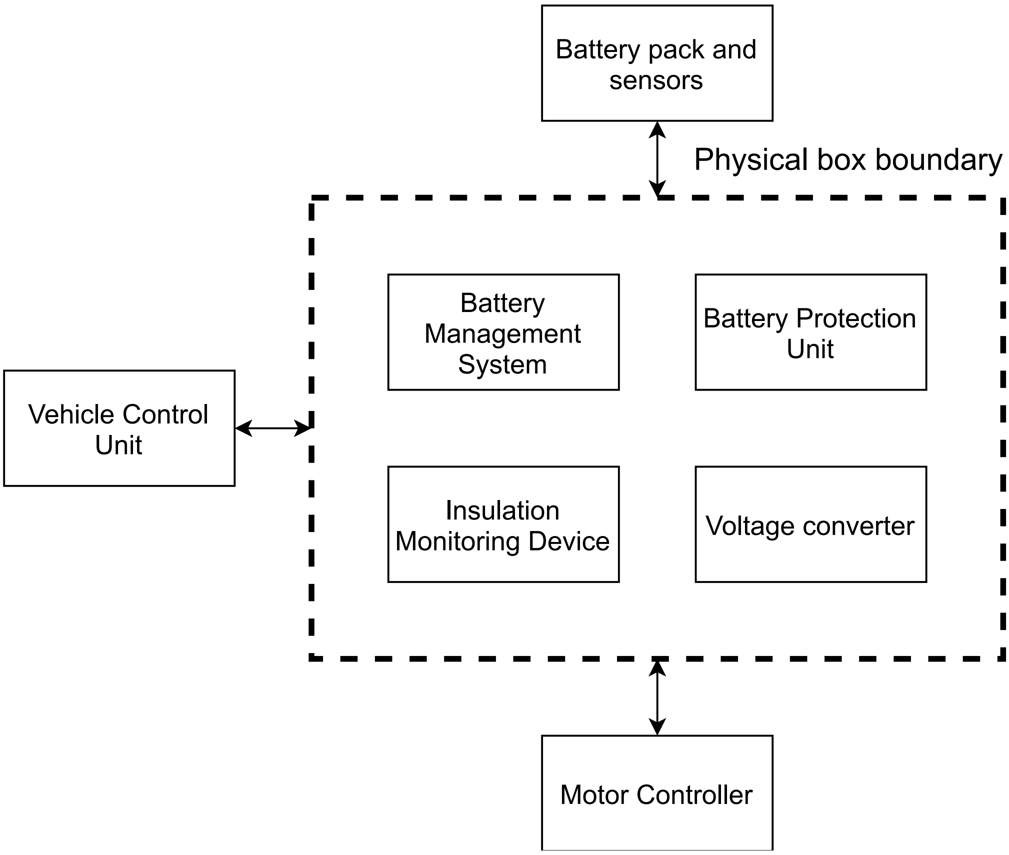


Figure 5.6: A diagram of the drive line management box

5.3 Mechanical systems

5.3.1 Suspension

Most of the suspension components for the prototype is a carry over from the latest model from RGNT to speed up the manufacturing process. Since the model x is to be a smaller motorcycle these components are generally too big in proportion to the rest of the motorcycle, which may give the feeling of a shrunken version of the current model instead. Most design parameters can be achieved with this hardware and does not need to be modified.

5.3.2 Steering Head

The steering head for the prototype was machined from steel, shaped like a thick walled tube with two bearing seats. As one of the most critical components this was selected to be made from steel even if a complete composite frame were to be done. Hence is needs to be possible to both weld it to a steel tube frame or laminate it into a composite frame. Hence a shoulder on the outside diameter was introduce helping the part to mechanically lock in a composite while also reducing the mass further.

For the frame made from press sheet metal it is still unknown if one can use the pressed surfaces as bearing seats in the steering head and similar occasions. Possibly a thin walled tube could be used to provide sufficient tolerances for the bearings to work properly. This would also make sure the bearings are collinear with each other.

5.3.3 Frame

The frame is to be made from pressed sheet metal as a self bearing unit. The body of the motorcycle will hence be carrying the loads allowing the volume of the motorcycle to be rather empty inside allowing space for brake hoses, internal electronics, wires etc. A frame prototype made from steel would be to expensive to test and therefore an alternative prototype frame made from steel tubes and composite panels was considered.

5.3.3.1 Steel Tube Frame

A steel tube frame was made as a temporary supporting structure for the components of the prototype to be able to feel the proportions and placements of the other systems. As time limited the build, the tube frame was complemented with additional tubing to create a frame possible to drive with. The frame was made from bent and notched tubes welded together.

5.3.3.2 Body Panels

Composites can replicate body panels or structures of sheet metal for a lower cost and time in a prototyping case. The composite panel can be constructed in a way so that both mechanical and physical properties can be tested. A pressed steel sheet component can be replicated in composites by making relatively cheaper tooling to laminate in. The composites component will also be easier to predict the geometry from since one do not need to consider spring back in the material.

Is case of a motorcycle frame from pressed sheet metal a replica of the component can be used to evaluate the mechanical properties but this would be more complex than the gain from it would be in this early stage. Hence the planned components were to be composites covers for the steel tube frame allowing testing and evaluation of the geometry.

5.4 Testing

This section describes the tests that were carried out to see if the sub-system designs works and what can be improved with them.

5.4.1 Swapping Batteries

In order to test if the battery swapping is a concept customers would like, people at RGNT will try to swap the battery pack in and out.

5.4.2 Handling

The model x prototype will be driven on tarmac to test the handling. The main focus will be put on determining the feeling of agility and the highway stability of it.

5.4.3 Range

Even though a proper range test with the drive cycle that is used at homologation will not be done, some real life testing and comparing to the latest model from RGNT will be done in order to see if the model for determining range is as accurate as it was for the latest model.

6
Results

This section describes what results came from the concept study and how that compares to the project goals set in the early stages of it.

6.1 Pre-study

From the initial interview with Dantar P. Oosterwal and Norbert Majerus it was found the project should focus on the parts of the motorcycle where the R&D can give the most value to the company. Some components are to far gone in the S-curve to be economically defensible to continue to develop.

It is found that several of the components with highest cost are included in the main research questions in the project. Since one of the challenges with the model x is to reduce the cost the most expensive components should be considered to reduce the highest costs if possible.

It was also found that a lot can be learned by analysing older models or competing products for starting the design on the new model. The pre-study also resulted in a requirement specification.

6.2 Frame and Suspension Geometry

The first thing determined was wheelbase, wheel size, seat height. The wheelbase of 1300 mm was chosen for the model x and it's prototype, this to make the motorcycle more agile than the current model but still remain stability at high speeds. The wheel size was determined in the Tyre and Rims chapter to be 17" both front and rear and the seat height was considered in the geometry comparison of the current model, a Honda Cub and the model x and was set to 800 mm.

The trail for the model x is set to 90 mm, which is between the current model and the Honda Cub. This will make the model x feel more nimble than the current model from RGNT while still more stable than the Honda cub, at least trail wise.

A suitable location for the center of mass was found to be half the wheelbase from the ground and halfway through the wheelbase in the longitudinal direction. This mainly means that one should strive to push components forward since a scooter type easily becomes rear heavy. It was also found that the wanted driving behaviour of the vehicle is not a racing feeling meaning that the final center of mass position is allowed to shift slightly from the found position.

6.3 Frame

At an early stage it was decided that the frame of the model x will have the style of vintage mopeds and alternative materials and processes to achieve this was compared. The frame was found to be made of steel using sheet press forming. If the frame is split into two halves the cost for one half was estimated to 95-590 SEK a piece using GRANTA EduPack. The specific steel alloy is not investigated and will need to be done if the method is to be used.

A surface model of the frame was not made during this project. This is also a stage expected to take a long time with lots of iterations based on subjective decisions. The lack of a surface model also excluded any structural analysis of the component. If the frame is to be made using the found method this is to be done in parallel with the surface design.

6.4 Tyre and Rim Selection

The tyres for the model x was determine by gradually eliminating alternatives from the dataset provided in Parts Europe. It was decided to go with 17" rims to not be the same size as on the larger motorcycle made by RGNT. The elimination was mainly subjective focusing on the looks if the thread pattern which was found to be on of the most important criterion for RGNT. Practical aspects as available sizes and speed- and load ratings was also considered finding the set of tyres to be Tyre company x model c.

Potential rims for the model x was not evaluated to a point where one alternative was remaining. Instead three options are left to be further investigated. The cheapest alternative of them are casting in aluminum which are common for modern rims. The design freedom is high, allowing good options for a vintage design. The second most expensive alternative is laced spokes rims which is an old type of rims often found on vintage motorcycles. The most expensive alternative of the three are machined rims from billet material. The design freedom is similar to the cast rims but the accuracy and material properties higher.

6.5 Range and Energy

The range calculations done are based on the WMTC II drive cycle where the required battery capacity for the model x is found to be 5,0 kWh to have a range of

100 km.

It was also found that the required power output from the battery to reach 100 km/h is 7,9 kW which needs to be considered when designing the final battery pack for the model x.

6.6 Charging

It was found that DC fast charging in CCS charging stations is not possible for model x since the system voltage is kept which is lower than the minimal available voltage. Instead it was found that an semi-permanently mounted single phase charger will be recommended for the model x. This way the motorcycle can be charged both at home and at charging stations.

6.7 Battery Pack Design

It became clear once that the swappable battery pack was manufactured that the 15 kg requirement was set too high and that it is likely to be significantly lowered for the next iteration of the battery pack solution.

Another realization is that it is challenging to fit enough batteries in a motorcycle which has the wanted look of the model x and also have a range of 100 km. The challenging part is that the inner volume of the frame shell is close to the volume cylindrical li-ion cells with a reasonable energy density needs to have enough energy needed for that range. Besides increasing the inner volume or finding battery cells with slightly higher energy density, the major things that can be done is to reduce the aerodynamic drag, the mass of the motorcycle can be reduced and the drive line efficiency could be increased. This would lead to a decrease in the energy requirement. Even though this would improve the range per unit energy, it might not be enough to get the wanted range with the frame volume wanted. The conclusion is that either the inner volume of the frame needs to be increased or the range requirement needs to be lowered.

6.8 Prototype

The results from having built and tested the prototype is a series of conclusions that would have been harder to make unless the theories would have been tested for real.

7
Conclusion

This chapter describes the conclusions that can be made from the results. It also covers some suggestions as to what RGNT could continue to work with after this project.

- It is more important to build and improve on previous motorcycle models than to find the theoretically best values when designing many sub-systems.

- A motorcycle that is going to be used mainly in inner city traffic does not need a suspension setup that gives the best cornering speed and grip. It is more cost effective to iterate from a previous model or take inspiration from an older model from a competitor and try it in a prototype.

- Choosing battery cells for a electric vehicle battery pack is challenging due to several factors. One big factor is that it is hard to come by an extensive database with most of the commercially available battery cells and their properties.

7.1 Building the Battery Pack

The battery pack design investigation resulted in a conclusion that the battery pack must be split into two smaller ones in order to fulfill the requirements. It also resulted in a suggestion as how to design the battery pack enclosure.

7.2 Overall Geometry, Size and Look

One of the big decisions that was taken early on in the project was that scooter tyres would be too small and that 17 inch rims were going to be used because there are most tyres to choose from in that size. When looking at the wheels assembled on the prototype with the different models next to each other, it looked almost the same. The width of the rims for the prototype made the tyres look wider than the latest model from RGNT. This could cause the prototype to look like a shrunken down version of the current model instead of making it look like the new concept wanted. The conclusion is that the tyre size needs to be reduced to make it look less like the previous model and that the leap to scooter tyres might need to be made.

7.3 Recommendations for Continued Work

Following is a list of recommendations for continued work.

- Investigate if a higher or lower battery voltage could be beneficial for performance of the motorcycle in regards to user experience and manufacturing cost.

- Investigate if there is anything to win from being part of the Honda, Yamaha, Piaggio and KTM swappable battery consortium could be beneficial. Also investigate when it is feasible to get a swappable battery charging station network in Europe.

- The specific alloy to be used for pressing the frame would need to be decided so some investigation and experimentation with this would be required.

- Buy components that have the proper sizes for the next prototype to get an even better picture of how it would look in the end.

- Consider making a composites frame to be able to test the packaging of the internals of the frame for the next prototype.

- Instead of making middle of the road estimations of what will work and not, make series of prototypes that try the limits. This is the only way of actually getting to know what can and can not be done in some areas.

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A

Overall Vehicle Requirement Sheet

RGNT	**Document type**	Requirements sheet		
Project:	*Model X*	*Overall vehicle*		
Author/s:	Ludvig Brodén		**Created**	2021-01-23
	Filip Jonsson		**Modified**	2021-05-30

ID	**Criterion**	**Target**	**Priority M=must W=want**	**Verification method**	**Stakeholder**	**Why?**
Main function						
	A smaller capacity, lighter and cheaper vehicle in comparison to latest model					
1. Performance						
1.1	Top speed	100 km/h	M	Design	RGNT	
1.2	Range	100 km	M	Simulation/test	RGNT	
1.3	Mass	<110 kg	M	Design	User	
1.4	Mass	<90 kg	W4	Design	User	
2. Usability						
2.1	Easy user ownership	-	M	Design	RGNT	
2.2	Connectivity	-	M	Design	RGNT	
2.3	On the go charging	-	M	Design	RGNT	
2.4	Maintenance	Non	W5	Test	RGNT	
2.5	Use as powerbank	-	W2	Design	RGNT	
2.6	Wireless phone charging	-	W3	Design	RGNT	
3. Geometry						
3.1	Seat height	700-830 mm		Design	User	5th percentile female - 95th percentile male
3.2	Wheelbase	1280-1320 mm		Design	User	
4. Ergonomics						
4.1	Fit 5th percentile female to 95th percentile male	-	M	Design	User / RGNT	
4.2	Allow a passenger	-	M	Design	RGNT	
5. Aestetics						
5.1	Classic/vintage look	-	M	Design	User / RGNT	
5.2	High quality look and feel	-	M	Design	User	
6. Safety						
6.1	No loose components	-	M	Design	User	To not cause sudden driving behaviour
6.2	Fulfill all trafic regulations	-	M	Design	RGNT	
7. Lifecycle						
7.1	Allow disassembly for repairs	-	W5	Design	User / RGNT	
7.2	Allow disassembly for reuse/-cycling	-	W2	Design		
8. Manufacturing						
8.1	Production cost	<XXXX SEK	M	Design	RGNT	
8.2	Possible to manufacture in Sweden	-	W4	Design	RGNT	
8.3	Annual manufacturing capacity	>2500 units	M	Design	RGNT	

B

Center of Mass Calculations

B.1 The Center of Mass of the Latest Model from RGNT

The Center of Mass (CoM) of the vehicle have a big influence on the behaviour of it. As a benchmark the CoM of the latest model from RGNT was determined. By having the rear part of the motorcycle inclined and measuring the reaction forces; a free body diagram and equilibrium equations leads us to the CoM of the motorcycle.
Also determine the total CoM with a close-to-mean driver on the motorcycle. This is done by getting the CoM of a mean driver in CAD and confirming that result with a real life driver on the motorcycle flat on the ground. If the mass distribution is close to what is seen in CAD, then we can assume the results to be right.

Calculating the Center of Mass

The reaction forces and horizontal mass distribution is first determined by putting an almost complete motorcycle by the current model on two scales, one under each tyre. The results from the measuring session is presented in Table B.1.

Table B.1: Results from measurements done with the latest model

Item	**Front** [N]	**Rear** [N]	**Total** [N]
Almost finished motorcycle	699	898	1597
Almost finished motorcycle 450 mm inclined in rear	-	810	1597
Almost finished motorcycle with driver	960	1404	2364
Driver 178 cm tall	-	-	768

To calculate the CoM the following variables are introduced together with two free body diagrams, one horizontal and one with the rear wheel inclined. The motorcycle is seen as symmetric around the YZ-plane and hence the CoM point is located on this plane.

Table B.2: Notation in equations

F_{front}	reaction force at front tire
F_{rear}	reaction force at rear tire
$F_{inclined}$	reaction force at rear tire when inclined
L	wheel base
z	vertical distance from front wheel center to of CoM
$\bar{z}$	vertical distance from ground to of CoM
$\bar{y}$	horizontal distance from front wheel center to of CoM
h	height of inclined rear wheel
θ	the angle of which the rear is inclined

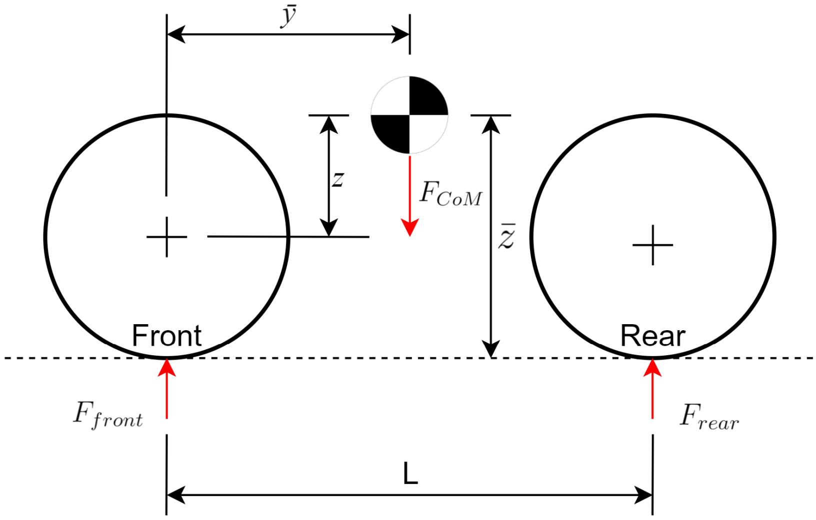

Figure B.1: Free body diagram in horizontal case

From the horizontal free body diagram in Figure B.1 we express the horizontal distance from the front wheel center to the CoM as

$$\bar{y} = \frac{F_{rear}}{F_{front} + F_{rear}} \cdot L \tag{B.1}$$

This distance is calculated to be $\bar{y} = 791{,}7$ mm without driver and a wheelbase of 1408 mm. With driver the distance becomes $\bar{y} = 836{,}1$ mm. Translated to mass distribution the motorcycle alone is 44/56, front/rear, and with driver seated it becomes 41/59.

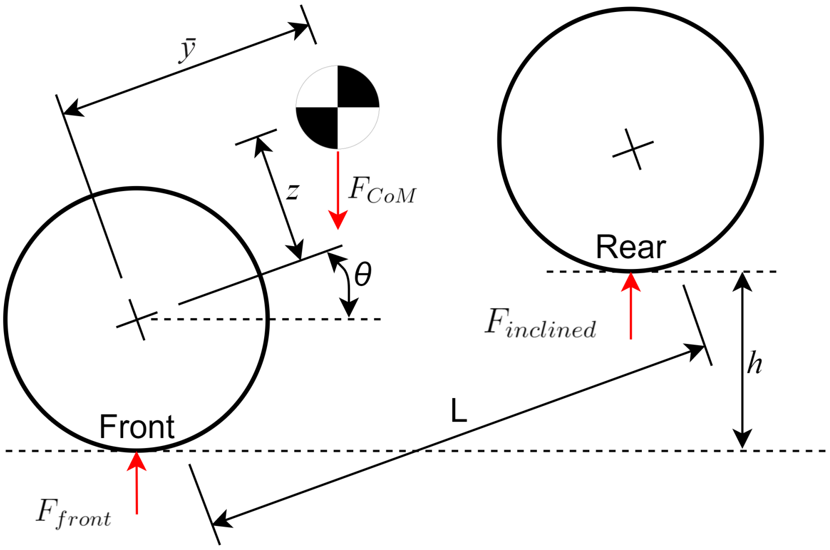

Figure B.2: Free body diagram in tilted case

To determine the CoM height position of the motorcycle the rear end is inclined as in Figure B.2 and z is described as

$$z = \frac{((F_{front} + F_{rear})\bar{y} - F_{inclined}L)}{(F_{front} + F_{rear})} \cdot \cot\theta \tag{B.2}$$

The distance is calculated to be z = 228,5 mm with a wheelbase of 1408 mm and the rear wheel inclined 450 mm creating an angle $\theta = 18,64°$.
The location of the CoM of the current model is thereby $\bar{z} = z$ + wheel radius = 538 mm, and $\bar{y}$ = 791,7 mm. The drivers CoM was determined in CAD using Catia Human Builder by replicating the driver size used in the actual weighing session and the driving position on the latest model. From this the combined CoM was calculated to $\bar{z}$ = 703,4 mm.

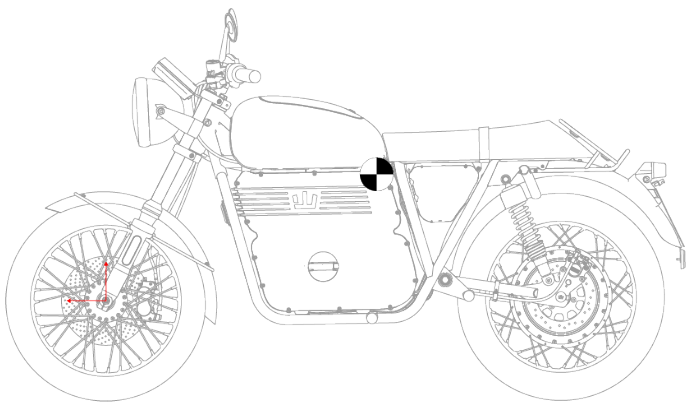

Figure B.3: CoM location on the latest model including driver

B.2 Calculating the Wanted Center of Mass for Model X

According to John Bradley the optimum CoM position is where the front and rear wheel lifts or loses traction at the same acceleration [4]. He describes these conditions with the following equations and we seek the CoM position resulting in the same acceleration for all cases.

$$\text{Acceleration to lift front wheel} = \frac{(L - \bar{y})}{\bar{z}} \cdot g \tag{B.3}$$

$$\text{Acceleration to spin rear tire} = \frac{\mu\bar{y}}{(L - \mu\bar{z})} \cdot g \tag{B.4}$$

$$\text{Retardation to lift rear wheel} = \frac{\bar{y}}{\bar{z}} \cdot g \tag{B.5}$$

$$\text{Retardation to slide front tire} = \frac{\mu(L - \bar{y})}{L - \mu\bar{z}} \cdot g \tag{B.6}$$

This provides the wanted CoM position of the vehicle including driver. From eqn. B.3 and eqn. B.5 we find that the front and rear wheel lifts at the same time if $\bar{y} = L/2$. From eqn. B.3 and eqn. B.4 with $\bar{y} = L/2$ we find that we spin the rear wheel at $\bar{z} = L/2\mu$. The position is hence dependent on the coefficient of friction (CoF) the tires to the ground. In a test done by SAE International in United States [13] the CoF between the tire and dry hot rolled asphalt is [0,99-1,36]. If a CoF of 1,0 is used the height of the CoM position becomes $\bar{z} = L/2$. We notice that the CoM position is increased in height for an decreased CoF, as for wet roads typically can be [0,5-0,7].

To select the CoM position the wanted vehicle behaviour is required. If the motorcycle has a horizontal CoM more forward of the vehicle it is likely to spin the rear tire at acceleration than lifting the front wheel from the ground. Vise versa it is more likely to lift the front wheel than to get wheel spin if the CoM is moved rearwards. A higher front end bias will fits modern race tires with a good suspension and rider, more room and driver effort to achieve the benefits from this setup are required [4]. The motorcycle concerned will not be a performance vehicle and hence a neutral behaviour is wanted, a horizontal CoM position of half the wheelbase with the driver seated is targeted.

As seen in the formulas describing the acceleration conditions a higher CoM is beneficial in wet conditions while a low is more suitable for dry conditions the CoM height from ground will always be conflicting. Since the motorcycle mainly is a vehicle used in dry conditions the CoM position should be adapted for this but it has to provide sufficient handling even in wet conditions to be safe to drive. Assuming the CoF to be in the interval [0,7-1,0] the CoM height $\bar{z}$=[650-929] mm.

C

Geometry Comparison of Motorcycle Models

Geometry and size comparison of the current model from RGNT, model x and 2019 Honda Super Cub C125. Figure C.1 shows a

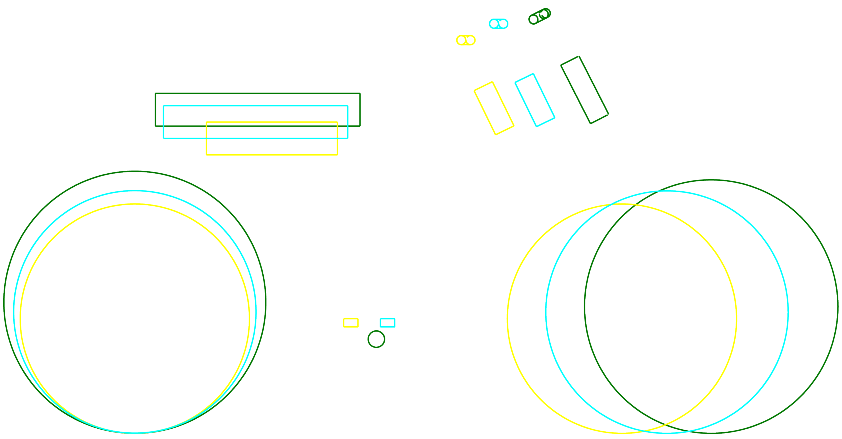

Figure C.1

- Green = Current model from RGNT. Wheelbase 1408 mm, seat height 828 mm, tire size front = 90/90-18 rear 110/80-18.
- Cyan= Model x. Wheelbase 1300 mm, seat height 800 mm, tire size front and rear = 100/80-17
- Yellow = Honda Cub. Wheelbase 1190 mm, seat height 760 mm, tire size front = 70/90-17 rear 80/90-17.

Drivers of different sizes was modelled in Catia human builder to visualize how the proportions between them and the motorcycles look. The latest model from RGNT, model x and the Honda Cub, which is a motorcycle of similar size and type are compared with three different driver sizes. To cover a large but still reasonable interval of driver sizes the smallest driver is a 5^{th} percentile German female and the largest driver a 95^{th} percentile German male. A 50^{th} percentile male is also included to illustrate the seating position of the most common driver size.

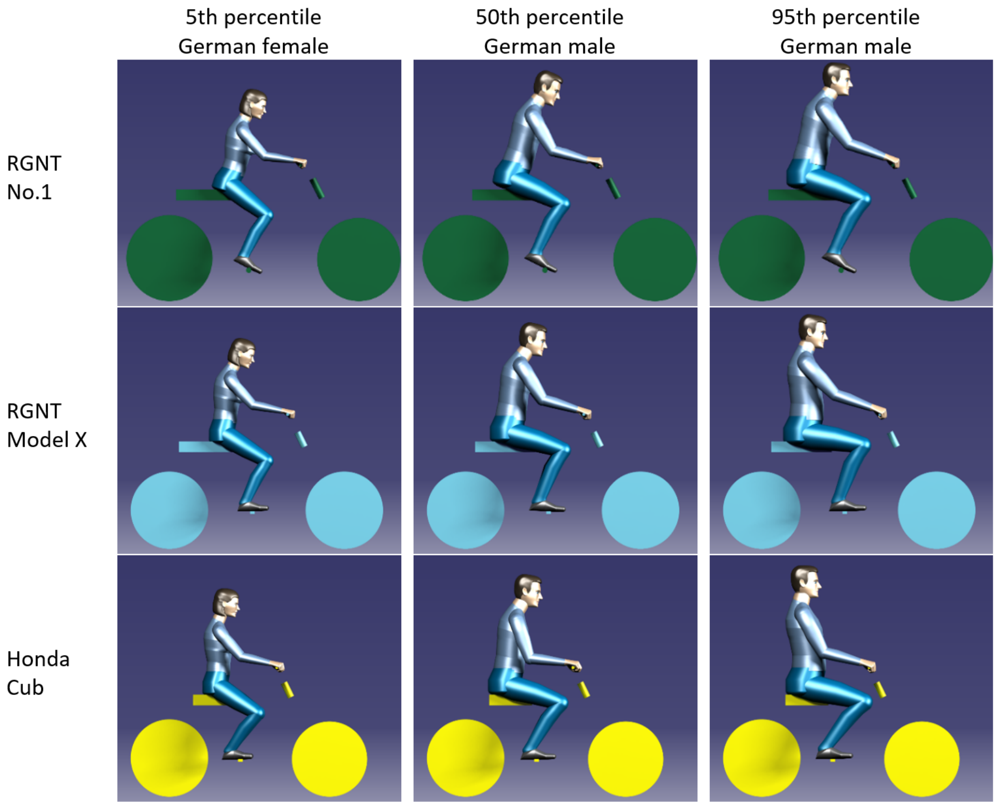

Figure C.2: Vehicle size comparison for three driver sizes

The longer wheelbase and the higher seat height of the latest model from RGNT combined with the 5^{th} percentile female driver can result in problems achieving a good driving position. This effect is reduced on the model x the motorcycle starts to look small for the 95^{th} percentile male. On the Honda cub the 5^{th} percentile female and the 50^{th} percentile male seems to have a good driving position but for the 95^{th} percentile male it looks crowded.

To reach the ground at stand still is an important requirement to be able to use the motorcycle safely. This was tested with the shortest, a 5^{th} percentile German female, sitting in the saddle stretching the leg to a point on a circle drawn from the center on the seat to the contact point of the tire to ground. If this line is reached the driver can support the motorcycle at standstill, possibly by a small tilt on the vehicle.
As seen in the illustrations in Figure C.3 the driver may struggle to balance the motorcycle at stand still on the current model from RGNT. To reach the ground a fully stretched leg and flexure is required. On the model x the driver reaches the ground but a fully stretched leg is still required. On the Honda Cub the driver has no problem to reach the ground and the seat height may even be raised to increase the ergonomics for the longer drivers.

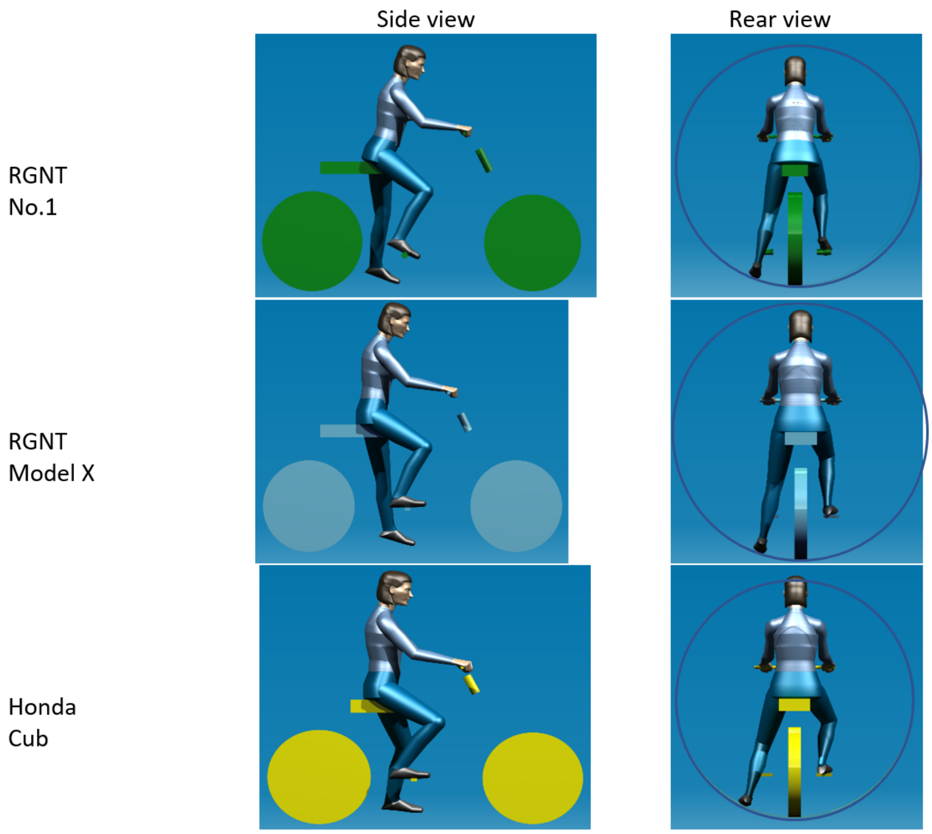

Figure C.3: Vehicle size comparison for three driver sizes

Conclusion: A 5^{th} percentile female may struggle to achieve a good driving position on the latest model from RGNT and at standstill she may have problems balancing the motorcycle with a fully stretched leg and flexure. The 5^{th} percentile female will have better balancing possibilities on a model x with a slightly lower seat height, but the leg still needs to be fully stretched. The shorter wheelbase allows for a better driving position for the shorter drivers while still being reasonable for the longer. On the Honda Cub the 5^{th} percentile female reaches the ground without fully stretching nor leg or flexure. This allows for an easy balancing but at the same time an awkward driving position for the longer drivers.

D

Frame

D.1 Pugh matrix Frame processes

Pugh matrix Round 1		Sheet forming	Casting	Machining	Additive manufacturing
Criterion	**Weight**				
Cost estimate	2	**Reference**	-	-	-
Formability	2		0	+	+
Surface finish	1		-	0	-
Mechanical performance	2		-	-	-
Process time	1		-	-	-
Mounting points	1		0	+	+
Sum +			0	3	3
Sum -			-6	-5	-6
Value		0	-6	-2	-3
Rank		1	4	2	3
Comment		Casting is significantly lower, eliminated. Machining and Additive manufacturing have benefits in formability and mounting point positioning but cost and productiuon time makes them non suitable.			

D.2 Pugh matrix Frame material and processes

Pugh matrix Round 1		Sheet Hydroforming	Sheet Hydroforming	Press Forming	Press Forming	Press Forming
Criterion	**Weight**	**Stainless steel**	**Aluminum**	**Steel**	**Stainless steel**	**Aluminum**
Cost estimate	2	**Reference**	-	+	-	-
Mass	1		-	0	0	-
Process time	2		0	+	+	+
Weldability	1		-	0	0	-
Corrosion resistance	1		-	-	0	-
Fatigue resistance	1		-	0	0	-
Sum +			0	4	2	2
Sum -			-6	-1	-2	-6
Value		0	-6	3	0	-4
Rank		2	5	1	2	4
Comment		Sheet hydroforming of aluminum and Press forming of aluminum shows considerably lower values and are eliminated.				

E
Battery Enclosure

E.1 Requirement Specification for Battery enclosure

RGNT	**Document type**	Requirements sheet			
Project:	*Model X*	*Battery pack enclosure*			
Author/s:	Ludvig Brodén		**Created**	2021-03-03	
	Filip Jonsson		**Modified**	2021-05-10	

ID	**Criterion**	**Target**	**Priority** **M=must** **W=want**	**Verification method**	**Stakeholder**	**Why?**
Main function						
	Provide energy for the motorcycle		M			
1. Performance / Marketing						
1.1	Allow top speed of	100 km/h	M	Simulation/test	RGNT	
1.2	Vehicle range	100 km	M	Simulation/test	RGNT	
1.3	Allow 1-phase charging 230/110 V	-	M	Design	RGNT	
1.4	Allow charging at charging stations	-	M	Design	RGNT	
1.5	Li-Ion cells	-	M	Design	RGNT	Marketing strategy set by RGNT
1.6	Nominal battery voltage	88.8 V	M	Design	RGNT	
2. Usability						
2.1	Docking time	<2 min	M	Design/test	User / RGNT	
2.2	Charging time	<3 h	M	Simulation/test	User / RGNT	
2.3	Charging time	<1 h	W3	Simulation/test	User / RGNT	
2.4	Maintenance (charging excluded)	Non	W4	Design	RGNT	
2.5	Tools not needed	-	W4	Design	User / RGNT	
3. Geometry						
3.1	Able to stand upright without falling over	-	M	Design	User	
4. Ergonomics						
4.1	Mass battery pack	<15 kg	M	Design	User / RGNT	
4.2	Mass battery pack enclosure	<2 kg	W5	Design	User / RGNT	
4.3	Single hand operation possible	-	M	Design/test	User	
4.4	Two hand lifting possible	-	W4	Design/test	User	
4.5	5th percentile female able to lift in and out of motorcycle	-	M	Design/test	User	
5. Aestetics						
5.1	If visible while driving aestethically apealing and fit the look of the motorcycle	-	M	Design	User	
5.2	High quality look and feel	-	M	Design	User	To make the user feel safe
6. Saftey						
6.1	Weather resistant	-	M	Design/test	User / RGNT	
6.2	Passive saftey on electrial connectors to aviod hazzards	-	M	Design	Ethics	Short circuts not possible
6.3	Mechanically safe docking	-	M	Design	Ethics	Risk of crushing
7. Lifecycle						
7.1	Allow disassembly for reuse/-cycling	-	W2	Design		
7.2	Battery retirement program	-	W1	Design	RGNT	
8. Manufacturing						
8.1	Manufacturing cost	<XXXX SEK/unit	W3	Design	RGNT	
8.2	Annual manufacturing capacity	>2500 units	M	Design	RGNT	
8.3	Adapted for DFMA	-	M	Design	RGNT	

E.2 Concept Generation and elimination Matrix Battery Enclosure

Feature		
1. Lifting device	Comment	Decision
Strap		Kept
Handle		Kept
Trolley		Kept
Integrated handle		Kept
Non		Kept
Axle strap	High lifting	Eliminated
Special lifting tool	Requires tools	Eliminated
Lift the motorcycle	Exceeds 15 kg	Eliminated
Mechanical mechanism extracting the battery	Complex solution	Eliminated
Electromechanical mechnism extracting the battery	Expensive componets	Eliminated
2. Electrical connection	Comment	Decision
2 pole EV connector		Kept
Type 2 connector		Kept
Automated connection		Kept
Inductive connection	Complex and not possible	Eliminated
Screw terminals	Risk of short circuts	Eliminated
Clamp terminals	Risk of short circuts, long time to connect, tools might be necessary	Eliminated
3. Passive safety	Comment	Decision
Female connector in enclosure		Kept
Terminal lids		Kept
Inaccessible pins		Kept
Electrical verification before potential is obtained	Not a passive solution	Eliminated
4. Fixation	Comment	Decision
Actuated locking pin		Kept
Leather strap		Kept
Blocked		Kept
Butterfly latch		Kept
Handle is locking mechanism		Kept
Screws	Requires tools	Eliminated
Eccentric lock	Risk of crushing	Eliminated
5. Enclosure material	Comment	Decision
Aluminum		Kept
Steel		Kept
Plastic		Kept
Composites	Expensive	Eliminated
6. Enclosure type	Comment	Decision
Cast		Kept
Extruded		Kept
Additive manufacturing		Kept
Injection moulding		Kept
Bent sheet metal		Kept

E.3 Morphological Matrix Battery enclosure

Feature	A	B	C	D	E
1. Lifting device	Strap	Handle	Trolley	Integrated	Non
2. Electrical connection	2 pole EV connector	Type 2 connector	Automated connection		
3. Passive safety	Female connector in enclosure	Lid	Inaccessible pins		
4. Fixation	Actuated locking pin	Leather strap	Blocked	Butterfly latch	
5. Enclosure material	Aluminum	Steel	Plastic		
6. Enclosure type	Cast	Extruded	Additive manufacturing	Injection moulding	Bent sheet metal

Concept 1: 1D-2C-3C-4C-5D-6D. An injection molded plastic enclosure with integrated handle. Locked in place by an actuated pin. Automatic electrical connection when battery is mounted with inaccessible connection pins.

Concept 2: 1A-2A-3B-4A-5A-6B. An extruded aluminum profile with plastic ends. Lifted in a strap and locked in place by an actuated pin. Electrical connection using a 2 pined EV connector protected by a lid.

Concept 3: 1C-2B-3B-4C-5B-6E. Bent sheet metal enclosure made from steel. Moved as a trolley mounted low in the vehicle to not require lifting and held in place by other blocking components. Type 2 AC connector protected with a lid.

Concept 4: 1D-2A-3C-4D-5A-6A. Cast aluminum casing with integrated handles. Locked in place wit ha butterfly latch. Electrical connection using a 2 pined EV connector with female end in enclosure.

Concept 5: 1E-2A-3C-4B-5C-6C. Plastic enclosure made using additive manufacturing. Locked in place with a leather strap and have no handles. Electrical connection using a 2 pined EV connector with female end in enclosure.

E.4 Pugh matrices Battery enclosure

E.4.1 Pugh matrix Round 1

Pugh matrix Round 1		Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Criterion	**Weight**					
Design simplicity	2	Reference	+	-	0	+
Robustness	2		-	-	0	-
Placement possibilities	1		0	-	0	0
Cost estimate	2		0	+	+	+
Ease of use	2		-	0	-	-
Disassembly	1		0	-	0	0
Quality feel	1		+	-	0	-
Manufacturing simplicity	2		+	+	+	0
Sum +			5	4	4	4
Sum -			-4	-7	-2	-5
Value		0	1	-3	2	-1
Rank		3	2	5	1	4
Comment		Concept 3 significantly lower value, eliminated				

E.4.2 Pugh matrix Round 2

Pugh matrix Round 2		Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Criterion	**Weight**					
Design simplicity	2	0	-		Reference	+
Robustness	2	0	0			-
Placement possibilities	1	0	0			0
Cost estimate	2	-	0			0
Ease of use	2	+	+			-
Disassembly	1	0	0			0
Quality feel	1	0	+			-
Manufacturing simplicity	2	-	+			-
Sum +		2	5		0	2
Sum -		-4	-2		0	-7
Value		-2	3		0	-5
Rank		3	1		2	4
Comment		Concept 5 significantly lower value, eliminated. Rank order similar for lowest rankings.				

E.4.3 Pugh matrix Round 3

Pugh matrix Round 3		Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Criterion	**Weight**						New
Design simplicity	2	-	Reference		-		-
Robustness	2	0			+		+
Placement possibilities	1	0			0		0
Cost estimate	2	0			0		0
Ease of use	2	+			-		+
Disassembly	1	0			0		0
Quality feel	1	-			-		+
Manufacturing simplicity	2	+			-		0
Sum +		4	0		2		5
Sum -		-3	0		-7		-2
Value		1	0		-5		3
Rank		2	3		4		1
Comment		New concept added. Concept 4 significantly lower value, eliminated.					

E.5 Kesselring matrix Battery enclosure

Weighing of criterion **Criterion**	**Robustness**	**Ease of use**	**Battery changing time**	**Cost estimate**	**Manufacturing simplicity**	**Quality feel**	**Two hand lifting**	**Disassembly**	**Retirement program**	**Sum**	**Sum relative**
A Robustness	-	0,5	0,5	1	0,5	0,5	1	1	1	6	0,167
B Ease of use	0,5	-	0	1	1	0,5	1	1	1	6	0,167
C Battery changing time	0,5	1	-	1	0,5	0,5	0,5	1	1	6	0,167
D Cost estimate	0	0	0	-	0,5	1	1	1	1	4,5	0,125
E Manufacturing simplicity	0,5	0	0,5	0,5	-	0	0	1	1	3,5	0,097
F Quality feel	0,5	0,5	0,5	0	1	-	0,5	1	1	5	0,139
G Two hand lifting	0	0	0,5	0	1	0,5	-	1	1	4	0,111
H Disassembly	0	0	0	0	0	0	0	-	0,5	0,5	0,014
I Reitirement program	0	0	0	0	0	0	0	0,5	-	0,5	0,014

Value 0 = Less important than -
Value 0,5 = Equally important as -
Value 1 = More important than -

Figure E.1: Relative comparison of criterion for battery enclosure

Robustness	
Variation risks	Value
High	1
	2
	3
	4
Low	5

Ease of use	
Nr of interfaces	Value
>4	1
3-4	2
2-3	3
1-2	4
1	5

Battery changing time	
Min	Value
>10	1
5-10	2
2-5	3
1-2	4
<1	5

Cost estimate	
SEK	Value
>500	1
350-500	2
200-350	3
50-200	4
<50	5

Manufacturing simplicity	
Nr of components	Value
>8	1
6-8	2
4-6	3
2-4	4
<2	5

Quality feel	
Subjective	Value
a	1
b	2
c	3
d	4
e	5

Two hand lifting	
Handle gripping	Value
Not possible	1
	2
Possible	3
	4
Comfortable	5

Disassembly	
Level of joining	Value
Permanent joining	1
	2
	3
	4
Semi-permanent joining	5

Retirement program	
	Value
Reconstruction	1
	2
	3
	4
As is	5

Figure E.2: Grading of criterion for battery enclosure

Kesselring matrix		Concept 1		Concept 2		Concept 6	
Criterion	**w**	**v**	**t**	**v**	**t**	**v**	**t**
Robustness	0,17	5	0,83	3	0,5	4	0,67
Ease of use	0,17	5	0,83	4	0,67	5	0,83
Battery changing time	0,17	4	0,67	4	0,67	4	0,67
Cost estimate	0,13	5	0,63	4	0,5	4	0,5
Manufacturing simplicity	0,1	5	0,49	3	0,29	4	0,39
Quality feel	0,14	3	0,42	4	0,56	5	0,69
Two hand lifting	0,11	5	0,56	3	0,33	5	0,56
Disassembly	0,01	4	0,06	3	0,04	3	0,04
Reitirement program	0,01	5	0,07	5	0,07	5	0,07
T		4,5416667		3,625		4,4166667	
Rank		1		3		2	

Figure E.3: Kesselring matrix for battery enclosure concepts

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