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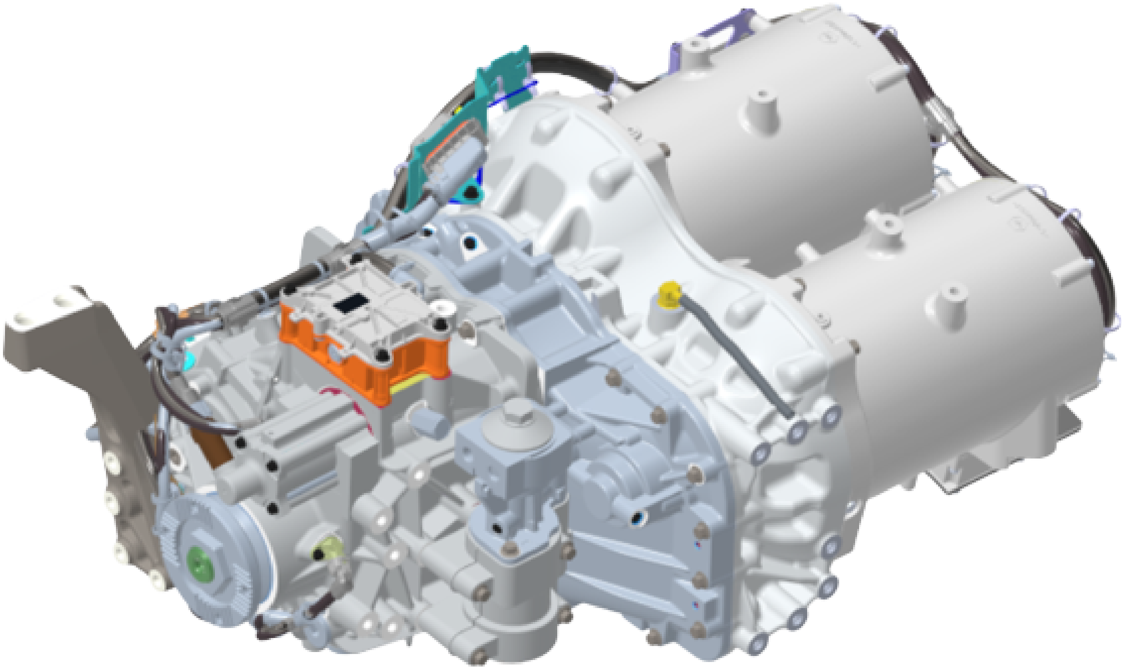

Design and Development of an Electrically Actuated Gear Shifting System

Bachelor's Thesis in Mechanical engineering

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Abstract

This bachelor thesis examines a potential implementation of an electrical actuator in a gear shifting system. The EPT gearbox has been provided by Volvo Group Trucks Technology whereupon selected components requires a potential reconstruction.

The final result has been achieved using research methodology, concept generation and construction of components. The study shows that an implementation of the electric actuator is possible with a orientation similar to today's pneumatic one.

Acknowledgements

We would like to express our appreciation to the employees at Volvo Group Trucks Technology who supported us during the progress of the work. We would also like to express our deepest gratitude to our supervisor at Volvo Group, Rikard Graas. Also, big thanks to our examiner at Chalmers University of Technology, Kjell Melkersson.

Cornelia Nielsen and Amelie Slobo, Gothenburg, June 2023

List of Acronyms

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

CAD	Computer-Aided Design
EPT	Electrical propulsion transmission
EVU	Extension Valve Unit
I-shift	Intelligent automated manual transmission

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1
Introduction

The purpose of the introduction is to provide a comprehensive understanding of the background and rationale behind the project. The fragments described and explained in the introduction will be used and refereed to throughout the report. Furthermore, the aim and possible limitations of the study will also be presented.

1.1 Background

Volvo's first modern truck without driveline components from passenger cars came in 1931 [1]. The gearbox in the modern truck was a heavy-duty gearbox equipped with four gears especially adapted for heavy vehicles. This type of gearbox was unsynchronized as the driver must control the adaptation of the engines revolution per minute manually. The synchronized gearbox was developed in 1950 with automatic shifting. However, Volvo Trucks' first automatic gearbox - powertronic - was launched in 1992. This version of trucks laid the foundation for the first generation of I-Shift that came in 2001. I-Shift brought increased functionality, reliability, drivability and fuel efficiency in comparison to previous truck series. The latest generation of I-Shift is an automatic gearbox with electronic control, equipped with optimized software.

1.1.1 Volvo Group

Volvo Group develops transport- and infrastructure solutions such as trucks, buses, construction equipment and engines for marine and industrial applications. The company has global goals in several different areas such as finance and development, of which the environmental impact is significant. Volvo Group supports the Paris agreement and therefore prioritizes the reduction of carbon dioxide emissions and have the ambition to be net-zero in there production chain by 2040 [2]. Electromobility plays a key role on the road as well as at sea to achieve fossil-free transportation.

1.1.1.1 Electromobility

Electromobility refers to vehicles – including cars, buses, trains and trucks – that are fully or partly powered by electricity, have a means of storing energy on board and are usually supplied via the grid. The main type of vehicle with an electric driveline is the BEV (battery electric vehicle), but there are also electric vehicles fuelled by hydrogen called fuel cell electric vehicles (FCEVs). Electromobility also includes the charging infrastructure and support services for range and route planning and other functions.

1.1.1.2 Volvo Trucks

For over a century Volvo Trucks has been one of the leading companies within the heavy-duty transportation. With their sleek and powerful design and commitment to sustainability, Volvo Trucks are determined to drive the development of sustainable transport solutions. Electric trucks produce no tailpipe emissions (nitrogen oxides, particle pollution) and have a low total climate impact when electricity from renewable sources is used. The electrification of trucks also entails that they are much quieter than conventional trucks [3].

1.1.1.3 Powertrain Serie EPT

The electric propulsion transmission series which will henceforth be referred to as the EPT is a powertrain with one or two electric motors combined with a 2-speed gearbox. In this thesis, the two different models will be further investigated, and What differentiates the models is primarily the number of electric motors, equipped with one electric motor and with two electric motors [4]. Furthermore, the geometry may also differ between the drive-units, for example within the gearbox. Models such as and are found in buses and light-duty trucks especially adapted to door-to-door deliveries in constrained city environments such as garbage trucks and urban distribution [5].

1.1.2 Automatic Transmission

A transmission is a mechanical component that transfers power from the motor to the wheels, allowing the vehicle to move (See Appendix [A.5]). It typically consist of a series of gears that engage and disengage to adjust the torque and speed of the wheels relative to the motor [6]. Transmissions play a critical role in determining the performance, efficiency, and safety of a vehicle, especially in heavy-duty applications as trucks. The design and engineering of transmissions require careful consideration of factors such as gear ratios, torque capacity, lubrication, cooling, and vibration and noise reduction. Transmissions must also be durable and reliable, as failures or defects can result in downtime, maintenance costs, or safety risks.

Automatic transmission have become increasingly common in the automotive industry, due to their ease of use and convenience. Unlike manual transmissions, automatic transmissions do not require the driver to manually engage and disengage gears. Instead, they rely on pneumatic systems and electronic controls to automatically shift gears based on the vehicle's speed, engine load, and other factors.

1.1.3 Pneumatic Actuator

A pneumatic system utilizes the force generated by compressed gas or fluid, which serves as the working medium. A pneumatic actuator involves a control valve which under high pressure fills with compressed air[7]. The pressure converts into mechanical energy either linear or rotary motion, enabling it to perform the intended work. In today's series of and , a pneumatic actuator converting air pressure to linear force which enables gear shifting. This type of actuator requires an air compressor in order to function.

1.1.4 Electrical Actuator

An electrical actuator is a device that converts electrical energy into mechanical force, enabling it to control the motion or positioning of a mechanism. An actuator receives an electrical signal which converts it into either a rotary or linear movement to drive a mechanical device [8]. Unlike pneumatic actuators, electrical actuators rely on electrical signals to initiate movement. Due to the ability to provide precise control, quick response times, and high accuracy, electrical actuators have become a widely preferred option in industries that necessitate accurate motion control.

In the case of gear shifting, the electrical actuator moves a shift rail, also known as rod, which facilitates the engagement of gears. The actuator's movement of the rod enables the vehicle to shift gears smoothly and efficiently. The electric actuator chosen for this thesis has been predetermined and verified by Volvo Group Trucks. Its motion is linear and its geometry can be customized to meet specific requirements.

1.1.5 Gear Shift Rod

In the context of a gearbox, the role of a rod, often referred to as a gear shift rod, plays an essential role in the gear shifting mechanism. The primary function of the rod is to transmit the motion and force from the actuator to the internal components of the gearbox, to promote the engagement or disengagement of gears. As the rod moves, it pushes or pulls the shift yoke. This action determines which gear pair to use and enables the transfer of the torque from the engine to the wheels. The precise movement of the rod, guided by the bushings, ensures smooth and accurate gear shifting.

1.1.6 Shift Yoke

A shift yoke is a mechanical component used in transmission systems to engage and disengage gears [6]. It is a fork-shaped metal piece which is assembled on a rod that is responsible for moving the engaging sleeve. The engaging sleeve is the component that locks a gear to the shaft. It rotates freely between the shift yoke's two legs which are separated by brass-pads to minimize resistance and noise during operation. Shift yokes are generally designed to serve two gear ranges. The first gear is attached when the engaging sleeve is synchronized with the shaft. The gear that is engaged is thus determined by the position of the rod, controlled by the electrical actuator, (see Appendix [A.4]).

1.2 Aim

The aim of this project is to investigate the possibility of implementing an electrical actuator in a gear shifting system. The main focus of the study is the EPT gearbox provided by Volvo Group.

1.3 Limitations

The thesis will include several different aspects and methods that concern the science of mechanical engineering. Despite the opportunity for variation and exploration, there are few limitations to which the thesis can be related.

The thesis will examine and discuss certain components inside the gearbox and not the entire drive unit of the EPT. The components that will be addressed are the rod, the shift yoke, the placement of the electrical actuator, the bushings attached to the rod and possibly the gearbox housing. Surrounding components and systems are assumed to have the same position to relate to.

Models and verifications of solutions will be done digitally through the software tool Creo Parametric. Volvo trucks will provide with Computer-Aided Design (CAD) models to relate to thus necessary simulations, analyses, measurements and models will be performed within this tool. Furthermore, the assembly of components during manufacture will be discussed to some extent, while the manufacturing method and financial aspects will be excluded.

2
Methods

The aim of the Method chapter is to provide a comprehensive account of the methods used to achieve the conclusive result. This chapter will present a chronological description of the methods used, followed by the associated software and tools. Its purpose is to give the reader a clear understanding of the steps taken to collect and analyze data, and how the research was conducted. By presenting the methods used in a logical manner, the reader can evaluate the validity and the reliability of the research and gain insight into the researcher's decision-making process.

2.1 Research Methodology and Investigation

During this process information and data was systematically gathered to increase a deeper understanding of the task. In the context of product development, research was conducted to increase insights into the needs, market trends, competitive products, and to identify technical and market constraints, to make knowledgeable decisions about the product.

2.1.1 Market Survey

A market survey has been implemented to further investigate and evaluate the concepts potential on the market. What was primarily interesting was whether there was any existing concept with developed geometry for a similar type of truck and comparable size of gearbox. The concept investigated in the market survey consists of components such as the electric actuator, the gear shift yoke, the rod and the bushings in relation to each other. Tools such as Google and Espacenet have been used during the investigation.

What can be stated is that a complete concept with desired components was not available to the public of potentially competing companies. Therefore, the exact geometry cannot be accessed. Moreover, there have been no CAD-models or detailed product descriptions of the gearbox either. Thus, the chosen concept for the thesis cannot be evaluated or compared based on other companies' solutions to the task.

2.1.2 Patent Investigation

To avoid potential legal conflicts related to the concept, a patent investigation was conducted as part of this thesis. The investigation aimed to identify any patents that could be relevant to the project's developed solution. However, it was found that no useful patents could be evaluated against the project's solution. Yet, it would have been of interest to investigate if there were any patents related to the subsystem, including the relation between the electrical actuator, rod, shift yoke, bushings and housing.

The project group has been assigned an electrical actuator by Volvo Group to be used in this project. Thus, it is assumed that a patent investigation has already been carried out by the company for that particular part, and no further investigation was considered necessary.

2.1.3 Requirements Specification

A requirements specification is a detailed document that outlines the specific needs, expectations, and constraints for the system, see appendix A.0.1. The purpose of the document is to ensure that the project group and the client have a clear understanding of what the concept should do and how it should perform. By defining the product requirements early in the process, the project team can assure that the final concept meets the needs of the intended users and performs as expected.

2.2 Concept Generation

This is the process of generating ideas for potential solutions to the need. The aim was to reach a wide range of ideas that had the potential to address the identified task in unique and innovative ways. The placement of an electrical actuator was thoroughly studied. Furthermore, the team shifted their focus towards a comprehensive examination of the rod, shift yoke and bushing points, evaluated against the requirement specification for each component. Moreover, this progression involved assembling of the generated components, incorporating the placement of the electrical actuator, to form a subsystem, thereby defining the final concept.

2.2.1 Brainstorming

To generate a large number of ideas in a short period of time the technique brainstorming was used. Brainstorming is a group method that encourages the free flow of ideas and creativity. During brainstorming sessions, participants was encouraged to generate as many ideas as possible, without criticism or judgment. The aim was to generate a large number of ideas quickly and efficiently, which can be further refined and evaluated at a later stage in the product development process. After the brainstorming sessions, a total of 12 potential concepts were generated, exploring the placement of the electrical actuator within each concept.

2.2.2 Concept Combination

Concept combinations involve the process of combining two or more generated concepts to create a new, innovative concept. Some of the generated concepts could be combined to create even stronger concepts. The concept generation and brainstorming resulted in 12 possible concepts, of which some could be combined. For example, one concept was that the actuator would be integrated and mounted inside the gearbox.

2.3 Construction of Components

To construct the concepts the software tool Creo Parametric was used to create 3D models and drawings. To validate that all parts would fit in the EPT gearbox together an assembly was created to confirm placement and that the requirements were met.

2.4 Valdiation of Subsystem

Two possible concepts were constructed, they were simulated and validated in Creo Parametric. During the simulation, the shift yoke was allowed to move in a linear direction, on which the shift yoke was fixed. The rod was moved with an applied force of [N] which demonstrated potential stress in the shift yoke.

The stress within the shift yoke was verified against the yield strength limit of cast iron, confirming the presence of excessive stress levels in certain areas. Consequently, a redesign and optimization of the shift yoke were necessary. Additionally, an iterative process of simulation and validation was carried out.

3

Description of System

The purpose of the Description Of System chapter is to explain how the gear shifting system of today's EPT series work. That is, to explain the function of each component and how they are positioned in relation to each other. In addition, assembly and manufacturing is mentioned to a certain extent but also several areas of improvement that will be of use when developing an optimized concept.

3.1 Description of Today's System

In today's EPT gearbox, a pneumatic actuator is implemented which is attached to the outside of the gearbox housing. Inside this actuator, there is an integrated rod that moves linearly. Thus it is the pneumatic actuator that converts the air pressure into the rod moving linear with a force of approximately   [N]. In order for the rod to be fixed in the remaining rotations and translations, bushing points are required that controls the movement. Hence there is a bushing integrated inside the actuator and an additional one integrated inside the gearbox housing (see Fig. [5.7]). The slide bushings used today are   mm wide and require no oil for lubrication.

Attached to the rod is a shift yoke that retains the engaging sleeve. It is thus the engaging sleeve which, by hooking the shaft, shifts gears. The shift yoke is in turn fixed to the rod with a sensor placed at the head. This sensor registers the position of the shift yoke and thus which gear is engaged.

Today, the manufacturing of the system consisting of the shift yoke, rod, bushings and actuator takes place in several steps. The shift yoke, rod and bushings are fully assembled inside the closed gearbox unlike the actuator which is installed from the outside. The actuator is divided into several components that are assembled separately and finally secured with screws.

3.2 Areas of Improvement

Volvo Group's target is to have 35% fully electric sales by 2030 [9]. Thus a constant optimization and electrification of vehicles is required.

There are several advantages to replace the pneumatic actuator with an electric one. A pneumatic actuator is controlled by air pressure, thus the shifting of gear is performed quick and with a high force. However, this type of system requires that the compressor runs constantly to retain pressure. Electric actuators, on the other hand, only need to run when required. The electric actuator enables movement by regulating current and variable resistance. Therefore, the force and movement can be fully controlled to suit certain application requirements. This type of system enables multi positioning unlike the pneumatic which has an end-to-end positioning. This results in high accuracy and repeatability. In addition, the reduction of force results in potentially less wear of components which increases the service life and may reduce the demand on materials.

The EPT gearbox was released in 2019, whereupon the demand was around pieces per year. The product development and production of the gearbox was thus adapted to that quantity. Today, the demand for and is estimated at an annual quantity of which is a definite increase. Since the actuator is mounted separately in the majority of parts, the assembly becomes time-consuming. There is thus a potential area of improvement within the assembly and manufacturing aspect.

A further area of improvement would potentially be to lower the center position of the rod. This could result in a reduction of material due to the gearbox housing and shift yoke. If the center point of the rod is lowered, there is remaining space on top of the gearbox housing that could potentially be removed and lowered. In addition, the shift yoke could be constructed smaller and thus possibly change material.

4

Evaluation of Concepts

In the Comparison of Concepts section, some of the 12 concepts that were generated through brainstorming and concept generation will be presented. The two further developed concepts will be described in detail after which similarities and differences will be compared. In addition to comparison, the pros and cons of components or subsystems will be further evaluated. This comparison is carried out in order to draw conclusions and arguments about which concept is suitable for the final concept.

4.1 Placement of Actuator

The concept generation and brainstorming resulted in 12 possible concepts. The development of these concepts were primarily based on the position and location of the electrical actuator. Thus, the 12 concepts have different geometries and locations for the actuator in relation to the gearbox housing.

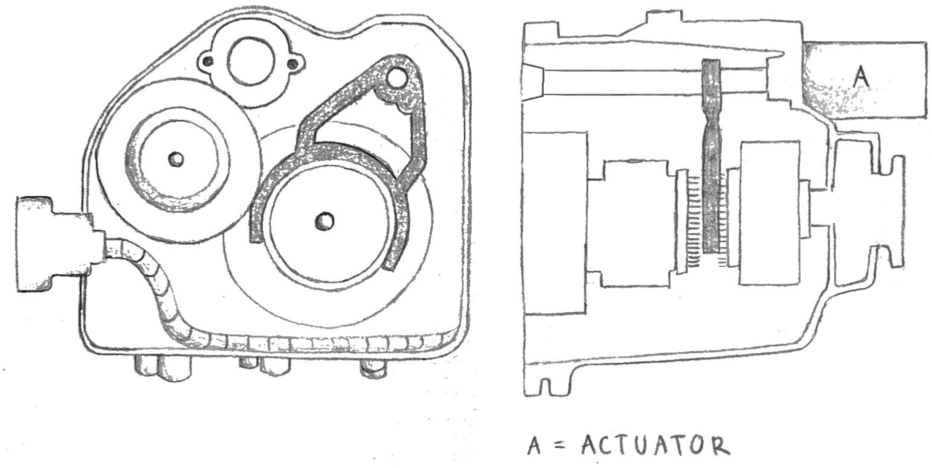
An example includes a concept where a lid has been integrated inside the gearbox housing. The actuator is attached to the lid which is then mounted in position with the remaining assembly of components inside the housing. Alternatively, all components of the subsystem would be included in the lid. Consisting of the actuator, rod, bearing points and the shift yoke (see Fig.[A.1]). An advantage is that the space inside the gearbox housing is optimized. However, a hidden installation takes place, which should be avoided. Therefore, this concept was eliminated.

In another similar concept, the electrical actuator is positioned enclosed inside the gearbox (see Fig.[A.2]). This concept would also imply an optimization of space. However, this entails complicated maintenance of the actuator as the entire gearbox needs to be opened. In addition, the actuator cannot realistically fit inside the gearbox as it is designed today. Therefore, this concept was eliminated.

This type of analysis, where advantages were set against disadvantages, was performed on all 12 concepts. Thereafter, two potential final concepts remained. The two concepts will henceforth be referred to as Concept 1 and Concept 2.

In Concept 1, the electrical actuator is placed in the same position as today's pneumatic actuator. The center axis of the rod is thus also in the same position (see Fig. [4.1]). The advantage of this is that the gearbox housing is adapted to this concept. Therefore, a major reconstruction of this is not needed. A possible disadvantage would be that there is leftover space in the gearbox that has not been utilized and optimized.

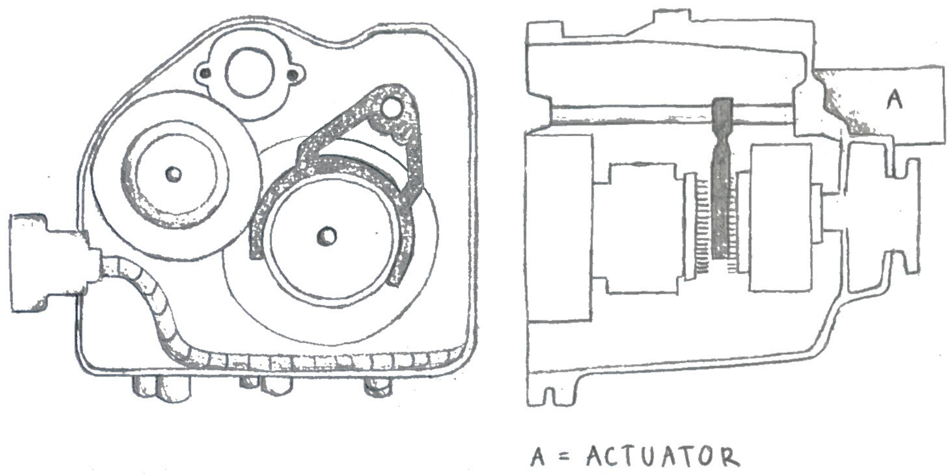
Figure 4.1: *Drawing of Concept 1*



Note: The placement of the electrical actuator is the same as today's pneumatic actuator.

For Concept 2, the electrical actuator has been placed in approximately the same position as today's pneumatic actuator. The difference is that the center point of the rod has been moved closer to the center point of the shaft (see Fig. [4.2]). The advantage of this concept is that the shift yoke can be designed smaller and that the housing can be reduced in height, potentially. This would result in a saving of materials to some extent. But instead, the gearbox housing had to be extruded on the side where the actuator is attached. The proportion of material saved is thus estimated to be marginal.

Figure 4.2: *Drawing of Concept 2*



Note: The electrical actuator in a lower position.

4.2 Comparison of Concepts

As previously mentioned, the main difference between Concept 1 and Concept 2 is the location of the electrical actuator. For Concept 1, the actuator and associated rod have the same position as today's pneumatic solution. While in Concept 2, the actuator and associated rod are placed closer to the shaft. For this reason, the gearbox housing, the position of the bushings as well as the size and design of the shift yokes differ.

4.2.1 Gearbox Housing

In Concept 1, the design of the gearbox housing will be similar to today's counterpart. The difference is that the EVU on the upper side will be removed. This entails that the housing can be lowered and in addition save material. In Concept 2, material can be saved on the top of the house, whereupon more material will be needed on the side. This is due to the bulge that disturbs the actuator's position, unless an extrusion is created similar to the model (see Fig. [A.3]). Concept 2 utilizes the space in the gearbox in terms of height unlike Concept 1. At the same time, the gearbox housing in Concept 1 can be partially lowered and retain its width, unlike Concept 2. Thus, Concept 1 is considered more advantageous than Concept 2 regarding the gearbox housing.

4.2.2 Shift Yoke

In Concept 1, the rod is centered in the same position as for today's solution. The construction and design of that type of shift yoke will therefore be similar to today's equivalent. The pneumatic system partially requires a sensor that affects the appearance of the shift yoke. Thus, the construction of the shift yoke will be corrected and optimized despite similar geometry to today's solution. The main difference between Concept 1 and Concept 2 is the size of the shift yokes. The size differs because the distance between the shaft and rod is significantly smaller in Concept 2 compared to Concept 1. This results in less material consumption for the shift yoke in Concept 2, which also makes it cheaper to manufacture.

4.2.3 Bushings

The position of each bushing differs slightly in the geometry between the different concepts. Common to today's solution compared to Concept 1 and Concept 2 is that one bearing-point is integrated into the wall of the gearbox housing (see Fig.[5.7]). The second bearing has had an undetermined location for both concepts. The bearing will probably be positioned on the opposite side of the gearbox housing, integrated onto the wall, for both concepts. Alternatively, the second bearing could be positioned in an external unit attached to the top of the housing. However, this would be difficult to manufacture and was thus eliminated.

4.2.4 Similarities

Despite the differences between the two concepts, there are many similarities. Both concepts include the same type of actuator and bushings that has been provided by Volvo Group. Moreover, the construction and assembly of the rod is the same for Concept 1 and Concept 2.

4.3 Summary

The concept chosen for further development and improvement was Concept 1. This is because Concept 2 required a major reconstruction of the gearbox housing. In addition, the project has a certain time constraint which makes the optimization of Concept 1 less complicated. This is because the rod of the electrical actuator has the same center point as for the pneumatic one. Therefore, measurements and interfaces already exist and can be utilized to a certain extent.

5

Evaluation of Components

This chapter plays a pivotal role in the product development process, involving a comprehensive assessment of individual parts and subsystems to determine their performance, reliability, and suitability for integration into the final product. Specifically, focus on studying the rod, shift yoke and bushing points, comparing them against the requirement specification for each component.

Today's solution of each component was compared to two different solutions developed by the team. These different solutions underwent an evaluation process against their requirement specification (see Appendix [A.0.1]), with each solution being assessed against each individual requirement and desire. The aim was to determine if the solutions met the criteria well (+) ; met the criteria less well (0) ; did not met the criteria (-) ; or need to be tested (?). Each solution reached a total score of (+), leading to the decision-making process of elimination based on the accumulated points.

Furthermore, the following step lead to assembling these components within the framework of Concept 1, specifically incorporating the placement of the electrical actuator, to form a subsystem, thereby defining the final concept.

5.1 Evaluation of Rods

The following figures illustrate three solutions of rods, one of today's solution and two alternative rod solutions, that were evaluated towards the requirement specification for rods. For a comprehensive overview of the requirements and desires in the rod requirement specification (see Appendix [A.0.1.1]).

Figure 5.1: *Solution One - Today's Rod*

Note. The rod in the figure above is specifically utilized in Volvo's EPT gearboxes. It consists of a fully cylindrical structure with a diameter measuring 20 mm. This rod extends from the interior of the actuator and enters the gearbox housing, where it connects to the bushings and shift yoke.

Figure 5.2: *Solution Two - A Homogeneous Rod*

Note. The design of the rod is specifically tailored to accommodate the requirements of the electrical actuator, necessitating a diameter of 14 mm. It consists of a seamless cylindrical structure, allowing it to extend from the interior of the actuator and penetrate the gearbox housing, where it establishes connections with the bushings and shift yoke.

Figure 5.3: *Solution Three -*

Note.

5.1.1 Summary

Solution one and solution two both involve the use of a single, uniform rod, which poses challenges in terms of efficient component assembly. The current process necessitates lowering the rod with the shift yoke into the gearbox in conjunction with the gear shaft, causing the rod to pass through the housing wall and extend outside the structure. Subsequently, the actuator is thoroughly added to the rod, one part at a time, leading to a time-consuming assembly procedure. Consequently, neither solution one nor solution two meets the requirement of being designed for ease of assembly (for further explanation, see Appendix [A.0.2]).

Solution three, utilizing two rods, offers a viable approach to streamline the assembly process. Initially, the main rod, accompanied by the shift yoke, is lowered into the gearbox in conjunction with the gear shaft. Subsequently, from the exterior of the housing, a larger hole adjacent to the main rod's existing hole, the actuator with the pre-mounted smaller rod can be docked onto the main rod. This approach enables a more efficient assembly process, reducing the time and effort required for integration.

Therefore, solution one and two are eliminated, and solution three advances to the subsequent stage where it will be integrated with a shift yoke and bushing point.

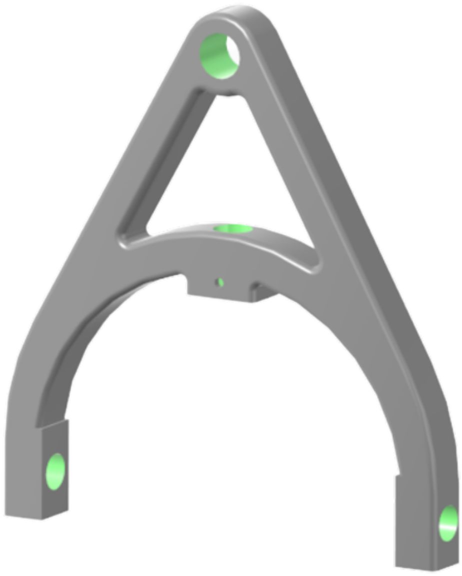
5.2 Evaluation of Shift Yokes

The following figures illustrate three solutions of shift yokes, one of today's solution and two alternative shift yoke solutions, that were evaluated towards the requirement specification for shift yokes. For a comprehensive overview of the requirements and desires in the shift yoke requirement specification (see Appendix [A.0.1.2]).

Figure 5.4: *Solution Four - Today's the size*

Note. The the size diff in the figure above is specifically utilized in Volvo's EPT gearboxes. It is equipped with a ramp on the side of its head, serving the purpose of providing positional information to the sensor. The feature allows the sensor to accurately determine the specific position of the shift yoke within the system. On the other side of the shift yoke's head, there exists an extruded cockscomb that is interconnected with a ratchet ball. This arrangement ensures the secure positioning of the shift yoke, preventing any unintended disengagement of gears.

Figure 5.5: *Solution Five - Shift Yoke*



Note. The design of this shift yoke incorporates a reduction in material usage, particularly evident in its thinner construction around the head and the presence of a larger hole in the upper section to optimize material savings. While the head exhibits a slim profile, the legs of the shift yoke retain a slightly robust structure.

Figure 5.6: *Solution Six - Drafted Shift Yoke*

Note.

5.2.1 Summary

Both solutions five and six do not incorporate the cockscomb and ramp on the head. This omission is a result of the system being controlled by an electric actuator instead of a pneumatic one. With precise gear control facilitated by the electric actuator, the presence of extrudes, such as the cockscomb and ramp, becomes redundant.

Due to the absence of the line on the side of the shift yoke in solution five, casting this component becomes problematic as it would be challenging to remove the part from the casting tool without it getting stuck. Consequently, solution five fails to meet the requirement outlined in criterion nine, which states that the component must be castable (for further explanation, see Appendix [A.0.3]). Therefore, solution five is considered impractical and is subsequently eliminated.

Solution four receives a total score of 7+ and solution six receives a total score of 6+. Consequently, both solutions advance to the subsequent stage, where they will be integrated with a shift yoke and bushing point to form a subsystem.

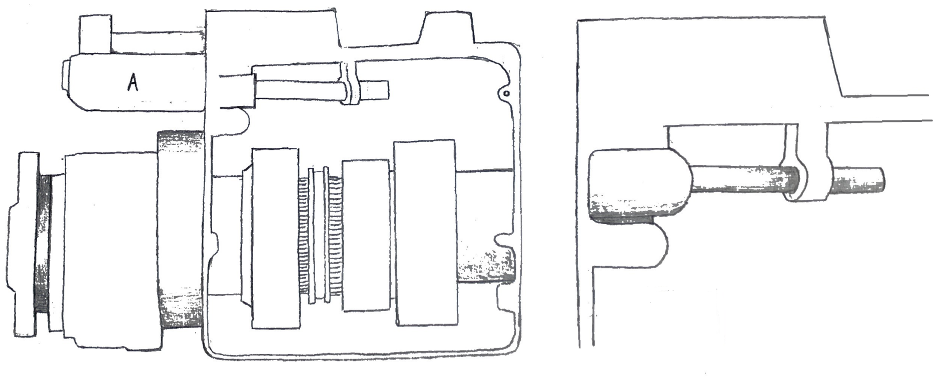
5.3 Evaluation of Bushing points

The following figures illustrate three solutions of bushing points, one of today's solution and two alternative bushing point solutions, that were evaluated towards the requirement specification for bushing points. For a comprehensive overview of the requirements and desires in the bushing point requirement specification (see Appendix [A.0.1.3]).

Figure 5.7: *Solution Seven - Today's Bushing Point*

Note. The bushing points in the figure above are specifically utilized in Volvo's EPT gearboxes. In the current design, there are two bushing points incorporated within the system. One bushing point is integrated directly into the gearbox housing, while the other is integrated internally within the actuator. These bushing points serve *to provide convenient and efficient placement for necessary components within the overall system architecture.*

Figure 5.8: *Solution Eight, Extended Bushing Point*



Note: Integrates one bushing point within the wall of the gearbox housing, similar to the current design. The second bushing point is attached to the gearbox housing using an extended arm that extends from the wall of the housing.

Figure 5.9: *Solution Nine, .*

Note.

5.3.1 Summary

Solution seven, today's bushing points, fails to meet criterion sixteen, which states the requirement for easy assembly (for further explanation see Appendix [A.0.4]). At this stage, it is not feasible to incorporate one of the bushing points within the electrical actuator, as was previously possible with the pneumatic actuator. Therefore, solution seven was eliminated from further consideration.

Solution eight, featuring an extended bushing point, does not meet the requirement stated in criterion fourteen, which states the need for ease of manufacturing. The current manufacturing process involves casting the gearbox housing as a single piece. However, casting the extended arm in solution eight would require a complex and costly casting tool, resulting in longer production times. Therefore, solution eight was eliminated from further consideration. Solution nine obtained a total score of 3+ and advanced to the subsequent stage, where it will be integrated with a rod and shift yoke to form a subsystem.

5.4 Combination of Components into Assembly

Among the available solutions, we have solution three, which involves the integration of two rods docked together. Additionally, there is solution nine, featuring bushing points integrated into the gearbox housing. Furthermore, solution four incorporates the current shift yoke design, while solution six is a shift yoke with a new design. Due to the incompatibility of combining solution four with the combination of solution three's two rods, solution four is eliminated from consideration.

Subsequently, the remaining components are assembled together to form a cohesive concept, which will be further explained and illustrated in the next chapter, Final Concept.

6
Final Concept

In this section, the final concept will be presented in detail with explanatory text and appendices. Since the concept consists of subsystems and several different components in relation to each other, the chapter will be divided according to these. In addition, the assembly of components will be further explained and also how these relate to each other.

6.1 Gearbox Housing

Figure 6.1: *Gearbox housing*

Note:

6.2 Actuator

6.3 Rod

6.4 Placement of Bushings

6.5 Shift Yoke

6.6 Assembly of Components

7
Further Development

In the Further Development section, possible areas of improvement for the final concept are presented. By areas of improvement, the report refers to parts or subsystems that could have been developed or optimized in the future construction of the concept. These areas of improvement were not taken into account when designing due to, among other things, lack of time and resources.

7.1 Gearbox housing

There are a few areas of improvement regarding the gearbox housing. One of these concerns the cabling that is located on the outside of the housing, (see Appendix [A.7]). Currently, the nozzle of this cabling is directed towards the actuator which prevents it's ultimate position. If the cabling would have been turned to the left, alternatively moved completely, the actuators associated components could have been turned. In this case, the roof of the housing could have been lowered and thus the space had been optimized. In addition, materials could also be saved.

7.2 Shift Yoke

Time was limited when constructing the shift yoke, thus an arbitrary optimization was performed. The optimized shift yoke meets the requirements and works perfectly for it's function. However, this could have been further developed and studied in more detail. In future development of the shift yoke, a possible change of material could have been implemented. The material could have been changed from cast iron to aluminium, for example. This would have resulted in a stronger and less brittle material. In addition, the shift yoke would have been less heavy.

8
Conclusion

After attempting to relocate the electrical actuator, it is concluded that a placement of the actuator is suitable in partially the same orientation as for the pneumatic one found on the existing gearbox. This relocation has entailed a redesign of the included components mentioned as rod, shift yoke, bushing points and gearbox housing.

The developed solution results in a potential saving of material on the gearbox housing as well as an easier assembly and attachment of the actuator. Also, the implementation of the electrical actuator enables movement by regulating current and variable resistance. Therefore, the force and movement can be fully controlled to suit certain application requirements. This type of system enables multi positioning which results in high accuracy and repeatability.

In case of future development and investigation of the final concept, an optimization of the shift yoke may be essential. Time was limited when constructing the shift yoke, thus an arbitrary optimization was performed. The material could have been changed from cast iron to aluminium, for example. This would have resulted in a stronger and less brittle material.

The conclusion of the bachelor thesis is that an implementation of an electrical actuator in a gear shifting system for light duty trucks is possible. The aim has thus been answered and confirmed.

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A

Appendix

A.0.1 Requirement Specifications

A.0.1.1 Requirement Specification - Rod

Criterion:	R = requirement, D = desire
C1 = Transmitting axial force $\leq 1000[N]$	(R)
C2 = Design for assembly	(R)
C3 = Cope with 3 millions of activation	(D)
C4 = Cope with temperatures -40 - +120 [°C]	(D)
C5 = Low purchase price	(D)
C6 = Low service cost	(D)

A.0.1.2 Requirement Specification - Shift Yoke

Criterion:	R = requirement, D = desire
C7 = Transmitting axial force $\leq 1000[N]$	(R)
C8 = Design for assembly	(R)
C9 = Castable	(R)
C10 = Cope with 3 millions of activation	(D)
C11 = Cope with temperatures -40 - +120 [°C]	(D)
C12 = Low purchase price	(D)
C13 = Low service cost	(D)

A.0.1.3 Requirement Specification - Placement of Bushing Points

Criterion:	R = requirement, D = desire
C14 = Easy to manufacture	(R)
C15 = Cope with temperatures -40 - +120 [°C]	(R)
C16 = Easy to assemble bushing into bushing point	(R)

A.0.2 Requirement Specification - Rod in Relation to Solutions

Criterion Requirement/Desire	C1 (R)	C2 (R)	C3 (D)	C4 (D)	C5 (D)	C6 (D)	Total
S1	+	-					1+
S2	+	-					1+
S3	+	+	?	+	+	+	5+

+ meets the criteria well
0 meets the criteria less well
- does not meet the criteria
? need to be tested

A.0.3 Requirement Specification - Shift Yoke in Relation to Solutions

Criterion Requirement/Desire	C7 (R)	C8 (R)	C9 (R)	C10 (D)	C11 (D)	C12 (D)	C13 (D)	Total
S4	+	+	+	+	+	+	+	7+
S5	+	+	-					2+
S6	+	+	?	+	+	+	+	6+

+ meets the criteria well
0 meets the criteria less well
- does not meet the criteria
? need to be tested

A.0.4 Requirement Specification - Placement of Bushing Points in Relation to Solutions

Criterion Requirement/Desire	C14 (R)	C15 (R)	C16 (R)	Total
S7	+	+	-	2+
S8	-			
S9	+	+	+	3+

+ meets the criteria well
0 meets the criteria less well
- does not meet the criteria
? need to be tested

Figure A.1: *Lid Concept*

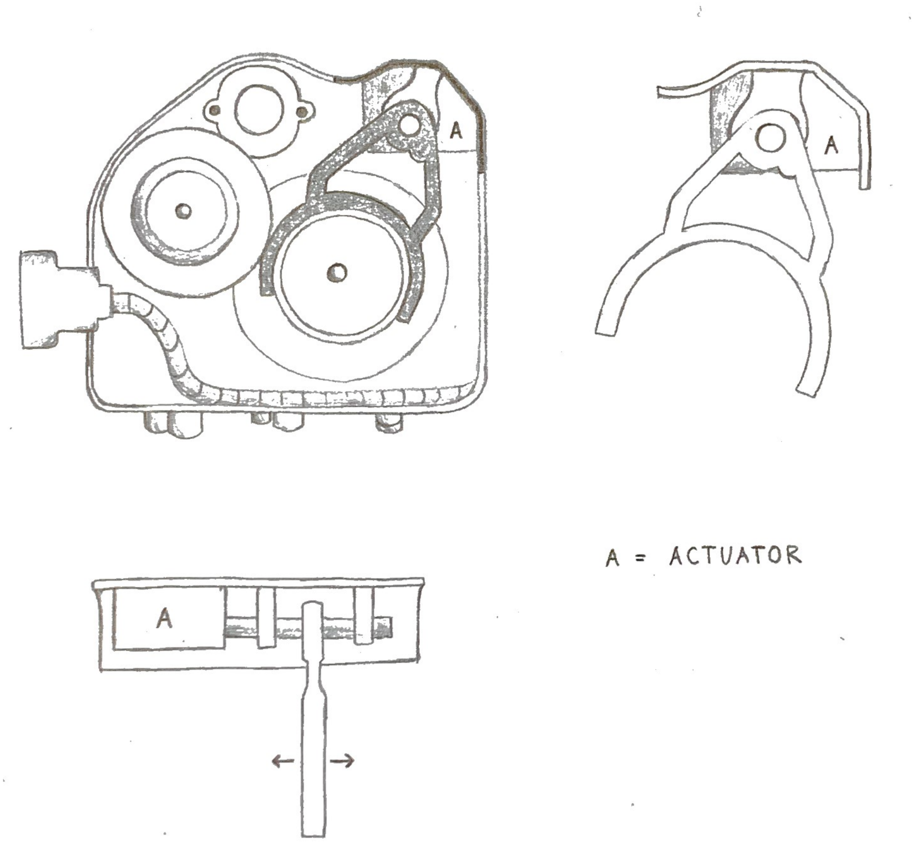


Figure A.2: *Enclosed Concept*

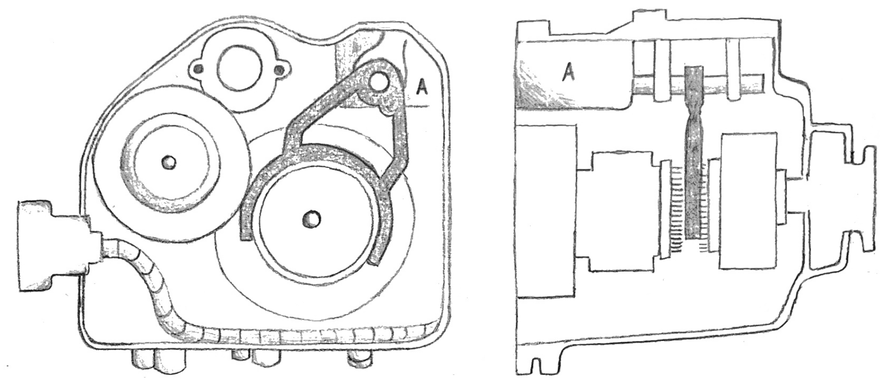
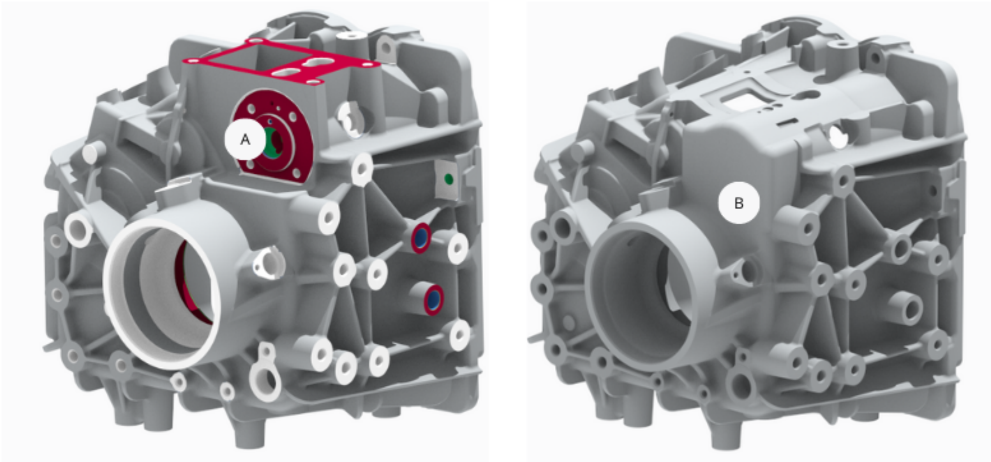


Figure A.3: *Reconstruction of Gearbox Housing*



Note: Symbol A shows the bulge that disturbs the actuator's position. Symbol B shows how the gearbox housing could have been reconstructed, after which material has been extruded.

Figure A.4: *Shift Yoke*

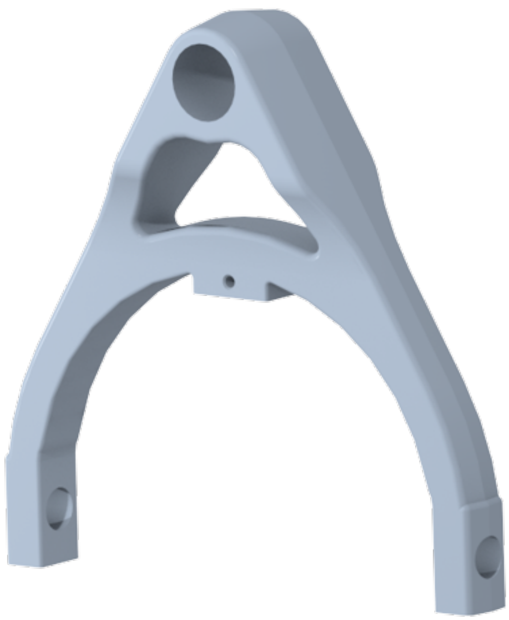


Figure A.5: *Gearbox*

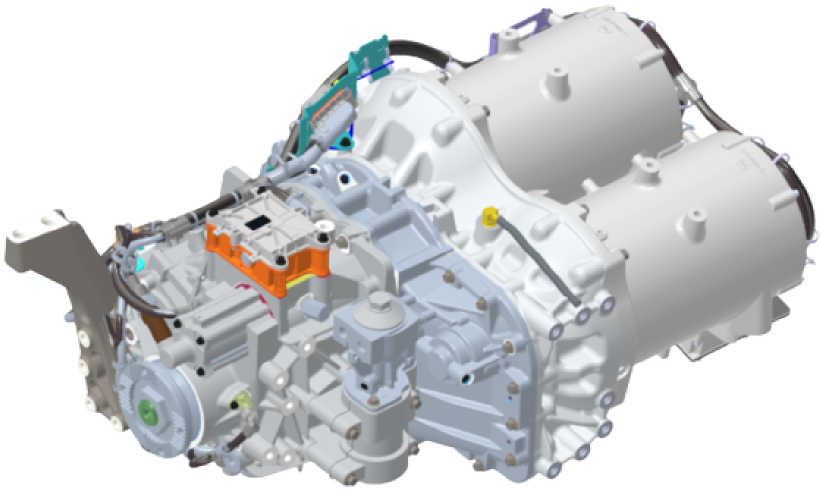


Figure A.6: *Placement of Electrical Actuator*

Figure A.7: *Further Development of House*

Figure A.8: *Drawing of Shift Yoke*

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