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Redesigning a hydraulic subsystem for a Volvo hauler, focusing on cost efficiency

Examensarbete inom högskoleingenjörsprogrammet TIMAL

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List of Acronyms

VCE - Volvo Construction Equipment

CAD - Computer Aided Design

CAM - Computer Aided Manufacturing

FEA - Finite Element Analysis

FEM - Finite Element Method

Abstract

The modern day hauler is a piece of heavy machinery used in moving large payloads within and between worksites. As the payload of the vehicle increases, so does the need for a robust and reliable hydraulic brake system, ensuring the safety of both the drivers and their surroundings. One of the companies working on producing and improving these machines are *Volvo Construction Equipment [VCE]*, who since 1966 have been in the forefront of engineering in this field. The aim of this thesis is to conduct a concept study for VCE regarding an upcoming design for a hydraulic system and to provide alternatives to reduce the overall price of the system, as well as the quality in regards to performance and leaks. The current design, serving as a reference to the project, includes a lot of complexities and has issues pertaining to the mounting of the system and the cost of production. This is due to several factors, including the narrow areas between components, overlapping parts, as well as the complexities of several valves and blocks. As the current design of the system is known, a reference for the layout and function is included, as well as an understanding of which functions are essential. Using the standards of product development and testing the systems layout and performance, this study explores a few different alternatives to the current concept by VCE and provides recommendations from the group, as well as aspects of the design that can be developed further by the engineers at Volvo. The proposed solutions have been put through a process of matrices and designed in the design program *CATIA V5*. In the end of the project a few results were concluded. Firstly a digital construction of the hydraulic system with modifications to the hydraulic distribution, layout and newly constructed blocks. This system is meant to serve as an inspiration for VCE to further develop their system in the future. Secondly two smaller concept studies were evaluated, where an attempt of moving a key component was made, as well as a concept replacing the hydraulic hoses with metal tubing. These concepts were deemed unfit for further development, serving as a concept study as recommendations to not develop further. Lastly a looser concept study was conducted to recommend the further development of an idea of merging several of the components in the design. This was never modeled, but serves as a recommendation to VCE for future research. Based on this investigation there are still factors that can be evaluated for further improvements. Thus, the results and discussion of this thesis may serve as a basis for what concepts that are and aren't relevant for future research.

Sammanfattning

Den moderna dumpern är en nyckeldel på många arbetsplatser, där dess kapacitet att förflytta stora laster är essentiell. När dessa laster ökar, gör även nödvändigheterna för hydrauliskt bromssystemen det för att försäkra säkerheten för föraren, såväl som dess omgivning. Ett företag som arbetar med att producera och utveckla dessa maskiner är *Volvo Construction Equipment [VCE]*, som sedan 1966 har legat i ingenjörskonstens framkant på denna branschen. Syftet med denna studie är att genomföra en pilotstudie för VCE angående en kommande design av hydraulsystemet till bromsarna och att ta fram alternativ för att reducera kostnaderna för systemet, såväl som dess kvalitet gällande prestanda och läckage risker. Den nuvarande designen som agerar som referens till projektet har problem gällande dess komplexitet, produktionskostnader och svår monterings procedur. Detta framkommer av ett flertal aspekter som trånga utrymmen mellan komponenter, delar som överlappar varandra och komplexiteten hos ett flertal ventiler och block. Då det nuvarande systemet är känt så har projektet en referens för dess layout, funktion och en förståelse kring vilka funktioner som systemet innefattar. Genom att använda en standardiserad metodik för produktutveckling och testa systemets utsträckning och prestanda, utforskar studien ett flertal olika lösningar som sedan kan vidareutvecklas av VCE. Detta kommer i formen av rekommendationer från skribenterna, såväl som delar av designen som kan vidareutvecklas av ingenjörerna hos Volvo. Dessa koncept har tagits fram genom ett flertal matrissystem och slutligen designats i *CATIA V5*. I slutet av projektet samlades ett flertal resultat: I första hand har en digital konstruktion av hydraulsystemet med de föreslagna modifieringar inom tryckfördelning, systemets sammanställning och ett flertal nya hydraulblock tagits fram. Sedan har två mindre konceptstudier utvärderats, där ett försök innefattar förflyttningen av en större komponent, såväl som ett koncept att byta ut hydraulslangarna mot metallrör. Dessa koncept kunde inte realiseras och ämnar därmed att stå som förslag för vad man inte bör handlägga för fortsatt undersökning. Slutligen så har en friare konceptstudie gjorts som rekommendationer kring vad man kan undersöka vidare. Denna inkluderar ihopslagningen av ett flertal block för att underlätta montering och produktion. Det sista konceptet har inte blivit konstruerat, men ämnar att vara inspiration för vidareutveckling för VCE. Baserat på denna studie så finns det där med faktorer som fortsatt kan utvärderas för vidare utveckling. Därmed så ämnar de resultaten och diskussionen av rapporten att agera som grund för vilka koncept som är relevanta och vilka som inte är relevanta för framtiden.

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1. Introduction

Volvo Construction Equipment [VCE], part of Volvo Group is a global enterprise that is continuously driving innovation within the world of heavy duty construction machinery. In their arsenal of products, their hauler models have been at the forefront of engineering since their introduction of the *BM-Volvo DR 631* in 1966 and they are still aiming to improve the capabilities of their products. The current-year designs include models such as the *A40G* and the *A60H* with the latter model having a load capacity of 55 000 kg and a maximum payload volume of 33,6 m³. When carrying these massive loads, the safety of both the driver and their surroundings is a huge priority and therefore an up to date system for the hydraulic brake system is a necessity. As the inner workings of the hydraulic system oftentimes can provide a high level of complexity, this may also provide exceedingly high costs for the production and assembly of the hauler.

In the current situation, a specific model of their haulers has come into focus, where its hydraulic system, connecting the machine's brake system, is to be evaluated for future improvements. To ensure that the system can be incorporated into the hauler, a few of the key design aspects have to be improved. This, in regards to simplifying it for manufacturing, assembly and service. As the current design yields high costs for both manufacturing and assembly as well as difficulties regarding service of the system, VCE has made an employment to conduct this case study to further develop what can be kept and what parts of the system that need reworking.

1.1. Project description

To improve the hydraulic system, a redesign of the system has been made. A few key points in the design have been focused on: *Reducing manufacturing cost, assembly cost and increasing serviceability*. Utilizing the standards of redesign and product development, the project focused on providing the company with recommendations on what to change about the design. The project is based on a 30 credit master thesis that has been limited to a 15 credit bachelor thesis.

1.2. Stakeholders related to the study

The stakeholders in this study are Chalmers University of Technology [Chalmers], Volvo Group and foremost Volvo Construction Equipment as well as the students who conduct the

study. Chalmers's main interest is to ensure the quality of their engineering graduates, making sure that they are ready for future working environments and able to provide a service that will keep the university and its education in high regard. Chalmers interacted with the project through a supervisor, providing advice and input during the project's span and with the final examination. Volvo group's and Volvo Construction Equipment's interest is ensuring the quality of the result from the study as they possess ownership of the results. It is therefore in their interest that the case study is useful both for this model, and as a reference for future work, thereby hopefully providing a revenue generating product for the company.

The interactions from Volvo were conducted through supervisors from VCE, who through the whole project interacted by providing input, information and guidance from the company. They also assisted with calculations akin to cost and assembly time, as well as models, standards and similar information relevant to the study. The students main interest in this project was to make a qualitative report, providing grounds for graduation, as well as a monetary compensation from VCE at the project's completion and future references as they venture out in the labor market.

By identifying the different stakeholders it was possible to get a better understanding of who and what affected this study and in which way. For example both Chalmers and VCE have their values and principles which influenced this study.

1.3. Aim

The aim can be defined by the help of the 5W1H method by answering the questions: What? Who? Where? When? Why? and How?

What?

The goal of the project was to create a redesign of Volvo's hydraulic system in one of their hauler models. The aim was a reduction in regards to costs, challenges with mounting and service, compared to the current design. In this however, it's imperative that the improvements in these key factors don't come at the cost of impairing the systems functions while adding functions that improve the overall product. The desired cost reduction from VCE was a decrease of 15%, this involves the components and the cost for assembly. The percentage decrease has served as a goal value for this pilot study, which in practice means

that the project has strived to reach the given value, however the success of the project hasn't rested on achieving that goal in its whole.

Once the new design has been completed, VCE will evaluate the concept for implementation into the system or further development. As this is a case study for the company, a finished analysis and design result is not expected. To achieve this the study needs to create a measurement system to compare the systems, create detailed CAD files and drawings of the new concept and specification of the materials and parts.

Who? Where? And when?

Two students at Chalmers have been working with the project and the study has been done in Gothenburg at Chalmers University of Technology. Where the work has been done remotely for VCE in Braås, with a few occasional visits. The study has been conducted during the spring semester, from February till June.

Why?

The project was conducted to create a better system than the current, which has problems with being overly complicated, taking up space and being slow to assemble. The goal was to construct a simpler system that saves assembly time, is more cost efficient and easier to maintain. The benefits aimed to result in a system that is cheaper, better and can produce more revenue. The new knowledge that has been a result from the study helps better understand the limitations and possibilities within the hydraulic layout for the machine. This aids the company in further development in the product, and also better grounds for development in future products.

How?

The study has been conducted through analysis of the current system. Doing a function analysis and finding new possible solutions which have turned into concepts. From there, a detailed construction and drawings can be produced.

1.4. Research questions

The scope of the project has been a pilot study for VCE to further develop the hydraulic system of their haulers. To achieve this, the following research questions have been evaluated:

How can the hydraulic system be simplified?

A cost reduction of the system can come from several independent factors. Both the material and manufacturing costs, as well as the assembly cost are affected by how complex the system is to work with.

How can a reduction in cost and assembly time be achieved by modifying the layout of the system?

The layout of the system is a vital point in how the different valves and connection points fit together. A change in layout may prove to be beneficial to manufacturing cost, the availability to provide service, as well as how simple the mounting process is.

What are the limiting factors that make the implementation of different concepts unsuitable?

As the evaluation of the product is conducted, the current concept is evaluated and broken down to subsystems. These subsystems have been further evaluated and used for the development of alternative solutions. To be able to produce a promising product, an understanding of what factors affect the suitability of these concepts are essential.

1.5. Demarcation

In this study, the frame where the system is mounted has not been included in any way. Neither have the internal designs and functions of the hydraulic directional valves, check valves, sensors and accumulators, as they are provided by other suppliers. There is also no regard to the aspects of vibrations, as it is outside the scope for the project. The electric controls are not included in this study.

This thesis is under a non disclosure agreement with Volvo Group. This implies that some information like numbers, values, pictures and other confidential material are not disclosed within the report.

2. Background

To get a good understanding of the problem and set a base level for the project the background defines tools of measurements, functions and demands.

2.1. Tools of measurement

To be able to measure and keep track of improvement in the design, a few parameters to compare between the systems has been deemed desirable. They are the following; assembly time, cost, reduction of number of possible leakage points (hoses), reduce weight and volume, and reduce the number of interfaces.

The assembly time and the final cost have been hard to know definitely but an estimation has been made with the help of resources at Volvo. Reducing leaking points is both reducing the number of hoses and also reducing the length of hoses, this also affects the cost. Reducing the weight and volume is beneficial in many cases, as it gives more room to other components, can reduce cost, and provides an easier assembly. By reducing interfaces the assembly time can be shortened, the system is easier to work with and diagnose.

2.2. Function

The system has a few functions that can be categorized in main function, secondary function and unwanted functions.

2.2.1. Main function

The main function of the system is to distribute pressure according to the hydraulic schematics. The system distributes inlet working pressure from one inlet through a number of hydraulic blocks, valves and accumulators to outlets. The majority of valves have electronic control. The system also returns fluid to the tank through a tank return block.

2.2.2. Secondary function

Secondary functions of the system are that it should be easy to assemble and service. There are a number of pressure sensors and electronic signals in the system. The system has a few measuring points that should be easily accessible. Another function is also the subframe which holds all the system components.

2.2.3. Unwanted function

An unwanted function of the system is the eventual need for service of the system. This can be done by ensuring fewer leakage points and mounting the different valves and blocks in a formation that makes maintenance easily accessible and avoids potential damage. The most usual forms of eventual service are replacements of hydraulic hoses and accumulators, as well as eventual adjustments done to the valves.

2.3. System reference

As a reference for the project, VCE has provided the current installation design of the hydraulic system to be analyzed and used as a reference in the development of the project.

Today's system contains eight hydraulic valves and six one liter diaphragm accumulators, one placed in the front of the system and five in the brake accumulator block in the back of the system. As the redesign of the system does not adhere to the imported valves and blocks, their functions are not relevant for discussion, given that they all are included in the new design. The function of the accumulators is the conservation of pressure in the case of larger hydraulic fluid flows. This can happen during situations such as a short distance stop for the vehicle, where the accumulator ensures that enough pressure is applied to the brakes to stop the hauler. There are 25 hydraulic hoses connecting the valves and blocks to the different brake systems. The mass is estimated at 23,7 kg, with a volume of 20 dm³ excluding the inlet pressure hoses, tank return hoses, and hoses that pass through to other systems. The component cost and assembly time has been estimated by VCE but as it is confidential information it will not be presented in the report.

As specified by VCE, this system will serve as a reference during the process of generating a new product, as well as a base measurement performance-wise.

2.4. Specification of criterias

The new design aims to meet the criterias and wishes that is specified in appendix 1. In the list, the demands are marked as either a criteria (C) or a wish (W). The criterias must be fulfilled and the wishes should be met in as high regard as possible. The wishes are ranked of importance on a scale from 1 to 5, where 1 is lowest and 5 is highest.

According to ISO 4413:2010, a hydraulic system shall be able to withstand higher pressure than the working pressure to some degree (Svenska Institutet för Standarder [SIS], 2010). The standard safety factor for hoses is 1:4 (Tubes international.com, n.d). and for the hydraulic block a slightly higher safety factor of 1:5 is adapted. This is so that the hose is the breaking point in case of a pressure spike, since it is easier and cheaper to change a hose than a hydraulic block.

In the list of demands, strength requirements and the environmental conditions that the system will be working under is specified. Aesthetic criteria such as markings on the blocks are specified according to ISO 16874:2004 (Svenska Institutet för Standarder [SIS], 2004). VCE have also provided a stp file that describes the maximum allowable volume for the system, shown in appendix 2 are a drawing of the given space claim.

3. Materials and methods

Following are hardwares, softwares and methods that have been used within the project.

3.1. Hardware

The hardware used for the project include the student computers located at *Chalmers university of technology*, as well as the personal computers of the thesis writers. The usage of the university's computer was essential to the project, as the licenses and software can be found on them, as well as the necessary processing power to run the heavier construction and design software. The use of the hardware where important to being able to run the necessary software to answer the research questions. With the help of the hardware it was possible to achieve results quicker and with more accuracy than without it.

3.2. Software

In this project, two different programs have been used to reach the resulting conclusions.

Firstly, within the concept generation, the usage of the program *morpheus* was utilized to compile all the possible solutions in a concept catalog. This is done by entering all the partial solutions for the desired functions into the program and defining which of the concepts are mutually exclusive. Thereafter, the program computes all the possible combinations of the different concepts, and presents them in a concept catalog. *morpheus* made the concept generation easier and faster. By using the software instead of doing it by hand, mistakes could be avoided in the Morphological matrix.

The usage of CATIA V5 was to view and analyze the current installation of the hydraulic system as well as the construction of the new products as well as the final concept and its complete assembly. To produce the desired concept, two different categories of the program were used: *Mechanical Design* and *Shape*. The mechanical design included the construction of the new blocks and subframe in the *Part Design* function, the *Drafting* tool to create the sketches for both the components and the whole system, and the *Assembly Design* to mount and assemble all the different components together. The *Generative shape design* function was used for the generation of all the hydraulic tubing, hydraulic hoses and the electrical wiring for the different valves in the system, to visualize the connection of the parts. The

choice of CAD software is motivated by the education at Chalmers mostly emphasized on CATIA V5 and that it is the standard software at VCE. The use of CATIA V5 simplified the process with the construction due the prebuild knowledge within the system and the non existing software barrier between the project and VCE.

3.3. Methods

The methods that have been used in this project can be described in three separated categories; understanding the problem, concept generation and concept construction.

3.3.1. Understanding the problem

To develop an understanding of the problem, consultation with VCE was made early on. Also CAD files of the current system were opened and analyzed in CATIA V5. This resulted in the possibility to set up tools of measurements and the underlying understanding of the problem at hand. By generating a good understanding of the problem it is easier to see what areas are important to the questions that shall be answered.

3.3.2. Concept generation

The concept generation was started in analysis of the function of the current setup with the help black box model and a function tree. A black box model showcases how different partial systems make up the system and how they interact with one and other. The function tree displays the separated parts from each partial system. An effort to try and simplify the system was put through before the new solutions to each partial system was created. Since some solutions to the partial solution could be deemed to not achieve the criterias and demands of the product, they could be eliminated before the morphological matrix. The rest of the partial solutions were run through the morphological matrix to achieve a concept catalog with a combination of all the partial solutions.

The concept elimination took the concept and compared them through a pugh matrix. The pugh matrix evaluates the different concepts if they are better, worse or even with a concept that is chosen as the reference. After three iterations of the pugh matrix, the concepts that had the lowest ranking were discharged. This was based on the standards of product development presented by Johannesson et al. (2013).

3.3.3. Concept construction

The concepts that were not discharged after the pugh matrix, normally would be run through a kesselring Matrix but due to lack of knowledge they needed to be constructed. The construction was made in CATIA V5 part design, assembly design and generative shape design. In the part design new components were made with the help of tools such as sketch, pad, hole etc. The newly constructed parts and the parts that were taken from the current installation were put together in assembly, where constraints could be applied and the layout could be positioned. Generative shape design was used to make tubes with the help of points and polylines. A sketch was made in a plane normal to the line, with the profile of the tube. The tool rib then ran that sketch through the polyline and created the tube. The process of creating hoses was the same as for tubes with one exception, spline was used instead of a polyline with a tangent in both ends.. The bending of the hoses are more similar to the shape of a spline with a tangent in both ends than to polyline. The construction was then rendered in CATIA V5 to help visualize it.

4. Concept generation

The concept generation is based on an analysis of the system reference, which defines the sub systems. A concept generation is made to find a new solution and through steps of elimination and a winning concept is established.

4.1. System reference function analysis

In [Figure 1](#) a black box function model can be seen. Even though valves, sensor and other prefabricated parts are not included in this study they are within the boundaries in the function analysis. This is because they are part of the main system, and to have them outside the boundaries would add a complexity to the diagram which would make it harder to read.

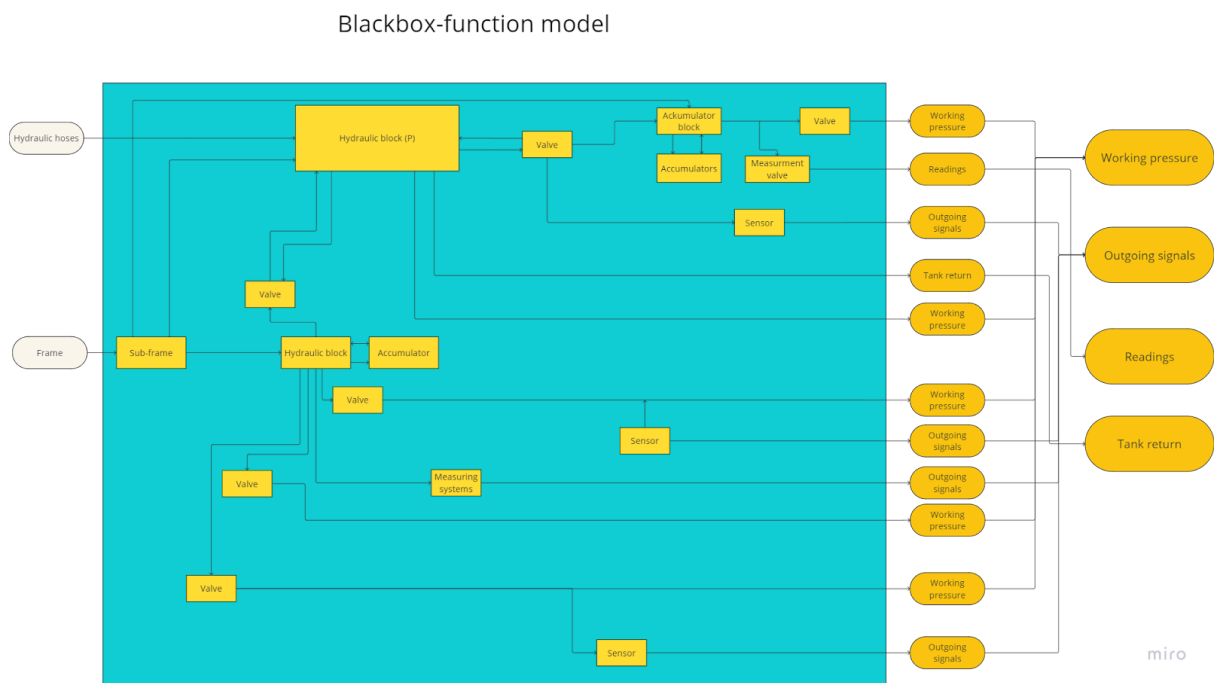


Figure 1. Black Box-function model.

From the function analysis, a number of subsystems can be seen. These include the working pressure connection block housing an accumulator, an interface block, a brake accumulator block on the backside, pressure sensors with signal lines, the subframe, hydraulic valves and the hoses that transport pressure within the system and across the boundaries. In [Figure 2](#) a tree diagram can be seen.

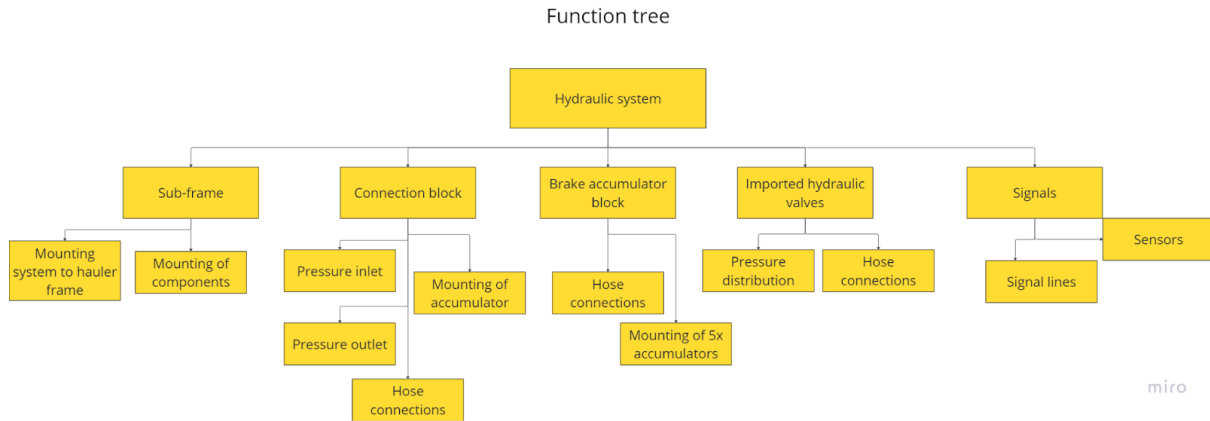


Figure 2. Function tree.

4.2. Simplification of the current installation

To achieve better concepts, the current installation is looked over for simplification of its content. In the current setup there are two different duplets of valves. It would be possible to combine the duplets into a one valve with bigger flow capacity, but because brakes are a necessary safety feature, there are redundancy demands. Therefore it is not possible to merge the duplets.

Another possible way to improve the current installation is to move the brake accumulator block that is on the backside of the hauler frame, to the front. This option needs to be evaluated in the construction of the concept, since it is hard to predict if it will be possible in advance.

4.3. Possible new solutions to the sub systems

The study mainly focuses on redesigning today's system and keeping the original functions. This while adding easy to assemble and increase serviceability, while decreasing the current cost for the overall process.

The idea generation process was started with free generation, resulting in what functions that were going to be tackled, as well as their solutions and the concepts aiming to fulfill the solutions presented in [Table 1](#).

Table 1. Morphological matrix.

Partial functions	Partial solutions	Partial concepts		
Layout	Layout simplification	Streamlined layout, left to right	Central connection	Today's layout
Pressure distribution	Ease of mounting and service and reducing leakage points	Hydraulic tubing	Hydraulic hoses	Mega casting
Connection block	Ease of mounting and streamlining hydraulics management	Split inlet, outlet and accumulator	Split accumulator from inlet and outlet	Inlet, outlet and accumulator in one block
Mounting method	Shorten mounting time per component	Bolted joint	Magnetic fastening	Clip fastening

When incorporating the different partial concepts, a resource asked to be considered by VCE is Poka-yoke. This is to be applied to all the concepts by themselves, and in the finished product as a whole to minimize potential errors in production, mounting and service.

Poka-yoke is in itself a production philosophy, focusing on error prevention by ensuring that components of a product or different products only fit together in one way. In their book 'ASQ Certified Quality Engineer Handbook' the author makes the example of a block with a square and a circular hole for placement of wiring, ensuring that the correct wiring product goes in the correct container (Laman, Scott A., 2022. page.330).

This process can be incorporated into this project to ensure that only the correct blocks and valves can be mounted at each place, as well as ensuring that all hoses only have one compatible way to be connected between them.

4.3.1. Layout

This category specializes in optimizing the layout of the different component blocks, mounted on the subframe. The reason why this is relevant is both to evaluate the complexity and manufacturing cost of the subframe and make component placement and maintenance easier and clearer. This can be tied back to the tools of measurement, specified in the background as a different layout may lead to a decrease in manufacturing cost, as well as ease of assembly and service. The solution to this function is *layout simplification*, where three partial concepts have been developed to provide different alternatives for construction.

a) *Streamlined layout, left to right*

The streamlined alternative for the layout bases itself on letting the flow of the hydraulics pass through the block in a clear start- to end-fashion. This is achieved by prioritizing the placement of the inlet and outlet channels on separate sides of the block. In this case placing incoming hydraulic fluid at the left side of the block, while letting the outlet working pressure exit at the right side of the block.

This can improve the spacing of the components, as well as ease the process of mounting and service by clarifying the general areas where the pressure distribution system will be headed.

b) *Central connection*

A central connection aims to ensure one singular connection point where all the components' respective pressure distribution system will be assembled. This is deemed a relevant alternative to pursue, as a central connection point can lead to a decrease in both the amount of connections, as well as the length of the hoses/tubing connecting the components to the connection block.

c) *Today's layout*

This partial concept aims to be a reference to the new concept, as to ensure that the change in layout doesn't make the block less suitable for implementation. In this case, the layout is described by the .stp file provided by VCE and using the system described under the caption 2.3 *System reference*.

4.3.2. Pressure distribution

Pressure distribution focuses on simplifying the distribution and the assembly of its parts.

Varying options for the distribution can be brought into light, where each one has its pros and cons. The options for this partial function are hoses, tubes and mega casting.

a) Hoses

The current system uses hoses for the pressure distribution. Hoses are easy to order since they are ordered by length and many different suppliers are available. Hoses also have the advantage of being flexible which is important if there is bending in the hose. One drawback is that hoses can be unfavorable during assembly because of the possibility of them being fitted wrong since they are flexible.

b) Tubes

Tubes are stiff and have the advantage of being manufactured for a specific path which makes assembly easier. Tubes can be routed in more constricted ways which can make the system more compact. Another aspect of tubing is that the pre bended tubes can eliminate the need of angled fittings on the components which reduces components in the system.

c) Mega casting

By doing a mega cast of the whole power distribution system and subframe will reduce assembly time significantly. This is because there is only one part that needs to be bolted on to the hauler and the valves can be fitted directly to the cast.

4.3.3. Connection block

One aspect of the current setup is the connection block which contains the working pressure inlet, tank return and one accumulator. A few suggestions to improve the system and streamline the layout include: keeping the current block, splitting it up into three separate blocks (Inlet, tank return and accumulator) and splitting it up into two separate block (Inlet together with tank return and accumulator)

a) *Three blocks*

By having three different blocks the layout can be simplified and the need for overlapping pressure lines can be eliminated. A negative aspect of this is the addition of two new components to mount and the price for machining three separated parts.

b) *Two blocks*

With two blocks there is still great potential to streamline layout and also keep the amount of components lower, and therefore price and assembly time compared to having three blocks

c) *One block*

Today's system has the lowest number of parts but it causes the need of overlapping hydraulic pressure lines. Thus, the layout provides difficulties in the assembly as well as in the situation that the system needs service.

4.3.4. Mounting method

The mounting methods for the different components is an aspect that may be worth evaluating, as it can provide a decrease in assembly time for the block. It is however important for this criteria that the improvement in time doesn't come at a cost to the overall cost of the manufacturing and materials for the block.

a) *Bolted joint*

The bolted joint method is the current method applied to the system reference. In this case, the components are mounted by fastening a bolt through a hole in the sub-frame, into a thread in the component block, acting as a screw-nut in this case. This can be quickly assembled using an impact wrench.

b) *Magnetic fastening*

An alternative for minimizing the assembly time is to outfit each of the component blocks, as well as the subframe with a strong permanent magnet to hold the component in place. This will provide a quick way to assemble, or disassemble the

block, for mounting and service purposes, as no screwing or further handling will be needed for either process.

c) *Clip fastening*

A similar processing effort alternative to the *magnetic fastening* is done by replacing the bolts with a clip-in alternative. This can decrease the assembly time, as no further handling in the form of screwing or bolting is needed. Some issues that can be noted is that depending on the weight of the components, a decrease in the structural hold between bolting and clipping the component in can be substantial, as well as a potential increased complexity in removing the component can be seen.

4.4. Elimination of concepts

Provided that some concepts generated in the free idea generation phase aren't realizable, an elimination of these concepts must be made. In this case, three different concepts were deemed to be unfit for further development.

a) *Pressure distribution - Mega casting*

While the mega casting is inventive, the problem is the technology is not suitable for this use since the hydraulic system is on a small scale and it would not be cost efficient to develop the tools and competence for this application.

b) *Mounting method - Magnetic fastening*

The magnetic fastening method of component mounting was analyzed for the project and deemed unfit due to several points of contention. Namely the problems arising with having a magnet that's either too strong or too weak. A weaker magnet may not suffice due to forces from the hauler moving being able to knock the components down from the subframe. A stronger magnet however may provide issues with dismounting the product from the subframe in the case that service needs to be done or a part needs replacement. Magnets holding the components may also provide a risk of crushing during the mounting phase as well as during eventual service, putting the factory workers, as well as the service engineers at a greater risk of injury.

The price of this method will typically be higher than using the standard bolted joint, meaning that the price of the product will increase, working against the goal of lowering production costs.

c) *Mounting method - Clip fastening*

The clip fastening method suffers similar problems as the magnetic one, as the structural integrity of the system may be worsened with clips, as compared to joining the components with bolted joints. It also entails that components for mounting still have to be added to the individual valves, which may increase the assembly process.

4.5. Comparative process

During the comparative process, the different concepts are produced and then ranked in a series of matrices presented below.

4.5.1. Morphological matrix

The remaining solutions are put into a morphological matrix presented in [Figure 3](#). The result is 18 solutions which can be seen in the appendix 3.

Sub-Functions	Sub-Solutions		
Layout	Streamlined layout, left to right	Central connection	Today's layout
Pressure distribution	Hydraulic piping	Hydraulic hoses	
Connection block	Split inlet, outlet and accumulator	Split accumulator from inlet and outlet	Inlet, outlet and accumulator in one block

Figure 3. Morphological matrix after elimination.

4.5.2. Pugh matrix

The original design was chosen as the first reference and kept in the matrix to ensure that the new design's performance is as good, or better than the original design. Three iterations of pugh matrices were made and these can be seen in appendix 4.

For this matrix, the following criteria were chosen: *Manufacturing cost, Assembly time, Serviceability & Poka-yoke*. The chosen criteria were chosen based on the list of demands produced earlier in the project, to ensure the relevance of the improvements. The concepts

that were deemed appropriate for further development are: *Concept 11*, *Concept 14* and *Concept 17*.

After final analysis of the three concepts the decision to remove *Concept 11* from further development, as it resulted in several hoses passing tightly over each other. With only two concepts left, a decision to further develop the remaining solutions was made, making the Kesselring matrix unnecessary.

5. Winning concept

As they were given a similar ranking, *Concept 14* and *Concept 17* were chosen to be further developed. These designs both incorporate a separation of the connection block and accumulator block, for ease of access and a simpler layout, as well as a rearrangement of the components into a more streamlined configuration. What separates the concepts is the chosen method of pressure distribution. *Concept 14* keeps the current solution of using hoses to transport the hydraulic fluid between the different subcomponents in the block, where *Concept 17* utilizes metal tubing for the distribution.

As both concepts provide different pros and cons, they have both been further developed and analyzed in this project and presented to VCE as potential solutions. These concepts will serve as inspiration for the company to produce a finished product for their haulers in the future.

6. Refining the final Concept

With new information from VCE that the hoses need to be a minimum of 300 mm and have a clearance of 25 mm in all directions, to allow flex, tolerances and avoid chafing. The tubing also provided some problems due to the stiffness and tolerances, as it puts constraints on the surrounding parts during assembly. To get around this, the components that are connected through tubing must have one component that is stiffly mounted and the surrounding components have to be able to slip slightly to ensure that the system isn't overconstrained. This has been achieved by mounting the connection block in a stiff configuration, while the surrounding system is mounted in elliptical holes to be able to adjust its position.

It was clear that for the streamlined layout to work, a mix of hoses and tubing was needed, to achieve near spacings of components. This will make sure that short tubings can be put in place and the hoses allow for tolerances and makes it possible to construct the concept without over constraints. Therefore the two different finishing concepts were merged into one concept.

7. Construction of concept

Construction of the concept started with the evaluation of the potential of placing the brake accumulator block at the front of the subframe. It was possible to fit all components in the front with enough space to enable service to the system. However problems arise as a consequence of the hydraulic lines. Since the brake accumulator takes up a lot of space and puts the other valves in an awkward position, the only possibility for the hydraulic lines is using metal tubes. This is due to the distance between components being less than 300 mm and involves a geometry with turns and bends that the hose deflection will not allow for. The usage of this many tubes to the same component creates an issue where the assembly most likely will be overconstrained. This increases assembly time, the complexity of the subframe and the production cost, making service harder. Therefore, the concept of moving the brake accumulator block to the front was deemed unsuitable for further development.

For the construction of the new blocks and subframe, the dimensions as hole spacing, wall thickness, thickness of the subframe was taken from components in the current installation. The application of hoses and tubing in the construction was made so the tubes would not lock the assembly. Tubes are constructed so they only put constraints in the two dimensions that are within a plane parallel to the subframe. The newly constructed components (see [Figure 4](#), [5](#) and [6](#)) were constructed to fit the desired layout and assembled together with the remaining valves, blocks, wiring and hydraulic distribution system.

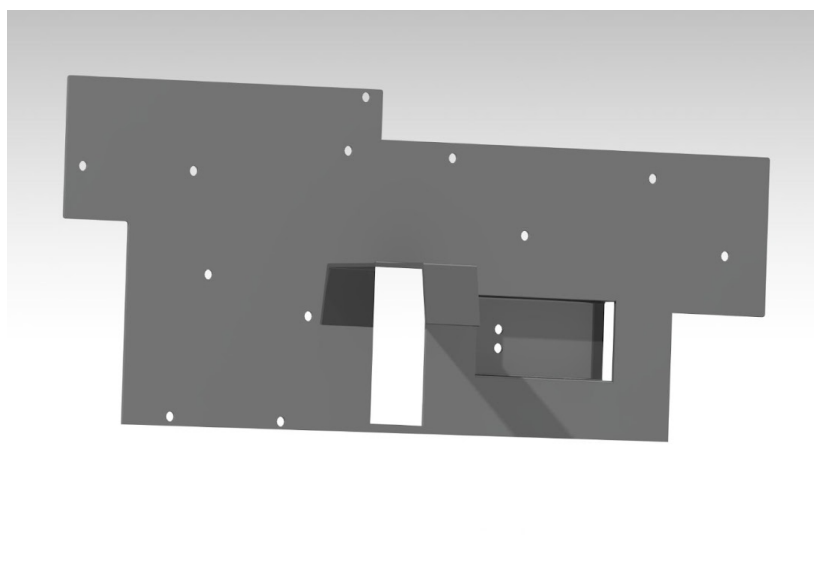


Figure 4. Rendering of the new subframe

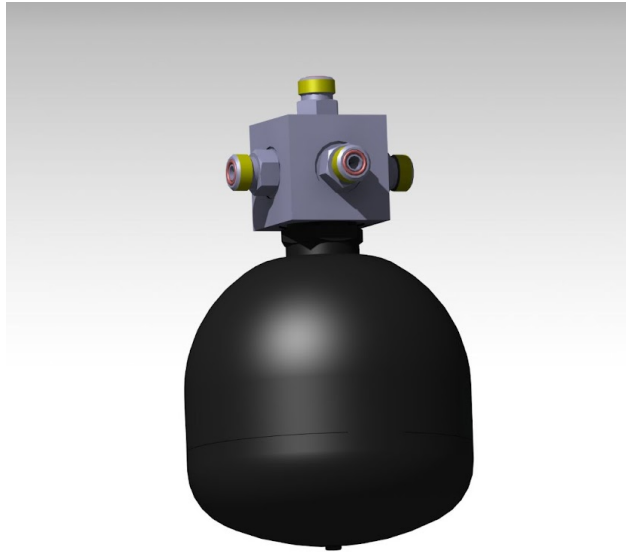


Figure 5. Rendering of the new front accumulator block

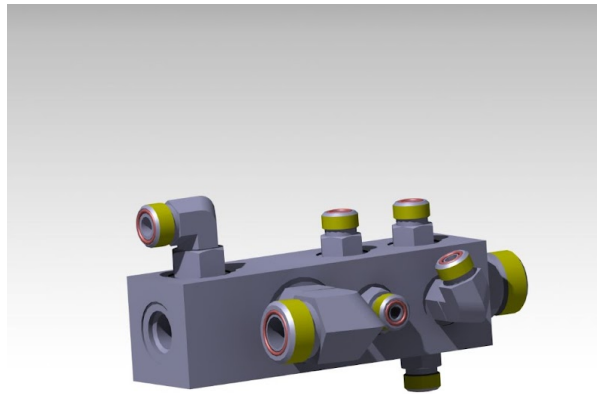


Figure 6. Rendering of the new connection block

Due to lack of time the construction of the concept was limited to a visual representation of the functional model. This means connections, distances, and mounting is not determined. The main objective with the concept is to ease the discussion about possible improvements, with this concept, while also forming the basis for further construction.

7.1. Reanalysis of the current installation

With the new information and knowledge about the system, a comparison is made with the current system. The current installation has a number of problems with short hoses, chafings between hoses and clashes. The clashes both exist between connections, electric harnesses and within the parts such as between nipples.

8. Results

With the concept generation and construction measures finished, a result was compiled in the form of a newly designed hydraulic system. The system consists of several new designs as well as a few valves and dimensions imported from the original design. The new designs include a restructured subframe, fitting the improved and streamlined layout of the system, as well as a block for housing and connecting the different components to the accumulator and an improved connection block, leading the pressure into the system, but also connecting the different valves to the tank return. As the demarcation states that the project doesn't concern the imported valves and systems, not developed by VCE, they remain with the same functions and inputs. However a few smaller changes in their layout has been made, including the placement on the subframe, as well as which ports are active, for an assembly with a lesser complexity. These blocks and valves include two pressure reducing valves, the front diff lock valve, two parking brake valves and the front electric brake valve. The interface block, constructed by VCE has also been left unchanged in the project, as it serves a key role in distributing the hydraulics from the system outwards the the haulers brakes.

The concept developed in the project displays a few key improvements, tied to the aim of the project, as well as a few notes that either have not been changed or have not been analyzed. Tying back to the three key notes from the project description (*Reducing manufacturing cost, assembly cost and increase serviceability*), the following improvements have been assessed:

The newly constructed design contains no clashes as a result of hoses. A reduction in the system's total volume has been made. No significant improvement has been made in regards to the manufacturing cost of the system. The amount of potential leakage points have been reduced by replacing four of the hoses with metal tubes, lowering the risk of leakage in eight points. The front accumulator has been placed at the front of the block to provide easier access. The assembly time for the system has not been analyzed, as the current data is insufficient to make assumptions.

An estimation of the relevant properties for the system has been made, including the volume and weight, as well as the amount of larger components (valves and blocks), tubes and hoses. The final concept is estimated to weigh 18,6 kg with a volume of 19 dm³ and nine larger components including three blocks and six valves. To distribute the hydraulics, the system

includes 17 hoses and four tubes for the shorter connections. The final render of the concept presented in [Figure 7](#), displays the hydraulic system with all the hydraulic distribution and their path. Note that due to the confidentiality of a lot of products, such as the valves constructed by external producers, they have not been included in the rendering.

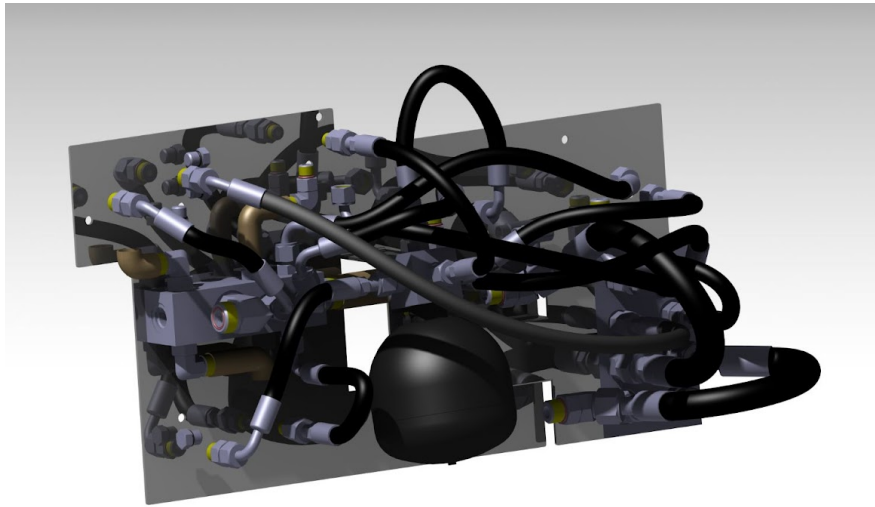


Figure 7. Rendering of final system

To be able to see the layout more clearly, a second rendering without the hoses and nipple connectors to the hidden valves was made (see [Figure 8](#)). Mounted on the subframe, from left to right, we can see the connection block and the metal tubing distributing the pressure to the surrounding valves, as well as taking in the returning pressure to the tank return. To the right of the connection block, the accumulator block, distributing extra pressure to the surrounding valves at need. Lastly, to the furthestmost right end of the subframe, the interface block is shown. This block connects all the components that pass through to the break accumulator block in the back, as well as surrounding hydraulic systems.

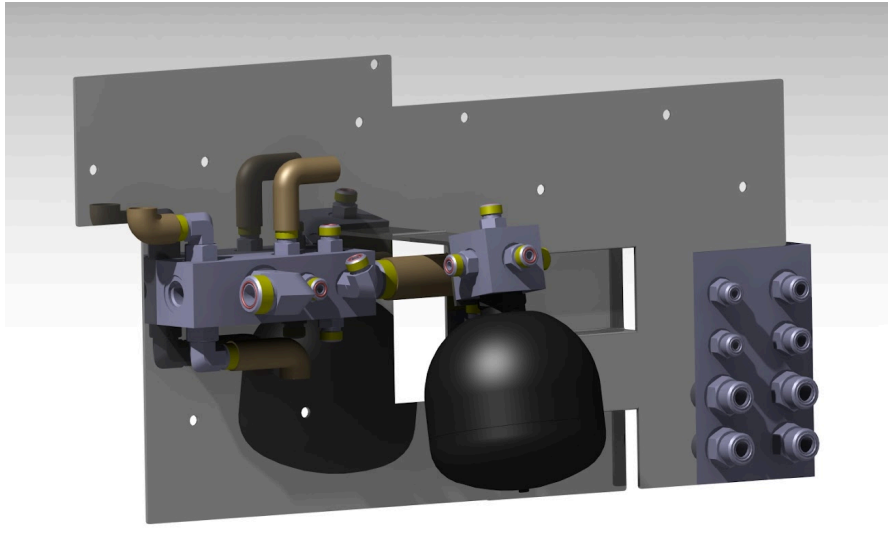


Figure 8. Rendering final concept without hoses.

9. Discussion

The three main points, serviceability, cost and assembly time, don't differ in favor of the new installation much. Due to the decision to split the front accumulator block from the connection block, costs have been increased by having two blocks, the same as for assembly time. These changes on the other hand also decrease assembly time since the layout is simplified and poka-yoke has been implemented. By inserting tubes for the high pressure inlet and reducing the length of many hoses also decreases the cost. The repositioning of the front accumulator has been changed and more accessible, also the angle of the accumulator has been decreased which ease the changing of it. Both weight and volume has been able to be decreased in the process, which result in a more compact design. Further analysis and work needs to be conducted to ensure a complete comparative process.

Concerning the new parts, neither flow, bursting pressure nor strength have been calculated. Since the dimensions have been brought over from the current installation, it can be said with enough certainty that the new parts would meet the standards of the previous installment. After a consultation with the supervisor at VCE, a standard to keep the load bearing components to at least the same dimensions as their concept was established. Thus ensuring that the new concept would be similar in stability, if not stronger. The reasons why neither calculations nor analysis through FEA and FEM have been conducted is due to the lack of time in the end phase of the project, leading to the prioritization of finalizing the construction. This is also the case for the simulated manufacturing of the newly constructed hydraulic blocks through CAM.

The reason the results don't line up with the expectations is due to a number of factors. The first factor is the time limitations. Since the original project was a master thesis scaled down to a bachelor thesis, demarcations were put in place to help scale down the project but limited the possibilities of the solution. It is very plausible that a better solution can be achieved with modifications to the frame and the hydraulic components that are provided by external suppliers. Another big factor was the lack of experience and knowledge within hydraulic lines, such as tolerances for tubes, deflection of hoses and awareness of the assembly procedure in question. This results in a lot of the project time being invested in acquiring the necessary competence, and when new information was attained it meant parts of the process needed to be reworked. Such instances were for example the length requirement of the hoses,

hose chafing and tolerance necessities with the tubes. During the timeline for the project the construction of the concept started in the latter end, as the product development methods that had been adapted inquired the working flow through problem definitions, problem solutions, concept generation and matrices. The point of waiting with the construction is to avoid a bias in the development, and keeping all concepts on the same level of detail.

One thing that also affected the outcome of the study is the hesitation to broaden the scope of the project, and a focus on the assembly and production point of view for the concepts. This resulted in small and easily realizable solutions at the cost of a broader potential in innovation.

9.1. Reliability of method

The method that has been used for the construction and generation of the concept has worked well. They are common practices for these types of projects and there has been no fault in them. On the other method for understanding the problem, a few points could have done better. First, getting knowledge with the standard workflow at VCE and firsthand experience with the assembly work of similar products. Also interviews with both the assembly workers and the planners could have been implemented to get a better understanding of challenges with assembly.

9.2. Discontinuation of investigated concepts

Tying back to the research questions, a few factors came forward during the concept generation, regarding the limiting factors for implementation. The three partial solutions, including *Mega casting* for the pressure distribution and *Magnetic fastening* and *Clip fastening* regarding mounting methods were eliminated during the concept generation. The removal of the partial solutions were due to the cost of producing said concept or due to issues with structural stability, as well as an inflated risk of injury.

The three concepts that were of interest to this project were the investigation of alternative placements in regards to the brake accumulator block, positioned behind the subframe, the possibilities of incorporating a tighter design with the use of metal tubing between the different valves and blocks, as well as a central connection based layout.

An evaluation of whether the brake accumulator block could be positioned at the front of the system was conducted, where it was deemed unfit for further development. As the block took up a large amount of space, the desired maximum volume for the system was surpassed and the construction of the subframe, as well as the connections would prove to be far too complex to be realizable.

To decrease the volume of the system, an attractive alternative was to replace the hoses in the system with metal tubing. A preliminary construction was made using this method, but was met with a few complications. The first issue was the manufacturing of the tubing, as the tight turns of the tubing would mean that bending the components would prove difficult and may result in an increased manufacturing cost. The second issue is that due to the high stiffness of the metal tubing, the tolerances would prove to be too narrow for a realizable construction.

The central connection layout, with the interface block to the right and connection block centralized, was rejected since the amount of hoses running through the same space, over the connection block, would make the conditions for assembly harder, increasing the risk of chafing. While also making the system more cluttered, make diagnosis of problems harder to achieve.

9.3. Possible future developments

Aspects to study further are to merge the interface block and the connection block into one product, and placing it closer to the center of the given volume. The positives of this is reduced cost with one block instead of two, and the center position of the interface block can reduce the overlapping of hoses. One disadvantage is the modification to the frame and the need to reconstruct other parts of the hauler. The inlet pressure could also be split by a tee connector rather than a hydraulic block, reducing cost and saving volume. Also merging the front accumulator with the brake accumulator block on the backside. By merging all accumulators they are placed in one space, allowing the service to the accumulators to be needed in one place, and reducing the cost of having two different accumulator blocks. The merging could be achieved by having both pressure-reducing valves flow merge in the interface block. The split the flow check valves can be put in the merged accumulator block. Another thing worth investigating further that has been overlooked in this study is to place the electric harness on the backside of the subframe. This would give more room for the hydraulic lines, and ease of assembly.

10. Conclusions

Tying back to the research questions from the introduction of the thesis, the simplification of the system, the layout and the limiting factors have been evaluated.

The simplifications in the system was focused on the blocks produced by Volvo. To achieve a simpler assembly and provide easier access to the components during service, the split of the accumulator block and connection block was central.

The analysis of the layout resulted in a less complex assembly, leading to a shorter appreciated assembly time and thereafter a reduced cost. However since the same components are present in all three layout designs, the cost of the material has not changed.

The conclusion is that further work needs to be conducted for the possibility of a promising solution. This is due in part to both the current installation and the concept from this study having a number of short hoses, risk of chafing and clashes between parts. Three concepts that can be excluded are the placement of the brake accumulator block at the front of the subframe, a concept where the whole pressure distribution is conducted with metal tubing and a concept with central connection layout.

A few concepts that may be of interest to VCE in the future include the merging of the connection block with interface block, merging the front accumulator block with the brake accumulator block, splitting the inlet pressure with a tee split, and placing the wiring harness on the backside of the subframe.

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12. Appendix

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Appendix 1 - List of demands

Chalmers	Dokument type Project	List of criterias Hydraulic Brake System				
Issuer: Magnus Andersson Einar Oldberg		Created: 2024-02-15 Modified: 2024-05-30				
Criterias	Target value	C/W	Importance	Verification method	Reference	
Functions						
Main	Distribution of hydraulic pressure according to hydraulic schematics	C		Test	Volvo Construction Equipment	
Sec.	Easy to assemble	C		Simulation	Volvo Construction Equipment	
Sec.	Easy to service	W	4	Simulation	Volvo Construction Equipment	
1. Performance						
1.1	Acceleration in Z direction > 4 g	C		Calculation	Volvo Construction Equipment	
1.2	Acceleration in other direction > 3 g	C		Calculation	Volvo Construction Equipment	
1.3	Working temperature Confidential	C		Calculation	Volvo Construction Equipment	
1.4	Corrosion resistant Withstand saltwater	C		Simulation	Volvo Construction Equipment	
2. Environment						
2.1	Shall not be on Volvo black or gray list	C		Control check	Volvo Construction Equipment	
3. Lifespan						
3.1	Lifespan Confidential	C		Calculations with Ansys	Volvo Construction Equipment	
4. Service						
4.1	Easy to adjust valves No need to remove other components	C		Test	Volvo Construction Equipment	
4.2	Change accumulators Easy access, an minimal risk of spill	W	5	Test	Volvo Construction Equipment	
4.3	Accessible measuring point	C		Test	Volvo Construction Equipment	
5. Cost of manufacture						
5.1	Max cost Current price	C		Cost calculation	Volvo Construction Equipment	
5.2	Minimize cost	W	4	Cost calculation	Volvo Construction Equipment	
7. Measurement						
7.1	See appendix 2	C		Calculations	Volvo Construction Equipment	
8. Mass						
8.1	Max weight for system 30 kg	C		Calculations	Volvo Construction Equipment	
8.2	Minimize weight <25 kg	W	2	Calculations	Volvo Construction Equipment	
8.3	Max weight per component 8 kg	W	3	Calculations	Volvo Construction Equipment	
9. Esthetics						
9.1	Correct markings on manifold	C		Test	ISO 16874:2004	
9.2	Easy to analyze for maintenance	W	4	Simulation	Volvo Construction Equipment	
10. Standards & obligations by law						
10.1	ISO 12100:2010 Safety of machinery – General principles for design – Risk assessment and risk reduction	C		Simulation	Standard	
10.2	ISO 4413:2010 Hydraulic fluid power – General rules and safety requirements for systems and their components	C		Simulation	Standard	
10.3	ISO 16874:2004 Hydraulic fluid power – Identification of manifold assemblies and their components	C		Test	Standard	
11. Ergonomics						
11.1	Safe assembly Minimal strain on workers while mounting to hauler	C		Simulation	Volvo Construction Equipment	
11.2	Safe for service and repairs	W	4	Simulation	Volvo Construction Equipment	
12. Safety						
12.1	Safety factor on hoses 1:4	C		Calculations	ISO 4413:2010	
12.2	Safety factor on hydraulic block 1:5	C		Calculations	ISO 4413:2010	
13. Assembly						
13.1	Lift mounts if components weight is over 8 kg	C		Test	Volvo Construction Equipment	
13.2	Poka-yoke Components can't be wrongfully installed	5		Test	Volvo Construction Equipment	
13.3	Assembly time < current assembly time	C		Test	Volvo Construction Equipment	

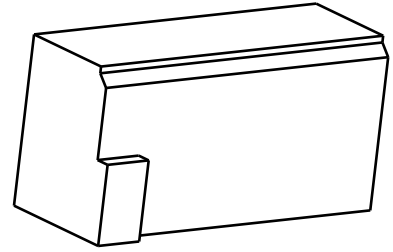
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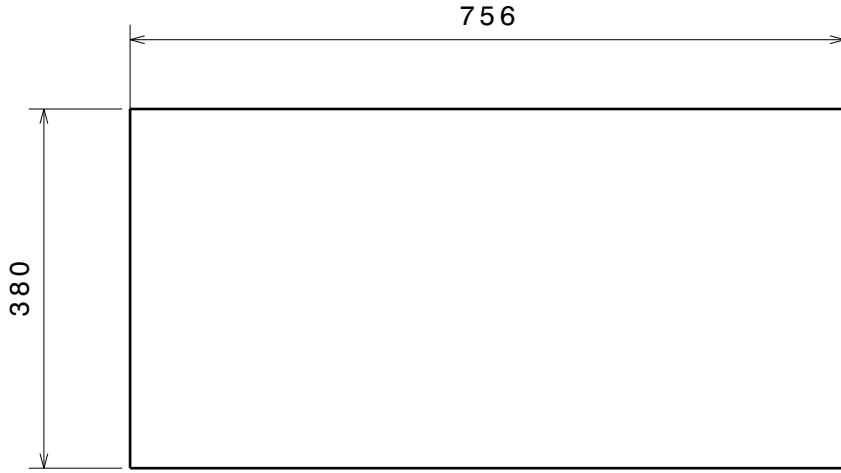
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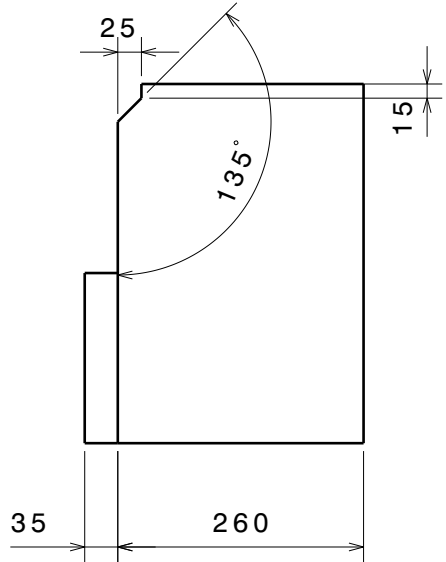
Appendix 2 - Maximum volume for system



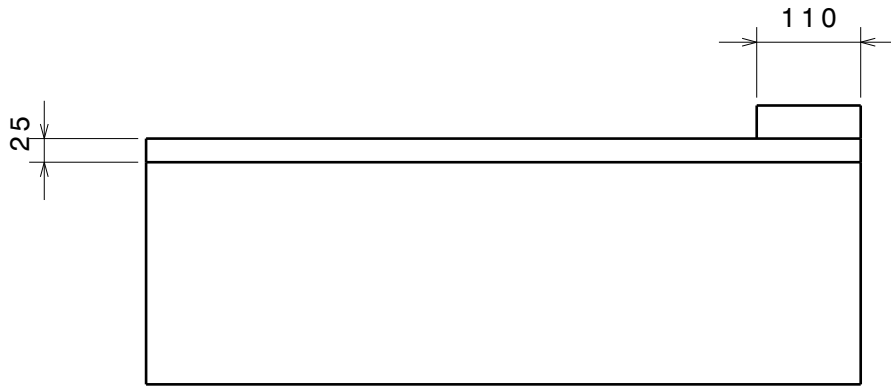
Isometric view
Scale: 1:16



Front view
Scale: 1:8



Left view
Scale: 1:8



Top view
Scale: 1:8

DESIGNED BY: Einar. 0	Ply Name	Maximum volume for system	I	-
DATE: 2024-05-26	Material	XXXX	H	-
CHECKED BY: XXX	Direction	XXXX	G	-
DATE: XXX	Thickness	XXXX	F	-
SIZE A4	SequenceID	XXXX	E	-
SCALE 1:1	GroupID	XXXX	D	-
			C	-
WEIGHT (kg) 74,87			B	-
			A	-

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D

A

42

Appendix 3 - Morphological Matrix

Name	Combination	Description	Sketch
Solution 1	Today's layout Hydraulic hoses Inlet ,outlet and accumulator in one block		
Solution 2	Today's layout Hydraulic hoses Split accumulator from inlet and outlet		
Solution 3	Today's layout Hydraulic hoses Split inlet ,outlet and accumulator		
Solution 4	Today's layout Hydraulic piping Inlet ,outlet and accumulator in one block		
Solution 5	Today's layout Hydraulic piping Split accumulator from inlet and outlet		
Solution 6	Today's layout Hydraulic piping Split inlet ,outlet and accumulator		
Solution 7	Central connection Hydraulic hoses Inlet ,outlet and accumulator in one block		
Solution 8	Central connection Hydraulic hoses Split accumulator from inlet and outlet		
Solution 9	Central connection Hydraulic hoses Split inlet ,outlet and accumulator		
Solution 10	Central connection Hydraulic piping Inlet ,outlet and accumulator in one block		
Solution 11	Central connection Hydraulic piping Split accumulator from inlet and outlet		
Solution 12	Central connection Hydraulic piping Split inlet ,outlet and accumulator		
Solution 13	Streamlined layout ,left to right Hydraulic hoses Inlet ,outlet and accumulator in one block		
Solution 14	Streamlined layout ,left to right Hydraulic hoses Split accumulator from inlet and outlet		
Solution 15	Streamlined layout ,left to right Hydraulic hoses Split inlet ,outlet and accumulator		
Solution 16	Streamlined layout ,left to right Hydraulic piping Inlet ,outlet and accumulator in one block		
Solution 17	Streamlined layout ,left to right Hydraulic piping Split accumulator from inlet and outlet		
Solution 18	Streamlined layout ,left to right Hydraulic piping Split inlet ,outlet and accumulator		

Appendix 4 - Pugh matrix

Pugh matrix 1																			
Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Manufacturing cost		-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	
Assembly time		-	-	+	-	-	+	0	-	+	+	-	0	+	+	+	+	+	
Serviceability	Reference	-	-	+	-	-	+	+	+	0	+	+	0	+	+	0	+	+	
Poka-yoke		-	-	+	-	-	0	+	+	+	+	+	0	+	+	+	+	+	
$\Sigma+$		0	0	3	0	0	2	2	2	2	3	2	0	3	3	2	3	3	
$\Sigma 0$		0	0	0	0	0	2	1	0	1	0	0	4	0	0	1	0	0	
$\Sigma-$		4	4	1	4	4	0	1	2	1	1	2	0	1	1	1	1	1	
Net value		0	-4	-4	2	-4	-4	2	1	0	1	2	0	0	2	2	1	2	2
Ranking		11	15	15	1	15	15	1	8	11	8	1	11	11	1	1	8	1	1

Pugh matrix 2																			
Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Manufacturing cost	+	+	+	+	0	-	+	+	+	+	0	-	+	+	+	+	Reference	-	
Assembly time	-	-	-	-	-	-	-	-	-	0	0	-	0	-	-	-		-	-
Serviceability	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-		0	0
Poka-yoke	-	-	-	0	0	0	-	-	-	-	-	-	-	-	0	-		+	+
$\Sigma+$	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1		1	1
$\Sigma 0$	0	0	0	1	2	1	0	0	0	1	3	0	1	0	1	0		1	1
$\Sigma-$	3	3	3	2	2	3	3	3	3	2	1	4	2	3	2	3		2	2
Net value	-2	-2	-2	-1	-2	-3	-2	-2	-2	-1	-1	-4	-1	-2	-1	-2	0	-1	
Ranking	8	8	8	2	8	17	8	8	8	2	2	18	2	8	2	8	1	2	

Pugh matrix 3																			
Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Manufacturing cost	+	0	-	-	-	+	+	0	-	-	-	-	+	Reference	-	-	-	-	
Assembly time	-	-	-	-	-	-	-	0	-	0	+	-	0		-	+	+	-	
Serviceability	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	+	0
Poka-yoke	-	-	-	-	-	-	-	-	-	-	+	+	-		-	0	+	+	
$\Sigma+$	1	0	0	0	0	1	1	0	0	0	2	1	1		0	1	3	1	
$\Sigma 0$	0	1	0	0	0	0	0	2	0	1	0	0	1		0	1	0	1	
$\Sigma-$	3	3	4	4	4	3	3	2	4	3	2	3	2		4	2	1	2	
Net value	-2	-3	-4	-4	-4	-2	-2	-2	-4	-3	0	-2	-1	0	-4	-1	2	-1	
Ranking	7	12	14	14	14	7	7	7	14	12	2	7	4	2	14	4	1	4	

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