CHALMERS

Routing of the hydraulic front wheel drive system in a production adapted way

Conceptual routing of the hydraulic system in Volvo´s truck FH-1825

Bachelor thesis in the university program Design and Product development

MARTINA PERSSON

Department of Applied Mechanics
Division of Dynamics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

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PREFACE

The project presented in this report is a bachelor thesis work performed at the Applied Mechanics Department at Chalmers University of Technology, Lindholmen. The project has been executed at ÅF AB for Volvo Trucks and was started at the 18th of January 2016 and finished on the 7th of June the same year.

I want especially to thank my supervisor Dennis Persson, design engineer at ÅF, Lena Larsson, the project manager at Volvo, Emil Pettersson, design engineer at ÅF, Marcus Persson, Martin 1, design at Avalon, Jacob 1, sales engineer at Bosch Rexroth, Mikael 1, Johan 1, manufacturing strategy manager at Volvo Trucks, Per-Anders 1, tool design engineer at Volvo Trucks and lastly Jörgen 1, at VCE Volvo Construction Equipment in Braås, who have been a major support and much helpful during the project.

Finally I want to thank my examiner and supervisor Sune Olsson, senior lecturer at Chalmers.

Martina Persson

Gothenburg, 2016

Chalmers University of Technology

ABSTRACT

This thesis work has been executed at ÅF, located at Lindholmen Gothenburg, for Volvo Trucks. Focus has been laid on routing the hydraulic hoses for the hydraulic system on one of Volvos truck, called FH-1825, in a production adapted way. Until today focus has not been paid on the routing of the hydraulic system which has led to an installation which is both time-consuming and not as optimal seen from a sustainable seen from a mechanical point of view. Therefore during this diploma work focus have been laid on investigation for what is desirable regarding installation of the transport channels. This proved to be an assembly which is fast to install and works in a sustainable way which therefore lengthen the hydraulic hoses service life.

During the project focus have only been put on receiving a conceptual solution on the routing of the hoses and the bracket to the wheel end spindles. This means that several tests and modifications are required on the final concepts in order for them to work perfectly in reality.

The work resulted in six different concept proposals on how the hoses could possibly be routed from the wheel end spindle over to chassis. After a Kesselring matrix, such as tests in the CAD program Creo Parametric, concept 3, where the hoses travel forward in an arch over to chassis, was proven to be the best. Due to the attachment points for the bracket on the wheel end spindle the wheel end spindles positions were changed with one another in order to receive the attachment points to the brackets on the opposite side. The wheel end spindles bracket design resulted is a construction of two parts where the part which is fastened to the wheel end spindle possibly could be pre-montaged at the axle factory in order to reduce the installation time. The other part, with the pipes already pre-montaged within, could be riveted at the production state.

The solution is much better when compared with the situation today since it allows the hoses to only move in one plane when the vehicle is moving in “normal state”. Although is it inevitably that the hoses will move in several different planes at some point but with this solution is avoided that the hoses is forced in to twisting already from the start, as it is in today´s solution.

SAMMANFATTNING

Denna rapport utgör sammanfattning av ett examensarbete gjort på ÅF, vid Lindholmen Göteborg, mot Volvo Lastvagnar. Fokus har legat på att dra hydraulslangarna för hydrauldriften på Volvos lastbil, som heter FH-1825, på ett produktionsanpassat sätt. Tills idag har inte fokus legat på slangdragning av hydraulsystemet vilket har lett till en installation som både tar lång tid och som inte är optimal ur ett hållbart perspektiv. Under detta examensarbete har därför fokus legat på att undersöka vad som är önskvärt för installation av de hydrauliska transportvägarna. Detta visade sig vara både att de ska vara snabba att installera men även fungera bättre ur hållbarhtetsperspektiv och därmed förlänga hydraulslangarnas livslängd.

Under arbetet har fokus enbart legat på att erhålla en konceptuell lösning på slangdragning och hjulkonsol vilket alltså medför att tester kommer behövas genomföras och modifikationer på konceptförslagen för att de ska fungera perfekt.

Arbetet resulterade i sex olika konceptförslag på hur slangarna skulle kunna dras från hjulspindel till chassit. Efter en Kesselringmatris samt tester i CAD – programmet Creo Parametric visade det sig att koncept 3, där slangarna går likt en båge framåt över chassit, var det bästa lösningen. Då den bästa placeringen av hjulkonsol för denna lösning skulle vara om konsolens fästningspunkter på hjulspindel var positionerade spegelvänt mot hur de är kostruerade, så bytte vardera hjulspindel plats med varandra. Utformningen av hjulspindelns konsol blev en tvådelad konstruktion där den del som fäster på hjulspindel kan tänkas förmonteras redan vid axelfabrik för att minska installationstid. Den andra delen, med rör förmonterade inuti, kan tänkas nitas fast vid produktionsstadiet.

Lösningen är betydlig bättre än dagens då den tillåter slangarna att bara röra sig i ett plan när fordonet kör i ”normaltillstånd”. Dock är det oundvikligt att slangarna kommer röra sig vid något tillfälle men med denna lösning undviker man att tvinga slangarna att vrida sig redan från början, som på det sättet det görs idag.

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1. INTRODUCTION

In this section the background is described as well as the expected achievements and delimitations of the investigation of the hydraulic routing.

1.1 Background

To increase the tractive force of a truck when driving on surfaces with poor traction a front wheel drive can be used, also called FWD (personal information, Persson, D. 15 December 2015). There are two types of front wheel drive, mechanical and hydrostatic. The purpose of FWD is to increase the vehicles tractive force at lower speeds in order to prevent that a wheel is spinning when the driver is starting the vehicle (Arcila & Bién, 2004). The driving shaft is often placed at the second wheel axle, see figure 1.1 (personal information, Persson, D. 13 April 2016). When the truck is driving without load the main weight is on the front axle. If the friction under the front wheels are to low when the truck is unloaded could the truck be left in no motion, i.e. the driving wheels are spinning. However if a FWD would to be connected to the front axle the truck could benefit on the weight on the front axle and therefore be able to get the vehicle moving, independent on the driving shaft in the second wheel axle.

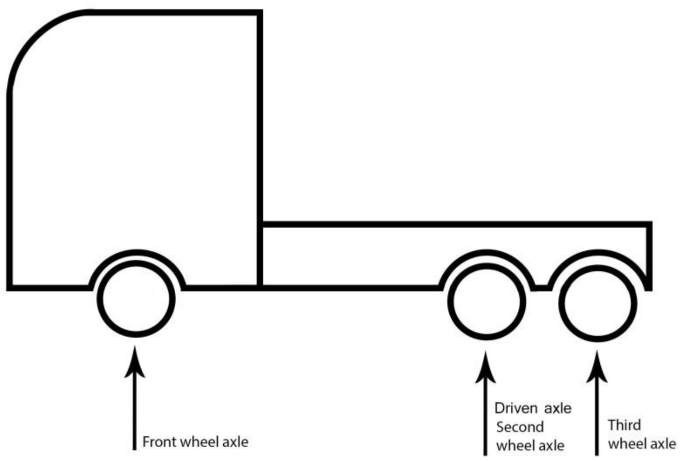


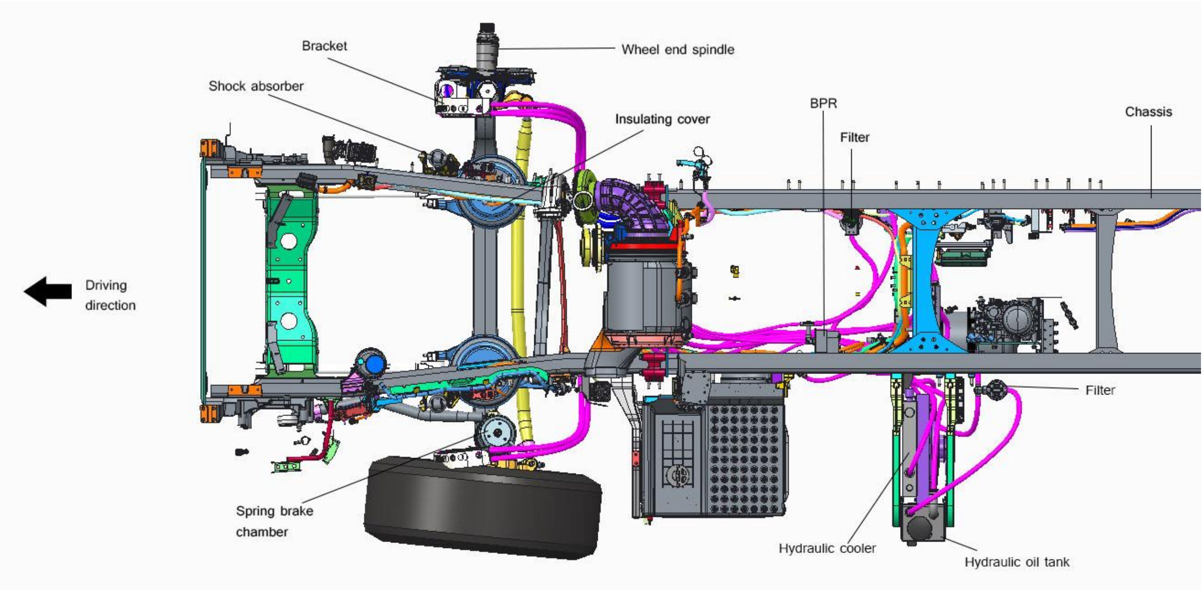
Figure 1.1 Positions of wheel axles. Authors own illustration.

Mechanical front wheel drive works in such a way that the front axle is connected with the gearbox, and through a cardan shaft is the mechanical drive on the second axle also transmitted to the first axle (Pettersson, 2012). The relation between force and velocity is regulated by the gearbox (personal information, Jacob 1. 3 February 2016). Since the mechanical front wheel drive is connected to a gearbox must, in this scenario, the gearbox be engaged in order to the system to work. Since the mechanism of the mechanical front wheel drive can take up more space than possible in the vehicle, a hydraulic system is preferable instead (Pettersson, 2012).

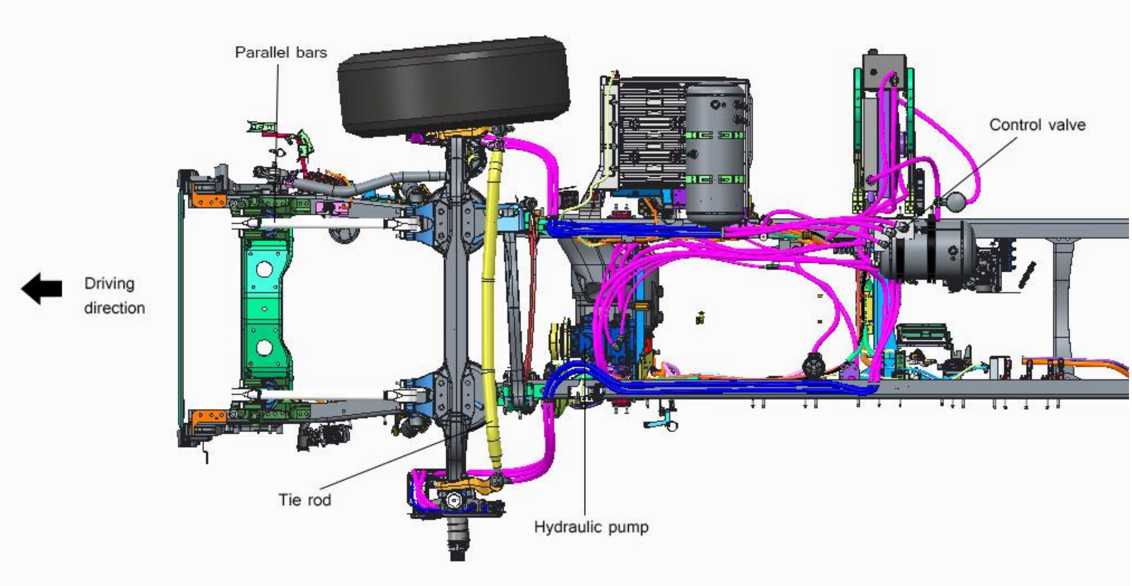
A hydraulic front wheel drive enables temporary drive on the front axle through hydraulic fluid, transported under high pressure, though only to a limited driving velocity (Arcila & Bién, 2004) (Pettersson, 2012). Since the wheel engines maximum torque is depending on a combination of the size of both the pump and the motors is the maximum driving velocity limited to 22 km/h, which applies only for FH-1825 since the speed limit depends on the components conditions in the system, when hydraulic drive is connected. The pump´s and engine´s change in displacement regulate the relation between driving force and velocity (personal information, Persson, D 9 May 2016). The hydraulic drive is commonly positioned on the front axle since the front axle carries most of the truck´s weight when not loaded (Arcila & Bién, 2004). A hydraulic system contains several different components, and to connect all these components and transport the fluid, hydraulic hoses and pipes are used. The first vehicle to have Bosch Rexroth´s hydraulic system installed was the FH-1672 were interest mainly was on having the system to work (personal information, Persson, D. 9 May 2016). Although at the new Volvo truck, FH-1825, interest has also been on making the hydraulic system production adapted. Hydraulic systems are both flexible and cost-effective when it is desirable to receive large forces and torques during low velocities (Audibmw, 2012). Since the hydraulic system is not depending on the gearbox or the drive axle, can the hydraulic front wheel drive be used without the gearbox engaged and independent on the second drive axle (personal information, Persson, D. 9 May 2016).

Interest today lays in a production adapted solution that will result in increased time efficiency during assemble of the hydraulic system without raising the production cost. The area around the wheel spindles is the most critical duo to the stress from vibrations and torsions and the limited space to route the hydraulic transport channels at, which makes this area the most interesting to find a solution for.

To further understand the construction of the hydraulic system and surrounding components in FH-1825 study figure 1.2 and 1.3.



Figur 1.2 Top view of FH-1825. Authors own illustration.



Figur 1.3 Bottom view of FH-1825. Authors own illustration.

1.2 Aim and Question Posed

The aim is to present a concept solution of how the hydraulic system´s routing of the new Volvo truck should be executed in order to be able to implement the system in a production adapted way. Interest also lies in finding a solution on the critical area around the wheel end spindles.

The following questions should be answered:

- Is there anything in earlier solutions that should be maintained?
- What would be the best solution of the routing for series production in a product adapted perspective?
- What would be the best solution of the routing for series production from a technical/ mechanical perspective?
- When is it most optimal to use hoses counter to pipes?
- How should the routing around the wheel end spindle be executed for maximal durability?
- Is the new routing causing any wearing on the hoses around the wheel end spindles?
- How strongly does the bending radius of the hoses affect the hoses and what are their consequences?

1.3 Delimitations

Following presented delimitations explains what this work will not discuss and will therefore be neglected from this thesis:

- Focus will only be on the hydraulic system at the front wheel axle.
- There will be no calculations on the manufacturing cost.

- The work will first and foremost be focused on the routing and not on any repositioning of the system´s components. Eventual investigation of the components positioning will only be done if time allows.
- No focus will be paid on positions of the different inlet and outlet ports of the hydraulic system´s components.
- Since a production adapted solution is desired no calculation will be made on the loads and bending affecting the routing

2. THEORY

Here the significant background facts are presented for further understanding, since much of the work is based on these facts.

2.1 Hydraulic transmission

The basic principle for a hydraulic transmission is to transfer power via hydraulic oil under high pressure (Jonsén, 2011) (personal information, Persson, D. 15 December 2015). The advantage of a hydraulic transmission contra a mechanical is, amongst other, that the components of the system are both lighter and can easier be placed in more narrow areas (Jonsén, 2011). The energy losses in the hydraulic transmission are minimal and energy can be transferred through narrow corners without any significant losses (Jonsén, 2011) (personal information, Jacob 1. 3 February 2016). The system also allows continuous exchange over wide velocity ranges (personal information, Jacob 1. 3 February 2016), smooth speed transformations and fast slowdown since the hydraulic transmission can be used as an extra engine break. The hydraulic system can be divided into closed loop systems and open loop systems which can be further studied in 2.2.2.

2.2 Components in the system

The hydraulic system in the truck consists of the following components:

- Hydraulic axial piston pump, mounted on the engine
- Two wheel end motors, on the front axle
- Oil cooler, positioned in chassis
- Hydraulic oil tank, placed either in chassis or behind the cab
- Control valve in chassis
- Two oil filters
- Boost pressure reduction valve in chassis
- Two wheel end spindles, positioned on the front axle

Hydraulic axial piston pump

The hydraulic pump converts the mechanical energy from the engine to hydraulic energy (Hydraulics & Pneumatics, n.d). Its basic principle is that the movement of the pump creates a vacuum which sucks the hydraulic oil in to the pump from the hydraulic tank. The pump pushes the oil out in the system and sets it in flow. The pump only generates flow and do not create any pressure.

Axial piston pumps have pistons rotating around the axis on a sheet in an oval movement, see figure 2.1. There are two types of hydraulic pumps, variable and constant displacement (personal information, Jacob 1. 3 February 2016). A variable pump allows the sheet with the pistons to be moved which allows adjustable pressure flow which can be helpful at bad ground conditions. Since the sheet is adjustable the pump can regulate the flow of the fluid and the hydraulic system can gain more or less oil when needed. A constant displacement pump delivers a constant pressure flow since the sheet rotates in the same track all the time.

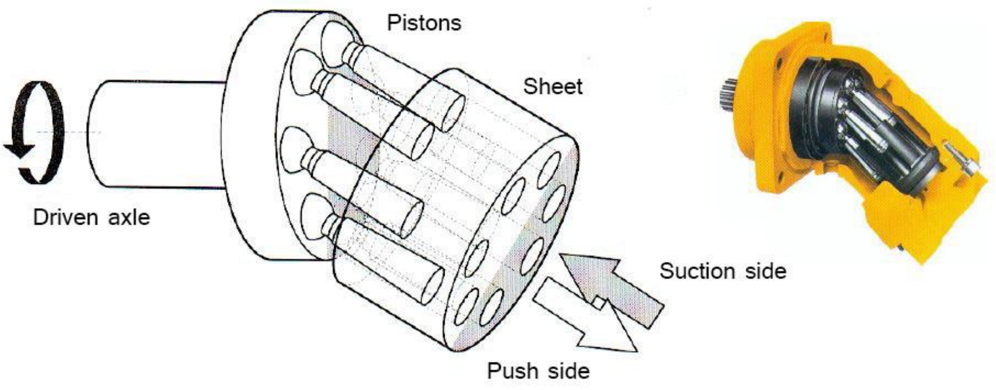


Figure 2.1 Illustration of an axial piston pump. Bosch Rexroth. Reproduced with permission.

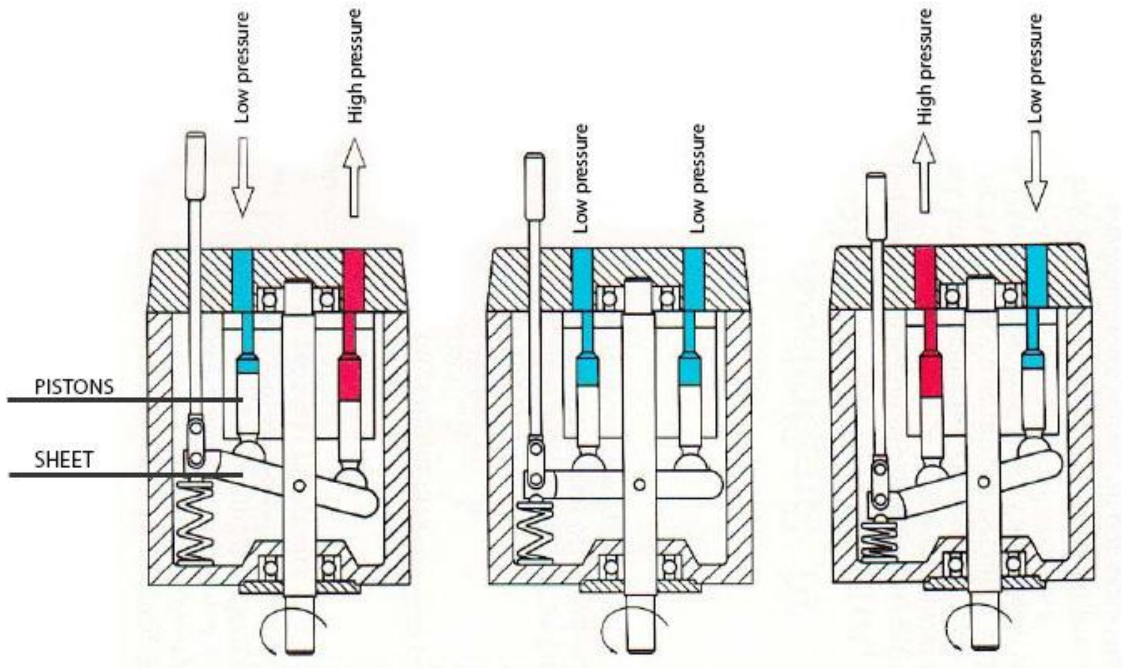


Figure 2.2 Function of a hydraulic axial piston pump. Bosch Rexroth. Reproduced with permission.

In the pump unit a so called feeder pump is integrated, which purpose is to keep the fluid in flow when the hydraulic drive is disconnected. For more information concerning the feeder pump see section 2.2.1, *Open loop*.

Wheel end motors

The motors on the wheels are equipped with pistons radially to the wheel axis. When pressure enters the wheel motor (through the wheel end spindle) the pistons are pushed against the wave patterned sheet which creates a rotating movement (personal information, Jacob 1. 3 February 2016). In figure 2.3 a wheel end motor is illustrated. The red circles represent the high pressure forcing the pistons to push the cylindrical coils, and as a result the wheel rotates. The blue circles represent the low pressure which enables the piston to retract through creating under pressure.

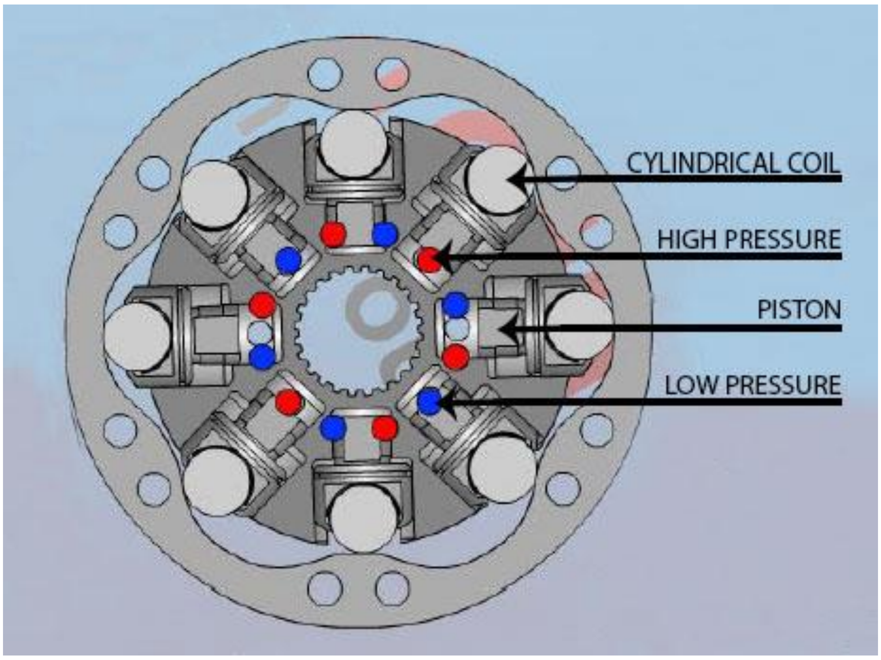


Figure 2.3 Wheel motor. Bosch Rexroth. Reproduced with permission.

Boost Pressure Reduction valve

The BPR´s function is to reduce pressure during idling mode, i.e. when the high pressure system is not in use (personal information, Persson, D. 24 February 2016). The purpose of the BPR is to reduce the pressure from the feeder pump from 25 bar to 6 bar. By reducing the pressure with the BPR, the losses in the system are reduced since the BPR prevent unnecessary high pressure i.e. 25 bar.

Hydraulic oil tank

It is very important that the pump never gets any air in the suction hose, if so a collapse would occur which could lead to extreme damages. Entering oil to the tank must go through a filter to ensure clean oil because of the high sensitivity of microscopic dirt in the piston pump and motors (Womack n.d)

2.2.1 System flow chart

The hydraulic system can be seen in figure 2.4, which gives a schematic overview of the components of the system and how the oil transports from each station.

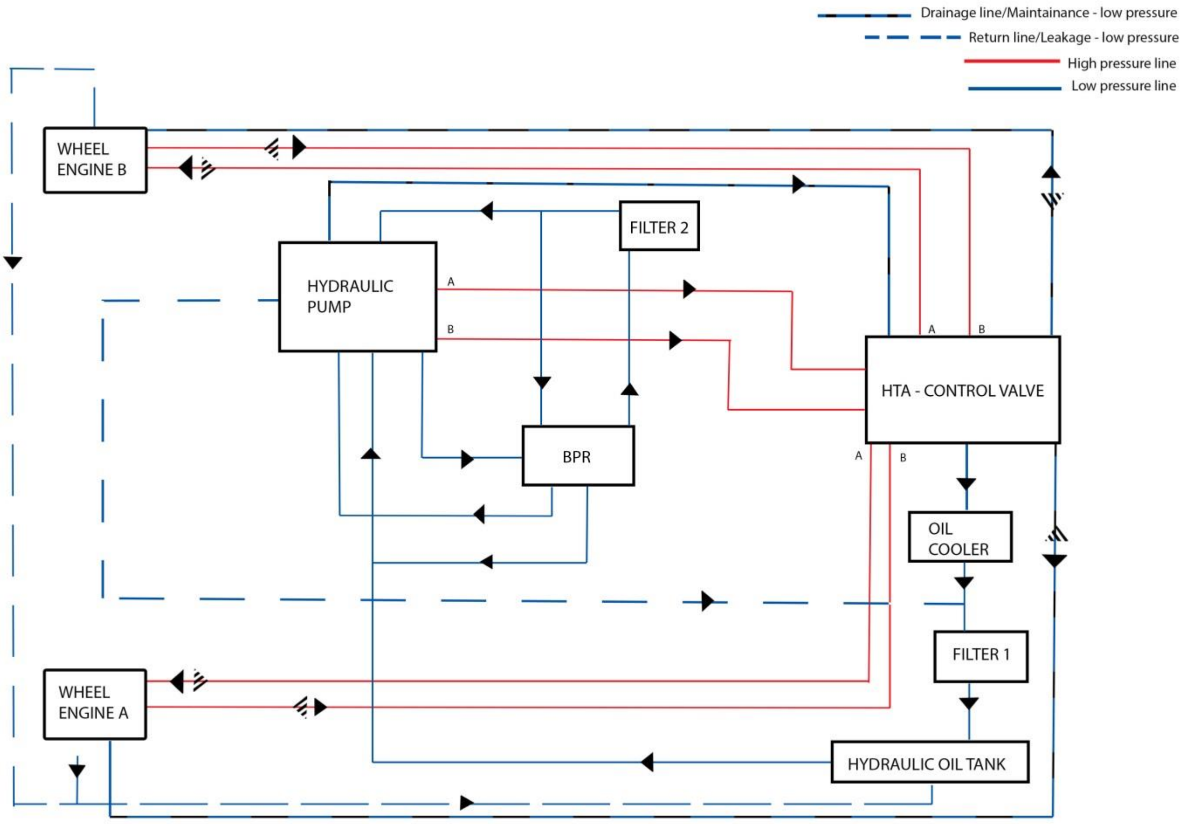


Figure 2.4 Hydraulic scheme. Authors own illustration.

As been pointed out in chapter 2.1 the hydraulic system can be divided into closed-loop and open-loop (personal information, Jacob 1. 3 February 2016). The whole system, figure 2.4, can be referred to as a closed system (which is in function while the hydraulic drive is connected). But this system can be divided into two different systems, closed and open.

Closed loop

When the hydraulic drive is connected the so called closed – loop system is running, which includes all components in the hydraulic system, and the oil flows as in figure 2.1. A closed loop hydraulic system is defined as a hydraulic system where the hydraulic oil flows from the consuming component(s) back to the pump (personal information, Jacob 1. 3 February 2016).

Open loop

The purpose of the open loop in the hydraulic system is to keep the oil in motion to prevent the oil from cooling since it otherwise would be too viscous, and to prevent the components from receiving air instead of oil which would cause them to break (personal information, Persson, D. 24 February 2016).

When the hydraulic drive is disconnected, i.e. when there is good driving condition and the vehicle drives at higher velocities (personal information, Jacob 1. 3 February 2016), a so called open loop system is running.

Instead of having the whole pump unit in work only the feeder pump is on stream since it is unnecessary to have the whole pump unit in function. The feeder pump is not powerful enough to be used in the closed loop but is enough when the oil only needs to be in motion. There will always be some amount of leakage from the pump which is conveyed to the hydraulic tank. The pressure in this system has to be confined, which is why there have to be a pressure constrainer which can be seen in figure 2.5 as the BPR. Figure 2.4 and 2.5 are simplified illustration of the hydraulic scheme in appendix A.1, and gives an overview of how the oil is being conveyed while the closed loop system is connected. As can be seen the oil flows from the tank to the pump (in this case only the feeder pump) were the oil is being conveyed between pump, BPR and one of the two filters. The black arrows symbolize the oil flow when the hydraulic drive is disconnected, i.e. during idling mode. The oil flows in the directions of the arrows and the wheel end spindles are filled, enabling the pistons in the wheel motor to retract.

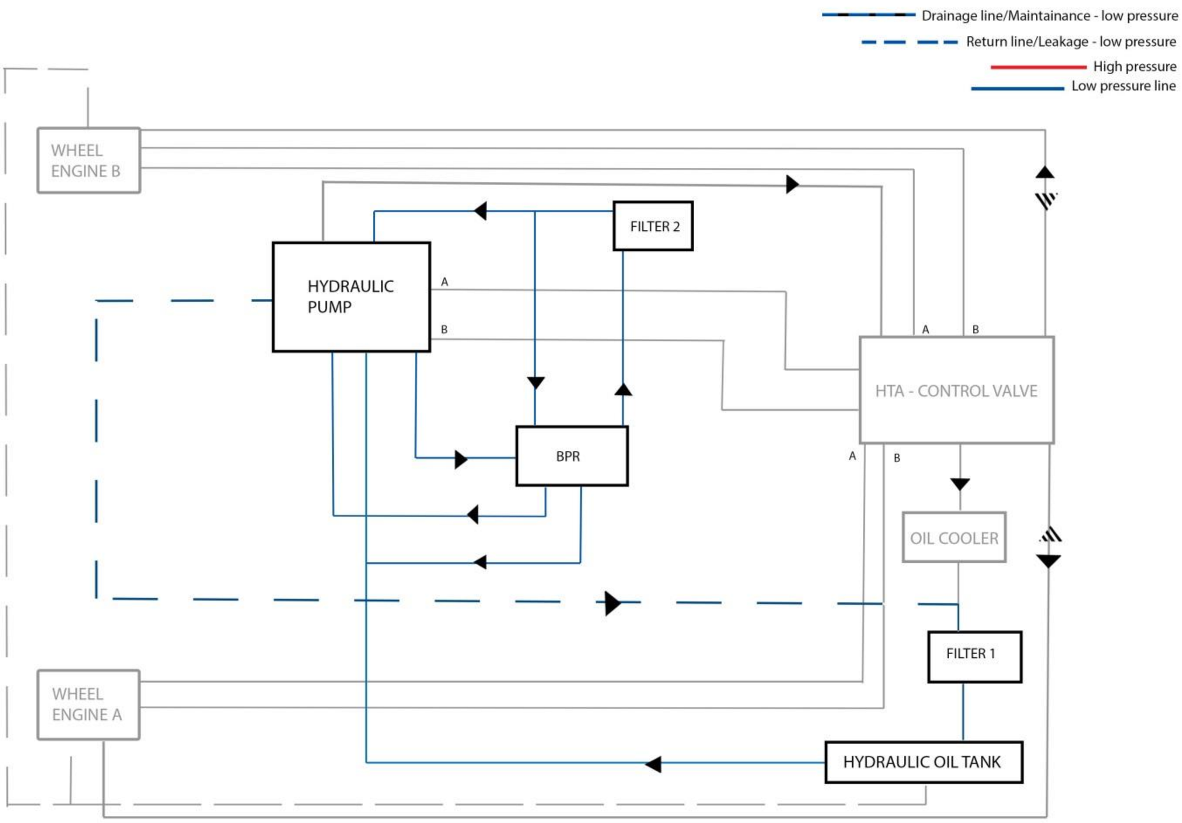


Figure 2.5 Hydraulic scheme Open – loop. Authors own illustration.

2.2.2 Transport channels

The conveyed media in the hydraulic system is transported through channels of either stainless steel pipes or hydraulic hoses (personal information, Persson, D. 15 December 2015). The hoses consist of three layers, an inner tube made of synthetic rubber, reinforcement of metal that makes the hose resistible to the fluid pressure and keeps it from bursting, and cover who protects the hose from the surrounding environment. This is illustrated in figure 2.6 (Kemper, 2010). The cover, such as the inner tube, is usually made of rubber. The inner tube shall resist factors like corrosion and temperature changes on the inside of the hose. The cover must work like a protection for both the tube and the reinforcement, and protect from factors such as abrasion, temperature changes and other ambient conditions. The reinforcement is supposed to hold the internal pressure of the tube (Parker, 2008).

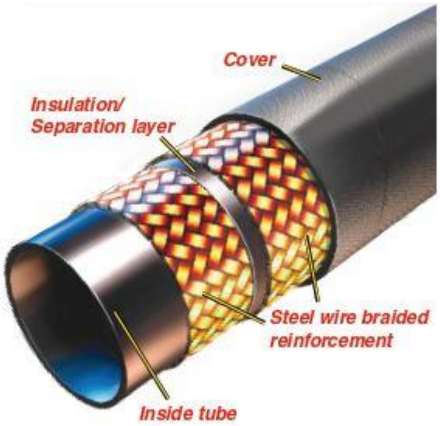


Figure 2.6 Illustration of the construction of a hydraulic hose´s three layers. Parker. (2008) Hydraulic Hose, Fittings and Equipment. Available from: http://www.parker.com/literature/Bulletin%20C4400-A%20UK%202008-06-04.pdf [2016-05-9]

Hoses

When routing a hydraulic system there are several aspects regarding the hoses that must be taken in consideration. The size of the hose is important since the flow rate is greatly dependable on this factor (Parker, n.d.).

When selecting a hose for a specific application, the affecting temperatures of the surroundings and the fluid within the hose must be taken into consideration (Parker, n.d.). Too high or too low temperatures of these will tear on the tube and shorten its lifetime. The endurable temperature varies depending on the type of fluid in the tube. However in general, a far too high temperature (combined with high pressure) will reduce the hose´s service life (Parker, 2008). A too low temperature makes the hose stiff which could make the hose less bendable, leading to cracks.

Thereafter the usage or application should be taken in consideration (Parker, 2008), including where, why and how the hose is to be put to use. Every different environment and possible use affects the hoses in different ways. For example a hose cannot be bent under its minimal bending radius, which will cause it to crack. If the hose would be bent below the minimum bending allowance, the consequence could be loss of the mechanical strength and hose failure. A correct bending should allow a straight length of 1.5 times the hose´s outside diameter from the coupling to the start of the bending, as showed in figure 2.4.

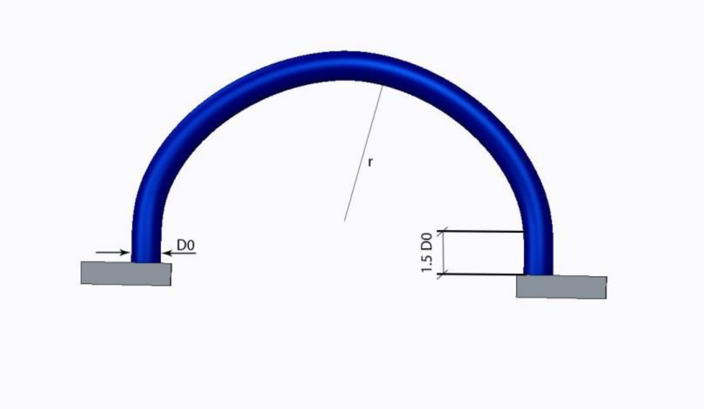


Figure 2.4 A bend hose were r is the bending radius, D0 the outer diameter and 1.5D0 is the straight length from fastener to the start of the bending. Authors own illustration.

The environment is going to affect the possible ways of placing the tubes and the couplings (Parker, n.d.). The hoses should never be assembled in such way that they are stretched, kinked, crushed or twisted at any time (Parker, 2008). If the hose is installed in such a way that it is straight, it must be assured that there is enough slack for the hose to allow changes in length that will occur when pressure is applied, see figure 2.5. This will allow the components of the system to move or vibrate without any misfortune like tension in the hose which will evidentially lead to cracks/collapse. Clamping is used to secure the hoses and control its movement when pressure is on. It is, whilst routing, important to know that high and low pressure hoses should never be clamped together since they change in length too much compared to each other.

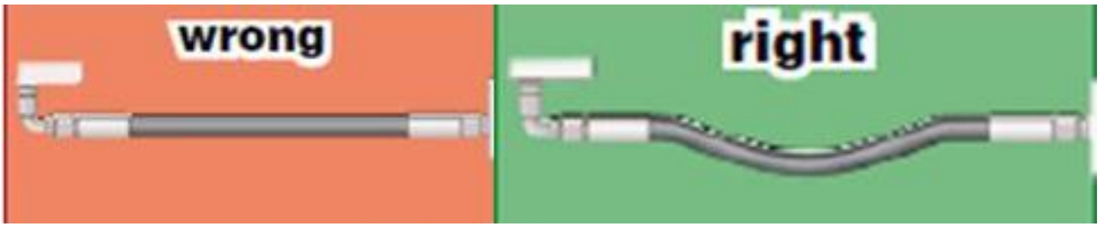


Figure 2.5 Illustration of wrong and right execution of routing a cable. Parker. (2008) Hydraulic Hose, Fittings and Equipment. Available from: *http://www.parker.com/literature/Bulletin%20C4400-A%20UK%202008-06-04.pdf [2016-05-9]*

It´s important to have knowledge about different pressures in the system, such as working pressure, the affecting pressure during operation, surge pressure, pressure that emerges from changes in the velocity (Ipexna, n.d), spikes and eventual extra high and low pressure differences (Parker, n.d.). The pressure in the hose must be equal or greater than the system working pressure, and more than the surge pressure and the evidential peak transient pressures.

Hoses can be divided into two different construction types, regarding the type of reinforcement, which is spiral or braided (Kemper, 2010). A braided hose is a flexible hose where several wires are wrapped around the hose in a way that they go under and over each other, creating a braided structure (Hose master, n.d.). Braided hoses are most common for low pressure transports (Parker, n.d.).

In spiral hoses the reinforcement is structured by wires going in a spiral along the tube (Kemper, 2010). Spiral hoses are used during circumstances with high pressure since their spiral structure on the reinforcement prevent the hose from self-wearing.

Pipes

The material of the pipes depends on its operational environment (Gshydro, 2014). Carbon steel is used in indoor conditions and stainless steel is used in more demanding environments, such as outdoors at humid conditions or at low ambient temperatures.

As with the hoses the selection of pipes must enable a certain temperature, different pressures, flow rate and compatibilities.

2.2.3 Couplings and Fastener

Couplings, also called fittings, are used to fasten the hoses and pipes to the components of the system (Parker, 2008). There are eight steps to follow when choosing the coupling that should be used in order to be able to execute a correct installation. The eight steps are the following:

1. **Applications –** The first step in choosing a suitable fitting is to analyze in which circumstances the device will be used and how that affects the hose and fitting. This could regard factors such as if it is going to be a suction application, what fluid that will be transported or the conditions of the environment.
2. **Size –** The size of the transport channel, often referred to as the inner diameter of the hose, affects the size of the fitting and must be adequate for each other to minimize pressure drops and to avoid damages that could occur from high fluid velocities or heat generation.
3. **Pressure –** As been said earlier the pressure is an important and somewhat sensitive factor in the hydraulic system. The selection of hose and fitting should enable the working pressure in the hose assembly (which is a hose and its fittings) to be greater than or equal to the maximum system pressure. The assembly should also involve that the surge pressure and the peak pressures are below the maximum working pressure. An incorrect installation of fitting could affect these pressures.
4. **Temperature –** Both the temperature of the environment around the hose assembly and the temperature of the conveyed media needs to be taken into consideration before choosing fitting. High temperatures along with high pressure can cause a radical life reduction. If it is known that the temperature of the conveyed fluid or the environment is high, a fitting made for higher temperatures should be selected.

   Cold temperatures could, in general, have the effect that the flexibility of the rubber reduces and becomes stiffer. Every hose has a minimum allowed temperature in which exposure could lead to cracks. Specialized couplings should be selected if the system is to be exposed to a colder environment.
5. **Fluid compatibility** – The hose assembly must be chemically compatible with the transported media. If not, the service life will be shortened and leaks could occur. To avoid this, the fluid characteristics must be taken into consideration.

6. **Hose fitting compatibility** – The fittings should be compatible with the hoses to ensure no leaks or shortened service life. The right coupling can be found by searching in catalogs.
7. **Hose assembly manufacture** – The most commonly used method of making a hose assembly is crimping. Crimping is also the safest and the fastest way to go. When crimping it is essential that the hose, fitting and crimping tool match perfectly to ensure a precise, leak free and tear proof assembly.
8. **Routing** – The last step in deciding a fitting is to consider how the installation will look. Briefly said, a correct fitting prevents that the hose is bent under minimum bending radius. Also unnecessary hose length should be avoided for a correct selection. A so called clamping is in some occasions needed. This is a sort of fastening that holds and supports the hose so that it will not take any damage by moving.

2.3 Calculations

Focus has not laid in calculations, although the ones which have been used are presented here. Formula, numbers and purpose of the calculations are explained at each time.

To calculate the bending length, see figure 2.4, i.e. the length between the ends of the coupling to where it starts to bend (Parker, 2008):

$$1.5D0 \qquad [1]$$

where D0 is the hose´s outer diameter. Minimum bending radii of a hose, when nothing other is specified as following (if nothing else is specified)(personal information, Persson, M. 3 Mars 2016):

$$2D0 \qquad [2]$$

3. METHODOLOGY

The methods that have been used are presented here in what has been done, why the methods were considered to be useful and how they were executed.

3.1 Knowledge building

An elaboration of hydraulic transmission was needed in order to get a deeper understanding of the subject. This was done by reading earlier reports of the hydraulic system, research on the internet and by study visits and interviews where several experienced engineers shared their knowledge about the hydraulic system and its components.

3.1.1 Literature studies

The first step in building up the knowledge about the subject was through literature studies. The literature studies, that included studying of reports and researching on the internet, was a fine way of gaining the first deeper knowledge of the subject since it offered a simplified explanation of the system and its components. The reports were the main source of obtained facts and the internet research functioned as a compliment for the aspects that the reports did not discuss neither explained any further.

3.1.2 Study visit

The study visits have been conducted at VCE, Volvo Construction Equipment, in Braås, Bosch Rexroth in Gothenburg and at Volvo Trucks also in Gothenburg. The main purpose of these visits was to obtain a greater understanding about the hydraulic system and the different contributing components. The visits where carried through with an experienced employee who lectured about their subject and discussions with questions were made.

The visit in Braås was considered helpful since the employees had a large knowledge about the hydraulic system and its components. Through the employee Jörgen 1 (whose surname will be called 1, which following contacts also will be called), several hoses and couplings were explained and examined, and Jörgen explained different scenarios that should be taken into consideration when constructing a hydraulic system. The purposes of this visit was to gain a deeper knowledge of how the hydraulic system works and which hoses and fittings that could be used, when these hoses and fittings are suitable and, lastly, what should be kept in mind when installing a hydraulic system.

During the visit at Bosch Rexroth the components in the hydraulic system were explained in detail. The function of the components should be known in order to understand how the routing should be executed. Therefore the main purpose of this visit was to understand the function of the hydraulic components in order to understand the purposes of the different hydraulic hoses.

Lastly there was a meeting at the production in Tuve made with Per-Johan 1 as contact person. Since the montage of the trucks are carried out in Tuve a study visit was beneficial for both an understanding of the different production stations and how they work, and to ask questions regarding the hydraulics at a production point of view. The idea of the study visit was to understand where the problems lay in the production state in order to gain important knowledge before the concept generation.

3.1.3 Meetings and Interviews

Meetings, both over Skype and in person, were executed in order to be able to answer the questions about the previous routing. The first meeting was executed at Volvo, Lundby were Johan 1, working at the production department at Volvo, attended in person and Nicolas 1, who have several years of experience of hydraulics, attended via Skype. The purpose of this meeting was to get an overview of what is good to keep in mind during the routing for a production adapted solution and what is the major problem while routing the hydraulic hoses, both in general but also where the critical areas are.

Another meeting over Skype was executed with Martin 1, who is the engineer that designed the wheel end spindle, which made him suitable for discussion about the area around the wheel end spindle. During the meeting some concept ideas regarding this area were shown to Martin in order to receive input from a person with deeper knowledge within the area. A continuous contact has later on been held due to Martins area of expertise.

In order to gain understanding about the hydraulic routing in FH-1825 a meeting with Mikael 1 was performed (who is the person who does the routing of the hydraulic hoses on FH-1825 today). Mikael answered several questions regarding todays routing and since the meeting was executed near the truck´s position the truck could be used as a guide during the discussions and this simplified the discussions.

3.2 Mapping of previous solutions

To have a foundation on how the routing has been executed today on one of Volvo´s truck, FH-1825, the hoses were drawn in the CAD-program Creo Parametric. The routing in Creo gave both an understanding of which hose will enter and exit which port, and functioned as a helpful reference during meetings since it allowed an easier discussion of the different and important aspects that should be taken in consideration while routing. The drawing in CAD also served as a source of inspiration during the concept generation state.

An Excel document was made that, amongst other, explains every hose that is to be routed in the system, what kind of port these hoses enter/exit, the pressure in each hose etc. As a complement to the Excel document a scheme was made of the system where every line is presented with a number. This number is connected to the numbers in the Excel document to clarify which line is which. The table and the scheme served as a helpful guide during the routing of the previous solution. In order to be able to make the scheme and the document over the hydraulic system a hydraulic scheme from Bosch was used. This can be found in appendix as figure A.1.

3.3 Requirement specification

A requirement specification was made since there are several specifications that must be fulfilled during the installation of hydraulic hoses and couplings. Neglecting these could have severe effects such as failure in the truck which could lead to danger for people in the surrounding. The requirement specification served as a helpful guide concerning which demands that must be fulfilled.

The content of the requirement specification was gained partly from the literature study, the study visits and, lastly, from the meetings and interviews. The literature study stood for the general specification of the hydraulic system and routing, such as general requirements regarding the hoses. The study visits, such as the meetings and interviews, contributed with specific requirements regarding a special factor or area. These gave requests that complemented the general specifications that were gained from the literature.

3.4 First concept generation

The concept generation were divided into two parts. One part where a brainstorming was executed in order to come up with many different ideas and importance laid in gaining many solutions. The the other one was more concentrated on fewer problem areas but the ideas were more worked out in detail.

3.5.1 Brainstorming

The first concept generation was made through brainstorming were the map of the previous solution in Creo was a guide that showed where the possible troubles could emerge. Thereby concept solutions could be constructed. The ideas were sketched on paper as a so called “quick sketching”. The purpose of this concept generation was to receive a large quantity of different types of solutions for later evaluation, and thereby have a base for a new generation of ideas with higher quality (Thylefors et al. 2010, 502-203).

3.5.2 Concept elimination

When many ideas had been sketched it was time to eliminate some of them in order to concentrate deeper on one area that was most in need of an improvement. The concept elimination was made through a meeting with Dennis Persson, were the sketches were showed and the thoughts around them were discussed. After analyzing the ideas with a production adapted point of view area was selected to investigate for a new concept generation.

3.5 Second concept generation

After the first concept generation, where many ideas were listed on the whole system, a new concept generation was executed only this time the ideas were specified on a specific area of the hydraulic system.

3.5.1 Brainstorming

During the second brainstorming session the concepts were drawn in Creo instead of sketched on a paper though this gave a clearer view of the situations e.g. the locations of components that affects the possible routings. In reality a hydraulic hose was used as a help to understand how the hoses behave when it is fastened in both ends and moves in different ways. This method made it easier to understand how the possible routing could be made in a more sustainable order.

3.5.2 Concept evaluation with Kesselring matrix

After having concentrated on a special area of the hydraulic system and after several concepts had been mapped an evaluation was made were the concepts on the selected area were investigated and the best ones were chosen to further development. The concept evaluation of the concept ideas from the second brainstorming was executed during a meeting with Lena Larsson, Dennis Persson, Marcus Persson, Emil Pettersson and Martin 1. Before the meeting a Kessler matrix and a power point of the concepts was made.

The purpose of the Kesselring matrix is to rate the different concepts on how well they fulfill the listed criteria and thereby which one is the best concept to further investigate (Johannesson, Persson, Pettersson 2004, 140-141). A Kesselring matrix is a matrix with several listed criteria and their importance. Each concept is presented in order to get a score on how well they fulfill the criteria. An ideal case is listed next to the concepts, which gets the highest possible score. The ideal case is to illustrate the best possible scenario. Afterwards the results shall be evaluated and reflected up on in their significance and balance in the rating score.

The power point contained illustrative pictures from Creo of the concepts and pros and cons for each concept. The pros were written in green color and the cons in red, to simplify the understanding of the differences. The power point made it easier to present the ideas in a structured way and therefor easier to understand.

3.6 Further investigation and iteration

After having evaluated the concept the most interesting of the concepts were further developed in layout and the design of contributing parts was constructed.

After the second concept evaluation the best concept (according to the Kesselring matrix) was chosen and its details was further investigated.

3.6.1 Test of concepts

In order to find out if the assemblies will co-work with the surrounding components and allow the wheels to turn the maximum and minimum angle without any mishap a simulation in Creo Parametric was executed. The simulation was performed through a certain Creo file that enables for adjusting the tires turning angle and roll angle, which is the two different movements the wheels will do that affect the possible ways of routing. Some of the concepts were therefore once again routed and through setting demands at the wheels angle the components position, due to the wheel cut and the roll angle, could be investigated. By measuring the hoses required length for each scenario of the wheels placement, the maximum length could be set on the hoses. This made it possible to see if the way of routing works with the required hose length.

3.6.2 Pugh matrix

After the simulation the different scenarios, as results from the simulation, were settled up in a Pugh matrix in order to decide which one is the best. A Pugh matrix is a product investigation method, were each scenario is compared with a reference in how well they fulfill listed demands, which in this case is today´s solution, (Johannesson, Persson, Pettersson 2004, 133-135). A plus in the evaluation column stands for “better than the reference”, a zero stands for “equally good as the reference” and a minus stands for “worse than the reference”. When each criterion had been evaluated for each concept the amount of plus and minus is summed and the concept with the highest score proves to be the best. The purpose of doing the Pugh matrix was to be able to decide which concept is the best, compared to today´s solution.

3.6.3 Investigation of chosen concept

When a concept was selected from the Pugh matrix as the best to work out in detail, the complete concept was determined in appearance and function. This was done through determining the routing in detail using Creo so that neither hoses nor pipes collide with surrounding components. When a functioning routing was found the configuration of possible brackets where designed.

3.7 Design of bracket

The design process of the bracket to each wheel end spindle is described here.

3.7.1 Concept generation of the complete design

The bracket´s configuration was determined through positioning the pipes in different ways in Creo, and through simulation of the wheels movement a list of pros and cons could be made for the concepts of the brackets. Thereafter one idea of a bracket could be chosen as a part in the final solution.

3.7.2 List of pros and cons

In order to select one of the proposals of bracket designs quickly a list of pros and cons was made (Mindtools, n.d.). Each concept was listed above two columns in an Excel document were one had the color green and one red. The pros of the concept were then written in the green column and the cons were written in the red. Thereafter which concept had the best result was evaluated and should be selected.

4. RESULTS

In this chapter the results of the methods are presented.

4.1 Previous solutions

The routing of the FH-1825 truck is presented here in pictures from the drawing in Creo Parametric. The Excel document, with the components ports and lines, and the scheme of the hydraulic system´s lines, which served as helpful guides, are presented in appendix as table A.1 and figure A.1. By studying the table and figure, an understanding is gained of which component is connected to which, how the lines are connected and what kind of line they are. Respective port listed in table A.1 can be found in the following figures in the appendix on each component separately.

In figure 4.1 the whole hydraulic system and its hydraulic components is presented. In figure 4.2 the hydraulic system is presented with the surrounding parts that are affecting the routing. Figure 4.2 helps to illustrate how critical the amount of space is in the truck´s chassis, and since nothing can be routed above the chassis within the area behind the pump unit (chassis are the gray beams at the sides in figure 4.1 and 4.2) the routing becomes even more complicated. For more illustrative figures of the routing see appendix figure 3 – 6 were the system´s routing is presented in two different views and with and without the affecting surroundings. Almost no couplings were fastened in the CAD drawing due to the time limit, due to the limited working time. It should be kept in mind when studying the following figures that there shall be a coupling at each port and therefore table A.1 and figure A.1 in appendix could make it easier to understand.

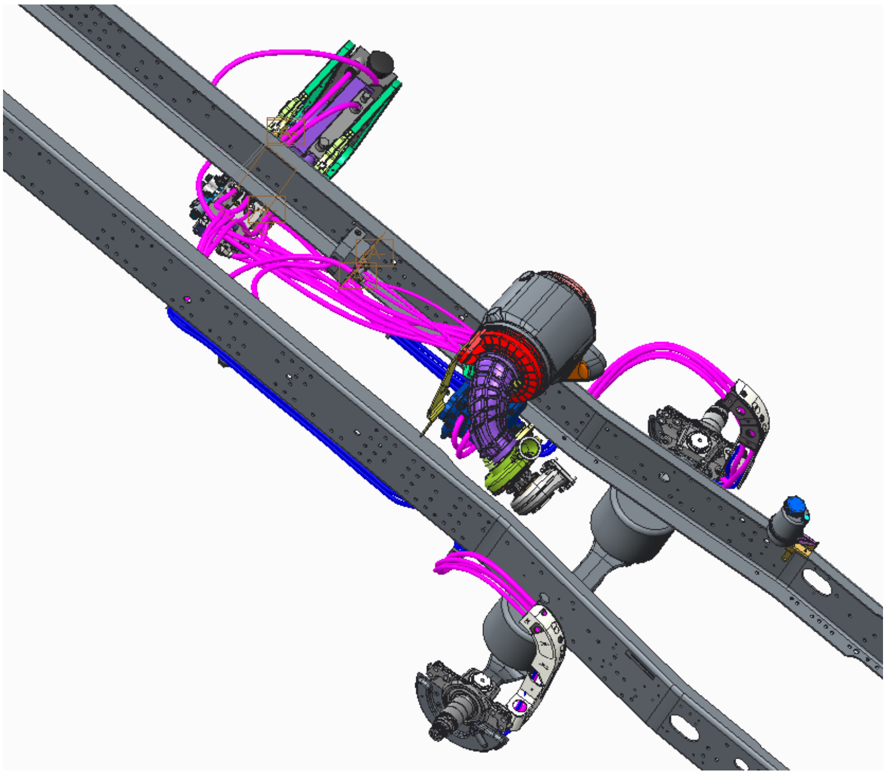


Figure 4.1 The hydraulic system with routing done on FH-1825

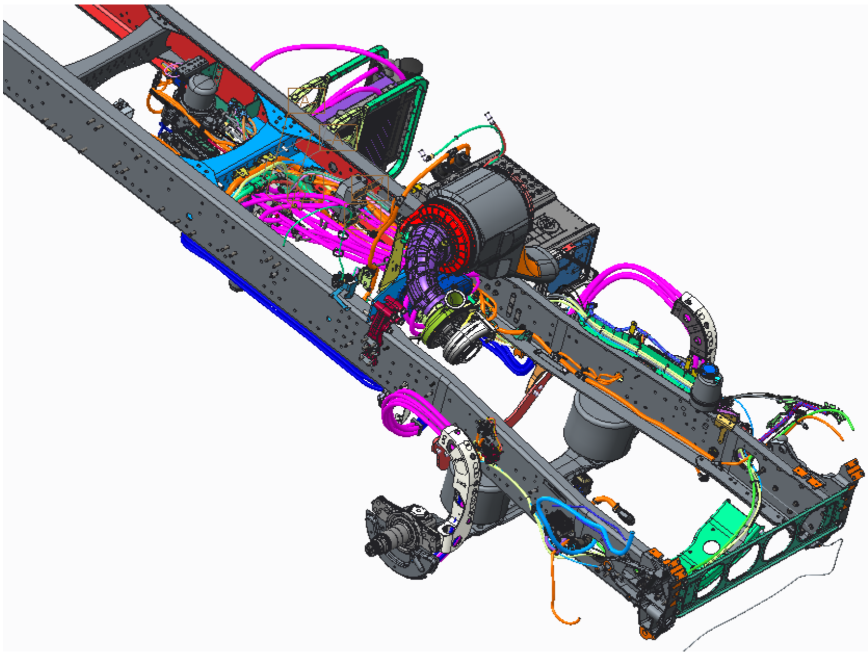


Figure 4.2 The hydraulic system with other surrounding components in FH-1825

Figure 4.3 illustrate the area around the pump where the pump unit is marked with a black circle. As can be seen eight different hoses are coming in and out from the pump which causes some difficulties during installation due to the absence of working space. The pipes are connected to the pump´s entrance and exit ports at this area to simplify the routing. This saves installation time since the difficulties of reaching the ports are avoided. If hoses were to be installed directly to the entry and exit ports instead, the assembler would have to spend a lot more time since these ports are hard to reach due to the surrounding components blocking the way, which pre montaged pipes avoids. To easier understand where the pipes are placed table A.1 and figure A.7 where the ports are marked can be studied.

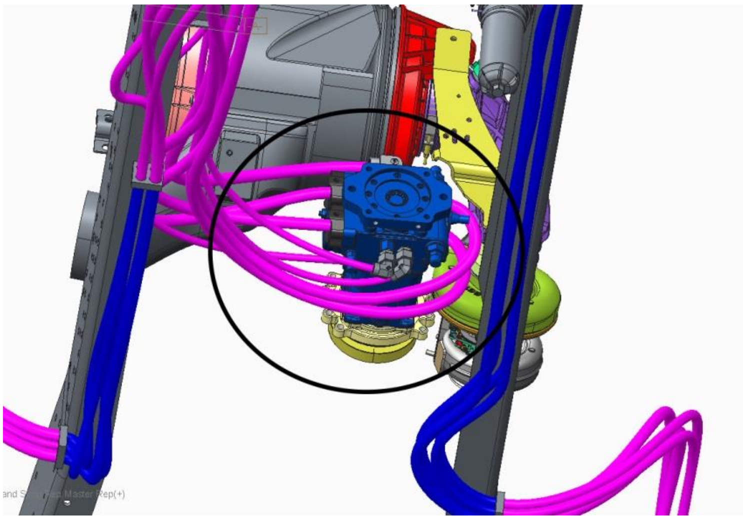


Figure 4.3 Hydraulic pump

Figure 4.4 shows the hydraulic routing with surrounding components that affects the possible placement of the hydraulic parts and the transport channels. As can be seen in figure 4.3 every hose is connected to the pump routed to one side, which is probably because the components that the fluid is being conveyed to or from is located on that side. The amount of hoses in the same place, going to different components, can be a problem since they all need slack and kept still to ensure no wear or collapse of the hoses.

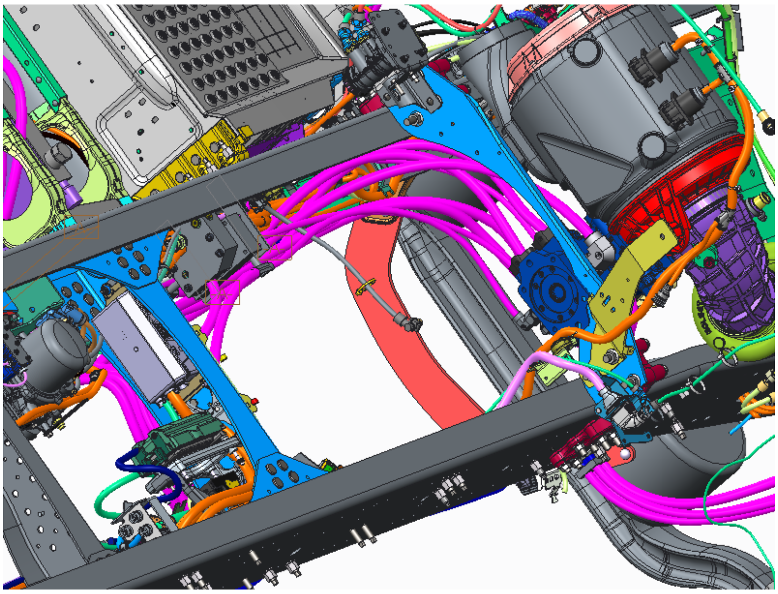


Figure 4.4 Complete hydraulic system, viewing hydraulic pump

The area around the wheel end spindles is one of the most critical areas regarding both the installation and during usage of the truck. The wheel end spindles areas are highly exposed since the wheels have to endure the different road conditions from up close. This leads to stones hitting the transport channels by the wheel end spindle and exposure to factors as mud and salt. This area is also critical because the hoses are bending in different directions at the same time and that since the hoses are not allowed any free space due to their close position to one another they are chafing on each other, se figure 4.5. All these factors reduce the service life of the hoses radically.

Figure 4.5 Hydraulic hoses at the wheel end spindles area which have chafed on each other

In figure 4.6 the wheel end spindle B is presented as the wheel end spindle on the right hand side.

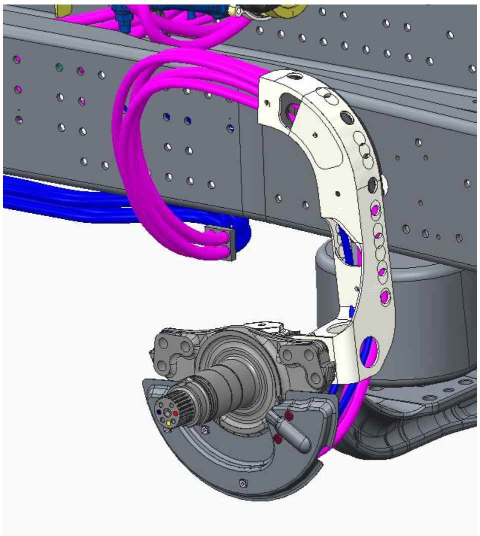


Figure 4.6 Wheel end spindle B

Since the wheel end spindle is exposed to a lot of different factors causing wear, the routing must be made in a way that the hoses endure the wear from the surroundings. Today, this is solved through pipes to the lines of drainage and leakage (the blue pipes in figure 4.6 and 4.7) and longer couplings to the high pressure hoses (the pink hoses in figure 4.6 and 4.7), instead of having hoses all the way.

Another critical moment in the area of the wheel end spindle is the way that the hoses must be bent in order to connect properly with wheel end spindle and the brick. A hose can never bend in more than one plane without being properly fastened, as can be seen in the requirement specification, appendix table A.2. These hoses are bending in too many planes which cause the hoses to twist in an unnatural way which leads to wearing and early collapse. The consequences are that the hoses must be changed more often than otherwise necessary.

The wheel end spindle and the bracket in figure 4.6 and 4.7 however are old models and are going to be exchanged in the new routing. Although these old models are used in present – days solution. The old and new wheel end spindle does not differ as much, although the new wheel end spindle are used in the concept generation and not the old one that is seen in this subchapter.

Another factor that complicate the routing around the wheel end spindle is the spring brake chamber positioned on top of the wheel end spindle, see figure 4.8 where the red circle surrounds the spring brake chamber. The spring brake chamber is not possible to move, only its entrances on the side, which means that the hoses must either be routed above, around or beneath it which makes it even more difficult to route.

To further understand the position of the ports at the wheel end spindles, see appendix figure A.8.

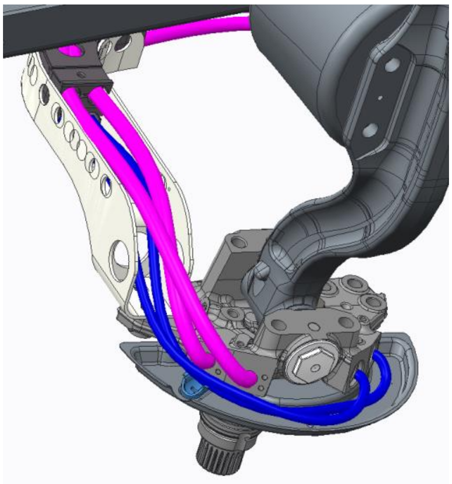


Figure 4.7 Wheel spindle B

Figure 4.8 The wheel area at the left hand side were the red circle surrounds the spring brake chamber. Authors own picture.

Both the BPR, figure 4.9 and 4.10, and one of the filters, figure 4.11 and 4.12, are placed in the middle of the chassis length. This is rather unnecessary becuase both the BPR and the filter are connected to the pump which makes the placement of these components much more logical if they where placed nearer the pump. As can be seen in figure 4.10 the area around the BPR is compact as a result of the amount of hoses. The filter´s position, se figure 4.12, also makes the routing slightly critical due to the hoses going along the chassis.

The BPR can be found in appendix figure A.9, where its ports are marked out. These ports are also positioned in the hydraulic scheme in figure A.1 and A.2, where the lines are explained in table A.1.

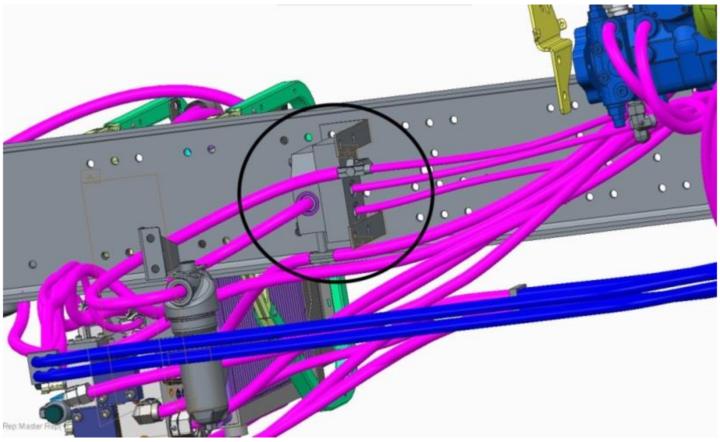


Figure 4.9 The hydraulic system, viewing the BPR

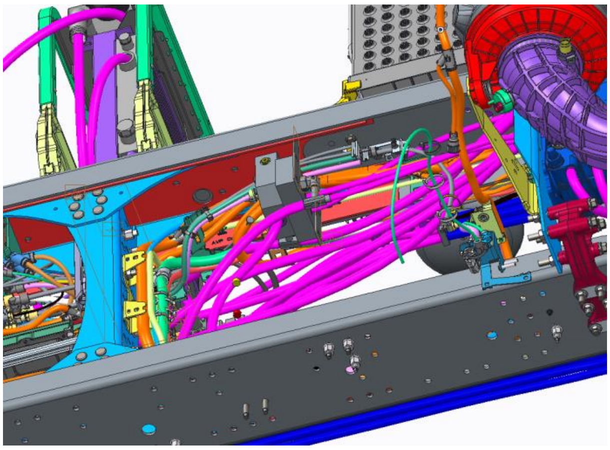


Figure 4.10 Complete hydraulic system, viewing BPR

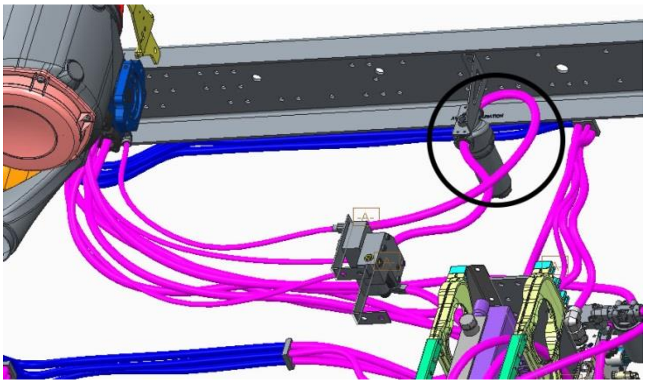


Figure 4.11 Hydraulic oil filter

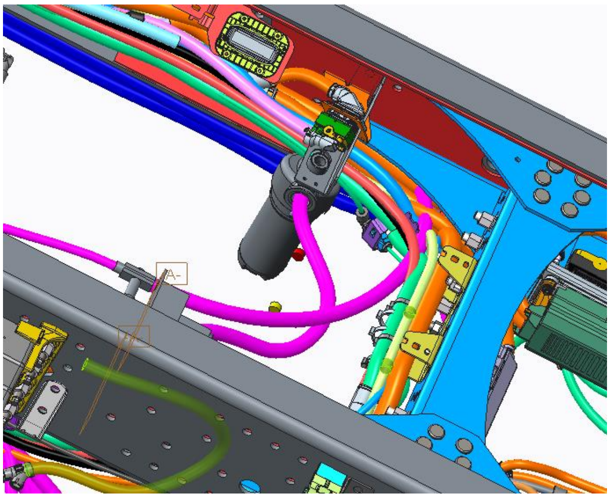


Figure 4.12 Complete hydraulic system, viewing hydraulic oil filter

In figure 4.13 the hydraulic tank, oil cooler and the other filter are illustrated.

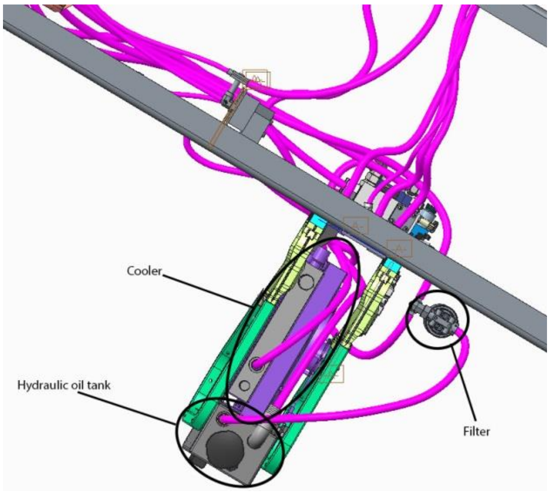


Figure 4.13 Hydraulic tank, cooler and filter

Since every hose and pipe (behind the pump) must be routed under or along the chassis, the routing to and from cooler, tank and filter is slightly critical. By studying figure 4.14 it can be supposed that the hoses going between cooler, chassis and HTA are positioned in such a narrow position that their possibility to move is highly limited. The routing to these ports can be presumed to be both complicated for the installer and therefore takes up unnecessary installation time.

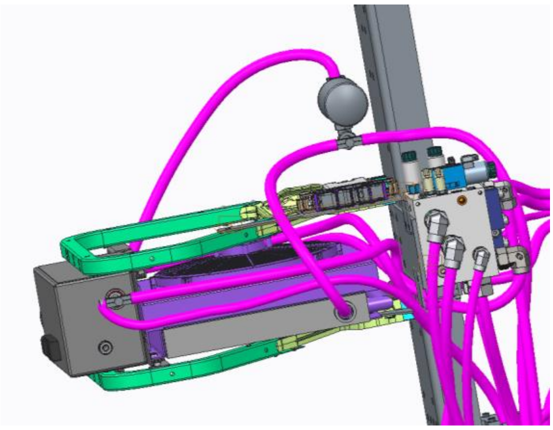


Figure 4.14 Hydraulic tank, cooler and filter seen from the underside

The HTA, figure 4.15 and 4.16, is kind of the center point of the hydraulic system since so many hoses goes to and from the HTA. A further understanding of the amount of hoses going to and from the HTA can be gained when studying figure A.11 in appendix.

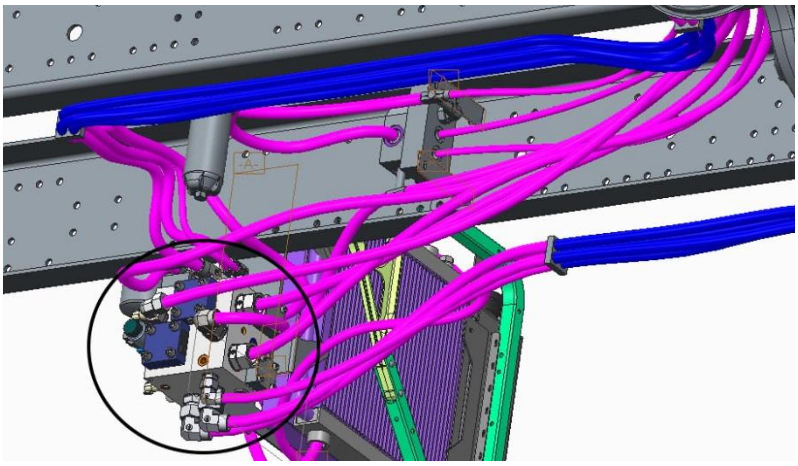


Figure 4.15 HTA

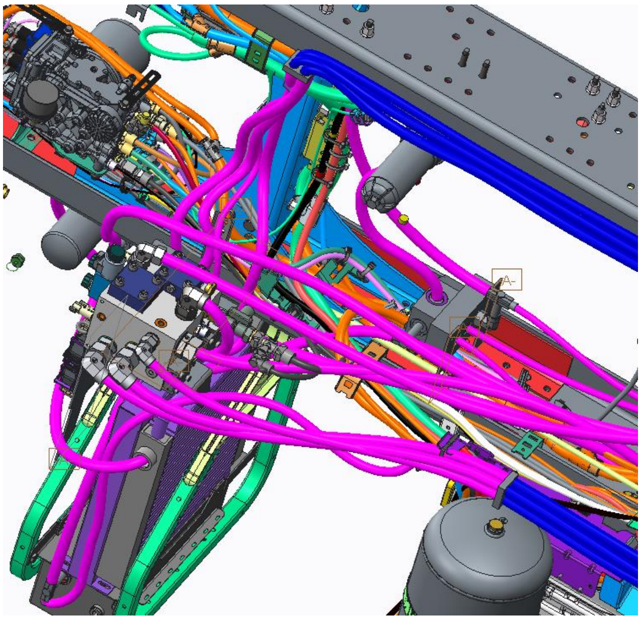


Figure 4.16 Hydraulic system with affecting surroundings, viewing HTA

The hoses going from the pipes (blue color) to both HTA and tank causes complicated routing since these areas are compact as a result of the surrounding components and therefore limit the possible ways to route.

The tank, HTA and cooler can also be seen in the appendix, in figures A.9 – A.11 which can be studied for a more advanced understanding.

4.2 Knowledge building

The knowledge building resulted partly in the chapter called "Theory" since the visits, meetings and interviews resulted in a collection of facts, suitable for the theory chapter.

4.2.1 Study visits

From the visit in Braås knowledge of the hydraulic system was gained. According to Jörgen (personal information, 20 January 2016) pipes should be used when the transport channels are fixed, i.e. when they do not need to be able to move. It is easier to route hoses since pipes need to fit exactly which could be complicated in series production. This depends on if a pipe would have the wrong measurements it must be exchanged or fixed. To fix a wrong measurement or bending on a pipe takes time to solve, while a hose is flexible and allows the length to vary. Hoses also have a much more flexible structure than pipes.

There should never chafe on a hose so that the outer rubber comes off, as in figure 4.5. If a crack would occur and water comes in contact with the metal reinforcement the reinforcement could corrode and the hoses will break. A protection against skidding made of plastic could prevent this type of wearing.

According to Jörgen, the couplings are the problem when it comes to wearing caused from weather and environment during usage. Hoses endure most of the weather and road conditions. The hoses cannot endure a too small bending radius since that would make the hoses chafe, which would later on lead to development of defects. Since it is desirable with a quick assemble of the hoses, pre montage, i.e. that the components comes delivered to the workshop with hydraulic hoses and couplings already installed, is a possible alternative.

The visit at Bosch Rexroth gave a deeper understanding of the components of the hydraulic system which can be studied in chapter 2.2. Jacob (personal information, 3 February 2016)also explained how to make out the hydraulic scheme, figure A.1 in appendix, where the different components are positioned, how the hydraulic system works and how that can be translated from this scheme. The understandings of this hydraulic scheme made it easier to create the table of routing, table A.1, and the routing scheme, figure A.2.

Jacob also explained the differences of open system and closed system, which can be read in 2.2.1, and the function of these systems and when they are applied.

At the trip to the production in Tuve it appeared that the main problem with the hydraulic system today (seen from a production perspective) is that it takes up to long time during installation (personal information, Per-Anders 1. 16 Mars 2016). A solution of the routing should offer an as short installation time as possible. As much as possible should be pre montaged, either at distributer or at one of the montage stations in Tuve, but it should never take up extra time neither cause an after treatment. Today the installation time are 7 minutes per station but are to be reduced to 4 minutes. If the installation would cross 5 minutes at installation at one station after montage is required. Today smaller objects are pre-montaged to the components, such as couplings, small pipes and valves and everything else small which would be hard to reach when the component is mounted. There exist a possibility of pre montage of coupling and smaller hoses and pipes at the production, which are encouraged since all pre montage speed up the installation process at chassis. However the pre montage cannot take up too much time since that would affect the whole production. Therefore there were recommended that some pre montage is done by the distributor.

The production is always aiming at working in an as ergonomic work condition as possible. This could affect the possibility of different placements of components since the installation of them could not be as ergonomic that it should.

There is a possibility to place the components where they should be in the system but not fasten them entirely until afterward in order to reach the entry port easier, if it would lead to shortened installation time. Although it is hard to know what is required for this kind of pre installation, if the hoses must be fastened in some way or if it is enough that the hoses are just fastened to one component.

Hoses are always to prefer while routing since the hoses are more flexible and do not need as accurate length as pipes. A pipe´s length and bending angle must be very accurate, which is sometimes complicated. It is also desirable to have the same kind of couplings with the same locking mechanism since this would speed up the time effectively. However it should also be clear, regardless who is installing the hoses, of where every hose will go. Unnecessary time will be spilled if the assembler must check the different ports because of doubtful placement.

4.2.2 Meetings and interviews

During the meeting with Johan and Nicola the hydraulic routing was discussed and focus laid on a solution that is production adapted. Johan (personal information, 2 Mars 2016) pointed out that the most critical area was the pipes going under the chassis (connected to hoses to wheel end spindle, HTA and oil tank), see picture 4.17 were the black ellipses mark the mentioned pipes. The problem is that these pipes are expensive, takes too long time to be installed and there is not much space for them to be routed at. Another problem with the pipes is that pipes are not as durable as the hoses since they cannot be stretched in any way and are not as flexible.

The connections between pump and transport channels is also a problem since the pump have several exits and entry ports, which all require a coupling of some kind, and this slows down the installation time. If a solution would enable a quick installation to these ports would that be of interest. For example could these parts be pre montaged already at the supplier.

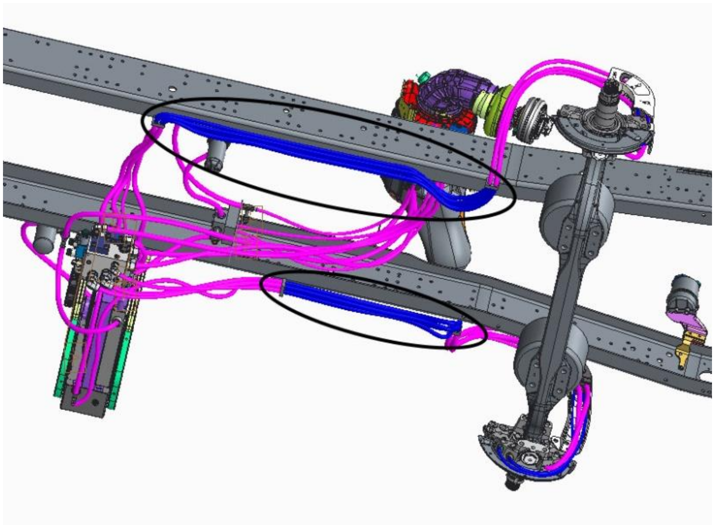


Figure 4.17 The previous routing of the hydraulic hoses

Important aspects to have in mind during the routing are that the assembly must be able to be performed in an ergonomic way, be easy to assemble, the hoses should not be exposed to wrong angles or twisting (see chapter 2.2.3), and the hoses and pipes should be able to be installed when the truck is upside down (the routing is performed when the chassis is upside down for ergonomic reasons).

Loose parts should be avoided since these tend to slow down the installation. The most optimal way would be to have as many assemblies (such as hoses with their couplings) preinstalled in the hydraulic components or to each other to increase the time efficiency. This since the less parts to install the better. According to Johan and Nicolai it a so-called quick-coupling should be considered in the routing since these enable a quick fastening of the hoses couplings to the components.

During the meeting with Martin 1 several aspects were discussed regarding the wheel end spindle and the bracket. According to Martin (personal information, 9 Mars 2016) the area around the wheel end spindle is an extremely exposed area, since the pipes and hoses have to endure dirt and stones coming up from the ground. High consciousness while routing the hoses is required since these have to endure stone shots, mud, cold environment and that the area is moving in different planes. There can never emerge any leakage of hydraulic oil, which could cause contact with the brake disc whose warmth could cause explosion.

The bracket and hose quality gets affected by the environment such as salt, winter and other possible environmental factors. The holes in today’s bracket, se figure 4.6, create flexibility in the material and reduce weight.

From the meeting with Mikael 1 an understanding of the routing as a process was discussed in how the routing is performed such as why and where eventual potential of improvement can be found based on Mikael´s point of view. Today it is Mikael who both bends the pipes and installs them. He established (personal information, 21 Mars 2016) that this could be done at the production line, but if so the exact length, bending angle and position of the pipes must be determined. Mikael established that the most critical area of the hydraulic routing is the routing of the hoses from the wheel end spindle to the pipes under chassis. This since the hoses are forced in to bending in more than one plane, and that Mikael has to twist the hoses in order for them to be able to follow the rotational movement that emerge when the wheels are turning. The routing of the lines which enters the wheel end spindle could also be seen as critical since they are exposed to the ambient environment, although this is solved with pipes and longer couplings, which is more durable than hoses. See figure 4.6 and 4.7 of the wheel end spindle.

It could be possible to pre-install shorter pipes directly to the hydraulic components before these are montaged on the truck assembly, in order to make the installation more effective. Although these pipes must in that case be clamped together in some way since it have to be sure that they are fixed. If a pipe is too long twisting could be emerged which causes leakage. To prevent this clamping are used which is also why the pre-installed pipes must be clamped together.

According to Mikael pipes are preferred when the assembly is supposed to be completely fixed and when the transport channel´s length and angle are exactly predefined. Hoses are preferable when the assembly is going to move and when the assembler needs extra flexibility and length during the routing. It is more common, while installing tee-couplings, to install the tee-coupling on a component so there are only two hoses entering the coupling. This depends on the need of making the coupling fix since it otherwise could move in a problematic way if it is positioned freely in the system. It is not impossible to place the tee-coupling freely and have all three hoses/pipes entering the coupling, but in that case the tee-coupling must be securely clamped in order to be completely still.

It could be possible to install safety quick couplings on the low pressure lines, although this could result in aggravated disassembly.

According to Mikael, for now, priority during the establishment of the hydraulic routing should be in durability and flexibility since the routing later on can be further adapted for time effectively but must be able to function correctly and under reasonable circumstances in order to be doable at all.

4.4 Requirement specification

The requirement specification is based on the facts that were gained from the literature and internet studies, the study visits and the meetings. During the concept generation the requirement specification was useful as a guide of what the limitations are and what must be fulfilled in order for the system to function as it should. One of the most important requirements that will affect the concept generation is that a hose can never be stretched, kinked, crushed or twisted at any time and neither can the transport channels be routed over the chassis behind the wheel area.

It is also important that the new concept have acceptable pressure drops, and do not increase the loss of pressure.

The complete list of requirements can be found in appendix, Table A.2.

4.5 First concept generation

As been said earlier the purpose of the first concept generation was to receive many different solutions on the whole hydraulic system, in order to be able to select one area to further investigate deeper in a second concept generation. From this concept generation both ideas were sketched for eventual replacement of the components in the system and different solution to simplify and speed up montage in different forms. The idea sketches can be seen in appendix as figures A.12 – A.16. The thoughts regarding the replacement were in order to move components closer to each other (when possible) and could the routing of these be simplified and therefore executed faster. Some hoses could be bundled before the installation in order to decrease the amount of parts to install. The hoses going to and from the wheel end spindle, tank and HTA for example could just as well be bundled together before installation.

The ideas regarding the wheel end spindles were mainly to speed up the installation process but importance also laid in a sustainable solution. The most “far of” idea regarding the wheel spindle is the coupling that is supposed to be preinstalled on the wheel end spindle and since the pipes also are going to be pre montage together as one two pipes can be installed as one, which minimalizes the amount of installations. These couplings are supposed to be fastened with a SAE flange. Quick couplings could possibly be placed in the ports on the new coupling for pipes, since these only transport low pressures liquid.

4.5.1 Concept elimination

After having discussed each idea with Dennis Persson in how they are thought to function and why these could be of interest, it was agreed that the area to further investigate should be the area of the wheel end spindle. This is because of the troubles regarding the hoses bending in several planes while going from wheel spindle to the console were they convert to pipe (se figure 4.6). The biggest problem today in the hydraulic system is to be able to route these cables in a sustainable way so that the assembly is durable and able to montage quick. The solution will be of no interest if it is not both lasting and quick to assemble.

4.6 Second concept generation

The second concept generation resulted in six different concepts regarding how the hydraulic hoses and pipes possibly could be routed for a lasting assembly that is also production adapted (quick to install). During the concept generation focus have been put on enabling for the hoses to move in only one plane at the same time shall the hoses not collide with the surrounding components. The hoses shall also be provided with enough slack at the same time as the hose have a bending limit.

The concept figures will be presented with thinner and thicker square couplings. The thinner couplings represent a possible entry port of a bracket and the thicker ones will represent regular couplings whose purpose are to keep the assemblies stationary. It should also be said that any eventual bracket that will be fastened at the wheel end spindle will only be fastened at the already positioned fastenings points, se figure 4.18 were the yellow circles represent the fastenings points.

This image could not be public viewed

Figure 4.18 Left wheel end spindle

Concept 1 – Hose routed along the steering axle

In the first concept focus was laid on how the hoses could avoid the surrounding components that both limit the possible ways to route and could chafe on the hoses. The solution was to route the hoses along the steering axle. The idea was to have the pipes installed on the wheel end spindle which will lead the following hoses along the axle which enter a coupling that steers the hoses at a 90 degrees angle in the direction of the rear side of the truck. Se picture 4.19, which illustrate the routing.

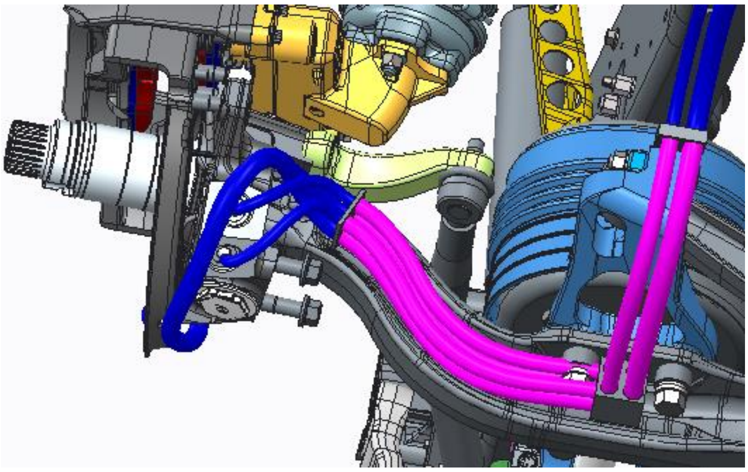


Figure 4.19 Concept 1 – Hose routed along the steering axle, left wheel spindle bottom view

Concept 2 – Hose routed under chassis

In the second concept the hoses from the wheel end spindle are routed as a loop going under the chassis. The loop is to give the hoses enough slack and the reason why the hoses are routed under the chassis is to avoid the surrounding components that compromise the routing above the chassis. In figure 4.20 it can be seen how the hose is thought to be routed. The reason why the hoses were guided to the front side of the wheel end spindle and not the rear (as it goes today) is that the hoses were believed to receive more slack this way and a more natural routing due to the fastening points of the bracket on the wheel end spindle.

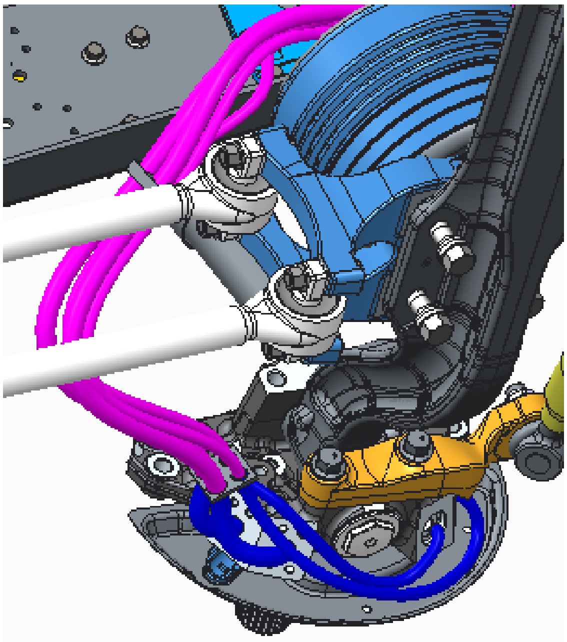


Figure 4.20 Concept 2 – Hose routed under chassis, bottom view on the right wheel end spindle

If there ought to be a bracket installed on the wheel end spindle to keep the pipes from vibrating this concept does allow for a small bracket that possibly could be as small that it can be preinstalled at axle fabric, and this reduces installation time. Since the bracket and the console can be installed at the same height, the hoses are believed to move in only one plane when the wheel turns.

Concept 3 – Hose routed as a horizontally curve over chassis

In the third concept the hoses are routed over chassis as a wide curve. In order to avoid surrounding components, especially the spring brake chamber, the hoses are guided through a bracket away from the spring brake chamber and through an arch, entering the console at the chassis. The hoses are then led to a new console with pipes under the chassis. Study picture 4.21 to further understand how the hoses are routed. The picture illustrates a bracket which leads the hoses from the wheel end spindle, which the hoses exit at the beginning of the curve. Since the hoses are going to be properly fastened at the brackets entry ports are they going to function as a new hose, and therefore not be bending in several planes. The routing at such high level also secures the hoses from wearing of the environments such as salt, stones and other factors that could reduce the service life.

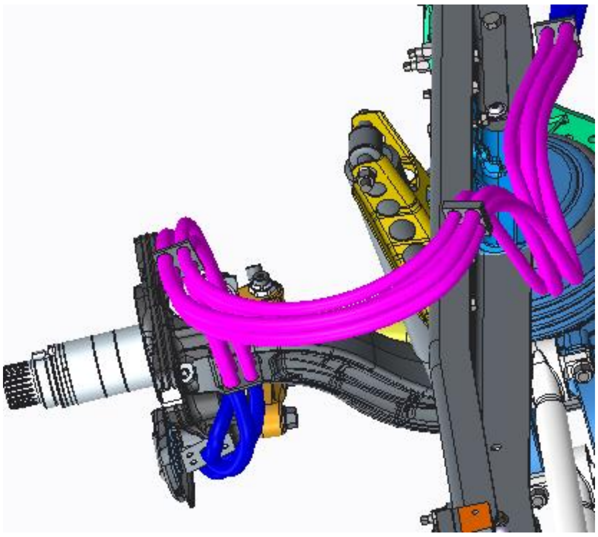


Figure 4.21 Concept 3 – Hose routed as a horizontally curve over chassis, front upper view, right wheel end spindle

One critical aspect that was seen already at this state was the cover (which is called noise shield) that is placed on the chassis, which possibly (if the hoses collide with the cover) could be solved with making a hole in the cover, se figure 4.22. The red arrow points out the cover and the orange arrow the type of hole that could possibly be made in order for this concept to work.

Figure 4.22 Cover on the chassis, top view at right wheel end spindle

Concept 4 – Hose routed as a vertical curve over chassis

In order to avoid making another hole in the cover at the chassis a similar solution to concept 3 was made, only this time the hoses are placed vertically over the chassis, se figure 4.23. A bracket, installed on the wheel end spindle, leads and protects the hoses until the curve starts from which the hoses will run freely to a fix console. This concept also makes it easier for reparation/disassembly of the hoses since each port will be easy to reach if it ever will be of interest to change any of these hoses after a while.

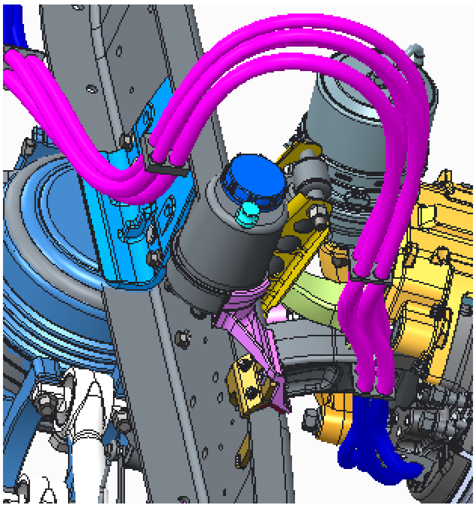


Figure 4.23 Concept 4 – Hose routed as a vertical curve over chassis, top view at left wheel spindle

Concept 5 – Bracket on the chassis

In this concept the large bending radius of the hoses was tried to be avoided with pipes instead of hoses. This was executed through placing pipes along the chassis side, se figure 4.24. The advance in using pipes is that they allow smaller bending radius.

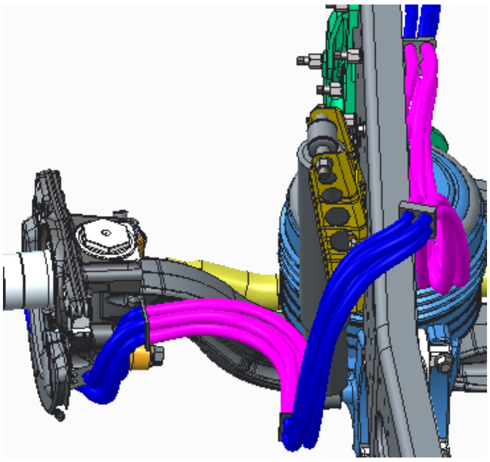


Figure 4.24 Concept 5 – Bracket on the chassis,
top view right wheel end spindle

In order to keep the pipes on the chassis fixed, or else the vibrations of the pipes could make the system collapse, a bracket must be installed on the chassis. The pipes on chassis should run through this bracket which will have its end and start at the square consoles seen in the figure. The hoses are going to run freely without any bracket but a bundle could keep the hoses safe from wearing.

Concept 6 – Rotating coupling on chassis

The last idea was invented by the constant problem of the hoses bending when the wheels are turning. This problem is supposed to be solved by a rotating coupling, placed on top of the chassis which will allow the hoses to move along with the wheel end spindle when the wheels are turning. The concept can be seen in figure 4.25 and 4.26 were the console on the chassis is fastened whit a sort of kin pin, allowing it to rotate around the kin pin´s axle.

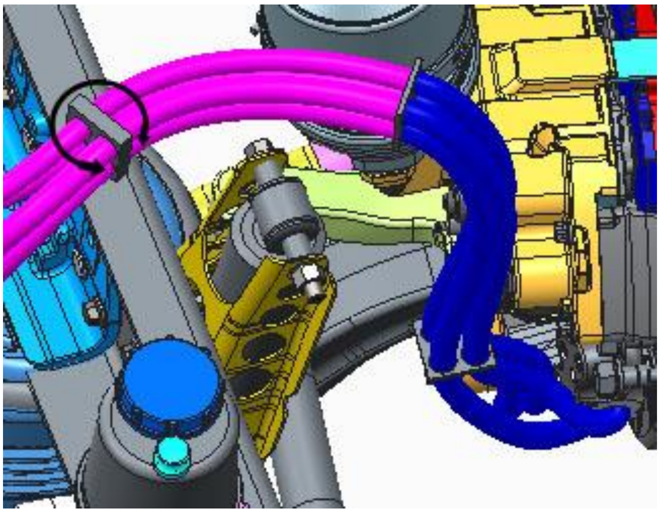


Figure 4.25 Concept 6 – Rotating coupling on chassis,
top view left wheel end spindle

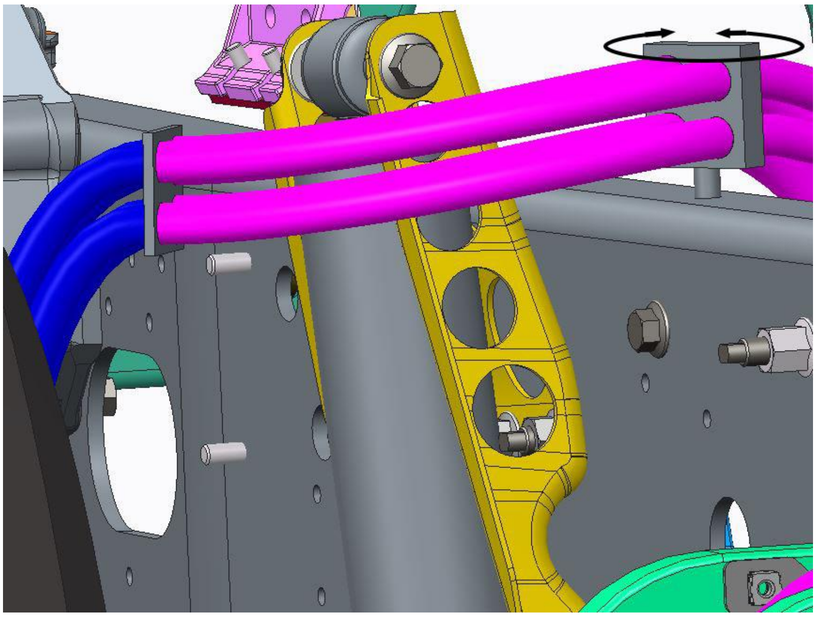


Figure 4.26 Concept 6 seen up close, rotating coupling to the left

Since the hoses are allowed to move along with the wheels movement, the slack of the hoses do not have to be as large as before. A bracket will be installed on the wheel end spindle which will keep the blue pipes from moving. These pipes could possibly be pre montaged in the bracket before the bracket is installed which will probably make the installation easier and quicker.

4.6.1 Concept evaluation with Kesselring matrix

From the concept generation each of the six concepts were presented in how they are supposed to be executed and thereafter what pros and cons they could result in, by judging from the sketches in Creo. Following comment on each concept idea is presented here:

Concept 1 – Hose routed along the steering axle

Even though this solution is avoiding the surrounding components that could otherwise tear on the hoses, this solution was seen as highly critical and hard to carry through. This is because of when the tires are about to turn the pipes on wheel end spindle will hit the hoses and the axle. The tie rod is clearly in the way for the hydraulic hoses and the narrow turn of the hoses along the axle is not to recommend for high pressure lines.

In this scenario it is also hard to give the hoses along the axle enough slack. In figure 4.2 the left wheel end spindle is presented which illustrates the recently listed problems. The fastening of the console, which was consciously wrongly placed on the picture since the bolt of the insulating cover on the steering axle is in the way, was thought to be able to integrate in the fastening mechanism for the insulating cover. Therefore the fastening of the console on the axle should not be the major problem in this concept.

Concept 2 – Hose routed under chassis

The comments regarding the second concept was that in order to be able to route the cable as in figure 4.3 the hoses must be routed closely to the tie rod, which is not preferable. The risk is that these will wear on the hose and that the assembly is both difficult to install and to exchange. Therefore, in order to avoid the tie rod, this concept could be executed laterally reversed. Although this solution would need some rethinking of how the bracket on the wheel end spindle should be designed. This type of routing could possibly cause high exposure on the hoses from the environment (salt, stones etc.). This kind of wearing on the hoses could be solved with an “armored sock” which works like a strong bundle and protects the hoses from possible ambient wearing.

There were also some comments on the possible difficulties of getting the proper length of the hoses due to the rotational movement. Also should, in this case, the console under the chassis and the end of the bracket be at the same height, otherwise the hoses will twist.

Concept 3 – Hose routed as a horizontally curve over chassis
Possibly this solution would be better if it was made laterally reversed due to the amount of space in front of contra behind the wheels. Although that would not necessary mean a radical change of the bracket. In case this concept proves to be of interest to further investigate a simulation of when the wheel is turning should be done, in order to find out if the shield on the wheels possibly could be in the way and wear on the hoses. In this case it could be pipes routed in the bracket instead of hoses since this part always will be fixed.

It should be possible to make a hole in the already mentioned cover (noise shield), that otherwise certainly will be in the way. Although another cover is supposed to align with the cover on chassis which could affect the placement of the hole and the execution of the fourth concept. See figure 4.27, were the mentioned cover is pointed out.

Figure 4.27 Noise shields on FH-1825

Concept 4 – Hose routed as a vertical curve over chassis
The vertical bow, fastened in the bracket on wheel end spindle and console on the chassis, will prevent the hoses from moving naturally and therefore make them twist when the wheel

is turning. If a swivel coupling is to be installed on the console at the chassis the hoses could be able to follow the wheels movement and therefore not twist.

If this concept is to be further investigated the amount of space inside the chassis should be investigated since this could be a problem due to the surrounding components.

Concept 5 – Bracket on the chassis

The first thought of this concept was that it gave the impression of a “clean” routing, i.e. not a lot of different hoses going in different directions. The pipes which will be installed in a bracket on the chassis side could possibly be placed further away from the wheel. Now the bracket is placed in such way that the hoses probably will wear on the components and maybe be bent too much, which will be avoided if the hoses are provided with longer length and more distance between other components.

Concept 6 – Rotating coupling on chassis

This idea was seen as innovative and possibly doable concept but the rotating console will need a lot of investigation on how it possibly could be constructed were the outcome would probably be a complex and expensive design.

The rotating console should be placed outside the chassis, or possibly under it (as concept 2), since it is preferable to avoid any installation on top of the chassis. It is also important that the exit port from the bracket is at the same height as the rotating console to avoid twisting.

Since the hoses are supposed to move along with how the rotation of the console will move around a lot inside the chassis which could wear on the hoses and on the surrounding components that could take damage from the moving hoses. The fact that the hoses are supposed to rotate along with the console creates a critical movement of the hoses going out from the console. This movement must be controlled since the hydraulic hoses never should move around freely. If this concept should be executed at some point these hoses inside the chassis should be securely fixed so that they do not move around, however they cannot be completely fixed.

Another problem that occur when there are moving parts is that this idea could cause noise since there will be movement of parts that otherwise are fix. This concept probably requires some sort of sound insulation. The mechanism will contain either roller bearing or ball bearing which must be able to be leakage free.

Kesselring matrix

The evaluation also resulted in a Kesselring matrix which can be found in appendix as figure A.17. The Kesselring matrix rated the third concept as the best, both regarding the listed criteria and when the perceived feeling was taken in to account. The hierarchy after number one came concept 2, 4, 6, 5 and last came concept 1. Considering the comments from the whole evaluation and the Kesselring was concept 2, 3, 4 and 5 chosen to further investigate in how they will move when the wheel is turning and also how they should be executed in more detail.

General comments

There were some general comments that regarded nearly all concepts which will here be presented here. The first establishment was that if the hoses at the “inside” of the chassis are supposed to be fixed, pipes should probably be used instead. Pipes would be to prefer in this case since they can be easy to pre montage, allowing a narrower bending radius and they are often cheaper. By the same reason the hoses in the hypothetical brackets could, and probably should, be exchanged to pipes since these will be fixed and preferably pre-montaged in the bracket. Due to the construction of the wheels and its components the bracket and the transport channels within must be bent in such way that they do not interfere with the wheel which also makes pipes preferable since these allow a smaller bending radius which make this installation easier.

A comment on every concept was also that none of the concepts really fully avoid bending in more than one plane. This depends on the wheels that will move vertically, regardless from the chassis, which will make everything attached to the wheels move in two planes, up and down as well as sideways.

For the investigation and further development of these concept, the selected concepts should also be simulated in order to fully know of they will endure the movements of the area.

It was appreciated if the routing could provide easy disassemble and reparation, as some concept does, since these hoses are going to be exchanged at some point.

4.7 Further investigation and iteration of the routing

In this chapter the investigation of concept 2, 3, 4 and 5 is presented. This lead to one winning concept which was then worked out in detail.

4.7.1 Test of concepts

The first concept to be investigated and simulated in Creo Parametric was the third concept. The simulation made it clear that the console on the chassis cannot be positioned as in figure 4.21, were the position of the console makes the hoses bend in a curve of 180 degrees. This was determined since the hoses “disappeared” when they were bending in a too small radius. This depends on that the hoses cannot at this position have the correct hose length without bending under minimum bending radius. This kind of routing also makes the hoses go through the shock absorber when the right wheel is turning right and vice versa as can be seen in figure 4.28.

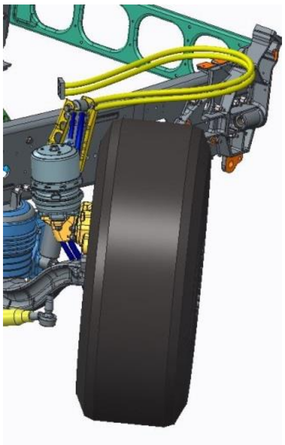


Figure 4.28 Wheel on the right hand side, routing of concept 3

When the first idea to route the hoses was proven not to work, several other possible positions of both brackets and console at the chassis were tried out in an attempt to find possible ways to route. From the concept evaluation it was said that the third concept possibly could benefit from being routed reversed which was investigated during the simulation. Figure 4.29 shows two routing scenarios where wheel A is routed reversed and B is routed as the concept was thought at first, with a few changes of the position of the console at chassis. It can be seen in the figure that the routing at wheel B the console is moved further away and angled towards the wheel to avoid hoses bending too much and collide with other components (as they do in figure 4.28).

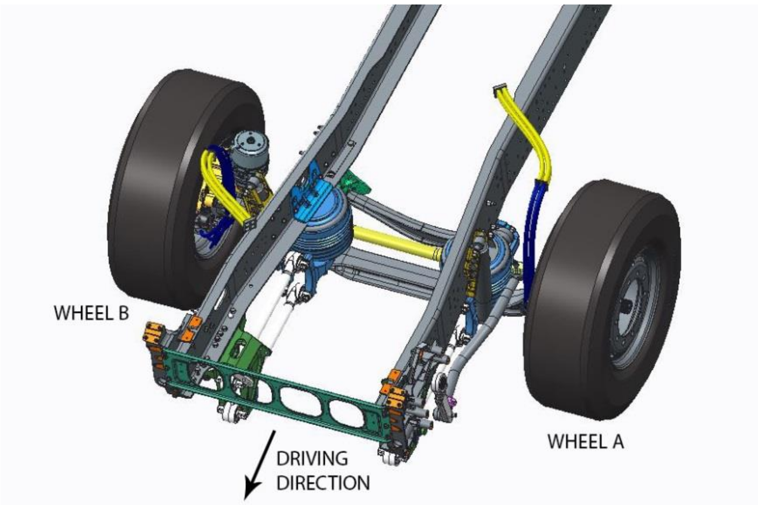


Figure 4.29 Illustration of the two different routing scenarios of concept 3

One major problem with the routing at wheel B in figure 4.29 is that the hoses are forced to pull out too much since the attachment on the wheel end spindle is at the left side of the right wheel spindle. The position of this attachment makes the hoses move a lot more since the bracket´s exit port are further away from the rotational point which is approximately in the middle of the spring brake chamber. This idea of routing is preferable since it is easier to place the console in front of the wheel area on chassis than back, due to the amount of other components that is in the way at the back of the chassis. This is the main problem with the idea of routing the hoses reversed, there are much more components that is in the way in the area behind the wheel which makes the possible ways of routing more difficult. The positive aspect, however, in routing as wheel A in figure 4.29 is that since the bracket´s exit port is positioned right under the rotational point the hoses are moving in a smaller span. This makes it easier to control the movements of the hoses.

Thereafter concept 2 was evaluated which proved to be not as preferable as thought. Since the hoses are going to be routed under chassis the risk of the wheel colliding with the hoses is high, which would wear extremely on the hoses and reduce the service life significantly. The hoses length could not be shortened due to the massive wheel movements which require longer hoses. The concept was at first routed in the direction as in the main idea (hoses going forward along the chassis). Although this was proven not to work since the stabilizer bar, which is the white parallel bars in figure 4.30, is moving up and down when the wheel cut is adjusted (the wheel is turning right or left). This makes it hard to route the hoses in this area and since the hoses will collide with the tire if the console on chassis were to be moved further in front, the only way of routing this concept was reversed. Although the lack of routing space behind the wheel area is making it almost impossible to route in a reversed way.

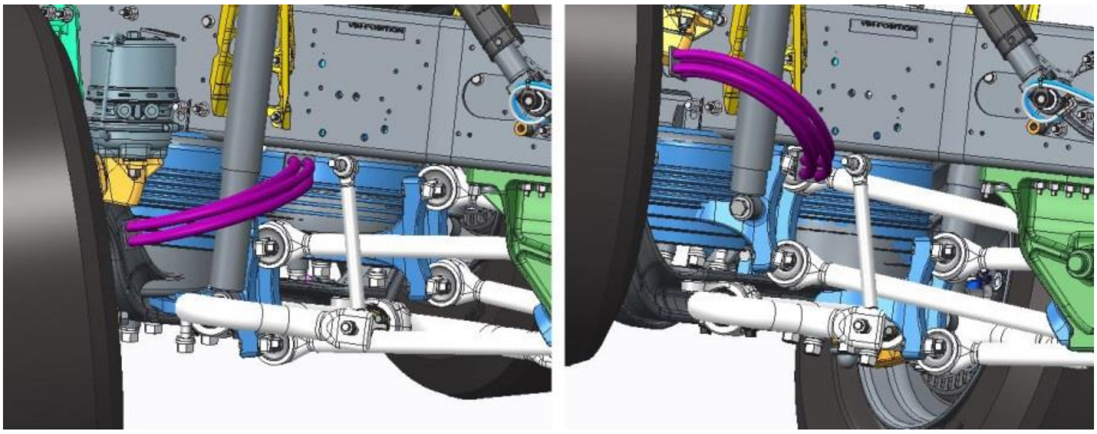


Figure 4.30 The movement of the stabilizer bar at the right hand wheel

Concept 5, with a console on the chassis, was a good way to route since the movement of the hoses became controlled. Although this concept was proven to cause similar problems as concept 2 were the hoses risk to either collide with the tire when the wheels are turning, or to come in contact with surrounding components which would wear on the hoses and could lead to damages on the components. In figure 4.30 and 4.31 a bottom view is showed on the simulation of the 5 concept were it can be seen that it is hard for the hoses to move correctly without leading to any risk of damages.

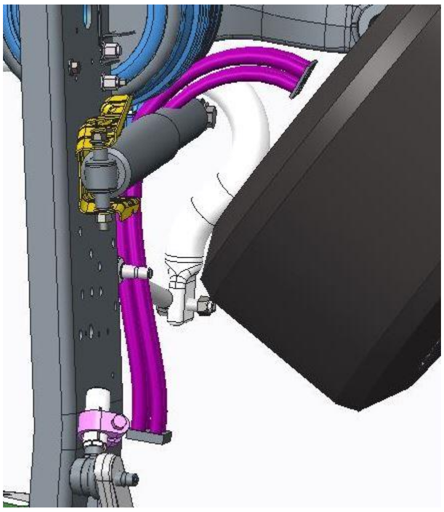


Figure 4.30 Bottom view, left hand wheel side

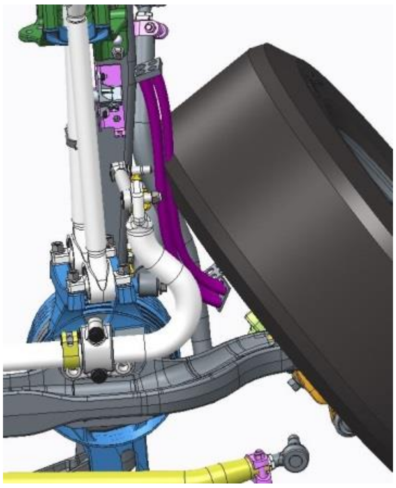


Figure 4.31 Bottom view left hand wheel side

Since this concept is based on a bracket on the chassis, this concept will be impossible to execute in a reversed way from the first idea (route the hoses at the back side of the wheel), based on the surrounding components on the FH – 1825 truck. One problem is also the wearing from the surrounding environment which will always be a cause of problem if the hoses are routed below the chassis, which is why pipes are preferable at lower levels near the ground.

Finaly concept 4 was simulated. At the concept evaluation this concept was thought not to work since the hoses probably are going to twist both when the wheels are turning, but even more when they are moving in different roll angles. This hypothesis was proven to be correct and since the hoses are routed as a vertical bow the covers on chassis will be in the way of the hoses. The way of routing these hoses was tried in different ways but it was proven that it was impossible to neither avoid the hoses from twisting nor from collide with the tire. The hoses could possibly be prevented from bumping into the tires if the console on the chassis was placed further in the chassis, but due to the lack of space this could not be possible. Also if the wheel end spindle´s bracket´s exit port could be placed right above the wheels rotational point (above the spring brake chamber) the movements of the hoses could be more controlled, although the lack of routing place is in this case making this impossible.

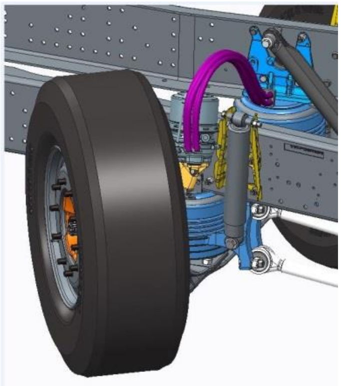


Figure 4.32 Wheel at the right hand side, seen from the front side

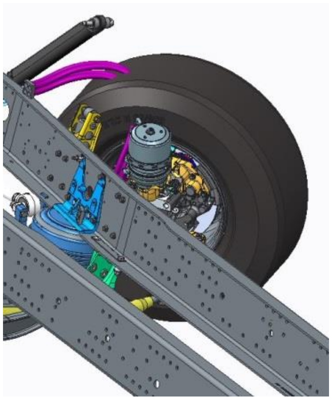


Figure 4.33 Top view, right hand wheel

4.7.2 Pugh matrix

The complete matrix can be seen in appendix, table A.18 were today´s solution is weighted against the concepts which was simulated in Creo Parametric. The simulated concept which were considered in the Pugh matrix were concepts 2, 3, 4 and 5. Some of the most important criteria that gave the most different results of the concepts was that the routing should prevent possible wearing from the nature, which is hard in those cases when the hoses is routed beneath the chassis. Another important criterion was that the hoses should not twist extremely when the wheels are moving in different directions. Though it was said during the concept elimination that each concept makes the hoses bend in more than one plane focus was on which concept allowed the hoses to bend as little as possible in more than one plane.

From the Pugh matrix it was clear that the best concept to further develop was concept 3, since this concept avoids surrounding components except for that the hoses will go through the cover on the chassis. This could be solved by making a hole in the cover. A negative aspect with this concept is that a special console must be constructed. This is because the simulation made it clear that the bracket´s exit port should be positioned at the rotational point, see figure 4.34 where the red arrow marks the rotational point, in order for the hoses to move correctly. Although if this bracket could be constructed in such way that the bracket´s exit port is near to the wheels rotational point is this the concept with the best movements of the hoses.

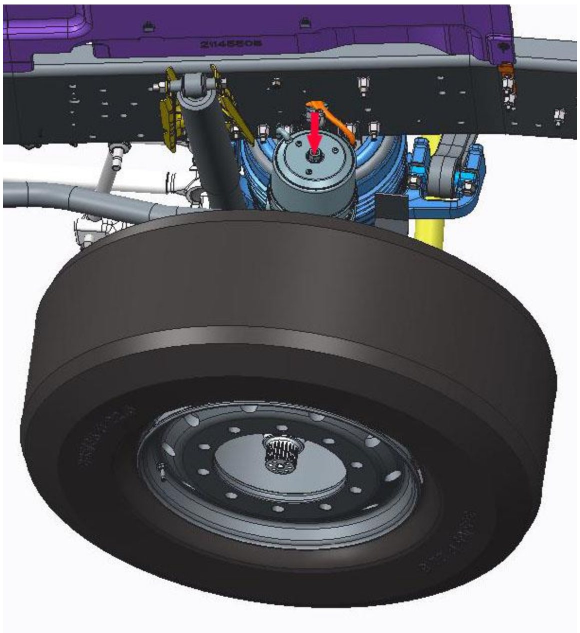


Figure 4.34 Left side wheel, top side view.

4.7.3 Investigation of chosen concept

When concept 3 was chosen as the most reasonable concept to develop, every component that possibly could affect the routing were put in to the Creo file, see figure 4.34. When every single part around the wheel end spindles areas was put into the model, it was discovered that the max and min values that have been used during the test of concepts were too extreme to be reasonable. I.e. the values of wheel cut and roll angle were too extreme to be reasonable since the wheels bumped into other parts. This was solved through examination of which values that was possible through adjusting the values until a reasonable outcome. The result can be seen in table 4.1. These values were used during the investigation of further specification of concept 3.

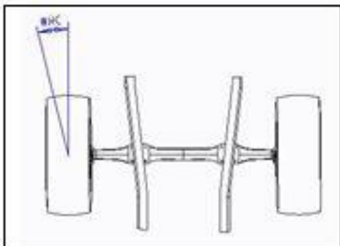
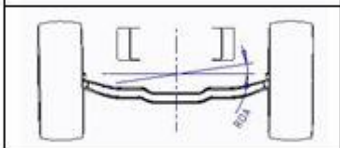
	WHC – Wheelcut	Outer max = 45,5° Inner max = -32°
	ROA1 – Roll angle	Over max = 6° Under max = -5,5°

Table 4.1 Adjusted data of wheel cut and roll angle

It was discovered that the wheel end spindle´s bracket´s exit port needs to be positioned above the rotational point in order for the hoses to move correctly. The bracket shall also be high enough so that the hoses do not collide with the tires when they are turning, nor wear on the shock absorber but also enough low so that the hoses do not wear on the wheel arch liner (the wheel cover). As can be seen in figure 4.34 the position of the console on the chassis is dependent on both the movements of the hoses and the surrounding components inside the chassis area. The console cannot be placed to far inside the chassis due to the requirement of a distance of 15 mm between other components, and it cannot be positioned everywhere lateral reversed due to the fastenings of the covers and the routing of other hoses which, are in the way. The console on the chassis and the exit port of the bracket should be at the same height when the roll angle is zero since this causes the minimal movement in several planes. It is also preferable that the routing of both sides (wheel A and B) are at equal height since this will simplify for a series production of brackets.

The final routing of the concept can be seen in figure 4.35, with all the affecting components of the routing, and figure 4.36 with some components hided in order to see the routing of the hydraulic hoses clearer. Note that the only components that have been put in the file are the ones that are affecting the routing of concept 3, in reality there is much more components behind the wheel areas. The left side and the right side could not be routed exactly the same way due to the different components laying inside the chassis, affecting the possible ways to route and thereby causes different positions of the consoles on the chassis.

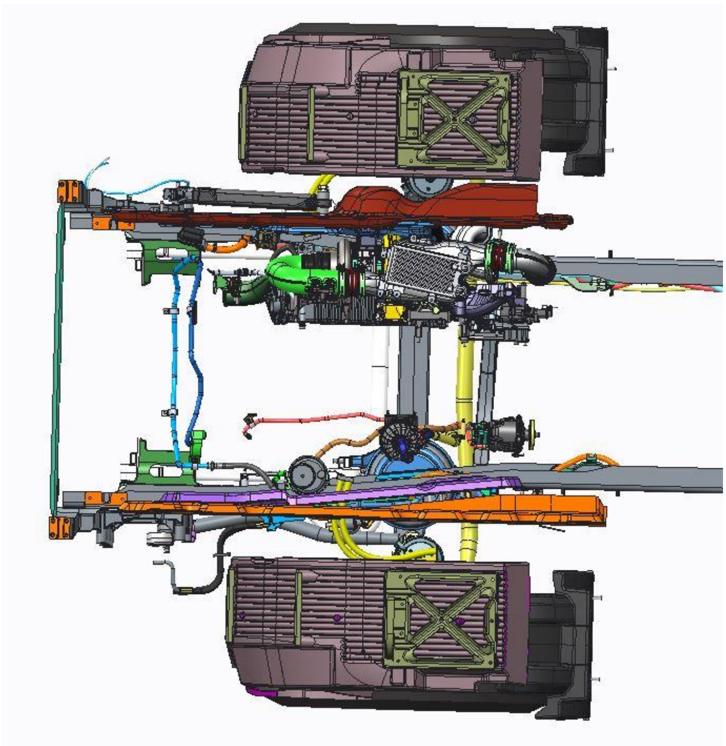


Figure 4.35 Top view with all surrounding components

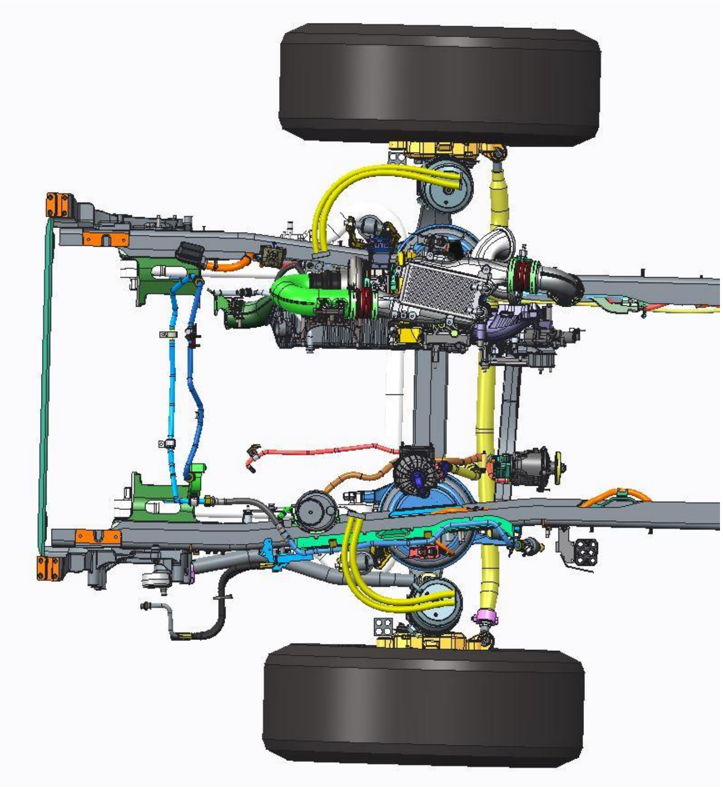


Figure 4.36 Top view of the routing without some components

At the left wheel much less components is interfering with the routing which allowed the console to be placed nearer the wheel axle. Although the two low pressure hoses "disappeared" when the wheel cut was set on -32 degrees and the roll angle on higher degrees than 5 and 5.5 degrees.

Some adjustments have to be made on the noise shields (covers on chassis) and the wheel arch liner (cover above the wheels). Since the hoses are bumping into the wheel arch liner and goes through the noise shields a hole on each cover is required. In figure 4.37 and 4.38 the movements on the hoses at the left wheel is illustrated. As can be seen the hoses are going through the inner side of the wheel arch liner which can easily be solved through constructing a hole as illustrated in figure 4.39.

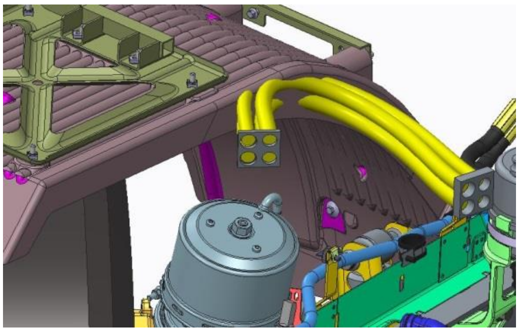


Figure 4.37 Left wheel, top side view from the inside

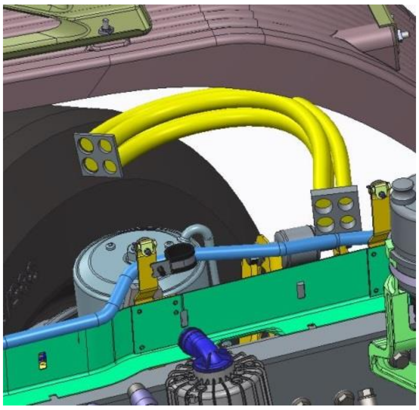


Figure 4.38 Left wheel, top side view seen from the inside

Figure 4.39 Left wheel arch liner, top side view seen from the inside

The movements of the hoses at the right wheel is illustrated in figure 4.40 and 4.41 where the hole is going to be a lot bigger than the cover at wheel A, which has to do with the farther away position from the rotational point of the console on chassis. The required size and position of the hole at the right wheel arch liner is presented in figure 4.41.

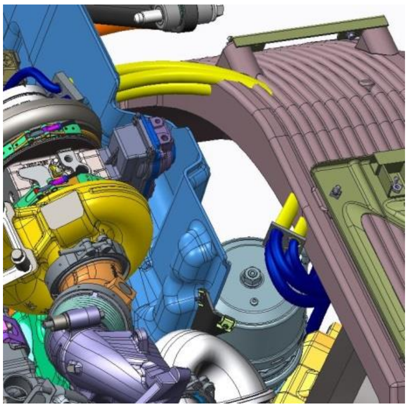


Figure 2.40 Right wheel, top side view from the inside

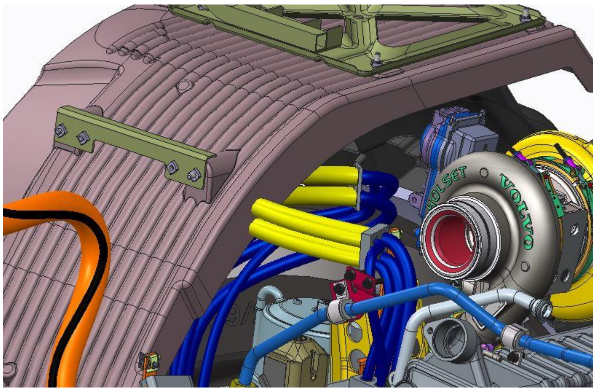


Figure 4.41 Right wheel, top view seen from the inside

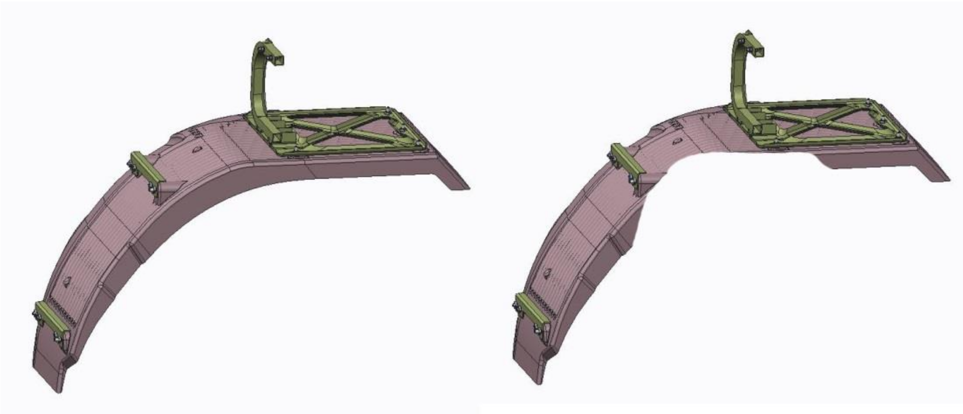


Figure 4.42 Right wheel arch liner, top side view seen from the inside

In figure 4.43 and 4.44 the noise shields on each wheel side are illustrated and where the holes should be positioned. These holes must be made in such a way that they enable the hoses to move along with how the wheels are turning and still have the distance of minimum 15 mm between hose and cover edge of the hole.

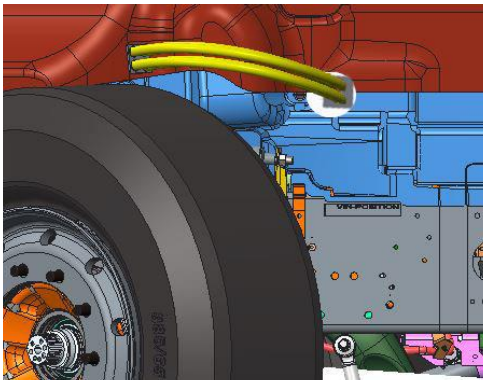


Figure 4.43Right noise shields, side view from the outside

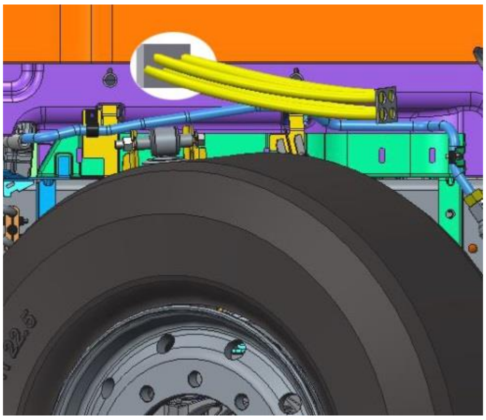


Figure 4.44 Left noise shields, side view from the outside

4.8 Design of bracket on wheel end spindle

The design process of the bracket on the wheel end spindle is presented here.

4.8.1 Concept generation of the complete design

Since it was said in the first concept evaluation of the routing that whenever the transport channels are fix they could be exchanged to pipes, are pipes instead of hoses routed inside the bracket. Based on the routing of the hoses following ideas of brackets (ways of position of the pipes) were designed:

Concept 3.A-1

The first concept of a bracket is seen in figure 4.45, where the bracket is fastened in the attachment points as was pointed out as the yellow points in figure 4.18. The pipes will enter the bracket in the lower square in the figure and bend in three 90 degree curves in order to exit as the concept requires. The pipes were first routed in such a way that they passed the spring brake chamber on the side instead of above it. This was proven not to work since there should be a distance between the wheels and pipes of 60 mm. It is also preferable to have the whole assembly's weight as near the attachments as possible to avoid that the bracket breaks.

If this concept would be presented as unstable, a kind of support that keeps the bracket and pipes from moving could be installed on the spring brake chamber.

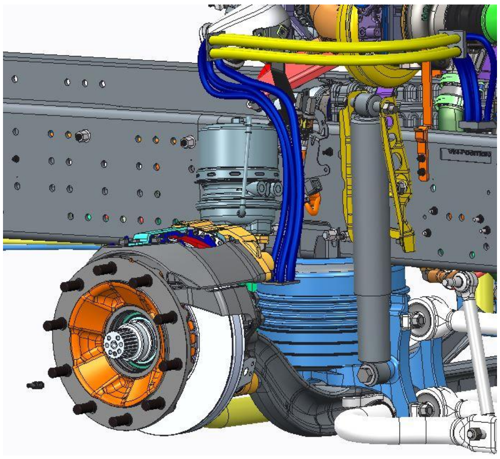


Figure 4.45 Concept 3.A-1 at the right wheel side

Concept 3.B-1

In this concept the bracket is supposed to be shaped as a half circle in order to lead the pipes as today´s solution. This idea makes the pipes move in a natural way and not make any unnecessary bending. Although the total weight of pipes and bracket could be too heavy for the conditions with only three attachments on the left side. The concept is illustrated in figure 4.46 where there is a similarity of today's bracket since the pipes are positioned in the opposite side.

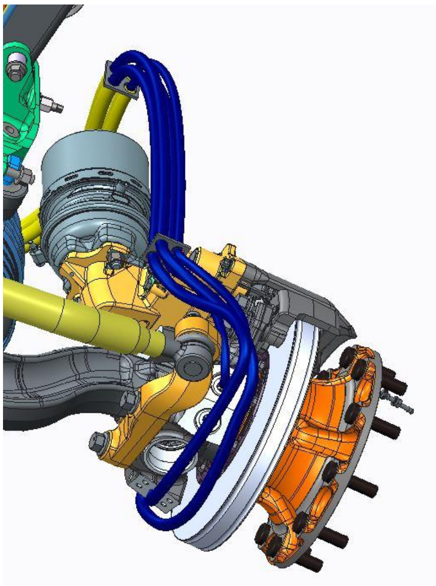


Figure 4.46 Concept 3.B bottom view at the right wheel side

Concept 3.B-2

This concept is based on the same pipe routing as in the former concept (3.B-1) but instead of having a bracket fastened on the wheel spindle, in this case, the bracket would be fastened at the side of the spring brake chamber. This would reduce the weight that is put on the bracket otherwise and enables the bracket to easily be pre-montaged before the spring brake chamber is installed.

Concept 3.1-1

Concept 3.1-1 is rather different from the other concepts since the solution aims at changing the surroundings instead of the bracket. This is thought to be done through changing position on the wheel spindles with each other. If the wheel end spindles changes with the other ones position the attachments to the bracket will be on the opposite side, which makes it possible to have a similar design as the one that is used today. Since todays bracket is a rather simple construction with the center of mass placed in a more reasonable position, are the assemblies more stable.

4.8.2 List of pros and cons

The list of pros and cons showed that either concept idea 3.B-1 or 3.1-1 is the best. Concept 3.B-1 was considered rather critical though, since the bracket´s center of mass is positioned far away from the attachment points, making the risk of collapse higher. Although this design enables for a kind of pre-montage of a part of the bracket, supposedly already at the axle factory.

According to Martin 1 it is possible to change the positions of the wheel end spindles, although it is more desirable to position the wheel end spindle in such a way that the high pressure lines are positioned in front of the steering axle. This is because the high pressure lines are believed to be more covered from the environment this way and it makes the assembly easier to montage. Since idea 3.B-1 needed support and therefore seen as a too complicated solution concept 3.1-1 was selected to make a model of, this required that the wheel end spindles exchanged place with one and other. The complete list of pros and cons can be found in appendix as Figure A.19.

4.9 Final solution

The final solution resulted in a concept routing of the hydraulic hoses and pipes at the wheel end area and also an idea of a bracket design. In figure 4.47 and 4.48 the final solution is presented where the majority of the surrounding objects have been hided in order to easier see the routing of the hydraulics.

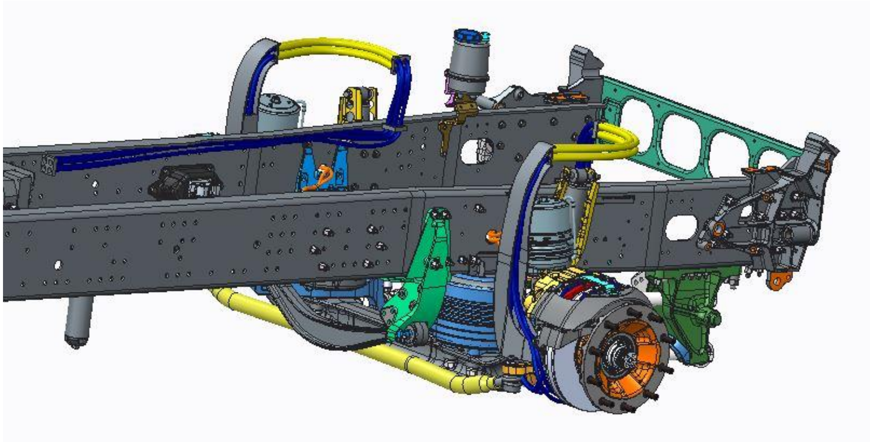


Figure 4.47 Final solution, seen from the right hand side at a top side view

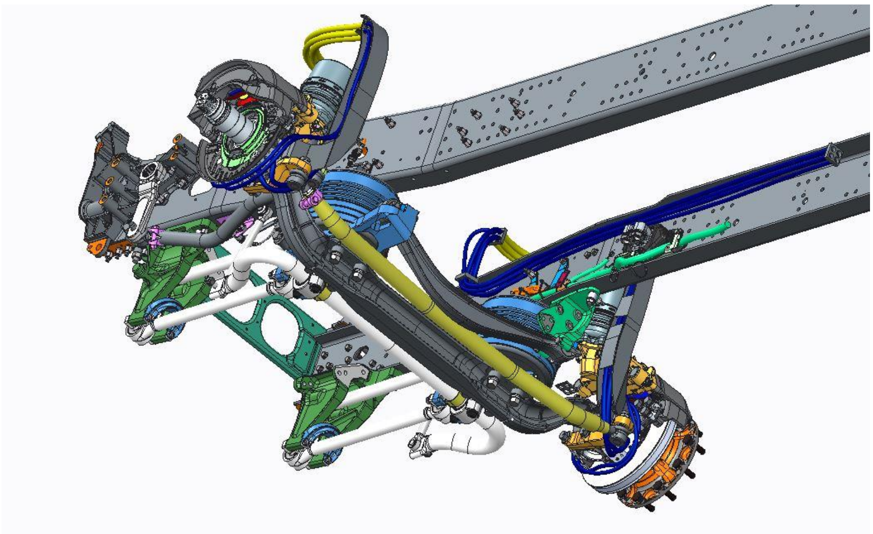


Figure 4.48 Final solution, seen from the left hand side at a bottom side view

The lines between wheel end spindle and the control valve such as the tank is routed with pipes since these will be fix and could therefore be routed at the first stage of the production line. It is also a profit to use pipes instead of hose in this case, since the pipes allow a smaller bending radius which enables for more complex routing and the diameter of the pipes are much smaller which is a profit due to the lack of space.

At the entry ports of the wheel end spindles pipes are used, which does not change to hose until the exit port of the bracket. The reason why there are pipes in the bracket instead of hose, as it is in today´s routing, is that these transport channels are supposed to be fixed which makes pipes more preferable. Pipes are also more resistant from the possible wearing from the environment (suck as salt, stones, mud etc.) which makes it necessary to have pipes this close to wheel and ground.

The final bracket was constructed in such a way that it enables for pre-installation, preferably already at the axle factory. The brackets can be seen in figure 4.49 and 4.50 where part 1 of the brackets is the piece which is supposed to be pre-montaged at the supplier. Part 2 can supposedly be installed through riveting with the pipes already installed. This way the production time is hopefully reduced since it reduces some of the installation moments.

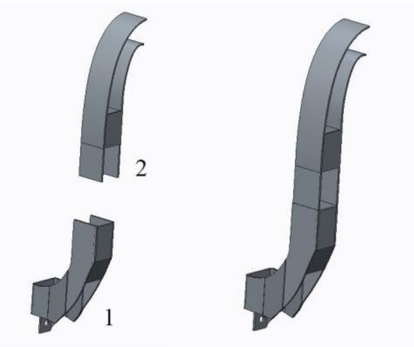


Figure 4.49 Left side bracket, to the left are the two parts and to the right when it is assembled

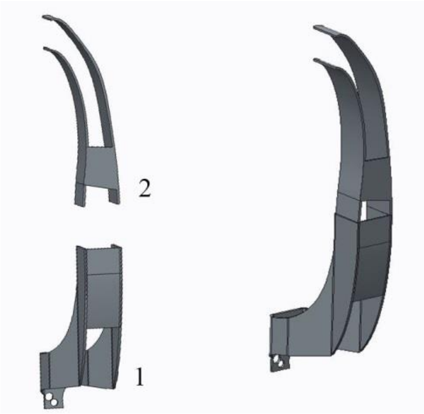


Figure 4.50 Right side bracket, to the left are the two parts and to the right when it is assembled

Although the brackets are designed to avoid colliding with the surrounding, it could not be avoided that the bracket collides with the steering axle on both sides and the upper noise cover at the right side. In figure 4.51 the right side bracket is shown when the wheels are turning right with a roll angle of -5.5 degrees. This could be solved by making another hole in this cover, in order to prevent them from colliding with each other. The problem where the bracket is colliding with the steering axle could, due to the limited time, not be solved which makes the brackets a concept design which have to be reconstructed further in order to function.

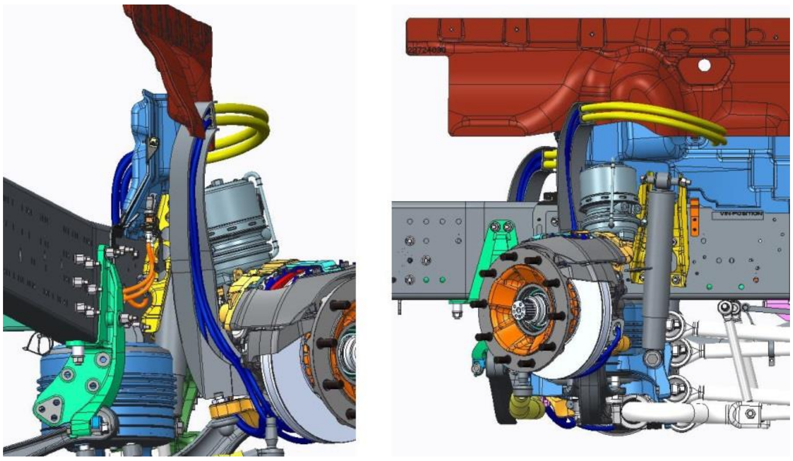


Figure 4.51 Right side´s bracket colliding with the upper noise shield

Lastly the hoses going from bracket to chassis could be routed as a one piece if the hoses where to be assembled in a so called “hose carpet” before the installation, which also reduces the amount of parts to be installed with shorter installation time.

5. DISCUSSION

The final routing is not an optimal solution since hydraulic hoses should never bend in more than one plane. The selected concept routing is moving in only one plane when the vehicle is driving in normal situation (when roll angle is zero) and at varying wheel cuts (when the wheels are turning). This depends on that the exit port from the bracket and the console on the chassis is at the same height, allowing better conditions at all time for the hoses. Although the hoses are forced to move in two planes when the roll angle of the wheels are more or less than zero. But due to the limited time this was the best solution possible. The concept routing is also better than the executed routing today since the hoses today are forced into twisting and are from start bent in several planes, making the conditions bad even from the beginning and even worse when the wheels are moving. Therefore this concept of routing is preferable over today's solution since the hydraulic hoses are given better conditions for a longer service life. Since the final result would also be even more accepted as a good solution if the attachment points on the wheel end spindle were positioned at the mirror side of today the wheel end spindles positions were changed with one another. This made the bracket´s appearance more similar to today, which enables for the most trustworthy design, seen from a long lasting point of view.

It should be said that probably the best solution for a product adapted system for a series production would be to make the routing, and other construction work, as symmetrical as possible in order to decrease the installation time. If the pipes were to be bend in the exact same way this could supposedly be done at the supplier. Although this is not possible due to the surrounding components in FH-1825, which creates different possibilities of ways to route. The outcome was designed to be as symmetric as possible but since the limitation of space varies on both sides this was a complicated affair.

It could be seen as a complicated installation of the pipes inside the chassis of FH-1825 if this were to be done by one man, but with two persons at this installation station this could be done in no time.

Regarding the low pressure hoses that disappeared due to the hoses bending in a smaller radius than allowed this was not considered as a possible problem. This because the Creo program does not give 100 percent correct simulation, and since it regarded only a degree difference of 1 degree and 0,5 degree (not that much difference from what was okay bending radius) this was accepted and therefore a physical test should decide if it is possible or not. It could also depend on the angle of the position of the brackets exit port or the console on the chassis, which must be tested to surely know.

6. CONCLUSSION

To summarize the gained results the question posed will here be answered.

Since focus were put on the wheel end spindles area instead of focusing on the whole system it could be said that at the moment everything except for the routing around the wheel end spindles can be maintained. In the future even these could be upgraded though some components probably could change position in order to come closer to each other but that should not be the first priority. The first priority should be on making an acceptable routing of the wheel end spindles areas.

The ideal case for this work would be to install the hydraulic system before any other component in the vehicle, and thereafter install the other components on due to the positions of the hydraulic components and their transport channels. However the pipes at chassis (going to and from the wheels to HTA and tank) should at least be installed at the first stations in the production line, since that would radically simplify the whole installation. If as many smaller components as possible could be pre montaged this would also decrease the production time on the line. Since the production always aims on having as few components as possible to install on the line, as much as possible should be pre-installed together, minimizing the different pieces to put together. Best scenario would be if the pre-installation would be done already at the supplier. If this cannot be done the pre-installation should be executed at the production but before the montage in chassis starts, which makes the installation process not as dependent on that every little part should be easily montaged.

Since hoses are more flexible and do not require an exact length when installing these could be preferable over pipes when the assemblies will move and when it is complicated to decide an exact length. Pipes are to prefer when the transport channels are supposed to be pre-montaged and when it is known that they are going to be fixed. Pipes are in general more durable than hoses, which is for example why there are pipes instead of hoses at the entry ports on the wheel end spindles.

The routing around the wheel end spindle should be executed in such way that no hose ever bends in more than one plane for increased durability. If a hose should be bending in more than one plane fastenings should be used in such a way that the hose is locked from twisting. The hoses shall also receive required slack and be prevented from bending under the minimum bending radius, which is specified for every hose type. The hoses should at all-time be safe from hitting other components, since this will cause wearing. The surrounding environment will also affect the hoses service life which should be avoided as much as possible. This could be made with an armored sock and through route the hoses at a higher level.

As been said the purposed routing is not optimal (since the hoses bends in more than one plane when the roll angle is greater or smaller than zero) but it is much better than today´s solution. Today the hoses are forced to both bend in several planes and to twist already from the beginning, which reduces the service life radically from what the purposed concept would do.

The bending radiuses of the hoses are one of the main affecting factors when routing. As been said earlier the hoses cannot be bend under minimum bending radius since this will cause the hoses to wear on themselves creating cracks. One of the largest problems during the concept routing was to find a suitable position of the entry ports of the hoses, which allowed the hoses to bend as they should but also avoid hitting other components.

7. RECOMMENDEATIONS FOR FURTHER WORK

Since two of the hoses at the left side´s wheel indicate a too small bending radius through their disappearance in Creo, this should be tested in reality. Since the simulation in Creo is not optimal and completely correct, this should be investigated with a physical test to state how well the hoses really interact at this type of routing.

It should also be investigated if the spring brake chamber could be removed or reconstructed to a smaller model. Due to the position of the spring brake chamber the routing around the wheel end spindles area and the construction of the bracket is highly limited. If the spring brake chamber was not to take up that much space above the rotational point of the wheels, a more optimal routing could be executed and thereby a more promising bracket be constructed.

Due to the limited time the more advanced concept ideas could not be investigated which was concept 6, the rotational console on chassis, and concept 4, with a swivel coupling enabling the hoses to move along with how the wheels are turning. This should be looked into since these ideas possibly would lead to even more minimized bending of the hoses than selected concept.

The fastenings of the entry ports of the brackets and the consoles on the chassis should be decided afterwards when the bracket is fully constructed. It should be looked in to if there would be any possibility of using the mechanism of quick fastenings at these fastenings, since quick couplings enables fast installation time.

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APPENDIX A.1 – Hydraulic scheme

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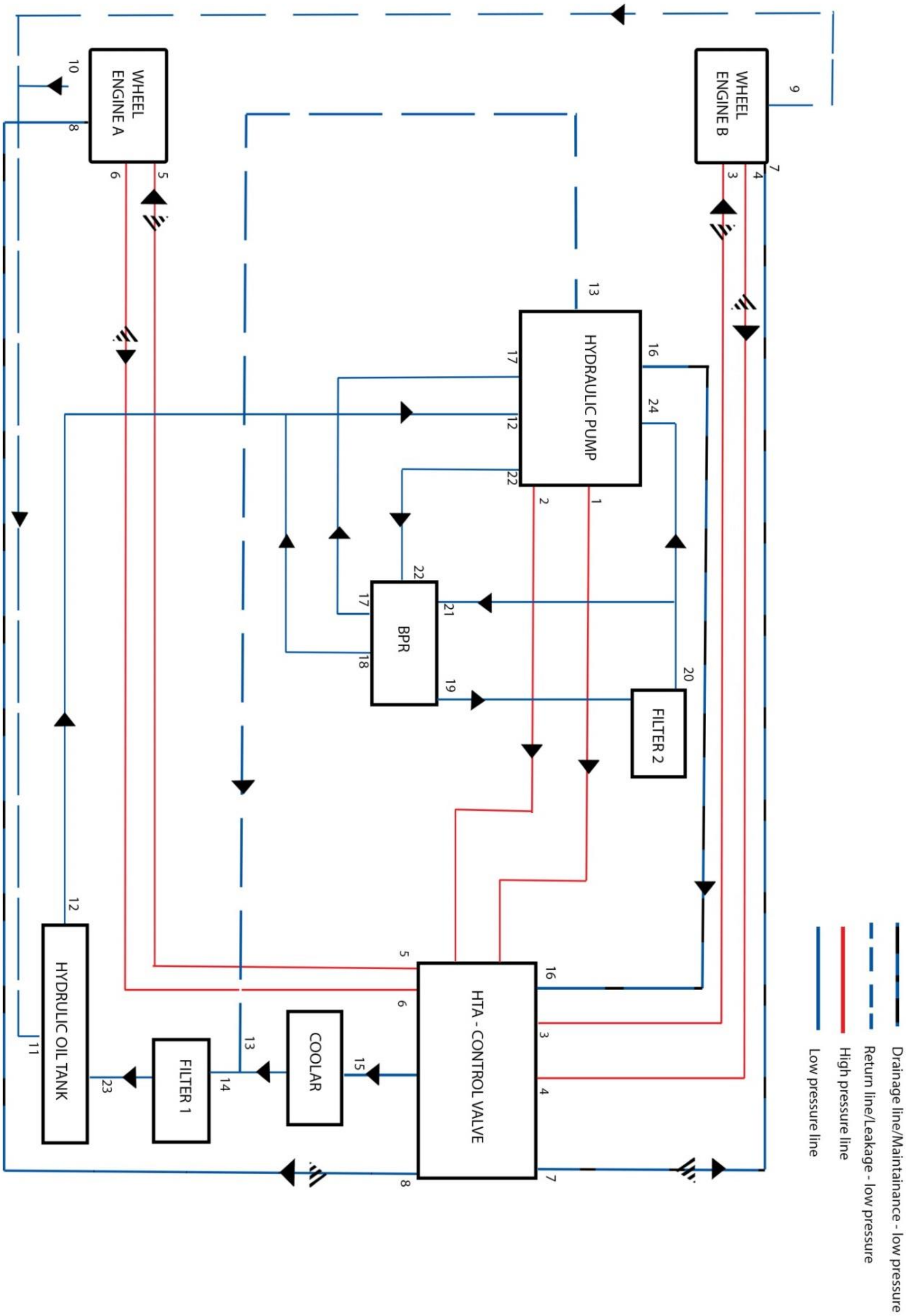
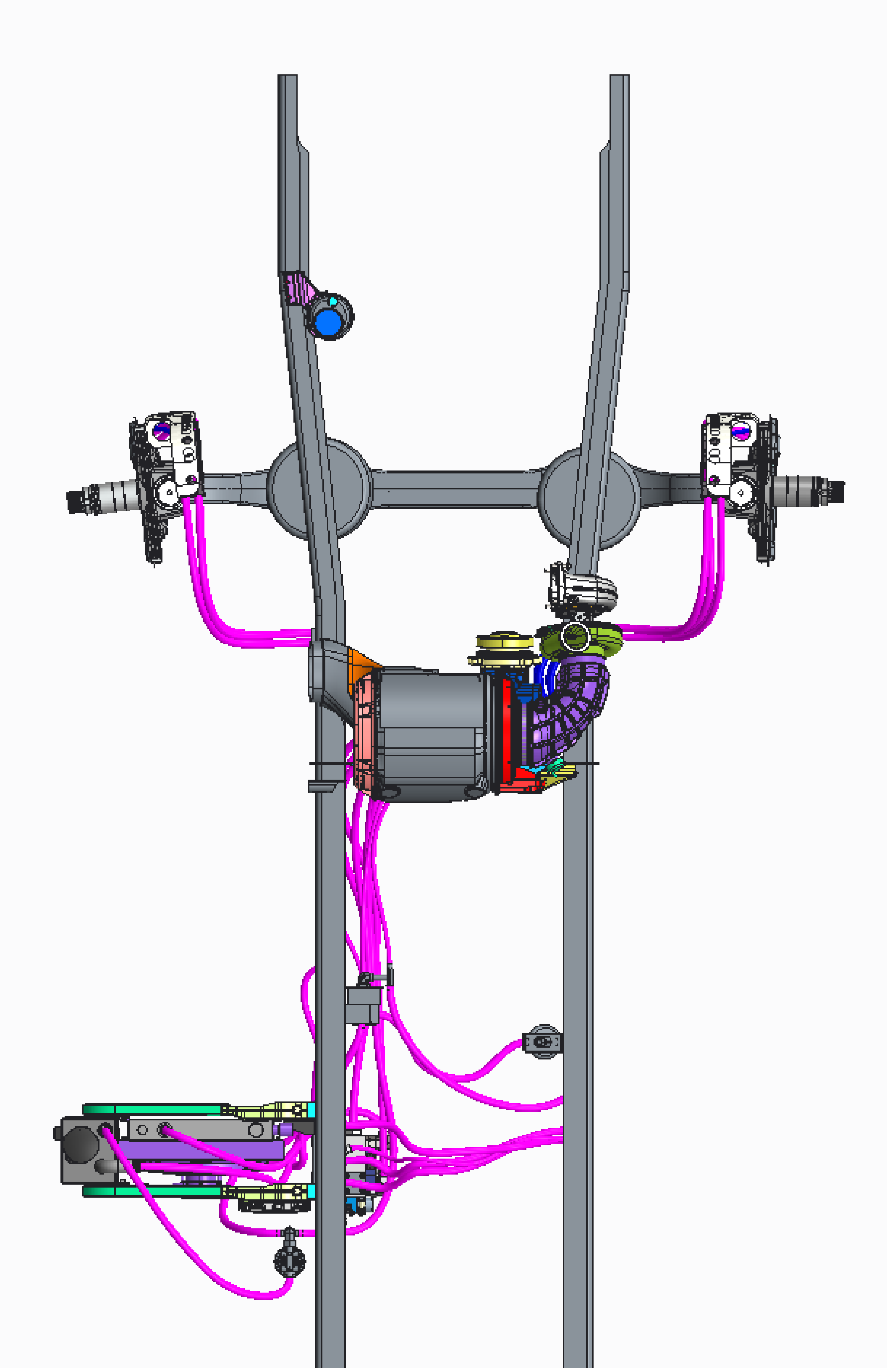
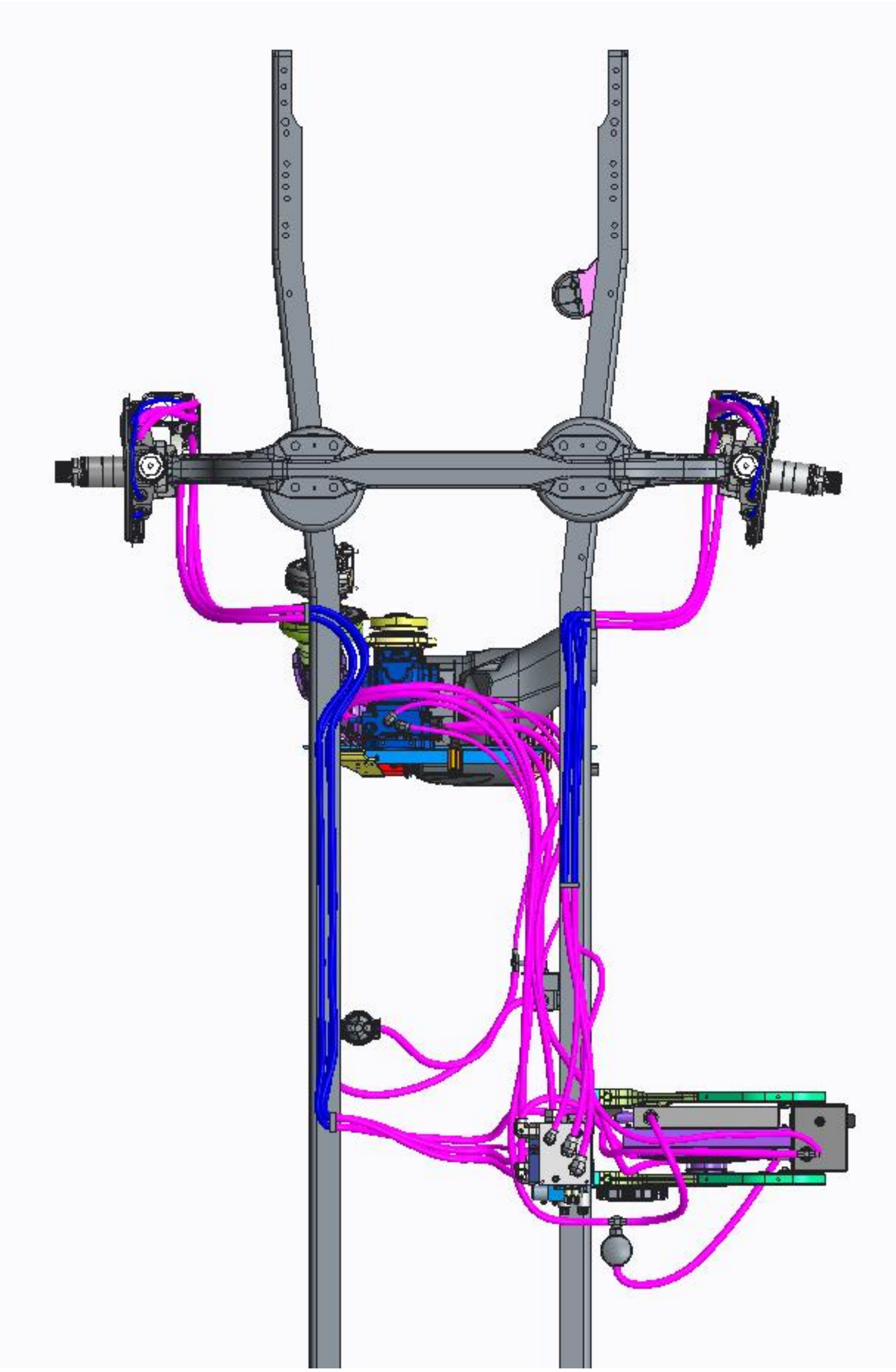
APPENDIX A.2 – Hydraulic routing scheme



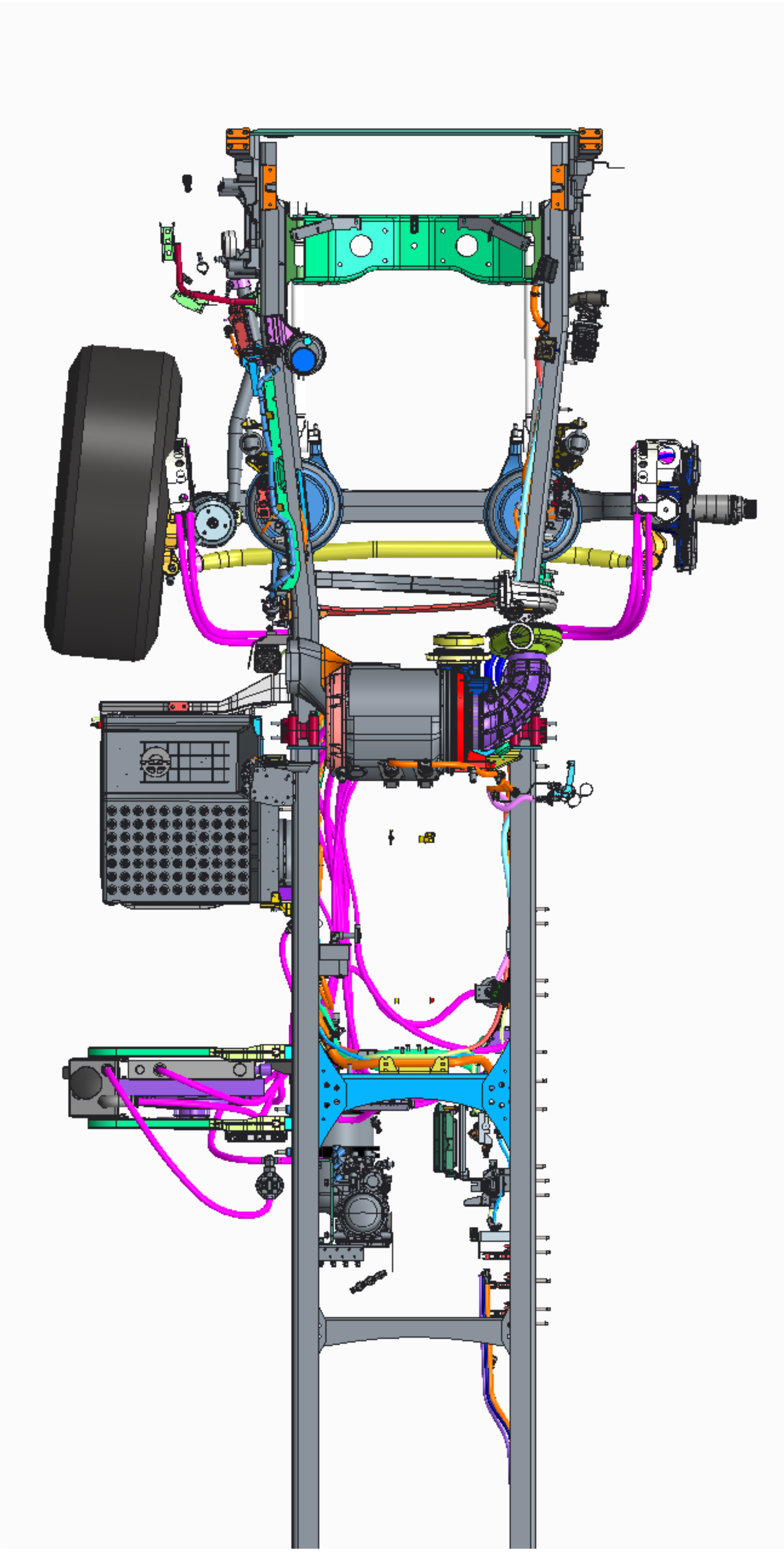
APPENDIX A.3 – Hydraulic system, top view



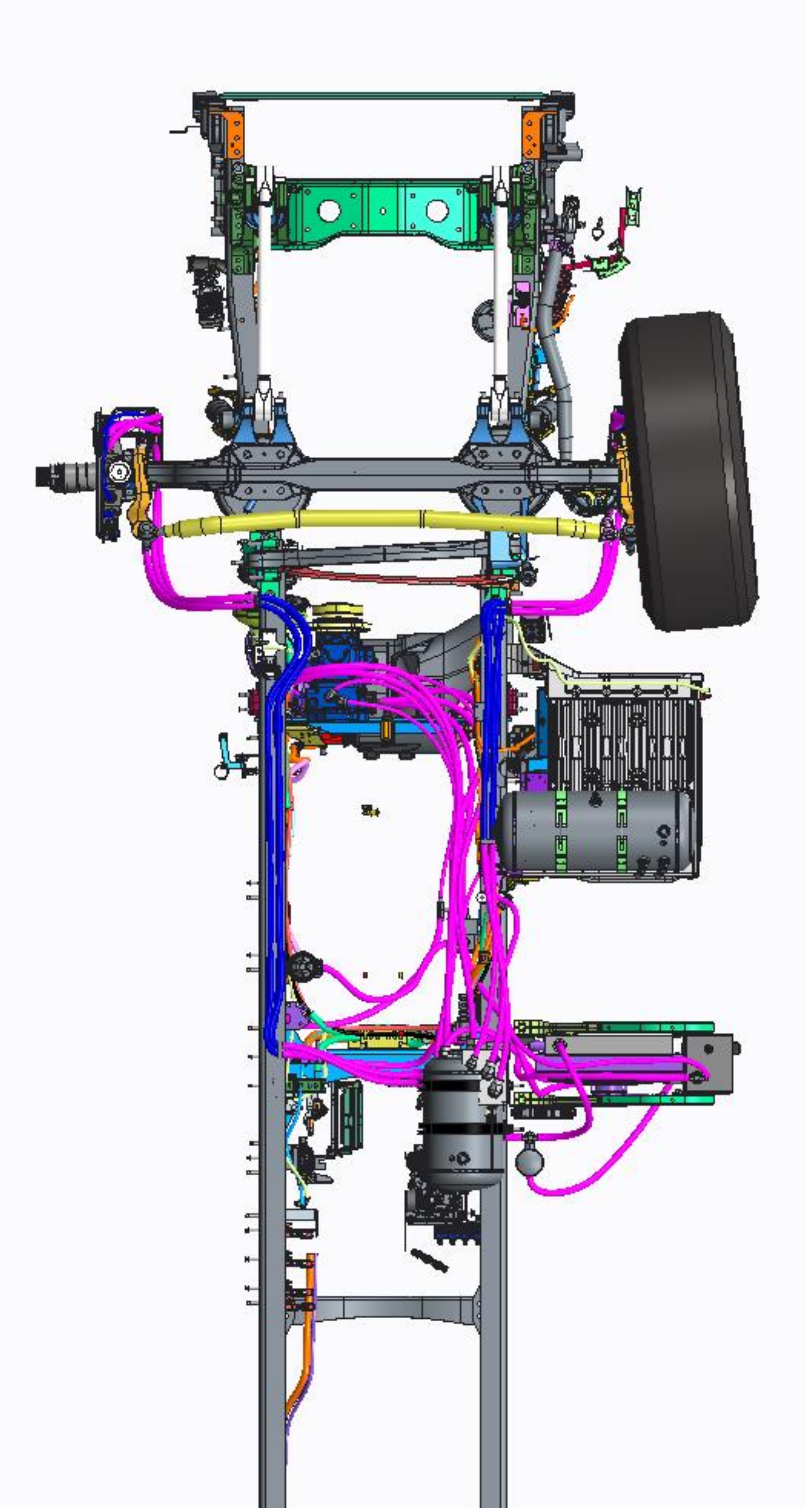
APPENDIX A.4 – Hydraulic system, bottom view



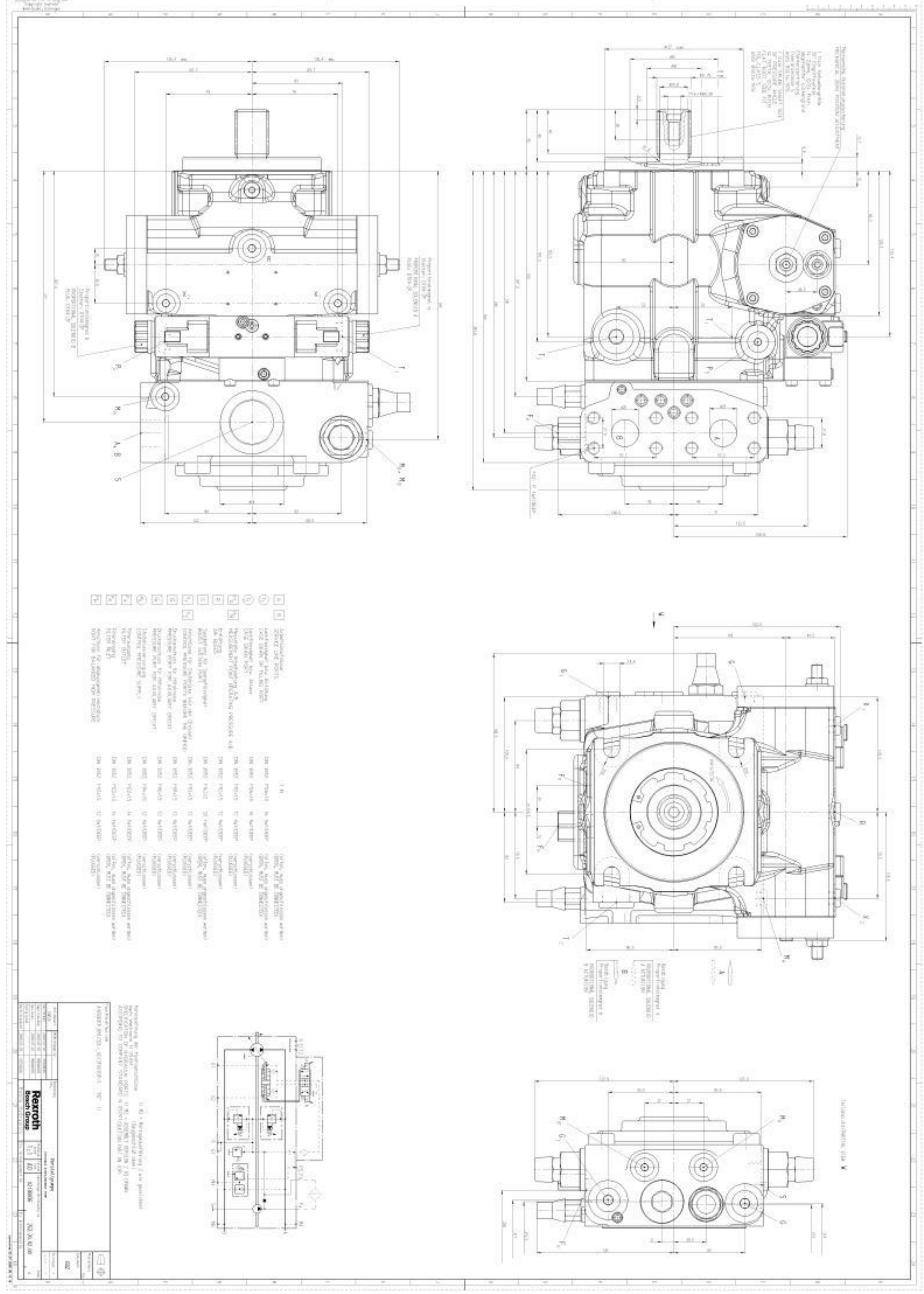
APPENDIX A.5 – Hydraulic system with affecting surroundings, top view



APPENDIX A.6 – Hydraulic system with affecting surroundings, bottom view



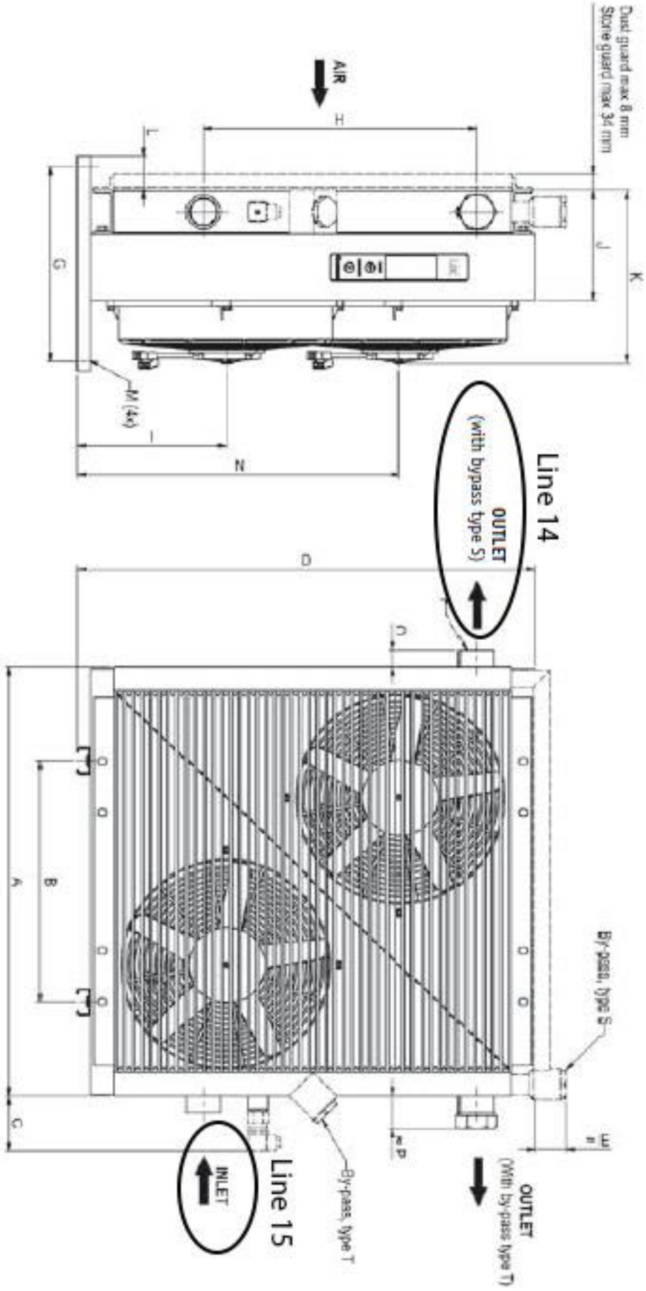
APPENDIX A.7- Hydraulic oil pump



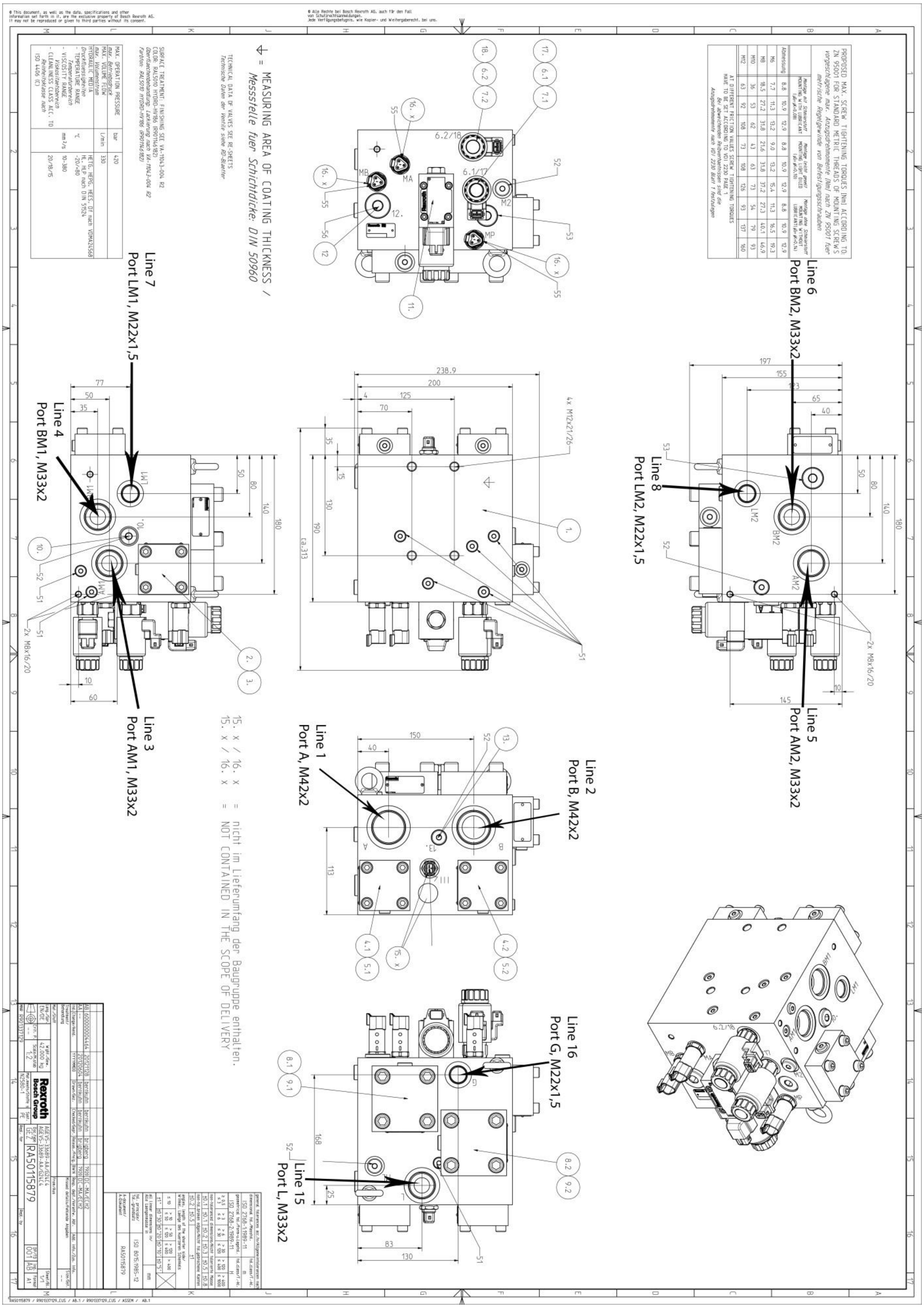
APPENDIX A.8 – Wheel end spindles

APPENDIX A.9 – Boost pressure reducer

APPENDIX A.10 – Hydraulic oil tank and cooler



APPENDIX A.11 – Control valve



APPENDIX A.1 – List of hydraulic hoses in the system

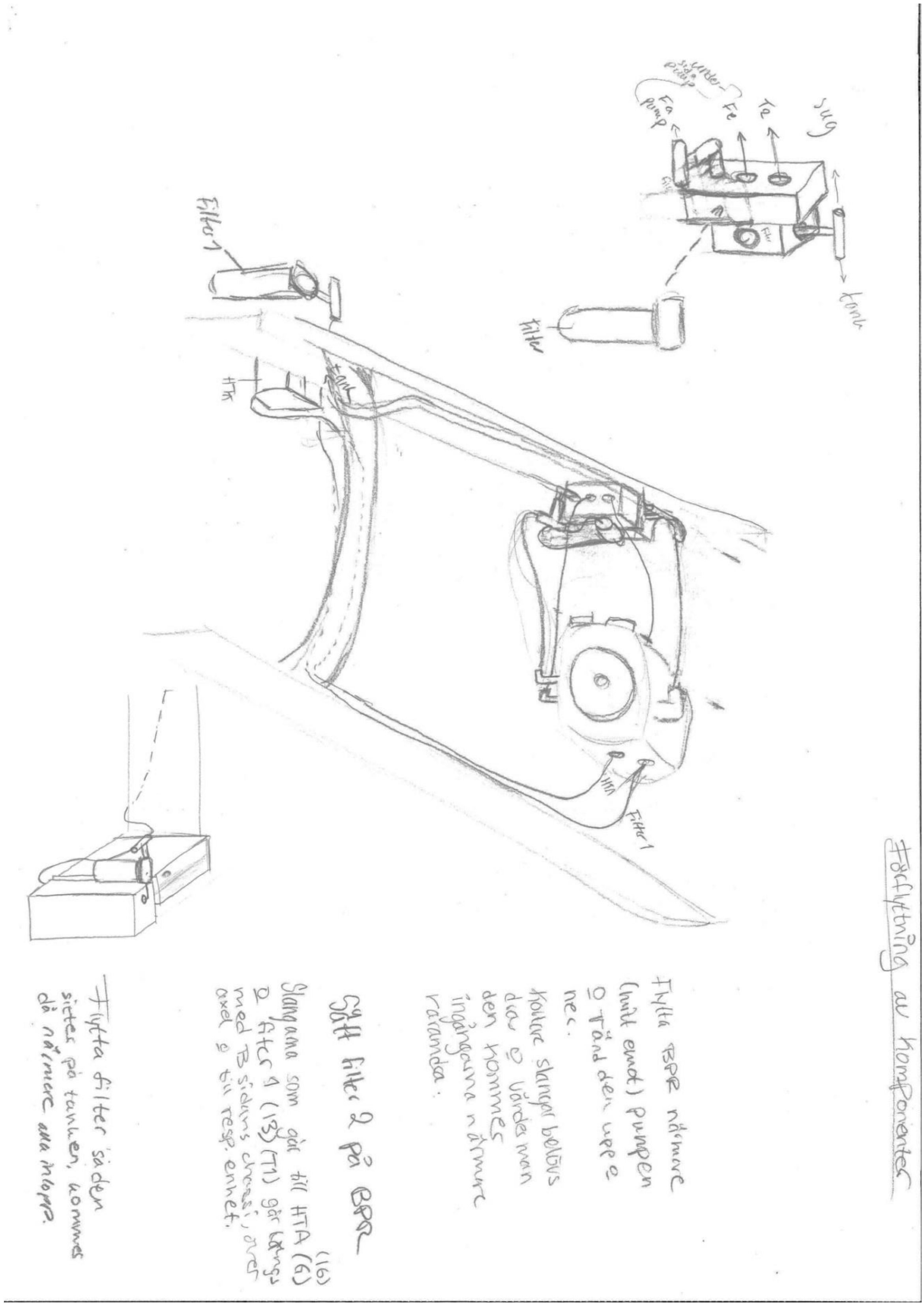
Nr	Standard	Component	Out-port	Flow direction	Component	In-port	Pressure [bar]	I.D. [Inch]	O.D. [MM]	Free lenght (1.5 O.D.) [MM]	Min. bending radii [MM]	Type	Futher explanation
1	DN25	Pump	A	→	HTA	A, M42x2	420	1"			165	797TC-16	This hose transport high pressure fluid from the pump to the HTA
2	DN25	Pump	B	→	HTA	B, M42x2	420	1"				797TC-16	This hose transport high pressure fluid from the pump to the HTA
3*	DN18	HTA	AM1, M33X2	↔→	Wheel engine A	B	420	5/8"	Hose: 23,9 → Pipe: 2	35,85	100		High pressure line. Depending on the vehicle travels forwards or backwards is the oil either flowing to the wheel spindle or from. This flow will always transport in the oposite way of the fluid in line 4.
4*	DN18	Whell engine A	A	↔→	HTA	BM1, M33X2	420	5/8"	Pipe: 20 → Hose: 23,	35,85	100		High pressure line that will either be transported in to the wheel spindle or from, regarding which way the vehicle drive. Allways flow in the opposite direction from the oil in Nr. 3.
5*	DN18	HTA	AM2, M33X2	↔→	Whel engine B	A	420	5/8"	Hose: 23,9 → Pipe: 2	35,85	100		High pressure line where fluid is transpored either to or from the wheel spindle, regarding the driving direction.
6*	DN18	Wheel spindle B	B	↔→	HTA	BM2, M33x2	420	5/8"	Pipe: 20 →Hose: 23,9	35,85	100		High pressure line which directoins is the oposite of the flow in line 6.
7**	DN12	HTA	LM1, M22x1,5	↔→	Wheel engine A	T	30	1/2"	20,4	30,6	130		Freewheeling drive that supplies the wheel engine with oil that enables the pistons to retract when the hydraulic drive is disconnected.
8**	DN12	HTA	LM2, M22x1,5	↔→	Wheel engine B	T	30	1/2"	20,4	30,6	130		Freewheeling drive that supplies the wheel engine with oil that enables the pistons to retract when the hydraulic drive is disconnected.
9**	DN3	Wheel spindle A	T2	→	Tee-coupling in t	Tee-coupling	10	0,12"	20,4	30,6	130		A case drain where superfluous oil is transported from the wheelengines back to the tank.
10**	DN3	Wheel spindle B	T2	→	Tee-coupling in t	Tee-coupling	10	0,12"	20,4	30,6	130		Case drain where superfuous oil is transported from the wheen engines back to the tank.
11***	DN3	Tee-coupling		→	Tank		10	0,12"					The line that transport teh superfluous oil from both wheel engines back to the tank.
12	DN35	Tank	SF	→	Tank	(S) M14x1,5 Tee-coupling at BP	10	1 1/4"					A suction line where oil is transported from the tank to the pump. The suction is created from the pumps movement.
13	DN20	Pump	T1, M26x1.5	→	Filter, tee-coupli	A, Tee-coupling	10	3/4"					A case drain wheresuperfluous oil is transported from the pump back to the tank, this drain is connected to the return line (Nr. 14) with a coupling.
14	DN25	Radiator		→	Filter, tee-coupli	A, Tee-coupling	10	1"					Return line that conveyes the fluid coming from the HTA through the radiator to the filter.
15	DN20	HTA	L, M33x2	→	Radiator		10	3/4"					Return line from HTA to the radiator.
16	DN15	Pump	G, M18x1,5	→	HTA	G, M22x1,5	40	5/8"					Boost pressure line which is the line that supports the freewheeling drive with oil when the hydraulic system is deconected.
17	DN12	BPR	Tk, M14x1.5	→	Pump	T2, M26x1.5	10	1/2"					Transports the medium from the BPR to the pump when the hydraulic drive is disconected.
18	DN15	BPR	Tee-coupling	→	Pump	S, M42x2	10	0,6"					Transports from the BPR to the pump through conecting to the line transporting oil from the tank to the pump (Nr.12)
19	DN20	BPR	Fe1, M33x2	→	Filter 2	A G1	50	3/4"	27,7		195	462-12	Fluid from the BPR flows to the filter where it is filtered and later transported to the pump.
20	DN20	Filter 2	G1 B	→	BPR tee-coupling	Fs, M33x2	50	3/4"	27,7		195	462-12	Oil flows at a low pressure from being filtered back to the pump or back to the BPR through line 21
21***	DN20	Filter 2		→	BPR tee-coupling	Fs, M33x2	50	3/4"					Oil from the filter is transported back to the BPR which from it is transported to the pump.
22*	DN20	Pump	Fe, M22x1.5	→	BPR	Fe, M33x2	50	Pipe: 18mm → Hose: 3/4"					
23	DN25	Filter	B	→	Tank		10	3/4"					Return line, oil is being filtered before entering the tank.
24*	DN20	BPR, tee-coupling	FS, tee-coupling	→	Pump	Fa, M22x1.5	50	Hose: 3/4" → Pipe: 18mm					
													*These lines starts as hose and then turns to pipes.
													** These lines represent a transport cannel that beginns as a pipe, turn to hose and then a pipe again. The colum "type" will here explain the used hose type and not the pipes (both are the same)?
													***These lines contains only of a tee-coupling that rejoine the hoses.

APPENDIX A.2 – Requirement specification

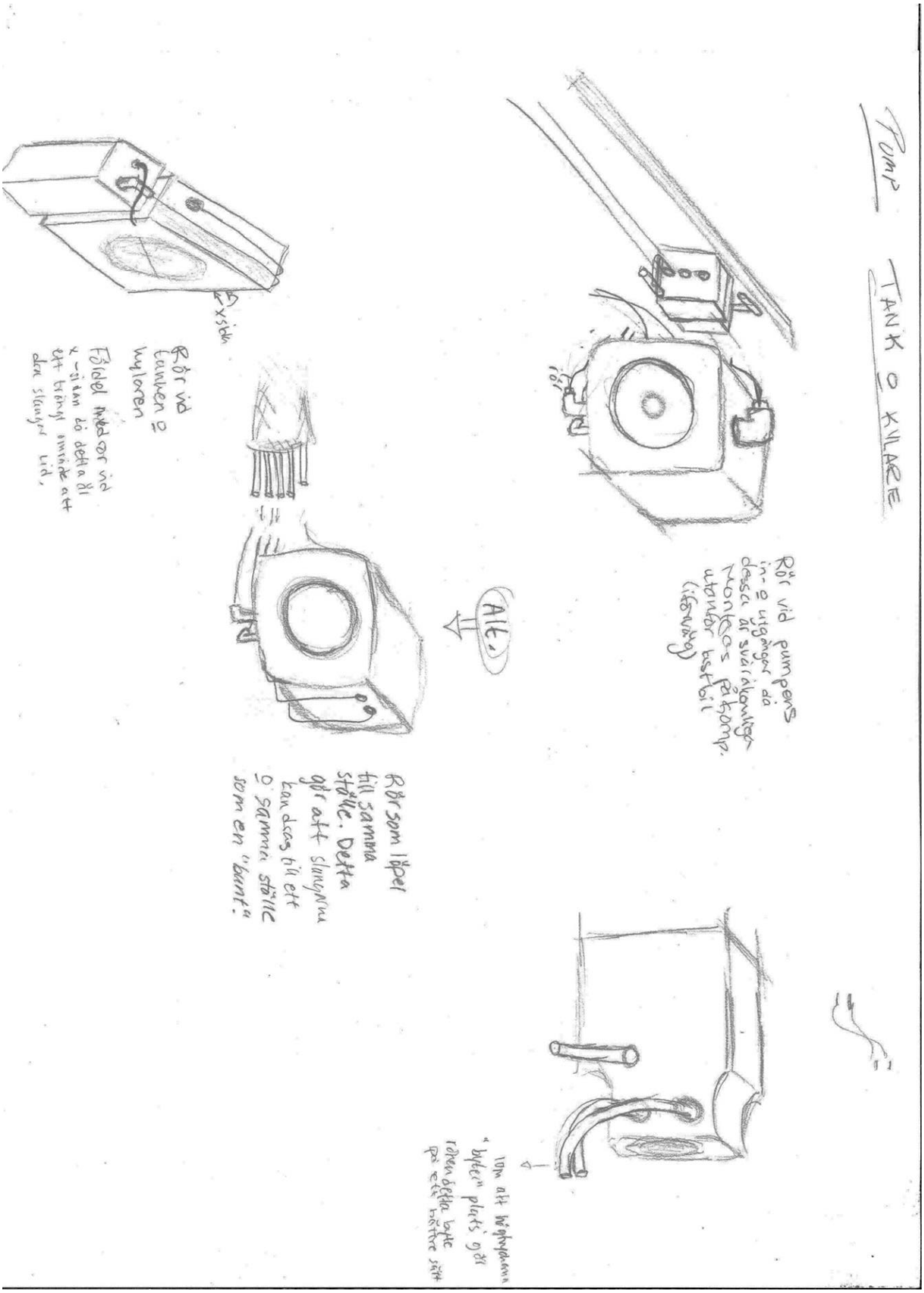
Requirement	Explanation of requirement	Standards Authority	Comment
Avoid “over chassis”-routing	Nothing can ever be routed above the cassis behind the area of the pump unit. Hoses and pipes shall be routed under or along with chassis.	Dennis Persson	
Provide hose movement	The hose should never be stretched, kinked, crushed or twisted at any time.	Parker	
Offer time effectively	The installation of the hoses cannot take more than 1 minute per line	Production	
Provide space around engine	Nothing can be placed in a distance of 20 mm near the engine	Production	
Allow poor driving conditions	The wheel spindle must endure that the wheel is up to 40% in mud	Marcus Persson	
Allow free space below gear box	Nothing can ever be routed below the gear box	Production	
Avoid minimum bending radius of hose	No hose should ever be bend under minimum bending radius	Parker	The minimum bending allowance depends on the hose
Permit easy installation	The system should be easy to montage	Production	
Permit easy disassembly	The system should be easy to disassembly	Production	
Pipes of stainless steel	The pipes should be of stainless steel in order for the system to maintain intact	Parker	
Avoid incorrect clamping	High pressure hose and low pressure hose should never be clamped together	Parker	
Allow correct hose bending	A bend hose should allow a straight length of 1.5 times the hose´s outside diameter from the coupling to the start of the bending	Parker	
Resist minimum ambient temperature	The assemblies must endure a minimum ambient temperature of -40 degrees	Marcus Persson	
Hose resistance of the fluids temperature	The hoses must endure the minimum and maximum temperature of the fluid	Parker	
Compatible fitting	The fittings must be compatible with the hose/pipe	Parker	
Compatible fluid	The fluid must be compatible with the hose assembly	Parker	
Avoid minimum bending radius of pipe	No pipe should ever be bend under minimum bending radius	Parker	The minimum bending allowance depends on the pipe and manufacturer
Endure vibrations and fatigue	The routing must be made so the hydraulic hoses and pipes don’t	Parker	

	collapse during usage		
Endure maximum working pressure	The hose assembly must endure the maximum working pressure	Parker	The maximum working pressure at each line can be seen in appendix as table A.1?
Endure desired working pressure	The hose assembly must endure the desired working pressure	Parker	The desired working pressure at each line can be seen in appendix as table A.1
Endure maximum flow rate	The hose assembly must endure the maximum flow rate of the conveyed fluid	Parker	
Acceptable pressure drops	The pressure drops in the system must be acceptable, i.e. not to big.	Parker	
Avoid hoses bending in several planes	A hose should never be bending in more than one plane. Hoses going to be bending in several planes should be correct clamping be performed.	Parker	
Routing above the wheel axle	The hydraulic hoses should not be routed lower than the steering axle.	Lena Larsson	
Minimum distance of 60 mm between wheel and components	There should be a distance of 60mm between wheel and other components	Marcus Persson	
Minimum distance of 15mm between components	There should be a minimum distance of 15mm between other components in the vehicle	Dennis Persson	

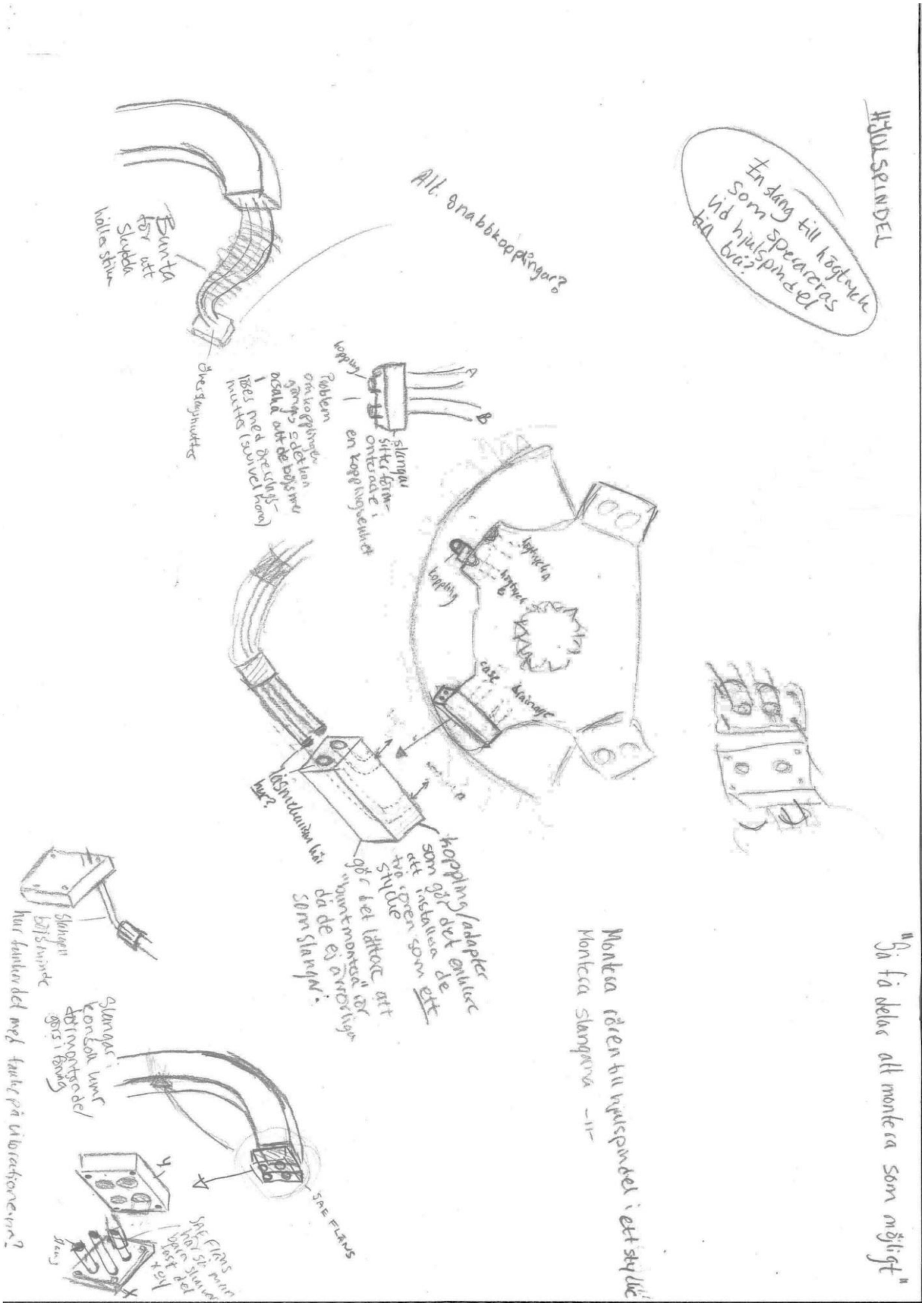
APPENDIX A.12 – Idea generation, Replacement of components



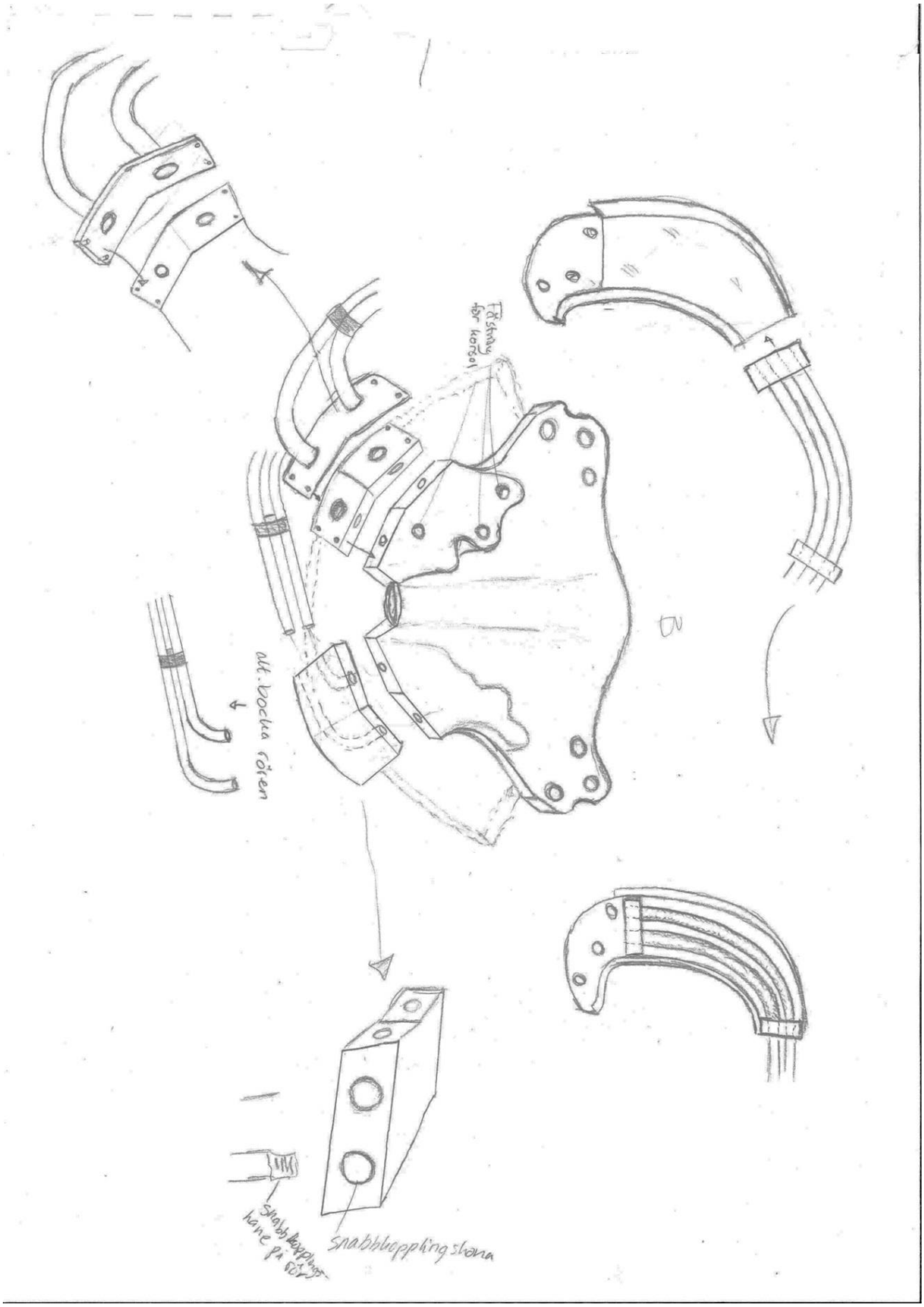
APPENDIX A.13 – Idea generation, Ideas regarding hydraulic tank and cooler



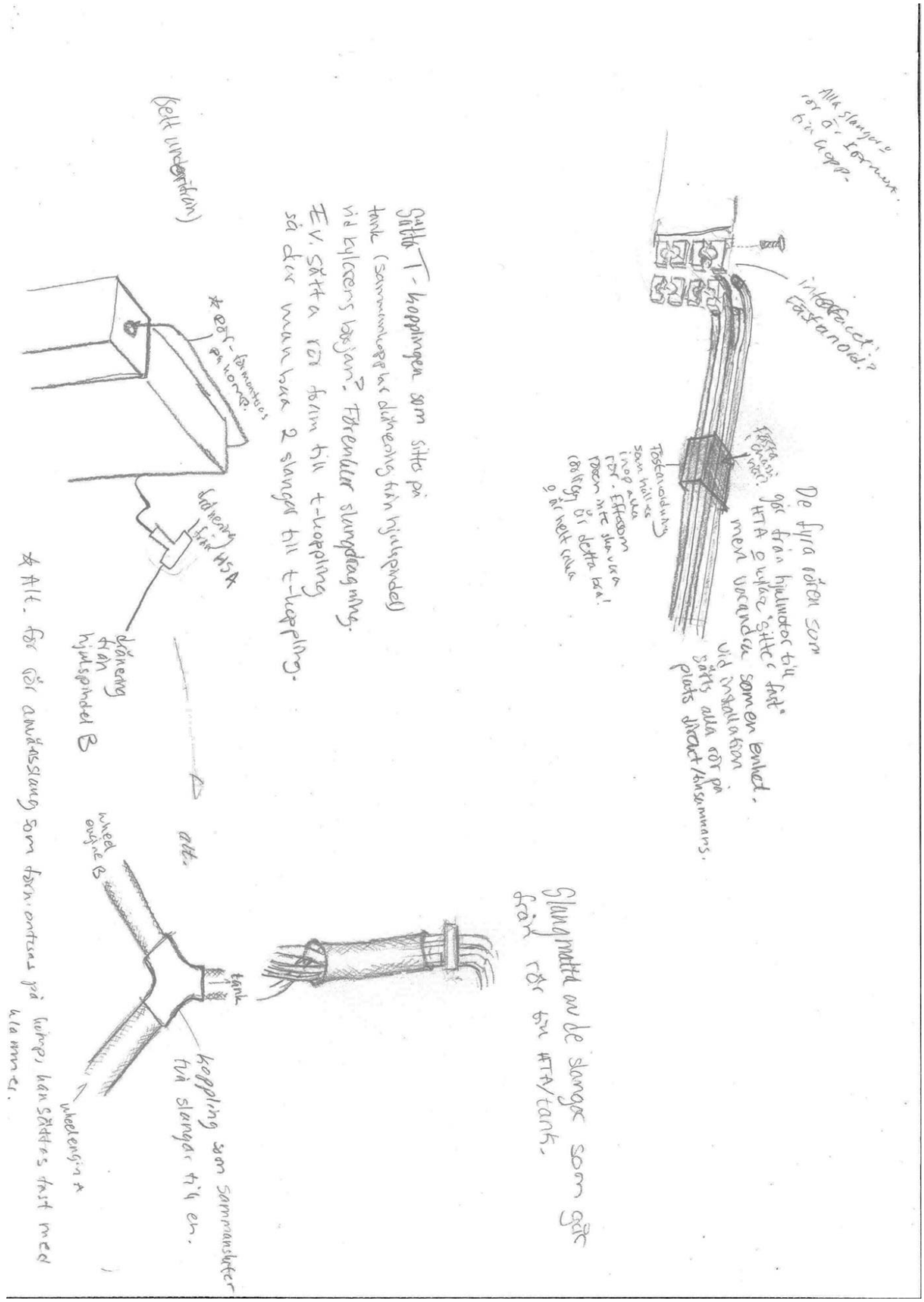
APPENDIX A.14 – Idea generation, ideas regarding wheel end spindle



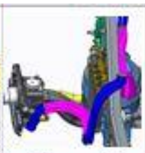
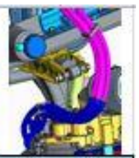
APPENDIX A.15 – Idea generation, ideas regarding wheel end spindle



APPENDIX A.16 – Idea generation, ideas regarding fastenings

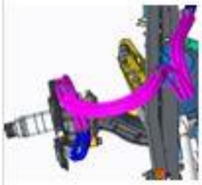
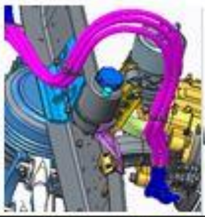
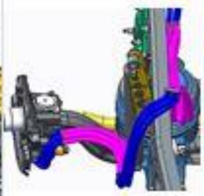


APPENDIX A.17 – Kesselring matrix

															
		Ideal		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6	
Criteria	Weight	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Able to provide the hoses with	5	5	25	1	5	3	15	4	20	4	20	2	10	2	10
Offer time efficiency during routing	4	5	20	2	8	2	8	3	12	3	12	2	8	2	8
Amount of parts	4	5	20	4	16	5	20	4	16	4	16	2	8	2	8
Simplify for pre installation	3	5	15	2	6	3	9	3	9	3	9	3	9	2	6
Service friendly	3	5	15	2	6	3	9	4	12	4	12	4	12	3	9
Avoid hoses bending under the minimum bending radius	5	5	25	1	5	3	15	3	15	4	20	2	10	3	15
Endure the possible wearing from the surrounding	5	5	5	2	10	3	15	4	20	4	20	3	15	4	20
Avoid any presseure drops as much as	4	5	20	2	8	4	16	4	16	4	16	3	12	4	16
Avoid hoses bending in more than one plane	5	5	25	4	20	2	10	2	10	1	5	2	10	3	15
Avoid hoses scraping on other components, which could lead to wearing on the	5	5	20	1	5	2	10	4	20	2	10	2	10	2	10
The concept possible to install directly today without any need of extra components that do not allready exist on the truck today	4	5	20	2	8	3	12	3	12	3	12	2	8	2	8
Reasonable concept that could be doable today without any large changes of associated components	4	5	20	2	8	3	12	2	8	2	8	2	8	2	8
Total score			**230**		**105**		**151**		**170**		**144**		**120**		**133**
Score relative to ideal			100%		46%		66%		74%		63%		52%		58%
Ranking				**6**		**2**		**1**		**3**		**5**		**4**	
Percieved feeling	5	5	20	1	5	2	10	4	20	2	10	3	15	3	15
Total score			**250**		**110**		**161**		**190**		**154**		**135**		**148**
Score relative to ideal			100%		44%		64%		76%		62%		54%		59%
Ranking				**6**		**2**		**1**		**3**		**5**		**4**	

APPENDIX A.18 – Pugh matrix



Criteria	Reference	Concept 2	Concept 3	Concept 4	Concept 5
No hose is twisted when wheel cut and roll angle is zero	0	+	+	+	+
No hose is extremly twisted when wheel cut and roll angle are more or less than zero	0	+	+	-	+
The hoses have enough slack to not be bent below the minimum bending radius	0	0	0	-	0
The hoses are bening in separate planes	0	+	+	-	+
The hoses are positioned in such way that the environment the truck is driving in do not wear on the hoses (stones, mud and salt for example)	0	-	+	+	-
There is no risk of the wheel colliding with the hoses	0	-	+	0	-
The hoses do not risk to scrape on sorrounding components, which could lead to wearing on the hoses	0	-	+	-	-
No extra construction work of sorrunding parts must be done with this concept (including bracket, consoles and modification of sorrounding components)	0	-	-	-	-
Total amount of -		-4	-1	-5	-4
Total amount of +		3	6	2	3
Total sum		-1	5	-3	-1

APPENDIX A.19 – List of pros and cons

3.A-1		3.B-1		3.B-2		3.1-1	
Avoids bumping in to tire	Risk of vibrations due to the loss of enough attachment points	Avoids smal bending radius on pipes	High weight on the attachment points, risk of vibrations	Simplify for pre montage	Unsure if the spring brake chamber can have anything fastened on it	Allowes the best position of the bracket´s center of mass	Contravene standars (highpressure line in front of the steering axle)
No risk of the bracket bumping in to other components ("slimmed" design)	Forces the pipes to be bend several times with smal bending radius	No risk of the bracket bumping in to other components	Needs some sort of support	Promising position of center of mass which iluminate unwanted vibrations	Most likely of the concept to collide with surrrounding components	The brackets design will not have to be changed more than a few adjustments	Forces the supplier of wheel end spindels to change the installation process
	Needs some sort of support	Possible for pre-montage some parts of the bracket on to the wheel spindle				Enables for pre-montage	

APPENDIX A.20 – List of personal information contacts

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