Minimizing of Drain Leakage on a Scania Retarder

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Abstract

To enhance the drivability and increase safety a major part of Scania's vehicles is fitted with a retarder. The retarder is a complementary brake system that assists the vehicles mechanical brakes. When running a retarder some oil leakage can occur. The main source to the leakage is oil sump ventilation but there is also some contribution from the solenoid valve block that controls the retarder.

Test results from the test rig shows that with rather simple methods the oil leakage in form of oil mist can be captured. The efficiency of for instance concept 1 with half the volume and a chicane interior was as high as 99 to 100 %. For the concept 2 with the expanded metal filter the efficiency was in the order of 96 to 100 %.

From testing it has also become clear that there is a problem to feed the oil back into the oil sump. Initial tests shows that the retarder is rather sensitive regarding the placing of the feedback channel. It is considered that the best option is to only use the feedback channel that enters the internal drain of the retarder.

Measurements show that the airflow in the tube from the accumulator could reach velocities up to 67 m/s. It is considered that the best solution is to have two separate chambers, one for the accumulator and one for the oil sump ventilation, the safety valve and the proportion valve. The reason for this is that the combination of oil in a chamber together with high airflow from the accumulator is disastrous and the retarder leaks far worse compared to original. The conclusion is therefore that it is important to separate air from the accumulator from places where oil can occur.

Tests also revealed that the size of an external volume is not of any great importance when it comes to colleting oil. There was no significant difference in between of using a volume of 0.64 l or 0.19 l. However regarding overfilling it is favorable to have a larger volume since this increases the retarder's capability to withstand oil leakage when it is overfilled.

Acknowledgements

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Table of Contents

Chapter 1

Introduction

1.1 Background

To enhance the drivability and increase safety a major part of Scania's vehicles is fitted with a retarder. The retarder is a complementary brake system that assists the vehicles mechanical brakes. In Figure 1 the retarder is shown fitted on the gearbox. In case of Scania, the retarder is a hydrodynamic brake that applies brake force to the drive shaft by forcing oil in between a stator and a rotor. The brake force is controlled by controlling the amount of oil that is situated between the stator and the rotor. The higher the amount of oil the larger the brake force becomes. The energy generated by the brake force is converted to heat energy in the oil. This heat energy has to be cooled by the vehicle ordinary cooling system. By using a retarder the vehicles mechanical brakes can be unburden, thus a decrease in wear.

To control the amount of oil in the retarder circuit a proportional valve and one solenoid valve is used. These two valves controls pressurized air which in turn controls those valves that regulates the amount of oil in the system. One solenoid valve controls the oil accumulator that is used to fill the system with oil rapidly to decrease the time it takes to activate. In the present configuration there is a communication between the surrounding air and the oil sump of the retarder to normalize the pressure in the retarder after engaging and disengaging. It is through this ventilation and from the solenoid valve block an oil leakage can occur.

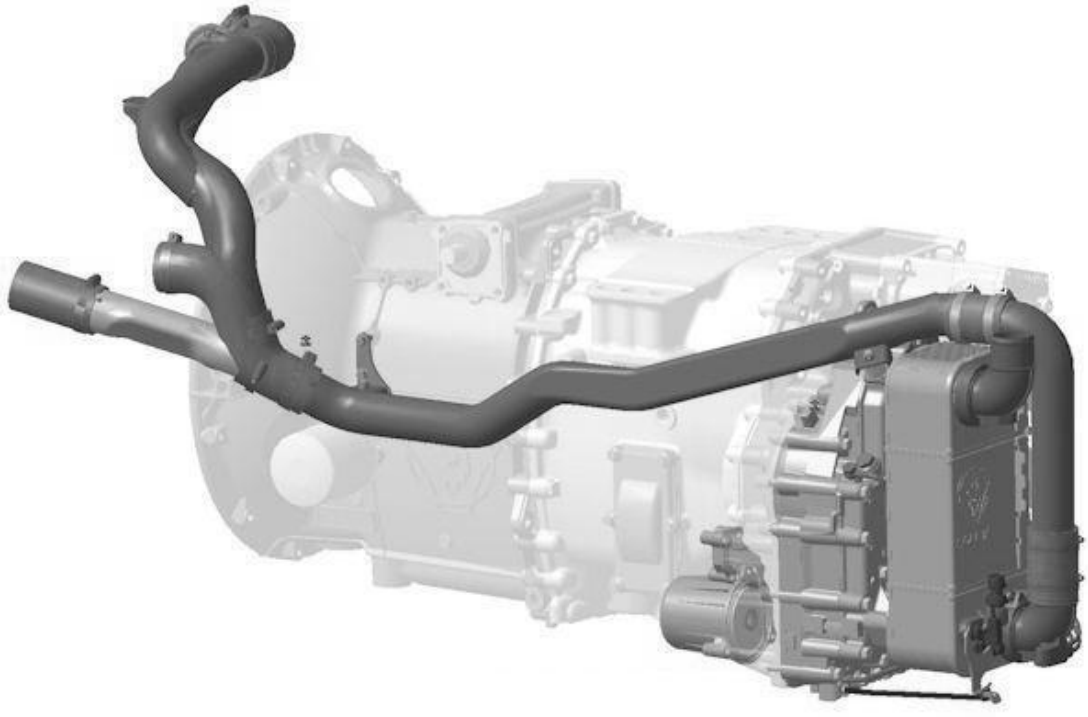

Figure 1. Gearbox fitted with a retarder

1.2 Problem

When running a retarder some oil leakage can occur. The main source to the leakage is oil sump ventilation where aerosol is ejected when the retarder is engaged and disengaged. There is also some contribution from the two solenoid valves and the proportional valve where aerosol is ejected when disengaging. The oil sump ventilation is necessary because the oil level in the oil sump changes when the retarder is engaging or disengaging. A sealed oil sump would therefore lead to that an over or under pressure is generated in the oil sump. When improving the current system to minimize the oil leakage it is important to have in mind that the proposed solution not affects the function of the retarder. For instance not create a too large of a resistance in the oil sump ventilation where it could lead to a slow system.

It is also desirable that the solution should cope with oil that is forced out due to overfill of the retarder as redundant oil is pushed out. When this occurs it is assumed that the flow of oil increases and which leads to other requirements. It is also of great importance to keep service points at a minimum to reduce costs and articles and it is therefore favorable to not add any extra service points.

1.3 Goal

The goal of this thesis is to propose a working solution to Scania that makes retarder becomes completely free from any oil leakage.

1.4 Purpose

One main purpose for Scania is to have a premium product and it is not desirable to have a truck that becomes soggy from oil. The purpose of this work is to minimize the leakage of oil that occurs partly from the ventilation from the oil sump and partly from the solenoid valve block.

1.5 Limitations

This work is a master thesis performed a Scania as a part of our education at the Royal Institute of Technology. The work is time limited to 20 weeks so the extent of the work is adapted to that. The major focus is to minimize the oil leakage by separating oil from the air in an aerosol mixture and feed the oil back to the oil sump. Due to long test times in the test rig to get satisfying results the focus in this thesis is rather to investigate and propose different types of solutions rather than verifying them.

1.6 Literature Study

In order to get a greater understanding of the problem and what work that already has been done, a study of literature and reports produced at Scania have been made. There has been some attempts trying to reduce the leakage from the retarder, some more successful than others. But the common denominator is that an external oil sump seems to have positive effects on the leakage. The first and current version of an external oil sump is presented in [1], is a small volume integrated in the oil sump cover. Though it contributed to great improvement of the leakage the volume is rather small and limited and there is room for development. Test has also been performed in [2] to determine the worst case scenario where the leakage from the oil sump ventilation becomes the worst. It shows that a rotational speed in the area of 1400 rpm and brake torque of around 3400 Nm is the operation point where the leakage becomes the largest. In [3] the solenoid valve block was connected directly back to the oil sump in an attempt to reduce the leakage. The results showed however an increase of the leakage rather than the predicted decrease.

Technical description on the retarder function [4] has been studied to get a deeper knowledge on the basic functions of the retarder. Subjects that are necessary to understand to propose a solution are for example; when the valves in the solenoid valve block activates or deactivates or where in the oil sump cover it is possible to feed back oil.

Since it is a rather narrow topic it has been difficult to find similar published work. The reports that also has been studied but that is not published by Scania, do not address the same type of problem but instead parallels have been drawn between the various fields of work. For instance in [5] ideas sprung for how to separate oil and air in an aerosol mixture.

Searches through different patent databases have also been made. This to assure that no patent infringement will occur but also to study the line of prior work that has been done in the area.

Chapter 2

Functional Analysis

2.1 Retarder Functions

2.1.1 Oil Sump Ventilation

To understand why the retarder has a leakage of oil it is necessary to understand how it works. It all due to the stator and the rotor, it is through these the braking torque occurs. The stator and the rotor are two turbines placed against each other and when oil is forced in between them a braking torque is generated. The stator is fixed mounted to the retarder housing while the rotor is mounted to an axle that is connected to the drive shaft through a set of gears. Both the stator and the rotor have blades that are inclined at approximately 45° to the plane of rotation, see Figure 2. Together they form ring-shaped areas similar to a torus. A torus is a mathematical body that has an appearance that resembles a doughnut (cookie), see Figure 3.

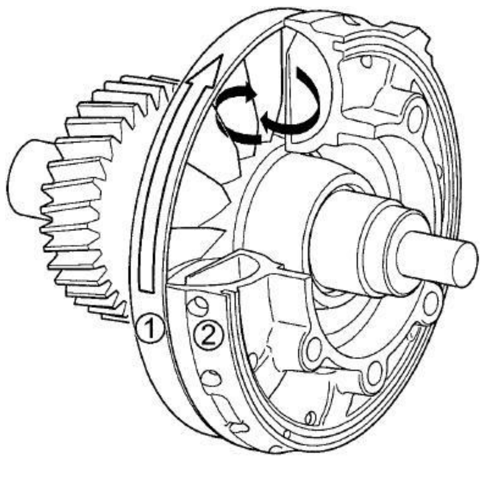

Figure 2. Stator and rotor

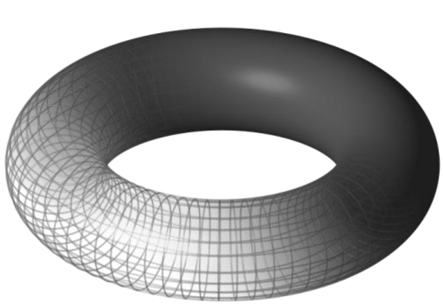

Figure 3. Torus

When oil is forced in between the turbines when the rotor is rotating the oil in the rotor is thrown against its outer diameter and thus over into the stator. Well within the stator the oil is forced against the inner diameter of the stator and back over to the rotor and thus the torus is formed. When this occurs a force in axial direction trying to separate the two turbines and a force in radial direction appears. It is this radial force that generates the braking torque. It is so to say the flow of the oil that is generating the braking torque and the greater the velocity of the oil becomes the greater the braking torque becomes.

The drawback of such a system is however; to generate an acceptable braking torque a rather high velocity of the oil is needed. A high velocity of the oil leads to a lot of friction when oil is passing the blades of the turbine, friction that is turned into heat in the oil. When repetitive deceleration at maximum braking torque the oil temperature can rise as high as 180°C and at that high temperature an oil aerosol can come to existence. This together with that the turbines mixes a fair amount of air into the oil so it becomes more like a foam rather than oil and increases in volume leads to that the retarder at some extreme scenarios may eject oil through the oil sump ventilation.

2.1.2 Accumulator

To shorten the time when engaging the retarder an accumulator is used. The accumulator consists of a piston with a diameter and stroke that is about 100 mm respectively 70 mm, this provides a potential volume of approximately 0.7 liters. The piston has a preloaded spring on one side and when engaging a solenoid valve provides compressed air on the other side that creates a pressure on the piston that overcomes the force from the spring and oil is pushed into the retarder circuit. The amount of oil that is pushed into the circuit depends on the current braking situation and is regulated by the control unit that controls the solenoid valve. To refill accumulator the pressure is released and the spring pushes back the piston, filling the accumulator with oil again. As the sealing between the piston and the cylinder consists of a gasket with a scraper ring there is some leakage. Partly this leakage is necessary to lubricate the piston to prevent wreckage but there may also be some traces of oil in the air evacuated.

2.1.3 Safety Valve and Proportional Valve

The final sources to an eventual oil leakage are from the safety valve and the proportional valve. Both the safety valve and the proportional valve have a design similar to the accumulator only smaller, the piston is in the order of 35 mm in diameter. With a loaded spring on one side and pressurized air on the other side that overcome spring force when engaged.

The safety valve function is to rapidly release the pressure when disengaging to remove the generated brake torque in example for an ABS-signal, but is also used under normal condition to empty the retarder circuit. The safety valve is controlled like the accumulator with a solenoid valve that controls the pressure on one side of the safety valve. When engaging the retarder circuit the safety valve is closed and the circuit is filled with oil which generates the braking torque. To empty the circuit again the pressure is released and the oil flows from the circuit back to the oil sump. Just like the accumulator there is a small amount of leakage between the valve's scraper ring and cylinder wall when the pressurized air is evacuated.

It is the proportional valve that controls that the right pressure is in the retarder circuit at a specific occasion. Because the brake torque is directly linked to pressure in the retarder circuit it is of great importance that the circuit is not over or under pressurized. This leads to an error in the brake torque that is being generated compared to the requested one. In difference to the accumulator and the safety valve that is controlled by a solenoid valve, the proportional valve enables a variable air pressure. However the actual design is the same as the safety valve so there is some leakage between scraper ring and the cylinder wall just like the safety valve.

2.2 Calculation of the air volume

In the beginning of the project it is important to examine the prevailing conditions. Scania has no prior data about the volume or the airflow from the retarder. From the accumulator and the safety valve it is possible to calculate these volumes with the general gas law though all the data is given.

The general gas law

$$pV = nRT \tag{1}$$

p = Pressure [N m^{-2}]
V = Volume [m^3]
n = Numbers of molecules [mol]
R = Gas constant [8.3145 J mol^{-1} K^{-1}]
T = Absolute temperature [K]

In this case it is only the proportion between the two volumes that are interesting which gives

$$p_{pressurized}V_{pressurized} = p_{atmosohere}V_{atmosohere} \tag{2}$$

This gives the air volume at atmospheric pressure that will flow out from the accumulator and from the two on/off-valves according to Table 1.

Table 1. Calculated air volume from the solenoid valve block

	Accumulator	Proportional valve /safety valve
Air volume [*l*]	4.6	0.2

2.3 Flow measurement

To investigate the characteristic of the air that is ventilated from partly the oil sump ventilation and partly from the solenoid valve block measurements is executed with an air mass flow meter. The mass flow meter that is used is a Manger+Wittman with a working area between 0 and 500 ln/min. Where ln/min is liter normal per minute that is a flow in liter per minute at 0°C and at 1 atm (1.013bar). An oil air filter from Norgren of type Excelion F72V is used to protect from any potential oil leakage entering the mass flow meter. It is not optimal to use a filter because it may have a pressure equalizing effect but it is necessary. The mass flow meter is connected to the measurement unit in the test cell where it also is supplied with DC 24 V. The flow meter is designed to generate an output between 0 and 5 V depending on the airflow, where 0 V correspond to no flow and 5 V a airflow at 500 ln/min.

To measure the oil sump ventilation the filter and the air mass flow meter is connected with an 8 mm tube through the bayonet coupling on the oil sump cover. The measurements are performed on a retarder during a life time test. At the time of measure the retarder had performed 50 000 engages where a life time is expected to be in the order of 300 000 engages. During 2 hour or 7200 s the test cycle is logged at a frequency of 10 Hz ending up with a log file with 72 000 values. In addition to the logged values from the air mass flow meter there is also information about for example the speed of the engine, the braking torque from the retarder etcetera. Just like the oil sump ventilation measurements are performed on the ejected air from the accumulator and the proportion valve. The air mass flow meter and the filter are connected to the corresponding tube for the accumulator respectively proportion valve on the solenoid valve block. No measurement is performed on the last source, the safety valve due to its similarity to the proportion valve. The relative small amounts of air that is ejected could in this context be neglected.

The measured data from the air mass flow meter is later plotted as a function of time and shown in Appendix 1. The most critical case for the oil sump ventilation is when the retarder is engaged, as the accumulator ejects oil in to the retarder circuit air/aerosol is forced out of the retarder through the oil sump ventilation. The largest peak in the measured data series is the one that contributes to the largest air flow and is therefore considered to be the systems worst case scenario i.e. the time when the largest amount of air exits the oil sump ventilation. By studying the volume of flow under this peak estimates on the amount of air and the velocity of the flow can be calculated. This extreme peak is inserted into Matlab[1] where the volume of air is determined by integrating with a trapezoidal method; thereafter the maximum velocity of the flow is calculated. The result of the measurements is shown in Table 2 below. Due to a measurement noise in the mass flow meter a correction is made to set the zero level to zero. This so the air volume could

[1] Matlab is a language and interactive environment that enables you to perform computationally intensive tasks.

be determined with higher precision. As shown in Table 2 it is the accumulator that contributes to both the largest air velocity in the tube as well as the largest air volume that is ejected. It is also notable that the air volume from the oil sump ventilation is relatively small. Also as mentioned above the air velocity and air volume from the proportion valve is really small and could almost be neglected.

Table 2. Results from the airflow measurement

	Accumulator	Oil sump ventilation	Proportional valve
Air velocity [m/s]	67.2	9.3	1.8
Air volume [l]	4.4	1.1	0.3
Air volume [l] corrected	4.4	1.0	0.2

Chapter 3

Concepts

3.1 Phase One

During phase one all ideas that possible can solve the task is considered, regardless of price, space or complexity. In this phase a broader selection of the possible solutions that have been found and invented during the literature study is presented. In this chapter the pros and cons are weighed against each other, and a few concepts are kept for further study and testing in phase two.

3.1.1 One Chamber

The contribution to the oil leakage comes from four different sources, oil sump, accumulator, proportional valve and the safety valve. The easiest way would be to lead all of these into the same chamber, this because the available volume is very restricted. The two main sources of aerosol are the oil sump and accumulator as shown in Table 2. The air from these two sources comes at normal use quite separated in time. From the oil sump ventilation the air bursts comes when the retarder is engaged and disengaged and from the accumulator approximately five seconds after engaging of the retarder when the accumulator is refilled. From the safety valve the air burst comes about five seconds after the disengaging of the retarder at normal use or directly at disengaging when the ABS-safety system requires a brake release. From the proportional valve it is more or less a continuous low flow of air. If more than one source is led into the same chamber it is important to evaluate which of the sources that can intermingle. One problem that can occur is that a pressure thrust can interfere with the functions of the retarder by pressurizing the air drain of the safety valve or proportional valve which can lead to long disengaging time or a sudden change in brake torque.

3.1.2 Two Chambers

NTBR[2] have previously made tests with an external volume. In these tests they could not find any differences in the results if they used a volume of 1 l or 0.3 l. Therefore it is decided to initially use two separate chambers. This is to avoid having to investigate the problem that is described above. This is further discussed later in the report.

[2] NTBR is the retarder department at Scania

3.1.3 Porous Plate

The porous plate principle is according to [5], see Figure 4. The airflow generates a circulation between the two plates. This circulation forces the oil particles towards the walls where the oil particles form larger oil drops and increase in size which are collected. The air is then pressed through a few holes in the next plate. This will accelerate the air and the oil that still remains in the air will continue in a straight line and crash into the wall where they form bigger drops and will be collected.

There is however some problems with this concept. From the retarder there are a quite low airflow during a short burst, this can cause problems to create a steady circulation. There is also the issue of plate how to drain back the collected oil after the to the sump without disturbing the airflow and function of the separator. There is a possibility to solve this with a check valve but it adds complexity and that is not desirable.

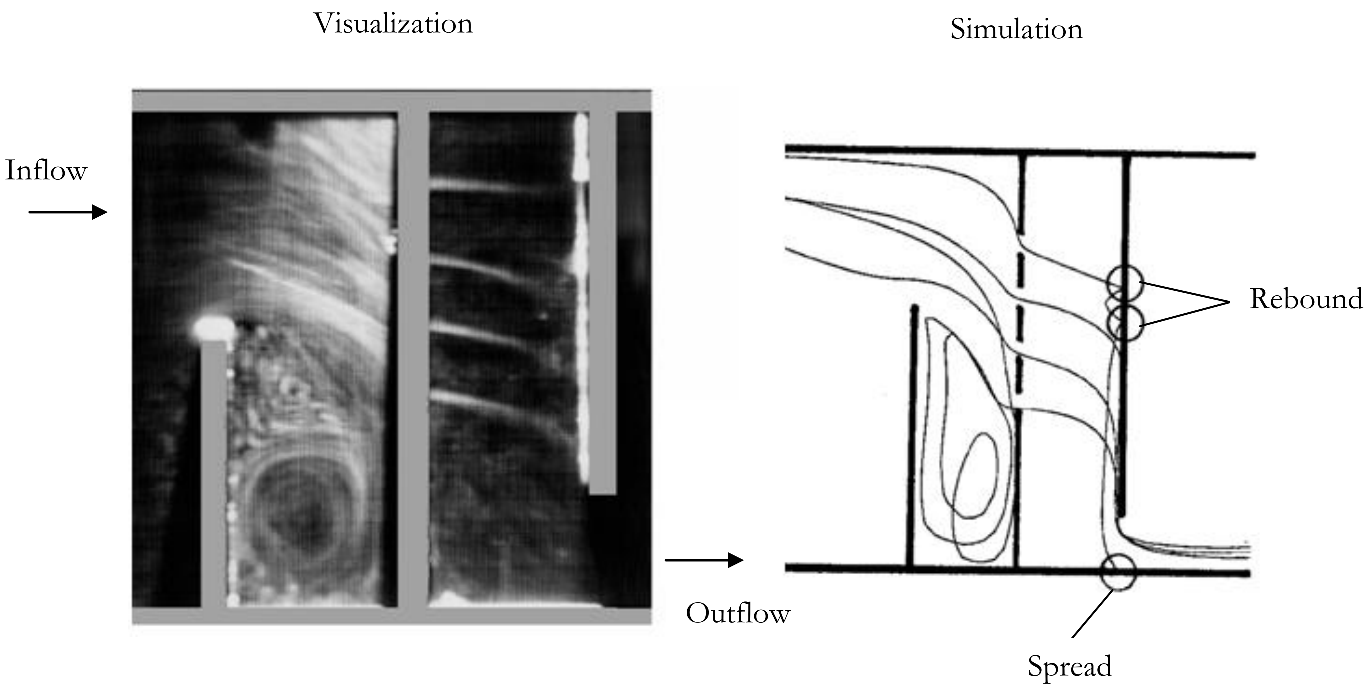

Figure 4. Porous/Baffle plate

3.1.4 Pickup Truck Principle

When designing the interior in the expansion chamber one theory is to make use of the phenomena that occurs when for example a pickup truck runs on highway at a higher speed. When the air flows over the truck a vortex is created in the cargo area, see Figure 5, that forces the particles in the air to the bottom of the cargo bed.

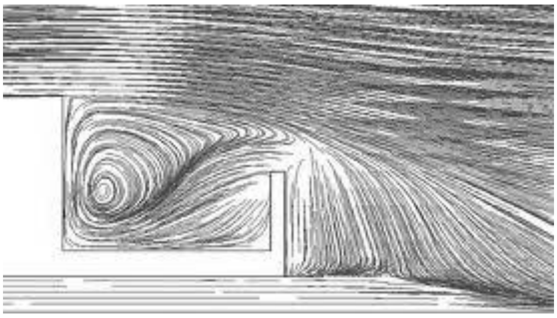

Figure 5. Airflow over a pickup truck cargo area

In [5] this phenomenon is investigated. In the initial phase of experiments this theory may be tested in one of the expansion chambers to investigate its effect. However because the complex geometry of the chambers leads to that it is hard to achieve this vortex, though it might have been interesting to analyze this.

3.1.5 Chicane

To reduce the amount of oil particles in the ejected aerosol, one possible solution is to make use of a chicane filter, Figure 6. The purpose of the filter is to get the oil particles to deflect from its trajectory and crash in to some of the walls to form larger droplets that could be fed back to the oil sump. The main advantage of such a solution is the simplicity and its low cost and no moving parts leads to that it almost is maintenance free.

The aerosol mixture enters the chicane filter through (1) in Figure 6 and hopefully some of the oil particles crashes into the first wall. The ones who do not crash continue along the path up until the first 180° turn, where hopefully the tight turn will make the oil particles to deflect from its trajectory and crash. This repeats itself depending on how many walls that are inserted in the filter and finally the air exits through the outlet (2) in Figure 6.

One drawback of this type of filter may partly be its efficiency. For the chicane filter to function a rather large airflow is necessary and it is also necessary that the oil particles are not too small. If the oil particles get to small they may branch off from the walls instead of crashing into them and follow the air out of the filter. To its advantages is however that it relatively easy could fit in the dedicated space and is easy to implement.

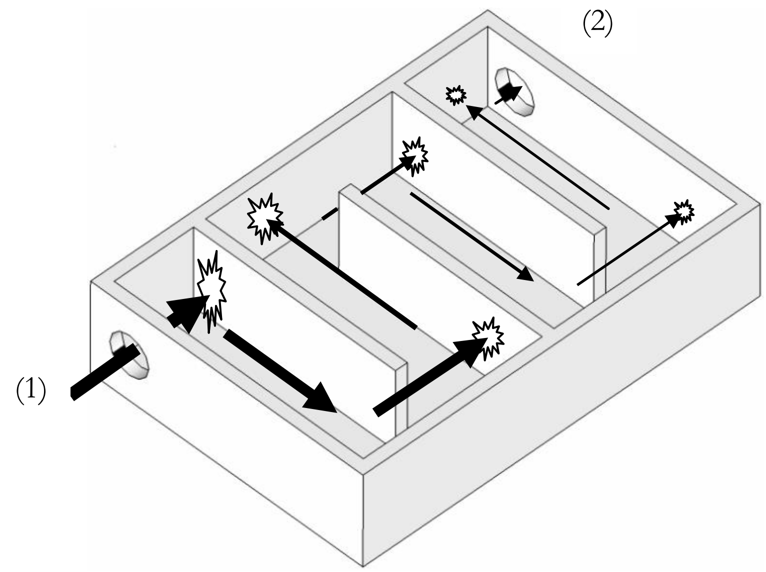

Figure 6. Chicane Filter

3.1.6 Cyclone Filter

One way of separating particles in aerosol from the air is to use a cyclone filter, see [6]. The cyclone filter makes use of the centrifugal force to separate particles from the air. One advantage of the cyclone filter is that there are no moving parts; this leads to that it is a relative simple construction that is durable.

Air and particles enter the inlet, (1) in Figure 7, at a high velocity. In the filter the aerosol start spinning along the vertical axis of the filter and a flow equivalent to a cyclone appears. As the diameter of the filter decreases the velocity increases and the particles are forced against the wall and a relatively clean area appear in the center of the cyclone. This relative clean air is then exhausted through outlet, (2) in Figure 7, that is placed on the top and center of the chamber. The particles that has been separated is drawn by the gravity to the bottom of the filter and ejected in outlet (3) in Figure 7 located in the bottom of the filter.

Cyclone filters are typically used in environments with high particle concentrations and the efficiency increases with the increase of the size of the particles. It is also necessary to have a relatively high and continuous flow so the cyclone appears and the filter becomes effective. For this application it is however at this point not suitable for several reasons. One problem is the lack of a constant air flow. The air that is ejected from the retarder is irregular and this leads to that it will be hard to form a cyclone inside the filter. This problem is solvable by perhaps having a pre-chamber to store up the air and then eject it in a more constant flow through a strangulation or perhaps adding compressed air to build up the cyclone. However this solution adds complexity and is not desirable. It also needs to be placed vertically in order to work. Another problem is the restricted space that is available that is not suited for this kind of application. For future development this may be an alternative but at this point it is not and the idea is disregarded.

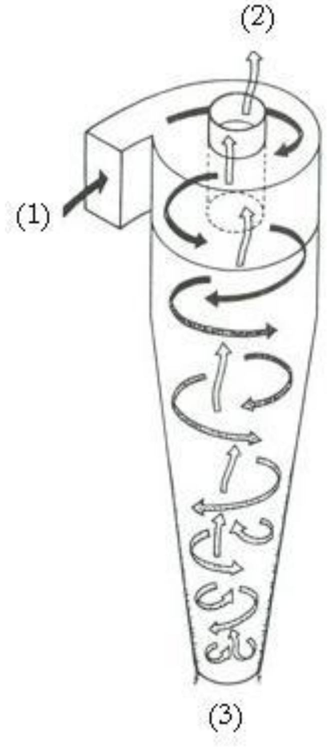

Figure 7. Cyclone separator

3.1.7 Centrifugal Impeller Filter

Another way of separating particles and air from each other in an aerosol mixture is to use a centrifugal impeller; analysis and design are further discussed in [7]. The centrifugal impeller filter is in this context a rather complex application with a rotating impeller that needs both space and drive in order to work. However the filter is highly effective and can manage submicron particles and high volume flows.

The inlet of the aerosol is in the center of impeller, (1) in Figure 8 and the outlet (2) on the outside of the impeller. The principle is that the impeller spins at a high velocity and when the aerosol passes through the inlet into the channels in the impeller; the particles will collide with the blades of the impeller and adhere. The particles, in this case the oil mist, will after collision coalesce with other droplets on the impeller blade and form bigger drops.

The function and the efficiency of this filter are desirable for this application but there are some obstacles that makes it hard to implement. The major issue is the drive of the impeller, the cost increases and maintenance is necessary which is not desirable.

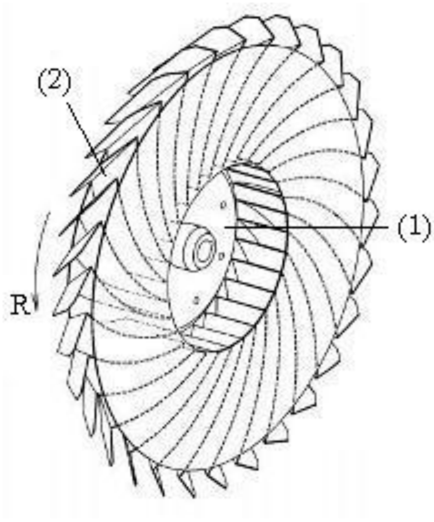

Figure 8. Centrifugal impeller, [7]

3.1.8 Increase the Airflow

Many of the principles above depend on a steady airflow to work properly and the airflow from the retarder is in short burst. A way to work around this problem could be to add airflow from the compressed air system of the brakes in order to maintain the circulation in for instance in a separator.

In order for this principle to work the added air must start the circulation/cyclone before the retarder air enters. One way to do this would be to have a constant airflow through the concept. But compressed air is quite energy consuming and this leads to a higher fuel consumption. If the compressed air only flow when its needed this would solve the energy problem. This demands a valve for the air that opens when the change of the retarder brake torque is requested (it is when the brake torque changes most of the air burst appears), and the actual retarder is delayed. This would be possible in most situations, but not for example when the ABS-system requires a disengaging of the retarder, there is no time to start the circulation and the oil would probably pass through the cyclone. However this solution also adds complexity and an increase in cost and that is not desirable.

3.1.9 Filter Medium

By filling the available space with a material consisting of for example a tangle of metal wire, a large surface area can be created. When the oil droplets hit the surface it may stick to it and when another droplet hit the surface the two droplets attract each other and in the extension form a larger drop, see Figure 9. These larger drops will not as easily follow the airstream out of the filter, but rather fall down to the bottom where they are collected and drained. This method is used with good results to filtrate the crankcase gases, and is described in the Scania report [8] written for the department DMBC[3]. Here they use expanded metal of aluminum see Figure 10 which is folded twenty times. This creates a porous material with a density of approximately 8% compared to a solid peace of aluminum. The problem with this technique is that it does not work for submicron particles though they tend to follow the air stream along the surface and not to attach to it, as illustrated in Figure 9. By doing the passage between the wires smaller the pressure drop over the filter becomes larger, this will slow down the airstream and smaller particles will hit the wires. But if the space becomes too small the capillary action becomes larger than the gravity force, and the filter will clog.

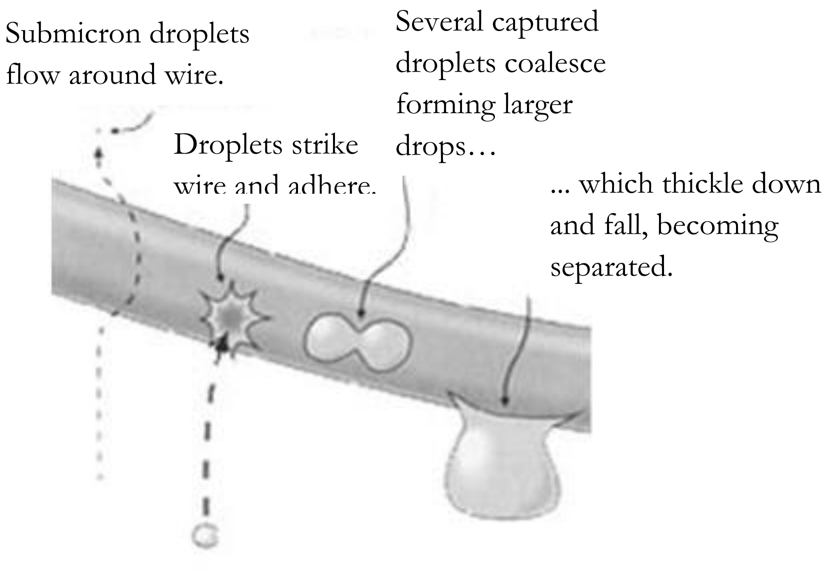

Figure 9. Illustration of filter mediums capability of catching droplets

[3] DMBC is the Camshaft Department at Scania.

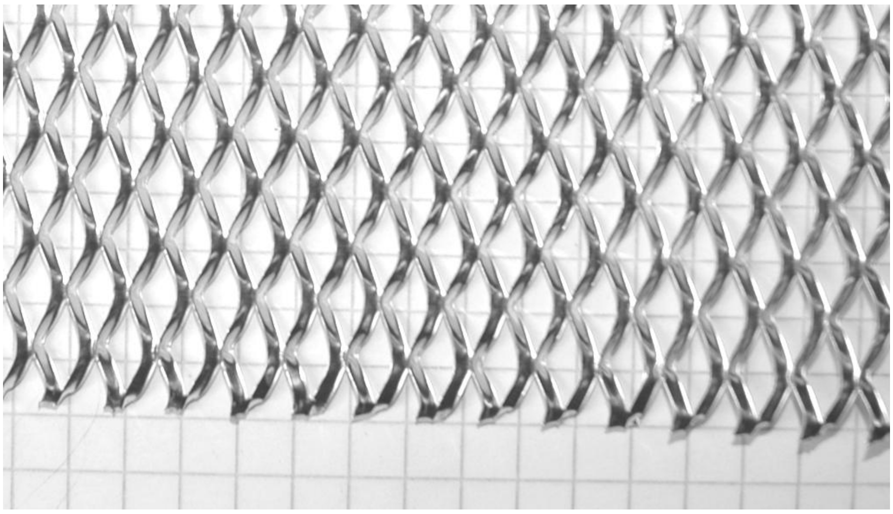

Figure 10. Expended metal of aluminum

There are also other possibilities regarding of what the volume could be filled with to increase surface area. A tangled metal filter may have a positive effect on catching the oil droplets but it rather fixed shape and geometry may cause trouble when fitting it in a volume with a complex geometry. Another solution may therefore to fill the volume with some kind of small balls to increase the surface area. The shape and size of these balls may differ from just smooth balls to balls with a more complex design for example the ones that are used in biological filters for aquariums see [9], see Figure 11. The advantage of using some kind of balls as filter material is that it is easy to fit as mentioned above in volumes with complex geometry and need no modification.

There are however a sea of variety of different filter material that could be used, but one of the main characteristic for all the filters is that it should not become clogged over time. The desire is that the solution should be free from maintenance and it is therefore necessary that when oil drops are large enough they should fall to the bottom and be fed back to the retarder circuit.

Figure 11. Biological filters for aquariums

3.1.10 Check Valve

When the retarder is braking without completely filled retarder circuit, air is mixed in with the oil which creates foam. When the retarder stops braking the foam is lead back into the oil sump. These foam bubbles then grow larger due to that the pressure in the circuit is higher than the one in the oil sump. When the oil sump is full of foam the risk that some of the oil reaches the drainpipe is of course increasing. However because the brake torque is controlled by the filling degree in the retarder circuit this operating point has to be allowed. To decrease the amount of foam that is generated one possible solution may be to let the oil foam pass through a check valve when exiting the retarder circuit. By letting the foam pass through a light prestressed check valve of ball type as described in Figure 12, the bubbles will burst and heavily decrease the amount of foam in the oil sump according to [10].

This solution may be interesting in the future, but since it is a major modification to the retarder housing it is decided to dismiss this idea at this state.

Figure 12. Schematic figure of a check valve

3.1.11 Electrostatic filter

In the rapport M29/035 from the NMBO[4] a test with electrostatic filter from Fleetguard[5] is described with very good results. Therefore a study of electrostatic filters may be interesting.

Cited from [11];

How it works

Electrostatic separators use electrostatic forces to separate particles from gases. A number of high-voltage, direct-current discharge electrodes are placed between grounded collecting electrodes. The contaminated gases flow through the passage formed by the discharge and collecting electrodes. The airborne particles receive a negative charge as they pass through the ionized field between the electrodes. These charged particles are then attracted to a grounded or positively charged electrode and adhere to it.

[4] NMBO is the department of lubrication systems at Scania
[5] Fleetguard is a manufacturer of filters

The collected material on the electrodes is removed by rapping or vibrating the collecting electrodes either continuously or at a predetermined interval. Cleaning a precipitator can usually be done without interrupting the airflow.

The four main components of all electrostatic precipitators are-

- *Power supply unit, to provide high-voltage DC power*
- *Ionizing section, to impart a charge to particulates in the gas stream*
- *A means of removing the collected particulates*
- *A housing to enclose the precipitator zone*

The following factors affect the efficiency of electrostatic precipitators:

- *Larger collection-surface areas and lower gas-flow rates increase efficiency because of the increased time available for electrical activity to treat the dust particles.*
- *An increase in the dust-particle migration velocity to the collecting electrodes increases efficiency. The migration velocity can be increased by-*
    - *Decreasing the gas viscosity*
    - *Increasing the gas temperature*
    - *Increasing the voltage field*

Electrostatic filters are most commonly used for indoor air cleaning, these types of filters require very little maintenance and there is no filter material that needs to be changed. These two arguments make it suitable for this task. But for this case it would not be possible to fit it in the available space. Furthermore an electrostatic filter is a rather costly and complex solution. Therefore it is not suitable for this problem at this stage. For future development this may be an alternative but at this point it is not and the idea is disregarded.

3.1.12 Change in Strangulation, Right Ventilation Channel

One previous detected problem is that oil has found its way up the right ventilation cannel when braking heavily. According to report [12] a test was carried out where the right ventilation channel was strangled to investigate if it could have any positive effect. The four cases that was tested was partly to block the channel completely, partly to have a strangulation with 1 mm respectively 2 mm hole and also a hole with 9 mm in diameter that was the current configuration. When completely blocking the channel no noticeable increase in pressure could be detected surprisingly enough however a completely blocked channel could lead to other problems and is therefore not desirable. Tests was later performed where the retarder was provoked in three different levels with different degrees of filling and when using the 1mm hole it was noticed that through the oil sump ventilation the retarder was completely sealed against leakage for all three levels of testing. For the 2 mm hole the retarder was sealed against leakage for the two first levels but not for the third. However for productions means it was decided that 1mm hole was a bit narrow and a 2 mm hole more suitable. Though there should be a possibility to optimize this. The area for a 2 mm hole is four times larger than a 1 mm hole according to

$$A_{circle} = \pi r^2 \tag{3}$$

hence there could be a more optimal solution somewhere in between. There is however limitations in the production that should be investigated.

3.1.13 Alternative oil

One theory to minimize the oil leakage is to minimize the oil foam that emerges when the retarder is braking. The oil foam emerge especially when the retarder is braking at part load. By changing to a different oil with additives that reduces the oils capability to form foam the problem partly may be solved.

3.1.14 Balloon

One of the more intuitive thoughts on how to solve the problem is to just put a plastic bag or a balloon on the "exhaust pipe" and the problem would be solved. However there are some issues by doing this. Theoretically it would be possible to do this for the oil sump ventilation and competitors like Voith [13] who uses this in example VR 115 HV[6] where the there is like a membrane between the oil and the air, see Figure 13. This enables for the oil change in volume while still being encapsulated and no leakage can occur. This is not however at the moment a possible solution mainly due to the fact that it requires heavy modifications to the current retarder. This solution is also more complex than the current system. For instance if there is an air leakage from the solenoid valve block in to the retarder, it would inflate the balloon. The air leakage can for instance be due to a damaged seal in the air/oil valves. This solution may be taken in consideration designing a completely new retarder but otherwise not.

Regarding how it is suitable for the other sources to the leakage, it is not. This because "new" air is added every engage of the valves. The safety valve, the proportional valve and the accumulator are fed with compressed air and if a balloon were to be placed on any of the exhaust tubes it would just inflate until it would explode.

[6] VR 115 HV is a retarder manufactured by Voith

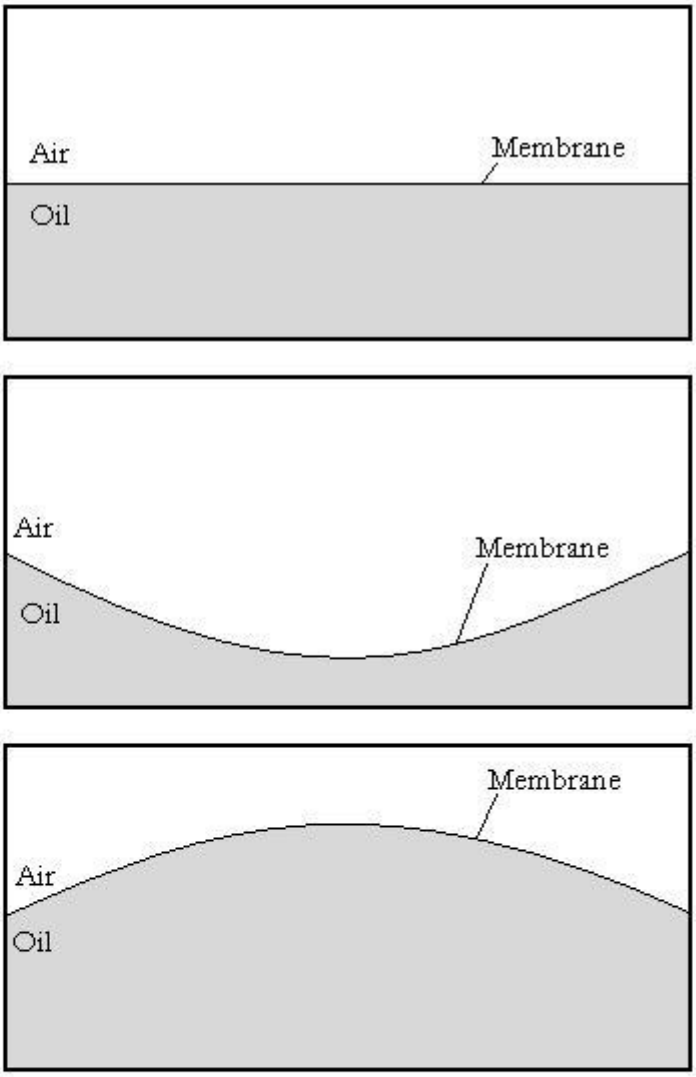

Figure 13. Illustration of oil sump with a membrane

3.2 Limitation and Requirements

3.2.1 Specifications of Requirements

In the specifications of requirements below, a list of the necessary (N) and the desired (D) requirements are shown. The desired requirements are not necessary to the concept to satisfy its main function, to minimize the oil leakage, but it is desirable. The necessary requirements must however be fulfilled and cannot be disregarded. These can also be seen as the limitations for the concept. The different concepts are later then evaluated on these grounds to determine the most suitable concept.

Low Weight	(D)
Be able to cope with an overfilled retarder	(D)
Be able to capture oil mist from the retarder	(N)
Have a feedback to the oil sump	(N)
Low cost	(D)
No maintenance	(D)
Easy to assemble	(D)
Include the bolts that holds the stator	(D)
Cope with oil temperatures up to 180°C	(N)
Be able to fit between the oil sump cover and the oil cooler	(N)
Instantaneous be able to cope with a pressure of 8.3 bar	(N)
Be able to handle surrounding temperatures between -40° and 125°	(N)
Withstand external influences such as water, oil, dirt, detergents etcetera	(N)
Be insensitive to wear and tear	(N)
A life expectancy equivalent to the retarder	(N)
Environmental	(D)
Simple, consists of as few components as possible	(D)
Be part of Scania's module system	(D)

3.2.2 Placing

There is a lack of space around the retarder but there is an available space between the oil sump cover and the oil cooler. Thus the potential volume is limited to the space between the oil sump cover and the oil cooler. It is also limited to the left by the frame and to the right by the drive shaft according to Figure 14 and Figure 15. If the volume would to be placed here it is of great importance to consider how the retarder is mounded at the assembly line. Therefore it not desirable to cover up any of the bolts that hold the oil sump cover, marked A in Figure 16, or place them inside the volume. However the four bolts that hold the stator marked B in Figure 18, are preferred inside the volume. This due to, that in some rare cases oil is pressed out pass the bolts from the pressurized brake circuit. With the boundaries that is established it is desirable to maximize the volume as large as possible. First draft of a maximum volume is shown in Figure 18. This volume called volume 1 is however in need of modification since there is a problem fitting the drains from the solenoid valve block at the bottom of the chamber. It is desirable to fit these in the bottom of chamber because its closeness to the solenoid valve block. Therefore the volume is redefined as shown in Figure 19, this is the basic layout that is further used.

The feedback channels are shown in Figure 17 and Figure 18. These are located to these places due to that; the feedback channels must return in a non pressurized part of the retarder and in the bottom of the new volume.

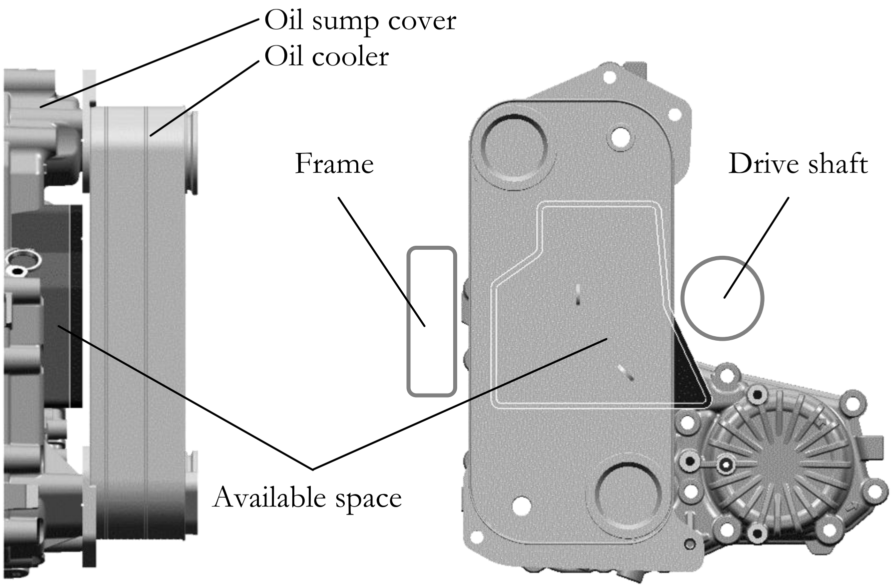

Figure 14. Oil sump cover plus oil cooler, side view

Figure 15. Oil sump cover plus oil cooler, front view

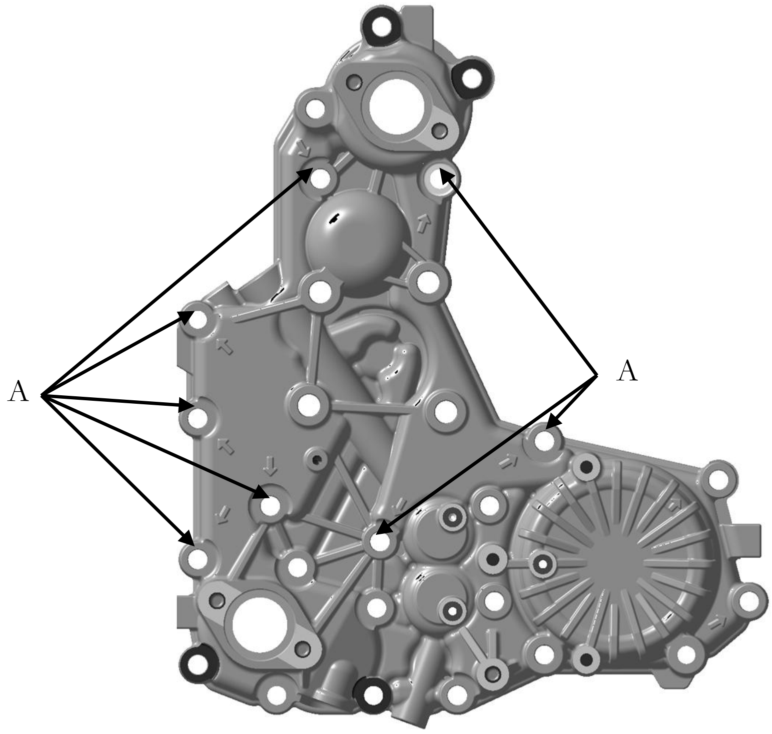

Figure 16. Original oil sump cover, front

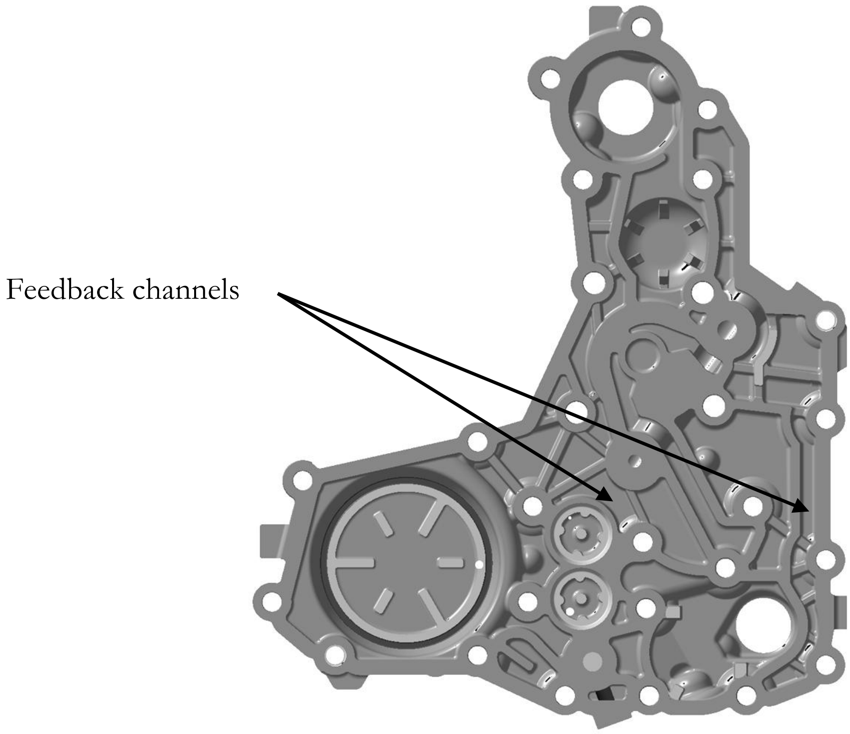

Figure 17. Original oil sump cover, back

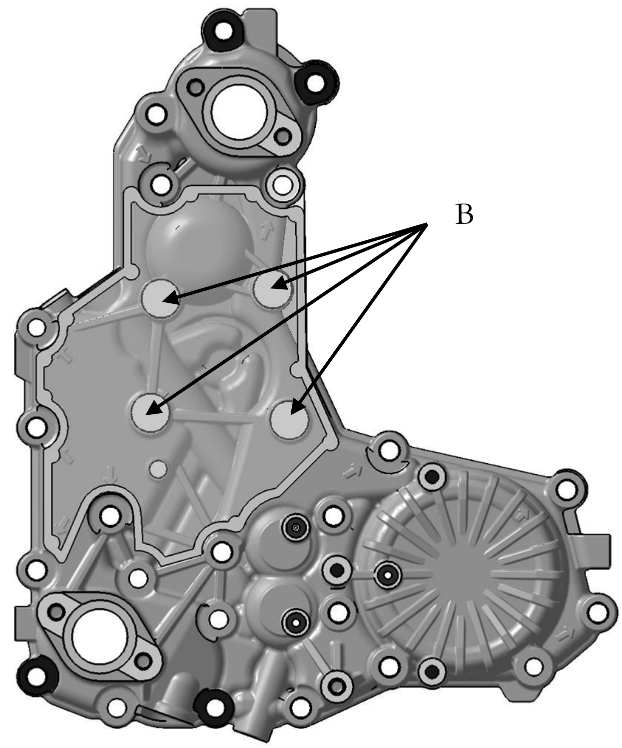

Figure 18. Maximal volume, V=0.70 liter

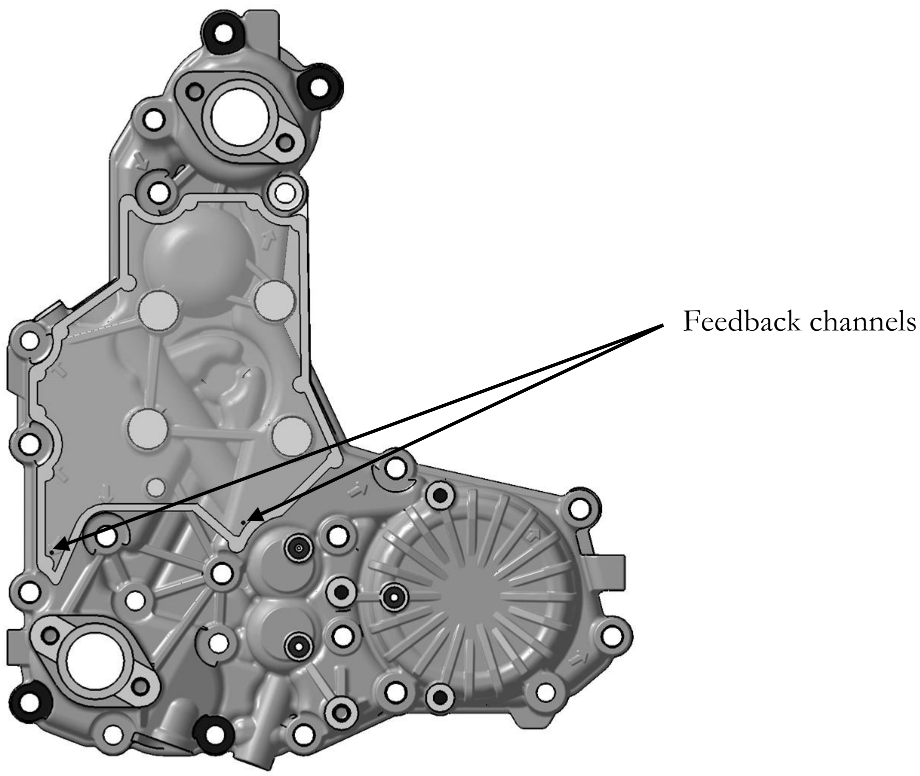

Figure 19. Redefined volume, V= 0.64liter

3.3 Phase Two

In phase two the concepts from phase one that meets the given requirements according to 3.2.1, or considered possible to modify so that they meet the requirements is further analyzed and tested. During this phase an alternative test rig is developed for additional and parallel testing.

3.3.1 Prototype 1

When developing and producing the first prototype it is suggested that instead of mounting the prototype at its correct location on the actual retarder, a replica of the oil sump cover with the chamber will be produced instead, see Figure 20. The actual place for the chamber is hidden behind the oil cooler. This is preferable for many reasons for instance, it enables testing separate from the retarder which speeds up and simplifies the testing of the basic concepts. It also enables the possibility to visually follow the sequence of events inside the chamber. The prototype is produced in plastic with Solid Freeform Fabrication (SFF) technique. This prototype is then mounted beside the retarder where it can be monitored. There may occur some deviations from the actual case especially regarding the feedback channels, where these channels will be fed back through approximately 300 mm long tubes instead of right through the oil sump cover. These longer channels creates a greater pressure drop compared to if it were fed back directly, which could lead to a lower flow rate through this channel. Using wider tubes in diameter with strangulation close to the chamber may partly compensate for this. However using wider tubes creates a greater overall volume but it should be negligible. Another deviation from the actual case is the temperature; the oil that circulates in the retarder can be as high as 180°C which means that oil sump cover is hot. Since the oil sump cover is one side of the volume, the oil mist that enters will not be cooled down in the same extent as when the volume is placed separately. The diameter of the feedback channels is not yet either determined but at an initial phase the best solution is considered to be with; as large strangulation as possible thus this imposes a minimal flow in this channel. To simplify for the case with an external volume, all connections are located in the lid of the volume. This because it is made of a acrylic glass plate and therefore it requires less time and work to modify/replace.

Prototype 1 will later be tested in both in the test rig T7 and S1. T7 is one of three ordinary test rigs belonging to the department NTBR where function and life tests are performed regularly. It is in T7 the tests on prototype 1 connected to an actual retarder will be performed. In S1 is a complementary test rig set up to enable testing of principles at a faster pace. A more thorough description of S1 is presented in chapter 4.2, test implementation.

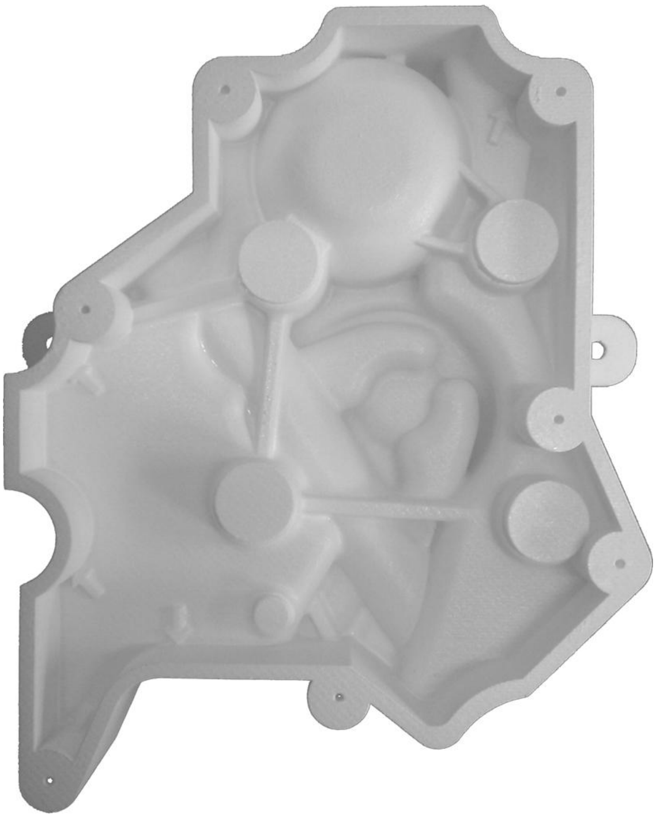

Figure 20. Prototype 1 produced with Solid freeform fabrication

3.3.2 Prototype 2

For testing of filter medium prototype 2 is developed. The main reason is that the topography of prototype 1 is very complex, and it makes it hard to fit the filter inside prototype 1, while prototype 2 is a box design to fit a square filter, see Figure 21 and Figure 22. Testing with a separate prototype also enables parallel testing, which leads to that the time consumed by testing can be reduced. The topological differences between the different prototypes is considered to be negligible due to that the box is filled with a folded filter medium that adds a large surface area and change the airflow considerably.

In difference to prototype 1 will prototype 2 only be tested in the complementary test rig S1 to verify different principles. The different tests for prototype 2 are more thoroughly discussed in chapter 4, testing. In this tests the filter medium that is used is expanded metal, this because it is available at Scania and it is already used in similar environments. But the principle is the same for non-absorbing materials, such as plastic and nylon that is easier to fit in the complex geometry of the real volume.

Figure 21. Prototype 2 with lid and inlet

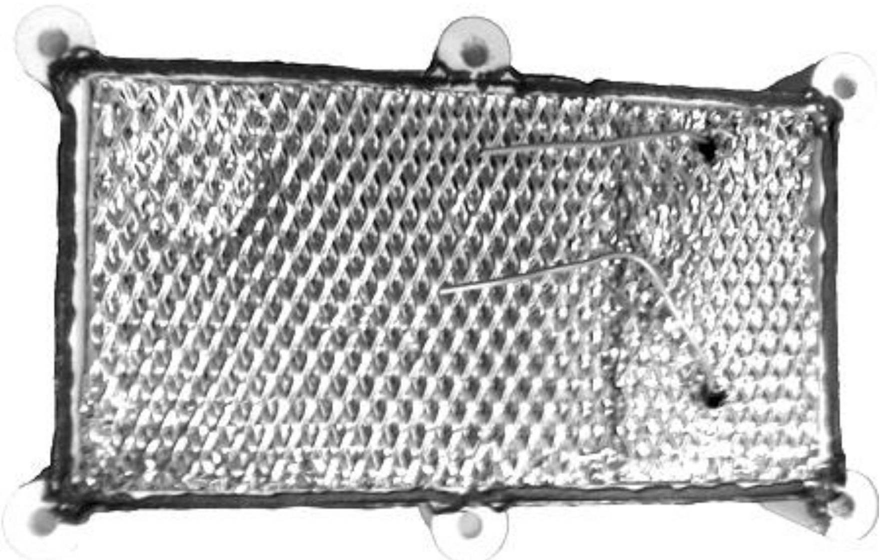

Figure 22. Prototype 2 open with expanded metal filter inside

Chapter 4

Testing

4.1 General

When testing different types of concepts it is of great important to have a test cycle that is standardized to be able to compare different tests to each other. When reviewing previous collected data about oil leakage it has revealed that there is great difference between the different retarder individuals and there is also no prior information if the leakage changes over time. It is therefore almost impossible to compare new results with old ones and the information it gives is a hunch of how large the leakage is. In Table 3 data is compiled from five different retarder tests. The worst case of these five is the oil sump ventilation in the R408UL test. Here the leakage is about 56 gram after 50 000 cycles which is rather small, a life cycle is expected to be around 300 000 cycles. It is therefore necessary to run a high number of cycles to get any accuracy in the measurements. However, the time limits how many cycles that is possible to run in a week to about 15 000 cycles. Together with the time restriction for the thesis it is not possible to run a test long enough to get satisfying results. The focus of the testing therefore lies in principles and not validation of the different concepts.

Table 3. The mean leakages after 50 000 cycles in grams

Date	Accumulator	Oil sump ventilation	Proportional valve	Safety Valve	Retarder
2010-11-15	3.1	55.6	2.3	1.1	R408UL
2010-07-02	0.7	23.0	0.6	0.4	R407
2010-06-03	0.1	25. 0	0.2	0.6	R401ULH
2010-04-12	3.4	18.2	1.6	1.9	R405L
2009-08-06	-	18.05	-	-	R400LH
Mean value	1.8	23.0	1.1	1.0	

4.2 Test Implementation

A complementary test rig S1 is developed to decrease the time for the tests, and increase the possibilities to separate changes the test parameters, such as airflow, oil share and in some way the droplet size. To assure that the tests are as close as possible to the actual case, airflow, pressure and time duration of the air burst are adjusted to emulate the oil sump ventilation with help of a pressure regulator, time switch and is verified with flow meter. The alternative test rig consist of a solenoid valve, a oil-mist lubricator see Figure 24, a collection vessel, flow meter, DC 24V transformer and a time switch, the setup is shown is Figure 23. The solenoid valve is fed with compressed air and is controlled by a control signal from the time switch. In the time switch the on respectively off time can be controlled individually. There is also a counter that keeps track of the amount of cycles and a function that stops the time switch when a preset number of cycles are reached. The oil-mist lubricator creates an oil aerosol mixture by dropping small drops of oil into flow of air that passes through it. The oil-mist lubricator also has a little oil reservoir that manually has to be refilled between each test. Together the solenoid valve and the oil-mist lubricator create a flow of aerosol mixture. The aerosol passes through different concepts and then into a collection vessel. Before and after each test the oil-mist lubricator, the concept and the collection vessel are weighed. These numbers then lay ground for the determination of the efficiency for the different concepts

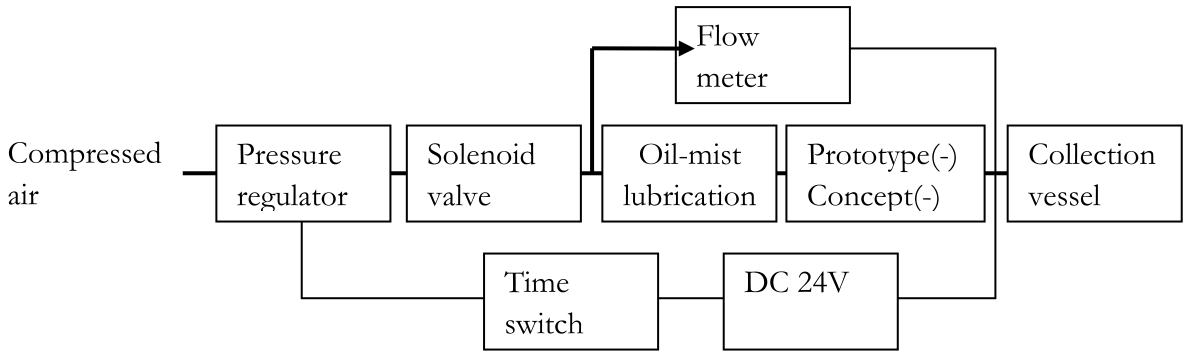

Figure 23. Schematic figure of the complementary test rig S1

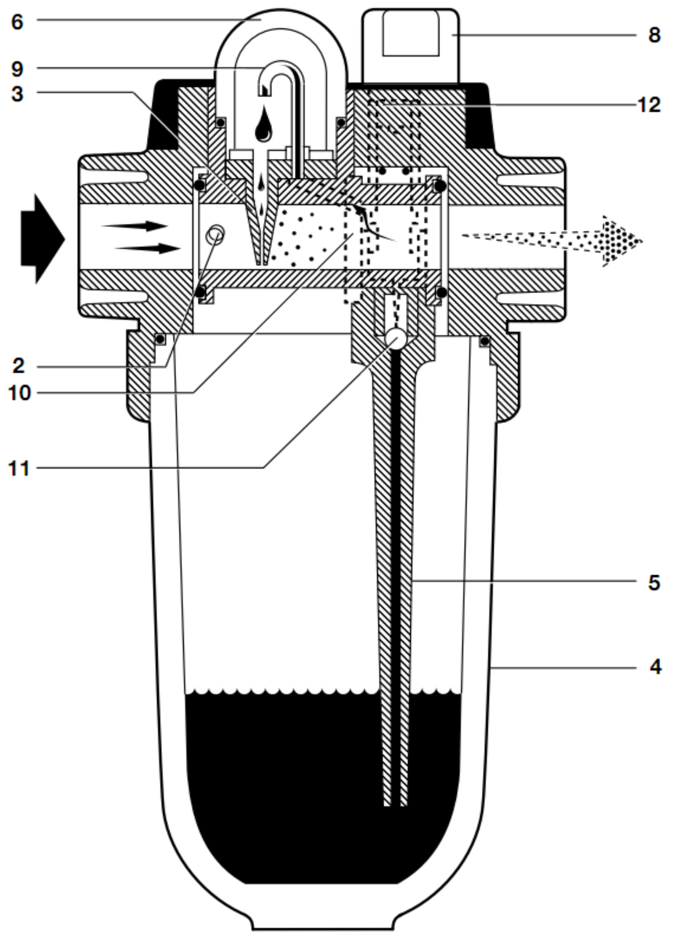

Figure 24. Oil-mist lubricator

Cited from [14].

How does it work

Air entering the lubricator pressurizes the bowl through the orifice (2). Air passing the flapper valve (3) causes a slight pressure reduction which is sensed through a small hole in the flapper valve itself. This lower pressure is sensed in the sight dome (6). Due to the difference in pressure between the main bowl (4) and the sight dome (6) oil is forced up through the feed tube (5) past the non-return valve (11), through the oil metering chamber (10) into the drip tube (9) and then out through the flapper valve (3) where it enters the main air stream. All the oil seen passing through the sight dome (6) is fed by the flapper valve into the main air stream where it is atomized.

The efficiency is calculated with two different methods, method 1

$$Efficiency_1 = 1 - \frac{\Delta B}{\Delta A} \quad (4)$$

Where

A = Oil, mist lubricator [g]
B = Collecting vessel [g]

Or method 2

$$Efficiency_2 = \frac{\Delta C}{\Delta A} \quad (5)$$

Where

C = Concept [g]

4.3 Importance of Volume Size

The first tests are made to collect basic information, how the volume size affects the oil/air separation efficiency. The data will also provide a norm for the efficiency of an empty volume, which enables the possibility of evaluate the effects for the more complex concepts. There is a previously made test at NTBR how an external volume is effecting the oil leakage from the oil sump ventilation. In the report 0 it were not detected any differences in collecting efficiency between a 1 liter and a 0.3 liter volume. Therefore it is here interesting to investigate if the test rig S1 had the same characteristics. This to assure that the test rig S1 is not too far from the actual case.

4.3.1 Test 1

The tests are performed on prototype 1 with different interiors. 100, 50 respective 30% of the entire volume, which is 0.64 liters. Every size is run twice to minimizing the effects of errors in measurements. In these initial tests the standard retarder oil Shell Rimula R3,see [15], is fed in to the oil-mist lubricator.

Result:

After analyzing the data from the tests it is not possible to detect any significant differences between the volume sizes. The efficiency is varying from ~80-100% according to appendix 2 depending on what method that is used for the efficiency calculations, the measurements errors are in a range of ± 5%. It has become clear from the tests that it is necessary to in some way provoke the tests in order to get any results.

4.3.2 Test 2

The collection capacity of the tested prototypes is at this stage too efficient. In order to provoke the test there is a few available alternatives; increase the airflow, change the characteristics of the oil such as droplet size or the concentration of oil in the air etc. It is desirable to keep the tests as close as possible to the actual case and therefore it is decided to start with the oil. In the performed tests the concentration of oil in the air in some extents already has been tested. This due to that the number of cycles that is needed until the oil in the oil mist lubricator is empty varies suggests that the oil concentration differs. Together with the design of the oil-mist lubricator this parameter is hard to control accurate. There are however other ways to change the characteristics of the oil. Smaller drops are harder to collect and therefore it is decided to reduce the size of the oil droplets instead. After consulting with experts at Shell and Scania the conclusion is, that the determining factor regarding the size of the oil droplet is the viscosity of the oil. The viscosity change in the oil is also highly dependent on temperature. In the retarder the aerosol emerge at a temperature over 100ºC and in extreme cases up to 180ºC. The viscosity of the Rimula R3 at 100ºC is about 11.5 cSt respective 3.2 cSt at 180ºC. The calculations for the viscosity are made with a macro in Excel given by Henrik Åström at Scania. In the test rig the oil temperature is about 20ºC which gives the viscosity of 204 cSt. For equipment and safety reasons it is not possible to perform the tests at this high temperature in S1. Therefore a way of solving the problem is to use a alternative oil with lower viscosity. But it is desirable to not change the characteristic of the oil to much, such as the chemical composition, surface tension, though these factors could change the way the oil drop stick to the walls or each other. The oil that is found that meet this criteria is the SpinWay XA 10 from Statoil, see [16]. It is a mineral based oil same as the Rimula R3 and has a viscosity of 21.7 cSt at 20°C.

Result:

The tests where repeated with the SpinWay XA 10 oil with no significant changes in the results compared to the ones performed in test 1 according to Appendix 2. Due to that there was no oil available with lover viscosity, a few tests was run with a SpinWay XA 10 and diesel mixture. The mixture had a lower viscosity but the mixture did evaporate when it was sprayed into the airstream which interfered with the test results.

4.4 Expanded Metal

For testing of prototype 2 the alternative test rig S1 is used, all the testes are performed with the SpinWay XA 10 oil. With the result from previous test in mind this test is run with a high airflow, as this has proven to be the most efficient way of testing.

4.4.1 Test 1

The first test is run without any filter medium inside the concept in order to get a norm for the collecting efficiency of prototype 2. During the first test the prototype is standing straight up with the inlet in the close to the bottom of prototype 2, and the outlet in the top on opposite side.

Result:

The test results showed that the collecting efficiency was about ~10% see appendix 3.

4.4.2 Test 2

In the second test when the volume is filled with the expanded metal filter described in chapter 3.2.2 prototype 2. Otherwise the test 2 is the same as test 1.

Result:

The collecting efficiency now rises to about ~95%. The expanded filter seems to have a really positive effect on the oil leakage.

4.4.3 Test 3

However the prototype 2 is a simple design without any feedback channels so the collected oil stays within the concept. So the new question is if the expanded metal filter has great collecting capacity, or if it works to slow down the airflow that enters the volume and has the effect of not whipping up and drag out the already collected oil. Test 3 therefore investigates this phenomenon. The bottom part of prototype 2 is filled with expanded metal to ensure that no free oil surface occurs but the inlet is not covered, see Figure 25.

Result:

Test 3 showed that collection efficiency was about ~95%, appendix 3, and almost the same as test 2 where the entire volume is filled with expended metal. From these results the conclusion is drawn that the most important factor has to be to avoid airflow together with free oil surfaces. The expanded metal filter probably a positive effect on oil mist as well but in S1 this effect cannot be demonstrated.

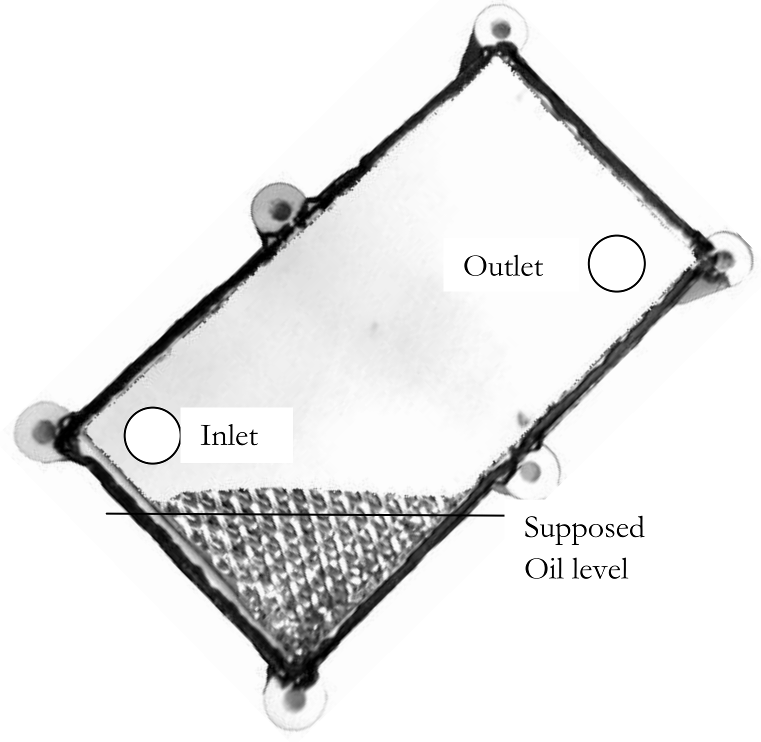

Figure 25. Prototype 2 partly filled with expanded metal filter

4.5 Difference in Feedback Connections

The first test that is performed in T7 on the actual retarder is to investigate if the placing of the feedback channels has any importance. In the first test the prototype 1 is divided into two separate chambers, see Figure 26. Each and one of these chambers has a feedback channel back to the oil sump of the retarder. But due to the geometry is the feedback channel in chamber one placed under the oil level in the oil sump while the channel in chamber two is placed over the oil level, see Figure 27. The reason why the feedback channel in chamber 1 is located under the oil level, where it looks like it placed over, is that the channel enters the current return channel of the retarder and this is located under the oil level. Initially will the aerosol from the oil sump ventilation be led into chamber one and the air evacuated from the accumulator into chamber two. This because it is these two sources that contributes to the major part of the oil leakage. The evacuated air from the proportion valve and safety valve will at the initial phase be neglected and led out into the surrounding air as the preset configuration.

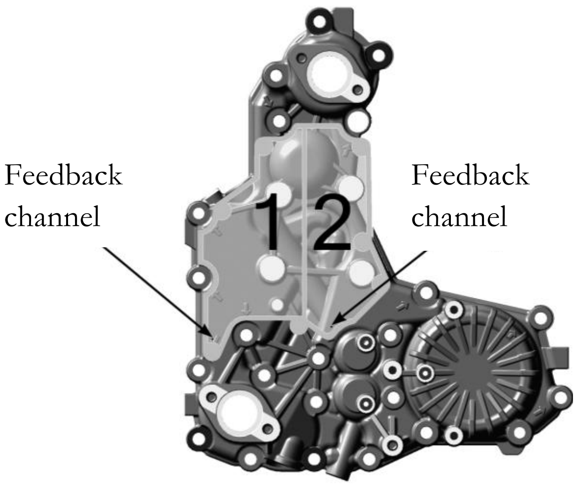

Figure 26. Oil sump cover front

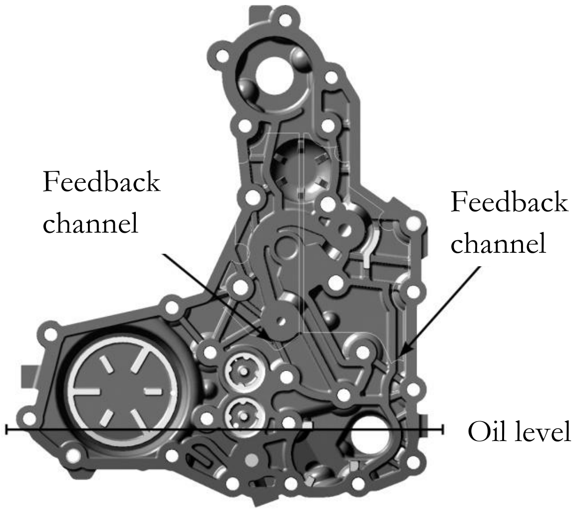

Figure 27. Oil sump cover back

The purpose of the first test is to investigate if there is any significant difference in the oil leakage whether the oil sump ventilation is connected to the first chamber and the air evacuated from the accumulator to the second, or the other way around where were the oil sump ventilation is connected to chamber two and the accumulator to the first. In theory there are benefits and drawbacks with both configurations.

The oil sump cover is modified according to Figure 28 where the two feedback channels are mounted. The tests are performed parallel with the test R416ULH that is life time test currently running in T7. The benefit of using a life time test is that it is mounted in the test cell for a long period of time and therefore available for testing during this time. The prototype is mounted on a stand so that the drains are level with the feedback channels on the oil sump cover. It is also placed as close as possible to the oil sump cover to make the tubes as short as possible to minimize the influence from them. The tests are recorded with the monitoring system in the cell, this to allow for analyze after the tests completed. The test cycle that is used is described in [17] and [18] and is the standard cycle for life time tests. The oil that is used in the test is ATF Q8 Auto 14, see [19], and not the Rimula R3 that is used in the other test. This to that Scania is about to change for unnamed reasons. But the properties of the two different oils are very similar and do not affect the results of the testing.

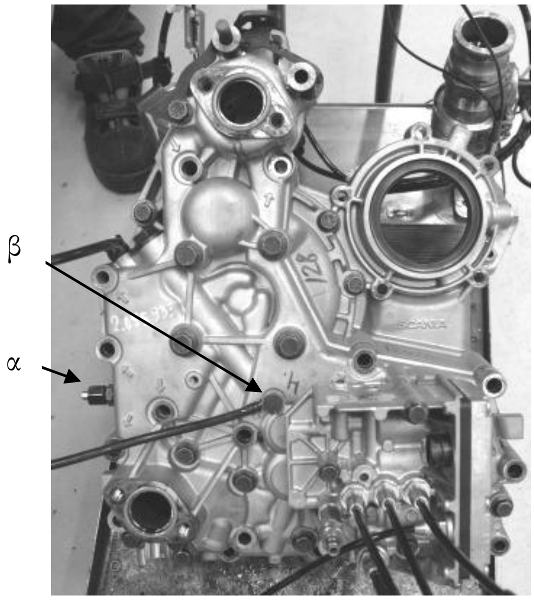

Figure 28. Oil sump cover modified with drains

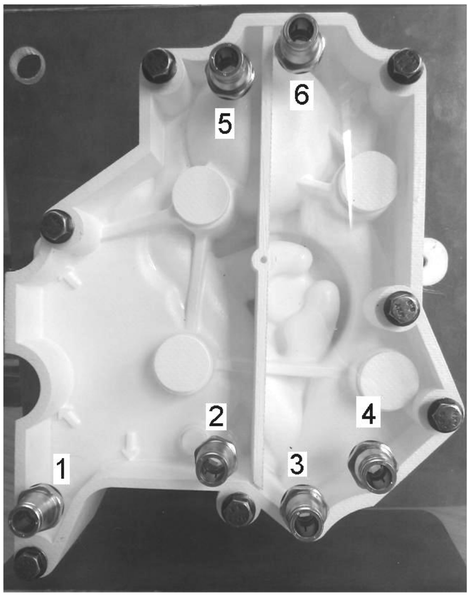

Figure 29. Prototype 1 with connections

Comment: In the following texts the numbers refers to Figure 28 and Figure 29.

4.5.1 Test 1

In the first test the air from the oil sump ventilation and accumulator are disregarded, therefore connection number 2 and number 4 are plugged. The reason to this is to investigate how much oil that emerge just from the feedback channels. It is desirable to only have flow from the chambers to back to the oil sump but that is impossible without a more complex solution like a check valve. The solution is therefore to use a strangulation of 2 mm in the feedback channel to reduce the flow in between. At first connection number 1 is connected to α and connection number 3 to β. Connection number 5 and number 6 are connected to two collecting vessels.

Result:

The result of test 1 showed that oil where pressed in to the right chamber from β when the retarder where disengaged. The maximum filling occurred when the retarder were disengaged after had been engaging for a long time. The reason for this is probably that the feedback channel β is placed quite close to the safety valve inside the retarder and when the retarder is disengaged this valve opens. From α there was no visual oil entering the chamber. In appendix 5 the course of events is presented.

4.5.2 Test 2

In test 2 the two largest contributors to the oil leakage are also included. The oil sump ventilation is connected to number 2 and the accumulator is connected to number 4. The other four connections are the same as in test 1, that is number 1 is connected to α, number 3 is connected to β and number 5 respectively number 6 are connected to two collection vessels.

Result:

At first sight result of test 2 looks the same as test 1 but when the air from the accumulator were released in to the right chamber, the chamber that fills up with oil, the air whipped up the oil and it was dragged with the air out of the chamber into the collection vessel. In a real case this is an unwanted leakage. In the left chamber there was still no visual sign of oil. In appendix 5 the course of events is presented.

4.5.3 Test 3

It is clear from test 2 that the high pressure from the accumulator and the oil that is pressed up in the right chamber is not a good combination. Therefore in test 3 the oil sump ventilation and accumulator switch chambers. The oil sump ventilation is connected to number 4 and the accumulator to number 2. Connection number 1 is still connected to α and number 3 to β. Number 5 and 6 are still connected to two collection vessels. The reason for this that the air from the oil sum ventilation has lower more smooth flow compared to the more aggressive flow from the accumulator. The expectation is that the lower flow from the oil sump ventilation will not drag the oil out of the chamber.

Result:

As seen in test 1 and test 2, oil is pressed up in the right chamber and no oil into the left chamber. But as expected the oil sump ventilation's low flow did not whip up the oil and dragged it out of the chamber in the same extent as the accumulator. The conclusion is therefore that the air from the accumulator should be separated from oil. In appendix 5 the course of events is presented.

4.5.4 Summary of tests 1-3

A short conclusion of the test 1, 2 and 3 shows that the chosen location for feedback channel β, right next to the safety valve, not is suitable for a feedback channel. This due to the fact that the oil level in the retarder under certain operating conditions obvious rise over this level which leads to a flooding of the external chamber. This in combination with the high airflow from the accumulator leads to a solution that is worse than the original retarder. It is also clear as mentioned above that the airflow from the accumulator should be separated from oil as much as possible.

4.6 Modified Prototype 1

As a result from tests mentioned above a new modified prototype is developed. In this prototype the feedback channel β is removed and only feedback channel α remains. However it still is desirable to have two chambers due to the harsh nature of the airflow from the accumulator. Instead of the old drain β the drain from the right chamber enters into the left chamber through a 2 mm hole in the wall that separates the chambers, see Figure 30. The bottom of right chamber is also raised so the drain enters a bit up in the left chamber, this allows for the oil level to rise in the left chamber without entering the right. For production purposes to minimize the use of pipes and fittings the outlet for the oil sump ventilation is moved from connection number 2 in Figure 29 to number 6 in Figure 30. This because the number 6 in Figure 30 correspond to the actual location of the inlet of the oil sump ventilation on the oil sump cover. In the left chamber are the oil sump ventilation, the control valve and the safety valve connected to 6, 4 and 5 in Figure 30 respectively. A deflector wall is also mounted in such way that the aerosol from three sources is forced downwards towards the oil-drain, this also result in that the aerosol have to take a longer way to reach the outlet number 7 in Figure 30 which enables for more time for the oil to stick to the wall.

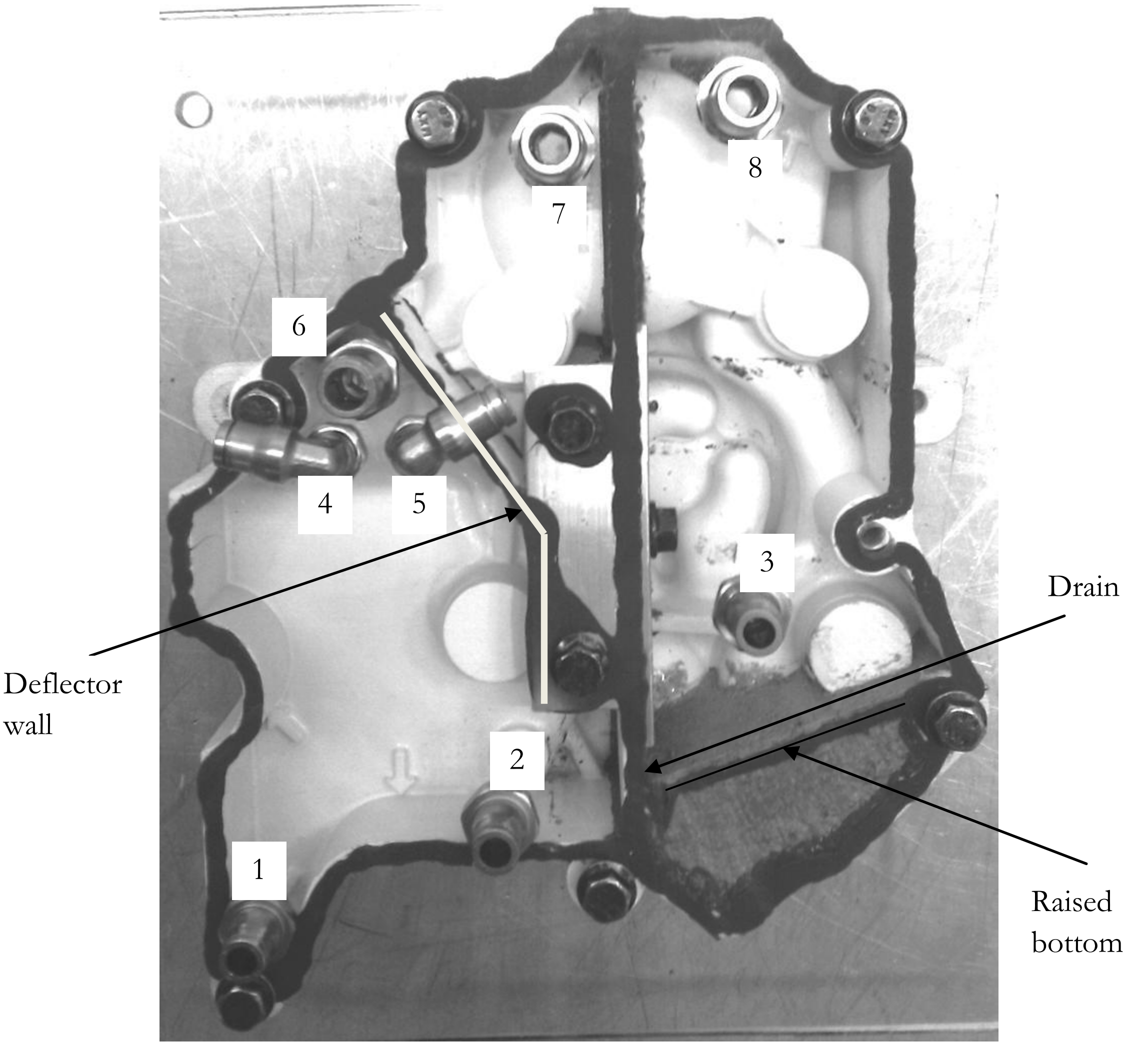

Figure 30. Modified prototype 1 with connections

Comment: In the following texts the numbers refers to Figure 30.

4.6.1 Test 1

In the first test of the modified prototype 1 the accumulator is connected to number 3 in the right chamber. In the left chamber the oil sump ventilation is connected to number 6, the control valve to number 4 and the safety valve to number 5. The feedback channel is connected to number 1 and number 2 is plugged. The two outlets number 7 and number 8 are connected to collecting vessels. The test is still performed parallel with ULH416H.

Result:

There were no apparent effects of the first test. No oil entered the left chamber through number 1 and the right chamber seemed fine. After 11 400 engages the two collecting vessels was weighted. The vessel connected to number 7 had increased 4 g and the vessel connected to number 8 had decreased 2 g. The two colleting vessels are per se connected to each other by the oil drain in the wall that separates the chambers but this should not affect so that one of the vessels decreased in weight. The decrease in weight should rather derive to uncertainty in the measurements. However if this is disregarded and the total weight increase is 4 g this would lead to an approximate leakage of 20 grams per 50 000 engages. This result would then show that prototype 2 either improve or impair the leakage compared to Table 3. The resistance against an over filling should however increased.

4.6.2 Test 2

Due to scheduled oil change on the retarder test 1 is aborted. When the retarder is restarted test 2 begins. The configurations of the connections are the same as test 1.

Result:

When test was restarted the left chamber started to fill up with oil. The oil came from oil sump ventilation when the retarder was disengaging, see Appendix 5. This phenomenon has not been seen in any of the test above, not for the prototype 1 or the modified prototype 1 and is believed to be descended from that the retarder is overfilled. The amount of oil that was ejected from oil sump ventilation when disengaging is estimated to be around 1 to 1.5 dl. When the left chamber filled up with oil a leakage arise. It was still the air from the accumulator that was the reason for this, same as test 2 for prototype 1. In difference to test 2 for prototype 1 there was no oil in the right chamber where the accumulator enters. But the air that passed from the right chamber to the left chamber through the new oil drain was so harsh so that it dragged some of the oil with it out of the left chamber into the collection vessel. Therefore before continuing with the test 2 the accumulator was disconnected.

The result of test 2 shows after 7000 engages the collection vessel was weighted and 10 g of oil had leak into it. For perspective of 50 000 engages this would correspond to approximately 70 g of oil and is more or less equal to the worst of the ones consolidated in Table 3, so in summary not impairing the leakage. However of the positive side the modified prototype 1 has increased the retarder's capability to cope with an assumed overfilling. Without the modified prototype 1 the 1 to 1.5 dl oil ejected from the oil sump ventilation would be a leakage.

Chapter 5

Results and Conclusions

Test results from the complementary test rig S1 showed that with rather simple methods the oil leakage in form of oil mist could be captured. The efficiency of for instance concept 1 with half the volume and a chicane interior was as high as 99 to 100 % depending on the method of how to calculate the efficiency. Also the concept 2 with the expanded metal filter showed a very high efficiency, in the order of 96 to 100 %. Since the tests are performed in S1 with simulated oil leakage it is not clear that the result can be directly translated to a result for an actual retarder, but it is a positive indication.

However to solve the leakage on the retarder the expanded metal filter is considered to have more favorable properties compared to the chicane. The main one is; if the volume is filled with oil the expanded metal filter prevents it from splashing.

After testing in both the test cells, T7 and S1, it has become clear that problem may in this case rather be to feed the oil back into the oil sump. In the initial tests concept 1 was divided into two equally sized chambers. Each of these chambers has an own separate feedback channel to the oil sump. The reason that the concept 1 was divided into two chambers was the harsh nature of the accumulator. Measurements showed that the airflow in the tube from the accumulator could reach velocities up to 67 m/s. Therefore it was decided that the best solution was to have two separate chambers, one for the accumulator and one for the other three sources.

When the first test of the concept 1 was performed oil entered the right chamber through the feedback channel. This is the feedback channel that is located close to the safety valve on the oil sump cover. Even though there was a strangulation of 2 mm in the feedback channel oil entered the right chamber. The right chamber is the one the accumulator is connected to. The combination of oil in the chamber together with high airflow from the accumulator was disastrous and the retarder leaked far worse than before. The conclusion is therefore that it is of great importance to keep the air from the accumulator separated from places where oil can occur.

To solve this problem it was decided to remove the feedback channel in the right chamber and only use the feedback channel in the left chamber. It is considered that the best option is to only use the feedback channel that enters the internal drain of the retarder. This because the tests show that fairly small amounts of oil enters the left chamber from this feedback channel.

Tests also show that the size of an external volume is not of any great importance when it comes to colleting oil. There was no significant difference in between of using the entire volume of the prototype 1, that is 0.64 l or 30% that is 0.19 l. However regarding overfilling it is favorable to have a larger volume. Since the oil comes out of the oil sump ventilation when it is overfilled, it is considered that the best solution is to maximize the volume of the chamber where the oil sump ventilation enters. This to increase the retarder's capability to withstand oil leakage when it is overfilled.

5.1 Proposed Solution

With above presented results taken into consideration a new concept is presented in Figure 31 and Figure 32. The chamber for the accumulator is therefore placed as high as possible to prevent that the air will wipe up any oil close to the outlet. Results showed that even when the oil drain from the accumulator chamber was strangled through a 2 mm hole the air wiped up any oil close to the outlet. It is therefore desirable to have the drain as high as possible to prevent that, but also to enable for that the lover volume could fill up with oil without leaking in case of an overfilled retarder.

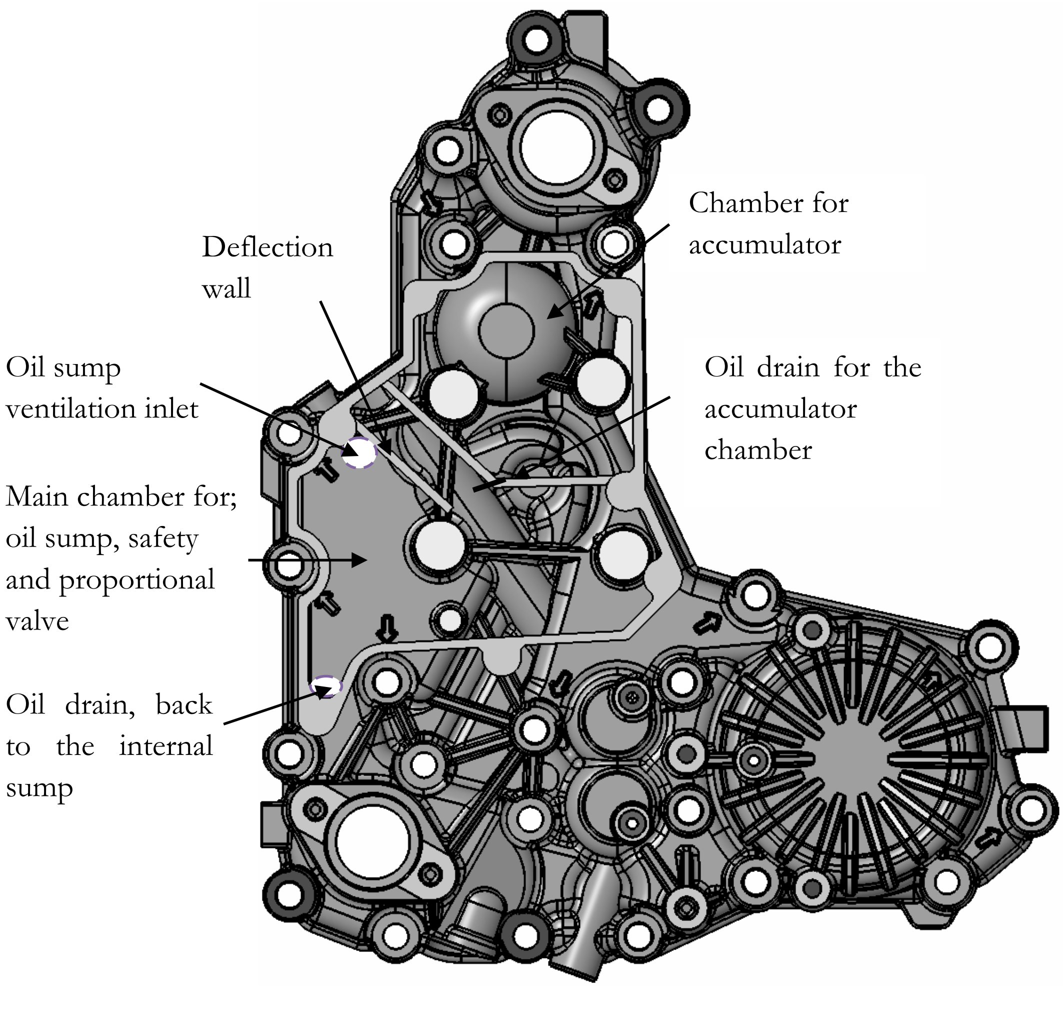

Figure 31. Oil sump cover with proposed modifications

In the proposed solution the oil sump ventilation inlet is a approximately 8mm hole through the oil sump cover and the oil drain is a 2mm hole due to production limits, see Figure 31. The oil drain from the accumulator chamber is through the wall into the main chamber see Figure 31. The test result from the modified concept 1 show that it is not desirable to have this hole in a direction towards any possible oil surface. The air inlet from the solenoid block is located in the lid and connected to the block with existing pipes. The air drain from both the chambers are through pips mounted on the lid, see Figure 32. This will facilitate the mounting at the assembly line so it is possible to mount all the pipes in advance. The two volumes is filled with expended metal or a similar non-absorbing filter medium to partly collect the oil mist but mostly to slow down the airflow. The filter is also preventing the strong airflow from the solenoid valve block to drag any collected oil out of the chambers. This solution is also preferable with regards to overfill. The final solution is presented in Figure 33.

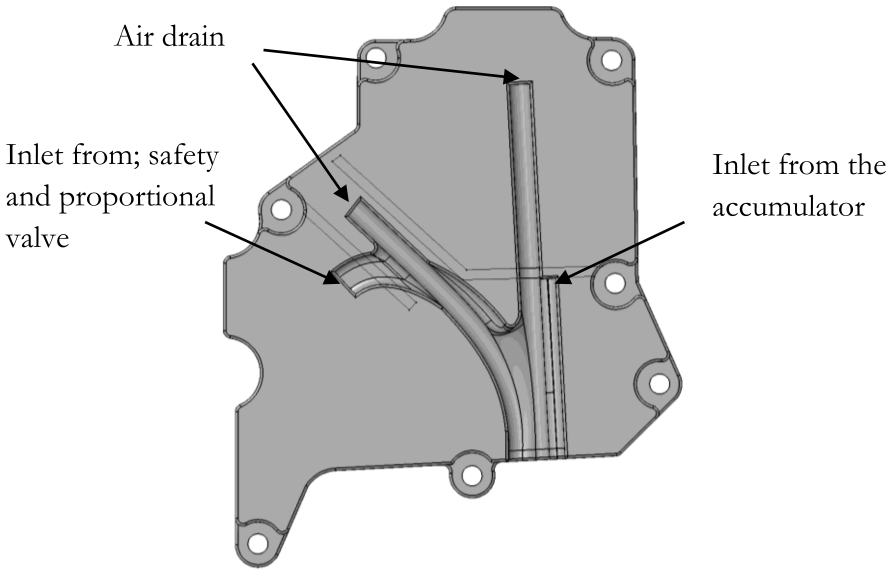

Figure 32. Lid for proposed solution

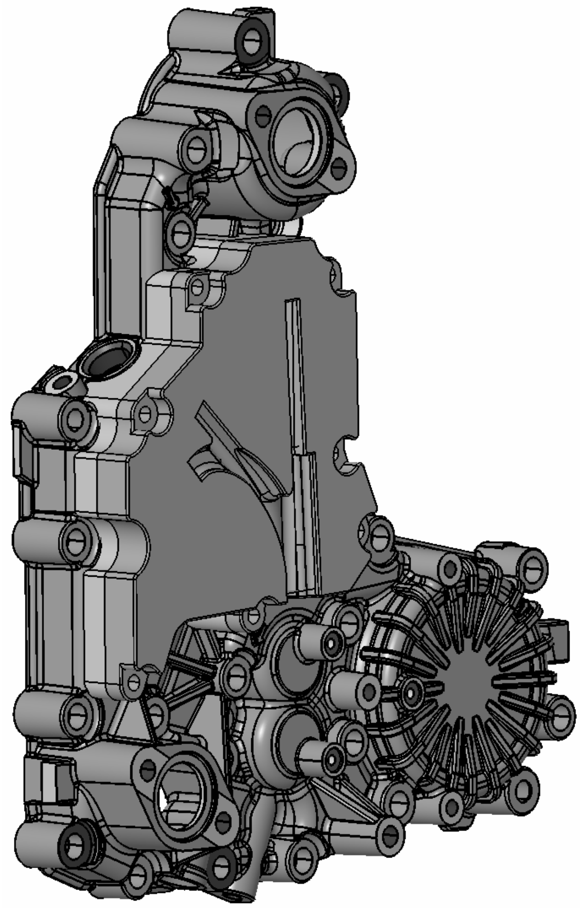

Figure 33. Proposed solution

Chapter 6

Future testing

The next logical step would be to run a test to verify the solution presented in chapter 5 Results and Conclusion. This test should include; a basic function test, an overfill test and a test consisting of at least 100 000 cycles to get any dependable results.

For a greater understanding of the oil leakage in the future, it is interesting to investigate the characteristic of the oil leakage; it is a constant ejection of oil aerosol, or does the leakage come more as a rare big oil ejection? How does the oil leakage vary over a time? This is important to know in order to evaluate future tests.

In chapter 3.1.12 the strangulation of the right ventilation channel is briefly discussed but as noted before this is something that could need further work.

As described in chapter 3.1.12 it could be interesting to investigate if a different oil have a impact on the oil aerosol.

Polyswirl is a fine oil mist separation system, developed of Polytec Groupe. Polytec contacted Scania after finding this master thesis on Scanias web page. This concept where presented to us late in the processes and has therefore not been evaluated.

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List of Figures

List of Tables

Appendix 1

Mass Flow

Estimated values

The general gas law

$$\mathrm{pV = nRT}$$

p = Pressure [N m^{-2}]
V = Volume [m^3]
n = Numbers of molecules [mol]
R = Gas constant [8,3145 J mol^{-1} K^{-1}]
T = Absolute temperature [Kelvin]

In this case it is only the proportion between the two volumes that are interesting which gives

$$\mathrm{p_{pressurized}V_{pressurized} = p_{atmosohere}V_{atmosohere}}$$

This gives the volume at atmospheric pressure that will stream out from the accumulator drain

$$V_2 = \frac{p_1 V_1}{p_2} = \frac{p_1 \cdot (\pi \cdot r^2 \cdot l)}{p_2} \approx \frac{8.3 \cdot \pi \cdot 0.5^2 \cdot 0.7}{1} = 4.6\ l$$

Volume from the two on/off-valves

$$V_2 = \frac{p_1 V_1}{p_2} = \frac{p_1 \cdot (\pi \cdot r^2 \cdot l)}{p_2} \approx \frac{8.3 \cdot \pi \cdot 0.175^2 \cdot 0.25}{1} = 0.2\ l$$

Measured values

Volume *(trapezoidal method)*

$$V = \int_{t_1}^{t_2} Q(t)\, dt \approx \frac{1}{2}\sum_{i=2}^{N}(t_i - t_{i-1})(y_i - y_{i-1})$$

Where

$$y_i = f(x_i)$$

and

V = Volume [m^3]
t = Time [s]

Air speed velocity in a tube

$$v = \frac{Q}{\pi r^2}$$

Where

v = Air flow velocity [m/s]
Q = Mass flow [m^3/s]
r = Radius of the pipe [m]

Accumulator

v_{acc} = 67,1988 [m/s]

V_{acc} = 4,3873 [l]

$V_{acc\ corr}$ = 4,3389 [l]

Oil sump ventilation

v_{sump} = 9,2840 [m/s]

V_{sump} = 1,0842 [l]

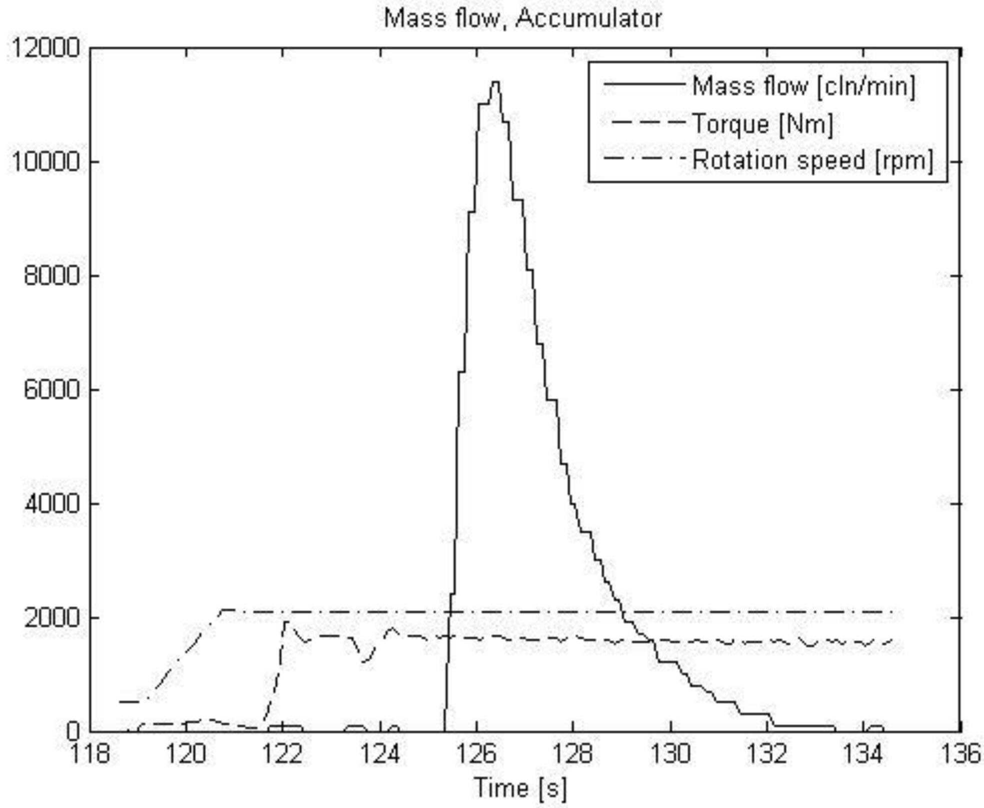
$V_{sump\ corr}$ = 0,9567 [l]

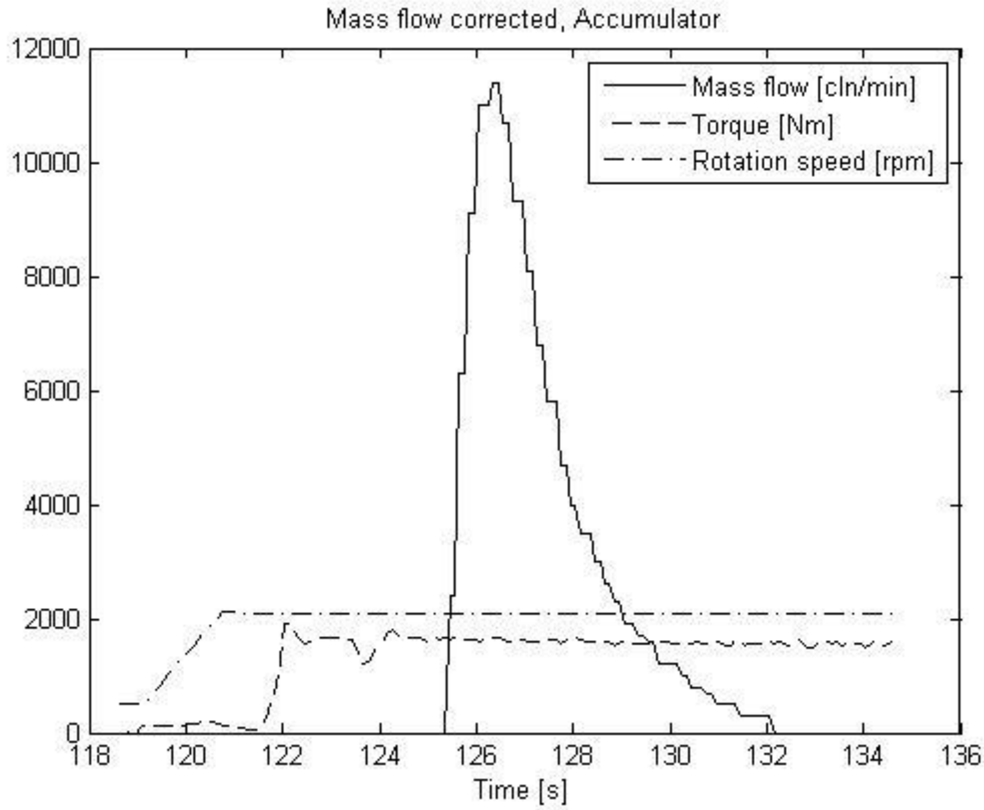
Proportional valve

v_{prop} = 1,7684 [m/s]

V_{prop} = 0,29853 [l]

$V_{prop\ corr}$ = 0,19155 [l]


Mass flow, Accumulator
Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
12000
10000
8000
6000
4000
2000
0
118
120
122
124
126
128
130
132
134
136
Time [s]


Mass flow corrected, Accumulator
Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
12000
10000
8000
6000
4000
2000
0
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120
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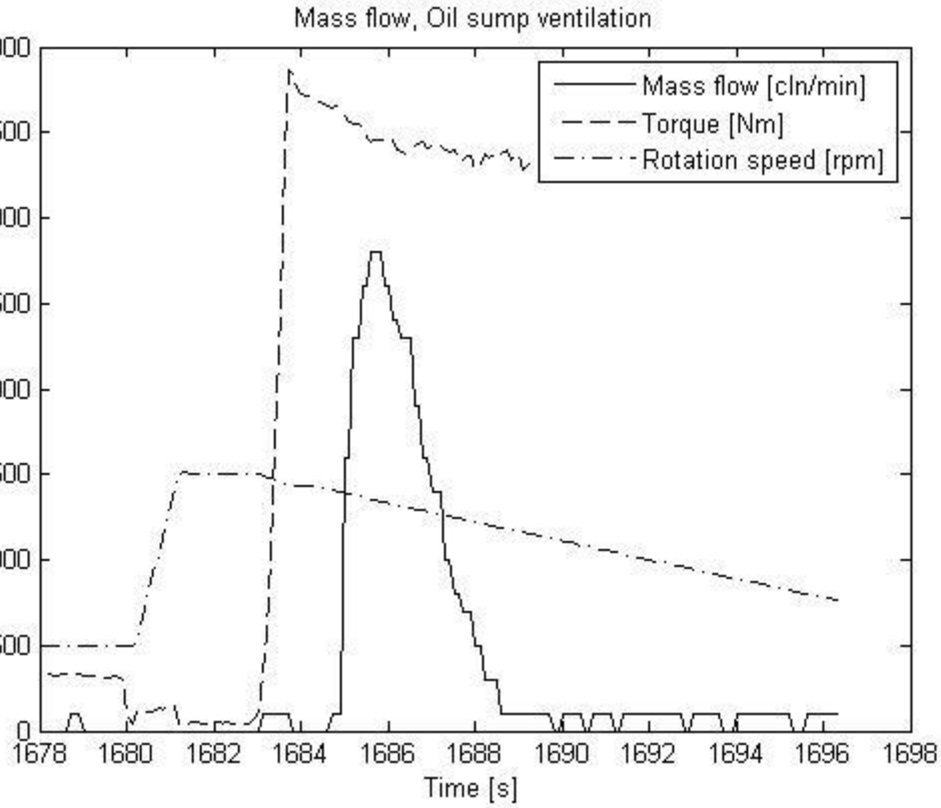
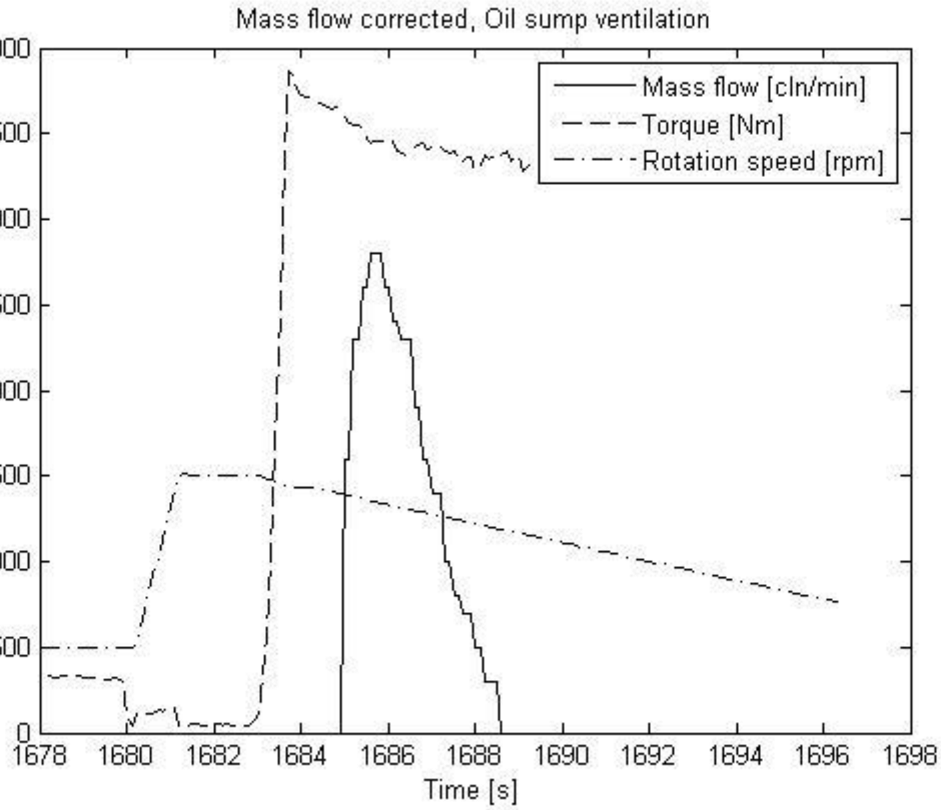
124
126
128
130
132
134
136
Time [s]


Mass flow, Oil sump ventilation
Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
4000
3500
3000
2500
2000
1500
1000
500
0
1678
1680
1682
1684
1686
1688
1690
1692
1694
1696
1698
Time [s]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Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
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3500
3000
2500
2000
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500
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1680
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1684
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1688
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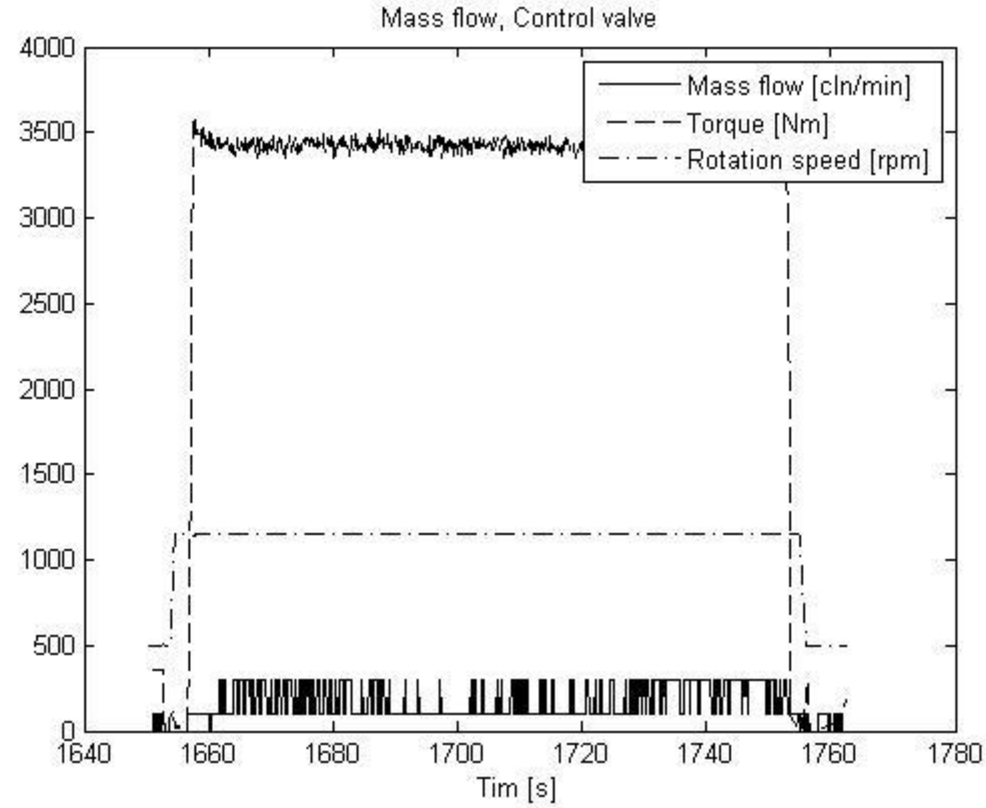
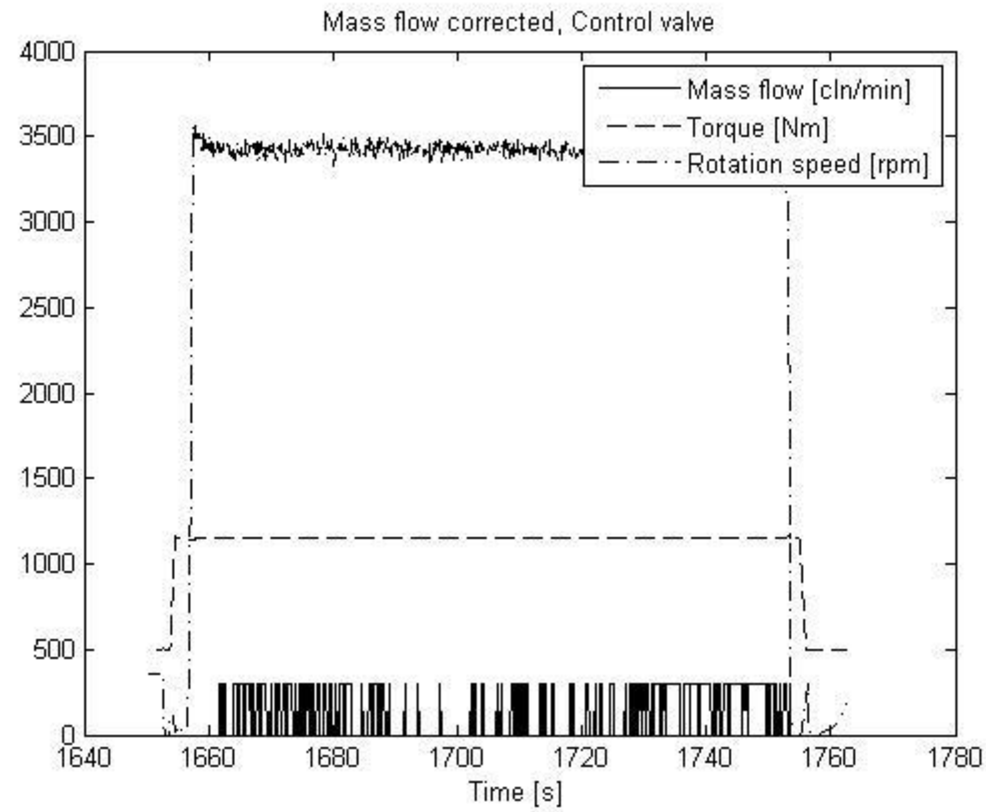
1692
1694
1696
1698
Time [s]


Mass flow, Control valve
Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
4000
3500
3000
2500
2000
1500
1000
500
0
1640
1660
1680
1700
1720
1740
1760
1780
Tim [s]


Mass flow corrected, Control valve
Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
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3500
3000
2500
2000
1500
1000
500
0
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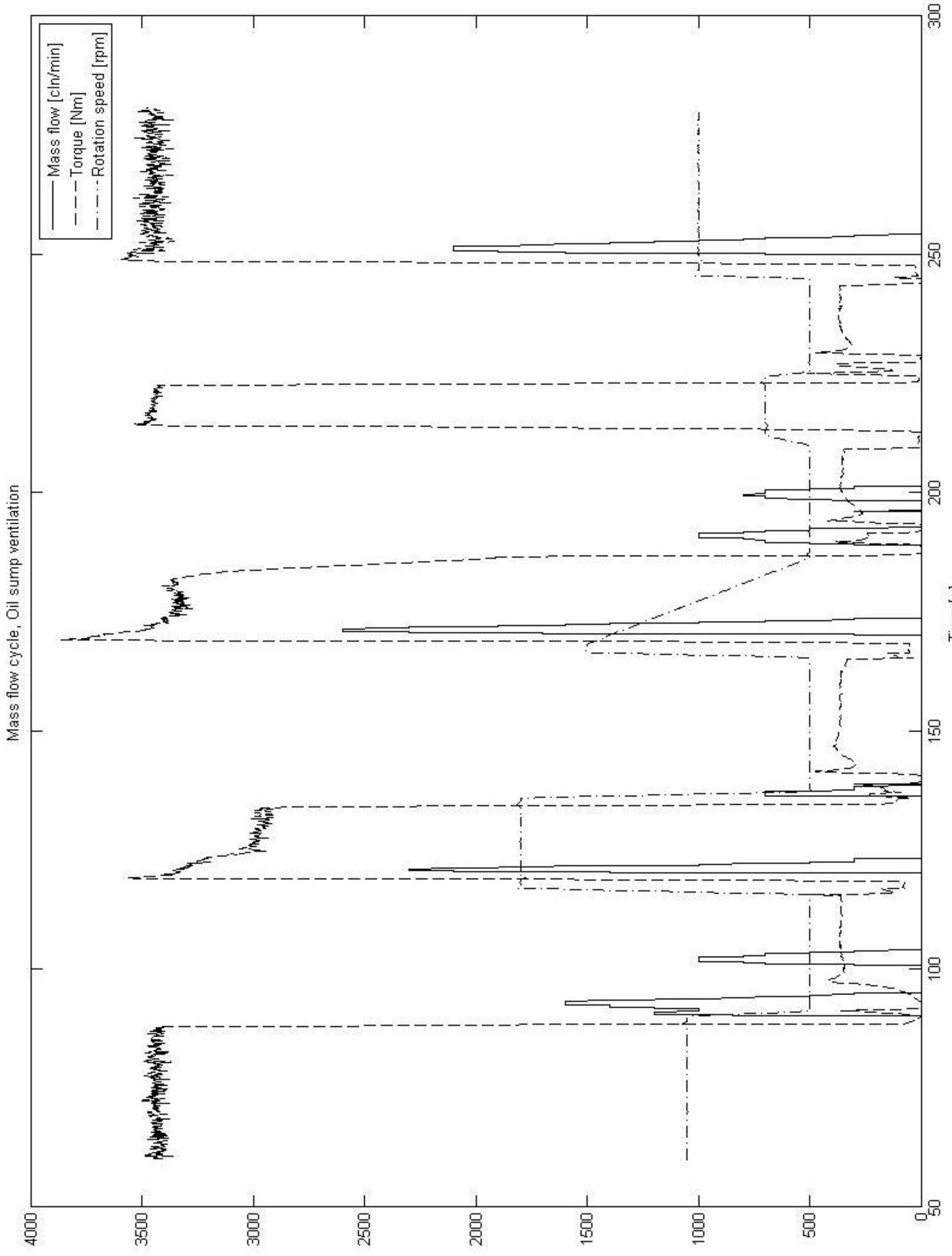
1660
1680
1700
1720
1740
1760
1780
Time [s]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Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
Time [s]
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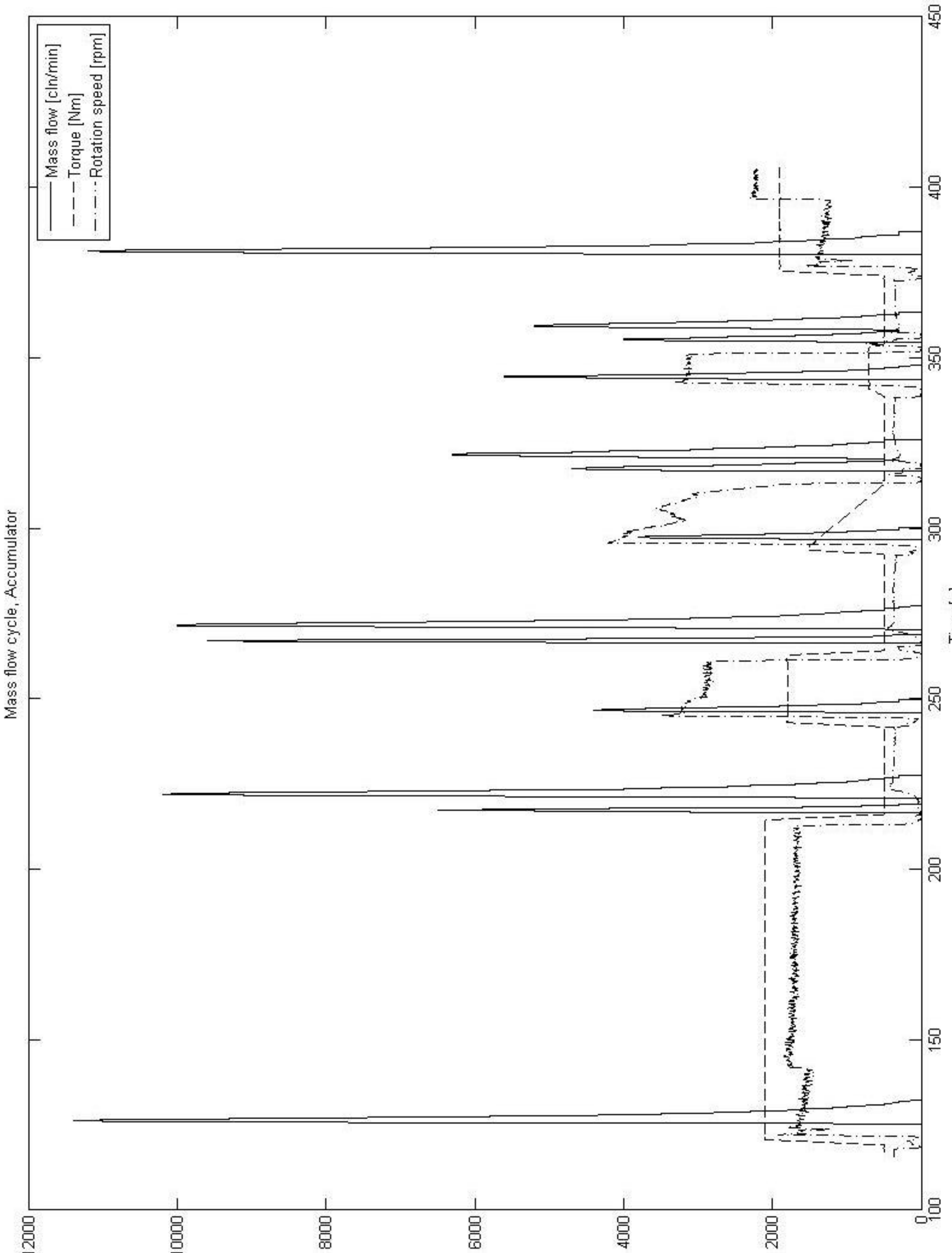
100
150
200
250
300
0
500
1000
1500
2000
2500
3000
3500
4000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Mass flow [cln/min]
Torque [Nm]
Rotation speed [rpm]
Time [s]
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2000
4000
6000
8000
10000
12000
100
150
200
250
300
350
400
450

Appendix 2

Measurements results from prototype 1 in S1 with Shell Rimula R3

Prototype 1

1) = The value is not measured, but all parameters are set as previous test.

*The scale that is used indicate only 0.1 g

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-18	412,0	426,0	-	0,424	4,5	1,5	15080	No concept where connected	Rimula R3 Multi	The oil buffer for the oil-mist	-	-	-
2011-03-21	383,0	455,0	-										
	-29,0	29,0											

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-21	411,0	455,0	-	1)	4,5	1,5	5000	No concept where connected	Rimula R3 Multi	There where some oil left in the oil	-	-	-
2011-03-21	385,0	481,0	-										
	-26,0	26,0											

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-21	416,0	480,0	1120,8	1)	4,5	1,5	4000	Prototype 1	Rimula R3 Multi	2=Inlet, 6=outlet, all the other	92,7%	90,5%	-0,4
2011-03-22	398,1	481,3	1137,0										
	-17,9	1,3	16,2										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-22	412,0	481,3	1122,0	1)	4,5	1,5	4000	Prototype 1	Rimula R3 Multi	2=Inlet, 6=outlet, all the other	91,3%	86,3%	-1,1
2011-03-22	390,1	483,2	1140,9										
	-21,9	1,9	18,9										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-22	410,4	495,0	1121,1	1)	4,5	1,5	3500	50% Left chamber	Rimula R3 Multi	2=Inlet, 5=outlet, all the other	100,0%	76,3%	-3,3
2011-03-23	396,5	495,0	1131,7										
	-13,9	0,0	10,6										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-22	412,5	495,0	1121,4	1)	4,5	1,5	6000	50% Left chamber	Rimula R3 Multi	2=Inlet, 5=outlet, all the other	91,0%	88,5%	-0,6
2011-03-23	389,1	497,1	1142,1										
	-23,4	2,1	20,7										

Measurements results from prototype 1 in S1 with Statoil SpinWay XA 10

Oil changes from Rimula R3 to Spinway XA 10

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-23	365,5	497,1	1123,2	0,452	4,5	1,5	5030	50% Left chamber	Spinway XA 10	2=Inlet, 5=outlet, all the other	92,8%	90,1%	-0,8
2011-03-24	336,2	499,2	1149,6										
	-29,3	2,1	26,4										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-24	366,7	436,8	1123,2	1)	4,5	1,5	4000	50% Left chamber	Spinway XA 10	2=Inlet, 5=outlet, all the other	96,5%	97,5%	0,3
2011-03-24	338,2	437,8	1151,0										
	-28,5	1,0	27,8										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-25	365,0	501,0	1104,4	1)	4,5	1,5	3250	Prototype 1	Spinway XA 10	2=inlet, 6=outlet all the other	110,0%	102,0%	-0,8
2011-03-25	355,0	500,0	1114,6										
	-10,0	-1,0	10,2										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-25	365,0	500,0	1114,6	1)	4,5	1,5	6000	Prototype 1	Spinway XA 10	2=inlet, 6=outlet all the other	89,1%	88,7%	-0,1
2011-03-28	338,4	502,9	1138,2										
	-26,6	2,9	23,6										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-28	355,0	500,0	994,1	1)	4,5	1,5	4000	30%	Spinway XA10		95,9%	94,2%	-0,3
2011-03-28	337,8	500,7	1010,3										
	-17,2	0,7	16,2										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-28	356,1	500,7	1010,4	1)	4,5	1,5	5000	30%	Spinway XA10		89,1%	87,0%	-0,4
2011-03-29	336,8	502,8	1027,2										
	-19,3	2,1	16,8										

Measurements results from Prototype 1 in S1 with Statoil SpinWay XA 10 mixed with diesel

Oil changes to Spinway XA 10 mixed with diesel

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-25	366,7	500,4	995,9	?	4,5	1,5	13000	30%	XA10 26,6% Diesel(weight)	Differential may be due to the diesel	94,4%	65,6%	2,6
2011-03-28	357,7	500,9	1001,8										
	-9,0	0,5	5,9										
Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-28	357,7	500,9	1001,8	?	4,5	1,5	2800	30%	XA10 26,6% Diesel(weight)	Big leakage from the SFF	101,9%	82,0%	3,2
2011-03-28	341,6	500,6	1015,0										
	-16,1	-0,3	13,2										
Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-28	365,3	495,2	1104,6	0,999	4,5	1,5	5000+2090	Prototype 1	XA10	After 5000 cycles, about one	83,5%	77,8%	2,2
2011-03-29	326,6	501,6	1134,7										
	-38,7	6,4	30,1										
Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-29	363,5	502,0	1702,9	1)	4,5	1,5	9000	50% Right	XA10	3=inlet, 5=outlet all the other	99,3%	94,6%	1,3
2011-03-30	335,7	502,2	1729,2										
	-27,8	0,2	26,3										
Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-30	362,9	501,7	1733,3	1)	4,5	1,5	1100	50% Chicane Right	XA10	2=inlet, 6=outlet all the other are plugged	99,6%	100,0%	0,1
2011-03-31	336,8	501,8	1759,4										
	-26,1	0,1	26,1										

Appendix 3

Measurements results from prototype 2 in S1

Prototype 2

1) = The value is not measured, but all parameters are set as previous test.

*The scale that is used indicate only 0.1 g

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-30	385,9	437,6	433,7	1,015	4,5	1,5	15000	Expended metal	XA10	The prototype have been standing up. completely filled with	100,3%	96,4%	1,3
2011-03-31	352,8	437,5	465,6										
	-33,1	-0,1	31,9										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-03-31	385,0	437,5	434,7	1)	4,5	1,5	15000	Expended metal	XA10	1)	98,0%	96,2%	0,6
2011-04-01	350,8	438,2	467,6										
	-34,2	0,7	32,9										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-04-01	389,8	437,5	362,5	1)	4,5	1,5	20000	Empty	XA10	The prototype have been standing up. inlet in the bottom.	13,2%	9,7%	1,5
2011-04-04	347,5	474,2	366,6										
	-42,3	36,7	4,1										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-04-04	387,8	474,3	362,5	1)	4,5	1,5	15000	Empty	XA10	1)	21,5%	19,6%	0,7
2011-04-06	351,5	502,8	369,6										
	-36,3	28,5	7,1										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-04-06	384,1	432,1	382,9	1)	4,5	1,5	15000	Partly Expended metal	XA 10	The bottom part of prototype 2 is filled with expanded metal, this to	102,8%	96,5%	1,8
2011-04-07	355,4	431,3	410,6										
	-28,7	-0,8	27,7										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-04-07	384,1	432,1	382,9	1)	4,5	1,5	15000	Partly Expended metal	XA 10	1)	102,8%	96,5%	1,8
2011-04-08	355,4	431,3	410,6										
	-28,7	-0,8	27,7										

Date	Oil-mist lubricator [g]	Filter [g]	Prototype(-) Concept(-) [g]	Air flow [V]	Time on [s]	Time of [s]	Cycles	Type of interior	Oil	Comments	Efficiency mist/Filter [%]	Efficiency mist/Concept [%]	Difference [g]
2011-04-08	387,7	431,2	374,7	1)	4,5	1,5	3400+20000	Empty	XA10	Test failed, large leakage from the prototype.	85,2%	3,2%	25,5
2011-04-13	356,6	435,8	375,7										
	-31,1	4,6	1,0										

Appendix 4

Measurements results from Modified prototype 1 in T7

1) = The value is not measured, but all parameters are set as previous test.

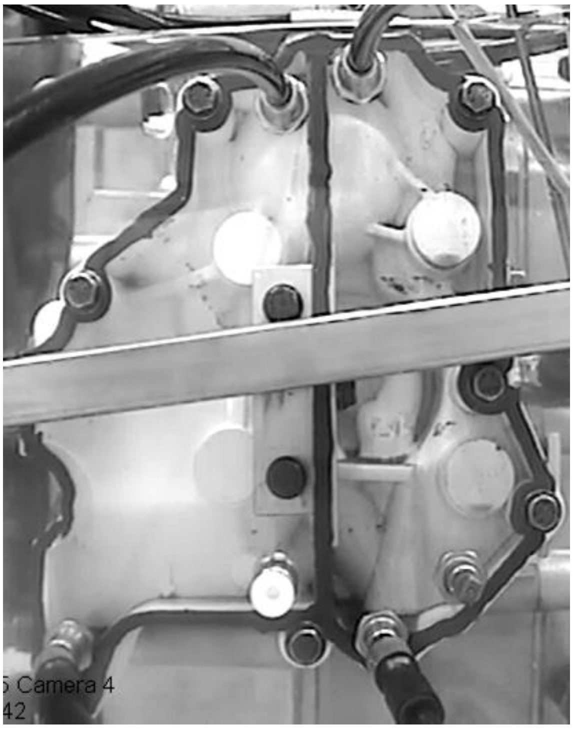
*The scale that is used indicate only 0.1 g

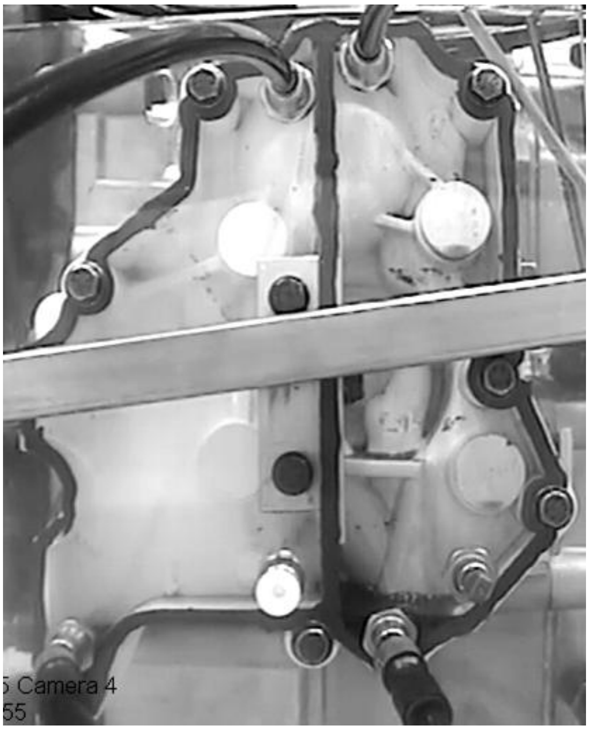
Modified prototype 1

Date	Filter oil-sump [g]	Filter Acc [g]	Cycles	Type of interior	Oil	Connected	Comments
2011-04-19	496,2	299,4	49 202	1)		See repport 4.6.3 Oil changes. Some overfill oil level 84 mm	
2011-04-26	540,3	300,1	65 570				
SUM	**44,1**	**0,7**	**16 368**				
2011-04-27	542		67 890	1)	ATF	See repport 4.6.4	Heavy oil flows from oil-sump ventilation, oil rises up through the feed back channel. Acc disconected.
2011-04-27	546,7		68 432				
2011-05-02	552		74 944				
SUM	**10**		**7 054**				

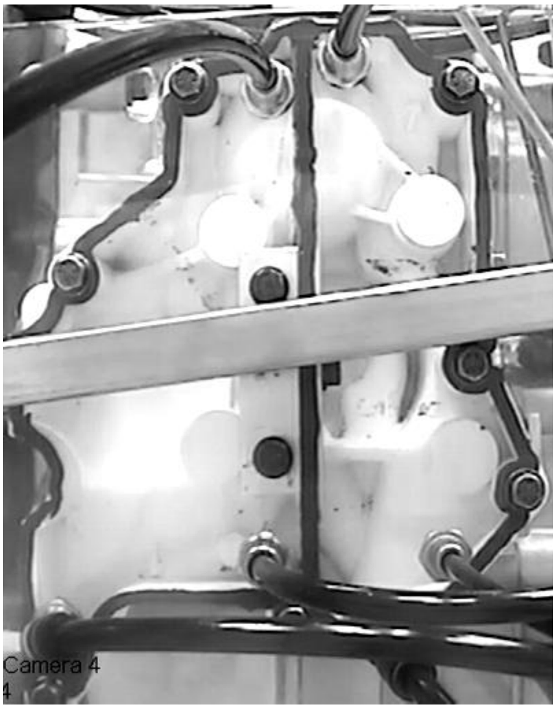
Appendix 5

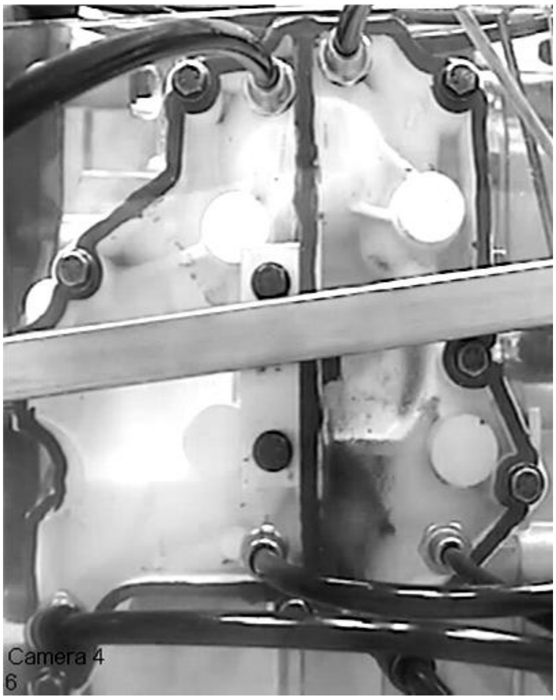
4.5.2 Result Test 1

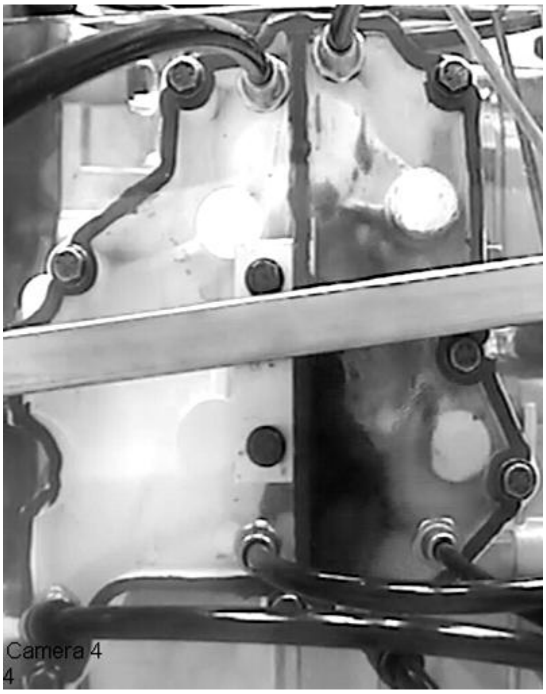


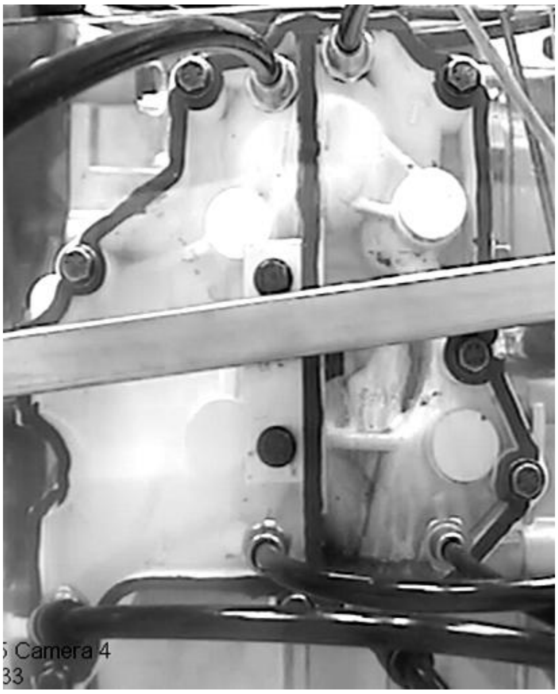


4.5.4 Result Test 2

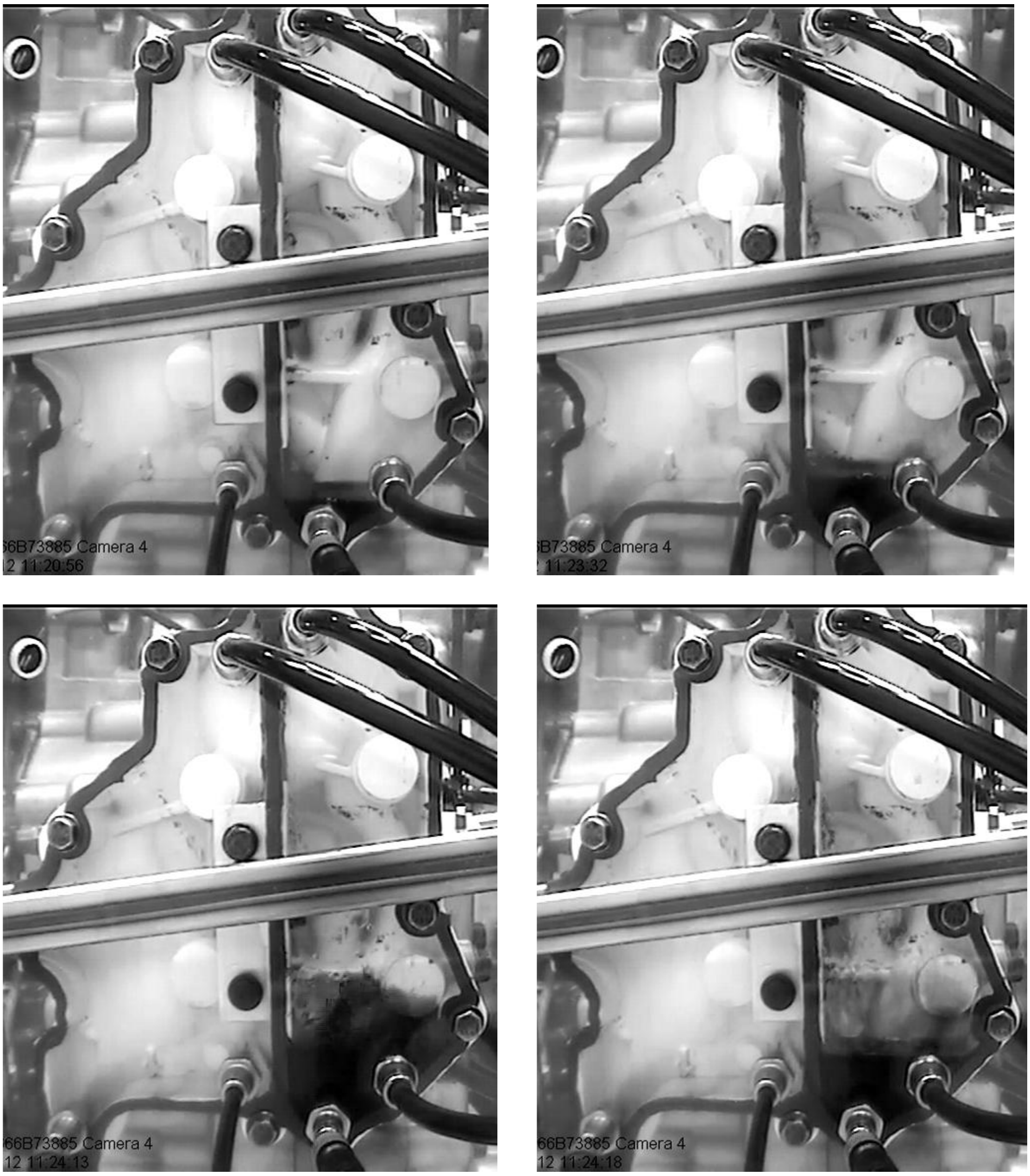








4.5.6 Result test 3



4.6.4 Result test 2