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TAMPERE UNIVERSITY OF TECHNOLOGY

VILLE MÄNNISTÖ
HYDRAULIC LOAD CONTROL IN REFUSE COLLECTORS

Master of Science thesis

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ABSTRACT

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The binlifts of refuse collectors have a problem with binlift oscillations when the binlift is lowered slowly. The problem escalates with hot oil that has lower viscosity. Most problematic the oscillations are with an accessory scale on the binlift as it does not tolerate oscillations in the position where it takes measurements. These oscillations are caused by load control valves and wrong directional control valve spools make these oscillations worse.

To figure out possible solutions for the oscillations the thesis has comprehensive load control valve theory part which summarizes all the traditional and latest inventions related to load control valves. This information is used in selecting valves for measurements.

In this thesis there are measurements with different load control valves, directional control valve spools, restrictors, hoses and sequence valves. Measurements are done with a rear loader and they include flow and pressure measuring. These measurements are done to figure out which combination is the best compromise between energy consumption, oscillations and cost. This compromise should also fill all standardization requirements. Several solutions are found that are not ideal, one solution which is recommended and a couple of which are recommended in case oscillations are still needed to be degreased.

Future solutions are also discussed but they require many changes to the hydraulic fundamentals of the refuse collectors. These solutions are likely to be possible for the coming generations of refuse collectors.

TIIVISTELMÄ

VILLE MÄNNISTÖ: Hydraulinen kuormanlasku jäteautosovelluksissa
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Avainsanat: kuormanhallinta, kuormanlaskuventtiili, vastapaineventtiili, lukkoventtiili, letkurikkoventtiili, jäteauto, hydrauliikka

Jäteautojen astianostimissa oli ongelmia värähtelyjen kanssa laskettaessa astianostinta hitaasti. Tämä ongelma oli pahimmillaan kuumalla öljyllä, koska tällöin viskositeetti laskee alhaiseksi. Kaikkein pahimmillaan ongelma oli astianostimen lisävaruste vaa´an kanssa, koska vaa´an toiminta ei salli värähtelyjä siinä kohdassa, jossa vaa´an lukema luetaan. Kuormanlaskuventtiilit aiheuttivat nämä värähtelyt ja niitä vahvistivat vääränlaiset suuntaventtiilin luistit.

Mahdollisten ratkaisujen löytämiseksi värähtelyongelmaan tässä diplomityössä on kattava kuormanlaskuteorian osuus. Tätä teoriaosuutta on käytetty hyväksi, kun on valittu kuormanlaskuventtiileitä mittauksiin.

Tässä diplomityössä tehdään mittauksia kuormanlaskuventtiileiden, suuntaventtiilin luistien, kuristuksien, letkujen ja sekvenssiventtiileiden kanssa. Mittaukset on tehty takaa lastaavalla jäteautolla ja ne koostuvat paine- ja tilavuusvirtamittauksista. Näiden mittausten tarkoituksena on selvittää paras kombinaatio energiankäytön, värähtelyiden ja hinnan suhteen. Tämän kombinaation tulee täyttää myös kaikki standardien vaatimukset. Työssä löydetään useita ratkaisuja, jotka eivät sovellu tähän käyttöön, yksi ratkaisu jota suositellaan käytettäväksi sekä muutama ratkaisu, jotka voidaan ottaa käyttöön jos värähtelyitä halutaan vähentää vielä lisää.

Mahdollisia tulevaisuuden ratkaisuja pohditaan myös, mutta nämä vaativat perustavanlaatuisia muutoksia jäteautojen hydrauliikkaan. Nämä ratkaisut ovat todennäköisesti mahdollisia tulevaisuuden jäteautomalleissa.

PREFACE

I am deeply grateful to NTM for giving me an opportunity of doing this thesis. I am also very grateful to my thesis supervisor Engineer Dan Storås as well as my thesis inspector Professor Jari Rinkinen for their guidance. I would also like to thank Technical Manager Anders Mickels for allowing resources that made it possible to do my thesis at NTM. Thanks also to the whole personnel of NTM, especially the assemblers and office staff for the understanding and flexibility they provided with the measurements and various questions.

I would like to thank my girlfriend Emmaleena who never stopped smiling and encouraging me during this journey. I would also like to thank my mother Tuula and sisters Anu and Marjo for their support over the years. Fellow students and friends also deserve thanks for supporting with studies and life. This path would have been a lot stonier without you all.

By far the biggest thanks goes to my father Osmo for being the most perfect role model in the early years of my life.

“So proud and strong you truly were,

I took it with me as a tool.

A gift from father to his only son.”

Volbeat, Fallen

Kurikka, 14.4.2016

Ville Männistö

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

A	Area A on the load control valve poppet
A_A	Area on piston side of hydraulic cylinder (chamber A)
A_B	Area on rod side of hydraulic cylinder (chamber B)
A_L	Area on the left side of load control valve poppet
A_R	Area on the right side of load control valve poppet
B	Area B on the load control valve poppet
B_{ventil}	B connection in 3G load holding valve
C	Area C on the load control valve poppet
F_L	Load force on cylinder
F_{Lp}	Force on the left side of load control valve poppet
F_{Rp}	Force on the right side of load control valve poppet
p	Pressure with unit bar
p_B	Pressure in the B chamber
p_b	Back pressure
p_L	Load pressure
p_p	Pilot pressure
p_{pA}	Pump pressure reduced in the chamber A via cylinder area ratio
p_{pd}	Pilot pressure demand
p_{pw}	Pilot pressure without back pressure effect
p_s	Relief setting pressure
p_{so}	Spring opening pressure
p_v	Pressure on valve port
Q	Flow with unit lpm (liters per minute)
R	Pilot ratio

Back pressure	Pressure in the valve port of a load control valve when the flow is from the load control valve to directional control valve, term used similarly also with pressure relief valves
Binlift	Waste container lifting device, a device designed to lift garbage bins inside refuse collectors
Cavity	Valve block drilling for cartridge valve which may require many drilling tools to be made
GVM	Gross vehicle mass, maximum operating overall mass of a vehicle
LS	Load sensing hydraulic circuit that is nowadays commonly used by the industry
NTM	AB Närpes trä & metall – OY Närpiön puu ja metalli, an engineering company focused on heavy vehicle installations
PLC	Programmable logic controller
RCV	Refuse collection vehicle

LIST OF FIGURES

1. INTRODUCTION

This thesis was written for Ab Närpes trä & metall (NTM) during 2015 and the spring of 2016. The main purpose of the thesis was to find and test new alternatives for load control valves that were in use at that time. Tests were related to measuring energy consumption as well as pressure curves for the new valves. The problems with the old load control valves included relatively high energy consumption and unstable behavior when lowering slowly. The unstable behavior is most problematic with an accessory scale on a binlift as it does not tolerate oscillations in the position where it takes measurements.

This oscillative behavior of load control valves has been discussed earlier by Handroos et al. (1993) and Andersson (2009). According to them, oscillations result from tight sealing that causes hysteresis and the fact that load control valves are piloted open from the inlet side of the cylinder. The latter can be solved with electrically operated load control valves and tight sealing can be avoided also in electrical solutions especially if precise load holding is not required. If there is no possibility to choose an electrical solution, then the case is traditionally solved either with proper directional control valve spool selection or with new pilot ratio selection on the load control valve, as stated in chapter 3, or with both of these. Some special types of valves that do not require special attention on pilot ratio selection are also available, for example, from Bucher. These valves and damping the oscillating valves are discussed in chapter 3. Also hose selection will have an effect on oscillations and this is focused on in chapter 5.

The thesis has a comprehensive load control valve theory part in chapter 3 which summarizes all the traditional and latest inventions related to load control valves. This type of summaries are rare as most listings are only done by the manufacturers and for their own product types. The thesis does not focus on developing the load control valves but this subject is discussed by Christensen (2007). Future aspects with electrically operated load control valves are discussed in chapter 4. Chapter 4 also describes standard demands, includes a discussion on load sensing (LS) system and has a description of load control at NTM. The measurements part of the thesis in chapter 5 includes not only load control valve measurements but also different types of directional control valve spools, restrictors, sequence valves and hoses are tested with a group of load control valves. The thesis will start with a company and refuse collector presentations in chapter 2 and ends in discussion and conclusions in chapters 5 and 6.

2. REFUSE COLLECTORS

2.1 The company

NTM is a company that was founded in 1950 by Lennart Nordin, Sigurd Lärka, Bengt Juthman, Hilding Nygård and Sigurd W. Lång. At the beginning of the company's history, there was a plan that wood products would be the main product. In the early years they mainly manufactured windows, doors, kitchen furniture, garden furniture and greenhouse parts. At that time, metal works mainly focused on producing agriculture equipment and repairing machinery and cars. In 1968, there was a need for big investments and a tax renewal which led other company owners to sell their shares on the business. This made Lennard Nordin the only owner of the company along with his children Astrid and Kurt-Erik, both with one share from the total of two hundred shares. (Lassfolk 2000)

The first car body built by NTM was a firefighter truck to Ylimarkku in 1950. The truck body building has continued ever since. Between years 1952-1957, the company produced seven busses which were built on, for example, Leyland bases. During the 1950s, heating radiators were also manufactured. The carpenter works were ending from the company in the mid-1950s. Vehicle axles were manufactured in the 1950s and 1960s. Since 1958, the company has produced cold vehicles for transporting, for example, food products. From 1970 to 1986 the company produced a total amount of 1850 pieces of roll-on-roll-off (RORO) trailers to be used in shipping. (Lassfolk 2000; History and key facts s.a.)

Nowadays, the company produces refuse collectors, trailers and bodies for vehicles. Refuse collector vehicles (RCV) are the biggest product category with over 50 % share from the turnover of the company. NTM has the widest range of refuse collectors in Europe. (History and key facts s.a.) First refuse collector was built in 1975. This was built according to the design drawings bought in co-operation with Almer Widberg from Malmö Flygplans Industrier (MFI) that was finishing its business with refuse collectors. The refuse collectors that were built according to the design drawings bought from MFI had quality problems and this led to NTM designing a new generation of refuse collectors in 1983. At the beginning of the 1990s, NTM designed their first multi chamber refuse collector. In 1993, came the side loader and in 1998 the front loader. During the 20th century, NTM has also started to produce hybrid vehicles. (Lassfolk 2000)

NTM sells refuse collectors mainly to the Nordic countries, Baltic countries, United Kingdom, Austria, the Netherlands, Poland and Germany. In 2000, about 80 % of sales went to export. In 2013, the turnover was just over 50 million euros. (History and key facts s.a.; Lassfolk 2000; NTM Närpes Trä & Metall Ab s.a.)

2.2 Rear loader refuse collectors

Rear loaders are the most sold type of refuse collectors made by NTM. Waste is loaded into the body from the rear and thus the compactor structure is as seen in Figure 1. Unloading the waste is done by lifting up the tailgate and using ejection plate to empty the compactor as seen in Figure 8. The rear loader models are K, KG, KGLS, KGH and MAS. Model K is a smaller refuse collector with from 6 to 16 thousand kilos gross vehicle mass (GVM) and with from 4 to 14 cubic meter refuse capacity. Although model K is small in size, it can also handle big 1280 liter bins. Model KG is a bigger rear loader with from 18 to 26 thousand kilos GVM and with from 12 to 19 cubic meter refuse capacity. Model KG can be equipped with a closed tailgate (KGBH) or a tailgate well suited for collecting organic waste (KGSH). Model KGLS is a lower version of model KG with from 14 to 18 thousand kilos GVM and with from 10 to 15 cubic meter refuse capacity. Model KGLS can be bought as a version ideal in collecting waste that is sensitive to wind (KGLS-H). Model KGH is the biggest rear loader with 26 thousand kilos GVM and with from 18 to 24 cubic meter refuse capacity. Model KGH can be equipped with a closed tailgate (KGHH). Model MAS is designed for waste that contains a lot of liquid. Model MAS does not have compaction and it is unloaded by tipping. (Refuse collectors s.a.)

Figure 1: Refuse collector NTM KGLS (NTM intranet)

As a standard, all these rear loaders are equipped, for example, with proportionally controlled hydraulic levers for the binlift, work lights and a rear view camera with an in-cab monitor. Rear loaders have various optional equipment including, for example, demountable body, auto lube, semi-automatic binlift, hydraulic oil heater, on-board refuse weighing equipment, binlift controls on both sides of the vehicle, winch and footboard in the rear with safety functions as seen in Figure 1. (Refuse collectors s.a.)

2.3 Front loader refuse collector

The model FL-P is designed to emptying the biggest bins with the maximum weight up to 3500 kg. Waste is loaded into the body from the front and thus the compactor structure is as seen in Figure 2. Unloading the waste is done by tipping over the reservoir that is behind the pendulum compactor section. Tipping can be seen in Figure 3. Model FL-P has a refuse capacity up to 36 cubic meters. (Refuse collectors s.a.)

Figure 2: Refuse collector NTM FL-P (NTM intranet)

FL-P has two or three cameras with in-cab monitor for loading and discharging. The lifting arms of the FL-P are operated with a joystick and programmable logic controlled (PLC) hydraulics. Optional equipment available are, for example, emptying device for smaller bins, auto lube and on-board weighting equipment. (Refuse collectors s.a.)


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Figure 3: Refuse collector FL-P unloading (NTM intranet)

2.4 Side loader refuse collectors

The most efficient refuse collector in the urban environment is the NTM OM side loader that can handle up to 1000 bins during an 8 hour shift. It is operated by one man from the cabin, the operator does not need to leave the cabin in order to empty the bin. Waste is loaded into the body from the side as seen in Figure 4. Unloading the side loader is similar to unloading the front loader in Figure 3 but the pendulum of the compactor rises with the reservoir. (Refuse collectors s.a.)

Figure 4: Refuse collector NTM OM (NTM intranet)

OM has a refuse capacity from 14 up to 24 cubic meters. It has a standard lifting capacity for 275 kg bins and it is optional for 450 kg bins. As a standard, the vehicle is equipped with loading and reversing cameras and an in-cab monitor. The optional equipment available are, for example, demountable body (Figure 5), auto lube, automatic replacement of a bin and hydraulic oil heater. (Refuse collectors s.a.)

Figure 5: Refuse collector NTM OM with demountable body (NTM intranet)

Demountable body in model OM (Figure 5) is useful, for example, when refuse is collected from an island that does not have its own refuse handling center and the refuse needs to be shipped somewhere else for handling. Containers allow that the trucks do not need to be shipped, only the refuse containers. (Storås 2015)

2.5 Multi-chamber refuse collectors

Rear loaders and side loaders are available with multiple chambers. The most advanced multi-chamber refuse collector is NTM Quatro (Figure 6) that has four chambers and it is able to empty all four bins at the same time. Model Quatro compacts the waste with pendulums in the similar ways as the front loader and the side loader. It is possible to install a FK module (Figure 7) in front of any rear loader. The FK module has its own elevator for loading the module and it is unloaded by tipping on the side. The FK module does not have a compactor. The two chamber rear loaders are the models KGLS-2B, K-2K and the KG-2K. The model KGLS-2B is equipped with two different tailgates and binlifts according to Figure 8. The model K-2K is a small model with one tailgate and the model KG-2K is a bigger model with one tailgate. A side loader is also available with two chambers and this model is the OM-2K. (Refuse collectors s.a.)

Figure 6: Refuse collector NTM QUATRO (NTM intranet)

Figure 7: Refuse collector NTM KGH-FK (NTM intranet)

Figure 8: Refuse collector NTM KGLS-2B (NTM intranet)

2.6 Electrical hybrid refuse collectors

All NTM refuse collectors can be equipped with a hybrid module. This module is installed between the cabin and the refuse compactor. When a vehicle is a hybrid, the hydraulics of the vehicle can be driven electrically. This allows a diesel (or gas) engine to be shut off when refuse is loaded in the vehicle. This saves a great deal of fuel as the diesel engine usually operates in low efficiency ratio while loading refuse in the compactor. The electrical battery of the vehicle is charged from the electrical grid or with diesel engine. The battery cannot be used in moving the vehicle. This has to be always done with diesel (or gas). (Storås 2015)

2.7 Trailer refuse collectors

NTM also has trailer refuse collectors in their product range (Figure 9). Trailers allow a bigger refuse capacity and they are demountable off the truck. As they are demountable, the truck can also be used for other purposes. The trailer seen in Figure 9 is used for collecting bottles with deposit. (Storås 2015)

Figure 9: Refuse collector NTM DUO (NTM intranet)

2.8 Crane loader refuse collectors

Crane refuse collectors are used for collecting waste from deep collection bins that are made, for example, by Molok Ltd. (Original Molok s.a.) Palfinger , Hiab and Alfa cranes are available to be installed on a refuse collector (Figure 10). (NTM Alfa s.a.)

Figure 10: Refuse collector NTM Alfa A 6500 H

3. LOAD CONTROL WITH DIFFERENT TYPE OF VALVES

3.1 Reasons for using load control valves

Load control valves can be used for both linear and rotary motion. In this thesis only linear motion is taken into account. Load control valves are also called motion control valves. (Lodemeier & Ashmore 2011; Load holding / Motion control s.a.) Load control valves are used for three reasons:

Firstly, to get the load controlled down. Load control valves prevent actuators (motors and cylinders) from running ahead of pump supply flow, which in turn prevents cavitation at the non-loaded side of the actuator. (Lodemeier & Ashmore 2011) Load control is smooth also with varying loads and speeds when using a load control valve. (Load and Motor Control Valves s.a.)

Secondly, to hold the load still when the directional control valve is in neutral position (Lodemeier & Ashmore 2011). This allows and forces at the same time the use of open-center (floating) directional control valves. Open-center directional control valves are allowed because the load control valves are almost leak free, which means that the load will not move with the open-center directional control valve. Closed-center directional control valves are prohibited because they block the load control valve pilot line which causes the pilot line to be unable to drain. When draining is disabled, the valve might not work as it should. Another issue that closed-center directional control valve might cause is pressure spikes when sudden switching or radiating heat occurs. When using load control valves with open-center directional control valves, the unwanted pressures will be eliminated. This means that the load control valve has pressure relief characteristics which also reliefs possible over pressure caused by temperature rise. (Dabholkar & Indulkar 2012; Load and Motor Control Valves s.a.) Sometimes the application may require a closed-center directional control valve and then balanced load control valves can be used. (Lodemeier & Ashmore 2011)

Thirdly, to prevent uncontrolled load movement when a line break occurs (Lodemeier & Ashmore 2011). This is the main reason why the load control valve should be installed as close to the actuator as possible, normally with cylinders this means the end cap. If this is not obeyed, there will be a possible structure between the load control valve and the actuator which can get broken resulting in uncontrolled load movement. Preventing uncontrolled load movement can be done with hose burst valves, but load control valves are not so viscous-dependent as hose burst valves. (Nysand 2007)

3.2 Counterbalance valves

Counterbalance valves are the traditional load control valves. They are the simplest type of load control valves but as a downside they have a very big energy consumption. (Dabholkar & Indulkar 2012) According to Dabholkar and Indulkar (2012), counterbalance valves were designed in the early 1930s by Harry Vickers` team. These developed valves were spool type and hence they had some leakage. Installation of a counterbalance valve on a cylinder actuator can be seen in Figure 11.

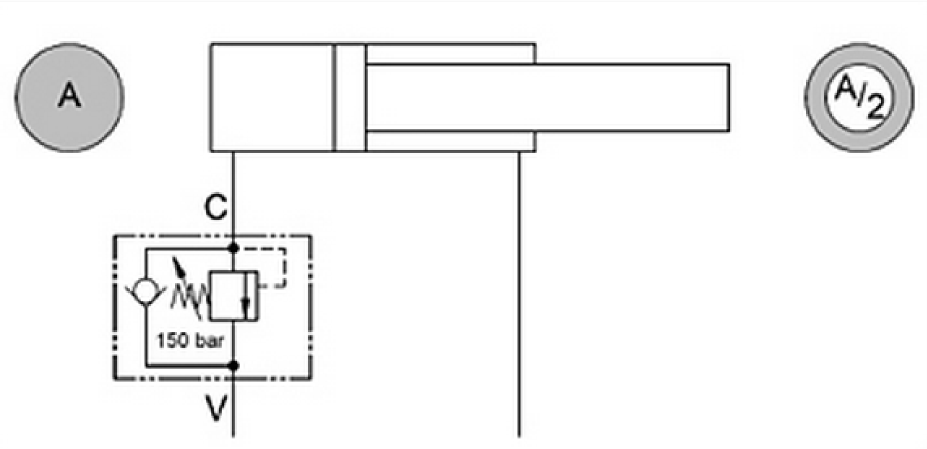

Figure 11: Counterbalance valve installed on an actuator (Dabholkar & Indulkar 2012)

The type of installation presented in Figure 11 controls the load in a retracting motion of the piston which is also called minus movement. In the other direction it lets the flow go almost freely through the check valve. During the retracting movement the valve maintains a counter pressure in location C in Figure 11. This pressure has to be produced by a load and a pump. If there is no load, all the pressure is developed by the pump. This consumes a lot of energy. For example, with the cylinder areas similar as in Figure 11 and with the valve setting of 150 bar, the pump should produce a 300 bar pressure on the rod side of the cylinder before the cylinder moves. (Dabholkar & Indulkar 2012) The pressure required from the pump to the chamber B in the situation of Figure 11 can be presented with an Equation

$$p_B = p_{pA} \frac{A_A}{A_B} = \left(p_s - \frac{F_L}{A_A}\right) \frac{A_A}{A_B} = \frac{A_A\, p_s - F_L}{A_B}, \qquad (1)$$

where p_{pA} is the pump pressure reduced on the chamber A, A_A is the area of the chamber A, A_B is the area of the chamber B, p_s is the relief setting (opening pressure of spring + effect of back pressure) and F_L is the load force (positive in retracting direction of cylinder).

Counterbalance valves can be described as relief valves with an integral free flow check. According to NhanLe (2015), care must be taken when using a conventional pressure relief valve for replacing a counterbalance valve, as at some stage of the operation the tank port will be subject to maximum circuit pressure and this is not permissible with many pressure relief valves. The relief section of the counterbalance valve spring is recommended to be adjusted at least 1.3 times the maximum load induced pressure in loads where impacts are expected and the load varies drastically. However, for cylinders moving horizontal loads, this can be as low as 1.05. This instruction applies to all load control valves ensuring that, although there is the maximum load on the actuator, it will not move before applying pilot pressure. Counterbalance valves, as well as other type of load control valves, are available with fixed or pre tension adjustable valve springs. (Load holding / Motion control s.a.; Motion control valves 2015; Dabholkar & Indulkar 2012)

Some manufacturers do call overcenter valves counterbalance valves and they are also considered as synonyms in many cases. (Counterbalance valves, Walvoil s.a. p. 4; Load holding / Motion control s.a.; Load and Motor Control Valves s.a.) This naming might result from history; functionality of the valve has changed but the name has not. It seems that traditional counterbalance valves are not so common in the market anymore because they have been replaced by more energy efficient overcenter valves. However, some manufacturers still exists; for example Tucson Hydrocontrols is making CBV valve. (CBV Counterbalance valve s.a.) On the other hand, this type of valves are used as sequence valves and also marketed as such, for example, Sun Hydraulics´ models SCCA and SCCB (Sequence cartridges s.a.).

3.3 Overcenter valves

Overcenter valves are advanced type of load control valves when compared to counterbalance valves. Nowadays, overcenter valves are widely used in load control applications. (Liimatainen 2015; Lampinen 2015) The difference compared to traditional counterbalance valves is the added pilot line which helps the valve to open. In Figure 12 the line is numbered 3.

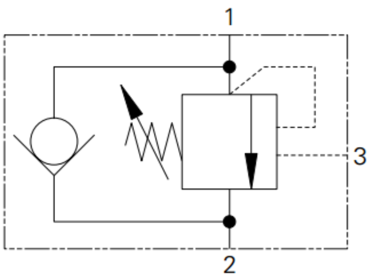

Figure 12: Drawing symbol of an overcenter valve (Motion control valves 2015 p. 12)

Pilot operation decreases the required pressure and energy to get the load down. The ratio that helps to get the valve open is called pilot ratio. The pilot ratio (also called area ratio) is the area of the pilot area (A2) versus the differential area of main poppet (A1) according to Figure 13. (Load and Motor Control Valves s.a.).

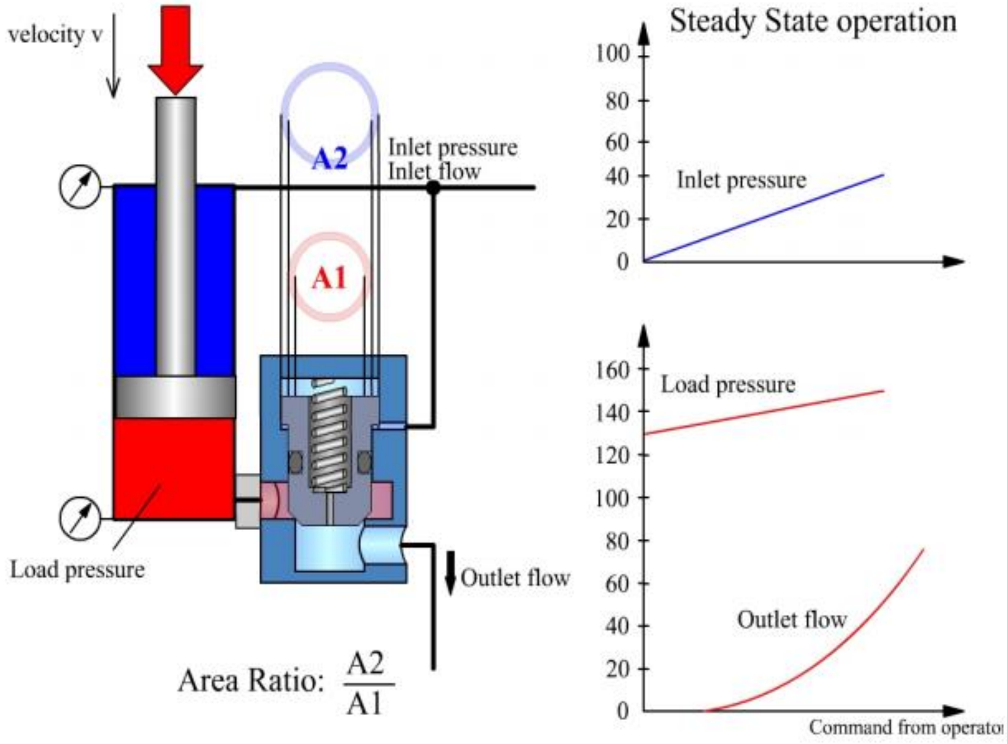

Figure 13: Simplified design and pilot ratio of an overcenter valve (Andersson 2009 p. 5)

The higher the ratio the easier the valve will open and the less energy will be used, (Lodemeier & Ashmore 2011) although high pilot ratio might cause stability problems. Usually pilot ratio choice is a compromise between energy consumption and stability. (LoadAdaptive™ counterbalance valves 2015) Low pilot ratio valves consume more energy and as they cause pressure to rise in both cylinder chambers they also make the cylinders more stiff which results in better stability. As a downside, this causes more strain to the cylinder seals. (Teittinen 2009 p. 110-111) Basically, overcenter valves are pilot-assisted pressure relief valves with an integral free flow check. (Dabholkar & Indulkar 2012) Free flow check valve can be seen in Figure 14. Check is made usually at the end of the cartridge. In Figure 14, the check is marked with violet print. On the Parker design the check is ball type according to Figure 15.

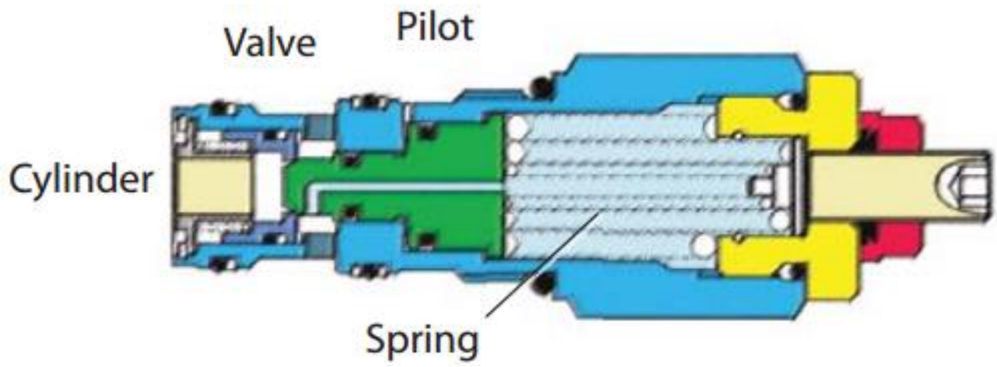

Figure 14: Standard overcenter valve Eaton 1CE (Lodemeier & Ashmore 2011)

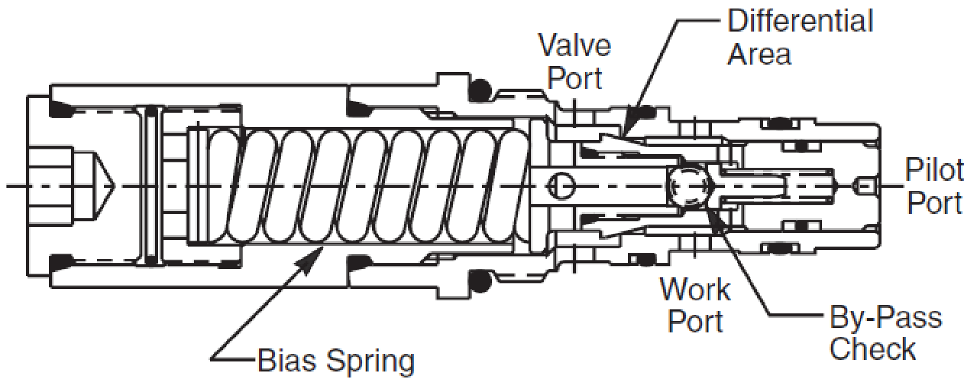

Figure 15: Standard overcenter valve Parker MHC-010-S-S (Load and Motor Control Valves s.a.)

The design in Figure 15 was the first type of the overcenter valve and it was designed by Racine. The design in Figure 14 was originally designed by Fluid Controls. (LoadMatch™ counterbalance valve, FAQ 2015) If these designs are compared, the biggest difference is the location of the pilot channel. This difference affects the housing and the cavity design as well as the dimensions of the cartridge. In both designs, the pilot pressure required to open the valve when pushing the load (situation on the left side of Figure 16) is

$$p_p = \frac{p_s - p_L}{\mathrm{R} + \frac{A_B}{A_A}}. \tag{2}$$

Where p_p is the pilot pressure, p_s is the relief setting (opening pressure of spring + effect of back pressure), p_L is the load pressure, R is the pilot ratio, A_A is the area in the cylinder chamber A and A_B is the area in the cylinder B chamber. (Load holding / Motion control s.a.; Counterbalance valves, CBF s.a.) Similar designs to Parker are, for example, G. Fluid PB010 and PB110. (Overcenter valve senkbremsventil s.a.)

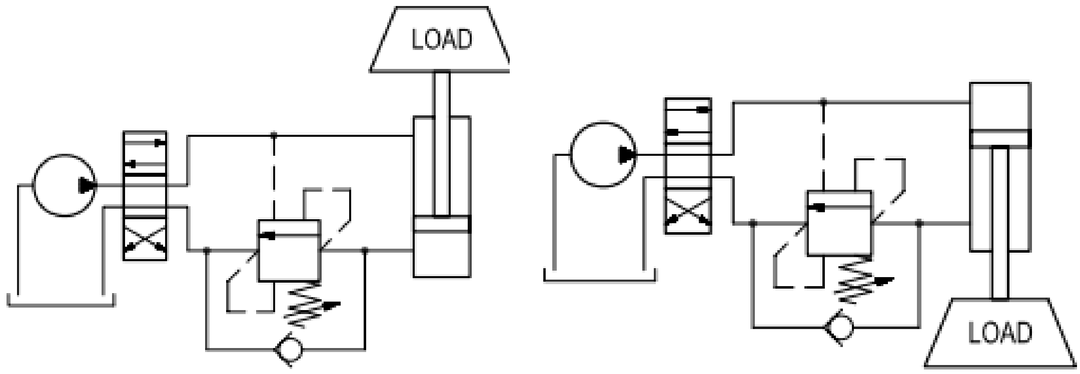

Figure 16: Load pushing the cylinder rod on the left and load pulling the cylinder rod on the right (Load holding / Motion control s.a.)

The pilot pressure required to open the valve when pulling the load is (situation on the right side of Figure 16)

$$p_p = \frac{p_s - p_L}{\mathrm{R} + \frac{A_A}{A_B}}. \tag{3}$$

In Equations (2) and (3), the back pressure effect is considered only in the way it consists in p_s. The back pressure affects the relief setting according to Equation (5). Equations (2) and (3) are often used simplified without areas A_A and A_B. (Lodemeier & Ashmore 2011; Dabholkar & Indulkar 2012; Load and Motor Control Valves s.a.) This is because in many cases the installation is not known and the cylinder area ratio usually does not make a big difference in the pilot pressure if standard hydraulic cylinders are used. The biggest difference on the pilot pressure results from the situation on the right side of Figure 16 if the piston rod is unusually thick. This installation causes the pilot pressure demand to drop remarkably. The simplified Equation that should be used carefully is

$$p_p = \frac{p_s - p_L}{\mathrm{R}}. \tag{4}$$

Although a bigger pilot ratio of the overcenter valve means that the valve will open easier, it does not always mean a better efficiency. This can be seen in Figure 17.

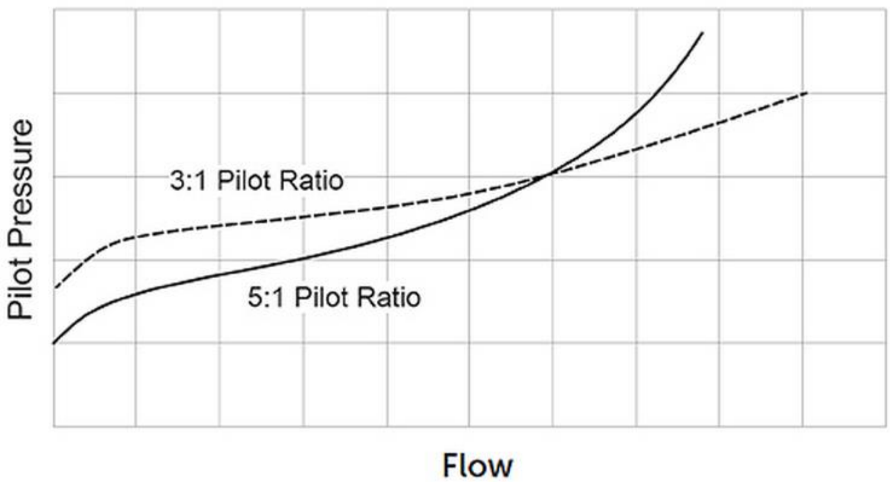

Figure 17: Pressure drop curves of two overcenter valves with different pilot ratios (Dabholkar & Indulkar 2012)

The efficiency might be even worse with a bigger pilot ratio than with a smaller one. This might be the case when a big flow is going through the valve as a valve with big pilot ratio can be more restrictive. (Dabholkar & Indulkar 2012) When choosing an overcenter valve, it should be noted that oversizing should be avoided because it can lead to instability in use. Control is gained by causing a restriction and the lack of restriction is why oversizing might lead to instability. (Load and Motor Control Valves s.a.)

Andersson (2009, p.7): "The main problem with over-centre-type of load holding valves is that they are controlled from the pressure in the inlet side of the cylinder, which, if the inlet flow is assumed to be constant, has a phase shift of 180 degrees when the system starts to oscillate with its natural frequency. This means that when the load pressure increases, the valve closes because of the decreasing inlet pressure and the load flow decreases instead of increases." This can be considered as a main reason for oscillation of traditionally installed load control valve. The statement of Anderson can be seen in Figure 18.

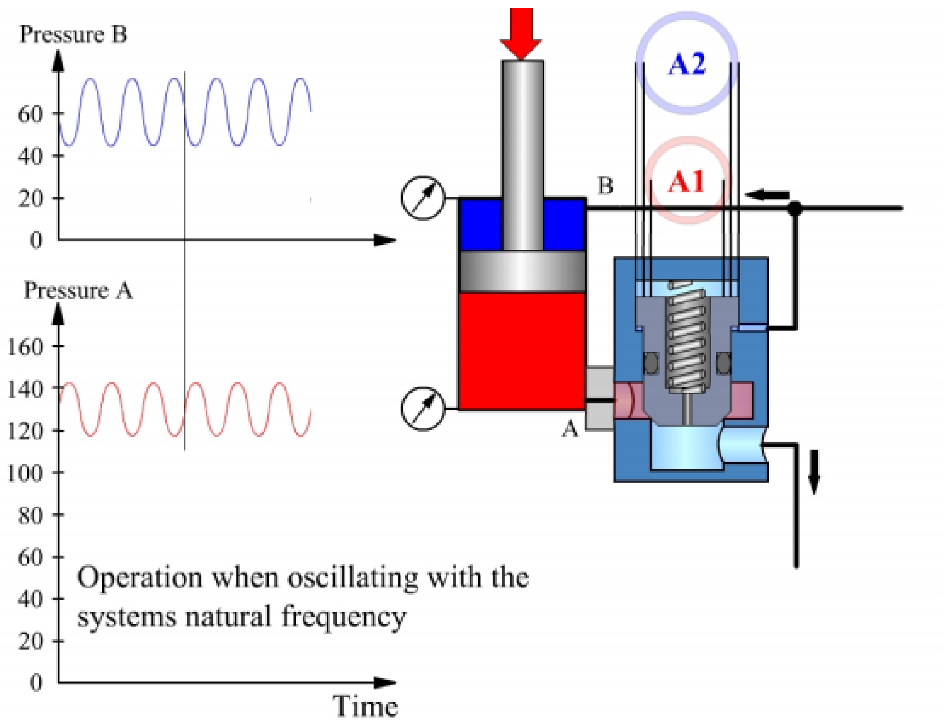

Figure 18: Chamber pressures when load is unstable and an overcenter valve is used (Andersson 2009)

Another big problem causing oscillations on load control valves is the fact that load control valves require a tight sealing between the spool and the housing. Tight sealing allows the valve to be leakage free but at the same time it causes friction and hysteresis. Hysteresis is the major cause of oscillations although the system parameters will specify how hazardous they will be. (Handroos et al. 1993; Kosarzecki 2003)

Examples of standard overcenter valve cartridges: Eaton 1CE, Argo Hytos SO5A (interchangeable with Eaton, cavity almost the same), Tucson OSI35 (interchangeable with Eaton, cavity almost the same), Bosch Rexroth VBSN-08HH (interchangeable with Eaton, cavity almost the same), Parker MHC-010-S-S, Fer Hydraulik FPO-C40, Comatrol CB10-HV and Hawe LHK. (Motion control valves 2015; Overcentre Valves s.a.; OSI35-Overcentre Valve s.a.; Bosch Rexroth Oil Control s.a.; Load and Motor Control Valves s.a.; Overcenter valves s.a.; Counterbalance Valves Quick s.a.; Over-center valves type LHK 2007) Hysteresis can be lowered with Bucher valves type CBPP as these do not have a pilot piston seal. This will result in a small amount of hydraulic fluid leak past the pilot piston (between valve and pilot ports), but on the other hand this will also provide warm oil circulation which makes the valve very responsive. Load holding capability at the cylinder port is retained also with this type of valve. (Kosarzecki 2003; Counterbalance Valve 2015)

The problem with standard overcenter valves is that the back pressure has an effect on p_s in Equations (2) and (3). With standard one cartridge overcenter valves the effect on valve setting is

$$p_s = p_{so} + (R + 1)\, p_b. \tag{5}$$

Where p_{so} is the opening pressure of the spring and p_b is the back pressure. (Lodemeier & Ashmore 2011; Load holding / Motion control s.a.) The effect of back pressure on the pilot pressure demand for opening the standard overcenter valve is

$$p_{pd} = p_{pw} + \frac{R + 1}{R + \frac{A_B}{A_A}}\, p_b \tag{6}$$

in the situation on the left side of Figure 16. Where p_{pw} is the pilot pressure without the back pressure effect (otherwise similar to p_p). The effect of back pressure on the pilot pressure demand for opening the standard overcenter valve is

$$p_{pd} = p_{pw} + \frac{R + 1}{R + \frac{A_A}{A_B}}\, p_b \tag{7}$$

in the situation on the right side of Figure 16.

3.3.1 Partially balanced overcenter valves

Usually the biggest problems with overcenter valves occur when the back pressure varies a lot because that will cause instability and the valve might open and close at a high phase. To overcome this there are balanced valves developed. Another problem comes with a closed center directional control valve and service-line pressure reliefs (also called work port pressure reliefs or shock valves). Pressure relief valves limit the inlet pressure but they are not able to limit an external load as the back pressure allowed by them and the closed center directional control valve prevents the standard overcenter valve from opening. To overcome this problem, there are developed partially balanced valves. These valves are also called relief compensated counterbalance valves by Bosch Rexroth (Bosch Rexroth Oil Control s.a.). One example of this type of valve is Eaton 1CER. As can be seen in Figure 19, the spring chamber is vented through the poppet to the valve port as in the standard model. The poppet annular areas which are affected by pressure from different sides are of the same size so the poppet is balanced. (Lodemeier & Ashmore 2011)

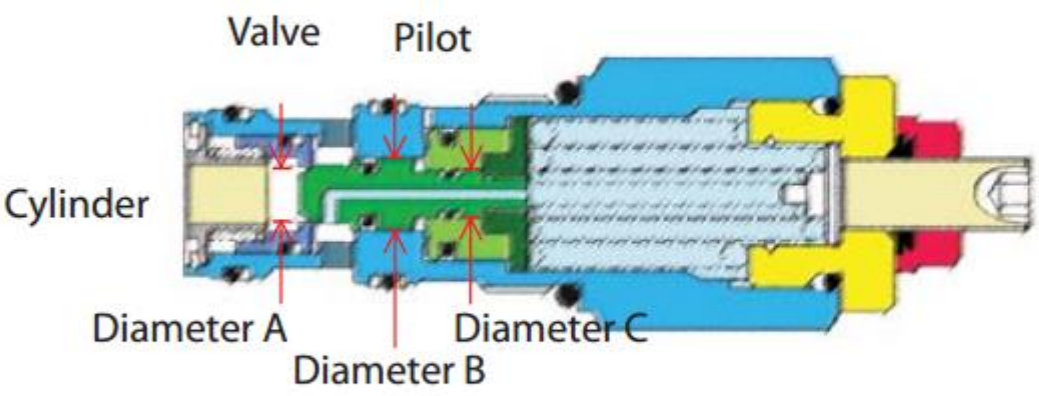

Figure 19: Partially balanced overcenter valve Eaton 1CER (Lodemeier & Ashmore 2011)

The balance of the poppet can be written in equations according to the Figure 19:

$$F_{Lp} = F_{Rp} \tag{8}$$

$$p_v\, A_L = p_v\, A_R \tag{9}$$

$$p_v \left(\frac{\pi B^2}{4} - \frac{\pi A^2}{4}\right) = p_v \left(\frac{\pi C^2}{4}\right) \tag{10}$$

$$B^2 - A^2 = C^2 \tag{11}$$

Where F_{Lp} is the force on the left side of the poppet (opening the valve), F_{Rp} is the force on the right side of the poppet (closing the valve), p_v is the pressure on the valve port, A_L is the annular area on the left side of the poppet and A_R is the circular area on the right side of the poppet. Diameters A, B and C are according to the Figure 19. (Lodemeier & Ashmore 2011)

It should be noted that back pressure affects also this type of valves if it is considered the pilot pressure required to open the valve. For example, with pilot ratio 5:1 standard 1CE overcenter valve, the back pressure has an effect with six-to-one ratio in valve setting p_s according to Equation (5). This means that the pilot pressure required to open the valve is affected by the back pressure with (6/5):1 ratio according to Equation (6) (if cylinder port is drained A_B/A_A is zero). Basically this means that a 10 bar back pressure on both 1CE and 1CER causes the required pilot pressure to rise 12 bars if the valves are with 5:1 pilot ratio and the cylinder port is drained in both cases. (Lodemeier & Ashmore 2011)

With partially balanced overcenter valves, the relief setting (cylinder port opening without pilot pressure) is always the same as the spring opening pressure p_{so}. In other words, the back pressure does not affect the pressure relief section. The effect of the back pressure on the pilot pressure demand for opening partially balanced overcenter valves is same as with standard overcenter valves in Equation (6) for the situation on the left side of Figure 16. For the situation on the right side of Figure 16, this is also the same as with standard overcenter valves in Equation (7). (Lodemeier & Ashmore 2011)

Examples of this type of valve cartridges: Eaton 1CER, Argo Hytos SOP5A (interchangeable with Eaton, cavity almost the same) and Bosch Rexroth VBSP-08HH (interchangeable with Eaton, cavity almost the same) (Motion control valves 2015; Overcentre Valves s.a.; Bosch Rexroth Oil Control s.a.).

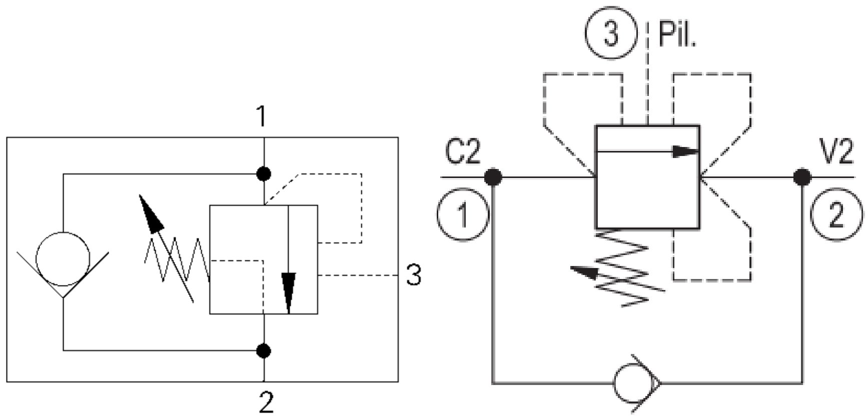

Figure 20: Drawing symbols of a partially balanced overcenter valve (Motion control valves 2015 p. 14; Load holding / Motion control s.a.)

As can be seen in Figure 20, manufacturers have their own ways of drawing symbols for partially balanced overcenter valves. This leads to that one cannot be sure which type the valve is with just plain symbol; a datasheet or a bill of materials is needed.

3.3.2 Fully balanced overcenter valves

Fully balanced overcenter valves have been developed to overcome the back pressure effect completely. The difference between fully and partially balanced overcenter valves in the Eaton products can be seen in Figures 19 and 21. (Lodemeier & Ashmore 2011)

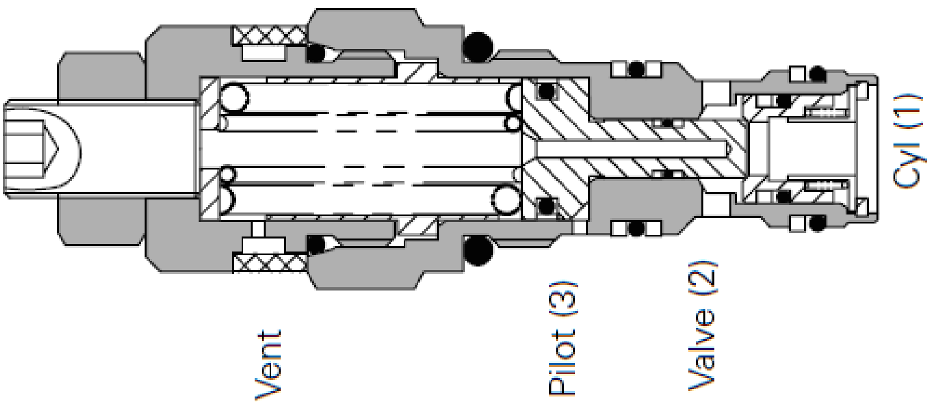

Figure 21: Fully balanced overcenter valve Eaton 1CEB (Motion control 2015)

When comparing the 1CER and 1CEB valves, it should be noted that the 1CEB spring chamber is vented to atmosphere. As a downside, atmosphere can be corrosive and this can cause leaks. (Lodemeier & Ashmore 2011) If an atmospheric vent is a problem, there are also valves with separate vent port available according to Figure 22. These valves are so called four-port counterbalance valves, as others are three-ported. If this type of valve is used, the vent port is connected to the drain line that goes directly into the tank. It is recommended that these types of valves should be used rather than atmospherically vented in order to avoid oil leaks and moisture from going into the hydraulic system. (LoadMatch™ counterbalance valve, FAQ 2015)

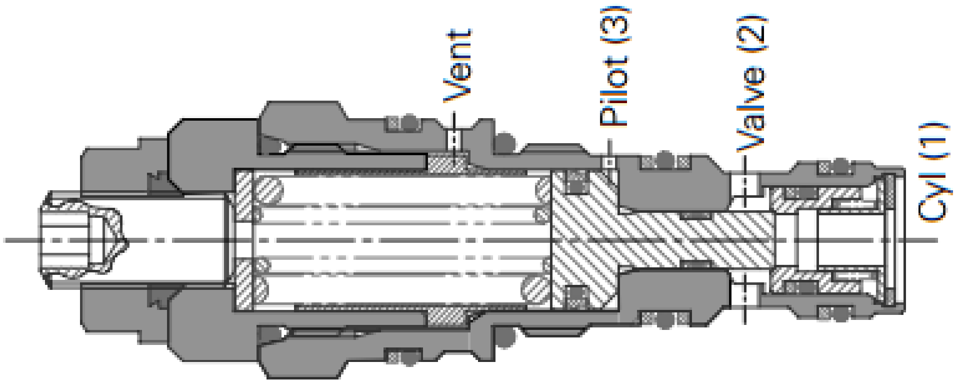

Figure 22: Fully balanced overcenter valve Eaton 1CEBD30 (Motion control 2015 p.20)

According to Dabholkar and Indulkar (2012), the overcenter valves that are used in conjunction with proportional valves should be fully balanced. This allows the downstream pressure to be high without having an effect on the relief setting. According to Bosch Rexroth (Load holding / Motion control s.a.), fully balanced valves should be used if the overcenter valve is used in a regenerative cylinder circuit where the oil from the annular chamber is fed into the full bore side or if the cylinder is used in a series actuator circuit. Fully balanced overcenter valves should be also used if the pilot is controlled by a low pressure signal generating joystick and the overcenter valve should maintain stable operation also with strong pressure fluctuations. Closed loop circuits likewise demand fully balanced overcenter valve as well. (Load holding / Motion control s.a.) With fully balanced overcenter valves there is no back pressure effect on the valve setting. Thus, the setting pressure is always the same as the spring opening pressure according to the Equation (12).

$$p_s = p_{so} \tag{12}$$

Examples of this type of valve cartridges: Eaton 1CEB, Argo Hytos SOB5A (interchangeable with Eaton, cavity almost the same), Bosch Rexroth VBST-08HH (interchangeable with Eaton, cavity almost the same), Fluid-Press FPOFB-25-C, Fer Hydraulik FPOB-S, Comatrol CB10-AV, Walvoil CC10A and Flucom CMC30. (Motion control valves 2015; Overcentre Valves s.a.; Bosch Rexroth Oil Control s.a.; FPOFB-25-C-*-*-* s.a.; Overcenter valves s.a.; Counterbalance Valves Quick s.a.; Counterbalance valves, Walvoil s.a.; Motion control or overcenter valves 2015)

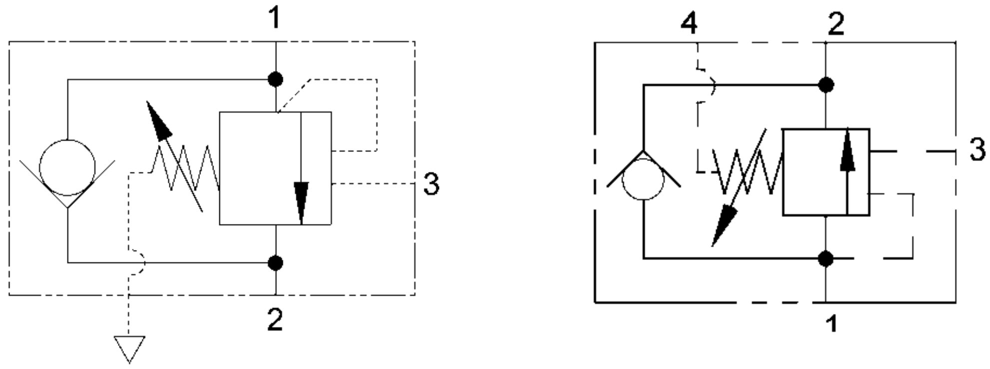

Figure 23: Drawing symbols of fully balanced overcenter valves, atmospherically vented on left side and four-ported on right side (Motion control valves 2015 p. 18; Motion control s.a. p.20)

3.3.3 Two-stage overcenter valves

Two-stage overcenter valves have two springs of which one effects on the inner poppet and the other one on the outer poppet according to the Figure 24. (Lodemeier & Ashmore 2011)

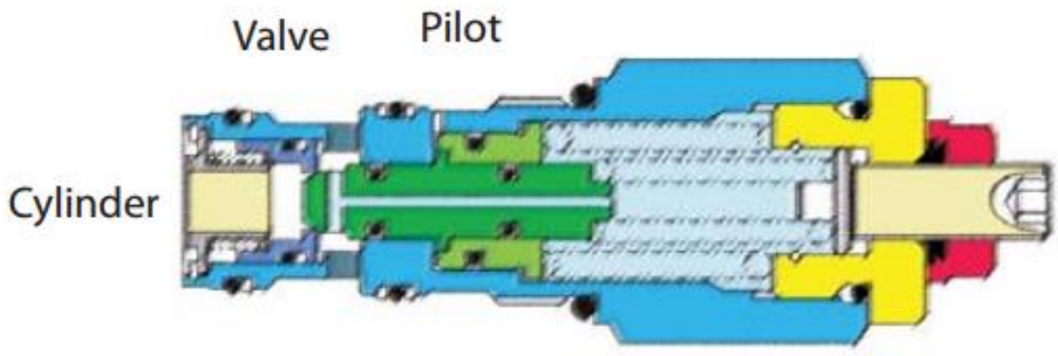

Figure 24: Two-stage overcenter valve Eaton 1CEL (Lodemeier & Ashmore 2011)

This structure causes the outer poppet to be able to open independently as well as the inner poppet to be able to close independently. Poppets do other movements linked together or independently, depending on situation. In practice, this means that two-stage valves are able to keep certain minimum pressures in both A and B chambers when considering a linear actuator. Pre-tension-adjustable inner spring in Figure 24 is affecting the inner poppet and thus generating back pressure on the actuator. This adjustable spring can also be seen in Figure 25.

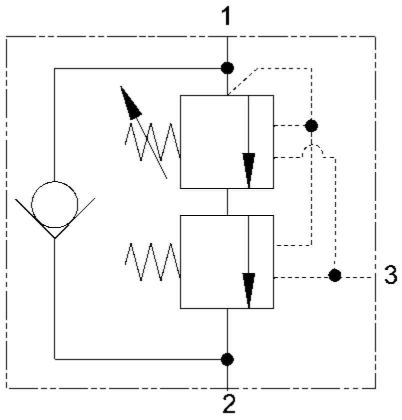

Figure 25: Drawing symbol of a two-stage overcenter valve (Motion control valves 2015 p. 22)

The two-stage overcenter structure will stabilize its behavior with unstable booms or lever structures when the cylinder is driven all way to the end. This is how the cycle would work with the overcenter valve without two stages: When the cylinder is driven to the end, the oil pressure rises to the main pressure relief-valve setting in the pressurized chamber and the overcenter valve locks the pressure in the chamber (the maximum locked pressure being the overcenter setting pressure p_s). After this while lowering, the valve will require less pilot pressure to open. This will result in the overcenter valve opening quickly and causing a rapid acceleration. This might also lead to instability that continues the entire cylinder stroke. (Lodemeier & Ashmore 2011) The two-stage overcenter valves are developed to avoid this type of instability.

Two-stage overcenter valves can be considered to be a combination of the traditional counterbalance valve and the overcenter valve. This is why they are also called counterbalanced overcenter valves. With Eaton 1CEL primary pilot ratio being 4.3:1, it can be considered as an overcenter valve (this is the outer poppet, lower one in Figure 25). Secondary pilot ratio in turn being 0.4:1, it can be considered as a traditional counterbalance valve (this is the inner poppet, upper one in Figure 25). In 1CEL, the secondary counterbalance pressure is always adjusted lower than the primary opening pressure of the valve. As 1CEL is dual-piloted, both poppets are also affected by the pilot ratio. There are also two-stage overcenter valves that are single piloted, whereas only the primary poppet is piloted. These valves are less energy efficient than the dual piloted models. (Lodemeier & Ashmore 2011)

3.4 Load matching valves

Sun hydraulics is providing a new LoadMatch^{TM} load control valve product family. The difference to the normal overcenter valve is that in Equation (4), p_s changes according to p_L. The construction aims to save energy by keeping p_s always 30% higher than p_L. This is why the valve is non-adjustable. The valve has a fixed relief setting for limiting the maximum load pressure. The LoadMatch valves are available non-vented or fully balanced with venting to atmosphere or separate drain port. In valves with atmospheric vent there is a new atmospheric seal which resists water intrusion. The sructure of the non-vented LoadMatch valve is presented in Figure 26. (Sun Saves Energy with LoadMatch^{TM} Technology 2014; LoadMatch™ Counterbalance Valves 2013)

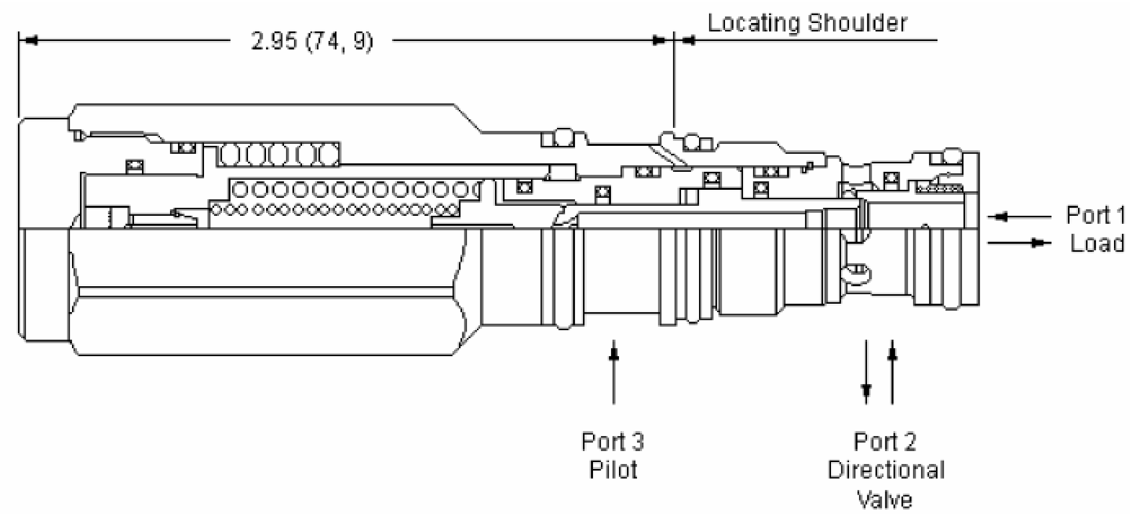

Figure 26: The LoadMatch valve series 1, capacity 60 litres per minute (LoadMatch™ counterbalance valve 2015)

The Figure 27 shows that the flow in the setting piston is unrestricted which allows safe load holding as the setting increases rapidly. The flow out in turn is restricted which allows stable and predictable modulation as the setting slowly decreases. The back pressure on port 2 in Figure 27 will increase the pilot pressure requirement for the LoadMatch valve. According to Sun Hydraulics, with the non-vented LoadMatch the increase on the pilot pressure requirement is less than with standard overcenter valves when comparing LoadMatch MBEP with the valves CBEA and MBEA which are both non-vented 3:1 pilot ratio valves. All the three previous valves are with rated 120 lpm flow capacity. Basically this means that in LoadMatch MBEP the back pressure is added with factor less than 1.33 to the required pilot pressure demand as that would be the factor with the non-vented 3:1 pilot ratio overcenter valves according to Equation (6) when the actuator areas are unknown. (LoadMatch™ Counterbalance Valves 2013)

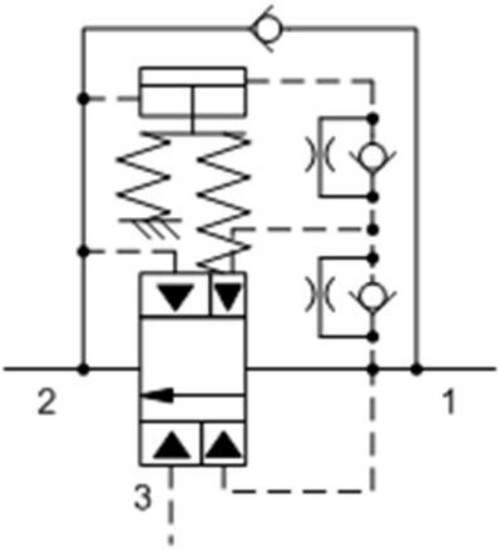

Figure 27: The detailed symbol of the non-vented LoadMatch valve (LoadMatch™ Counterbalance Valves 2013)

3.5 Load adaptive valves

Sun hydraulics is providing a new LoadAdaptive^{TM} valve. The difference to the normal overcenter valve is that the LoadAdaptive changes its pilot ratio during operation. Low pilot ratios are used when required for stability and high pilot ratios are used when the actuator is not moving or it is not in the area prone to oscillations according to Figure 30. This functionality allows energy savings as well as increase in stability. The structure of the LoadAdaptive is seen in Figure 28. (LoadAdaptive™ counterbalance valves 2015)

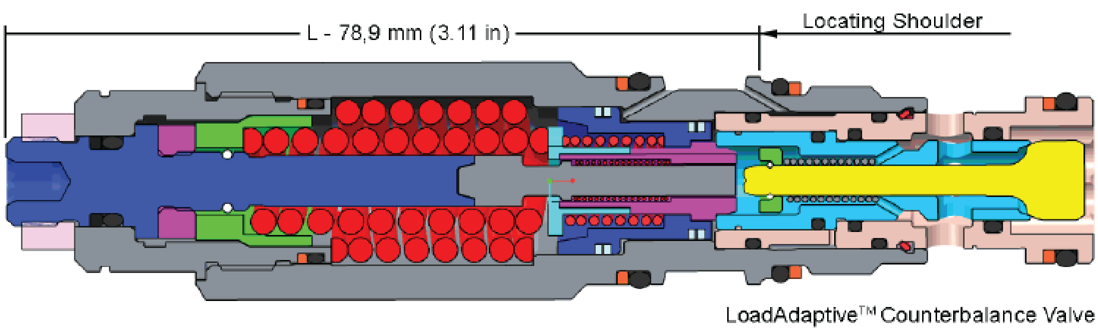

Figure 28: The Sun LoadAdaptive valve (LoadAdaptive™ counterbalance valves 2015)

Figure 29 illustrates power saving potential when varying from a 1.5:1 pilot ratio to 10:1 pilot ratio. Power saving can be calculated by multiplying the pilot pressure difference with the flow rate. It is notable that the saving potential is the biggest with small load pressures. (LoadAdaptive™ counterbalance valves 2015)

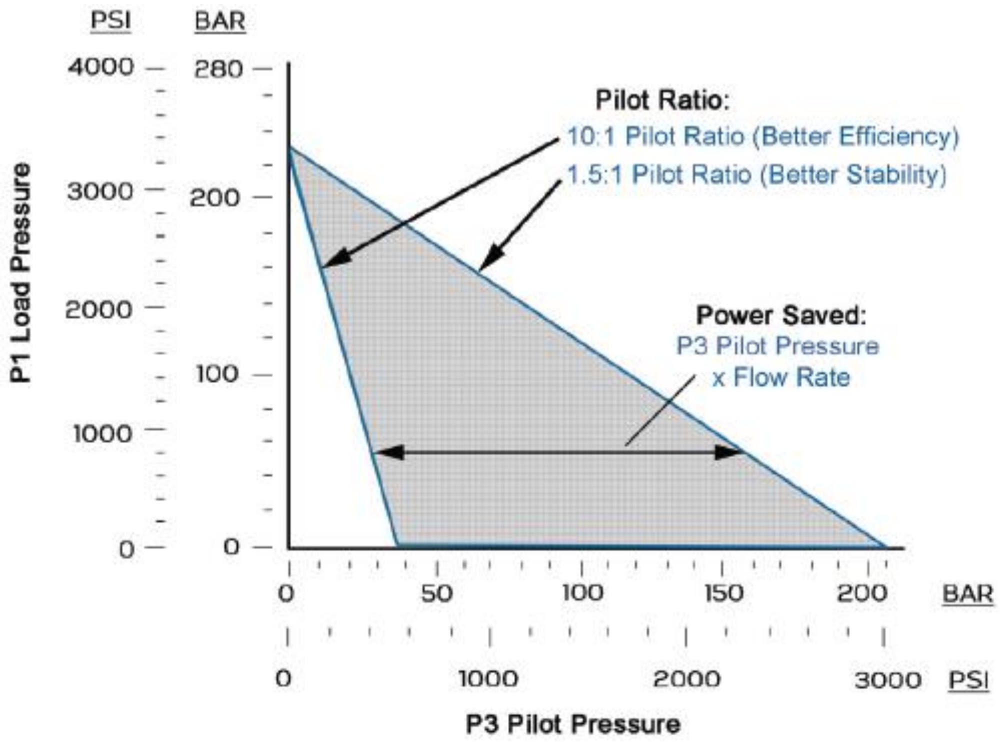

Figure 29: Power consumption of different pilot ratio valves (LoadAdaptive™ counterbalance valves 2015)

The fixed inlet section in Figure 30 is a section where the load is not moving yet. This is the region where the cylinder does not move and thus it cannot oscillate or go unstable which means that a low pilot ratio is not required. This is the reason why the LoadAdaptive valve uses a high (10:1 in Figure) pilot ratio in this region to minimize power consumption. The load is grounded -section in Figure 30 is a section where the load is positive (not overrunning) as it requires a high pilot pressure but has only a small load pressure. Neither this operating point requires a low pilot ratio. This is the reason why the LoadAdaptive valve uses a high (10:1 in Figure) pilot ratio in this region to minimize power consumption. The region where low pilot ratio is required is the load moving dynamically -region. This is the region where the LoadAdaptive uses a low (3:1 in Figure) pilot ratio for stability. Note that in the higher curve of the Figure the flow is constant 60 lpm, in the lower curve of the Figure the flow is 2 lpm and at zero pilot pressure the valve is at its mechanical setting. (LoadAdaptive™ counterbalance valves 2015)

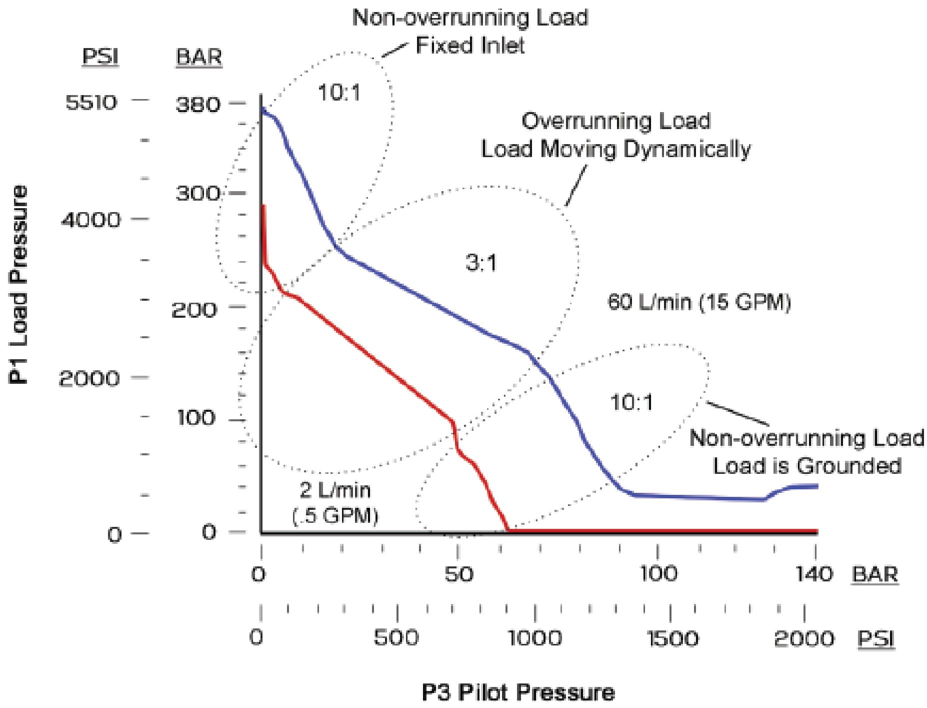

Figure 30: The LoadAdaptive functionality (LoadAdaptive™ counterbalance valves 2015)

Load adaptive valves are available only non-vented and thus the back pressure has an effect on the setting of the valve. They are available with six different pilot ratio areas. The load adaptive valves should be used in situations where the minimum load pressure exceeds 35 bar and the maximum load pressure does not exceed 280 bar as can be seen in Figure 31.

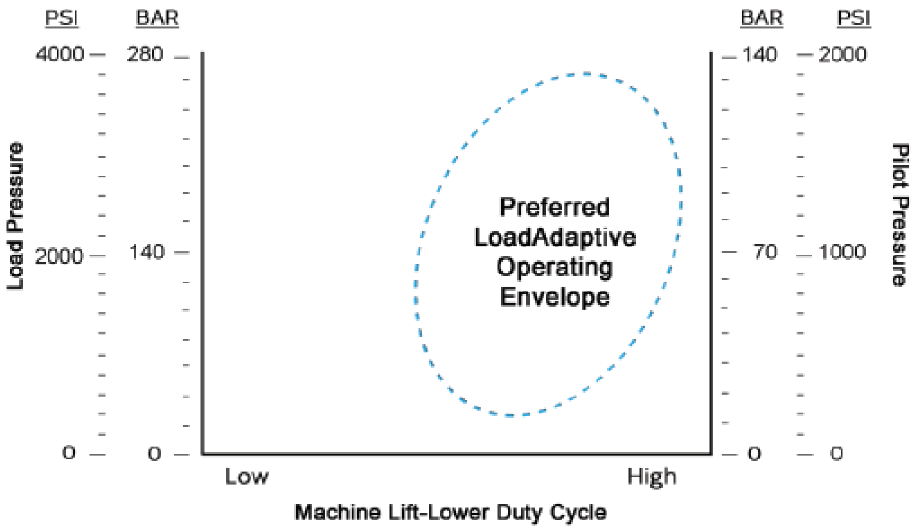

Figure 31: The LoadAdaptive operating envelope (LoadAdaptive™ counterbalance valves 2015)

The pilot pressures for the valve should be less than 140 bar. According to Figure 31, a machine lift-lower cycle should also be quite high to get value for the money spend on a more complicated valve. (LoadAdaptive™ counterbalance valves 2015)

3.6 Lock type load control valves

In lock type load control valves the load pressure is acting against the pilot pressure. This means that the load pressure is closing and the pilot pressure is opening the valve. (Dabholkar & Indulkar 2012) The major advantage of this types of valves is that the hydraulic pressure caused by the load is not supported by the spring. Thus, if the spring breaks, the load will not come down. These type of valves are also leak free, therefore they hold the load steadily in the wanted position. Basically, these types of valves are pilot-operated check valves but there are also more complex structure valves which are lock types. These are, for example, the flow modulating Bucher Cindy and Bucher BBV6 valves that both have basic structure as shown in Figure 32. The structure of the cartridge type BBV6 is presented in Figure 33. (Kuormanlaskuventtiili Cindy 2010; Safety for Hydraulics 2015) Lock type load control valves do not have a pressure release function but they can be equipped with a pressure release valve connected parallel with the valve according to Figure 34. Pilot-operated check valves are pure on-off valves which means that they have only unintended load lowering prevention and load holding functions. They are not able to provide controlled load lowering. That must be done, for example, with a spool of directional control valve. The pilot-operated check valves should never be used in paired cylinders as there is likely to be a problem with one valve opening and the other one staying closed as the increasing load pressure keeps it closed. (Pilot operated check valves s.a.)

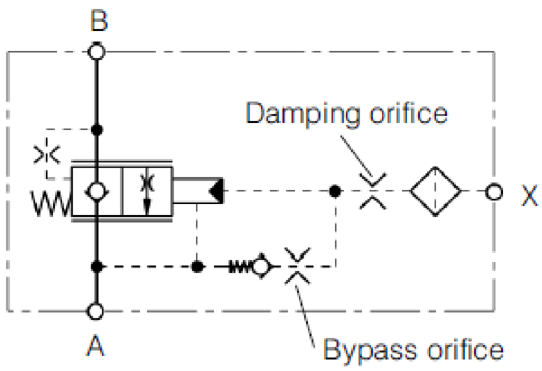

Figure 32: The drawing symbol of Bucher BBV6 (Safety for Hydraulics 2015)

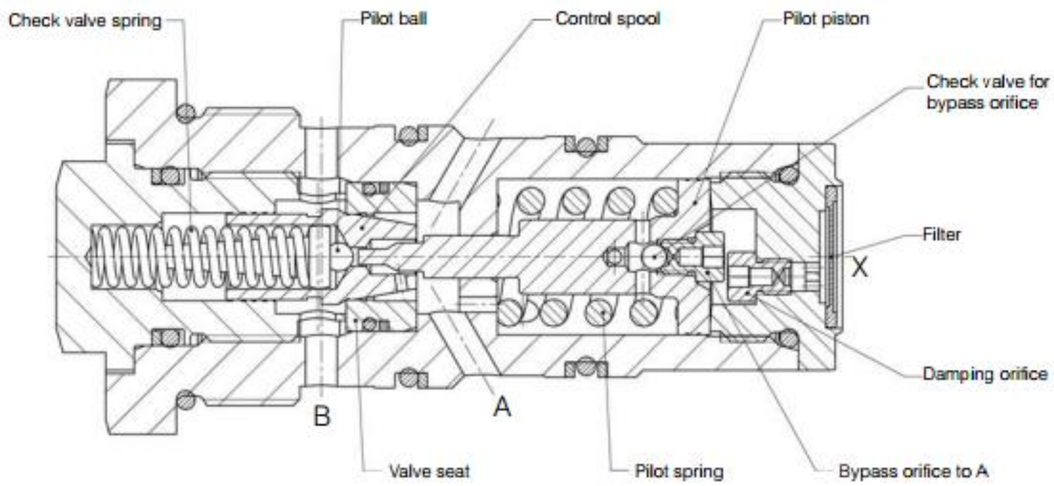

Figure 33: The lock type Bucher BBV6 (Safety for Hydraulics 2015)

The flow modulating lock type load control valves are advanced lock type load control valves with low energy consumption and more complicated structure. These valves provide controlled load lowering. Bucher Cindy is the valve commonly used in really demanding applications such as paper mills, harbour cranes and bridges. (Teittinen 2015) Cindy has many advantages compared to other types of load control valves. In addition to already stated there are, for example, these advantages: Cindy has no dynamic sealing and thus hysteresis is very small. It is insensitive to load changes and the load always moves with the same speed with a certain joystick position. It can also be overcompensated as in Figure 34 (arrangement on the left side). This means that a bigger load comes down slower and this is available only with a joystick-operated pilot pressure control. Cindy can be damped in many different ways so it is not so likely to have oscillations. It can be operated with the pilot pressure either from the opposite actuator line or from the hydraulic joystick as in Figure 42. An electrically operated Cindy is also available. If operated as in Figure 42, it should be noted that the directional control valve and the load control valve should be adapted to fit the openings of each other to allow smooth operation. The pilot pressures required by the Cindy are small so the positioning of the load is accurate with both the joystick and the opposite actuator line pilot pressure control. This is because the cylinder is only pressurized with small pressures and therefore the oil does not compress that much. (Kuormanlaskuventtiili Cindy 2010)

There is also one major disadvantage with the flow modulating lock type load control valves. When these valves are used in double cylinders, there is a great probability that one valve is opening and the other one is still staying closed. This can be avoided with three different kinds of special arrangements. These are: using a balancing tube, circulating oil through one load control valve, or connection of three valves according to Figures 34, 35 and 36. The balancing tube is a small tube that connects load pressures between the cylinders. If a hose is used, it requires hose burst valves in both ends or pilot operated connections as in Figure 34. In the Figure, the tube is between the two E ports. (Kuormanlaskuventtiili Cindy 2010)

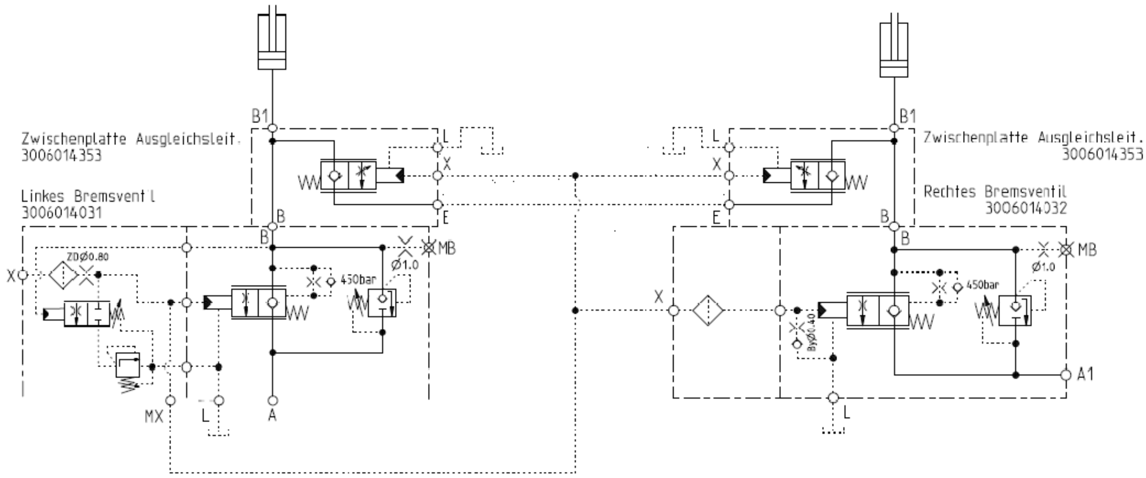

Figure 34: The balancing tube and the pilot operated balancing connections in Bucher Cindy (Kuormanlaskuventtiili Cindy 2010 p.46)

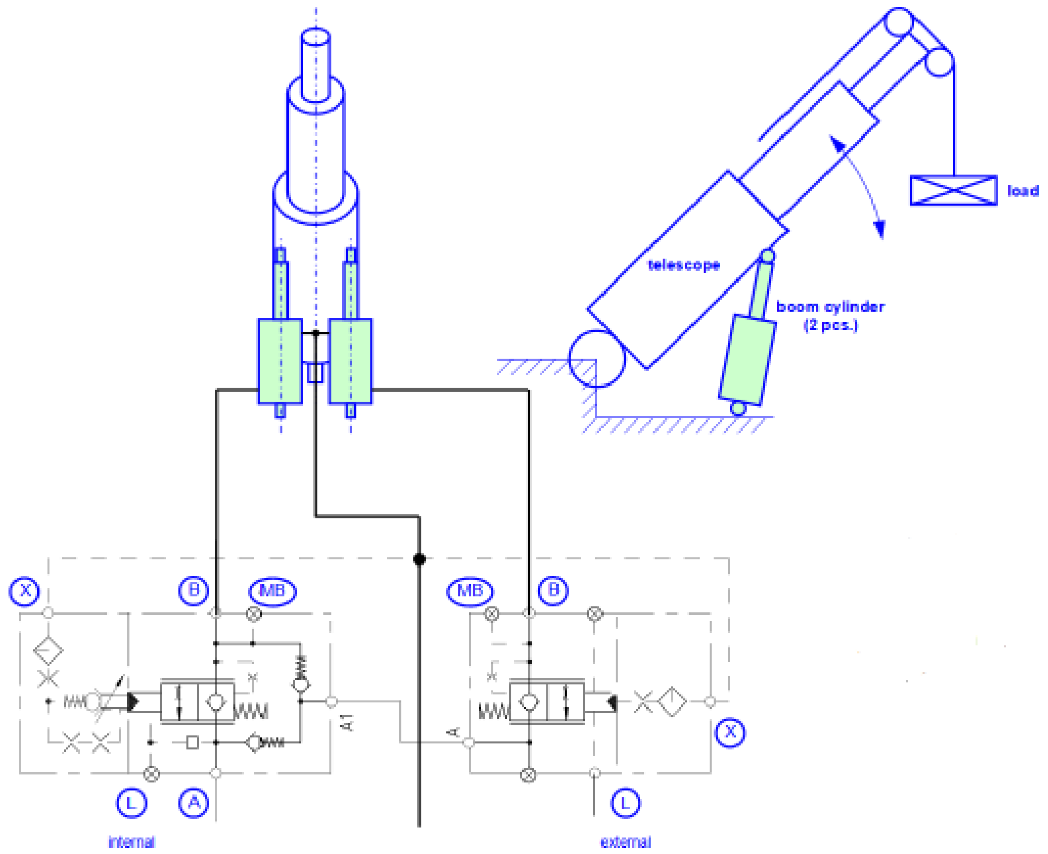

Figure 35: Circulating oil through other load control valve (Kuormanlaskuventtiili Cindy 2010 p.38)

When circulating oil through one load control valve, the left valve in Figure 35 is handling the actual lowering. The valve on the right side is acting only as a pilot-operated check valve and it does not have a dampening. This type of connection is reasonable only with small flows; a maximum of 40 liters per minute per cylinder. (Kuormanlaskuventtiili Cindy 2010 p.39) A connection of three load control valves as in Figure 36 can be applied to flows up to 500 lpm. Two upper flow control valves in the Figure are acting only as a pilot-operated check valves and they do not have a dampening. They are opening fast in lowering and they do this before the third one opens. The third load control valve is the one handling the actual lowering. The third load control valve must allow double flow through the valve compared to other load control valves. (Kuormanlaskuventtiili Cindy 2010 p.41)

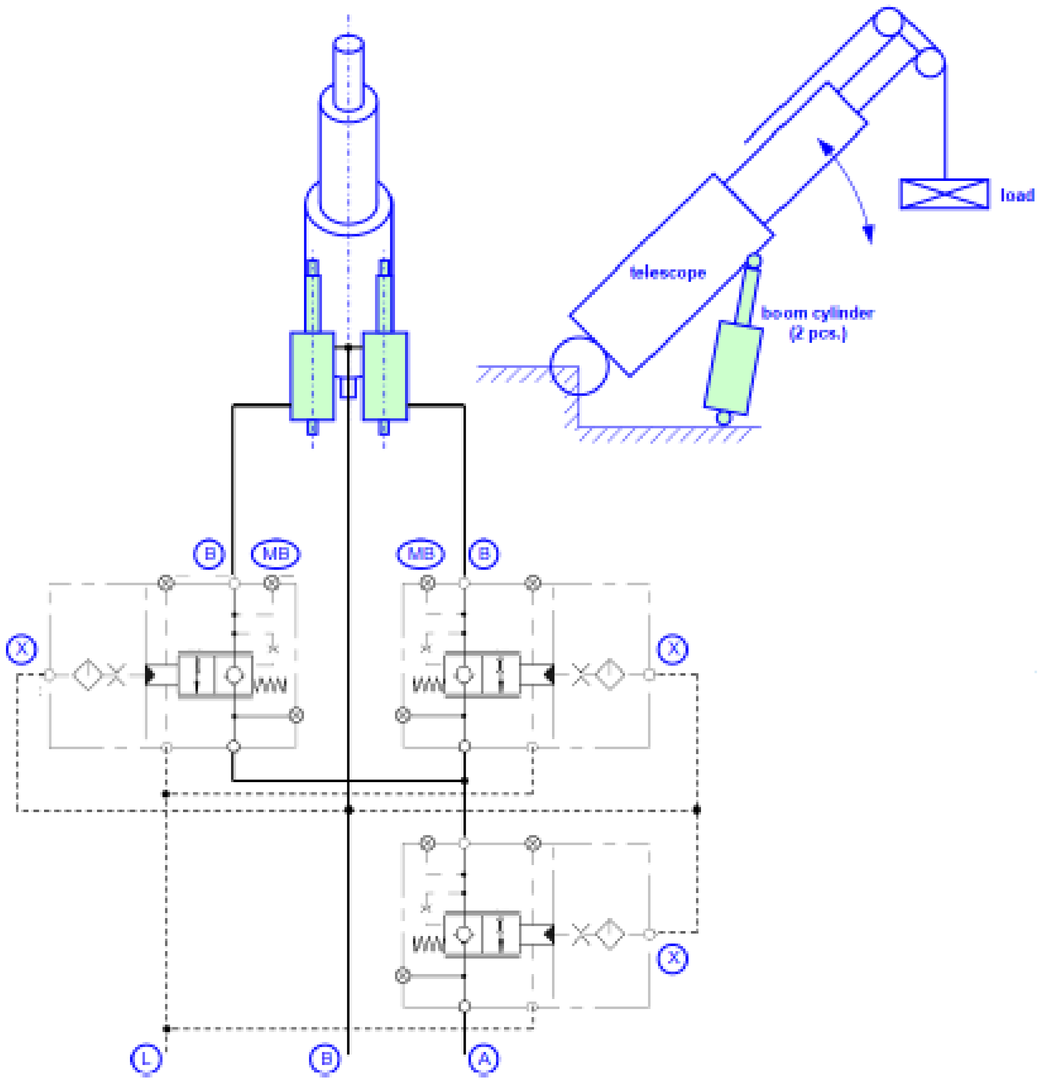

Figure 36: Connection of three load control valves (Kuormanlaskuventtiili Cindy 2010 p.40)

3.7 Non-load-reactive load control valves

All previous valves in chapters 3.2 – 3.6 are influenced by load pressure in different ways. However, there are also load control valves that are not influenced by load pressure according to Figure 37.

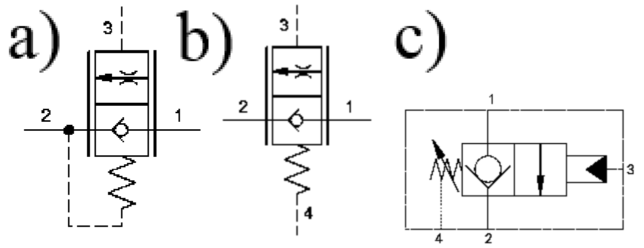

Figure 37: a) symbol of the Sun hydraulics balanced load control valve b) symbol of the Sun hydraulics balanced vented load control valve c) symbol of the Eaton zero differential overcenter valve (Balanced load control valve 2015; Vented, balanced, load control valve 2015; Motion control valves 2015)

The Sun valves are available only as big-sized; max flows 120 liters per minute and up. Hydac is also offering smaller-sized non-load-reactive load control valves that are so called pilot ratio 0 valves in their catalog. These Hydac valves are the RSM10121 and the RSM12121. (Counter balance valves s.a.) Bosch Rexroth also has these type of valves but not as cartridges in smaller sizes that has a flow under 100 lpm. One manufacturer for this type of load control valve cartridges is Atlantic Fluid Tech with products CBST and CBSN. (Kantola 2015) Eaton has named these types of valves as zero differential overcenter valves, one example being the 1CPBD30 according to Figure 38 (Motion control valves 2015 p.24). Parker calls these types of valves equal area counter balance valves and states that they have 1:1 pilot ratio. (Load and Motor Control Valves s.a. p. 5)

It can be seen in Figure 38 that the poppet is balanced with a hole that is going through the poppet from the cylinder port. This is why the load pressure does not have an effect on the functionality of the valve. Eaton 1CPBD is commonly used in the Eaton BoomLoc application which is designed for excavators and backhoe loaders according to ISO8643. In BoomLoc, there is a pressure release valve connected parallel to the 1CPBD in order to avoid pressure peaks. This is a problem solver for pressure peaks that might be a problem when using non-load-reactive load control valves. In these applications, it is common to take the pilot pressure from somewhere else than from the opposite actuator line. (World-Class Control 2009 p.1204-1206) The pilot pressure source can be, for example, hydraulically operated control pressure of the directional control valve.

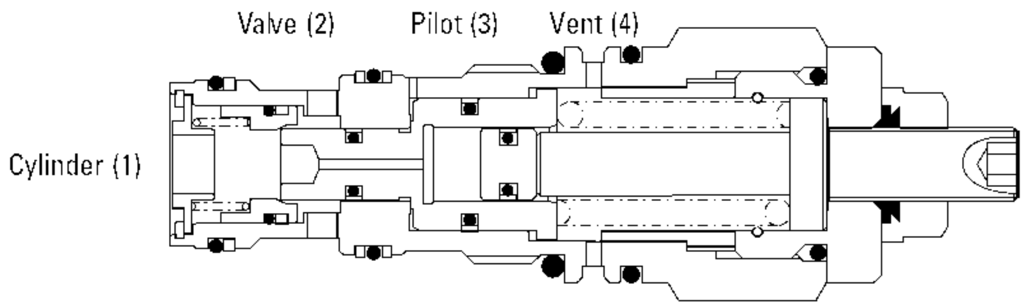

Figure 38: The Eaton 1CPB(D) zero differential overcenter valve (World-Class Control 2009 p.1204)

3.8 Load holding valve - 3G LHV

The load holding valve type 3G was developed in Linköping University and was revealed at the 11th Scandinavian International Conference on Fluid Power, SICFP`09 on 2009. This valves will be produced and marketed by Nordhydraulic, Hydac International. Unfortunately, this valve is not yet available in 2015 (Puhakka 2015). The principle of the valve can be seen in Figure 39. (Andersson 2009)

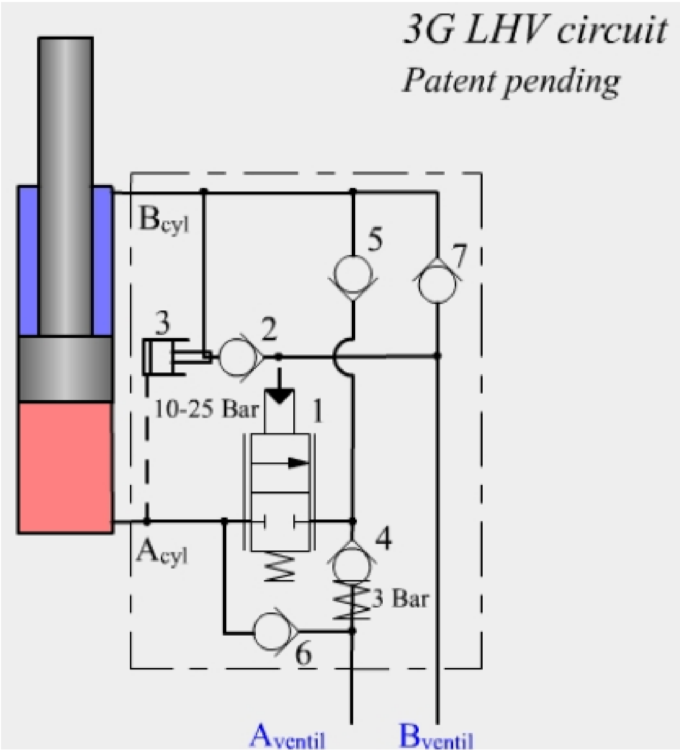

Figure 39: The 3G load holding valve (Andersson 2009)

This valve is primarily developed for systems that are operated with manually directional control valves. The principle of the valve is to eliminate oscillations by separating the pilot port of the valve from the cylinder inlet. This is done so that the additional pilot pressure hose or the electrical signal between the directional control valve and the load holding valve are not needed. Basically, the opening of the valve is proportional when lowering the load as can be seen in Figure 39 (part 1). The energy saving with this valve comes from the fact that when lowering, flow is not required from the pump. The load will by itself fill up the B chamber as in the case of Figure 39. The excess flow is going through the check valve and the directional control valve to the tank and this flow is the one adjusting the speed of the actuator. In other words, this is called meter-out speed adjusting. If the case is similar to right side of Figure 16, there must be an additional flow to the outlet flow to avoid cavitation in the chamber A. (Andersson 2009)

If the load is pulling upwards the cylinder rod as in the case of Figure 39, there is no load pressure on the piston closing the check valve (part 3 on Figure 39). This allows the flow to go from the directional control valve to the cylinder chamber B when driving the cylinder downwards (minus movement). In this case, the cylinder works normally and allows, for example, actuator pushing to the ground. (Andersson 2009)

In Figure 40 can be seen the flow through the 3G valve as a function of command pressure (Signaltryck) in B_{ventil} in Figure 39. The flow is in blue and the red is the pressure drop across the 3G load holding valve. (Andersson 2009)

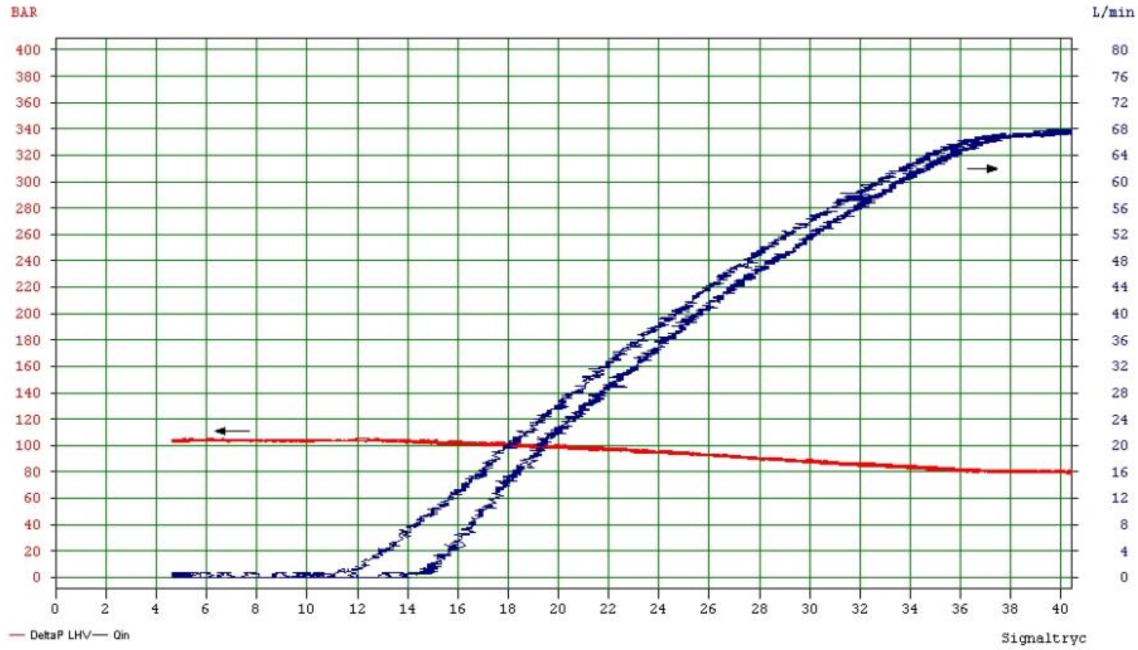

Figure 40: Flow and pressure of the 3G load holding valve (Andersson 2009, p. 11)

Figure 40 shows a smoothly increasing flow. This curve is the ideal case but in many applications it is possible that the command pressure is rising so rapidly that the 3G valve is able to work proportional only when starting the movement. After this, the smooth operation must be carried out by the directional control valve of the system. This is probably why it is called the holding valve and not the control valve.

3.9 Dampening of load control valve

If the load control valve oscillates and changing the type of valve does not help, dampening of the valve could be tried. One option is to dampen the pilot piston with suitable orifice as the pressure fluctuations at pilot piston affects the most on the functionality of the valve. (Load holding / Motion control s.a.)

According to Bosch Rexroth (Load holding / Motion control s.a.), pilot piston dampening is normally done in five different ways according to Figure 41.

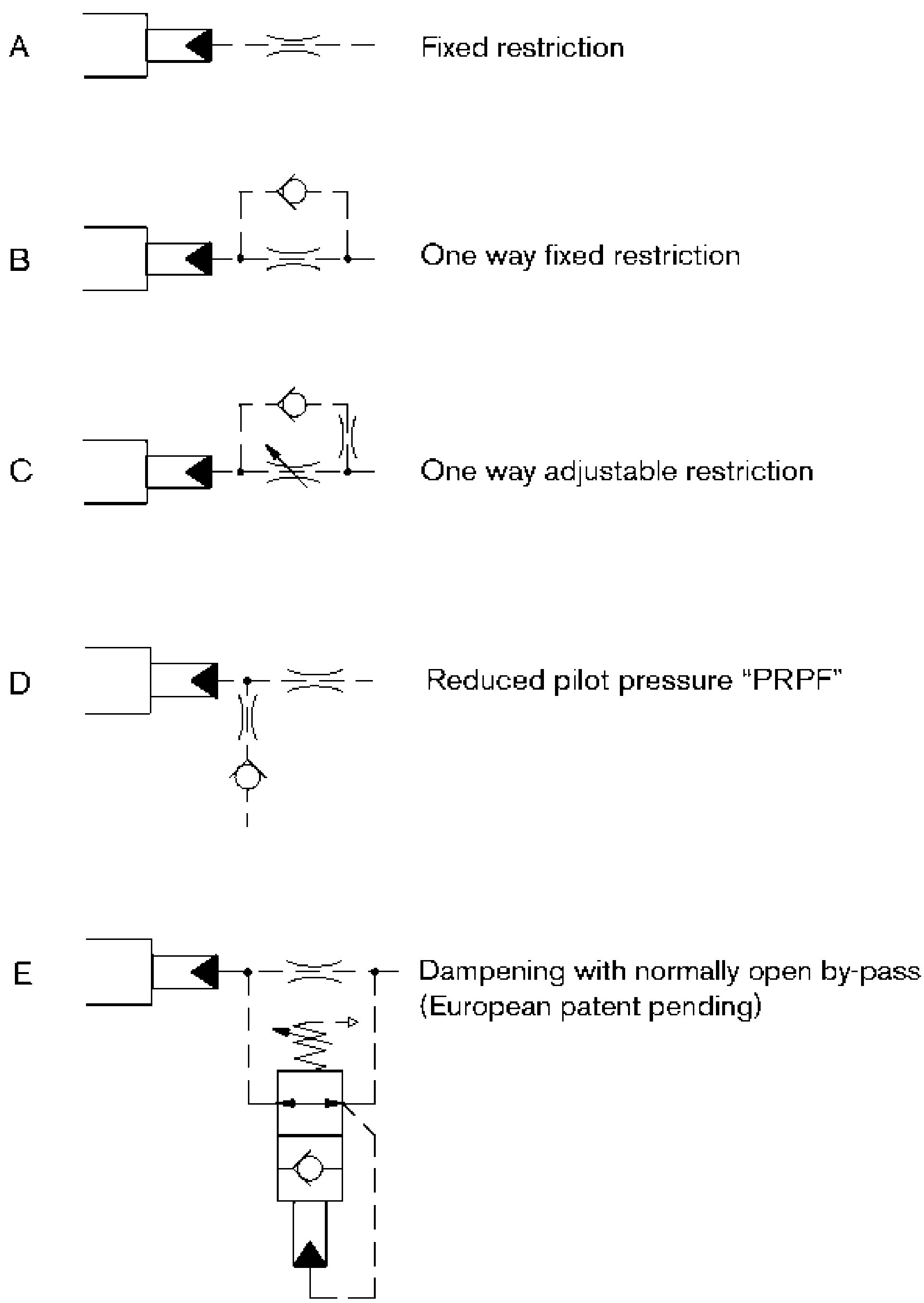

Figure 41: Five different ways to pilot piston dampening (Load holding / Motion control s.a.)

Restrictions are fitted in the pilot line between the pilot port and the pilot piston. Suitable restrictor allows the pilot piston to move smoothly and thus keeping the signals stable. A check valve is often installed according to B and C in Figure 41. The task of the check valve is to let the pilot pressure to release quickly if the pressure drops in the system. This makes the valve to stop moving immediately and safely. The type D dampener in Figure 41 is ideal when the main control valve is load sensing and a load control valve is used. Types A-D in Figure 41 are effective for pilot dampening but they are very sensitive to viscosity variations. The type E dampener has been developed to overcome viscosity problems. In rapid lowering the VEM valve, which can be seen in E (Figure 41), locks almost immediately and after that the pressure increase in the pilot chamber is controlled by the restrictor. In slowly lowering, the VEM lets the flow go freely into the pilot chamber; only the final pressurization is going through the restrictor. (Load holding / Motion control s.a.) As stated by Nordhammer et al. (2012), increasing volume between the directional control valve and the actuator is also a common way to stabilize a load control valve.

Another way of load control dampening is also related to pilot pressure. As stated by Andersson (2009) and seen in Figure 18, the main reason for load control oscillations is controlling the pilot piston from the inlet of the cylinder. This means that the pilot piston of the load control valve should be controlled with a pressure that is separated from the inlet of the cylinder. If the directional control valve is operated by a pilot pressure, the load control valve can be used with the same pilot pressure as in Figure 42. According to Andersson (2009), this is a common solution, for example, in excavators.

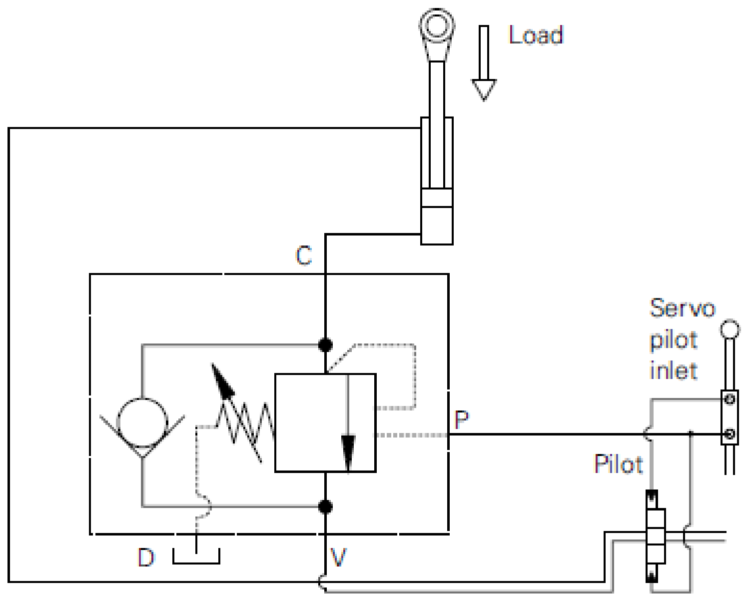

Figure 42: The same pilot pressure for a directional control valve and a load control valve (Motion control valves 2015 p. 134)

Although this solution sounds simple and reliable, there are some drawbacks. Firstly, you need to add more hoses or pipes to transport the operating pilot pressure of the directional control valve to the load control valve(s). Secondly, the operating pilot pressure of the directional control valve might be quite low. For example, in NTM products, the Parker VPL directional control valve is already fully open with a 15 bar pilot pressure. This 15 bar is quite low for a load control valve but it is enough for some lock type or pilot ratio 0 load control valves such as Eaton 1CPB valves (Motion control valves 2015; Storås 2015).

3.10 Control without specific load control valve

Controlling with a proportional directional control valve that has a pressure compensation is a considerable alternative for load control. This is possible when the loads are relatively light so that cavitation is not a problem. With bigger loads, the spool might require a special design so that the meter-out control (flow to the tank) would be restricted enough. In many cases this type of load control requires hose burst valves (velocity fuses) that are installed directly on the cylinders. Unfortunately some bad experiences have been reported about the hose burst valves (Nysand 2007). The disadvantages with the hose burst valves are related to cold weather and the fact that the viscosity of the fluid rises in cold temperatures. If the hose burst valve is adjusted properly, it might still activate before it should in cold environment. This might lead to the actuator getting stuck in the upper position. (Nysand 2007; Kuormanlaskuventtiili Cindy 2010) If the hose burst valve is adjusted for cold environment it might not work at all when needed at a normal temperature.

Another option to avoid hose burst when controlling the load with a proportional directional control valve is to install an electrically operated valve directly on the cylinder. This valve could be a normally closed on-off type valve, normally closed check valve, or an electrically adjustable pressure relief valve. These valves can be controlled either electrically immediately fully open when the handle is moved or proportionally when the control can be more on the valve than on the proportional directional control valve. The assembly in this type of solution would be similar to Figures 44 and 45.

4. LOAD CONTROL OF BINLIFTS

4.1 Situation when starting the thesis

In the case of NTM, the normal cycle is to lift the full bin into the refuse collector and to lower an empty bin. As stated by Andersson (2009), operating on a light load gives a higher power loss than operating on a heavy load when load control valves are considered. This is due to the p_L (Equations (2) and (3)) which is smaller on light loads which leads to a higher pilot pressure demand. Unfortunately the load control setting p_s in Equations (2) and (3) has to be set according to the highest load that can be lifted with binlift (except non-load-reactive and lock type load control valves) because the load control valve also has a hose burst function. This is what makes the NTM case difficult and energy-consuming. Energy savings are wanted especially because NTM has hybrid vehicles in production and the saved energy on the bin lifts could help to downsize the hybrid battery. (Storås 2015) Another fact that further complicates things is that the rear and front loader binlifts have two cylinders, one on both sides of the compactor. This makes it hard to use certain types of valves as they would need special arrangements to ensure that the both sides work simultaneously. These types of valves are, for example, the lock type load control valves. There are three ways to get these working simultaneously and they are presented in Figures 34, 35 and 36. If none of these arrangements is used, the binlift will lower one side before the other and this might twist the metal structure.

The most used load control valves at the beginning of the project at NTM were the Eaton 1CE30 series with valves 1CE30N16S5 and 1CE30N27S5. They are standard overcentervalves with the fixed pressure settings of 160 and 270 bar. In addition to these valves, also Eaton 1CE30N23S5, Eaton 1CER30F35S2.5 and Sun CWEA-LHN are used. The 1CE30N23S5 is similar to the previous Eatons but with a 230 bar setting. The 1CER30F35S2.5 is a partly balanced adjustable overcenter valve and used if there is a scale on the binlift as it has less oscillations. The CWEA-LHN is a fully balanced overcenter valve and it is used in longer booms which are more unstable. There is also the VBSO-DE-NN double overcenter valve from Bosch Rexroth which is used very rarely. (Liimatainen 2015) This so called dual counterbalance valve with its own housing is not discussed in this thesis.

At NTM products, cartridges are in use when load control valves are considered. There are undisputed advantages that cartridges provide: “Cartridge valves offer the same control as traditional hydraulic valves but are generally smaller, lighter and more tolerant of vibration and fluid contamination.” (Lodemeier & Ashmore 2011 p. 1) “With the ability to be mounted straight into machined manifolds that internally connect the valves rather than external piping as in the case of traditional valves, these hydraulic integrated circuits (HICs) eliminate unnecessary tubes, hoses and fittings. As each fitting provides two potential leakage points, the basic principles of hydraulic machinery operations are upheld to a higher standard." (Dabholkar & Indulkar 2012) All these facts presented are important to the NTM products. The small size allows a compact installation of cartridges on the cylinders in the way that is seen in Figure 43.

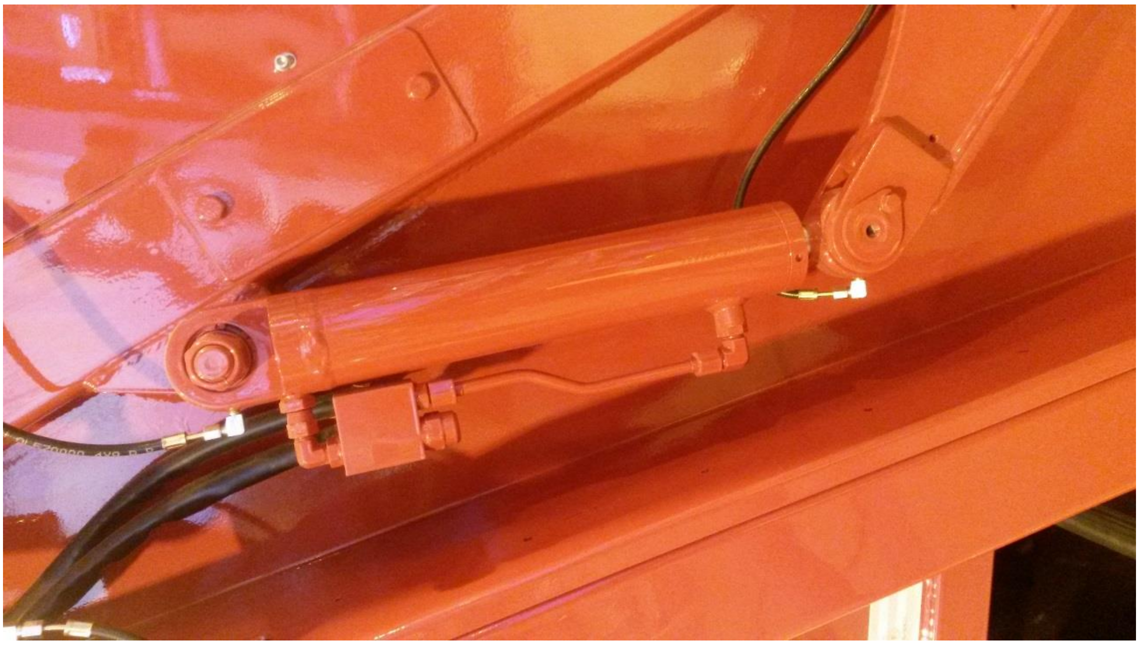

Figure 43: Installation of the cartridge valve on the cylinder

Other structured load control valves would also be available, for example, the so called B family load control valves from Bosch Rexroth and the VOSL/SC/F from Hansa. These would have some benefits, for example, with the valve Bosch Rexroth VBSO-SE, the effect of the back pressure is smaller than with a standard cartridge type overcenter valve. This valve structure has a separated check valve, a pilot operated pressure relief valve and a pilot piston inside a common block. (Load holding / Motion control s.a.; Lodemeier & Ashmore 2011; Overcenter valves index s.a.) However, these types of valves are too big for mounting on the cylinders at NTM. The cartridge type valve is suitable because then the housing can be self-designed to fit the cylinder perfectly.

4.2 Load sensing system on oscillations

Most NTM products have a load sensing (LS) pump installed. The ones that do not have the LS pump have a fixed pump with the LS function in the inlet section of the main directional control valve Parker VPL. This means that the excess flow goes to the tank when the pump pressure is higher than the LS pressure. Also the engine revolutions per minute (rpm) are lowered when no function is used. Most functions in NTM products are pressure-compensated prior to the directional control valve spool. (Storås 2015)

According to Eriksson (2010), LS systems are poorly damped. The damping is especially poor if pressure compensators are used. Damping from a valve is obtained by degreasing the flow when the load pressure is increasing and vice versa. In pressure compensated LS systems, the primary principle is to achieve as low as possible influence on the flow by the load pressure. This is the reason why the pressure compensated LS systems are poorly damped and at specific points of operation they can display oscillatory behavior. (Eriksson 2010; Axin 2013) According to Paavilainen (et al. 2007), the LS systems are more sensitive to oscillations than the traditional hydraulic systems and oscillations during drive are typical of the LS systems due to the load pressure feedback.

4.3 Standardization for binlift hydraulics

Standard SS-EN 1501-5:2011 (E) part 5.5 specifies: ”The hydraulic waste container lifting device shall be equipped with safety devices for hose burst protection (e.g. hydraulic restraint valves mounted directly on the lifting cylinders) or with other devices to prevent unintended lowering. They shall be rigidly hydraulically connected onto the lifting cylinder(s) and, if fitted, onto the lifting carriage cylinders(s).” In other words it is enough to have hose burst valves on the binlift and load control valves are not necessary. Although hose burst valves would be enough, it is not desirable to use them as their functionality is viscous-dependent. The products of NTM are used in various temperatures and the viscosity varies because of that.

Standard SS-EN 1501-5:2011 (E) part 5.1.1.8 specifies: “The minimum waste container emptying cycle time, excluding the horizontal extension movement and dwell time, shall be 6 s for designated waste containers with a capacity up to 400 l, 10 s for designated waste containers with a capacity up to 1700 l and 20 s for other waste containers.” In addition to this, the allowed peripheral speed of the waste container is also limited by the standard. As NTM mostly sells binlifts with a capacity between 400 l and 1700 l, the cycle time is limited in production by limiting the movement of the directional control valve spool.

4.4 New load control alternatives

There are various cartridge load control valve manufacturers and valve alternatives. Manufacturers are, for example, Eaton (old Integrated hydraulics), Sun Hydraulics, Bosch Rexroth / Fluid control, Parker, Hawe, Atlantic Fluid Tech, G. Fluid, Argo Hytos and Tucson Hydrocontrols. The selection of the new valve is a combination of many factors. Oscillations, size, energy consumption, delivery time and price should be as low as possible. There should not come new hoses from the valve selection but still the valve should be as reliable as possible. This is what makes atmospherically vented and four ported models hard to use in NTM products. At the same time, with all the previous requirements, it would be a great benefit if the new valve would fit into the old cavity so that there would be no need to change the block. Also the installation of the assembly should be as easy and fast as possible.

If the binlift control levers are changed from hydraulic to electrical in the future, it could also be considered that the on-off valves are installed on the bottom of the binlift cylinders to replace both load control and hose burst valves. These normally closed on-off valves should be check valve types and they would operate on electrical signals from the levers as in Figure 44. Comatrol SVP10-NCR is one example of this valve type. (2-Way Poppet SVP10-NCR 2015) They would open only when movement downwards is wanted and opening would happen immediately when the lever is moved. These valves demand a closed center spool on the directional control valve because with an open center (floating) spool there could be problems with the downwards over running load when the valves are suddenly opening and the hoses between the valves and the directional control valve have been drained into the tank. With closed center spools, pressure could build up because of changes in temperature and there might be pressure peaks from the sudden stop of the movement. High pressures could also be avoided with work port pressure reliefs on the directional control valve but they are not able to limit all pressure peaks between the cylinders and the on-off valves. Similar setup is also introduced by Nachtwey (2007). In Nachtwey`s design, the on-off valve is not a check valve type and this demands the coil to be energized also when lifting the load.

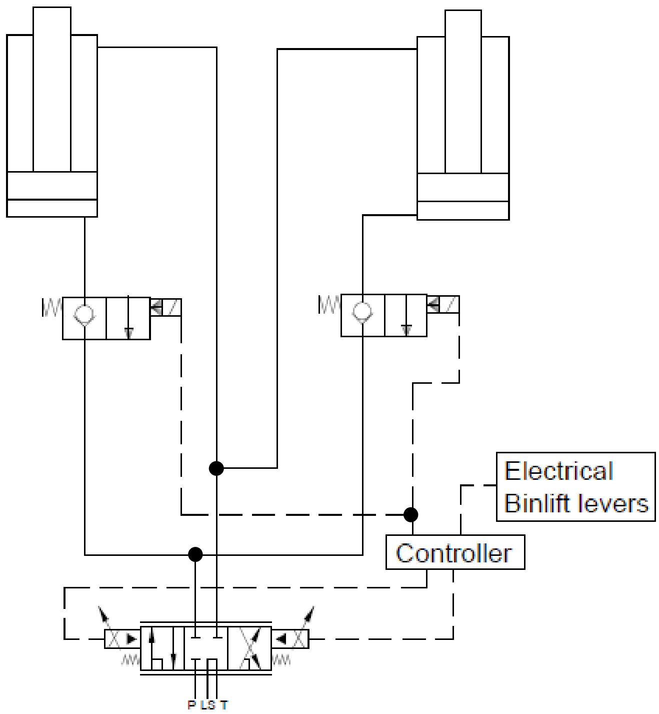

Figure 44: A binlift with electrical control levers and electrically operated check valves

If the assembly in Figure 44 is causing too high pressure peaks, the electrically operated pressure relief valves with a tank port that can be pressurized would be a good option in the assembly as in Figure 45. Hydac PDB08PZ-08 is one example of this valve type. This valve requires a check valve connected parallel if it is taken on this application. The valve can also be equipped with an on-off solenoid on demand. (Compact Hydraulics Product Catalogue 2013 p. 532-534) A closed center spool should not be used with these types of valves as it would prevent pressure relief function from working and the operation of the assembly would then be approximately the same as in Figure 44. High pressure could also be avoided with work port reliefs but they are not able to limit all pressure peaks between the cylinder and the pressure relief valve as the back pressure will have an effect on the pressure relief valve setting if the valve is not a vented model. A better option is to take an electrically operated pressure relief valve with a proportional coil and use an open center spool with that as in Figure 45. In the case of the proportional coil, the opening of the pressure relief valves with respect to opening of the directional control spool should be optimized to minimize power consumption and to maximize smooth handling. Basically this means that when going downwards, the pressure relief valve should be more restricting than the directional control spool at the beginning and with faster speeds the pressure relief valve would be fully open and controlling would be done just with the directional control spool.

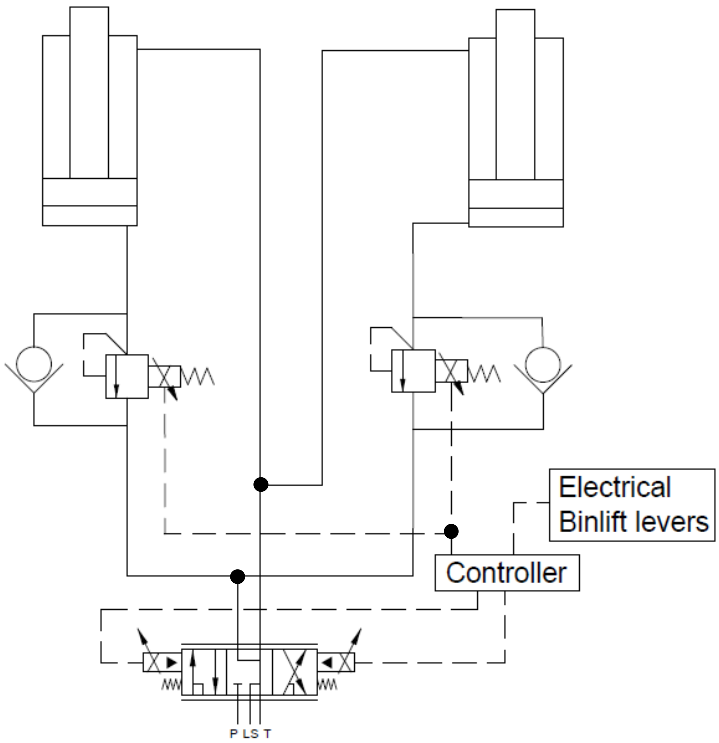

Figure 45: A binlift with electrical control levers and electrically operated pressure relief valves (electrical load control valves)

All in all, the suggestions for assembly with electrical levers would be according to Figures 44 and 45 or 45 with closed center spool if vented pressure relief valves are available and work port pressure reliefs are used. These suggestions should be carefully tested before taking them into production. With electrically operated load control valves, there is no problem with the valve piloted from the inlet side of the cylinder which Andersson (2009) states to be major cause for oscillations. Also Comatrol SVP10-NCR and Hydac PDB08PZ-08 do not have a tight sealing which is stated by Handroos et al. (1993) to be major cause for oscillations.

5. HYDRAULIC MEASUREMENTS OF BINLIFTS

5.1 Measurement equipment

Parker Service Master Plus SCM-500-01-01 was the hardware of the measurements. This device operates very well with CAN sensors. Pressure and flow were measured with the help of this device. The pressure sensors used were Parker SCPT-400-C2-05 (maximum 400 bar). They are equipped with temperature sensors. The flow meter was the turbine type Parker SCFT-150-02-02 (maximum 150 lpm). The used software was Parker SensoWin. All accuracies of the equipment are seen on a Table 1.

Table 1: Accuracy of equipment used in measurements

	Accuracy from full scale (%)	Accuracy from indicated reading (%)	Temperature dependent accuracy (% / °C)	Time dependent accuracy (% / year)
Parker Service Master Plus	± 0.25	-	± 0.02	-
Parker SCPT-400-C2-05	± 0.50	-	-	± 0.20
Parker SCFT-150-02-02	± 0.15 (flow < 22.5 lpm)	± 1.00 (flow > 22.5 lpm)	-	-
Wika CPH6200	± 0.20	-	-	-

The Service Master Plus has an accuracy of ± 0.25 % from full scale which means ± 1.0 bar for pressure sensor and ± 0.375 lpm for flow turbine. In addition to this, there is an accuracy of ± 0.02 % / °C from full scale. Temperature errors are not considered in this thesis as temperatures are relatively constant in the measurements that are compared with each other. The accuracy of the pressure sensor SCPT-400-C2-05 is ± 0.5 % plus 0.2 % / year from full scale. Response time for pressure sensors is 1 ms. Accuracy for flow turbine SCFT-150-02-02 is ± 1 % from indicated reading, however it is always at least ± 0.225 lpm. Basically this means that flows below 22.5 lpm have an accuracy of ± 0.15 % from full scale which is ±0.225 lpm. Flows over 22.5 lpm have an accuracy of ± 1.0 % from indicated reading. When energy calculations are considered, they are driven with full 40 lpm speed. In this case, the accuracy of the flow turbine is ± 0.4 lpm which is ± 0.26 % from full scale. Response time of the flow turbine is 50 ms and this means that all oscillations are not visible in the flow graphs. (SensoControl® 2013)

There is a Wika CPH6200 hand-held pressure indicator with an accuracy of ± 0.2 % from full scale at NTM. This pressure indicator is calibrated every year and it is used for checking the accuracy of other pressure sensors. The Wika indicator was also used to check SCPT-400-C2-05 pressure sensors that were used in this thesis. As this checking was done during this thesis, the total accuracy of the pressure sensors in the measurements is ± 0.5 % from full scale. This means ± 2 bar with these sensors. According to the CPH6200, it seems that these sensors are more accurate than the manufacturer states. More realistic value with these four sensors combined with the error from the Service Master Plus would be ± 0.3 % from full scale. This means ± 1.2 bar with these sensors. This value is used in Appendix C calculations.

5.2 Measuring and adjusting of overcenter valves

Parker PCCM600S was used according to Figure 46 as a two-way flow control valve when measuring and adjusting the opening pressures of the load control valves. According to Eaton, there are 5 liters per minute flow used for adjusting the pressure settings of the valves and this flow is adjusted with the knob that is on PCCM600S.

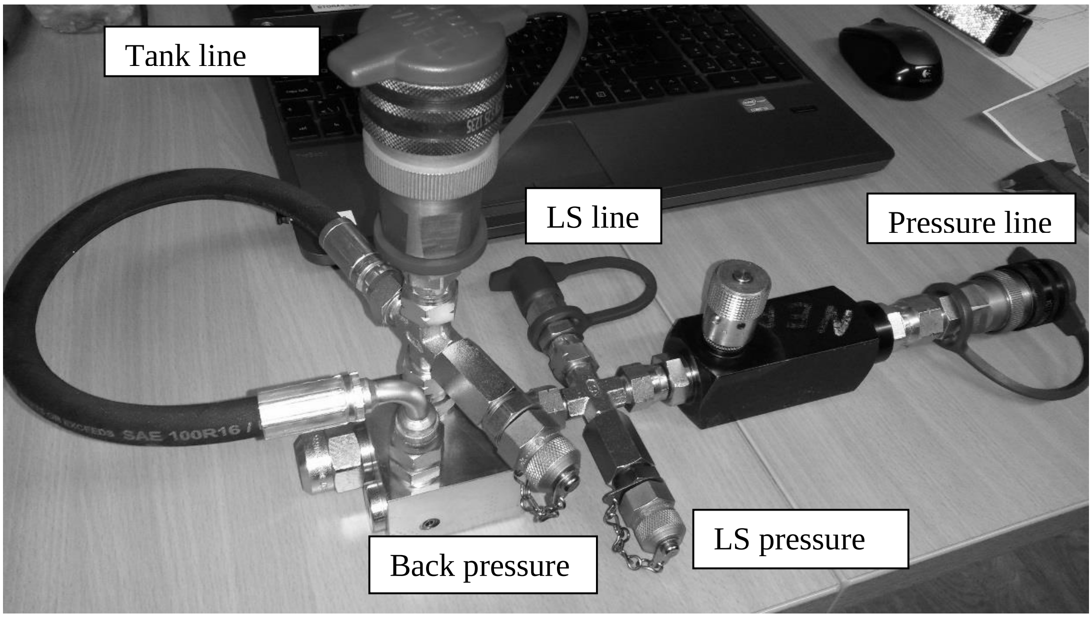

Figure 46: The adjusting assembly for load control valves

In Figure 46, the smaller female quick coupling on the right side is for the pressure line hose and the bigger female quick coupling is for the tank line hose. The male quick coupling is for the load sensing (LS) line hose. There are two measuring points in Figure 46: The one that shows the LS pressure which is at the same time the load pressure of the load control valve. The other measuring point is for checking the back pressure of the load control valve. The hose in Figure 46 is for draining the pilot to the tank in order to make sure that there is no pilot pressure which could be the case if there were leaks on the valve.

All tested valves were adjusted in 160 bar setting as that is the pressure used in the binlift overcenter valves. The binlift function is restricted to 120 bar in up direction so this pressure setting is valid in most models. Some models also use 230 bar overcenter valves but these were of a lower priority in testing.

The used hydraulic machinery was built for testing and adjusting of the refuse collector directional control valves. The machinery is equipped with a load sensing pump. When testing the directional control valves, the load sensing line will drain through directional control valve spools when all spools in the directional control valve are in center position. This will not happen with built testing assembly. When the load sensing line is not able to drain and no functions are in use, the result with this machinery is a slight increase in the pressure which makes the machinery pressure to rise to the level of the main pressure relief valve setting which is 305 bar in this case. This in itself is not a problem, but the problem will occur when shutting down the machinery while the pressure is still on in the pressure line as it cannot be drained. As the machinery does not have a check valve in the pressure line, it will cause the pump to rotate in the wrong direction for a while when shutting down. This will result in cavitation when the machinery is started next time. To overcome this problem, there was a free flow valve installed in the pressure line of the machinery according to Figure 47. The free flow valve will connect pressure and tank line together when the machinery is shut down. This will prevent the pump from running backwards.

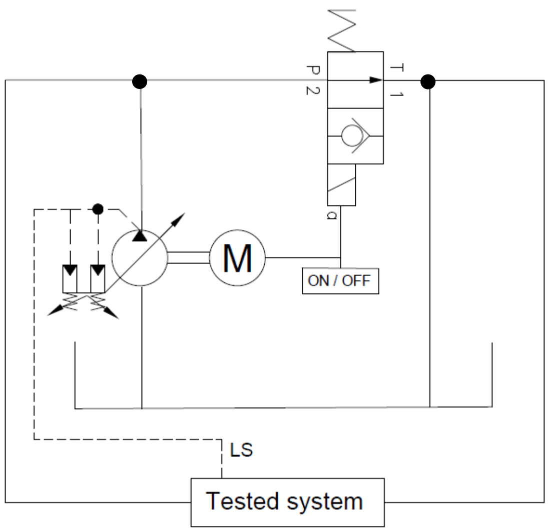

Figure 47: Free flow valve installation of testing machinery

The SF08-21 valve from Hydra Force was used according to Figure 47. A check valve was not installed on the pressure line near the pump because it could make quick couplings connection harder as the check valve would seal the pressure on the pressure line. The hoses in the Figure 47 are going through the floor down to the hydraulic room where the adjustment is made.

5.3 Binlift test weight modifications

The test weight had to be modified because it could not simulate all the bins in its original form. As can be seen in Figure 48, the test weight was originally made only for a comb lifting device.

Figure 48: Test weight before modification

The modifications were done according to SS-EN 840-3:2012 (E) and this means that trunnion lifting was made possible according to Figure 49. According to the worst case scenario, an old Otto 1100 liter roll top bin was selected as a model for the test weight. Nowadays, this brand is ESE and a similar 1100 liter bin is on the market. This bin has the most difficult geometry for lifting as it has the mass center most low and most far away from the binlift. The bin can lift up to 510 kg weight although the standard only demands 440 kg. (1100L DIN LIL s.a.; HISTORICAL MILESTONES s.a.)

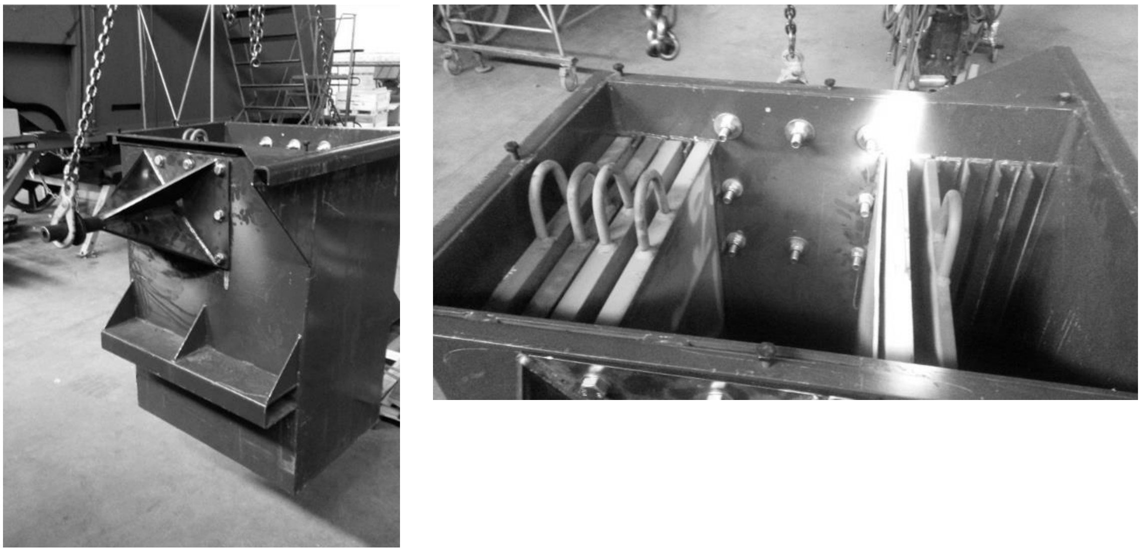

Figure 49: Test weight after modification with total of 850 kg mass

As can be seen in Figure 49, it was possible to set the weights inside in the way that the mass center was coming in the right position which is aligned with the trunnions. This can be noticed when the test weight is hanging in a straight position as in Figure 49. In the Figure, there is a total mass of 850 kg. The design drawings and the assembly picture of the trunnions are in Appendix A. Unfortunately, it was not possible to test real trunnion arms with 850 kg, but the trunnions were also handy with 500 kg mass when balancing the test weight.

5.4 Arrangements for binlift measurements

In Figure 50 can be seen the compactor that was used for testing different combinations of load control valves, sequence valves, directional control valve spools and restrictors in the binlift function. This compactor is NTM KGH-HL which is a really common high rear loader.

Figure 50: The compactor and the testing equipment used in the binlift measurements

The KGH-HL binlift is equipped with 63/32-420 cylinders and 3/8” hoses. The load situation is similar to the left side of Figure 16. The testing equipment and machinery can be seen in Figures 50 and 51. In these Figures, the sensors are attached as they were used in every measurement. These are: a flow sensor in the machinery pressure line, a pressure sensor in the machinery pressure line and a pressure sensor in the directional control valve (Parker VPL) LS connection port. The Parker VPL valve can be seen in Figure 66 with the testing assembly for a single load control valve.

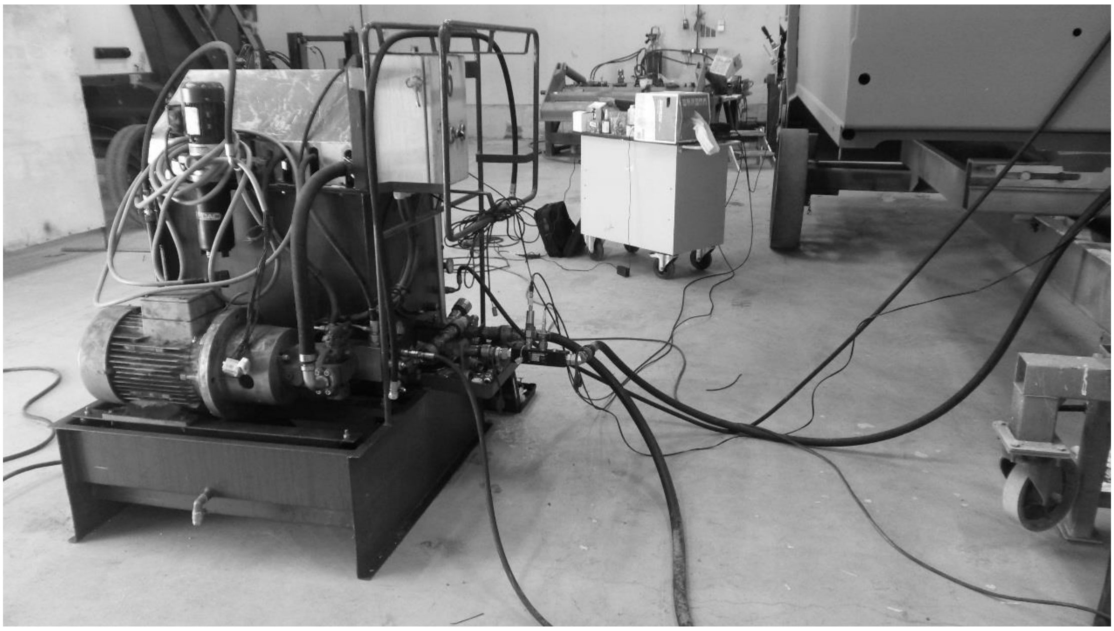

Figure 51: The hydraulic machinery used in binlift measurements

Later on during the tests it was noted that the previous sensors were not enough because the back pressures and the pilot pressures of the load control valves were also needed to be known. In order to get this information, pressure sensors were added according to Figure 52.

Figure 52: Pressure sensors for pilot and back pressures

The sensor on the left side of the Figure 52 is for the pressure in the chamber B of the cylinder which is really close to the pilot pressure of the load control valve; the pressure loss in the short hose is negligible when there is no restrictor installed at the left end of the short hose. The sensor on the right side of the Figure 52 is for the back pressure between the load control valve and the Parker VPL directional control valve.

5.5 Realised binlift measurements

Binlift load control was tested with an empty binlift and with a special cycle. As in a real life situation only the empty bin is lowered, the binlift was also tested with an empty bin. As oscillations are smaller with an empty bin and the cycle cannot be driven repeatedly all the way in both ends with an empty bin, these measurement figures are not included in the thesis. A typical testing cycle which was done to the valves can be seen in Figure 53. The cycle includes three parts which all are started with the binlift in a down position:

1. Four times up-down run with full speed up and slowly down.
2. Two times similar to part 1 but with a small break in the upper position of the binlift to fade away the shakes from hitting the end.
3. Three times up-down run with full speed in both directions.

This testing cycle is driven with an empty binlift which makes it possible to drive pistons all the way in the end in both directions. Later on in the tests, it was noted that it is easier to interpret energy from the data if there is a small stop at both ends. This lead to adding a fourth part which is:

4. Three times up-down run with full speed in both directions but with a small break at both ends.

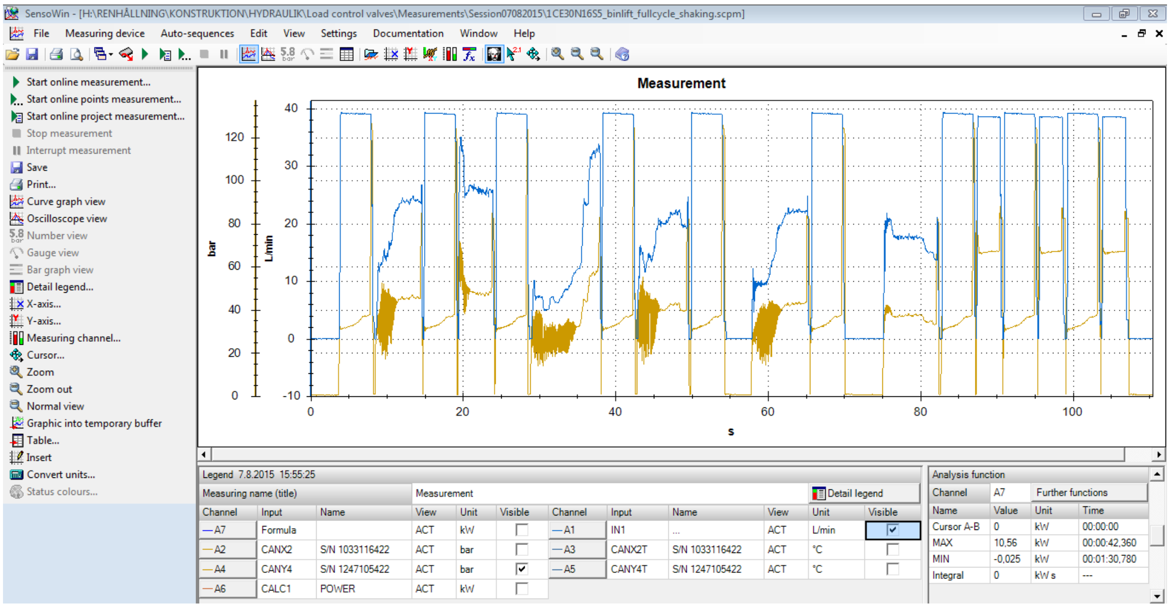

Figure 53: Typical measurement with Parker SensoWin and Eaton 1CE30N16S5

All load control valves and directional control valve spools used in this thesis are listed in Appendix B at the end of this thesis. The Appendix includes technical details. As it is not easy to interpret figures such as 53, the following figures will only contain one up-down cycle from the measurement. This cycle is selected by choosing the worst oscillations including the cycle from the measurement. Note that the compactor used for the measurements still has an unadjusted spool movement of directional control valve, so the maximum speed might be faster than in a real application.

5.5.1 Load control valve - Eaton 1CE30N16S5

Eaton 1CE30N16S5, which was the most used load control valve of NTM products at that time, was naturally tested first. The measurement can be seen in Figure 53. In the Figure, the pump flow is presented with a blue color and the LS pressure with a brown color. From the LS pressure we can interpret that there are big oscillations when slowly lowering the binlift. These oscillations are the biggest in the upper position and they fade away as the binlift moves downwards.

The procedure in Figure 53 presents how oscillations usually show up. In the upper position, the cylinders are as long as they can be and the situation is similar to the left side of Figure 54. According to Andersen et al. (2005), the worst oscillations are in the upper position when the lowering situation is similar to the situation on the left side of Figure

16. This matter is also discussed by Axin (2013). Axin states that when there is a large volume on the outlet side of the cylinder, such as in the situation of the binlift oscillations, the damping becomes low even if the outlet orifice on the directional control spool is designed close to the optimum value. A high damping that could decrease oscillations would be achieved with a large volume on the inlet side of the cylinder and the outlet orifice on the directional control valve spool designed close to the optimum value.

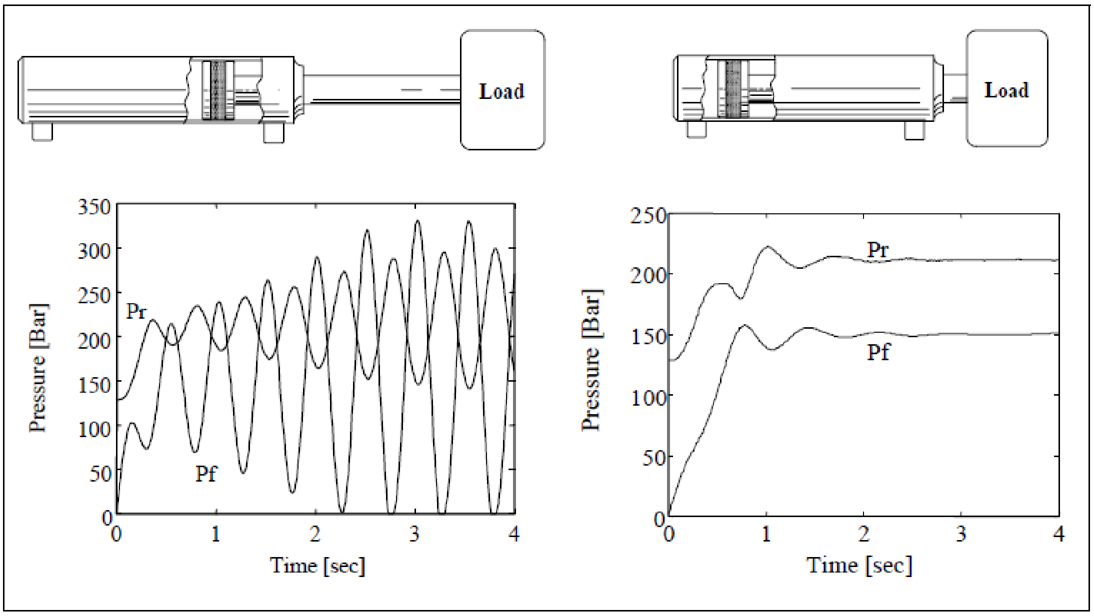

Figure 54: Stability is depending on the piston position (Andersen et al. 2005)

5.5.2 Pilot restrictors in load control valve cartridge blocks

The first attempt to remove oscillations was to install 0.5 mm pilot restrictors in the cartridge blocks according to Figure 55. The restrictors were first tried with Eaton 1CE30N16S5.

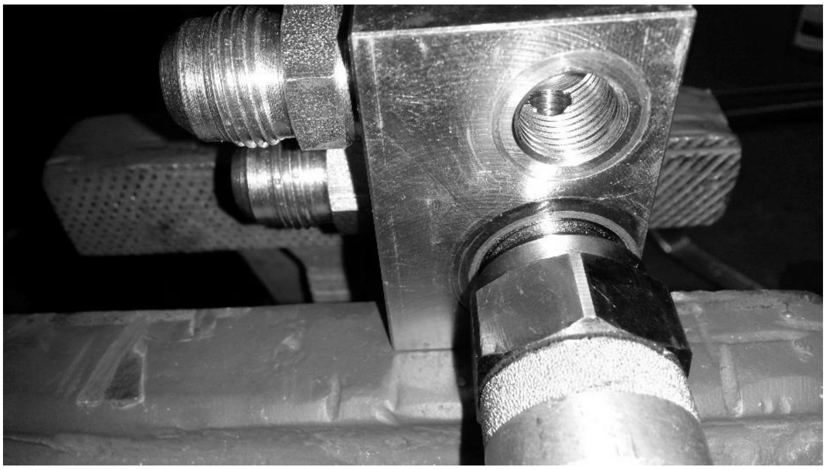

Figure 55: Pilot restrictor thread in cartridge block of load control valve

The restrictor is installed inside the big hole where there is a smaller hole and a thread for a screw-in restrictor according to Figure 55. There was no help from the pilot restrictors on blocks for the oscillations and this can be seen in Figure 56.

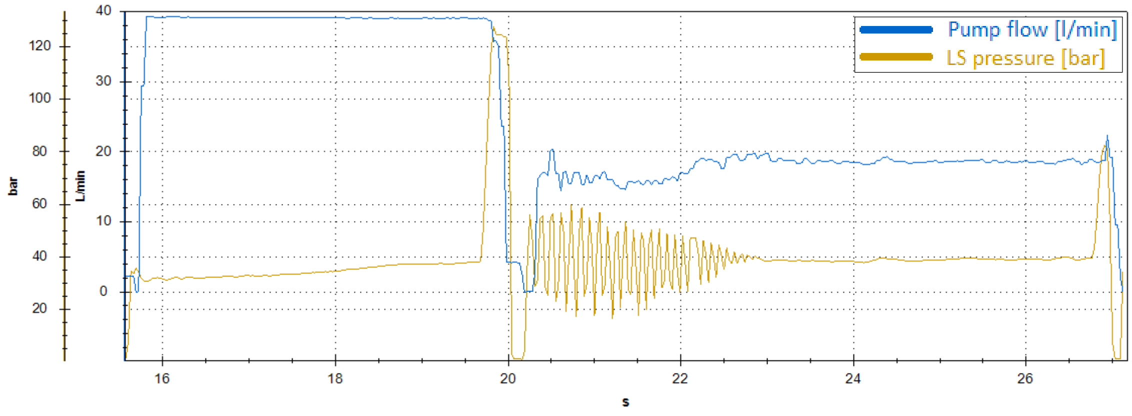

Figure 56: Oscillations with Eaton 1CE30N16S5 and the 0.5 mm pilot restrictors on the blocks

Figure 56 has a binlift run up from 16 s to 20 s and a binlift run down from 20 s to 27 s. The following figures will be with similar runs. The 0.5 mm restrictors as well as 0.3 mm were also tried with fully balanced Eaton 1CEB30F35S5 with a 160 bar setting. The one with 0.5 mm had a bit smaller oscillations according to Figure 57. Although the pressure oscillation amplitude seems to be a lot of smaller in Figure 57 than in Figures 56 and 58, in real life, the difference was not that big; the binlift was bouncing too much in every case. The small differences could also depend on human made errors as the binlift is driven down from a handle and the speed is fluctuating as can be seen from the flows.

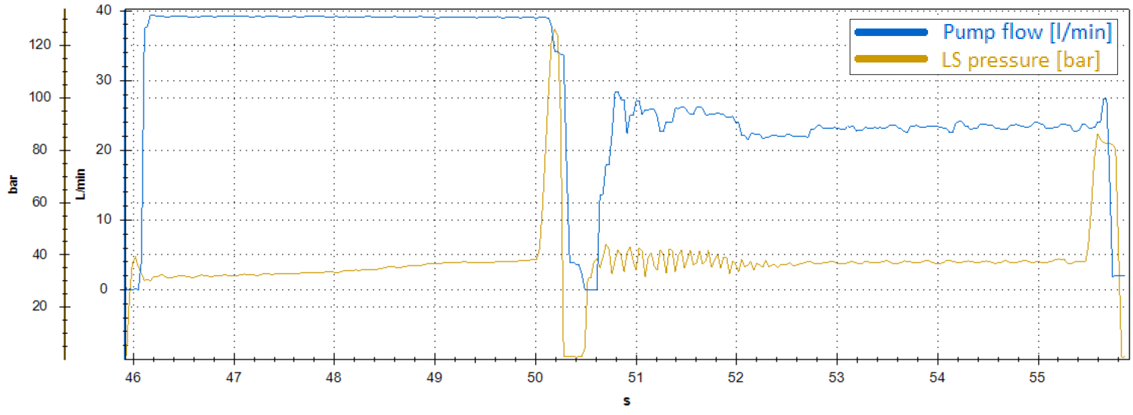

Figure 57: Oscillations with Eaton 1CEB30F35S5 and the 0.5 mm pilot restrictors on the blocks

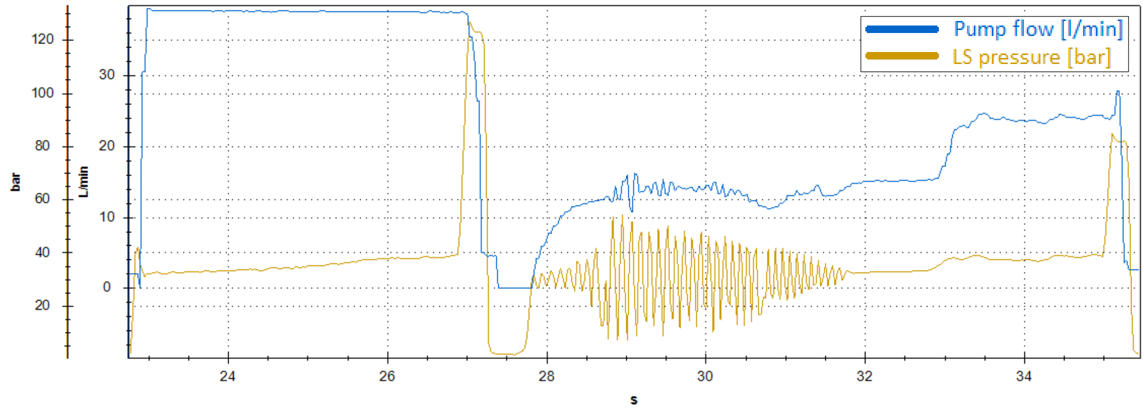

Figure 58: Oscillations with Eaton 1CEB30F35S5 and the 0.3 mm pilot restrictors on the blocks

5.5.3 Load control valve - Eaton 1CEL30F20S150-x

The valve to be tried after the pilot restrictors was the two-stage overcenter valve Eaton 1CEL30F20S150-x where x presents various pressure settings. The optimum pressure setting was 32 bar with no shakings and the smallest energy consumption according to Figure 59 and Appendix C. With the smaller settings there were oscillations and with the higher setting the energy consumption was higher. When lowering the 500 kg weight, there were similar oscillations as in Figure 93.

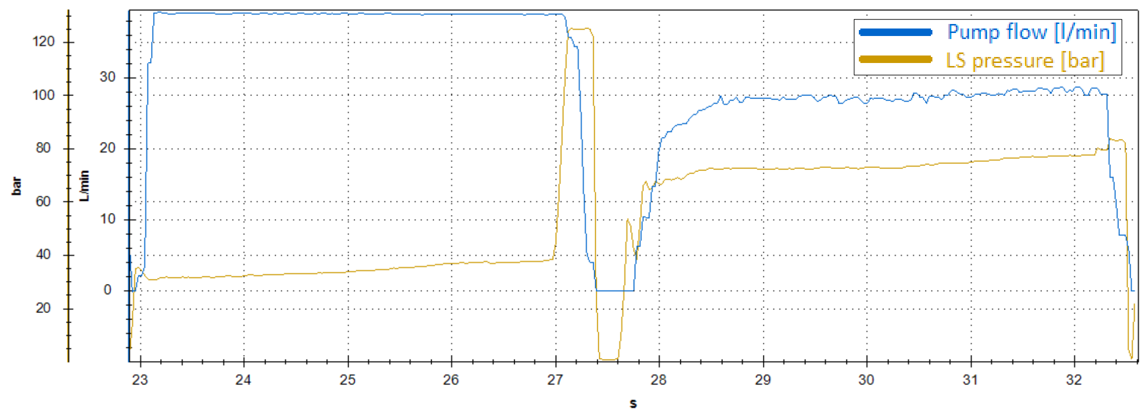

Figure 59: No oscillations with Eaton 1CEL30F20S150-32 and empty binlift

This valve could still be optimized further. For example, outer spring with a setting of 125 bar and inner spring with a setting of 35 bar could be tried. The only problem is that the manufacturer does not make this valve with looser main springs than the 150 bar that was tried.

5.5.4 Load control valve - Eaton 1CE30N16S25

Eaton 1CE30N16S25, which is with 2.5:1 pilot ratio but otherwise the same as 1CE30N16S5, was tested even though it was well known that it requires more energy than the 1CE30N16S5. There were only very small oscillations with this valve according to Figure 60.

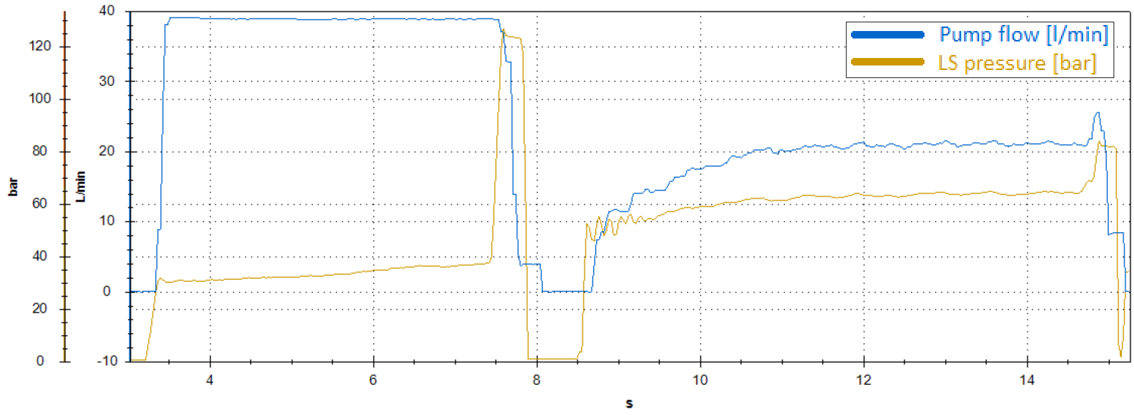

Figure 60: Very small oscillations with Eaton 1CE30N16S25 and empty binlift

Although the valve was acting almost without oscillations with an empty binlift, there were bigger oscillations in lowering when the 500 kg weight was applied on the binlift. These oscillations were similar to those in Figure 93. These oscillations would not be a big problem as normally the bin is not lowered with a load.

5.5.5 Load control valves - Eaton 1CER30F35S2 and 1CER30F35S4

Eaton 1CER30F35S2, which is a partly balanced overcenter valve with 2.5:1 pilot ratio, was also adjusted to 160 bar setting in these tests so that it would be easy to compare it with the 1CE30N16S5 valve that is used nowadays. There were no oscillations with this valve according to Figure 61, but there were also some oscillations in lowering when the 500 kg weight was applied on the binlift. These oscillations were similar to those in Figure 93.

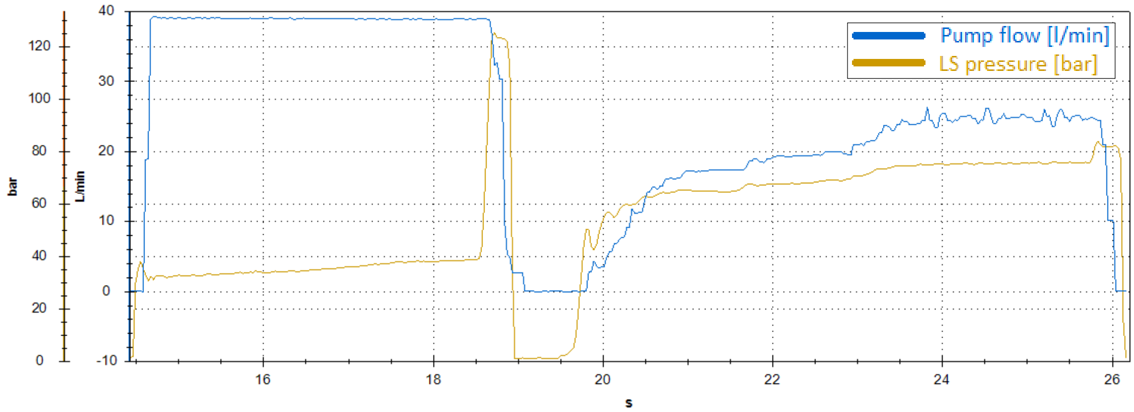

Figure 61: No oscillations with Eaton 1CER30F35S2 and empty binlift

A partly balanced valve with pilot ratio 4:1 was also tested. First, the test was run without any restrictors and then equipped with 0.3 mm and 0.5 mm restrictors on blocks according to Figures 62, 63 and 64. For some reason it was hard to make the shakes visible in a typical test cycle with a 0.5 mm restrictor of a diameter so a special cycle had to be driven after the typical test cycle. There were oscillations in every case with the Eaton 1CER30F35S4.

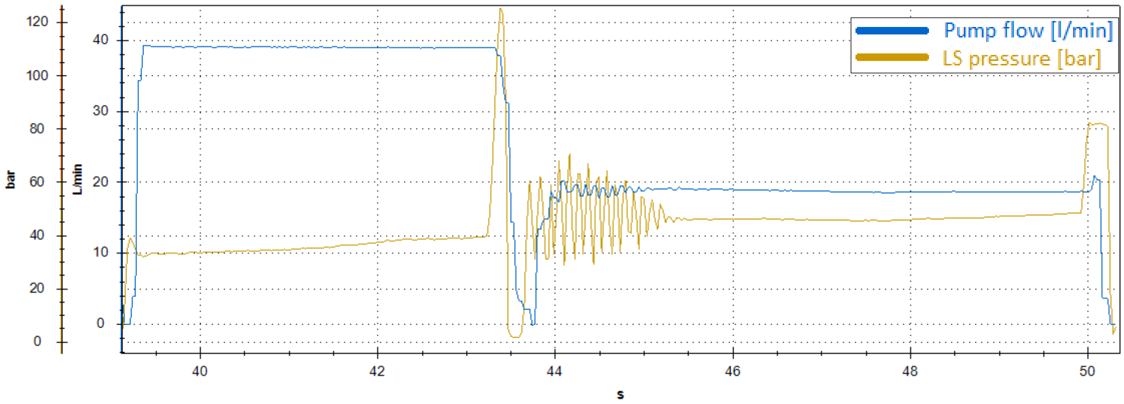

Figure 62: Oscillations with Eaton 1CER30F35S4 without pilot restrictors

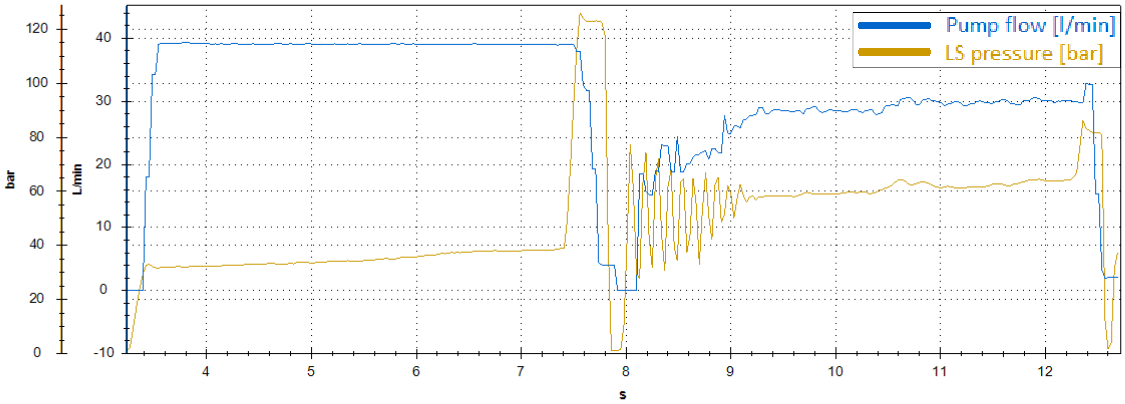

Figure 63: Oscillations with Eaton 1CER30F35S4 and the 0.3 mm pilot restrictors of a diameter on the blocks

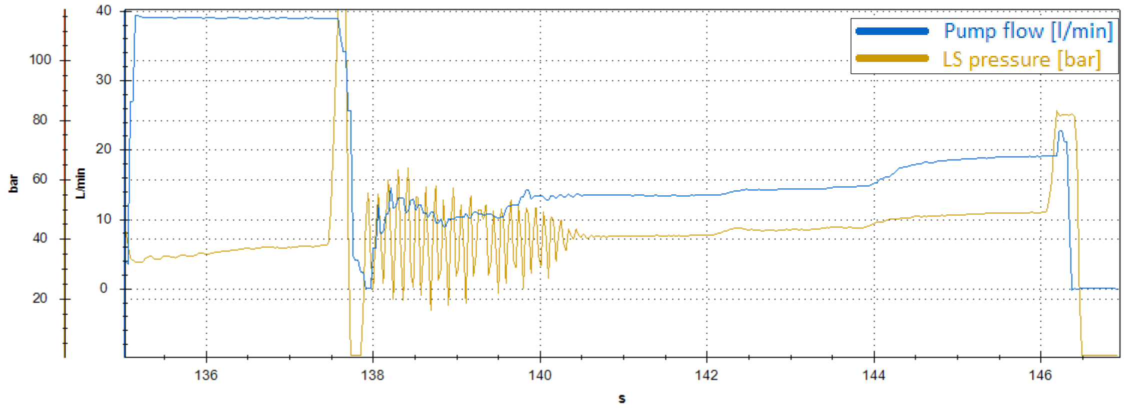

Figure 64: Oscillations with Eaton 1CER30F35S4 and the 0.5 mm pilot restrictors of a diameter on the blocks; the Figure is not from typical test cycle

5.5.6 Load control valve - Sun LoadMatch MBDPDHN

Sun LoadMatch MBDPDHN was tested and it was noted that it had also some oscillations according to Figure 65. The oscillations became really bad with this valve when the 500 kg test weight was applied on the binlift according to Figure 95.

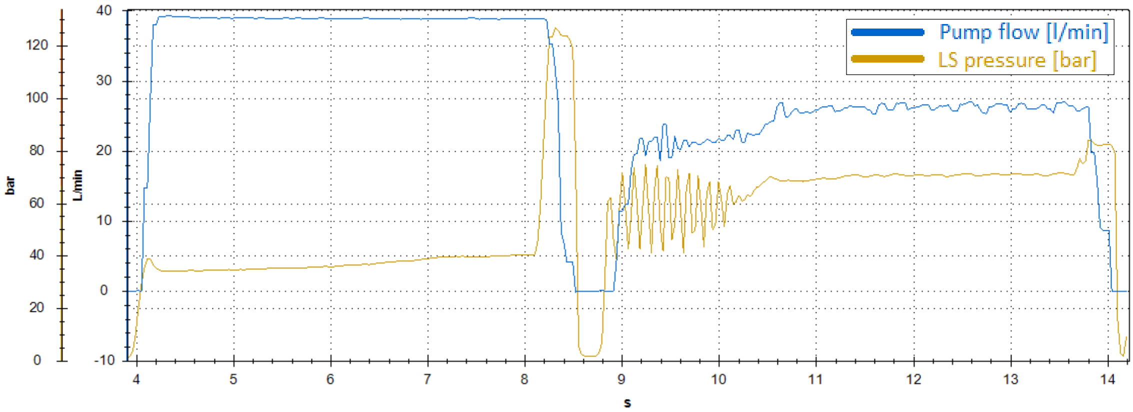

Figure 65: Oscillations with Sun LoadMatch MBDPDHN

A single Sun LoadMatch MBDPDHN was tried to be installed according to Figure 66 as a possible cure for the shakes. The load control valves were taken away from the cylinders in this installation.

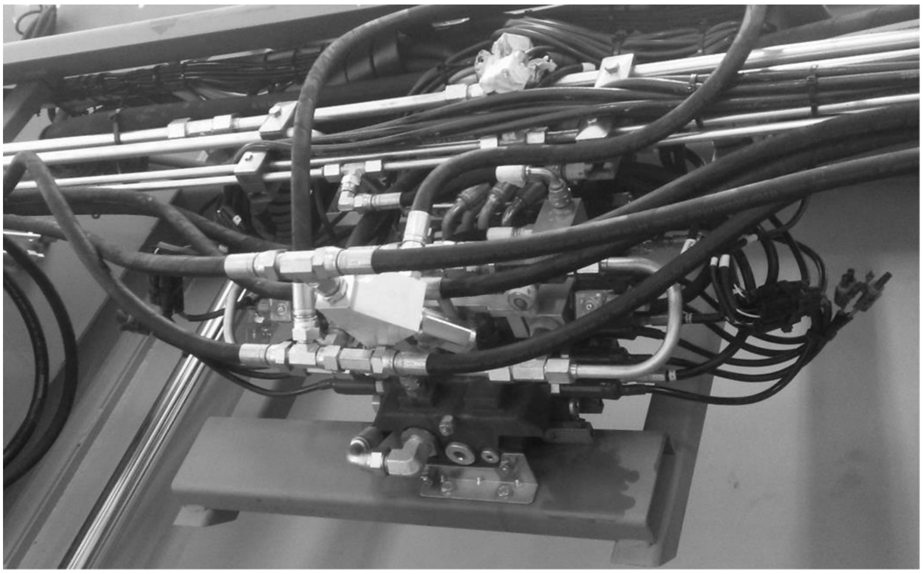

Figure 66: Single Sun LoadMatch MBDPDHN installed on a directional control valve Parker VPL

As can be seen in Figure 67, there was no crucial help on the shakes from switching to a single MBDPDHN. The energy consumption for the dual connection was 36.4 kWs and that is high when compared to the values in Appendix C. According to Polarteknik, which is a representative of the manufacturer, this valve is designed for over 140 bar pressure levels and this could be the reason why it is not working smoothly and no energy is saved with tested pressure levels (Lampinen 2015).

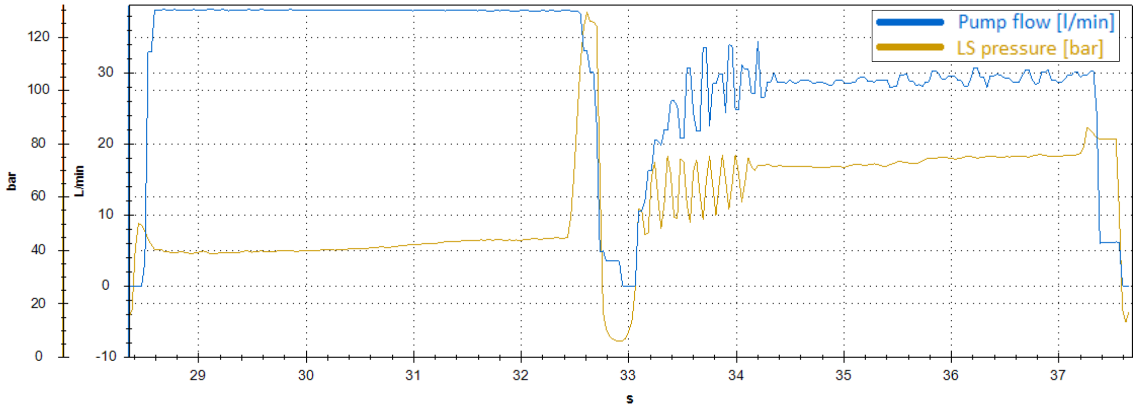

Figure 67: Oscillations with single Sun LoadMatch MBDPDHN

It was needed that the pilot restrictors were also tested with single load control valves. The installation of the restrictor was easy to make in a hose assembly. The restrictor was installed on a hose that was before the pilot port. This means that there were about 400 mm of ¼” hose between the restrictor and the pilot port. Figure 68 presents the result with the single Sun LoadMatch MBDPDHN and a 0.4 mm restrictor of a diameter on the pilot hose. It was noted that the restrictor in a hose shortened the oscillation time. The hose seems to work as a small accumulator and this helps the load control valves to settle down. Theoretical point of this fact is discussed by Zähe (1995 p. 71). The capacitance of the line between the restrictor and the load control valve is affecting the behavior and oscillations of the valve. As a drawback Zähe states that the response time will become longer with the restrictors.

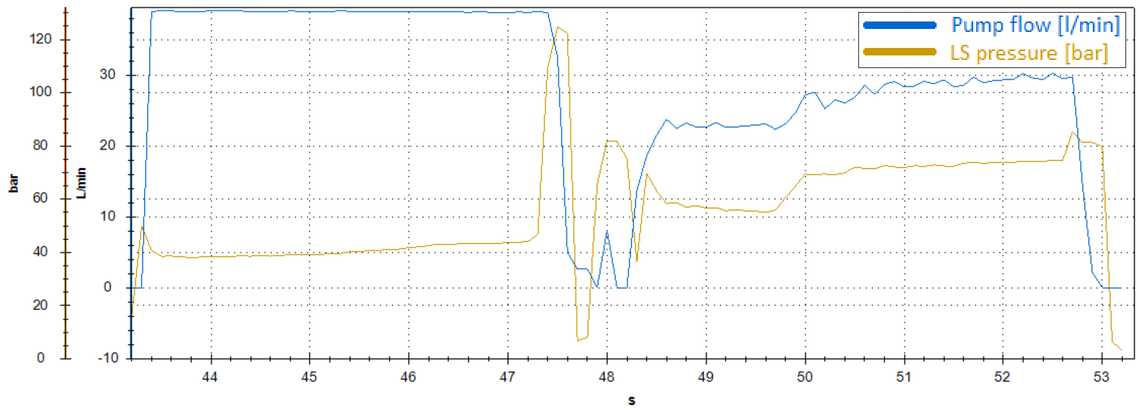

Figure 68: Oscillations with single Sun LoadMatch MBDPDHN and the 0.4 mm pilot restrictor on the hose; sample rate of the measurement 100 ms instead of typical 30 ms

5.5.7 Pilot restrictors on load control valve pilot hoses

Also Eaton 1CE30N16S5, 1CER30F35S4 and 1CEB30F35S5 were tested (160 bar setting with every cartridge) as single but they were not acting any better than with a regular dual installation. In addition to this, if only a single load control valve was used, the hose burst valve function would be missing from the assembly. This means that separate hose burst valves should be added. For the sake of these facts, it was decided to move on and test these valves with a dual installation and restrictors on the pilot hoses as that installation had a reducing effect on the oscillations.

Eaton 1CE30N16S5 was tested with 0.5 mm and 0.3 mm pilot restrictors of a diameter on the pilot hoses. The measurements are shown in Figures 69 and 70. Although different speeds are driven in the Figures and thus it is complicated to compare them, it was clear that with 0.3 mm restrictors the oscillations were not that big and long lasting as with 0.5 mm restrictors. As a drawback, the binlift responded to lever movements more slowly than the smaller the restrictor.

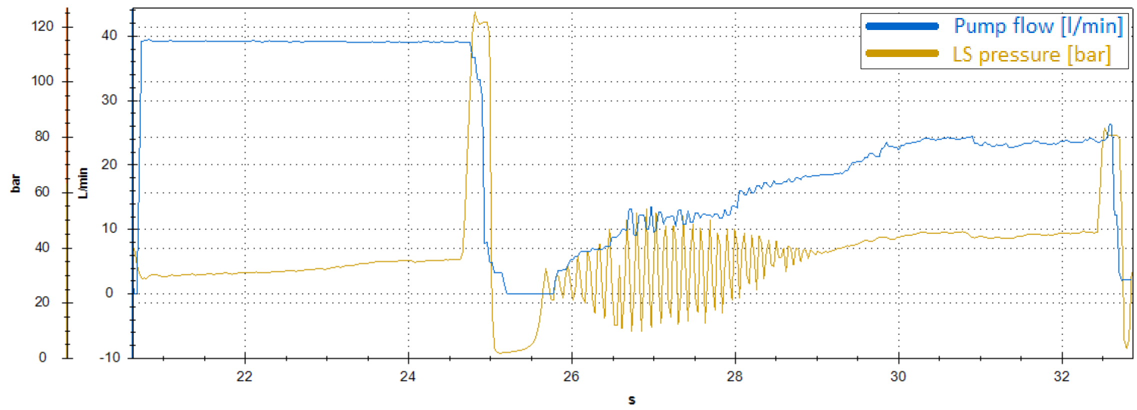

Figure 69: Oscillations with Eaton 1CE30N16S5 and the 0.5 mm pilot restrictors on the hoses

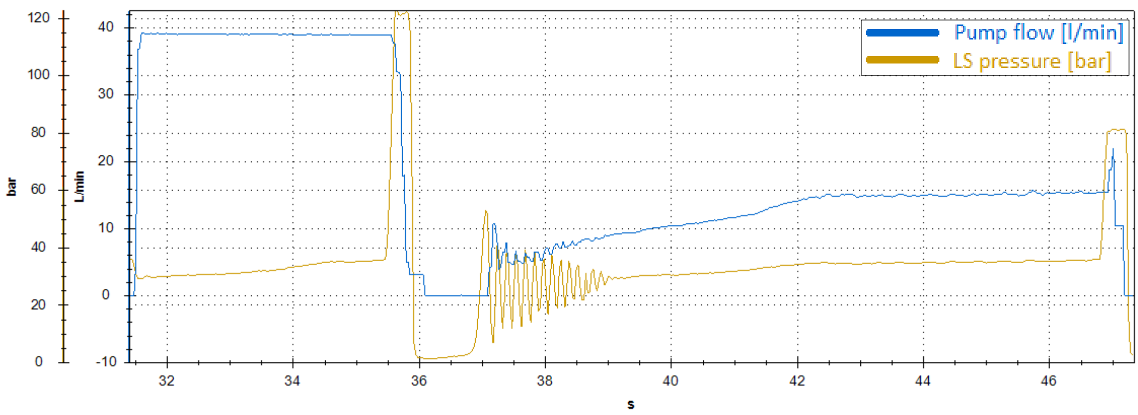

Figure 70: Oscillations with Eaton 1CE30N16S5 and the 0.3 mm pilot restrictors on the hoses

Eaton 1CEB30F35S5 with 160 bar setting was tested with 0.5 mm and 0.3 mm pilot restrictors on the pilot hoses. The measurements are shown in Figures 71 and 72.

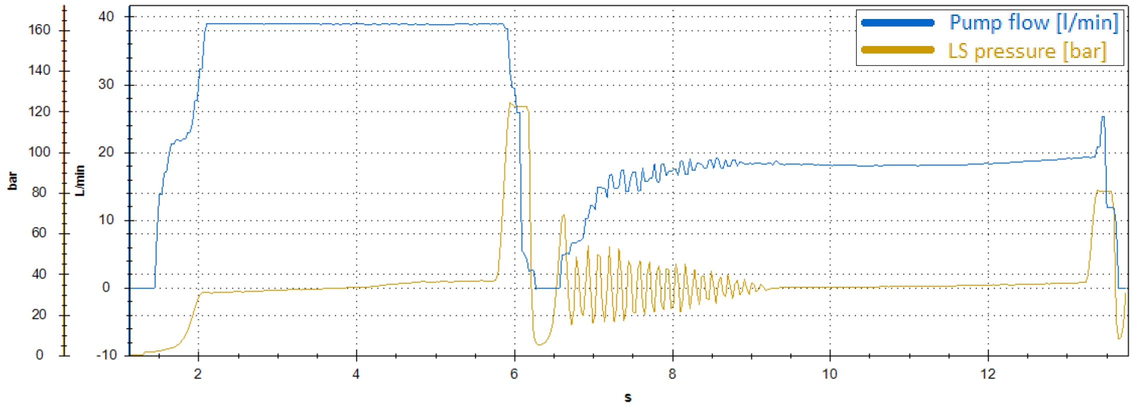

Figure 71: Oscillations with Eaton 1CEB30F35S5 and the 0.5 mm pilot restrictors on the hoses

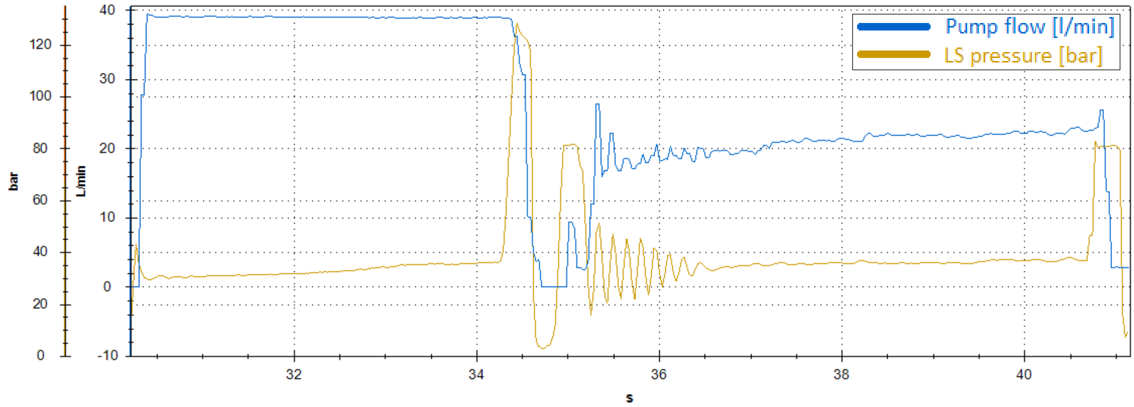

Figure 72: Oscillations with Eaton 1CEB30F35S5 and the 0.3 mm pilot restrictors on the hoses

The speeds in the Figures are quite similar so it is easy to compare the results. It is clear that with 0.3 mm restrictors the oscillations are not that long lasting as with 0.5 mm restrictors. As the restrictors make the binlift slow to respond to lever movements and thus not so user friendly, this kind of solutions cannot be taken to production. Another problem with the restrictors is that they are very viscous dependent and thus there might be problems with functionality with hot or cold oil.

5.5.8 Load control valve - Sun CBBGLJN

Sun CBBGLJN with 160 bar setting was tested and the results can be seen in Figure 73. This valve had really stable operation without oscillations but as a drawback the energy consumption was also very high according to the Appendix C. With the 500 kg load on the binlift there were some small oscillations but they were tolerable.

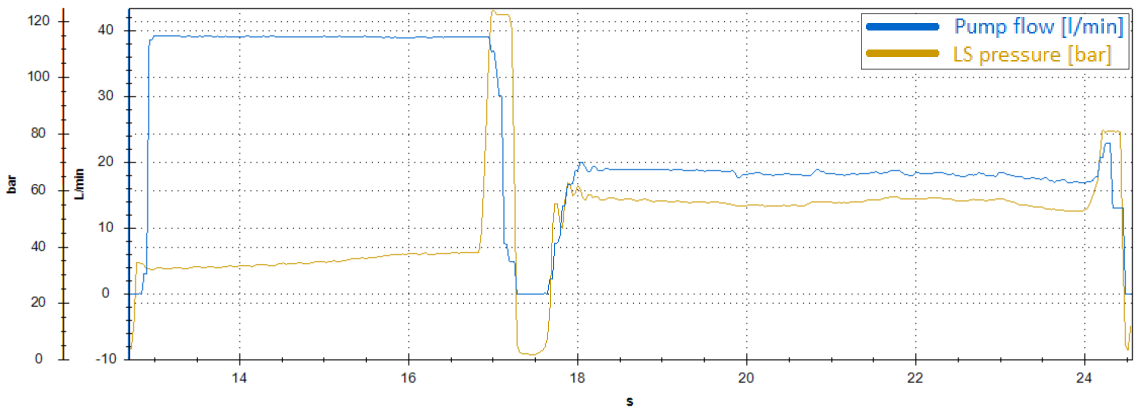

Figure 73: No oscillations with Sun CBBGLJN

This valve is so called restrictive valve and rated only for 20 lpm flow. These are the main reasons for higher energy consumption. The flow per valve does not go over 20 lpm as there are two valves dividing the flow. This can be seen in Figure 73.

5.5.9 Operating without load control valve

When running the tests it was noted that the Parker VPL spool 424 acts very well as a load controller without a specific load control valve. The measurement can be seen in Figure 74.

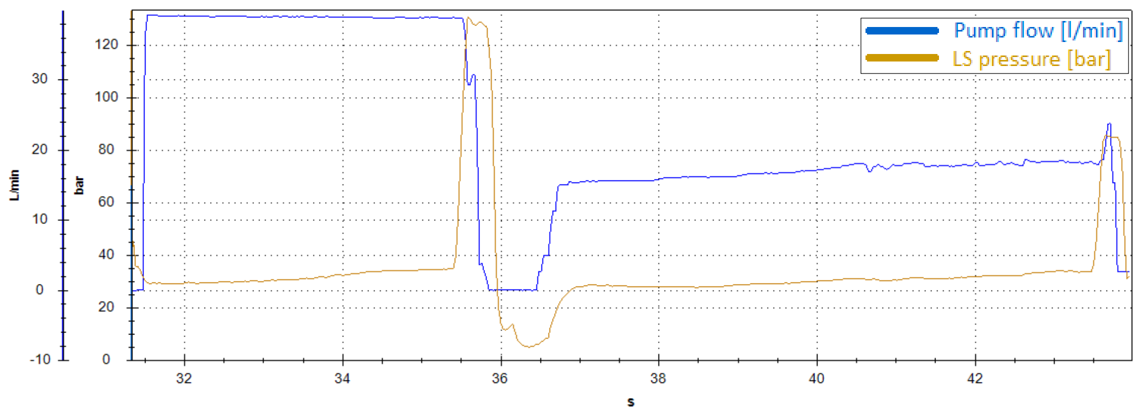

Figure 74: No oscillations when operating with spool 424 without load control valves

The movements are really stable both up and down. This is because the valve is pressure compensated which provides a constant flow regardless of the load pressure, pump pressure, or any other load in the system. The spool VPL424 is a spool with rated 40 liters per minute flow and closed center position. The VPL524 spool was also tested and it was as easy to handle as the VPL424. The difference between these spools is that the VPL524 is rated for 65 liters per minute flow. (Load Sense, Pressure Comp. 2015) The energy consumption is really good with both spools according to the Appendix C. With the 500 kg load on the binlift there were no oscillations either. The only problem with this type of load controlling is a slightly decreasing load when starting the movement upwards.

This is caused by the load sensing system, which functions a bit slowly in variations as the system has some flexibility. This nodding (micro-sinking) can be eliminated with a similar load sensing signal copy spool that the Parker L90LS directional control valve has. (L90LS Mobile Directional Control Valve s.a. p. 4 + 16) If the load is controlled this way only with a proportional directional control valve then hose burst valves are needed.

5.5.10 Load control valve - Sun LoadAdaptive CEBCLHN

Sun LoadAdaptive CEBCLHN had no oscillations in tests according to Figure 75. This valve should be energy saving but with these low load pressures it is not working as it should. Thus the energy consumption is quite high, almost as high as with 1CER30F35S2 according to Appendix C.

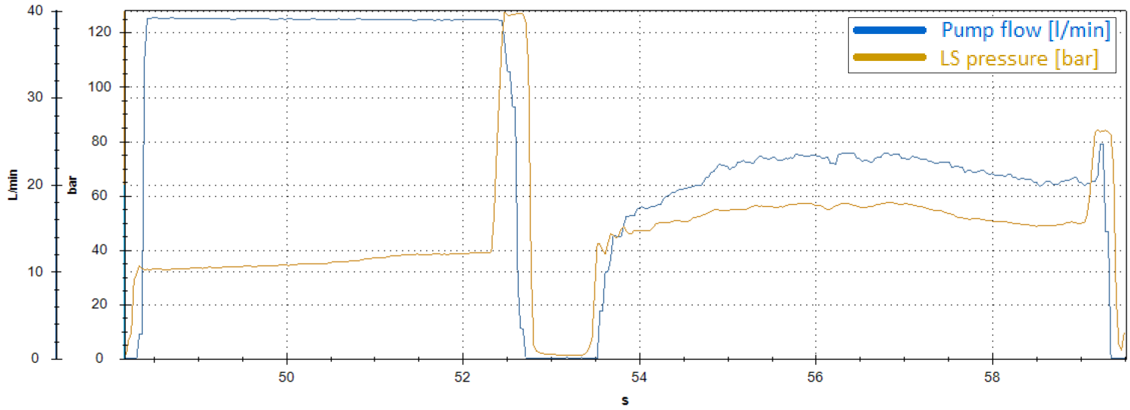

Figure 75: No oscillations with Sun LoadAdaptive CEBCLHN

The valve is clearly out of the operating envelope presented in Figure 31. This is because the minimum load pressure in the cycle is under 35 bar.

5.5.11 Load control valves operated with half inch hoses

Eaton 1CE30N16S5 was tested with 1/2” hoses from the load control valves to the Parker VPL directional control valve. There were oscillations according to the Figure 76. A change was seen in the oscillation frequency when changing to 1/2” hoses. With 3/8” hoses the frequency was between 9.5 Hz and 10.0 Hz (Figure 53) whereas with a 1/2” hose it was between 8.5 Hz and 9.0 Hz. These frequencies were taken straight from SensoWin as there is a tool for checking frequency from oscillations.

The installation with the 1/2” hoses takes less energy in the cycle than with 3/8” hoses as can be seen in Appendix C. The 1/2” hoses are the biggest possible hoses that can be fitted on the refuse collector structures of NTM. (Storås 2015) Thus, bigger hoses were not tested although they would increase the volume between the actuator and the load control valve which would decrease oscillations according to Nordhammer et al. (2012).

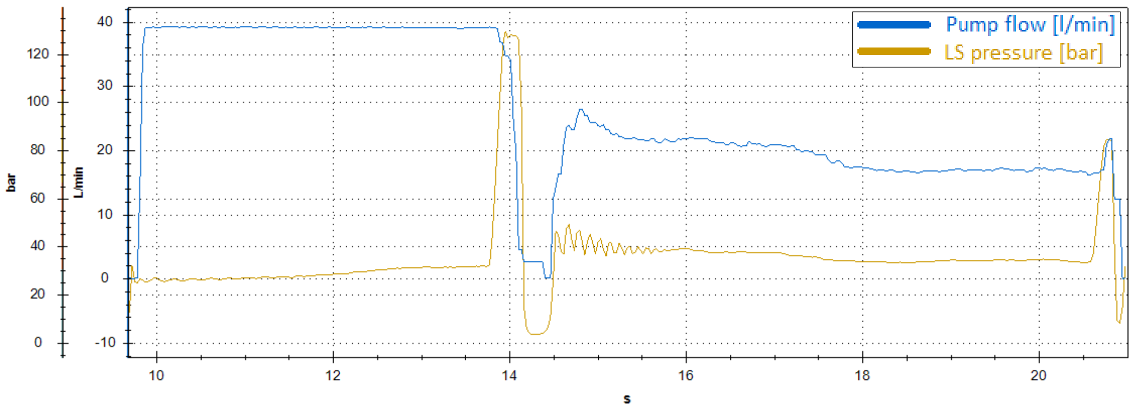

Figure 76: Oscillations with Eaton 1CE30N16S5 and 1/2” hoses

5.5.12 Pilot and back pressure of the load control valves

At this point it was figured out that extra information was needed on the system pressures of the binlift. Pressure sensors were installed on the binlift cylinder as in Figure 52. Pressure on the cylinder B chamber is sensed with the pressure sensor on the left side of the Figure. This is a pilot pressure of the load control valve when lowering the load. The pressure between the load control valve and the main control valve Parker VPL is sensed with the pressure sensor on the right side of the Figure. This is the back pressure of the load control valve when lowering the load and the cylinder chamber A pressure when the load control valve is not used. A typical measurement with these sensors can be seen in Figure 77.

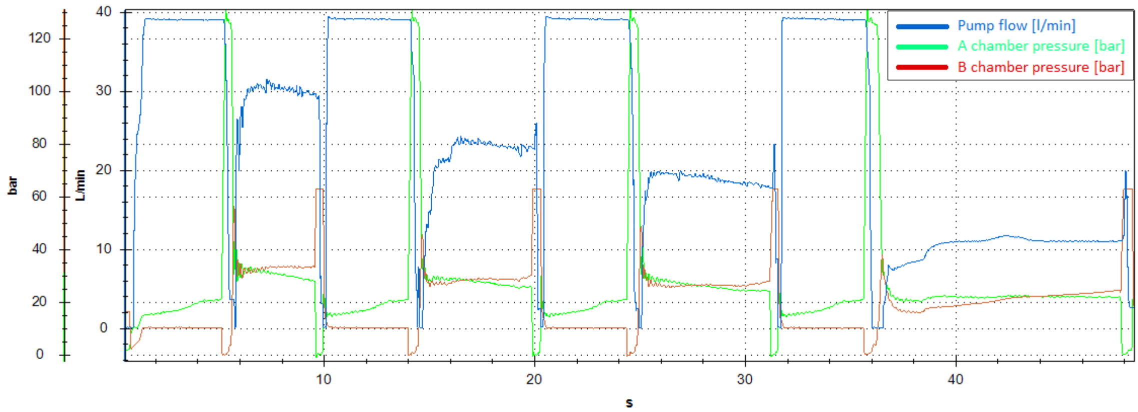

Figure 77: Flow and pressures with spool VPL424 without load control valves

The blue curve in the Figure 77 is the flow in the pressure line of a hydraulic machinery, the green curve is the pressure in the chamber A and the red curve is the pressure in the chamber B. The LS pressure and the pump pressure were taken off of the Figure in order to make it clear. As the Figure shows, the chamber B pressure is limited in 63 bar. This is due to the pressure sensor which had its maximum at that point. The spool used in the measurement of the Figure is the VPL424 which is a closed center spool with rated maximum flow of 40 lpm (Series VPL Proportional Valves 2004). As the system was stable without any load control valves, there was an idea of having as high a pilot ratio load control valve as possible in order to make it open as fast and easily as possible (Myllyniemi 2015). With this type of valve, the idea is that the load control valve would only act as a hose burst valve and the directional control valve Parker VPL would control the lowering. It can be seen in Figure 77 that with a slowly lowering, the chamber B pressure which is the pilot pressure when using load control valves, can be as low as 16.0 bar. The load creates about 13.0 bar pressure in this case. This means that with a 160 bar setting the load control valve should be with minimum

$$R = \frac{p_s - p_L}{p_p} - \frac{A_B}{A_A} = 8.4 \tag{13}$$

pilot ratio to open the valve without oscillations (notice Equation (2)). With smaller ratios the valve might open and close in a high phase. The problem is that when you are lowering even more slowly it will require a higher pilot ratio all the time.

It can be seen in Figure 77 that with a slow lowering (40 – 48 s, 10 lpm flow), the pressure in the chamber A is about 20.5 bar and with rapid lowering (5 – 10 s, 30 lpm flow) it is about 28.0 bar. If a pilot ratio 5:1 standard overcenter valve is considered, these pressures will add on a load control valve setting p_s with 123 bar and 168 bar (factor of six). This sounds really bad, but the situation with the spool VPL544 is a bit different when operating with a pilot ratio 5:1 valve according to Figure 78.

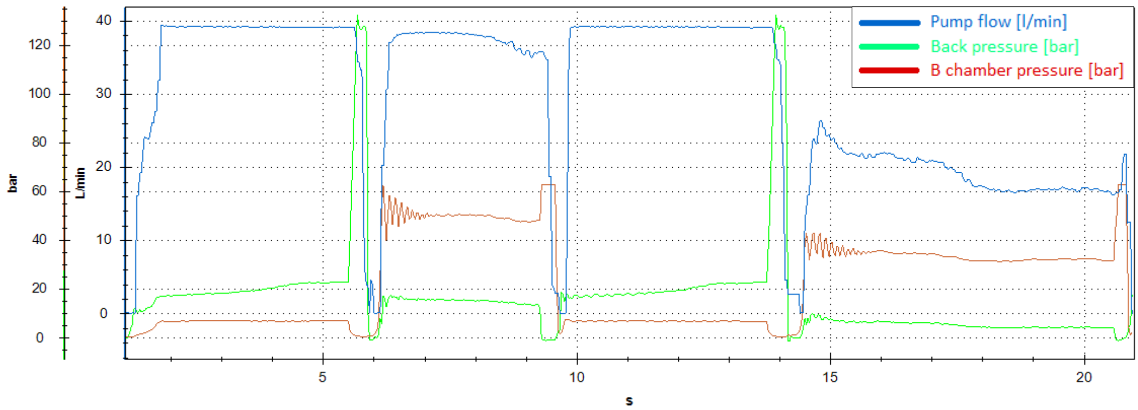

Figure 78: Flow and pressures with 1CE30N16S5 and VPL544 spool

The spool VPL544 used in Figure 78 is a so called motor spool. It is equipped with floating center and it has rated maximum flow of 65 lpm. The purpose of this spool is to minimize the back pressure between the exit from the cylinder and the Parker VPL. In other words, it does not have meter-out restriction lands. (Paisley 2015) This is a good spool when standard overcenter valves are used, as this minimizes the back pressure and the effect on the overcenter valve setting, but as a downside there might be some oscillations with this spool. It can be seen in Figure 78 that with a slow lowering (20 lpm flow), the back pressure is about 6.0 bar and with rapid lowering (38 lpm flow) it is about 17.0 bar. If a pilot ratio 5:1 standard overcenter valve is considered, these pressures will add on a load control valve setting p_s with 36 bar and 102 bar (factor of six). This is the reason why standard overcenter valves should not be used with proportional directional control valves although many factors, as for example robust construction without moisture problems, support using them.

5.5.13 Load control valve - Sun B10322UJ08

The Sun Hydraulics special cartridge valve B10322UJ08 tailored for Polarteknik was tested on the binlift with 160 bar setting. This valve is a 9:1 pilot ratio valve with an atmospheric vent. It is almost similar as the CACH-LGN valve, the difference is that the CACH-LGN is with 10:1 pilot ratio. (10:1 pilot ratio, vented 2015) As can be seen in Figure 79, there were oscillations with this valve. Pilot restrictors on hoses, back pressure restrictors after the load control valves and sequence valves after the load control valves were tested as possible cures for oscillations. The results can be seen in Figures 80, 81, 83 and 84.

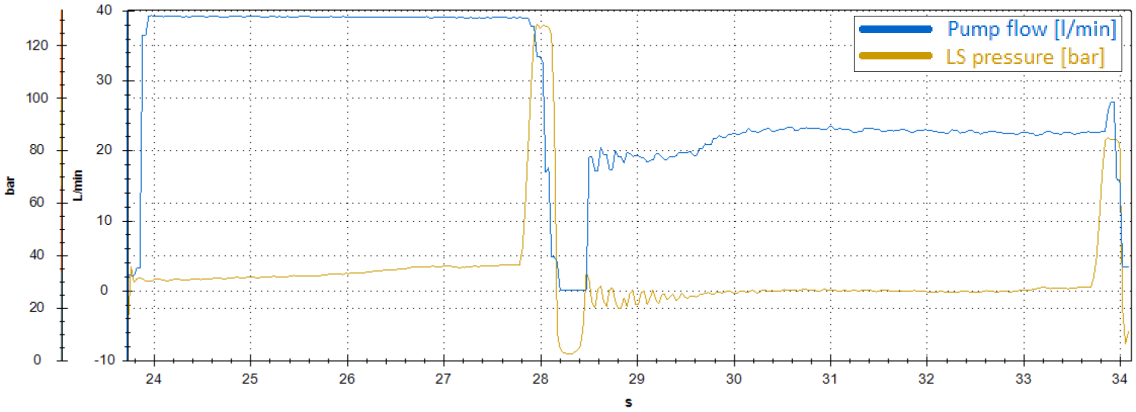

Figure 79: Oscillations with Sun B10322UJ08

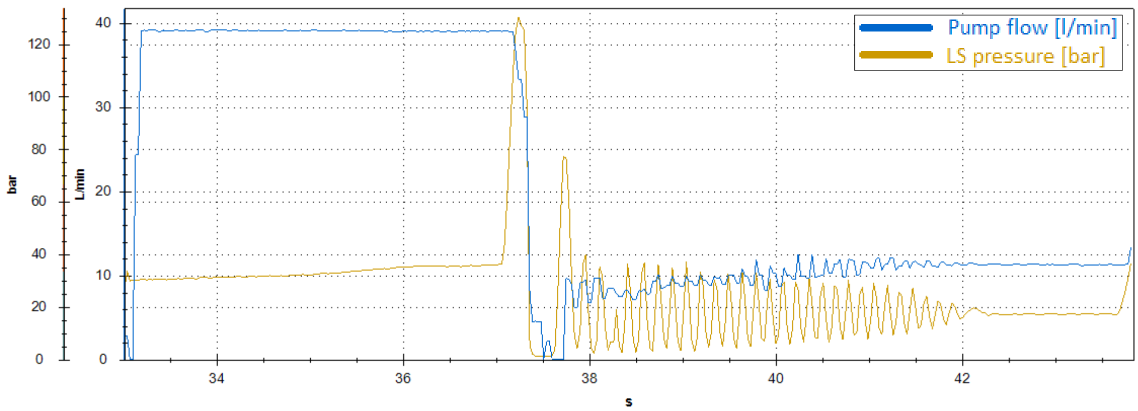

Figure 80: Oscillations with Sun B10322UJ08 and the 0.4 mm restrictors on the pilot hoses

As can be seen in Figure 80, the pilot restrictors are not the cure for oscillations. The Figure also shows that with smaller flows the oscillations will become worse.

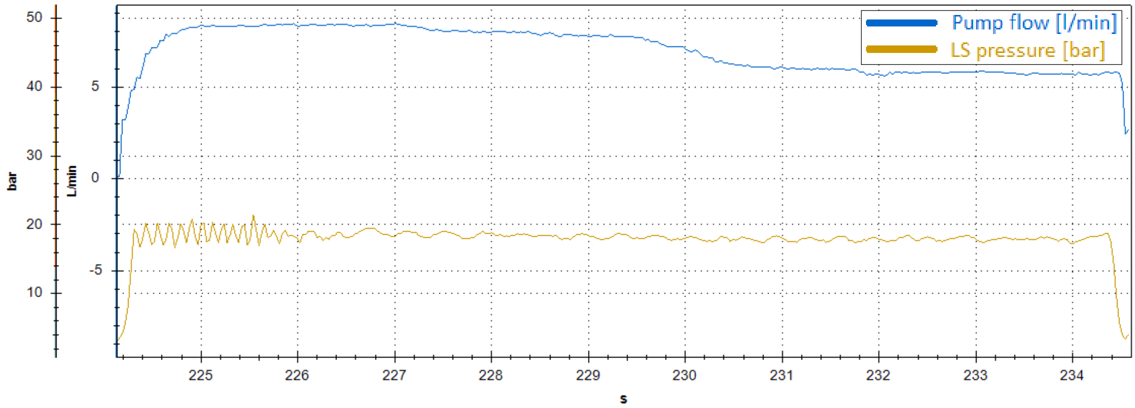

Figure 81: Oscillations with Sun B10322UJ08 and the 2.2 mm restrictors after load control valves

As seen in Figure 81, the oscillations were smaller than without the 2.2 mm restrictors. The Figure has only the lowering from the cycle as it was difficult to get the oscillations visible in a normal test run cycle. The problem with these restrictors is a really high energy consumption (43.6 kWs up-down cycle, compare on an Appendix C. This is based on the fact that the restrictors have to be small enough to make the pressure level to rise also with small flows. A high pressure level affects as a high pressure in the chamber B which is a high pilot pressure at the same time. This will make the vented load control valve open easily. The problem appears when the binlift is driven fast as these small restrictors cause a high pressure drop and thus consume a great deal of energy. From this problem came the idea of installing a sequence valve after the load control valve as in Figure 82.

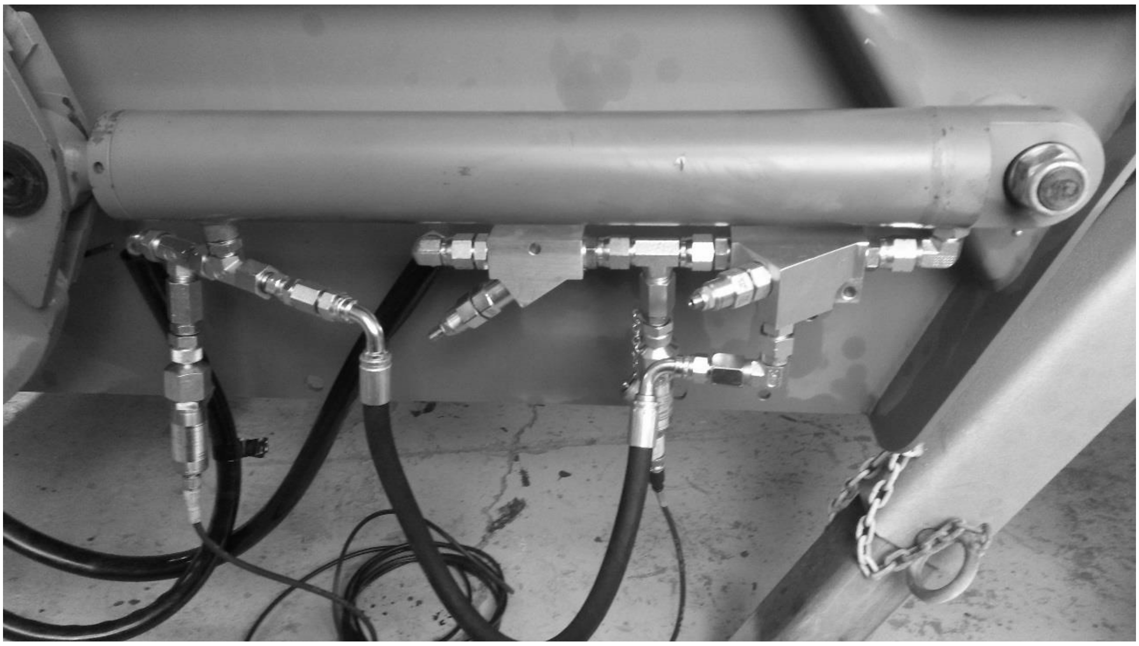

Figure 82: The Sun B10322UJ08 load control valve with the Sun SCCBLAN sequence valve installed to increase the pressure level

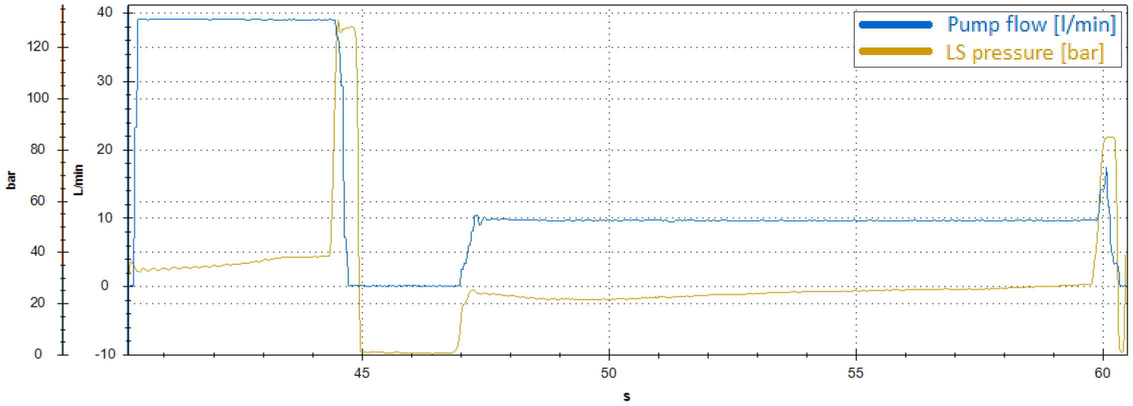

Figure 83: No oscillations with Sun B10322UJ08 and Sun SCCBLAN adjusted to 38 bar

The sequence valve first installed after Sun B10322UJ08 was the Sun SCCBLAN. The SCCBLAN was adjusted to various pressures but at 38 bar setting it was working the best and with minimum energy consumption according to Figure 83 and Appendix C. The SCCBLAN has the adjusting range from 35 bar to 210 bar. It is possible to adjust the valve under 35 bar, but then the behavior will not be stable. The reason for instability could be that in pressures under 35 bar, the pre-tension force of the valve spring is lost. The SCCBLEN is the solution to this as it is similar to the SCCBLAN but with adjusting range from 7 bar to 28 bar. In Figure 84 can be seen the result with the SCCBLEN and the optimum pressure setting of 26 bar. This is a good alternative also regarding energy consumption, as can be seen in Appendix C. Energy consumption could still be improved a hint by installing sequence valves on the cylinder B chambers to increase only the pilot pressures. If the cost is considered, two SCCBLEN could be replaced with one bigger sequence valve that would have the same pressure setting but it would be connected near to the directional control valve to create the back pressures for load control valves on the both sides.

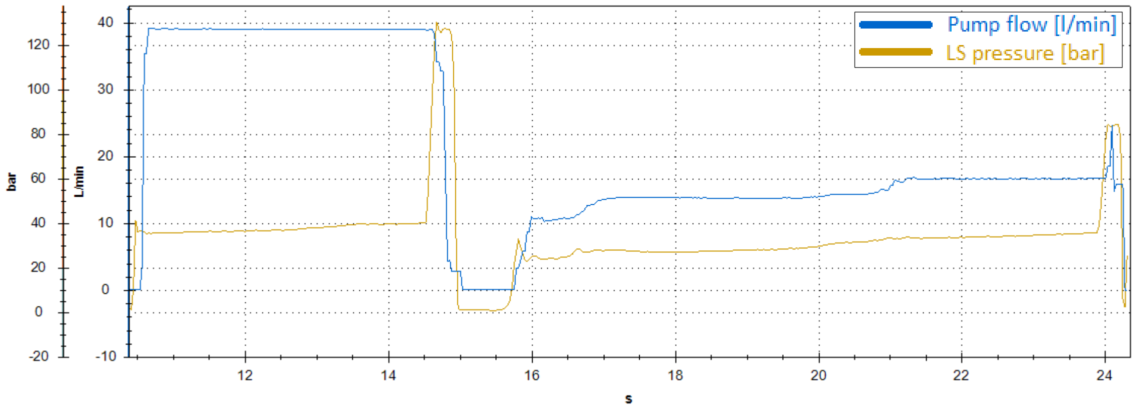

Figure 84: No oscillations with Sun B10322UJ08 and Sun SCCBLEN adjusted to 26 bar

5.5.14 Load control valves with a pilot ratio 1:0

As for pilot ratio 1:0 valves (also called as pilot ratio 0 valves), two types of load control valves were experimented on: Atlantic Fluid Tech CB000100-M-A and Eaton 1CPB30F2S. Both of these valves had a reducing effect on oscillations when they were set on small pressure levels; the CB000100-M-A was set on 10 bar and the 1CPB30F2S on 6.5 bar. As an example, small oscillations can be seen in Figure 85 with the 1CPB30F2S.

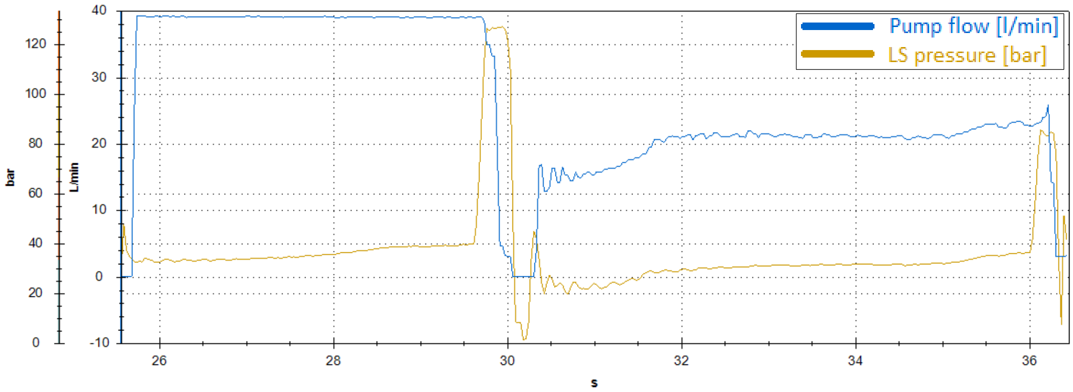

Figure 85: Small oscillations with Eaton 1CPB30F2S

Energy for up-down cycle is 30.6 kWs for CB000100-M-A and 27.3 kWs for 1CPB30F2S (3/8” hoses). The energy consumption of these valves was at a good level when compared to other solutions in Appendix C. Despite these positive facts, a major problem came up with these valves. When the binlift was lowered slowly, it was possible that only one of the valves was opening. This resulted in the binlift coming down sideways. This could bend the metal structure of the binlift and thus it is unacceptable. This problem was present even though the valves were adjusted really precisely using the same setting. Another problem that was especially present with CB000100-M-A was pressure peaks when lowering big weights and stopping instantly. With 1CPB30F2S these were tolerable, but with CB000100-M-A they were in the structure limits. These peaks could be avoided by installing separate pressure relief valves parallel to the load control valves.

Pilot ratio 1:0 valves were also tested with different control. They were controlled with the same pressure as the directional control valve spool as in Figure 42. This is a low pressure signal that is generated with a hydraulic handle and it was directed to the pilot port of the valves. This type of control also had a problem with the binlift coming down sideways in slow lowering. In addition to this, the binlift was also slow to respond to lever movements even though air was bled out from the pilot hoses. According to Teittinen (2009, p.71), long piloting connections of a load control valve will result in sluggish boom responses to the operator`s commands. This could be the reason also in this case as there were quite long pilot hoses (about 20 meter in total) which have a big volume and thus they require some time to pressurize. Another reason could be that there still was some air trapped in the hoses even though bleeding was already done. All in all, this assembly is not suitable for production with these problems.

The problem with the binlift coming down sideways can be avoided with three ways stated by Teittinen Hydraulics in Figures 34, 35 and 36. Connecting the A chambers with a small hose would require hose burst valves in both ends of the hose. This would be a cheap solution but it is not desirable to use hose burst valves as they are viscous dependent and an extra hose from one side to the other neither is a good addition. Pilot operated balancing connections, on the other hand, would require more valves and the assembly would be too complicated and expensive. Circulating oil through the other load control valve would require the other valve to be bigger in size than the valves that were tested. It would also require couple of check valves to be assembled on the bigger load control valve, one hose installed from one side to the other and a bigger hose between the bigger load control valve and the directional control valve. This function would require at least one 5/8” hose when both return flows are going through one hose and this would be too big to fit all the holes that different refuse collectors have in their body. When considering all these facts, this type of connection would be too complicated and expensive. A connection of three pilot ratio 1:0 valves (as in Figure 36) was also tested but it took too much energy to be taken to production. It took 34.9 kWs which is quite a lot compared to the options in Appendix C. This design could be even further optimized with a bigger third load control valve. This time, two parallel CB000100-M-A were used to replace one bigger load control valve. Although this could be optimized, the solution would be quite expensive with three valves and the energy saving potential is still not more than about 10 % for the whole cycle (Appendix C versus energy consumption with 1CPB30F2S).

5.5.15 Single acting cylinders on binlift

Connecting binlift cylinders as single acting cylinders was also tested. This idea from Erkkilä (2015) was tested according to Figure 86.

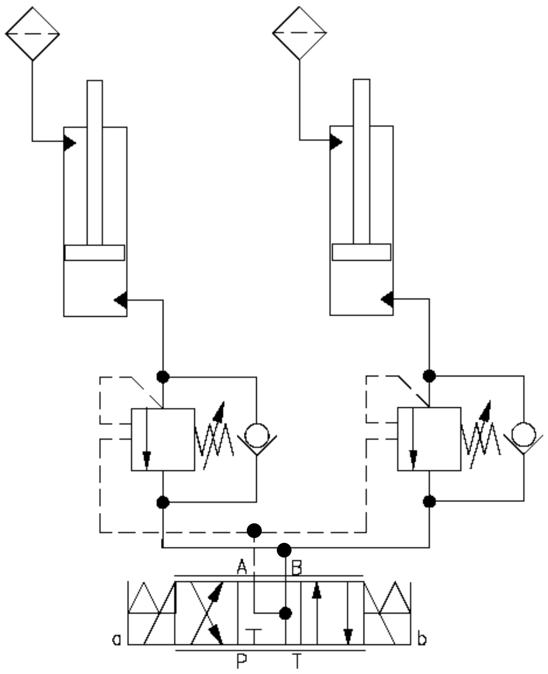

Figure 86: Single acting cylinders and load control valves connected to Parker VPL

The assembly was working without oscillations but the problem was that the empty binlift came down too slowly. The time for coming down should be around 5 s and now it was 10 s. In addition to this, the motor spool VPL544 that was used brought the heavy 850 kg weight down too fast. This is due to the motor spool design that does not restrict the flow to the tank (Paisley 2015). More suitable spools for this applications are available, for example VPL574K2 which is similar to VPL544 with the difference that it restricts the flow to the tank. This design could be further developed, for example, with spring or gas in the cylinders´ chamber B and possibly equipped with an accumulator.

5.5.16 Hose burst and load control valve dual connection on binlift

As hose burst valves are not a considerable option in a mobile equipment operating at low temperatures, a dual connection of hose bursts and load control valves was experimented on according to Figure 87.

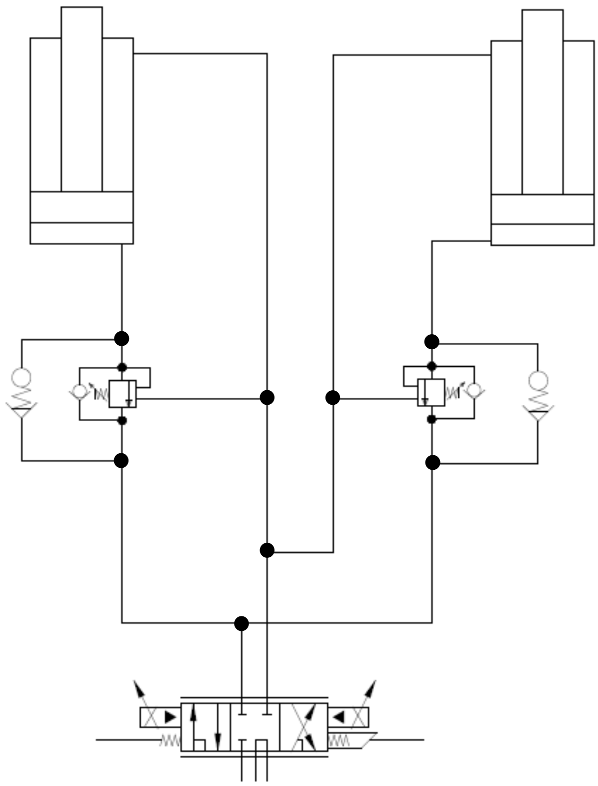

Figure 87: Hose burst valves installed parallel to load control valves

The idea of the assembly was that in a normal cycle the flow would go through the hose burst valves and when the hose burst valves would activate, there would be the flow control valves to take the control. This assembly would give energy savings, smooth control of load and at the same time provide reliable functionality in cold temperatures. The assembly was experimented with two different types of load control valves. First, Eaton 1CE30N16S5 was tried. With this valve, there was a problem with just the other hose burst valve activating which resulted in the binlift coming down sideways. With the other load control valve (Sun B10322UJ08), everything was working really fine until a 500 kg test weight was lowered with a fast speed. This resulted in the both hose burst valves blowing at the same time which created a big bounce. The cause for the bounce was the descending pilot pressure when adding the 500 kg test weight. This was causing the load control valves to stay closed until the hose burst valves were activating.

This is not a good assembly if the hose burst valves are expected to close several times during their lifetime. This is because, according to manufacturers, hose burst valves should be replaced or at least inspected if they are closed during operation. (Hose break valve s.a. ; Insert type Hose burst 2010)

5.5.17 Spool selection on directional control valve

It was noted that just replacing a load control valve is not good enough solution. There were problems, for example, with high energy consumption, the binlift coming down sideways, expensive assembly and not robust atmospheric venting valves. This led to experiments with different types of directional control valve Parker VPL spools combined with different types of load control valves.

At first, there were tests run with VPL524 spool with different types of load control valves. That is because this spool was available at the company warehouse. It was noted that this spool had a reducing effect on oscillations compared to the original VPL544 spool. As these tests were promising, it was decided to try also VPL574 and VZL30306K2. The spools VPL544, VPL574 and VZL30306K2 are otherwise similar open center (floating center) spools but they are restricting flow to the tank in different ways. VPL544 is called a motor spool and it is restricting flow to the tank as little as possible, VPL574 has a small restriction to the tank and VZL30306K2 has the biggest restriction to the tank. VPL524 is similar to VPL574 but it has a closed center. As closed center spool should not be used with load control valves, the spool VPL524 was used just for testing purposes to simulate the VPL574 spool before the VPL574 spool was available for testing. (Series VPL Proportional Valves 2004; Paisley 2015)

Experiments with the VZL30306K2 directional control valve spool went really well at first. There were several load control valves that were working well without oscillations with this spool. For example, the high pilot ratio (more than 9:1) valves with atmospheric vent, such as Comatrol CB10AV-1-C-1E-B-SE and Sun B10322UJ08, were really good with this spool. The energy consumption with full speed was in many cases under 30 kWs for up-down cycle which is good when compared to Appendix C. The problem with this spool was evident with smaller speeds. As this spool heavily restricts flow to the tank when operated slowly, it also took a great deal of energy when operated slowly. In the case of the binlift, the flow needs to be restricted a little in order to avoid too fast operation and this is why it is not acceptable to have a big energy consumption with smaller speeds. The flow is restricted by limiting the movement of the spool. It was not accurately tested how big the energy increase was from full speed to the correct restricted speed but according to other measurement data it is more than 30 % just for the lowering of the bin. The same number can be more than 60 % if operated with smaller pilot ratio valves such as Eaton 1CEB30F35S5 which is with 5:1 pilot ratio. These are not acceptable increases in energy consumption. With these facts considered, the spool VZL30306K2 should not be taken in the application if it is not necessary.

The VPL574 spool was successful in the tests. This spool has a reducing effect on oscillations compared to the original VPL544 spool. It is not able to remove all the oscillations but it makes the situation much more tolerable. The spool VPL574 consumes a bit more energy than VPL544 but this difference can be compensated by selecting one size bigger hoses as can be seen in Appendix C. With the VPL574 spool (VPL524 similar results) there are several load control valves that can be chosen, as all tested valves operate with less oscillations than with the VPL544 spool. The most energy efficient among the tested would be Parker MHC-010-VJSH-00B according to the table Appendix

C. This valve is really big in size and it is manufactured in Mexico which causes the delivery time to be long. Considering these facts, it was decided that this is not the valve wanted to be used in the application. The valve G Fluid 6PB110A000GNOR00 was also good with this spool, but as the energy consumption was roughly the same as with 1CE30N16S5, it is not justified to select for the application this valve that is vented to atmosphere and has a different cavity than the 1CE30N16S5. The valve 1CE30N16S5 that is used on the binlift nowadays gave surprisingly good results according to Figure 88. Even better results were reached with 1CE30N16S2, but this takes about 8 to 15 % more energy according to the Appendix C and the measurements. The valve 1CE30N16S2 also requires the pressure setting to be raised from the directional control valve if the same speed is wanted to be obtained in lowering the binlift. With VPL574, it was common that slow operation took less energy than driving with full speed unlike with the spool VZL30306K2.

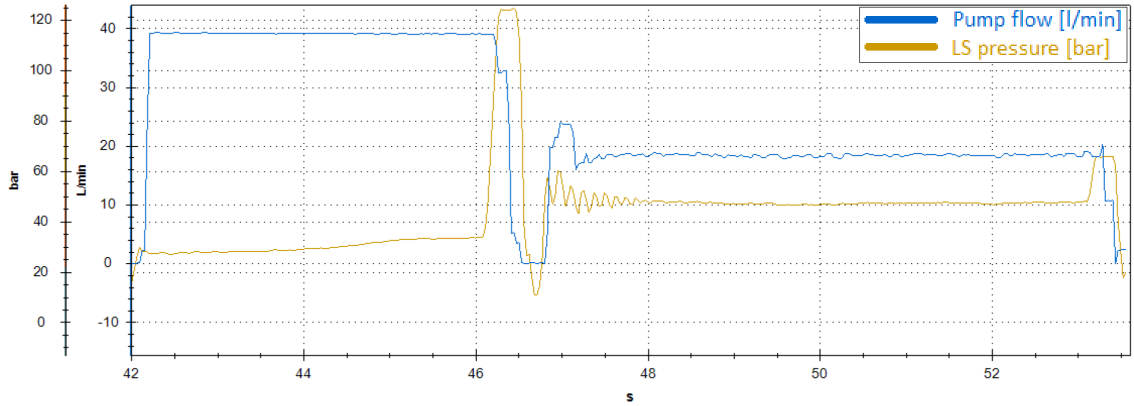

Figure 88: Eaton 1CE30N16S, VPL574 spool and 1/2" hoses (recommended assembly)

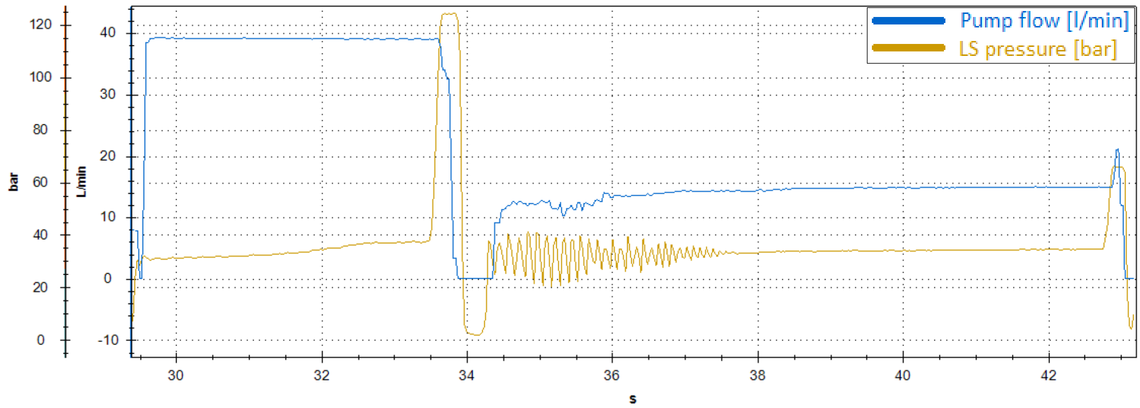

Figure 89: Eaton 1CE30N16S5, VPL544 spool and 3/8" hoses (original assembly)

When Figures 88 and 89 are compared, it can be seen that a combination of bigger hoses and different spool reduces oscillations significantly. The oscillation time degreased from 3.4 s to 1.5 s (56 %). The peak-to-peak amplitude of the shakes degreased from 20 bar to 14 bar (30 %). The oscillations seen in the Figures are with an empty binlift. When an empty bin is added to the binlift, the shakes are reduced even more. When moving from the original to the recommended solution, energy consumption is reduced 3 % according to Appendix C.

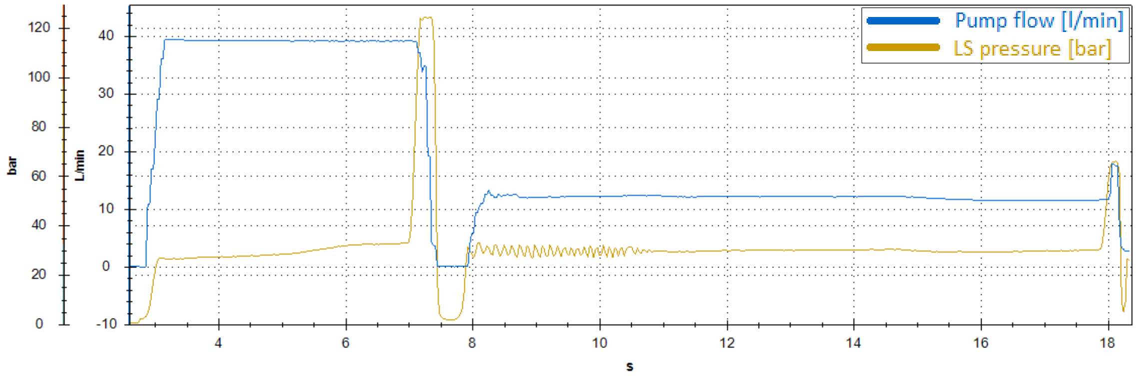

Figure 90: Eaton 1CE30N16S5, VPL544 spool and 1/2" hoses

When Figures 89 and 90 are compared, it can be seen that selecting a bigger hose will degrease the amplitude of the shakes. In this case, the oscillation peak-to-peak amplitude degreased from 20 bar to 5.7 bar (72 %) just with a hose change. The amplitude degreasing seems to be fluctuating between 21 % and 72 % so it is heavily dependent on the lowering speed and other parameters. When comparing Figures 89 and 91, it can be seen that when selecting more restrictive spool to the tank, the oscillation time will degrease. In this case, the oscillation time was degreasing from 3.4 s to 2.4 s (30 %) just with spool change. Figures from 88 to 91 are all measured with oil temperatures between 23 to 28 degrees Celsius.

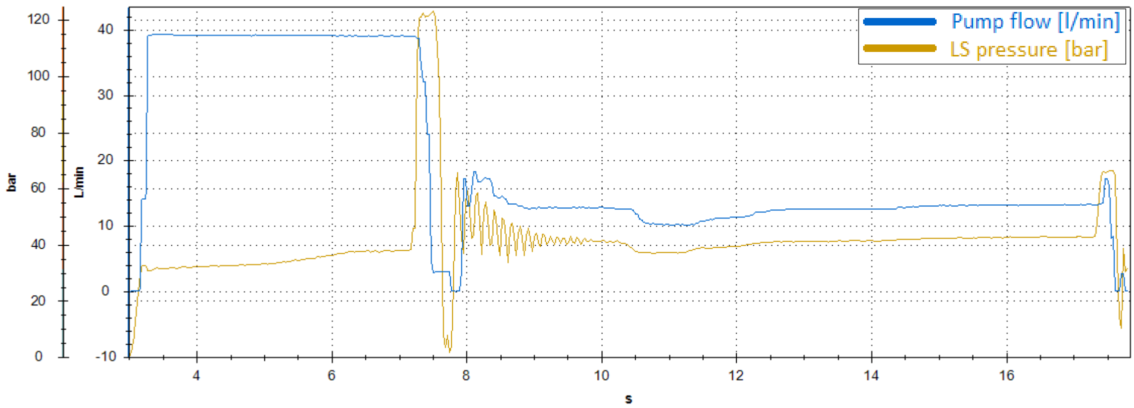

Figure 91: Eaton 1CE30N16S5, VPL574 spool and 3/8" hoses

During the spool tests, it was noted that when the return flow to the tank is restricted, there may be higher pressures on the actuator ports than what is set on the directional control valve pressure limiters seen in Figure 92 (two pressure relief valves on upper left). Pressure limiters are limiting the LS pressure and relieving the excess pressure to the actuator port connected to the tank. Due to restricted flow to the tank, here might be over pressure on the tank port which is also the back pressure after the pressure limiter. This back pressure has an effect on the pressure limiter setting as the pressure limiters are not vented, as can be seen in Figure 92. These bigger pressures in the actuator ports created a problem in the function that was driven, as there were no work port reliefs (two pressure relief valves on upper right on Figure 92). This problem should always be taken into consideration when restricting flow to the tank. VPL slides are also available with a common pressure limiter for both actuator ports and with this there is no problem with back pressure as these pressure limiters relief straight to the tank line, not through the spool. (Series VPL Proportional Valves 2004)

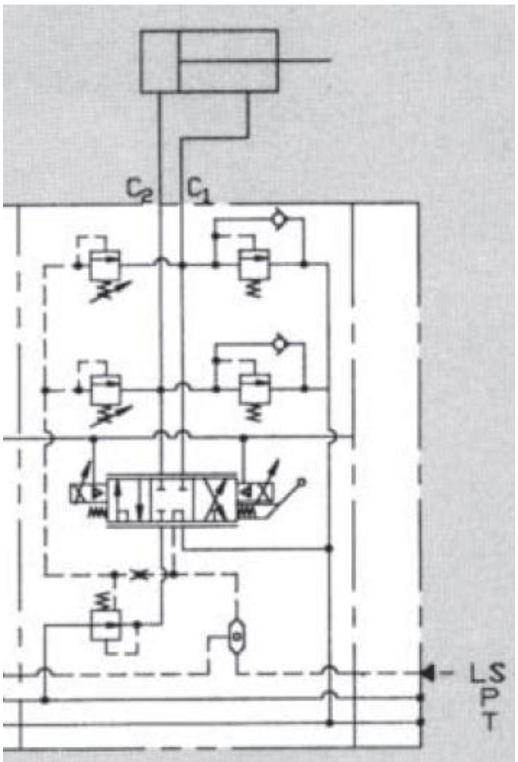

Figure 92: One slide from VPL valve (Series VPL Proportional Valves 2004)

5.5.18 Big weight on binlift

Most of the tested load control valves had small oscillations with the motor spool VPL544 and when lowering the 500 kg test weight. These oscillations were similar to those seen in Figure 93. These oscillations would not be a big problem as the bin is not usually lowered with a load. As can be seen in Figure 94, the oscillations were slightly smaller with the spool VPL574 when comparing the lowering cycles which were driven approximately the same speed. In Figure 94, the measurement was tested in a compactor that was already installed on a truck. This also makes the oscillations smaller as truck suspension and tires fade away part of the oscillations.

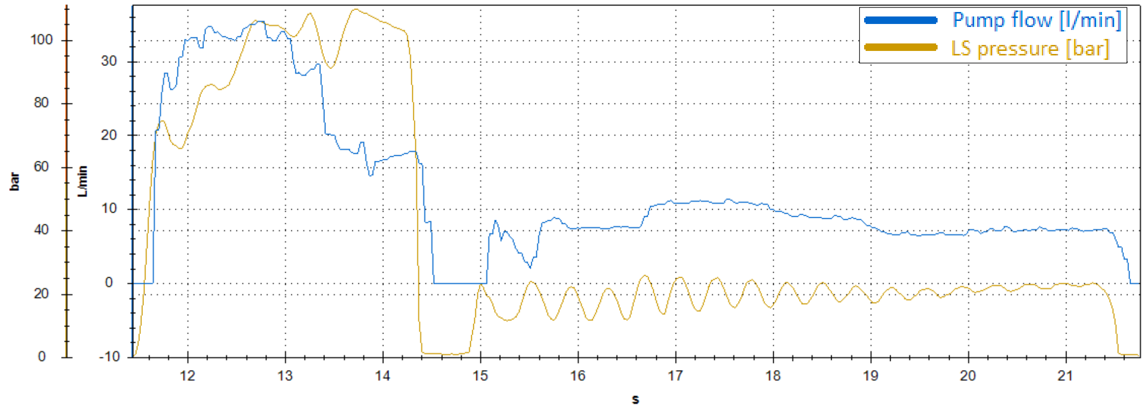

Figure 93: Eaton 1CE30N16S5, VPL544 spool and 500 kg test weight

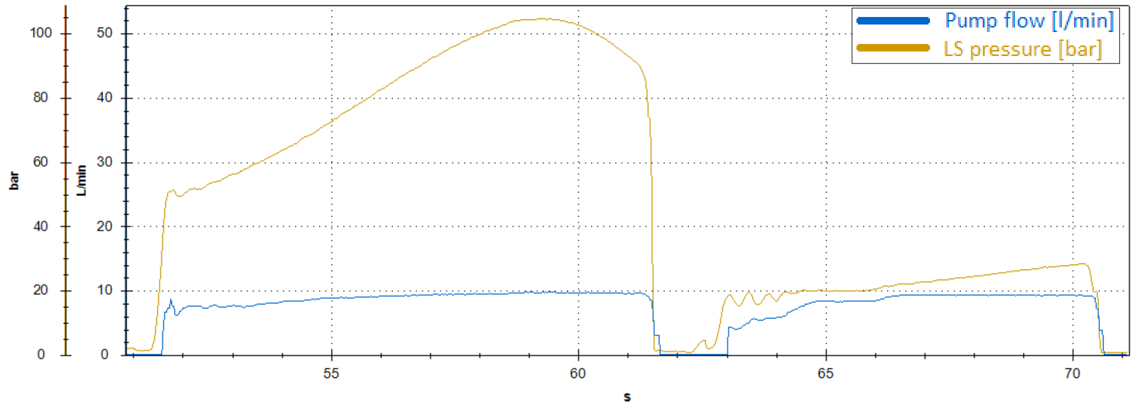

Figure 94: Eaton 1CE30N16S5, VPL574 spool and 500 kg test weight

As can be seen in Figure 95, there were really big oscillations with certain type of load control valves when big weights were lowered. In Figures 93, 94 and 95, there is a 113 bar maximum pressure which tells us that the load control valve setting 160 bar used with the 500 kg lifting binlift has the safety factor of 1.42, which is better than the 1.3 recommended by manufacturers.

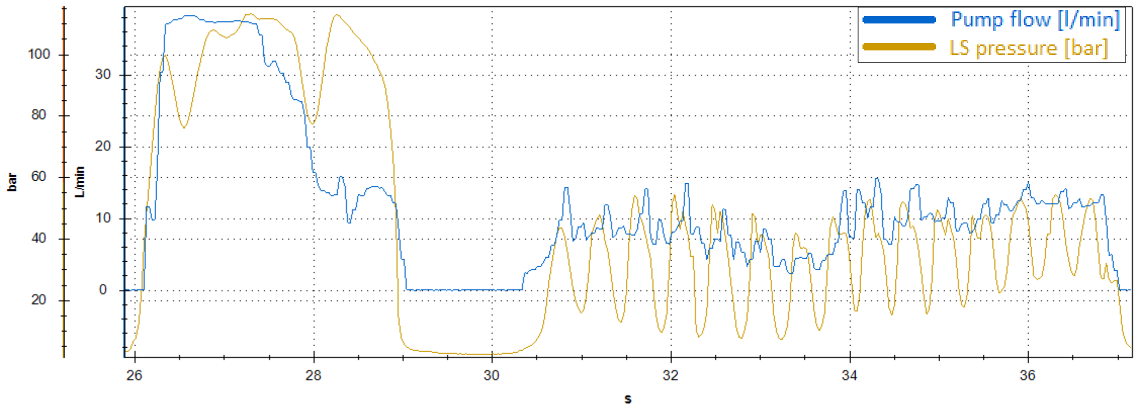

Figure 95: Sun LoadMatch MBDPDH, VPL544 and 500 kg test weight

5.5.19 Temperature effect on load control valves

In the tests, it was noted that the oscillations always become worse when the temperature rises. The rise in temperature causes the viscosity to drop. Oscillation changes can be clearly seen when comparing Figures 96 and 97. The assembly in both Figures is exactly the same with 3/8” hoses, Eaton 1CE30N16S5 load control valve and with the same directional control valve spool VPL574. In Figure 96, the oil temperature is about 37 degrees Celsius and in Figure 97, the oil temperature is about 65 degrees Celsius. All tested valves were acting the same way with a temperature increase.

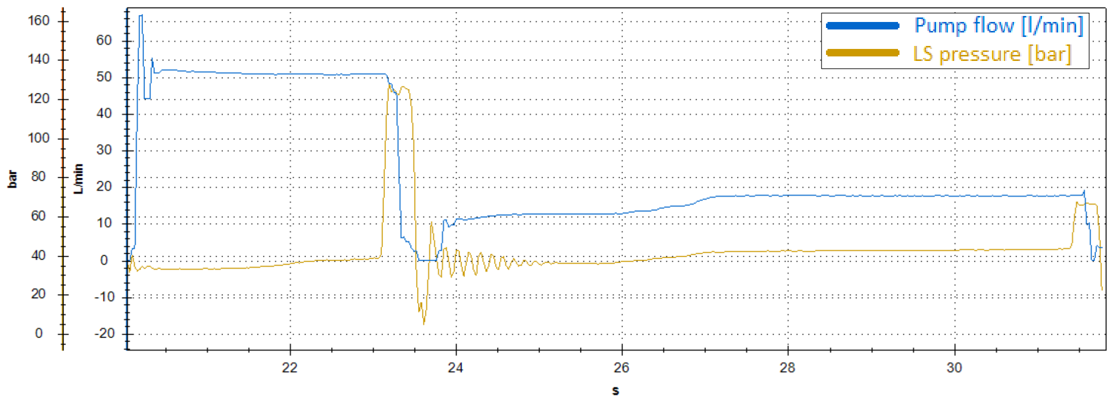

Figure 96: Eaton 1CE30N16S5 and VPL574 spool in 37 degrees Celsius

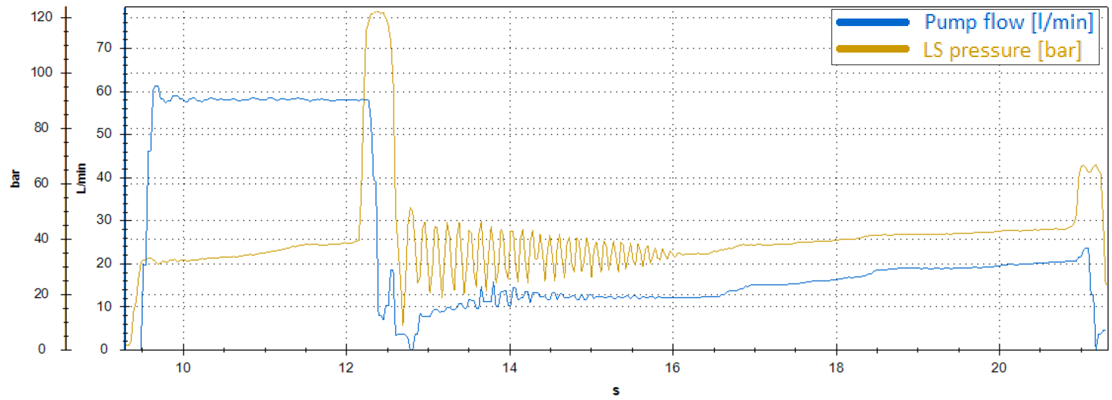

Figure 97: Eaton 1CE30N16S5 and VPL574 spool in 65 degrees Celsius

It should be noted that even though Figure 97 does not look well, the spool VPL544 would have roughly the same oscillations already in 35 degrees Celsius, which is 30 degrees less than in Figure 97. This can be seen in Figure 98.

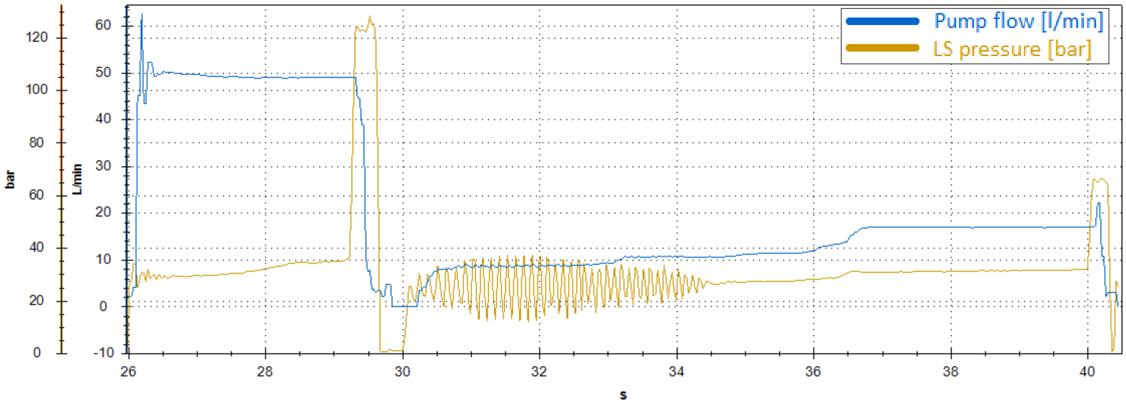

Figure 98: Eaton 1CE30N16S5 and VPL544 spool in 35 degrees Celsius

Figures 96 and 98 are ideal for comparing spools VPL574 and VPL544 as these Figures have roughly the same settings and situation. Both of these assemblies have 3/8" hoses and the Eaton 1CE30N16S5 load control valve. Temperature differs only with two degrees Celsius.

5.6 Energy consumption and accuracy of measurements

The accuracy of the measurements was calculated according to Ellman (2002 p. 28-45) and the information provided in section 5.1. The energy consumption and accuracy of some valve assemblies that worked properly with an empty binlift without too large oscillations are presented on a Appendix C. The first assembly in Appendix C is the original assembly which has some oscillations, it is in the table just for energy reference. The last six rows of the table are the assemblies that have had good functionality but are not recommended to be taken in production. The Sun CEBCLHN load adaptive is not recommended as it is a rather expensive valve and the energy consumption is also quite high. Sun B10322UJ08 with SCCBLEN is not recommended because the installation would be complicated and expensive. This installation could be simplified by replacing two SCCBLEN with one bigger sequence valve installed near the directional control valve. The last four rows are with assembly that has no load control valve and thus the assemblies do not have hose burst protection. This is not according to standard SS-EN 1501-5:2011 and this is why they are not acceptable in production. Assemblies with a load control valve and the directional control valve spool VPL524 were created only to simulate VPL574 spool before it was available for the tests. Energy consumption and functionality between these two spools are approximately the same. The difference is that the VPL524 spool has a closed center and thus it should not be used with load control valves.

Energy consumptions in Appendix C are measured with a full speed up and down as that is the normal cycle driven. The accuracy depends on the loading situation and that is why it was calculated with SensoWin software. The calculation was continuous according to Figure 99.

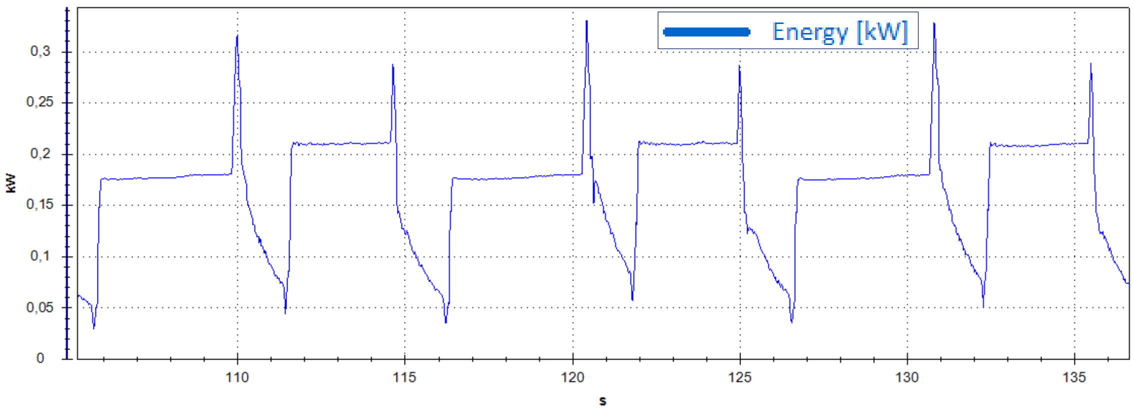

Figure 99: Accuracy of energy consumption with the 1CE30N16S5 valves and three up-down cycles

There was a problem in these calculations as flow and pressure were reaching zero in measurements. This is why 0.01 lpm and 0.01 bar on flow and pressure curves were added to SensoWin. This causes a minor error but it allows the calculation to be made without dividing by zero. The accuracy of the cycle (mean accuracy) in Appendix C was calculated by integrating similar curves as in Figure 99. This was then divided with three as there were always three up-down cycles. As can be seen in Appendix C the accuracy of the measurements is rather good, the maximum of ± 2.00 kWs error is present. The same pressure sensor was always used for the energy measurement (pump pressure sensor) which means that all measurements have more similar errors than there would have been if the pump pressure sensor would have been changed between measurements. This allows the energy consumptions to be more easily comparable with each other.

The energy consumptions could still be lowered, for example, with selecting bigger diameter piston rods in every binlift. The energy save would come from the degreased flow demand on lowering the binlift. The lowering with an empty bin requires pressure in the chamber B (rod side cylinder chamber) only slightly to overcome, for example, dynamical friction. A degreased flow demand would mean, for example, smaller pressure losses. This would be good from the energy point of view but this could increase oscillations. As stated by Axin (2013), a high damping that could decrease oscillations would be achieved with a large volume on the inlet side of the cylinder and the outlet orifice on the directional control spool designed close to the optimum value. Selecting bigger diameter piston rods would thus lower the damping.

The original binlift energy consumption is 31 kWs for one up-down cycle and rear loaders are able to empty up to 600 bins during an 8 hour work day. (Storås, 2015) This means 18600 kWs in a day. If there could be 10 % saving made on energy consumption, this would be 1860 kWs in a day. With Diesel fuel this 10 % saving would be up to 1.7 dl saving per day if a Diesel engine is expected to run with a 30 % efficiency ratio and Diesel is 10.05 kWh/l (Polttoaineiden lämpöarvot 2010). This does not sound much but it is 43 liters of Diesel in a year with one rear loader, as there are approximately 252 work days in a year. This becomes more fruitful if future aspects are considered. As can be seen in Appendix C, up to 32.5 % of energy can be saved when compared original solution with the most energy efficient solution. The most energy efficient tested solution is not according to the standards but this can be solved with assemblies according to Figures 44 and 45. With these solutions it is possible to get near the 32.5 % energy saving. The estimated energy saving with these solutions is 27 %. Basically, this would equal up to 117 liter Diesel savings in a year with one rear loader. If you consider the amount of rear loaders produced during a year at NTM, which is about 300 rear loaders, this would make up to 35000 liter saving in a year. This is already a number that matters.

6. DISCUSSION

As stated before, load control valves are valves that are a compromise between energy consumption and oscillations. (LoadAdaptive™ counterbalance valves 2015) This compromise forces on decisions that are not easy to make but must be done. In the case of NTM, load control valves are used just for the hose burst protection purpose required by standard SS-EN 1501-5:2011 (E) part 5.5. There is no need to hold the load precisely still and smooth load control without cavitation can also be done without load control valves.

This research found many assemblies that do not work in the way wanted. Low pilot ratio load control valves might work without oscillations, but they are not energy efficient. A special directional control valve spool with high back pressure to the tank port will force many vented high pilot ratio load control valves to work without oscillations, but as a downside, a special spool will consume a great deal of energy with a slow lowering. Vented high pilot ratio load control valves are also valves that can be fully opened with the help of sequence valves and this assembly was also energy efficient and oscillation free in the tests. As a downside, this assembly is complicated and expensive when compared to the original, but it could be further developed which means that one sequence valve could be removed from the assembly.

The two-stage load control valve Eaton 1CEL30F20S150-x was tested. This valve was oscillation free with certain pressure settings. The problem was high energy consumption with these settings and the fact that the valve is not supplied with a looser outer spring (primary spring). The looser outer spring would allow energy consumption to be lowered.

New LoadMatch and LoadAdaptive valves provided by Sun Hydraulics were also measured, but the problem with both of these was that they are out from the operation range in the case of binlift. This means that binlifts have too low load pressures in lowering so the valves are not working as they should. LoadMatch was oscillative and energy consuming. LoadAdaptive was stable but took a great deal of energy.

The pilot ratio 1:0 load control valves were functioning without oscillations with small pressure settings. These valves are prone to pressure peaks with big loads and fast stopping especially when driven downwards. This can be solved by installing a pressure relief valve parallel with the valve. This was not the biggest problem in the case of the binlift. There are paired cylinders in the binlift. With paired cylinders, these valves have the problem that one could open and the other one would still stay closed when lowering. This was exactly what happened with a slow lowering in this case. This may also cause the metal structure to bend if this happens with a big weight on the binlift. This could be solved with three different ways stated in Figures 34, 35 and 36. These assembly solutions would be complicated and expensive and this is why they are not implemented. For the same reason the Bucher valves BBV6 and Cindy were not tested.

Pilot-operated check valves were not tested in the binlift as they should never be used in paired cylinders as there will likely to be a problem with one valve opening and the other one staying closed as the increasing load pressure keeps it closed. (Pilot operated check valves s.a.)

If single acting cylinders are used as in Figure 86, load control valves are not prone to oscillations. This is a good solution if the actuator is able to come down fast enough without forcing it with hydraulic pressure. In this research, the binlift was not able to come down fast enough, so this solution could not be utilized. This could be further developed by using, for example, a spring or gas to push down the binlift.

Small enough pilot restrictors also caused the load control valve oscillations to fade away when some oil was left between the restrictor and the load control valve. As a drawback, they made the binlift really slow to respond on lever movements.

Hose burst and load control valve dual connection was tested during the research. This assembly was done according to Figure 87. This was working really well with the Sun B10322UJ08 valve until the 500 kg test weight was lowered with fast speed. This made both the hose burst valves to blow at the same time, which created a big bounce. The cause for the bounce was descending pilot pressure when adding the 500 kg test weight. This was causing the load control valves to stay closed until the hose burst valves were activating. This problem might still be worse when the oil is cold so this assembly cannot be used.

It was noticed during the thesis that controlling the binlift without the load control valves is really smooth. This solution would require hose burst valves, according to standard SS-EN 1501-5_2011 (E) part 5.5. However, hose burst valves are really viscous dependent and it is not desirable to use them because they might cause problems when operating with cold oil (Nysand 2007).

Also the choice of hose will have an effect on oscillations. According to the measurements, bigger hoses are causing a decrease in the oscillation amplitude. This is based on the fact stated by Nordhammer et al. (2012). They state that increasing the volume between the directional control valve and the actuator is a common way to stabilize a load control valve.

Also the effect of temperature was studied and it was noted that the warmer the oil, the more there will be oscillations with the load control valves according to Figures 96 and 97. As can be noted, there is no perfect solution for problems regarding load control. The solution is always a compromise between oscillations, energy consumption, reliability and cost.

The reliability of this research is rather good. The matter to reduce reliability was the short time available for the measurements. Every single combination and, for example, every temperature situation could not be tested in the course of the research. This led to concluding some assembly behaviors and thus leaving them untested as there was no time to run the less important tests.

7. CONCLUSIONS

In this research, a solution was found for making the oscillations smaller on the binlift. This solution is based on using the original 1CE30N16S5 overcenter valve but changing the directional control valve spool from VPL544 to VPL574 and changing the hoses into bigger ½" hoses when possible due to compactor constructions. This solution is not removing all the oscillations, but it is a robust solution as the valves used do not have atmospheric vents and thus they do not have moisture problems. These valves have also proven to be long lasting during the years they have been in use. It is also a major advantage that installation is not going to be more complicated and there are no changes on the cartridge blocks either. The oscillations of the recommended assembly can be seen in Figure 88 and the bigger oscillations of the original assembly in Figure 89. When these Figures are compared, it can be seen that the new solution, which is a combination of bigger hoses and a different spool, reduces the oscillations considerably. The oscillation time degreased from 3.4 s to 1.5 s (56 %). The peak-to-peak amplitude of the shakes degreased from 20 bar to 14 bar (30 %). This new solution saves about 3 % in energy consumption according to Appendix C.

If oscillations are wanted to be reduced even more in the future, 1CE30N16S5 can be replaced in the assembly with 1CE30N16S25, but this will consume more energy. This valve has the same block drilling cavity so it is easy to change. The pressure level on the function may also need to be raised to maintain the same speed with the new valve that has a smaller pilot ratio. Also the other load control valve options, such as Sun CBBGLJN and G Fluid 6PB110A000GNOR00, are available but these require a new cartridge block as they have a different cavity. Eaton also has other options with the same cavity, such as 1CER30F35S2 and 1CEL30F20S150/32, but these are unnecessarily complicated which effects the price of the valves. All these consume more or about the same amount of energy as 1CE30N16S5 according to Appendix C. All in all, the VPL574 spool and the ½" hoses should be used no matter which load control valve is chosen.

More promising new solutions would be the assemblies according to Figures 44 and 45 if the binlift levers are switched to electrical. These two solutions should save energy and remove oscillations. The first assembly to be tested could be according to Figure 44 and if this has pressure peaks in chamber A, assembly according to Figure 45 is an option. Work port pressure reliefs (also called shock valves) are recommended with the solution according to Figure 44.

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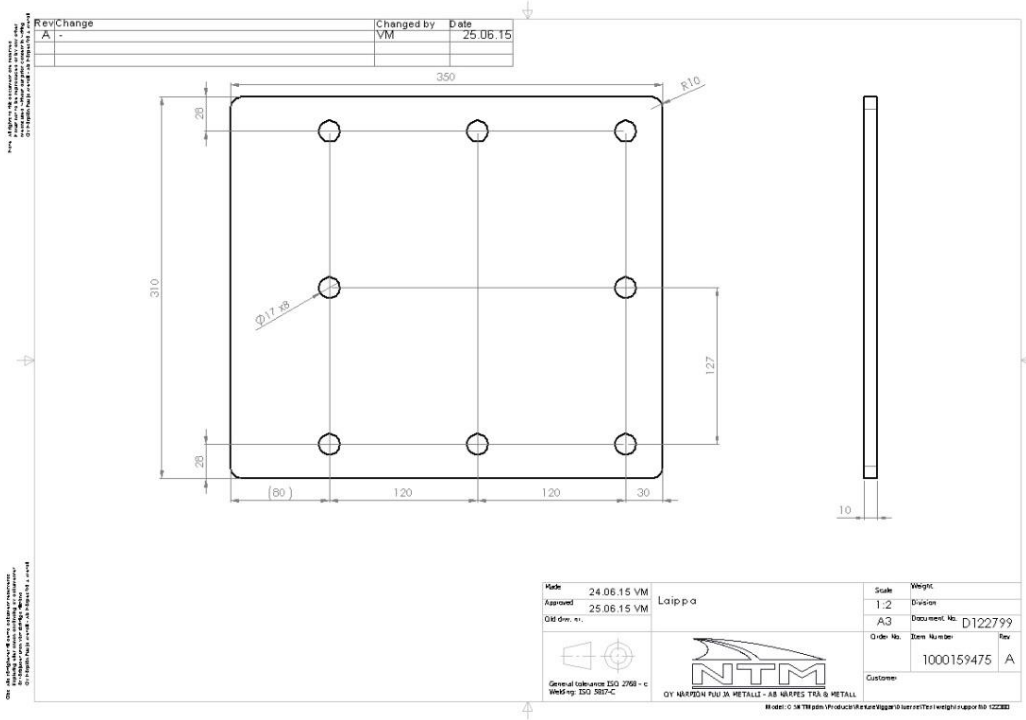
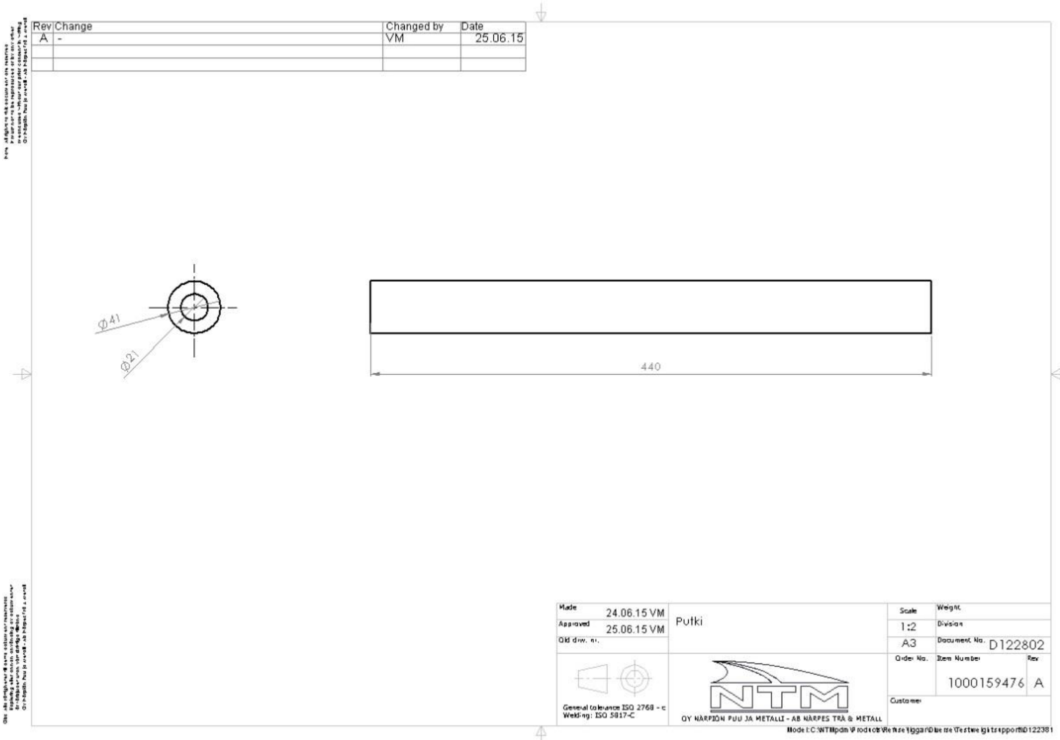
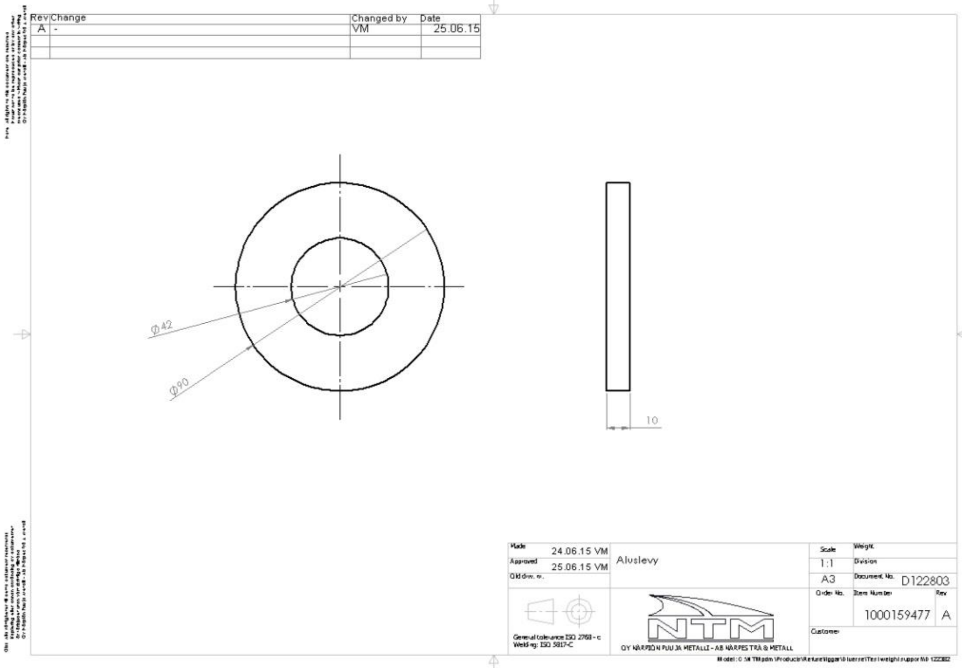
APPENDIX A: DESIGN DRAWINGS AND ASSEMBLY PICTURE OF THE TRUNNIONS







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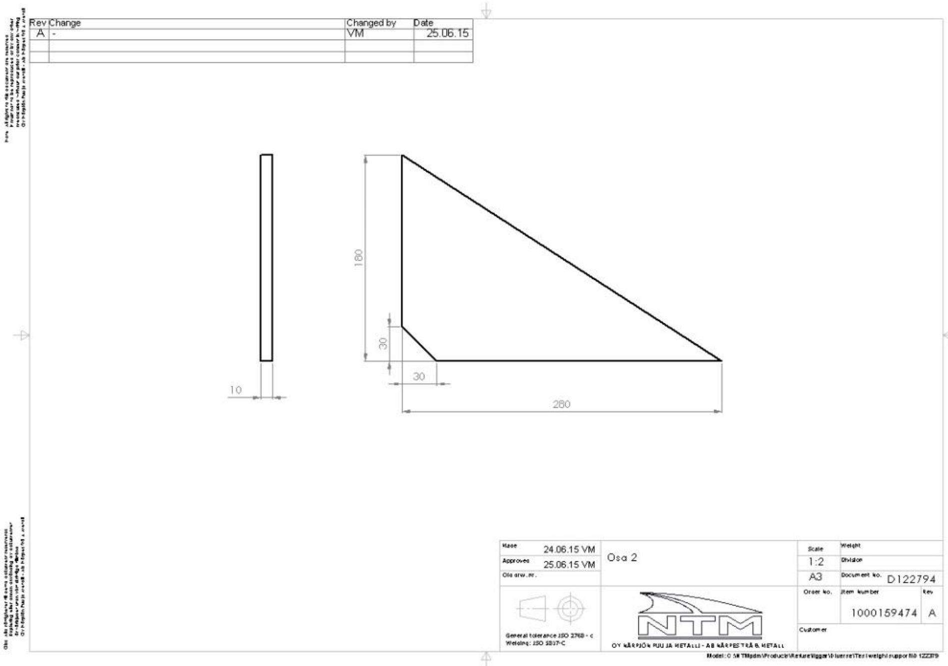

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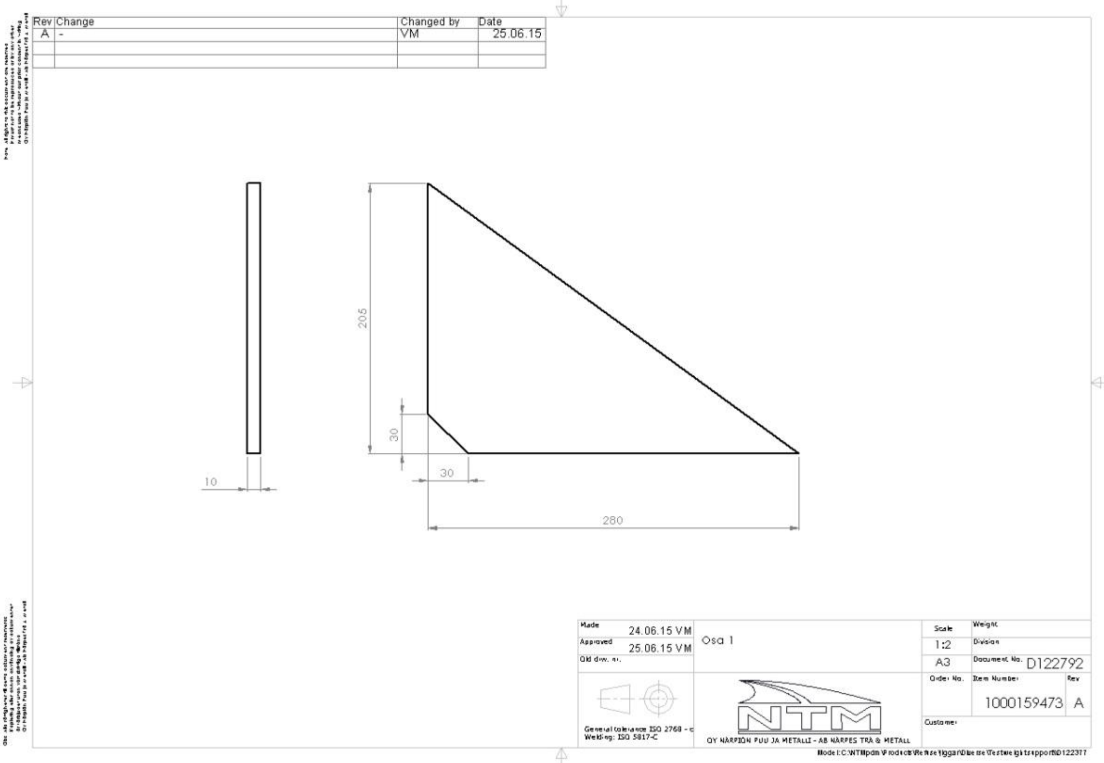
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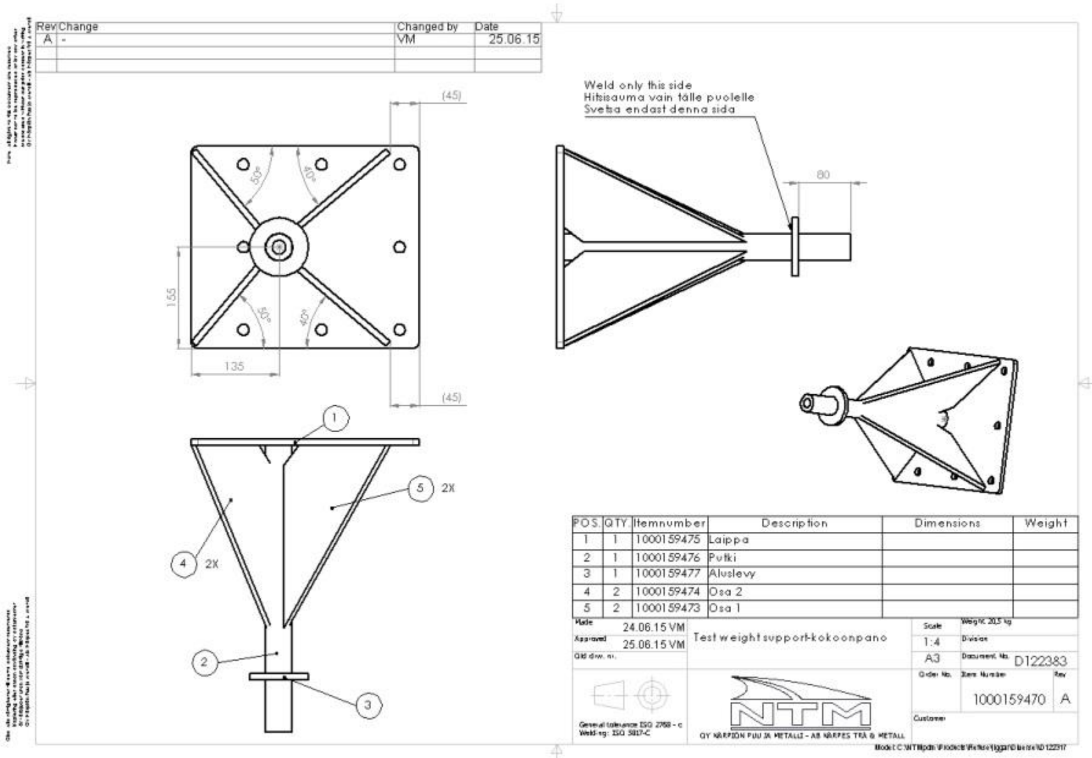
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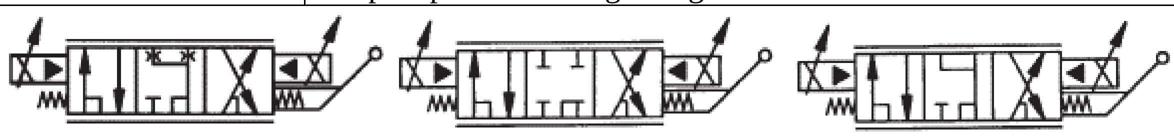
APPENDIX B: LIST OF VALVES AND VALVE SPOOLS USED IN MEASUREMENTS

Load control valve	Features
Eaton 1CE30N16S5	Standard overcenter valve, 5:1 pilot ratio, 30 lpm flow, fixed 160 bar setting
Eaton 1CEB30F35S5	Fully balanced overcenter valve, 5:1 pilot ratio, 30 lpm flow, adjustable pressure setting
Eaton 1CEL30F20S150-x	Two stage overcenter valve, primary pilot ratio 4.3:1, secondary pilot ratio 0.4:1, 30 lpm flow, pressure setting fixed 150 bar + adjustable x bar
Eaton 1CE30N16S25	Standard overcenter valve, 2,5:1 pilot ratio, 30 lpm flow, fixed 160 bar setting
Eaton 1CER30F35S2	Partially balanced overcenter valve, 2,5:1 pilot ratio, 30 lpm flow, adjustable pressure setting
Eaton 1CER30F35S4	Partially balanced overcenter valve, 4:1 pilot ratio, 30 lpm flow, adjustable pressure setting
Eaton 1CPB30F2S	Pilot ratio 0 overcenter valve, 30 lpm flow, pressure setting from 5 to 20 bar
Sun CBBGLJN	Standard overcenter valve, 4,5:1 pilot ratio, 20 lpm flow, adjustable pressure setting
Sun MBDPDHN	Sun Hydraulics LoadMatch, 60 lpm flow
Sun CEBCLHN	Sun Hydraulics LoadAdaptive, 3:1 pilot ratio, 40 lpm flow
Sun B10322UJ08	Fully balanced overcenter valve, 9:1 pilot ratio
Atlantic Fluid Tech CB000100-M-A	Pilot ratio 0 overcenter valve, 40 lpm flow, pressure setting from 10 to 30 bar
Comatrol CB10AV-1-C-1E-B-SE	Fully balanced overcenter valve, 10:1 pilot ratio, 60 lpm flow, adjustable pressure setting
Parker MHC-010-VJSH-00B	Fully balanced overcenter valve, 10:1 pilot ratio, 37.5 lpm flow, adjustable pressure setting
G Fluid 6PB110A000GNOR00	Fully balanced overcenter valve, 12:1 pilot ratio, 40 lpm flow, adjustable pressure setting

Directional control valve spools	**Features** (Series VPL Proportional Valves 2004)
VPL544	65 lpm (motor)spool according to Figure VPL*44, open flow 57 lpm at 3.5 bar
VPL574	65 lpm spool according to Figure VPL*14, open flow 2 lpm at 7 bar
VZL30306K2	Special spool according to Figure VPL*14
VPL524	65 lpm spool according to Figure VPL*24
VPL424	40 lpm spool according to Figure VPL*24



VPL*14 VPL*24 VPL*44

Sequence valve	**Features**
Sun SCCBLAN	Atmospherically vented, 60 lpm flow, 35 - 210 bar pressure setting
Sun SCCBLEN	Atmospherically vented, 60 lpm flow, 7-28 bar pressure setting

APPENDIX C: ENERGY CONSUMPTION OF SOME SOLUTIONS THAT HAVE GOOD FUNCTIONALITY

Load control valve	Directional control valve spool	Accessory	Setting (bar)	Oil temp. (°C)	Energy down (kWs)	Energy up (kWs)	Energy up-down cycle (kWs)	Accuracy with 95,4 % reliability level (kWs)
Eaton 1CE30N16S5	VPL544	Just a reference, there are oscillations with this	160 bar	19	16.8	14.2	31.0	± 1.76
Eaton 1CER30F35S2	VPL544	3/8" hoses	160 bar	17	21.8	14.5	36.3	± 2.00
Eaton 1CE30N16S25	VPL544	3/8" hoses	160 bar	25	21.4	14.1	35.5	± 1.67
Eaton 1CEL30F20S150/32	VPL544	3/8" hoses	160 bar	26	21.3	14.4	35.7	± 1.71
Sun CBBGLJN	VPL544	3/8" hoses	160 bar	24	20.8	14.5	35.3	± 1.87
Parker MHC-010-VJSH-00B	VPL524	3/8" hoses	160 bar	24	13.9	14.7	28.7	± 1.69
G Fluid 12:1 6PB110A000GNOR00	VPL524	3/8" hoses	160 bar	20	16.0	16.1	32.1	± 1.75
Eaton 1CE30N16S5	VPL524	1/2" hoses	160 bar	23	16.5	13.1	29.5	±1.69
Eaton 1CE30N16S5	VPL574	1/2" hoses + B chamber pipe	160 bar	25	16.5	13.6	30.1	±1.79
Eaton 1CE30N16S5	VPL574	3/8" hoses + B chamber pipe	160 bar	23	17.7	14.6	32.3	±1.83
Sun CEBCLHN Load adaptive	VPL544	3/8" hoses in both chambers	160 bar	22	20.7	14.6	35.4	± 1.87
Sun B10322UJ08	VPL544	SCCBLEN with 26 bar setting for pressure level rise, 3/8" hoses	160 bar	20	14.3	15.0	29.3	± 1.75
No load control valve	VPL524	3/8" hoses	-	24	10.7	13.4	24.1	± 1.60
No load control valve	VPL524	1/2" hoses	-	26	8.7	12.2	20.9	± 1.52
No load control valve	VPL424	3/8" hoses	-	26	13.4	14.8	28.2	± 1.65
No load control valve	VPL424	1/2" hoses	-	21	11.8	13.6	25.4	± 1.69