RWTH AACHEN UNIVERSITY

IFAS Institut für fluidtechnische Antriebe und Steuerungen

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Written Examination „Fundamentals of Fluid Power“

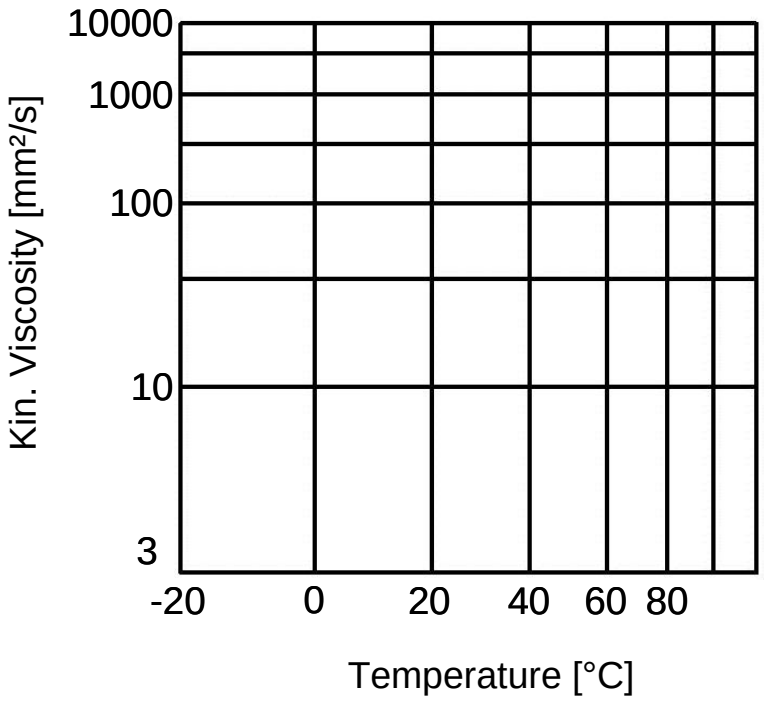
February, 25th 2016

1. Exercise / 15 Points

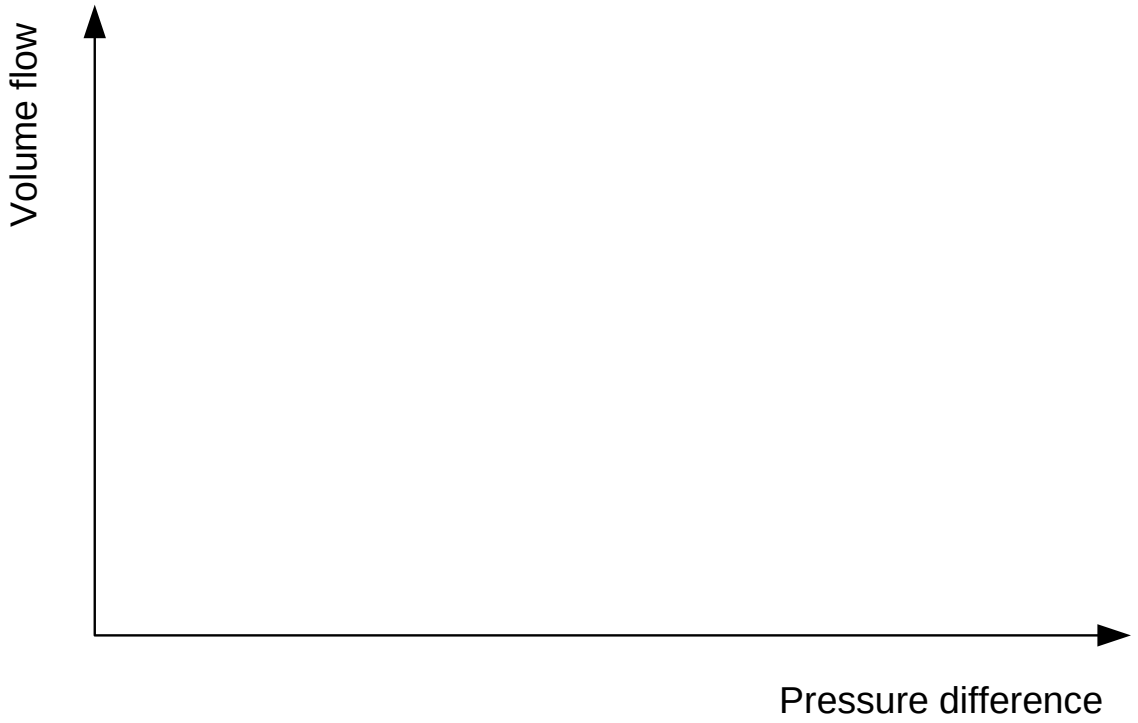
1.1 Name an advantage and a disadvantage of hydraulic drives and controls. (1 Points; 0.5/correct answer)

Advantage ☺	Disadvantage ☹

1.2 Plot the qualitative course of the kinematic viscosity of HVLP68 into the graph shown below. Additionally, plot the course of the kinematic viscosity of HLP68. Mark the curves clearly. (1.5 Points)



1.3 Plot the characteristic curve of an orifice and a throttle into the graph shown below. Mark the curves clearly and state the corresponding flow law for each resistor. (2 Points)



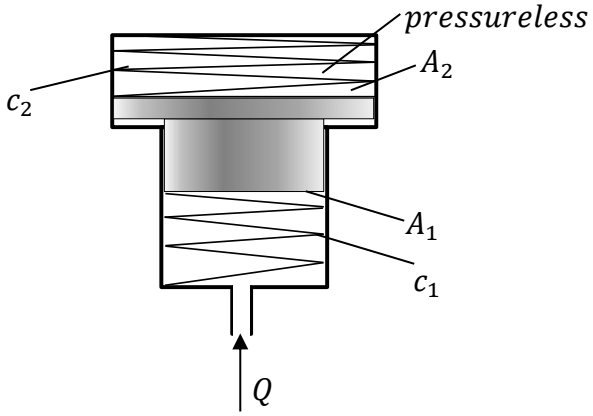
1.4 A colleague tells you: „An eccentric positioning of piston and cylinder bore in axial piston machines has no influence on the leakage.“ Please mark the right statement with a cross. (0.5 Points)

- ☐ Statement is right
- ☐ Leakage increases with increasing eccentricity
- ☐ Leakage decreases with increasing eccentricity

1.5 Due to an eccentric positioning of the piston and cylinder bore in axial piston machines friction increases and temperature rises. How does a temperature rise affect leakage here? Please mark the right statement with a cross. (0.5 Points)

- ☐ Leakage does not change here
- ☐ Leakage increases here
- ☐ Leakage decreases here

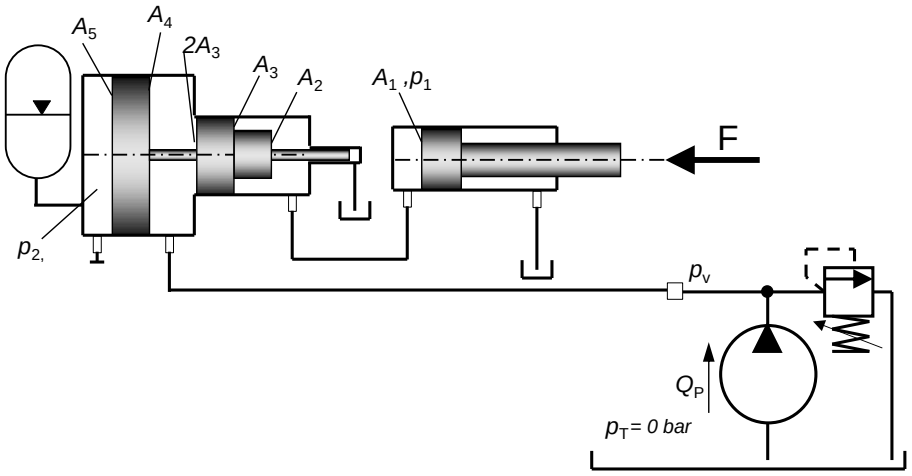
1.6 Please calcuclate the hydraulic capacity for the piston accumulator with two springs, as shown below. Given: $A_2 = 2A_1 = 2000\,mm^2$ and $c_2 = 2c_1 = 5000 \cdot 10^3\,N/m$. Please give the result using the unit [(l/min) / (bar/s)]. The two compression springs are preloaded. (1.5 Points)



1.7 Please calculate the change in density $\Delta\rho$ for HLP 46 due to a change in temperature from 15°C to 50°C. Given: $\rho_{15°C} = 880\,\frac{kg}{m^3}$, $\gamma = 0.0008\,\frac{1}{K}$ (1 Punkt).

1.8 Calculate the pressure p_2 (1.5 Points).

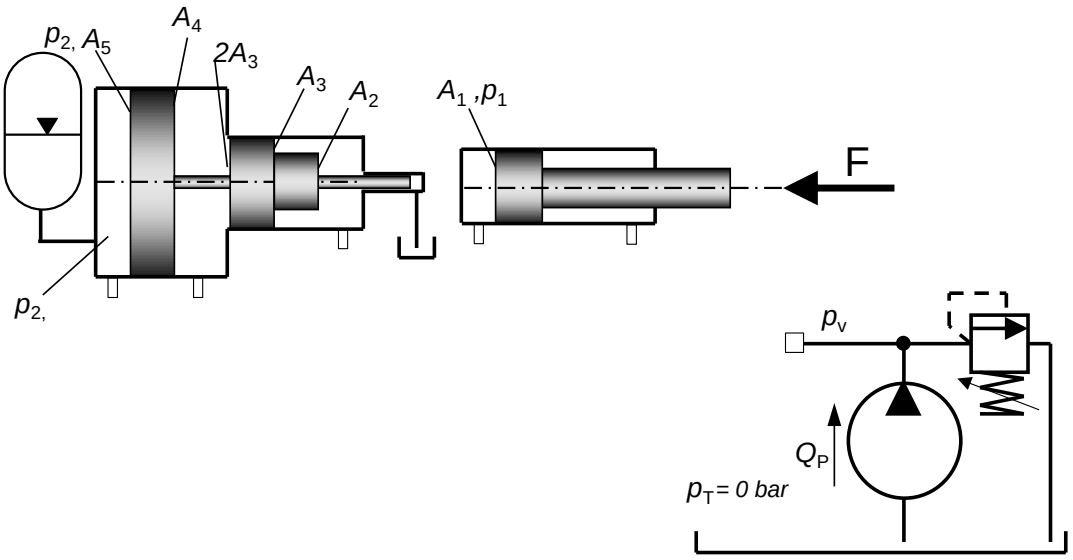
Label	Value
Area $A_1 = A_2 = A_3$	10 mm²
Area A_4	40 mm²
Area A_5	60 mm²
Pressure p_v	5 bar
Force F	1 N



1.9 Please change the interconnection in a way that the following relation applies:

$p_2 = \frac{F}{A_1}\frac{2}{3} = p_1 \frac{A_4}{A_5}$. Either connect ports or close them!

Please <u>draw</u> your changes into the picture. (0,5 Points)



Last summer the young and highly motivated researcher Horst Pauer used the institute's car without permission. Due to speeding he crashed the car into a tree and destroyed the world's only hydraulic hybrid car. His boss is not amused and gives him the task to staple all sheets of paper for the upcoming written exams. This task annoys Horst Pauer and he decides to build a hydraulic stapler. In the lab he finds a hydraulic pump (displacement V_P) driven by an electric motor. The motor controller keeps the rotational speed always constant at n_{pump}. Additionally he finds a hose with very low stiffness. The hose's diameter is huge and therefore the hydraulic resistance of the hose can be neglected. The hose has a hydraulic capacity C_H. The inductance inside the hose can be neglected as well. Furthermore he finds a manually actuated 3/2-ways valve. This special valve can be treated as a linear resistance R_H (throttle). Finally he finds a cylinder with two separate chambers that are directly connected by a massless piston rod. However the pistons themselves have a mass m_1 und m_2 and the piston areas are $A = A_1 = A_2/2$. The 3/2-ways valve is mounted onto the cylinder. So resistance, capacity and inductance of all connections between the 3/2-ways valve and the cylinder chambers can be neglected. The force applied by the springs is very small and can be neglected as well.

During operation of the stapler the pressure is slightly lower than the PRV's opening pressure.

[ALL EXERCISES CAN BE SOLVED INDEPENDENTLY FROM EACHOTHER!]

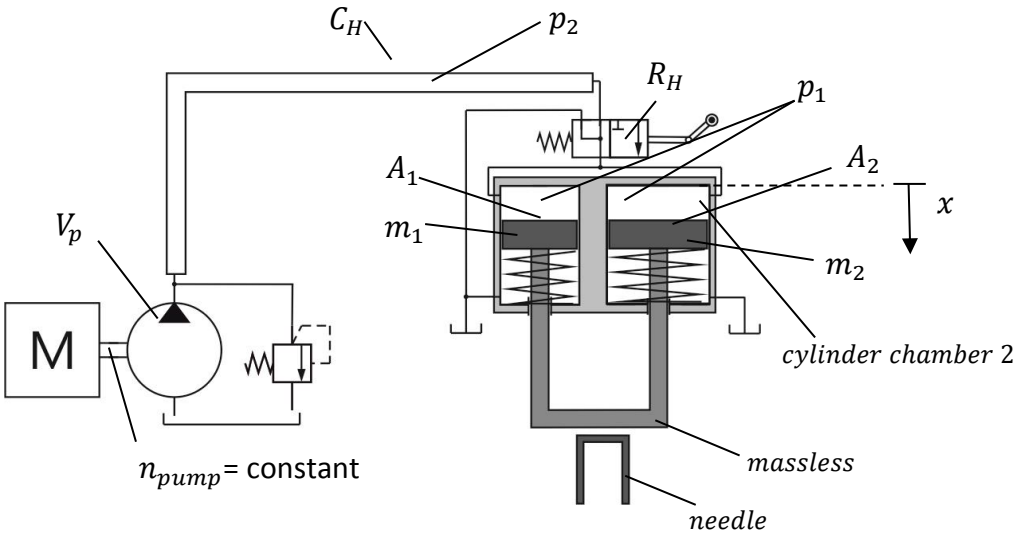


Figure 0-1: Layout of the hydraulic stapler

1.10 Please calculate the inductance of the cylinder $L_{H,Zyl}$. (0.5 Points)

1.11 When the valves lever is pressed, the valve switches immediately. Please derive the differential equation for p_1. Now the hydraulic inductance $L_{H,Zyl}$ of the cylinder is given. (3Punkte)

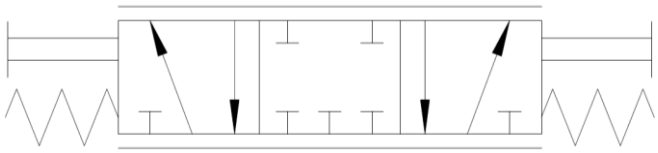
(The previously derived expression for $L_{H,Zyl}$ doesn't have to be inserted in equations.)

1.12 The stapler's performance doesn't satisfy Horst Power, so he changes the interconnections. He decouples cylinder chamber 2 from the 3/2-ways valve. Instead he connects this chamber to the tank. Now the 2/3-ways valve is only connected to the other chamber. Will the PRV open now? Please explain your answer briefly. (1 Point).

1.13 Under steady state conditions by how many percent does the velocity of the piston change, if the layout of the stapler will be changed according to the previous exercise? (0.5 Points).

2. Exercise / 10 Points

2.1 State the full name of the valve shown below. (0,5 points)



Name:_____

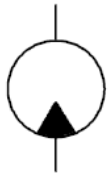
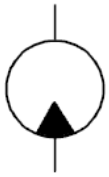
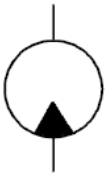
2.2 Why do certain valves contain pilot stages? (0,5 point)

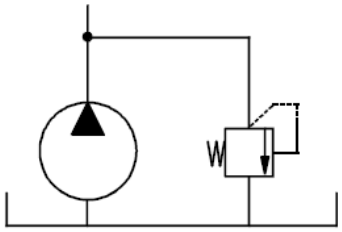
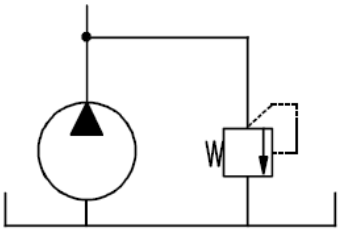
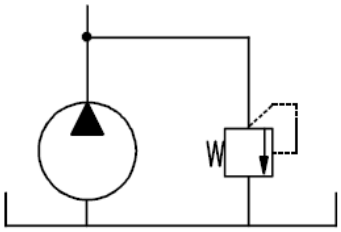
_____

_____

_____

2.3 What kind of flow control valves exist? Complete the sketches below and name the three valves completely. (1,5 points)

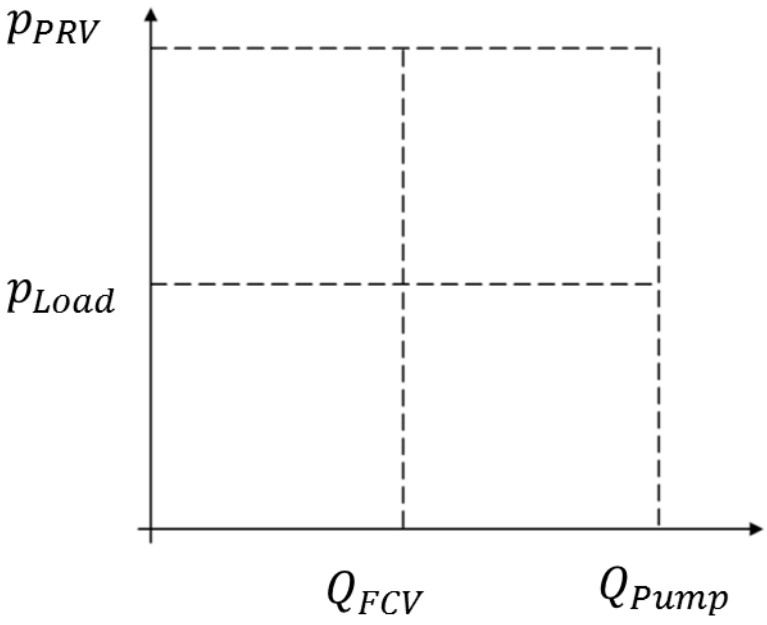
_____ _____ _____

_____ _____ _____

2.4 Imagine you are an engineer in an enterprise which designs and manufactures combine harvesters (see picture below). For the reel drive of an attachment a flow control valve to control the rotational speed shall be chosen.

Source: claas.com

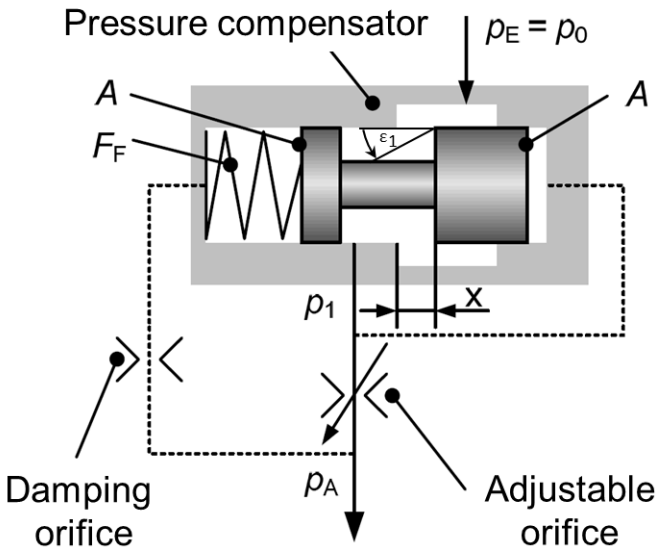
You chose a 2-way flow control valve. Draw the usable power, the dissipation and the corner power in the diagram below. Furthermore, name the places where dissipation occurs. (1,5 points)



Places, where dissipation occurs:

2.5 You have chosen a 2-way flow control valve, without having thought about why it is the right solution for the reel drive. You present the solution to your head of construction. He asks you why you have chosen a 2-way flow control valve. Explain why (exact motivation)! (In a combine harvester hydraulic system the reel drive is a load among various other loads.) (1 point)

2.6 The 2-way flow control valve you have chosen looks, simplified, like the valve in the sketch below. A damping orifice is applied for reasons of stability when the valve is operated dynamically. In this task the valve is operated stationary. If the valve is completely open, the spring is preloaded with a deflection x_{pre} (no pressure installation situation). The spring is loaded with a closing movement of the spool. The reel drive is connected to p_A. Calculate the preload deflection x_{pre}! Also take into account the flow force on the valve spool! (4 points)



$\alpha_{D,PC} = 0{,}6$ $K_{MO} = 4\ \frac{l}{min\sqrt{bar}}$

$p_0 = 220\ bar$ $n_{reel} = 300\ \frac{1}{min}$

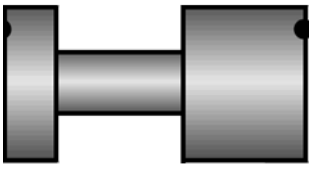
$p_A = 200\ bar$ $V_{reel\ drive} = 50\ cm^3$

$A = 12{,}6\ mm^2$ $\rho_{oil} = 890\ \frac{kg}{m^3}$

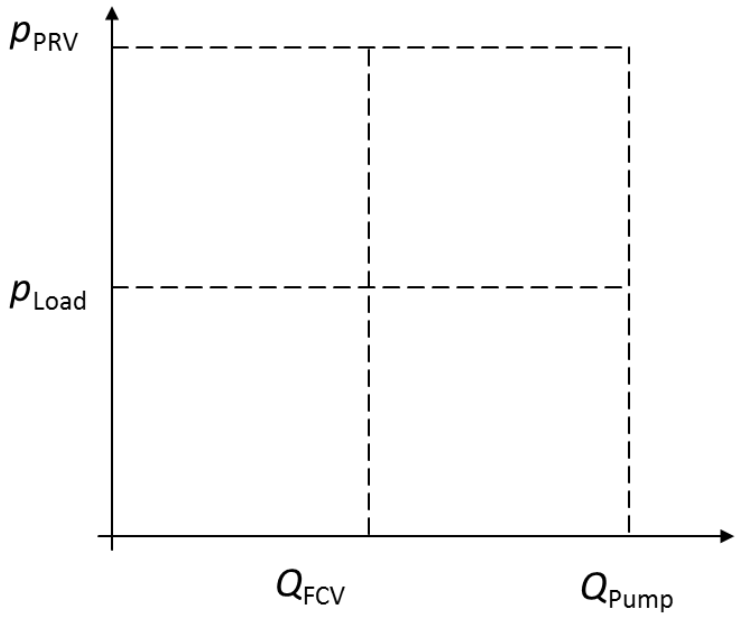
$c_S = 2{,}5\ \frac{N}{mm}$ $\varepsilon_1 = 30°$

$x_{max} = 2\ mm$

Direction of the flow force on the valve spool:



2.7 A commission can be received by the one who can provide a possibility to improve the efficiency of the system. As the engineer responsible for the hydraulics in the attachment, you want to calculate the losses of the resistive controls. The 2-way flow control valve for the reel drive is also part of this category. Calculate the losses of the 2-way flow control valve for the reel drive! (1 point)



3. Exercise / 10 Points

3.1 Name the different axial piston machine designs known. (1.5 Points)

_____

3.2 Name the axial piston machine design which lends itself to a variable displacement design. (0.5 Points)

_____

3.3 Why are an uneven number of pistons most commonly used in piston pumps? Please give a concise reasoning, which includes formulas. (1 Point)

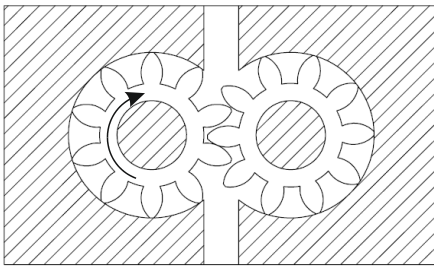
_____

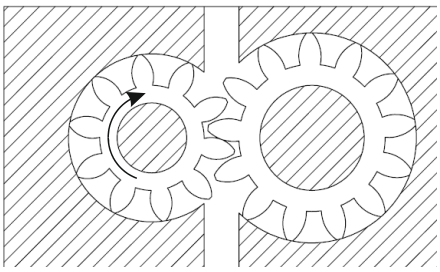
_____

_____

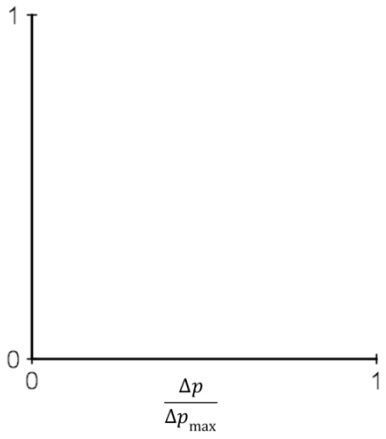
3.4 Please calculate the non-uniformity degree according to Thoma and compare your result with the approximation for the kinematic flow ripple of a six piston machine. (2.5 Points)

3.5 Does the flow rate for both external gear pumps differ from another? Give a short explanation! Assume that the driving gears as well as the rotational speeds are identical for both pumps. (1 Point)





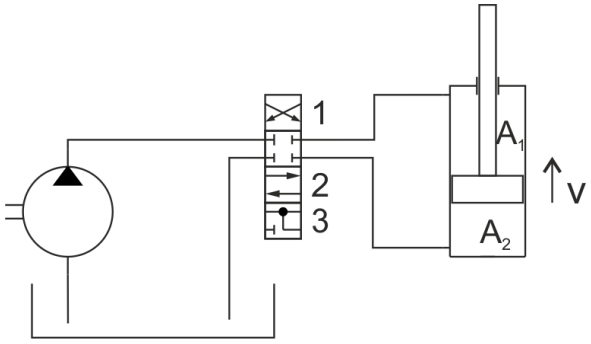
3.6 Please sketch the graphs for the hydraulic-mechanical and volumetric efficiency in relation to the system's pressure. Please label the graphs clearly. (1 Point)



3.7 Please sketch a double-stroke vane motor with external ports. Also, please indicate a direction of rotation. Corresponding to the direction of rotation, please label the high and low pressure ports. Furthermore, label the rotor and stator. (2.5 Points)

4. Exercise 4 / 10 Points

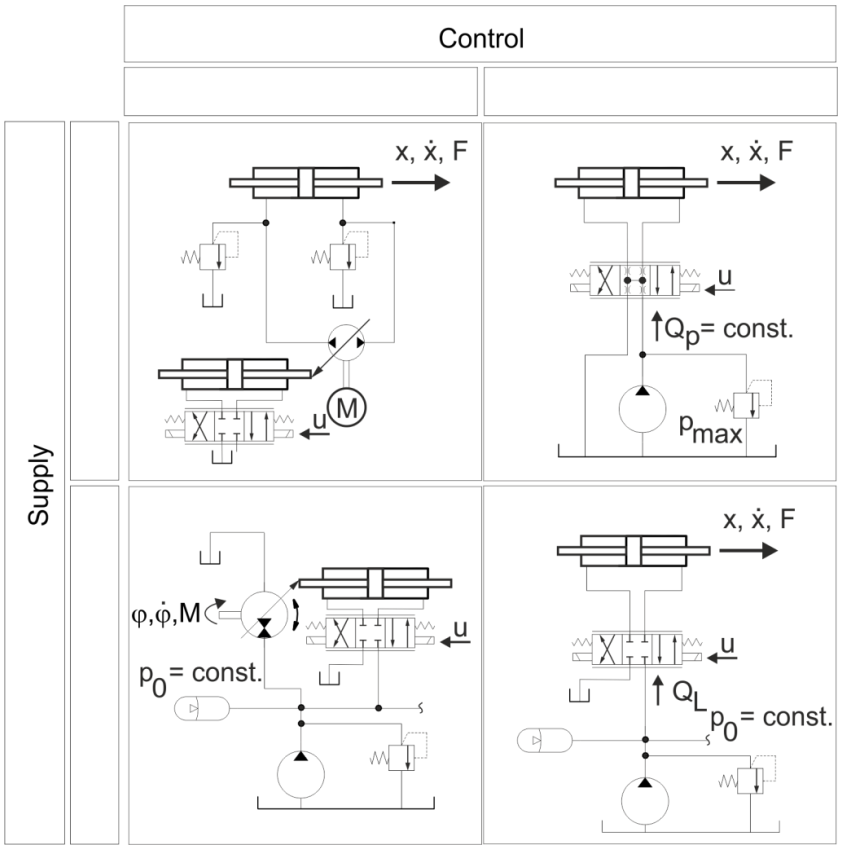
4.1 Calculate the ratio of the cylinder velocities, which occurs for the same pump volume flow and for the valve positions 1, 2 and 3. (1 point) Note: The cylinder area ratio is A_1/A_2=0,5.



$v_2/v_1 =$

$v_3/v_1 =$

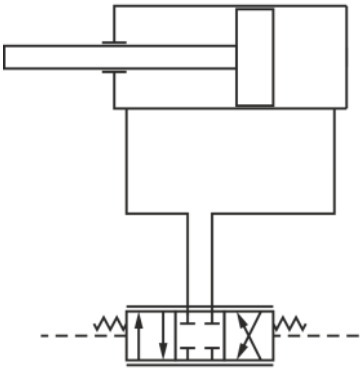
4.2 Fill in the boxes with the right controls and supplies! (1 point)

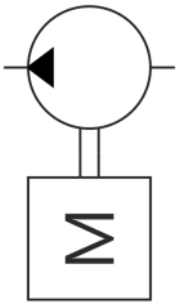


4.3 Draw a circuit of a hydraulic system suiting the requirements stated below! (3 points)

For a cylinder drive the main components have been selected already. Now the circuit, the pilot control and the secondary functions need to be defined. For this following requirements have to be met:

1. The cylinder must be driven by the drawn valve, the power for moving the cylinder must be provided by the drawn pump in an open circuit
2. The valve driving the cylinder must be pilot controlled hydraulically. However, the necessary pilot valve is not capable for the full high pressure. Accordingly, the pilot pressure needs to be below the operational pressure of the pump.
3. The power for the pilot circuit must be taken from the main circuit
4. For covering cylinder peak power an accumulator must be integrated in the circuit.
5. For improving the efficiency, the pump must be switched into unpressurised circulation when the pressure in the accumulator exceeds a predefined value.
6. Components for long life and reliable operation must be integrated in the secondary circuit. No additional combustion engine or electric motor can be used.

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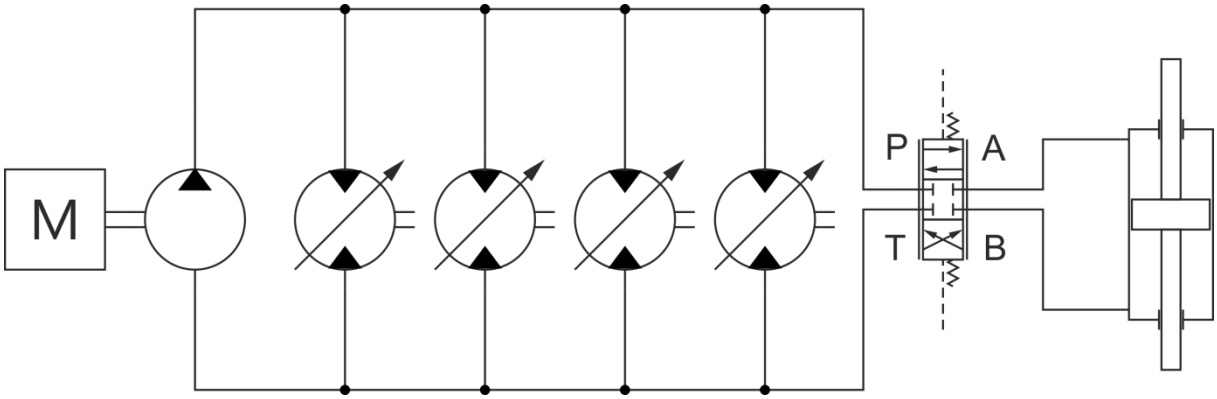
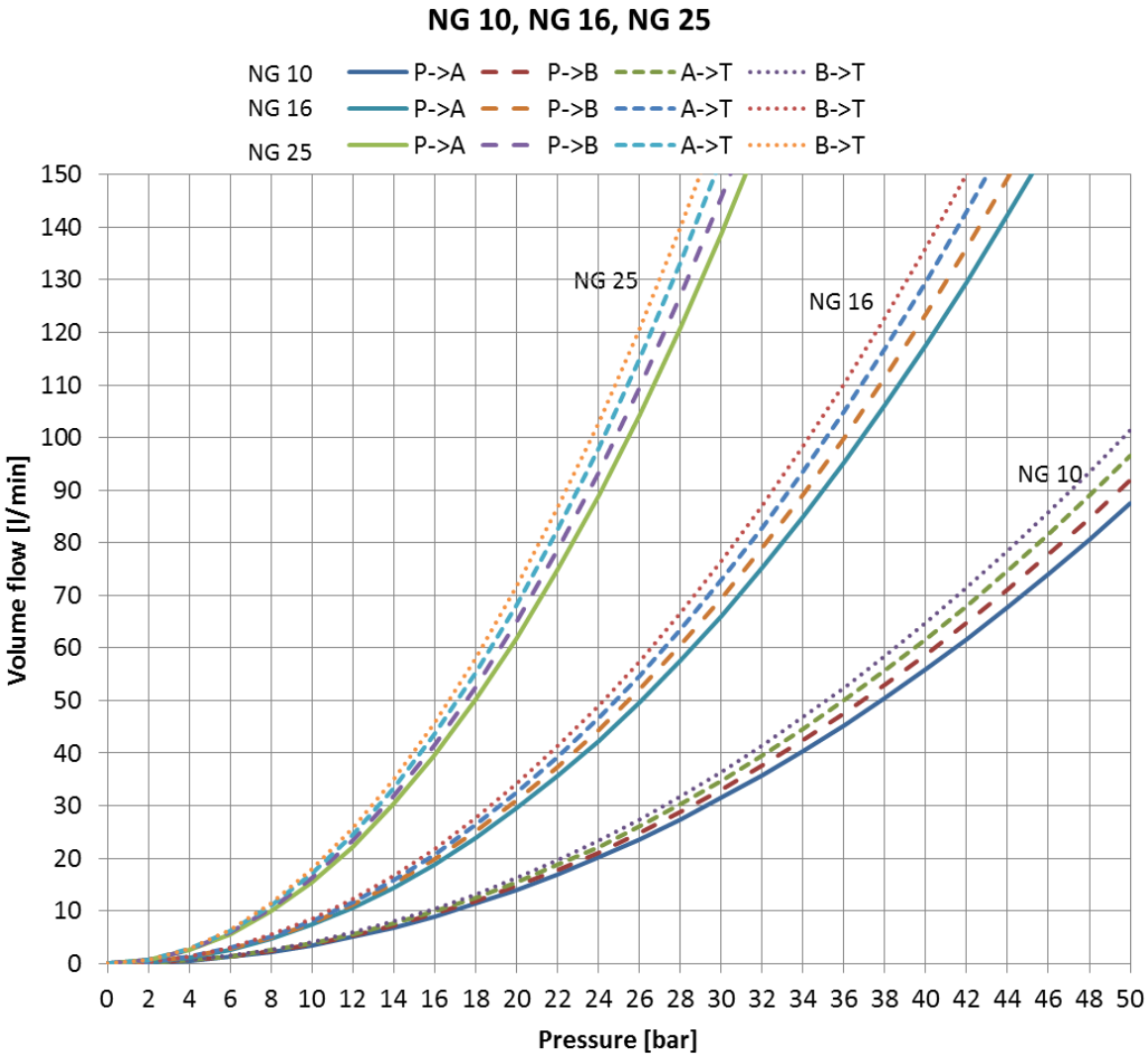
Following, the circuit for a driving and working hydraulic, as shown below, is analysed. It has the following parameters:



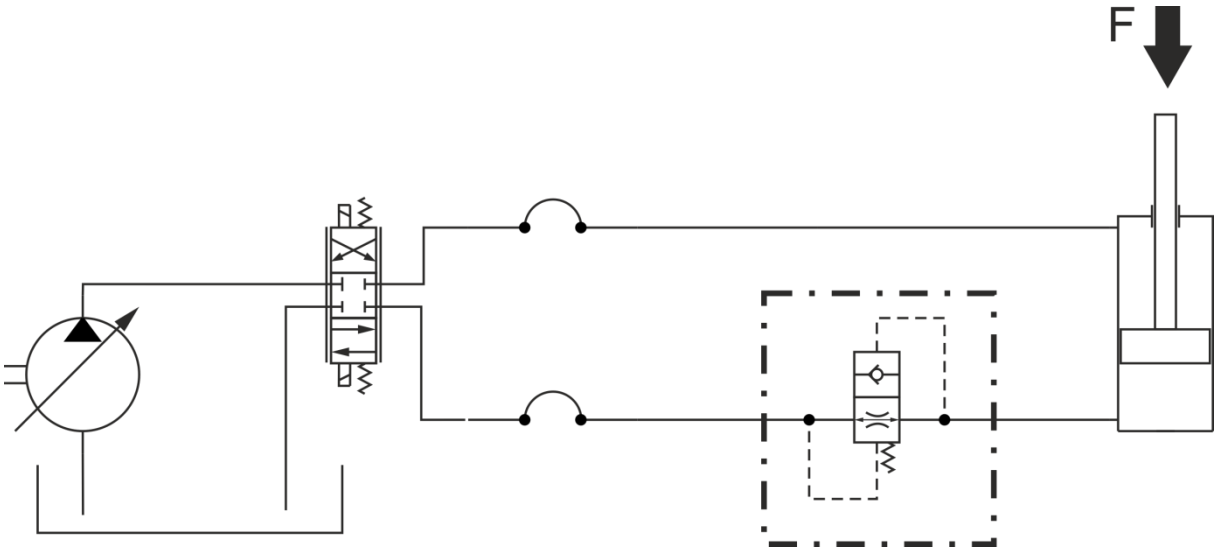
Given:	High pressure	P_{HP}=210 bar
	Low pressure	P_{LP}=10 bar
	Cylinder area	A = 4000 mm²
	Cylinder velocity	v = 0,2 m/s
	Cylinder force	F = 65000 N
	Torque per motor	$T_{\text{single motor}}$ = 100 Nm
	Amount of motors	Z_{Motors} = 4
	Motor displacment	V_{Motor} = 40 cm³
	Motor leakage	Q_{Leakage} = 9 l/min
	Hydromechanical efficiency of motors	$\eta_{\text{hm, Motor}}$ = 95 %
	Rotational speed of pump	n_{Pump} = 1800 U/min
	Pump displacement	V_{Pump} = 250 cm³
	Pump swash plate angle	α_{Pump} = 100 %
	Volumetric efficiency of pump	$\eta_{\text{vol, Pump}}$ = 90 %

4.4 Which valve size (NG10, NG 16, NG 25) fits best with given cylinder velocity and force? Why? Note: Use the valve diagram below. The solution needs to be traceable. (1,5 points)



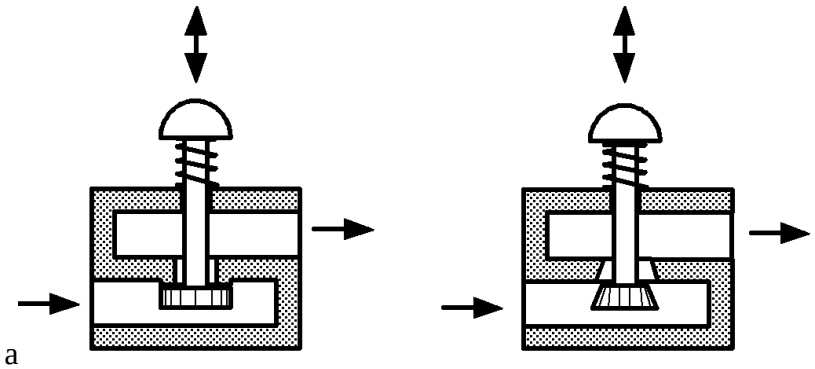
4.5 What is the motor speed, when each of the motors provides the given torque? Note: Simultaneously the cylinder is operated. If you have not been able to calculate the volume flow of the cylinder please use 200 l/min for this. (2,5 point)

4.6 For what safety function during which incident is the valve in the framed area used? (1 point)



5. Exercise / 15 Points

5.1 Name the two designs of valve seats shown in the figure (1 point)



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5.2 Give a definition of the terms below (1.5 points)

Static pressure:

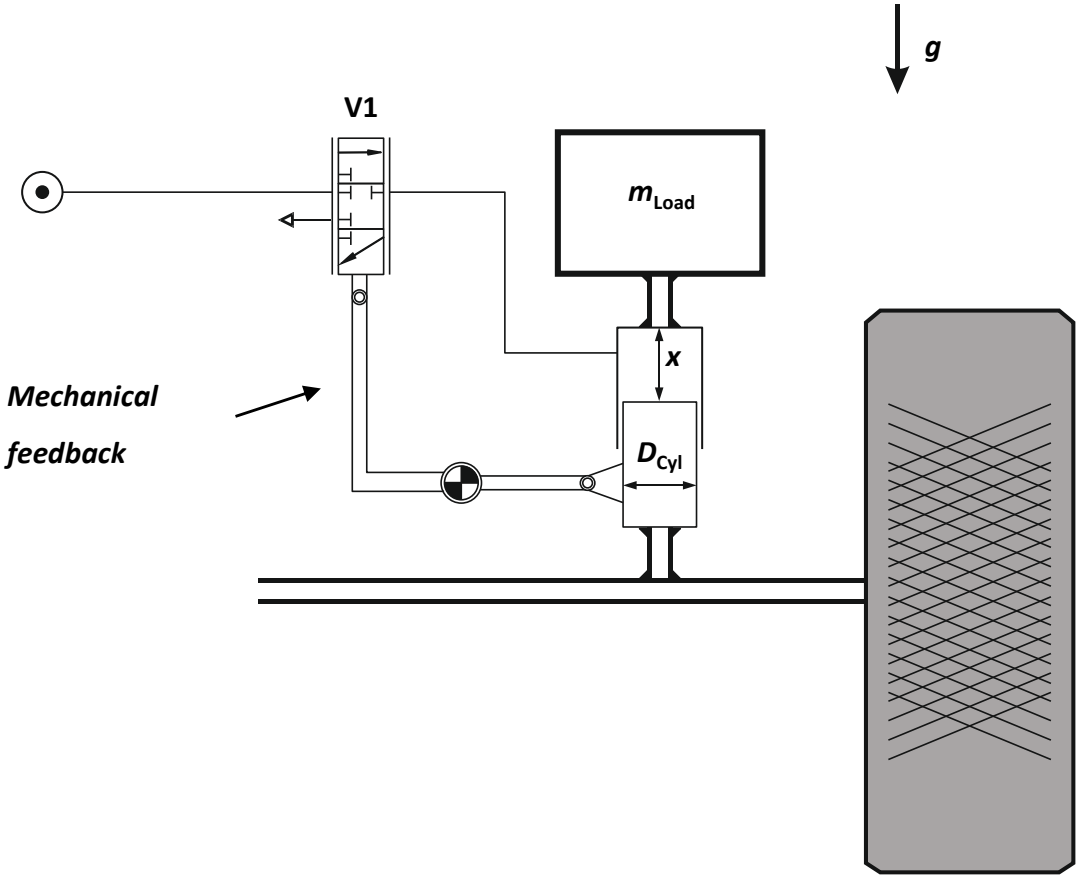
Dynamic pressure:

Total pressure:

5.3 Name three properties of air as a pressure medium and one advantage and one disadvantage in comparison to oil for each property (4.5 points)

Property	**Advantage**	**Disadvantage**

Today, modern busses are mostly equipped with air suspension based on bellows cylinders providing the ability of an automatic level control of the bus. Additionally, such a system can include a so-called “kneeling-function“, where the bus is lowered on one side when the bus is at a stop. This enables the passengers to get in and off the bus nearly at ground level. The figure shows a simplified sketch of the system.



System for automatic level control

5.4 Give the correct and complete denomination of valve V1 (1 point)

Note: The valve is only actuated by the mechanical feedback.

5.5 What is the static pressure in the cylinder with valve V1 closed? (1 point)

Given: m_{Load} = 2.5 t D_{Cyl}= 160 mm

5.6 How far does the cylinder move in, if the load on the wheel (m_{Load}) is increased by 400 kg. The valve V1 stays closed. (2 points)

Note: Assume a slow movement.

If you did not solve exercise 5.5 assume a starting pressure in the cylinder of 15 bar.

Given: Displacement before loading: x_{max} = 120 mm

5.7 Which (technical) standard volume has to be applied to the cylinder to compensate the lowering? (1 point)

If you did not solve exercise 5.6 assume a necessary pressure of 20 bar.

If you did not solve exercise 5.6 assume a lowering of 20 mm.

5.8 What is the technical work done by the compressor, if the standard volume to compensate the lowering is compressed from technical standard conditions to a maximum pressure of 20 bar? Assume an isentropic process. (1,5 Punkte)

If you did not solve exercise 5.7 assume a standard volume of 6 l.

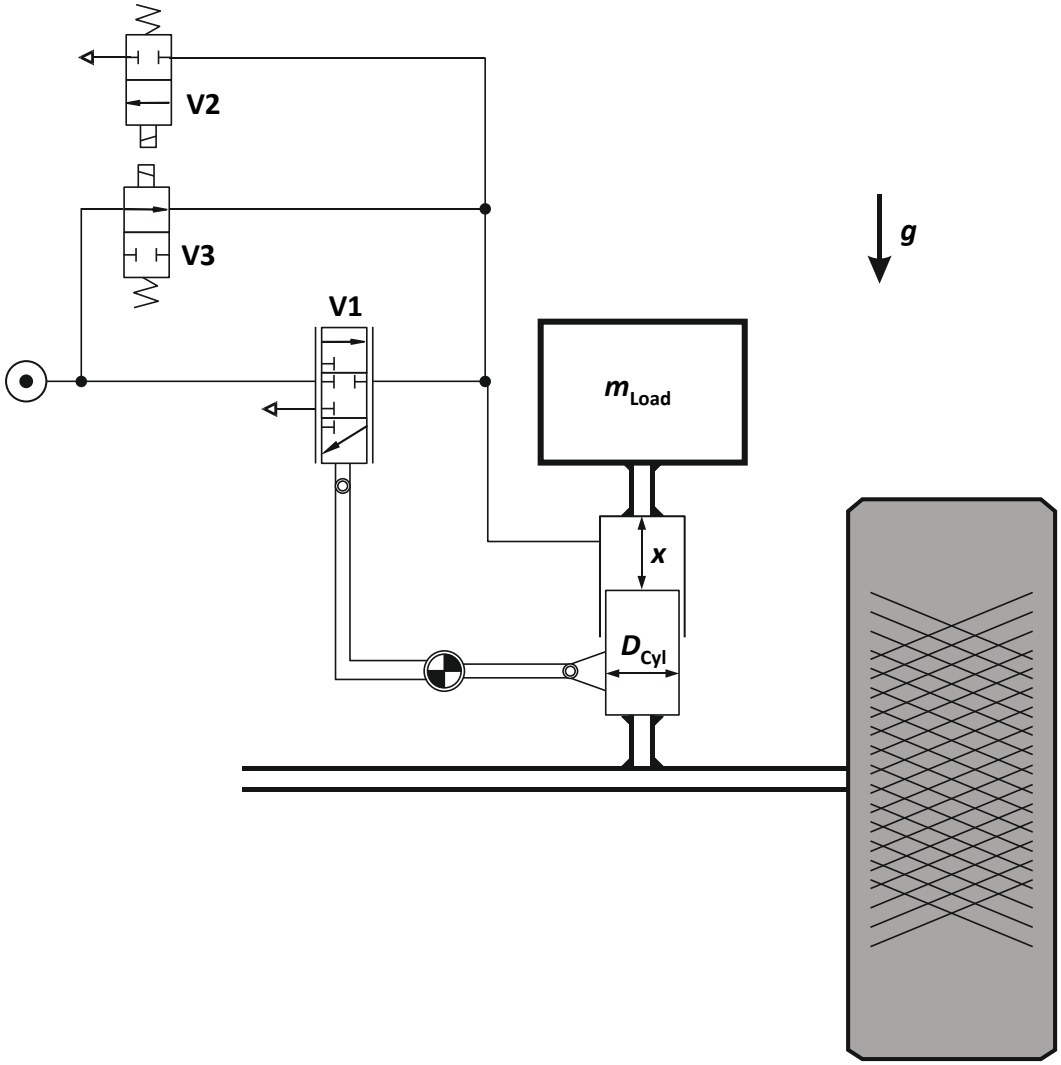
Given: $\kappa = 1{,}4$

5.9 To make the boarding of the bus more comfortable, two additional valves are added. They enable a lowering of the bus on one side at bus stops. Within 2 s, the bus shall be lowered by 80 mm at a constant speed. It comes to rest at a mechanical stop. Calculate the necessary sonic conductance of valve V2 (see next page).

Calculate the conductance in $\frac{\mathrm{Nl}}{\mathrm{bar \cdot min}}$

Changes in temperatures can be neglected.

Valve V1 is locked mechanically in its center position. (1.5 points)



Given: Δx = 80 mm b = 0,5 $T_{cyl} = 20$ °C

Cylinder displacement before lowering: x_{max} = 120 mm

6. Exercise / 10 Points

The bus manufacturer of exercise 5 is planning to implement a vacuum handling system for the transport of window panes. Figure 6-1 shows the simplified schematic of a vacuum gripper that is controlled by an ejector for the suction of a window pane. All tasks can be solved independently.

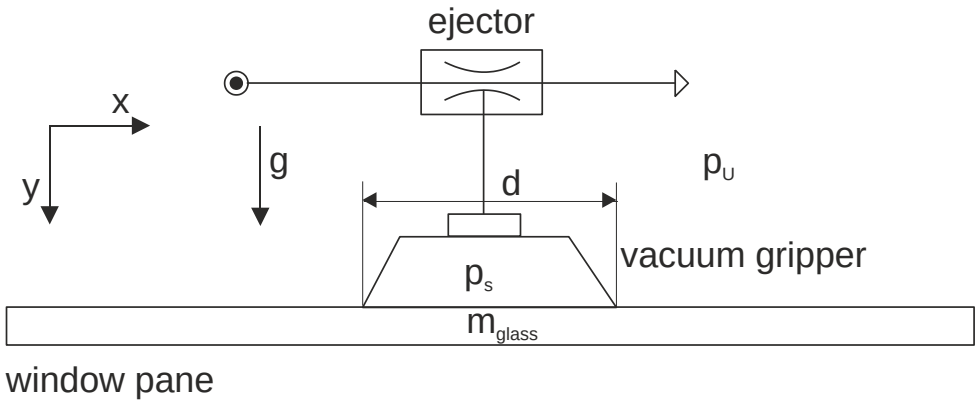


Figure 6-1: Ejector and vacuum gripper for the suction of a window pane

Window pane mass	m_{glass} = 15 kg
Ambient pressure	p_u = 1 bar
Graviational acceleration	g = 9,81 m/s²
Gripper diameter	d = 12 cm
Vertical acceleration	a_{max} = 2 m/s²

6.1 Besides gravitation the window pane is accelerated by a_{max} in negative y-direction. Determine the vacuum pressure p_s which is necessary to hold the window pane. (2 Points)

Hint: *Neglect any friction force and use absolute pressure values.*

Controlling the ejector some other pneumatic components are needed which you are about to add to the circuit diagram.

Note: *Please draw into the circuit diagram located below task 6.4.*

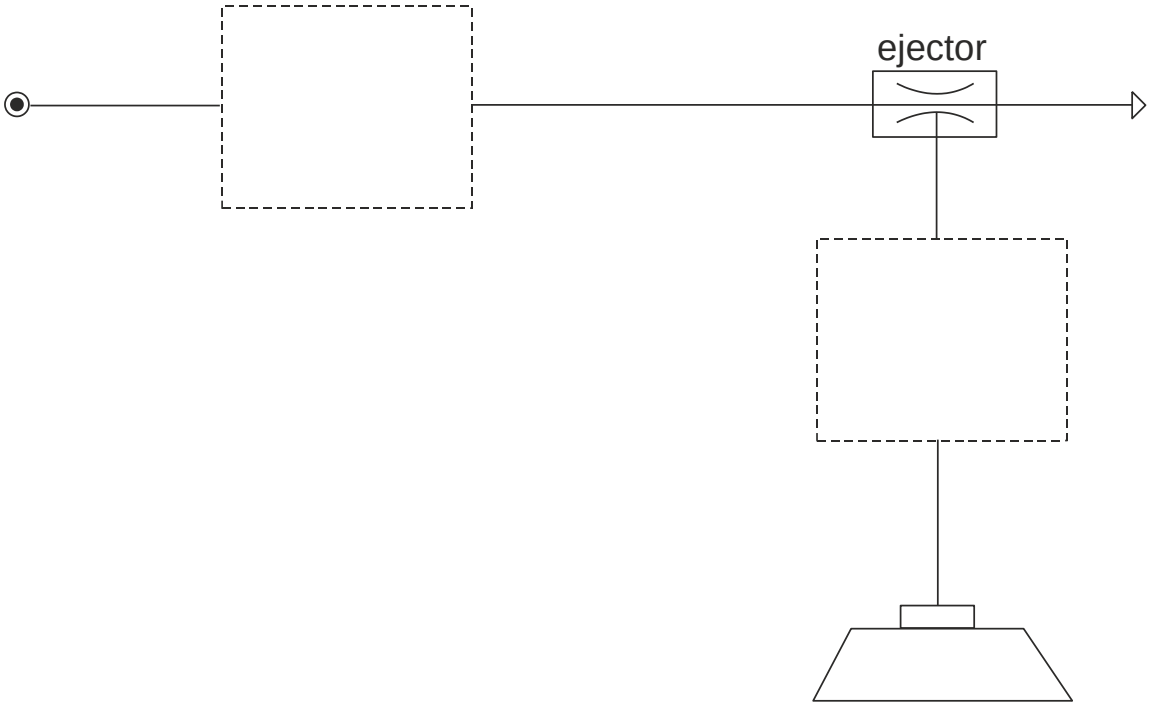
6.2 Add a 2/2-way valve to the inlet connection of the ejector which is normally closed and manually controlled to open. (1 Point)

6.3 In order to keep the vacuum even when the ejector is shut off or in case of pressure loss a component is needed between ejector and gripper. Draw the component and state the correct name. (1 Point)

Component: _____

6.4 After transportation the window pane is supposed to be released by another, **electronically** controlled valve. Add the valve to the schematic. (1 Point)

Circuit diagram for tasks 6.2-6.4:



In the subsequent process a time-dependent sequence control shall be used. The necessary components are shown in Figure 6-2.

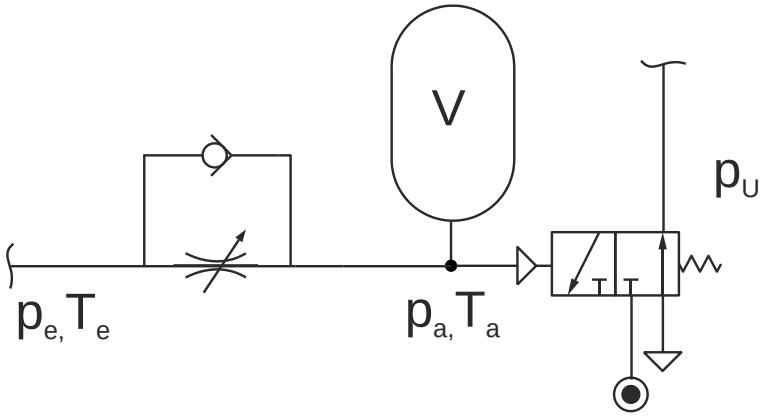


Figure 6-2: Pneumatic time-dependent sequence control

Total volume	V = 0,1 l
Inlet pressure	p_e = 7 bar
Inlet temperature	T_e = 293,15 K
Valve spool diameter	d = 10 mm
Max. spool displacement	s = 2 mm
Spring pre-tension	F_{pre} = 10 N
Spring rate	c = 2 N/mm
Flow coefficient of the throttle	$\alpha_D \cdot \psi_{max}$ = 0,3
Specific gas constant	R = 288 Nm/(kgK)
Ambient pressure	p_u = 1 bar

6.5 Determine the pressure that is necessary for the **full** opening of the valve. (1 Point)

Note: *Neglect friction and flow forces.*

If you could not solve task 6.5 assume p_a as 3 bar in the following.

6.6 Calculate the pressure ratio among the adjustable throttle and name the occurring flow state (1 Point)

Pressure ratio: _____

Flow state: _____

If you could now solve task 6.6 assume supercritical flow in the following.

6.7 The adjustable throttle should be adjusted to achieve the opening pressure p_a after t = 3 s. Determine the area of the adjustable throttle A. (3 Points)

Note: *Assume isothermal conditions. Only consider the total volume V that has to be filled after the throttle. The volume is initially filled with air under technical standard reference conditions.*