Institut für fluidtechnische Antriebe und Steuerungen

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Written Examination „Fundamentals of Fluid Power“

August, 25th 2016

Matr.-Nr.:

1. Exercise / 15 Points

A flywheel for energy storage is driven by a hydro motor. In loaded condition, the wheel requires $P_{2,mech}$ = 1.5 kW, to maintain the speed. It rotates at n_2 = 10,000 min^{-1}. The necessary effective flow rate amounts to $Q_{2,eff}$ = 105.26 l/min. The motor's hydraulic mechanical efficiency η_{2hm} is 0.92 and the volumetric efficiency η_{2vol} = 0.95.

1.1 What is the value of the effective torque at the motor shaft $M_{2,eff}$? (1 point)

1.2 What is the value of the displacement of the motor V_2? Give all intermediate steps and results. (2 points)

1.3 How great has to be the pressure difference over the motor to fulfil the task? Give all intermediate steps and results. If you did not solve the previous tasks, use $M_{2,eff}$ = 1.8 Nm and V_2 = 12 ccm for your calculations. (2 points)

1.4 The supplying pump for the motor has an overall efficiency of η_1 = 0.85. How much of the hydraulic system's power is dissipated? Give your result in percent (1 point)

1.5 Why is a hydraulic system used to drive the flywheel? Name two advantages of hydraulic systems. Furthermore, name two disadvantages. (2 points; 0.5 points for each correct answer)

1.6 Orifices are commonly used in hydraulic systems to regulate the volume flow. Sketch a typical orifice. Please include the streamlines. How is the contraction coefficient α_K defined? Mark the relevant spots and values in your sketch. (2 points)

1.7 Name the other hydraulic resistance used in hydraulic systems. What is the main difference to an orifice? (1 point)

1.8 You extract an oil sample of a system and measure a particle-count according to ISO 4409 of 18/15/11. Explain this specification. Write your result in the following table. Note the extract of ISO 4406. (1.5 points)

Specification	**Explanation**
18	
15	
11	

Particle-count per ml from	to	Ordinal number
2500000	-	> 28
1300000	2500000	28
640000	1300000	27
320000	640000	26
160000	320000	25
80000	160000	24
40000	80000	23
20000	40000	22
10000	20000	21
5000	10000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14

Particle-count per ml from	to	Ordinal number
40	80	13
20	40	12
10	20	11
5	10	10
2,5	5	9
1,3	2,5	8
0,64	1,3	7
0,32	0,64	6
0,16	0,32	5
0,08	0,16	4
0,04	0,08	3
0,02	0,04	2
0,01	0,02	1
0	0,01	0

Level of purity according to ISO 4406:1999

1.9 Name 5 kinds of additives, which can be added to hydraulic oil. (2.5 points)

2. Exercise / 10 Points

2.1 Hydraulic fluids can be separated in 4 groups. Name two of those groups and give an example of a fluid for each group! (1 point)

1. ____________________ Example: ________________________________
2. ____________________ Example: ________________________________

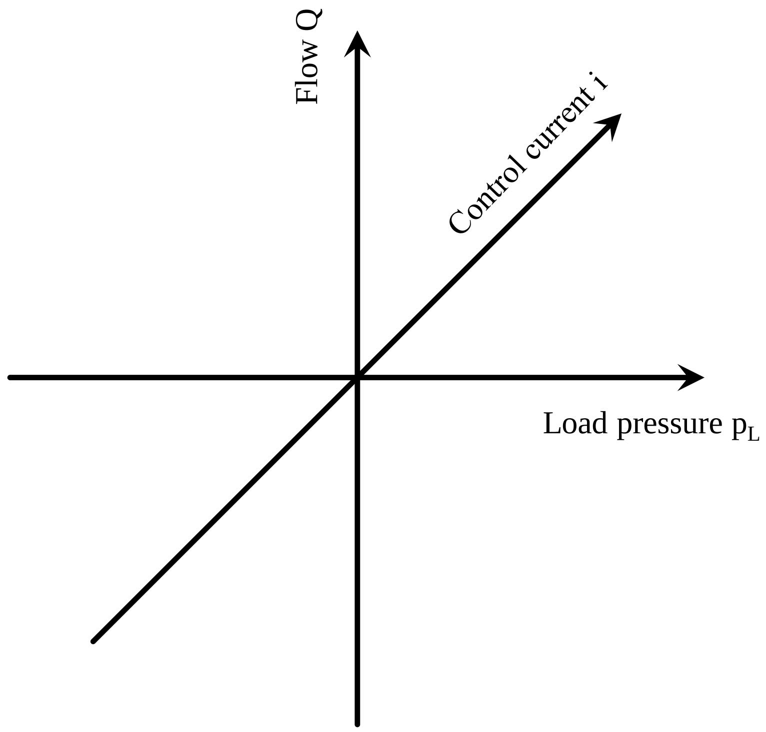
2.2 The dynamic viscosity depends on the pressure of the fluid. Write down the formula for the pressure dependency of the dynamic viscosity for a constant temperature. (0.5 points)

Formula: ____

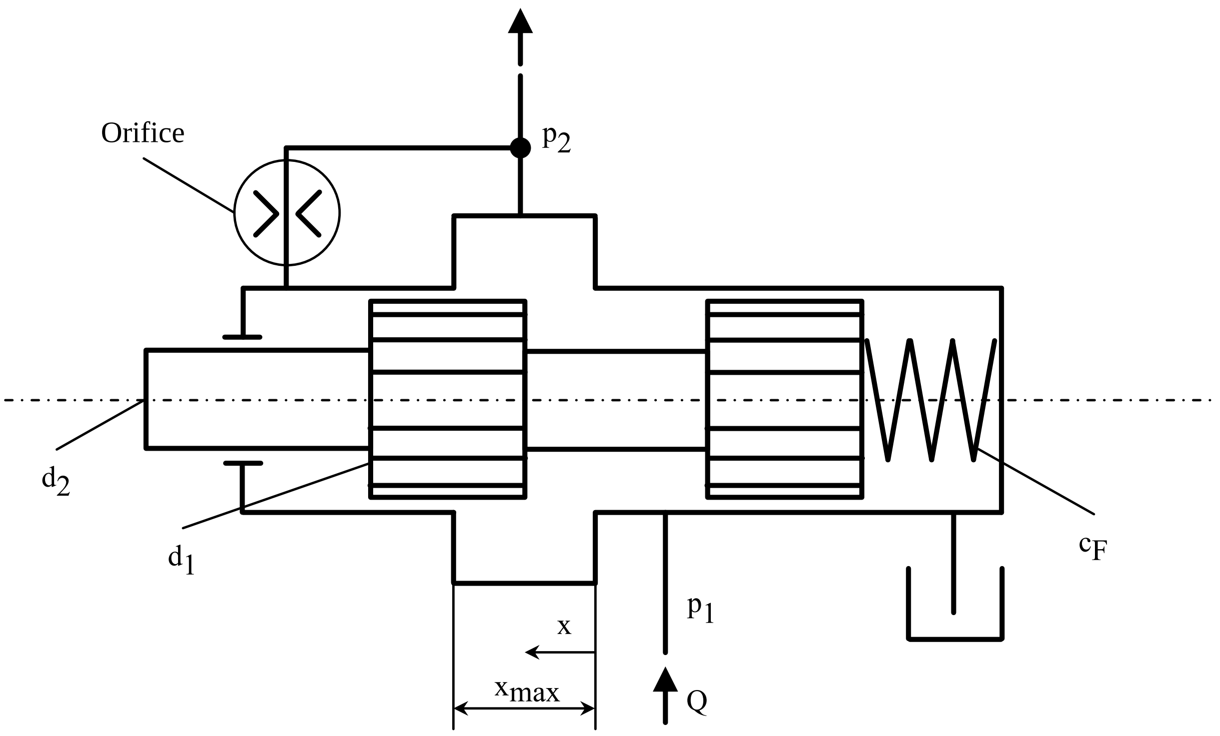
2.3 Name two filtration principles! (1 point)

1. ____
2. ____

2.4 Draw the stationary characteristic curve for a directional control valve ($y \sim i$) in the diagram below ($Q = f(p_L)$). Also draw the dependence of the characteristic curves on the control current i! (1 point)



2.5 The following valve is given by a sketch:



What kind of valve is drawn above (purpose of the valve)? (0.5 points)

Valve: ____

What purpose does the orifice serve? (0.5 points)

Purpose of the orifice: ____

The stationary operating point and the data of the valve are given:

$Q = 200$ l/min

$x_{max} = 5$ mm

$p_1 = 200$ bar

$c_F = 100$ N/mm

$p_2 = 100$ bar

$\alpha_D = 0{,}6$

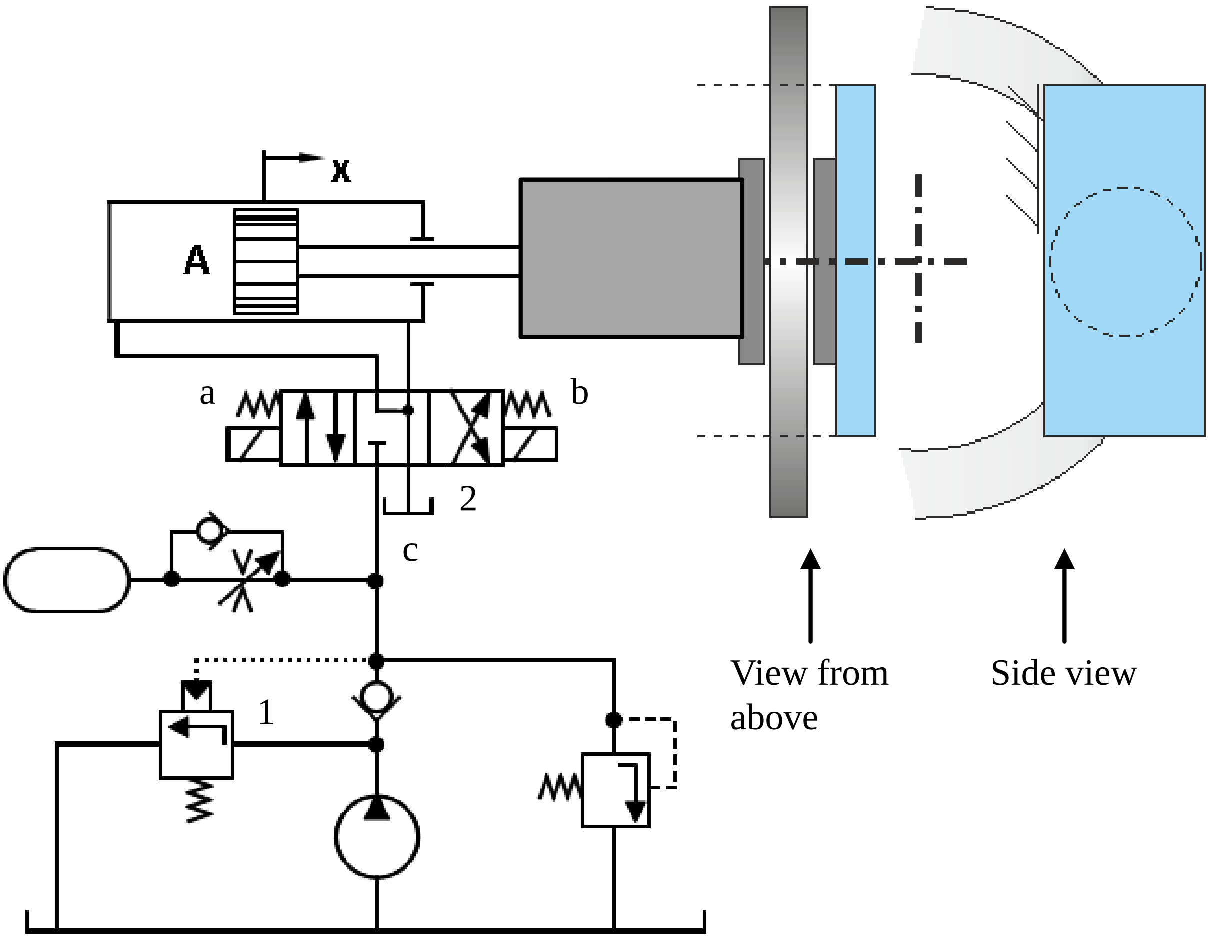
$d_1 = 15$ mm

$\rho_{oil} = 870$ kg/m³

$d_2 = 10$ mm

Calculate the preload stroke x_{pre} for the given operating point! The valve spool touches the left end of the chamber, when the valve is completely open ($x=x_{max}$). Spring preload is applied by mounting the cap on the right end of the valve. The cap closes the spring chamber, which is connected to the reservoir. (2.5 points) Note: Flow forces can be neglected.

2.6 The following hydraulic parking brake with an electrically controlled accumulator charging circuit is given:



Given:

Total accumulator volume $V_0 = 1l$

Ambient- and beginning temperature T_0 = 293 K

Gas filling pressure $p_0 = 10$ bar

Piston surface A = 78.5 cm²

Gas: diatomic, ideal gas

Isentropic exponent $\kappa = 1.4$

Brake operating pressure $p_1 = 80$ bar

While operating the accumulator has to hold the brake operating pressure and to compensate the leakage losses in the circuit. The losses due to leakage can be neglected in the following tasks. When the operating pressure drops below a certain value, valve 1 closes. Otherwise, valve 1 is open and the pump works in unpressurised circulation.

After a longer pause, the pump is switched on and pressure is built up very fast to p_1, while valve 2 is switched to position c (middle position). Which volume ΔV is pumped into the accumulator? (0.5 points)

To which temperature does the gas heat up shortly after p_1 is reached? (0.5 points)

When p_1 is reached, the pump fails. What is the stationary value of the system pressure? (1 point) Note: Every component of the system, except for the diatomic ideal gas, can be considered non temperature dependent and leakage free.

After the pressure and the temperature have reached their stationary values, valve 2 is switched to position a. The piston is moving very fast and reaches a stroke of $\Delta x = 20$ mm. It is thereby closing the brake. With which force F_{brake} does the piston press on the brake disc? (1 point)

3. Exercise / 10 Points

3.1 One of the causes for pulsation is the kinematic pulsation. Please name the other type of pulsation. (0.5 points)

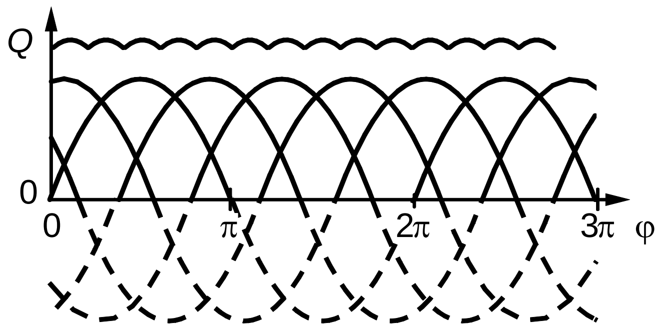
____

3.2 Which displacement principle does not allow for variable displacement? Please give two examples of said principle of displacement. (1.5 points)

____

1. Example ____
2. Example ____

In order to calculate the kinematically induced ripple it is necessary to know the maximal as well as the minimal flowrate throughout one revolution. The diagram below shows the flow rate of a 5-piston pump in relation to the rotational angle. With such a diagram it is possible to calculate the kinemativally induced ripple. But the exact solution requires an equation.



5 – piston pump

3.3 Under which circumstances does a minimal flow occur? (1 point)

____

____

3.4 Which rotational angle corresponds with the first maximum of the flow rate? (0.5 points)

____

____

3.5 Please give the expression $\left[\sum \frac{dV_K}{d\varphi}\right]_{min}$ for a 5-piston pump. Simplify the expression. (1 point)

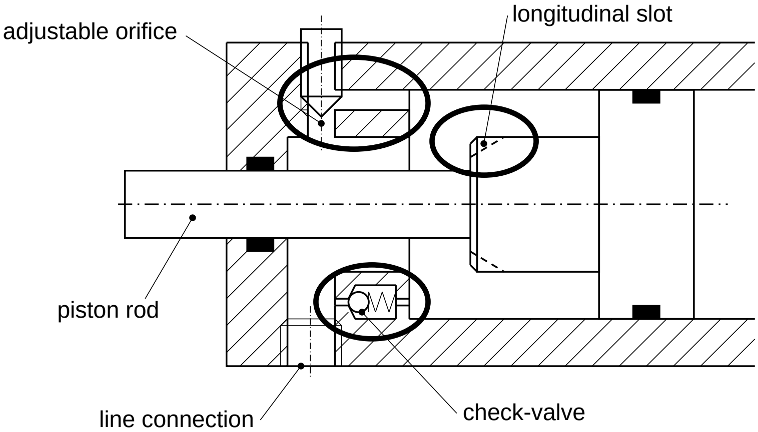
$$\left[\sum \frac{dV_K}{d\varphi}\right]_{min} =$$

3.6 Calculate the exact degree of non-uniformity for the discussed 5-piston pump. (1.5 points)

Many hydraulic pumps and motors can be designed with a continuous shaft.

3.7 Which pump design is not compatible with a continuous shaft? (0.5 points)

3.8 Using the cylinder cross-section given below, explain the marked features and explain briefly their purpose. (1.5 points)



Adjustable orifice: ____

____

Longitudinal slot: ____

____

Check-valve: ____

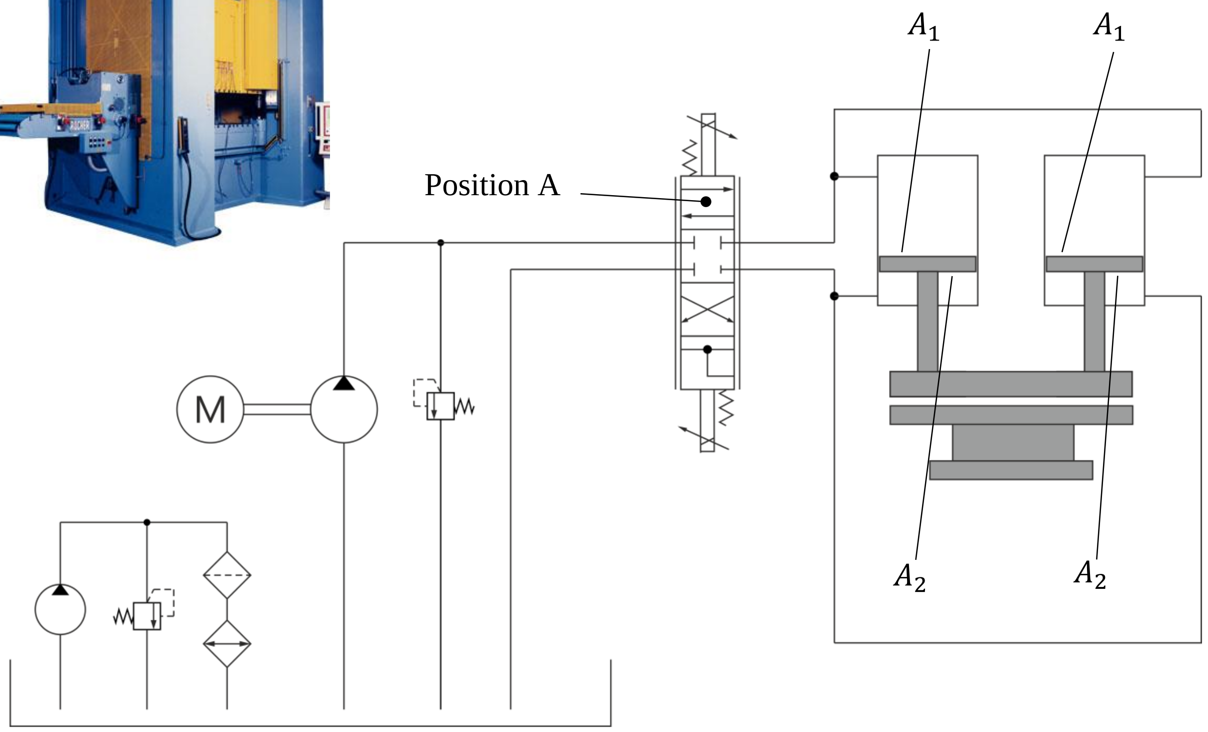
____

3.9 Please sketch an axial piston machine as a bent axis design. It is sufficient for you draw only one piston in the cross-section. Please label the used components. Furthermore, please remember to include in your drawing the centre lines. (2 points)

4. Exercise / 10 Points

Horst Pauer has been charged with developing a hydraulic press. Now the hydrostatic press drive has to be designed. All necessary parameters are given in the table below. The hydraulic schematic is given below as well. (Gravity forces are negligible)

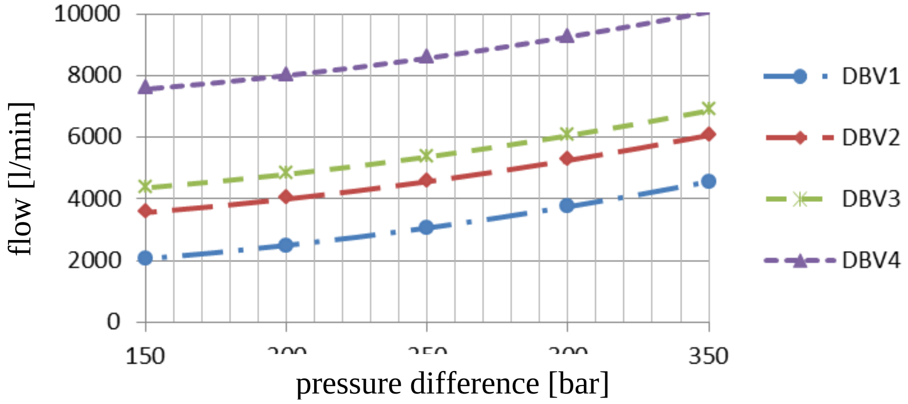
Motor speed [rpm]	1500
Oil density [kg/m³]	870
Area valve [mm²]	5000
Flow coefficient valve [-]	0.9
Piston area A_1 [mm²]	60.000
Piston area A_2 [mm²]	20.000
Volumetric efficiency η_{vol} [-]	0.93
Mechanical efficiency η_{mech} [-]	0.92
Maximum force [N]	2400kN



4.1 Calculate the minimal pump displacement necessary to close the press with a maximum velocity of $v_{max} = 1\ m/s$. (1 Point)

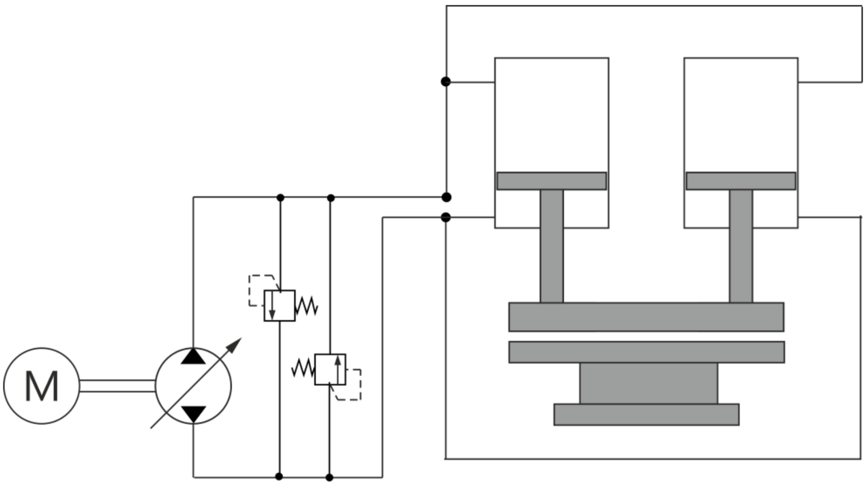
4.2 Calculate the maximum pressure drop at the valve between the pump port and the cylinder port that can occur during operation. Assume the valve is in position A. (1 Point)

4.3 Please choose the appropriate PRV from the diagram below. During operation the press should always generate the required maximum force and should not exceed it more than 5%. Your solution has to be clear and comprehensible. (1.5 Points)



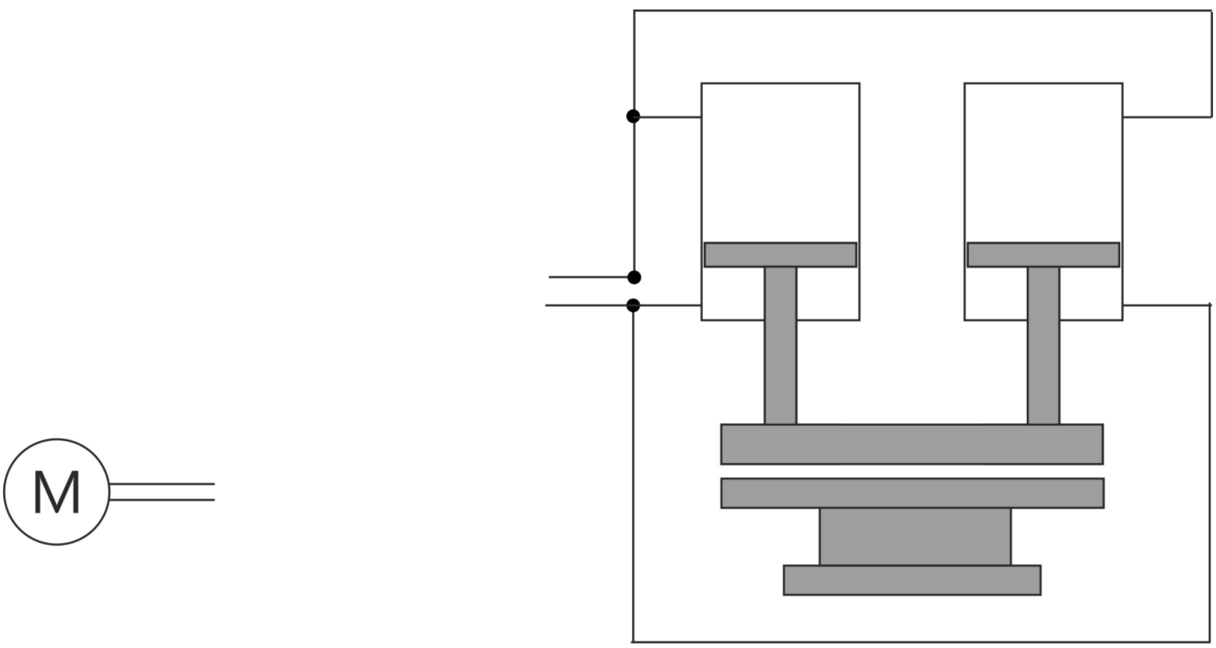
4.4 Now the valve is in position A and the press is closing (moving downwards). During the closing procedure the pressure at the high pressure side shall be 100 bar. Calculate the necessary torque required of the electric motor. (1 Point)

4.5 A colleague of yours wants to avoid the valve between pump and cylinder. He proposes an alternate design for the drive. Explain briefly, why the drive shown below is unable to operate. (0.5 Points)



4.6 How could your colleague modify the drive to make it viable? Complete the layout given below <u>without using valves</u>. (1 Point)

(It is not required to add peripherals or PRVs for overload protection!)



4.7 Assign the first press drive (**Drive 1**) from Excersie 4.1-4.3 and the new drive designed by your colleague **(Drive 2)** from Excersie.4-4.5 to the corresponding field in the classification below. (Only write <u>Drive 1</u> and <u>Drive 2</u> into the correct fields) (1 Point)

		Control	
		Resistive control	Positive displacement control
Supply	Volume flow supply	I	III
	Pressure supply	II	IV

4.8 The manufacturer Grimmig develops a new self-propelled harvester ULTRON. Now the hydrostatic transmission has to be designed. Below you find a list with recquirements that have to be fullfiled. For drawing the layout please use the next page and the same symbols (DIN ISO 1219) used in the tutorials. (3 Points)

Essential Requirements for the hydrostatic transmission

- Closed loop hydrostatic transmission
- Oil that has to be throttled, shall be used at a lower pressure level, if possible
- High pressure side has to be protected against overloads
- Low pressure side has to be protected against overloads
- Leakage losses have to be replaced by the supply pump

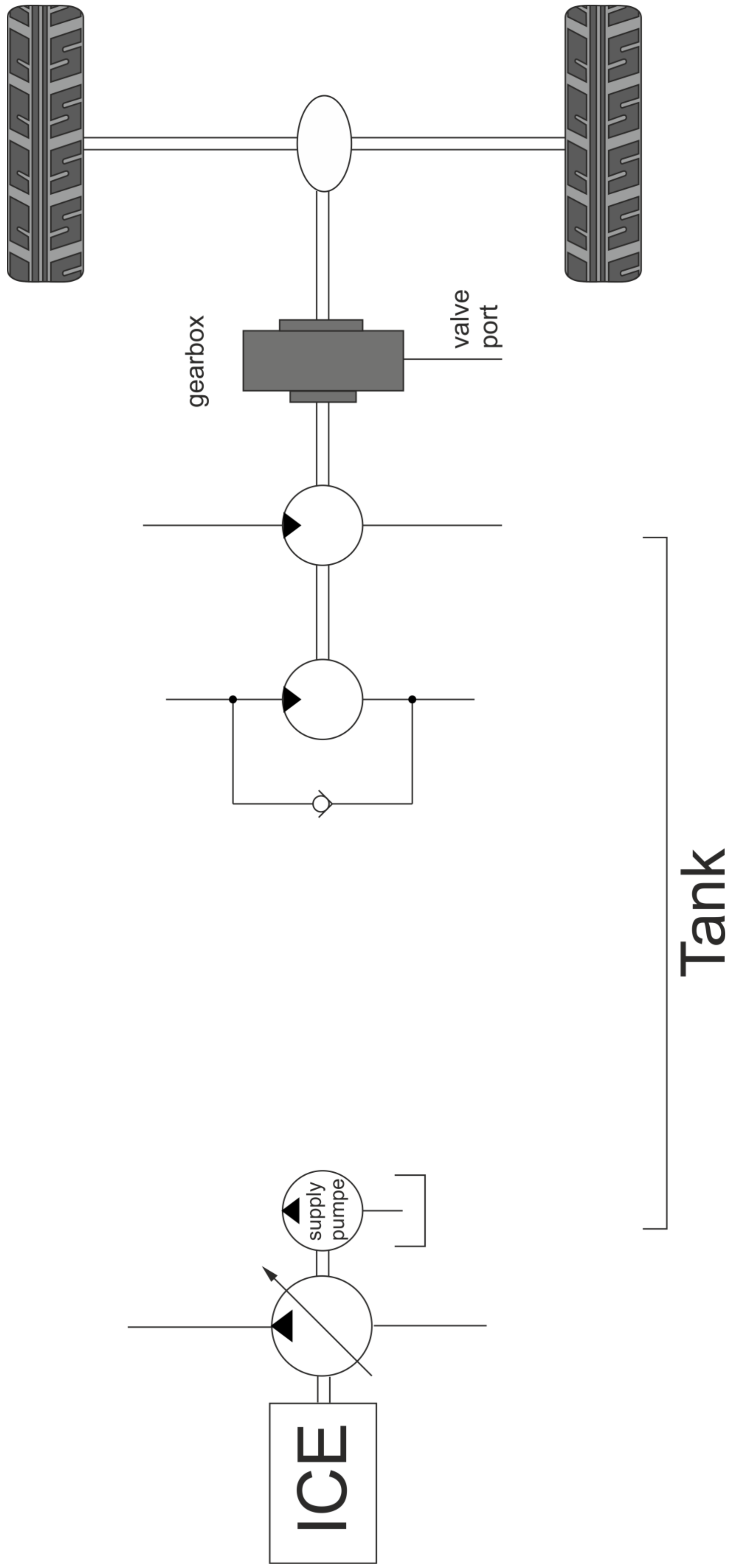
Shifting between to transmission ratios

- To increase the transmission ratio further (beside the variable pump displacement) additionally at the motor side a variation of total displacement connected to the high pressure side shall be realised. For this purpose the motor that <u>is not mounted next</u> to the gearbox has to be connected to the high pressure side by a 2-way valve.

- **Actuation of the gearbox**
  The gearbox has two gears, a forward and a reverse gear. If a pressure level higher than tank pressure is connected to the gearbox's valve port, the harvester moves backwards. Otherwise it moves forward. Please add an efficient hydraulic actuation to the gearbox's valve port.

Add all necessary components to the circuit layout on the next page to fulfil the upper requirements.

Please note: For each fulfilled single requirement points are given!


gearbox
valve port
Tank
supply pumpe
ICE

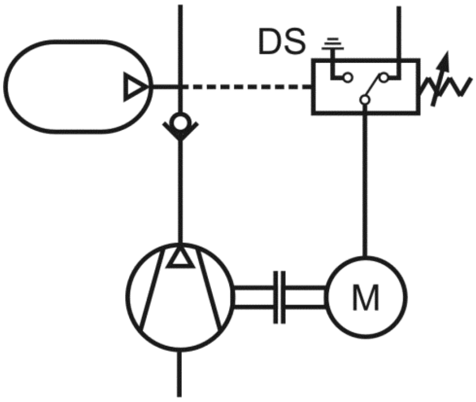
5. Exercise / 15 Points

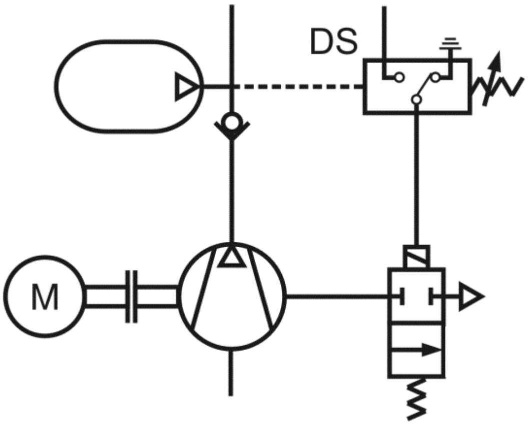
5.1 Name two properties (a positive and a negative one) of the medium air which are due to the high compressibility. (1 Point)

Positive	**Negative**

5.2 In pneumatics there are four special kinds of polytropic changes of state. Draw the trend of the change of state qualitatively in the p-v-diagram and name the lines. (2 Points)

5.3 Below, two kinds of internal, discontinous compressor controls are shown. Name both types and encircle the one which has the lower energy consumption. (1,5 Points)





Type: ____________________________ Type: ______________________________

5.4 The flow through an ideal nozzle can be calculated analytically by the first law of thermodynamics considering specific requirements. Name the requirements which are necessary to achieve the mass flow as: (2 Points)

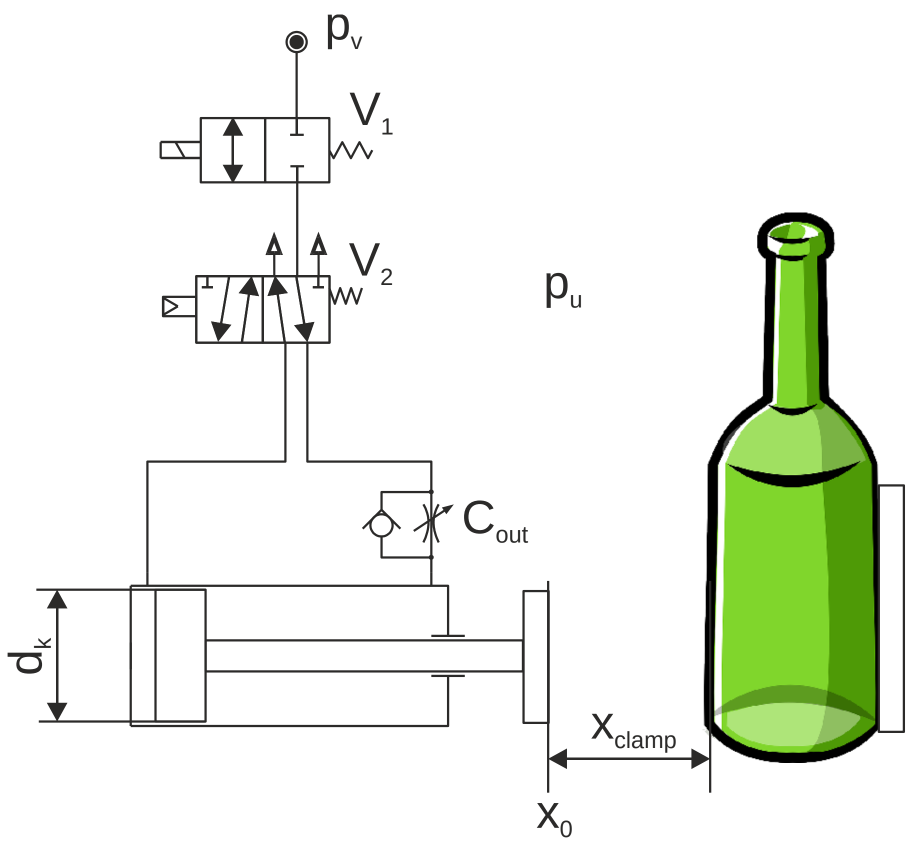
$$\dot{m} = A_2 \Psi p_1 \sqrt{\frac{2}{RT_1}}$$

5.5 The pressure of a dimensionally stable, air filled cube with an edge size of $l = 10$ cm is supposed to be pressurised to $p_2 = 3.5$ bar in 1,6 s by a constant heat flow. The initial state is given by $p_1 = 2$ bar. Calculate the necessary heat flow. (2.5 Points)

Hint: Consider the spec. heat capacity to be constant during this change of state.

Given: Spec. heat capacity **(isobaric)** $c_p = 1009 \frac{\mathrm{J}}{\mathrm{kgK}}$

Now, a clamping device for a bottle filling process (cf. drawing below) of the IFAS-Bräu brewery must be dimensioned. First of all, read through all hints and given parameters.



Hints: All valves are free of losses.

Friction is not considered at all.

All changes of state are **<u>isothermal</u>**.

Pressures must be given as absolute values.

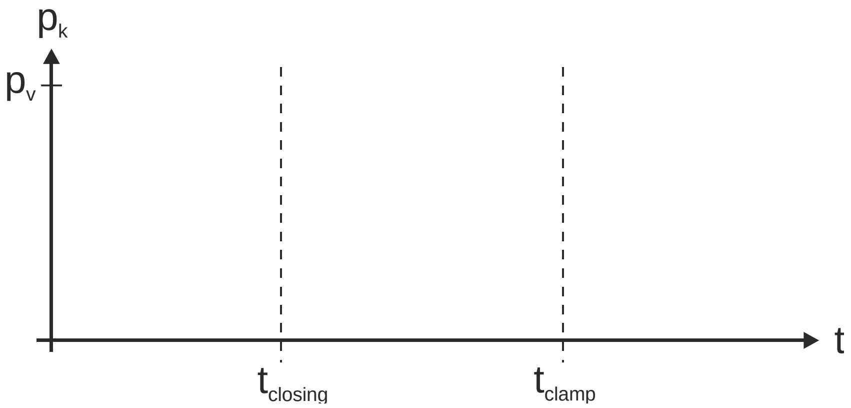
Given:	Piston diameter	$d_k \;=\; 20$ mm
	Actuator stroke (clamp stroke)	$x_{clamp} \;=\; 20$ cm
	Supply pressure	$p_v \;=\; 7.5$ bar
	Environment pressure	$p_u \;=\; 1$ bar
	Area ratio A_K/A_R	1.2

5.6 Calculate the minimal pressure to achieve a clamp force of 150 N. (1 Point)

5.7 To avoid the damaging of a bottle the actuators constant velocity of $v = 0.05\ m/s$ is set by an exhaust air throttling. Calculate the necessary conductance, C_{out}, of the ideal nozzle in Nl/min/bar. (2 Points)

5.8 Valve V_1 will be closed before the actuator reaches its stroke end to reduce the energy consumption by the usage of the available compression energy. Outline the trend of the actuator's pressure (piston sided) qualitatively and mark the necessary clamp pressure on the y-axis. (1.5 Points)

Hint: Highly dynamic processes before closing the valve can be neglected.



5.9 The clamp force must be applied after the stroke x_{clamp} (cf. drawing) despite of cutting-off the supply pressure. Calculate the earliest point of time when the valve is allowed to be closed. (1.5 Points)

Hint: The velocity is kept constant (as in exercise 5.7) $0.05\ m/s$

Neglect any dead volumes.

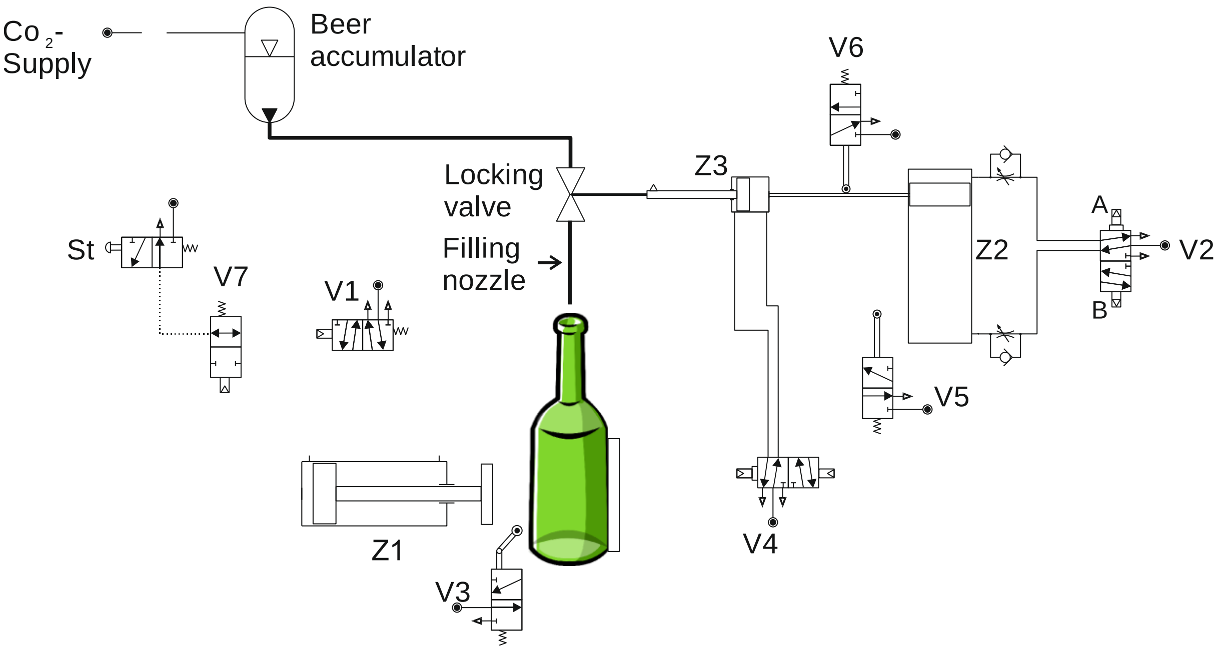
If you were not able to solve exercise 5.6, consider a necessary clamp pressure of 4.5 bar.

6. Exercise / 10 Points

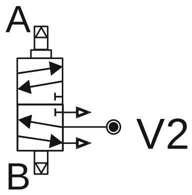
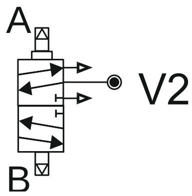
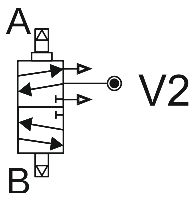
The brewery IFAS-Bräu needs a new pneumatically actuated bottling plant which is therefore designed by hobby engineer L. Uftikus. Control of the plant shall be realised by a pneumatic sequence control. Your task is to help Mr. L. Uftikus to implement the control scheme.

Hint:

- *Use the solution sheet*
- *Signal lines do **NOT** have to be dashed lines*
- *All valves are depicted in their position at the beginning of the cycle*
- *If not stated otherwise, the actuation for resetting the system shall not be considered*
- *Valve V2 is actuated by depressurising the pilot valve (See table)*
- *Cylinder Z3 opens and closes the locking valve*



Positions of Valve V2

Port A	Port B	Position
pressurised	depressurised	
depressurised	pressurised	
depressurised	depressurised	
pressurised	pressurised	Valve remains in current position

6.1 The beginning of the bottling process is controlled by manual actuation of valve St. The bottle shall be clamped in a defined position. Therefore, cylinder Z1 moves out with a constant velocity without the occurrence of a start-up jump. The inward movement is to be carried out with maximum velocity. Add the necessary element(s) and name the control concept. Actuation of the cylinder is carried out by valve V1. (1.5 points)

Control concept: ____

6.2 After the outward movement of cylinder Z1 cylinder Z2 will move the filling nozzle into the bottle by moving downward. Reaching the end stop of cylinder Z2 applies the signal for the inward movement of cylinder Z3 which starts the filling process of the bottle by opening the locking valve. Add the necessary components and signal lines. (1 point)

6.3 Name one positive characteristic of the control strategy of cylinder Z2 (1 point)

6.4 A pneumatic end cushioning shall be added in the downward direction of cylinder Z2. Complete the sketch of Z2. (1.5 points)

6.5 The locking valve shall be kept open by cylinder Z3 for a defined period of time after the beginning of its inward movement. After this time, the cylinder shall move out again and close the locking valve again. Add the components necessary for this task. (1.5 points)

6.6 By releasing the manual actuation of valve St, first cylinder Z2 shall move up again. Afterwards, cylinder Z1 releases the clamping of the bottle. Add the necessary components. (2 points)

6.7 The beer supply from the accumulator to the bottle is realised by directly connecting the CO_2 to the beer accumulator. To avoid foaming and to ensure a defined volume flow to the bottle, the CO_2-pressure in the accumulator needs to be adjustable. Add the necessary component to the CO_2-line and name it. (1.5 points)

Component: ____

Matr.-Nr.:

Solution sheet exc. 6