RWTH AACHEN UNIVERSITY

IFAS Institut für fluidtechnische Antriebe und Steuerungen

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Written Examination „Fundamentals of Fluid Power“

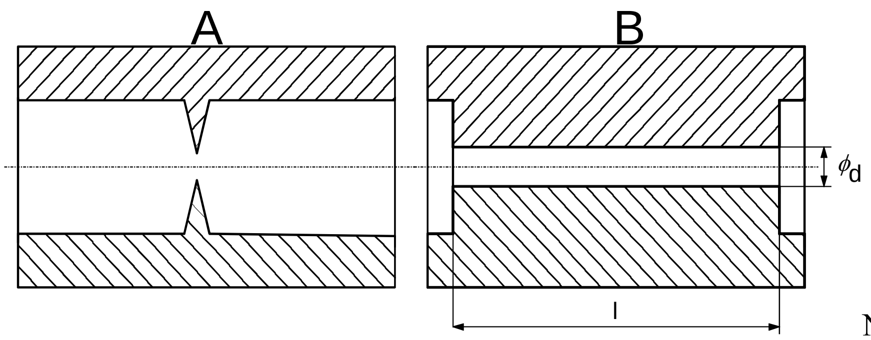
August, 20th 2015

1. Exercise / 15 Points

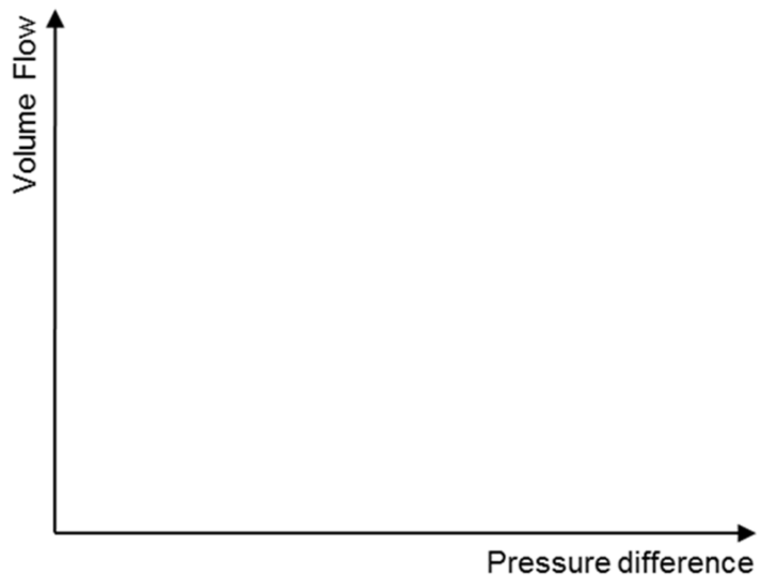
1.1 Name two advantages and two disadvantages of hydraulic drives and controls in comparison to electrical and mechanical drives. (2 Points; 0.5/correct answer)

Advantage ☺	Disadvantage ☹

1.2 Name the hydraulic resistances given in the picture below. Plot the characteristic curve of both resistances into the graph shown below. Mark the curves clearly and state the corresponding flow law for each resistor. (2 Points):



Note: d << l



1.3 Which resistance is preferably used in hydraulics? Please explain your answer briefly. (1 Point)

1.4 A hydraulic plunger type cylinder with a force of 10 kN at a velocity of 1.5 m/s is used. The cylinder's diameter is 30 mm and at the cylinder's inlet there is an orifice. For the calculation of the orifice the simplified equation $Q = K\sqrt{\Delta p}$ is given with $K = 50\ l\sqrt{bar}\ /min$. Calculate the needed supply pressure. (1.5 Points)

1.5 Name both pulsation phenomena occurring in axial piston units (1 Point)

1.____

2.____

1.6 Name a hydraulic pump that does not generate pulsation. (0,5 Points).

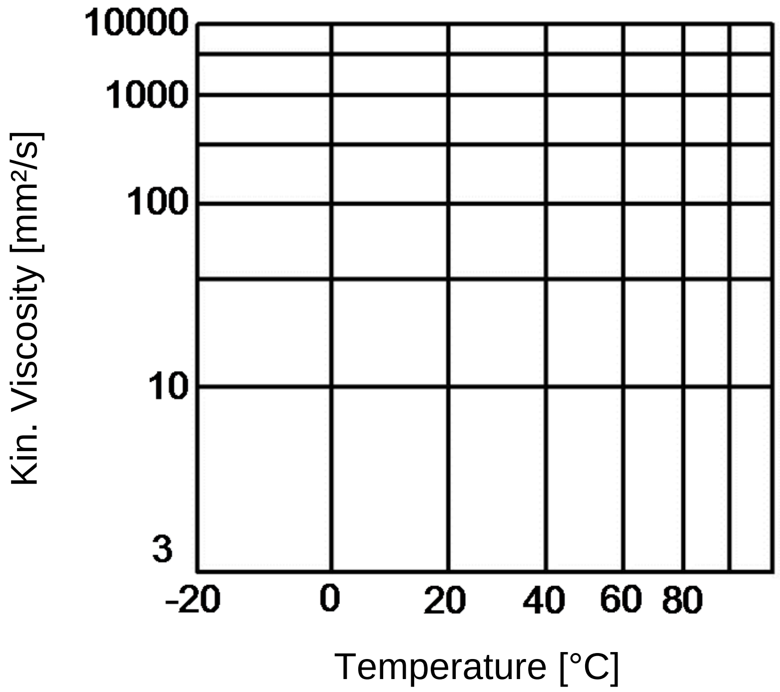
____

1.7 Name the primary task and a secondary task of a medium used in a hydrostatic transmission. (1 Point)

Pirmary:____

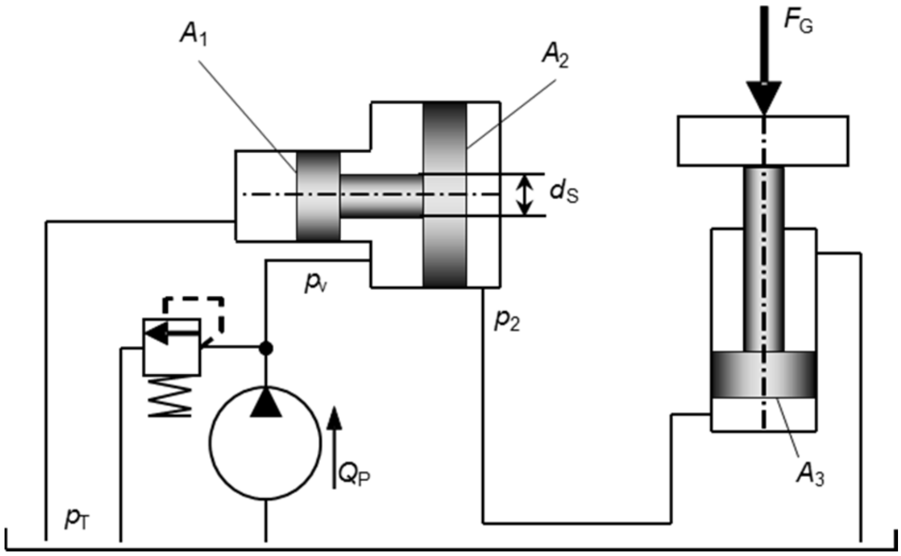
Secondary:____

1.8 Plot the qualitative course of the kinematic viscosity of HLP46 into the graph shown below. Additionally plot the course of the kinematic viscosity of the same oil after VI-Improver has been added. Mark the curves clearly. (1.5 Points)



1.9 Calculate the pressure p_V (1,5 Points).

Term	Value
Area A_1	2000 mm²
Area A_2	70000 mm²
Area A_3	40000 mm²
Force F_G	300 kN
Pressure p_T	0 bar
Rod diameter d_s	30 mm



1.10 An industry partner of the young scientific staff member Horst Pauer gives him a ride with his new electric roadster. Horst Pauer is impressed by the car's acceleration potential. Suddenly the very high power density of hydraulics comes into his mind and he decides to use hydraulics to further increase the cars acceleration. At the evening down in the lab he creates a hydraulic circuit that can be used during the acceleration of the car. The layout of the circuit is show in Figure 1-1. The circuit works as follows, if the acceleration process is initiated, the valve opens and the very large accumulator is connected to the pipe and the flow Q_R passes the valve (the valves linear resistance is R_H). Via the piping (hydraulic capacity of the piping is C_H) the valve is connected to the motor (inductivity of the hydraulic motor is L_H). Due to the accumulator's large volume the pressure inside the accumulator p_0 remains constant during the acceleration process. The pressure at the motor's outlet equals the ambient pressure $p_u = 0\ bar$. Horst Pauer designed the system well and the pressure relief valve remains closed during the acceleration. In order to optimize the system the differential equation for p_1 is needed. Therefore, derive the differential equation and assume there is no load torque acting on the wheel. Neglect the hydraulic inductivity of the piping. Pay attention to unambiguous indexes. (3 Points)

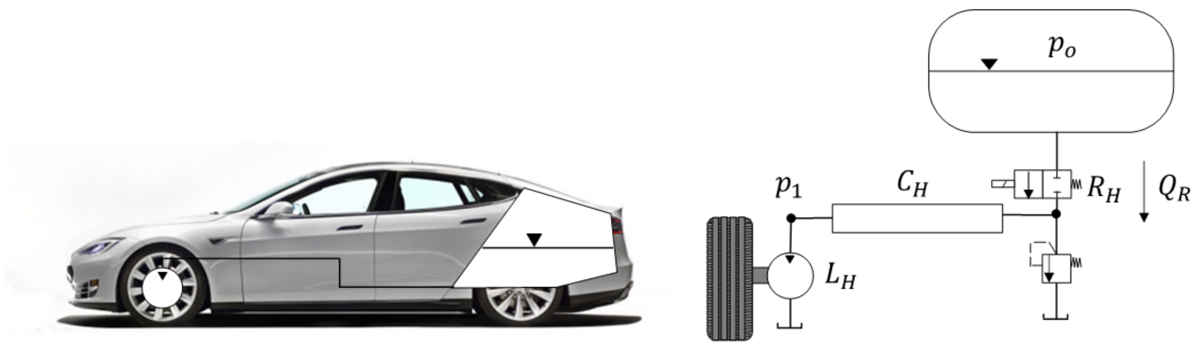
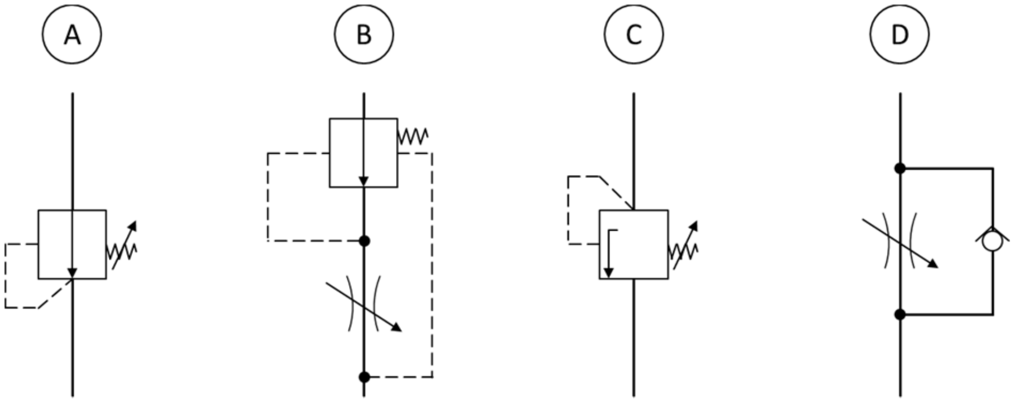


Figure 1-1: Layout of the hydraulic circuit

2. Exercise / 10 Points

Following valves are given:



2.1 State the exact description for all valves. (2 points)

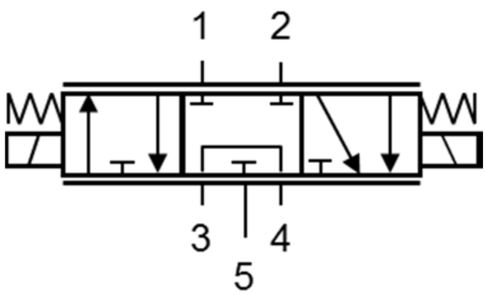
A: ________________________________

B: ________________________________

C: ________________________________

D: ________________________________

2.2 Specify the complete name of the valve below. (1 point)



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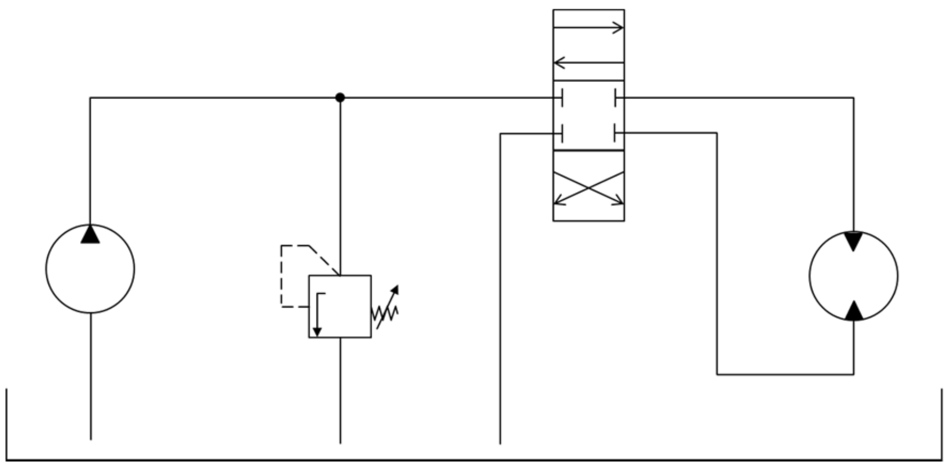
You are a proud owner of a wheel loader and your neighbor parks his car on your land wrongfully, again. Now, you want to help your neighbor to remove his car from your land. Because you are a good person, you want to push the car only that strong, so it is moved to your neighbor's land smoothly.

tank pressure	p_{Tank}	0 bar
flow coefficient	α_{D}	0,6
oil density	ρ	850 kg/m³
vol. displacement hydro motor	V	100 cm³
diameter of the spool	d	5 mm

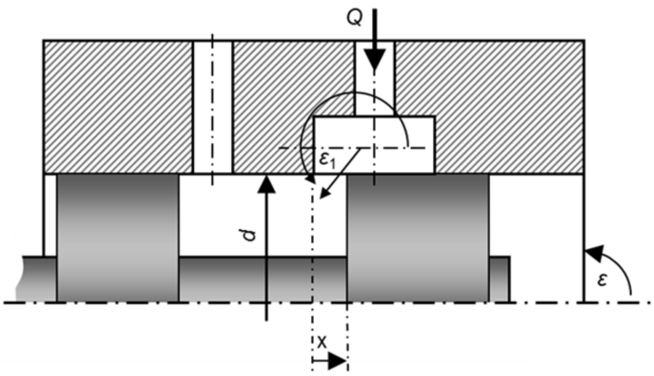
2.3 Calculate to which pressure the PRV has to be adjusted so that the drive torque of the hydro motor (1 hydro motor for the drive train) is 50 Nm at <u>standstill</u> of the wheel loader. (1 point)



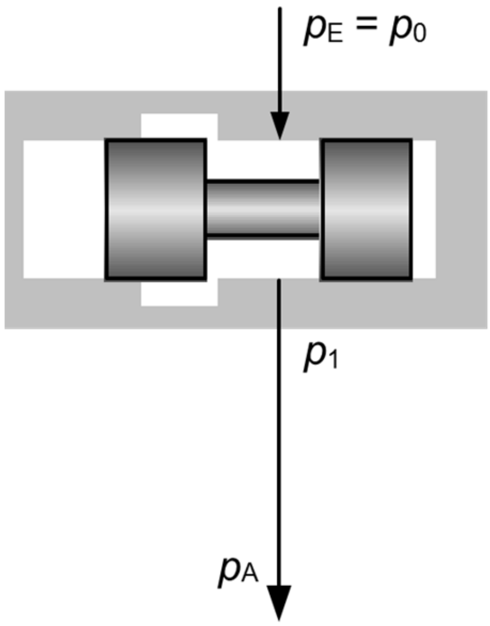
2.4 Now you want to move the car. Calculate the spool displacement x, when there is a pressure drop over the hydro motor of 20 bar and the hydro motor shall run at 60 rpm. (2 points)

2.5 Calculate the flow forces for a flow rate of now 10 l/min, when the fluid is entering the valve chamber with the same spool displacement under an angle of $\varepsilon_1 = 60°$ and leaves the chamber under $\varepsilon_2 = 90°$. (1 point)

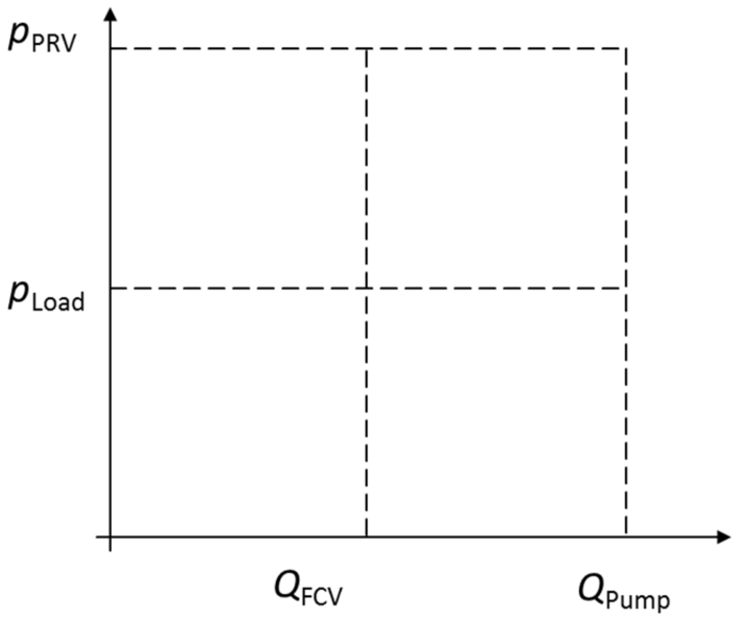
If you could not solve 2.4, you can go on with $x = 0.5$ mm.



2.6 Complete the sketch of the 3-way flow control valve so that it works properly. (2 points)



2.7 The system consists of a constant pump, a PRV and a 3-way flow control valve (FCV). Mark the effective power and the losses in the diagram. (1 point)



3. Exercise 3 / 10 Points

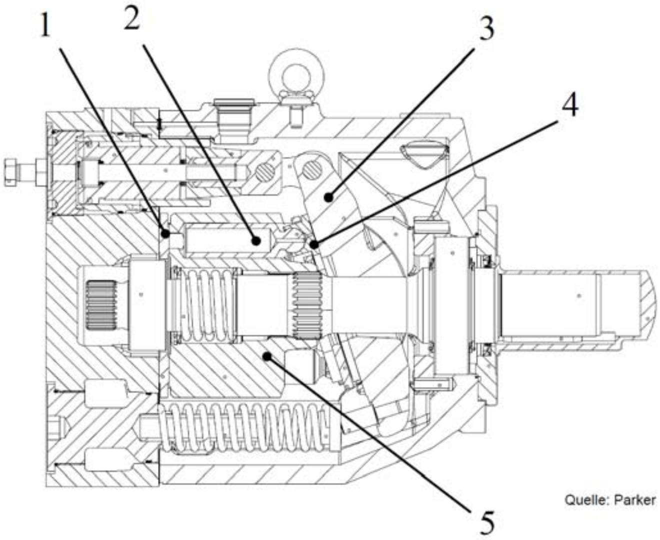
3.1 Name two adjustable designs of an axial piston unit. (1 Point)

____

____

3.2 Please give the full name of the depicted pump. (0.5 Points)

____



3.3 Please name the marked components. (2.5 Points)

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________

3.4 Please give the formula to calculate the displacement volume of a single stroke radial piston unit und name the variables including their units. (1 Point)

3.5 Which is more significant for the ripples in a hydraulic system, the kinematic ripples or the compression conditioned ripples? (0.5 Points)

Horst Pauer decides to spend some of his spare time by putting together an axial piston machine in a swash plate design with nine pistons. While he assembles the machine a small screw falls into each piston bore. Since Horst Pauer is fairly lazy, he does not get them out and finishes the assembly with the screws in the dead space. He assumes that everything will be alright and the screws will not interfere with the pistons in any way. Later that afternoon the pump is put on a test bench. Astonishingly enough the pump does work for a brief amount of time before Murphy's Law manifests itself. One of the screws eventually interferes with the stroke of one of the pistons and causes a peak in torque. As a consequence the test bench performs an emergency shutdown of the system. The control software for the test bench was implemented by Horst Pauer's predecessor.

3.6 Horst Pauer is quite surprised to see a reduction of pulsation. How is that possible? (0.5 Points)

Horst Pauer also noticed that the relation of compression work to usable work decreased.

3.7 Calculate the compression work. Derive the necessary expression starting from $W_K = \int F dx$. (2 Points)

Given:

Area of one piston	2,15 cm²
Dead space of one piston	1 cm³
Volume of one screw	0,21 cm³
Number of pistons	9
Bulk modulus of oil	16.000 bar
Operating pressure difference	400 bar
Bore circle diameter	135 mm
Swash plate angle	16°

3.8 Would the relation of compression work to usable work increase or decrease without the small screws? Why? (1 Point)

____

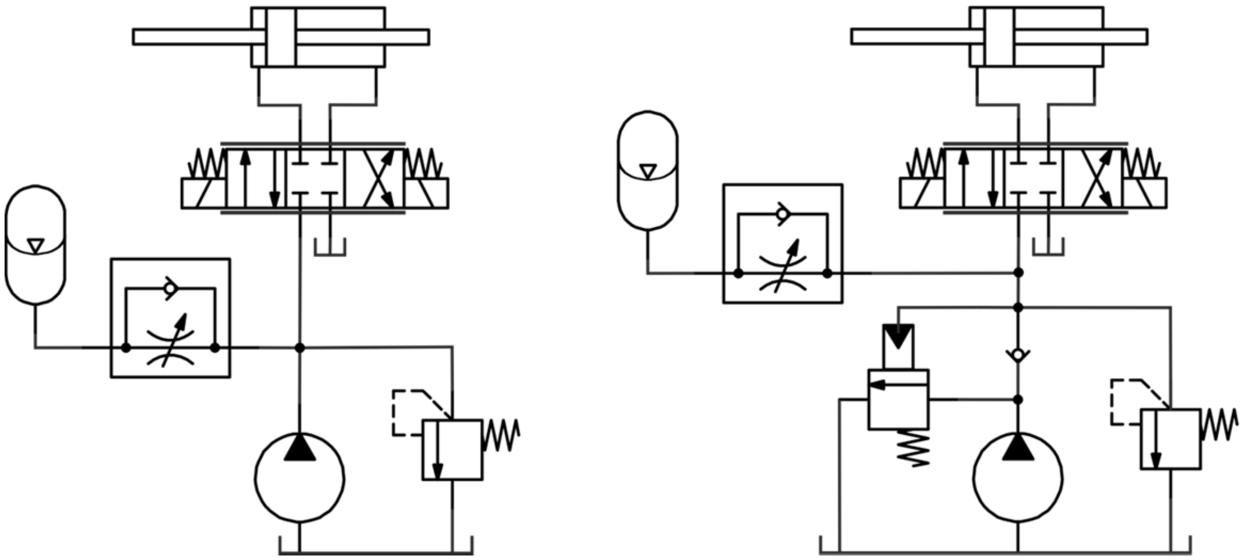
____

____

3.9 Calculate the hydraulic inductivity. Assume the moment of inertia to be 35.81 kgm² and the operating pressure to be 400 bar. Please give your result in $\frac{bar}{\frac{l/min}{s}}$. (1 Point)

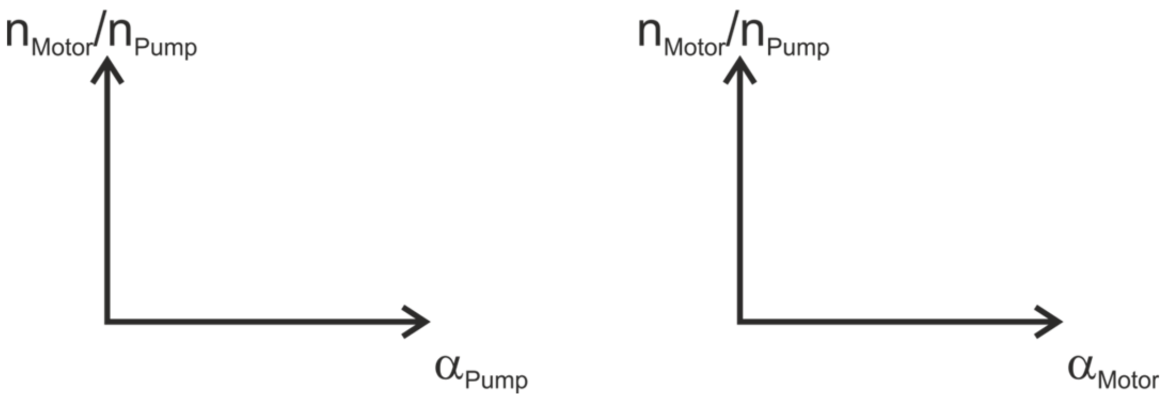
4. Exercise 4 / 10 Points

4.1 Marc the system below, which requires less energy for an operation in which the cylinder does not move for some time! For both systems a constant speed of the pump is assumed. (0,5 points)



4.2 Draw the transmission ratio of motor speed divided by pump speed for each system in the according diagram. Marc the point of equal speed! (1,0 points)

Note: Both units have the same nominal displacement



For an application in which two rolls are driven with a constant speed ratio, a new hydraulic concept shall be developed with these requirements:

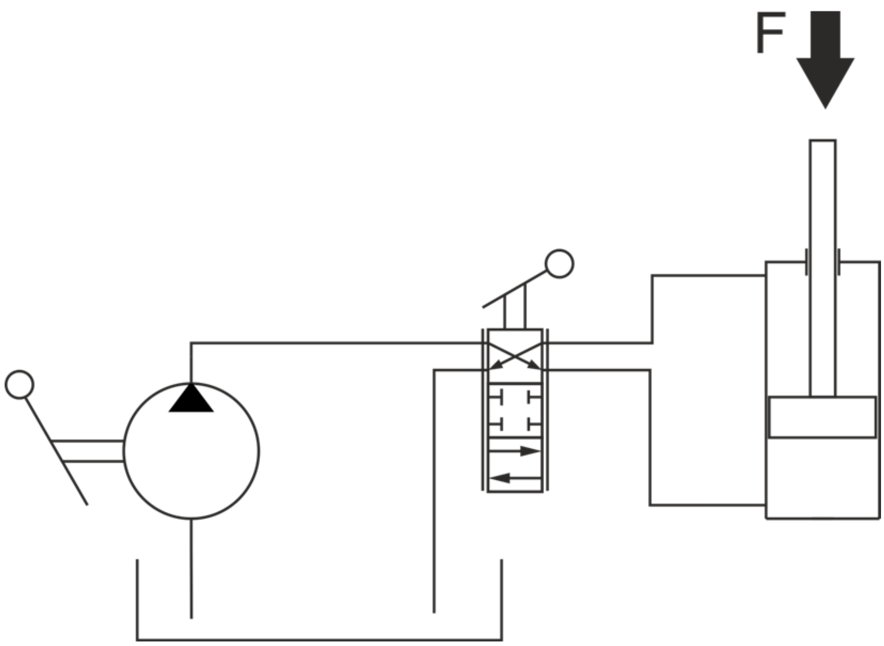
1. One combustion engine shall drive the entire hydraulic system
2. One variable displacement pump shall provide the whole volume flow driving the rolls.
3. Two same sized constant displacement motors shall be used for driving the rolls at constant, but different speeds
4. The system shall be operated as an open loop system
5. The system shall be operated in a safe and long-time enduring manner.

4.3 Draw the circuit of a hydraulic system suiting the above mentioned requirements! (3,5 points)

Following, the cylinder drive, as shown below, is analysed. It has the following parameters:

Given:	Displacement of the hand pump	$V_{\text{Displacement, Hand pump}}$=3 cm³
	Volumetric efficiency of pump	$\eta_{\text{vol, Pump}}$ = 90 %
	Hydro-mechanic efficiency of pump	$\eta_{\text{hm, Pump}}$ = 60 %
	Pumping velocity	v_{pumping} = 30 Strokes/min
	Hose volume	V_{hose} = 0,5 l
	Equivalent bulk modulus of total system	E_{System} = 8000 bar
	Cylinder bore diameter	D = 40 mm
	Cylinder rod diameter	d = 35 mm
	Stroke of the cylinder at the beginning	x = 5 mm
	Cylinder leakage	Q_{Leakage} = 0,01 l/min
	Sum of breakaway force and process force	F_{Process} = 75 kN
	Friction force	F_{Friction} = 4 kN

The valve needs to be considered in the position drawn. Any pressure drop over the valve is neglected.

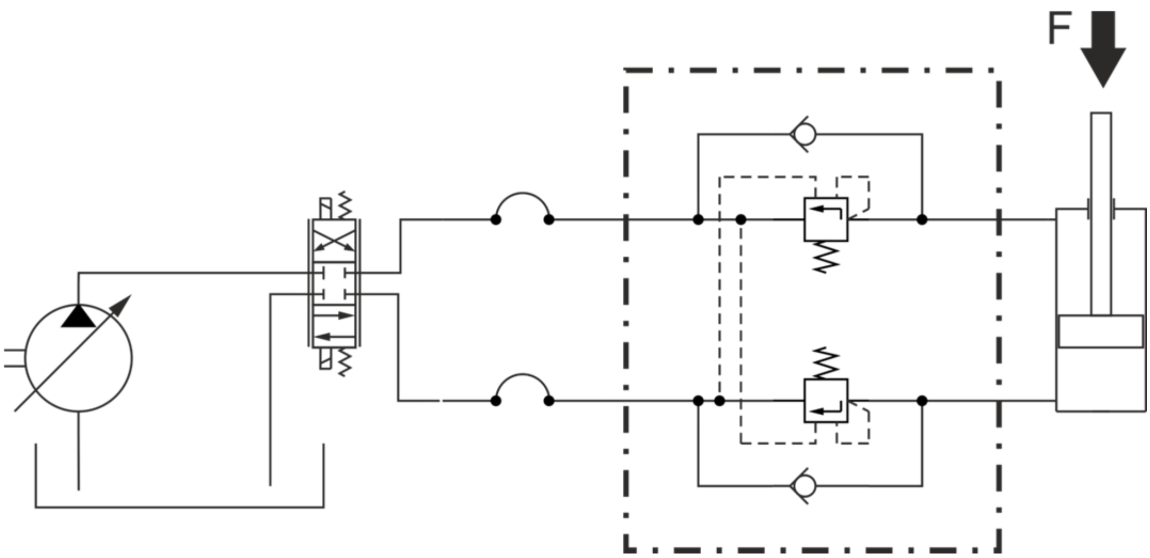


4.4 What power is required from the operator to move the cylinder continuously? (1,5 points)

4.5 How fast moves the cylinder during this operation? (1,5 point)

4.6 How many strokes are necessary at the beginning of the process to build up the required pressure, to overcome break away friction and process force? (1,0 points)

4.7 For what safety function is the valve combination in the framed area used? (1,0 points)

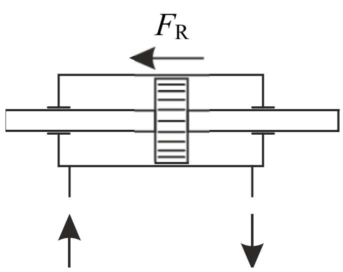


5. Exercise / 15 Points

5.1 Pneumatic valves are often offered as spool or seat valves. Name one advantage and one disadvantage for each design. (2 Points)

	Advantage	**Disadvantage**
Spool valve		
Seat valve		

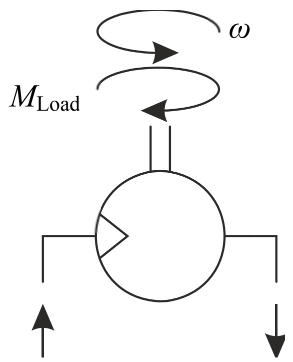
5.2 Cylinder drives and rotational drives show a different behaviour concerning their input and output values. Add the corresponding relations (<, >, =). (2 Points)



$p_A \quad > \quad p_B$

$\dot{m}_{in} \qquad \dot{m}_{out}$

$Q_{in} \qquad Q_{out}$

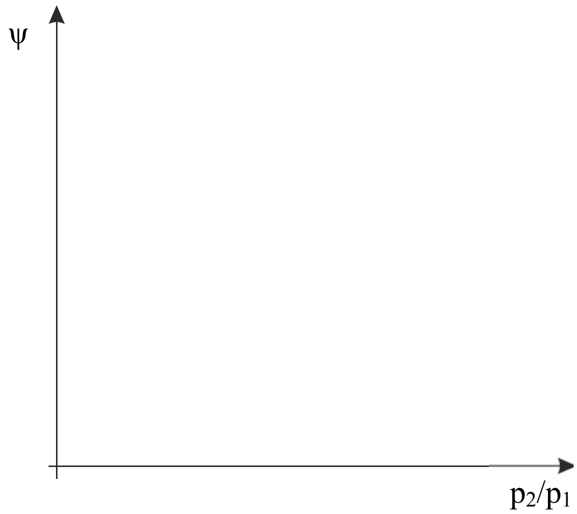


$p_A \quad > \quad p_B$

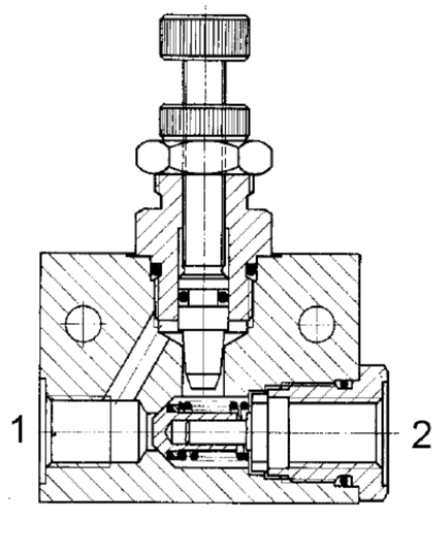
$\dot{m}_{in} \qquad \dot{m}_{out}$

$Q_{in} \qquad Q_{out}$

5.3 Draw the graph of the exiting flow function Ψ in dependence of the pressure ratio p_2/p_1. Highlight the range of sub- and supercritical flow and the maximum exiting flow function. (1,5 Points)



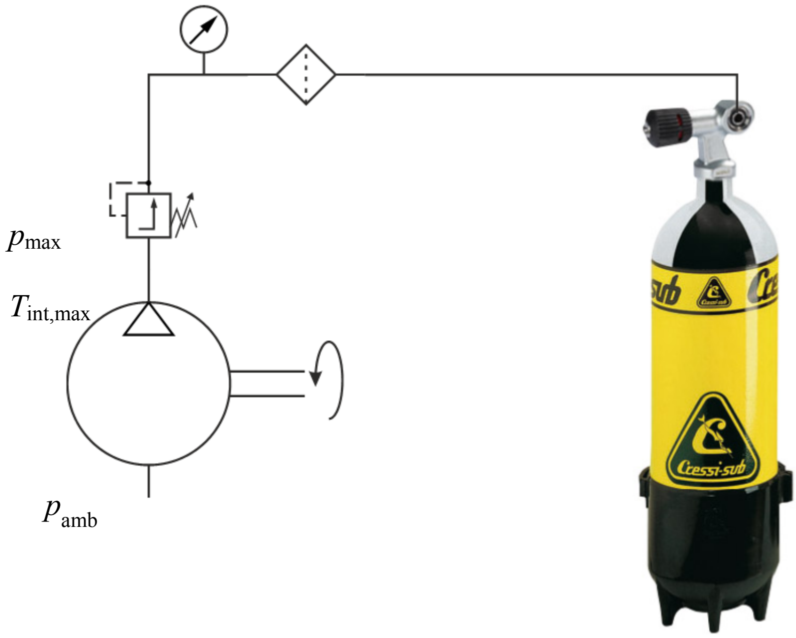
5.4 Name the valve shown in the figure and sketch the symbol according to DIN ISO 1219. (1 Point)



Denomination:

Symbol:

Compressed air bottles used for diving are often operated at a pressure of 200 bar. Due to the high pressures and the needed purity of the air, multi-stage piston compressors are used.



Given: $V_{Bottle} = 6$ l $p_{max} = 200$ bar $p_{amb} = 1$ bar

$T_{amb} = 20$ °C

Air shall be considered as an ideal gas throughout the whole range of temperature and pressure.

All pressure values are absolute values and shall be given as absolute values.

All compression processes in the stages shall be considered adiabatic.

Start-up and shut-down processes may be neglected.

Standard conditions are defined as technical standard conditions according to ISO 6358.

5.5 Name the most important advantage of multi-stage compressors against a single state compressor and give a short explanation. (1 Point)

5.6 The compressor shall fill an air bottle with a volume of 6 l at a pressure of 200 bar within a time of one minute. Which standard volume flow (in Nl/min) is necessary for this application? (1 Point)

5.7 The compressor has three stages. The first stage raises the air pressure up to 20 bar. How high is the air temperature at the stage outlet? (1 Point)

Given: $p_1 = 20$ bar $n = 1.2$

5.8 Which maximum pressure ratio per stage may be set if the outlet temperature of each stage is limited to 220 °C? How many stages would be necessary in this case? The air is cooled down to ambient temperature before each stage. The cooling process is isobaric.. (1.5 Points)

Given: $T_{amb} = 20$ °C $T_{max} = 220$ °C $n = 1.2$

5.9 How high is the heat flux that has to be discharged at each stage of the compressor, if the air volume flow is cooled from its maximum temperature to ambient temperature? (2 Punkte)

If you did not solve exercise 5.6, assume a standard volume flow of 250 Nl/min.

Given: $T_{\mathrm{amb}} = 20$ °C $T_{\mathrm{max}} = 220$ °C $c_{\mathrm{p,air}} = 1000$ J/kgK

$R_{\mathrm{air}} = 287$ J/kgK

5.10 How high is the technical power supplied to the first stage if the pressure ratio calculated in Exercise 5.8 is assumed? (2 Points)

If you did not solve Exercise 5.8, assume a pressure ratio $\frac{p_1}{p_{\mathrm{amb}}} = 10$. If you did not solve Exercise 5.6, assume a standard volume flow of 250 Nl/min.

Given: $T_{\mathrm{amb}} = 20$ °C $T_{\mathrm{max}} = 220$ °C $c_{\mathrm{p,air}} = 1000$ J/kgK

$R_{\mathrm{air}} = 287$ J/kgK $n = 1.2$

6. Exercise / 10 Points

For scientific research purposes a coupling device has been developed in order to perform a fully automated, conductive charging procedure for electronic busses at IFAS (Figure 6-1)

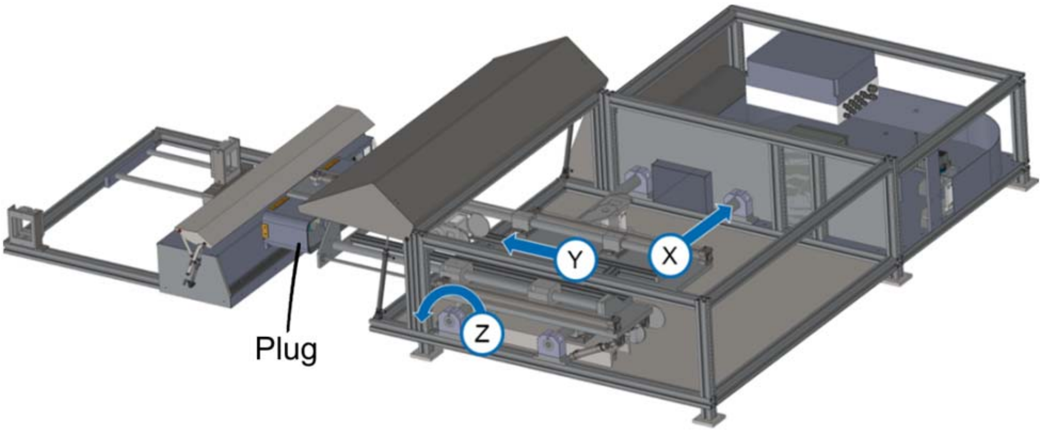


Figure 6-1: Coupling device – bus part (left-hand) and stationary part (right-hand)

Using mechanical kinematics the plug can be positioned in a cuboid-shaped three dimensional space. As a prospective engineer, the challenge is on you to design a part of the pneumatic control system. Considering that, the answer sheet (Page 28) which contains the simplified model of the **extended** coupling device should be helpful. Ensuring an easier illustration of the mechanism it is broken down into two planar surfaces – two actuators for the Y-Z-Plane (left-hand) and one actuator for the X-Y-Plane (right-hand).

Hints:

- *Task 6.1 to 6.5 has to be answered in the boxes with dotted outlines on the answer sheet (Page 28)*
- *To task 6.1: Bistable valves are considered here. Therefore, return springs are **not** necessary*
- *The connecting lines between the answering boxes are intended to assist you and, thus, shall be used*
- *Fractional scores are achievable*
- *Only one actuator per degree of freedom is shown*

6.1 The shown three actuators X, Y and Z are supposed to be controlled by three 5/2-way control valves which can be actuated either electronically or pneumatically. Draw the corresponding valve symbols with connecting lines referring to the actual actuator displacement. (1 Point)

6.2 Add the components that ensure a stationary, constant speed of actuator Y during extension **and** retraction and name the corresponding circuit. (2 Points)

Circuit: ____

6.3 Now, consider the retracted coupling device. To avoid an involuntary acceleration (negative Z-direction) of the extended plug (e.g. due to burst of the hoses connected to actuator Z) during extension of actuator Y, the actuator Z should be equipped with a safety component.

Add such a valve at the right place to the answer sheet (1,5 Points)

For safety reasons, a pneumatic actuated circuit has to be implemented achieving the opportunity to return the coupling device to the initial state (retracted) during power outage.

6.4 Add a sequence control to the circuit which firstly retracts actuator Z by manual operation of valve St until the roller lever of support valve V1 is affected. Subsequently, actuator Y is supposed to be retracted as well. Ensure that actuator Y is only moved when both of the valves St and V1 are switched. (2 Points)

6.5 Furthermore, the safety circuit of task 6.4 shall be expanded in the way that actuator X is retracted time-controlled after actuation of actuator Y. (2 Points)

6.6 Calculate the necessary conductance C in Nl/min/bar to ensure a load independent velocity v of actuator X during retraction. (1,5 Points)

Given: $v = 1$ m/s $T_{piston} = T_0 = 293{,}15$ K (isothermal)

$d_{\text{piston}} = 32$ mm $p_U = p_0 = 1$ bar

Answer sheet of task 6.1 to 6.5