RWTH AACHEN UNIVERSITY

IFAS Institut für fluidtechnische Antriebe und Steuerungen

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Written Examination “Fundamentals of Fluid Powers“

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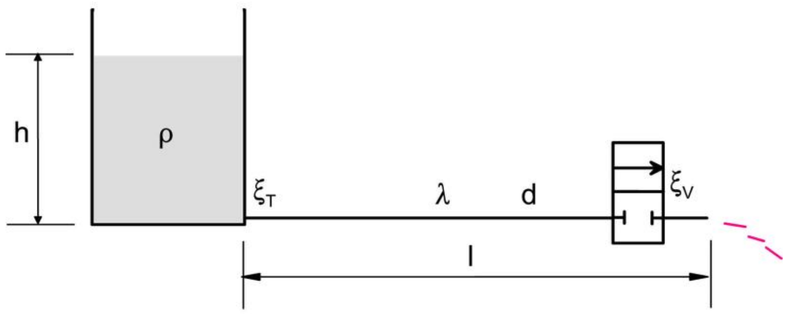
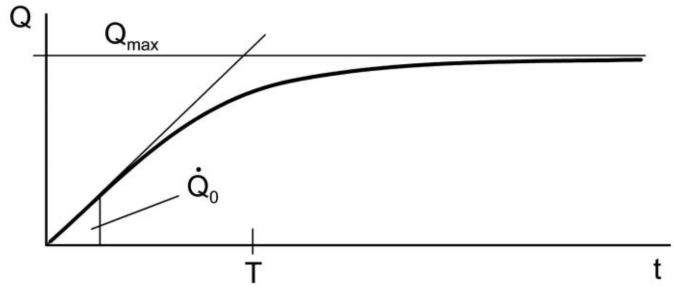
Exercise 1 (15 Points)

The oil tank shown in the picture is connected to a pipe closed with a valve. Behind the valve there is atmospheric pressure. As soon as the valve is opened the flow rate rises as shown in the chart until it reaches a maximum value.





Oil density	ρ = 900 kg/m³	Pipe length	l = 20 m
Kin. viscosity	ν = 50 mm²/s	Pipe resistor coefficient	λ = 0.03
Tank level	h = 10 m	Resistance tank opening	ξ_T = 0.3
Gravitational acceleration	g = 9.81 m/s²	Resistance valve	ξ_V = 3.0
Pipe diameter	d = 50 mm		

1.1 Calculate the medium flow velocity v inside of the pipe at a fully opened valve ($Q = Q_{max}$). Thereby a turbulent flow state is taken into consideration at first. (2 Points)

1.2 Check if the assumption "turbulent flow", which was made for the estimation of the pipe resistor coefficient λ, was right using the Reynolds number Re. (2 Points)

1.3 Calculate the flow rate Q_{max} when the valve is fully opened. (0.5 Points)

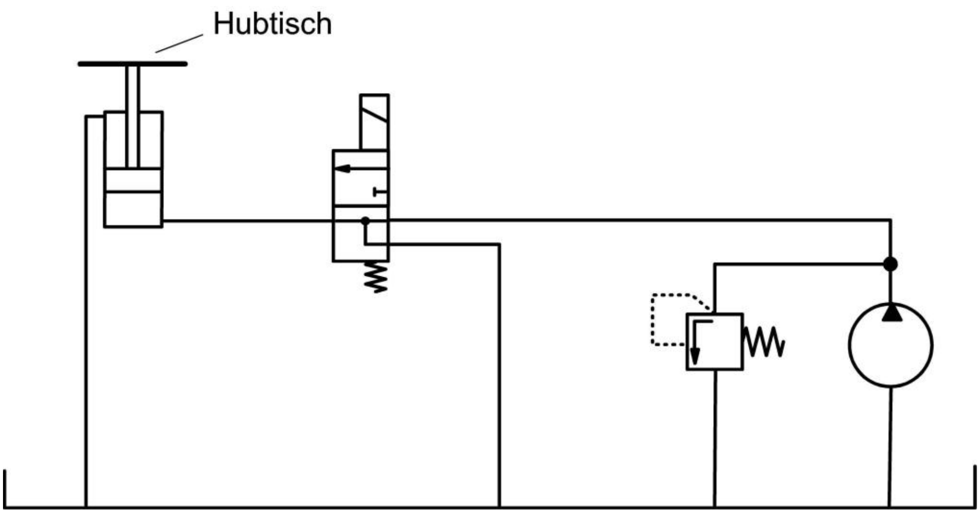
1.4 After opening the valve the flow rate gradually increases at first due to mass inertia (inductance). Calculate the acceleration of the flow rate $\dot{Q}_0$ when opening the valve. (2 Points)

1.5 What big is the time constant T shown in the chart for reaching the maximum flow rate? (1 Point)

1.6 A liquid sample was analyzed by an automatic particle counting device. The lab report contains the following result: ISO 4406:1999 23/19/15. Fill in the corresponding quantity of particles per 1 ml for every class. (1.5 Points)

Class	Max. quantity of particles
> 4 µm	
> 6 µm	
> 14 µm	

1.7 Mark the position where the circuit suction filter and the return line filter are attached in the circuit diagram shown below. Use and label the normed filter symbol. (2 Points)



In the product data sheets of an oil provider three hydraulic oils with the following viscosity indication are documented:

Appellation	Blackline 46	Greenline A	Greenline B
Type	HLP 46	HEES 32	HEES 46
V40 [mm²/s]	46.1	35.1	44.2
V100 [mm²/s]	6.9	7.1	8.2

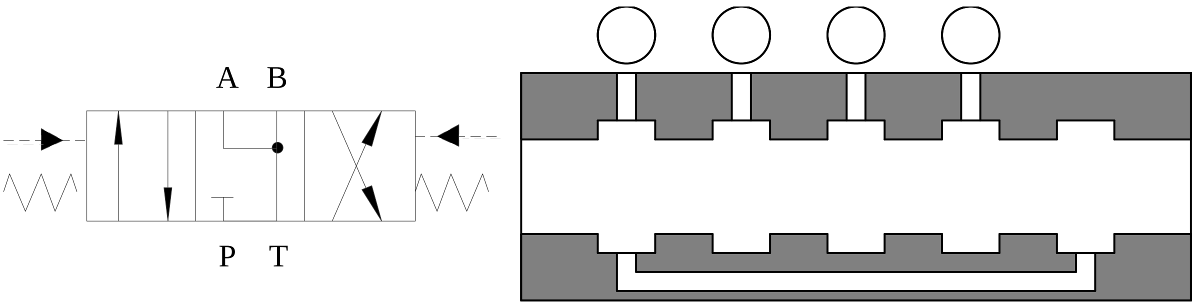
1.8 Of what do oils with the appellation HEES consist? (1 Point)

1.9 What is the meaning of the number behind the type appellation in the table above? (1 Point)

1.10 Which of the oils mentioned in the table above has the lowest viscosity index (VI)? Justify your decision in a few words. (2 Points)

Exercise 2: Valves (10 Points)

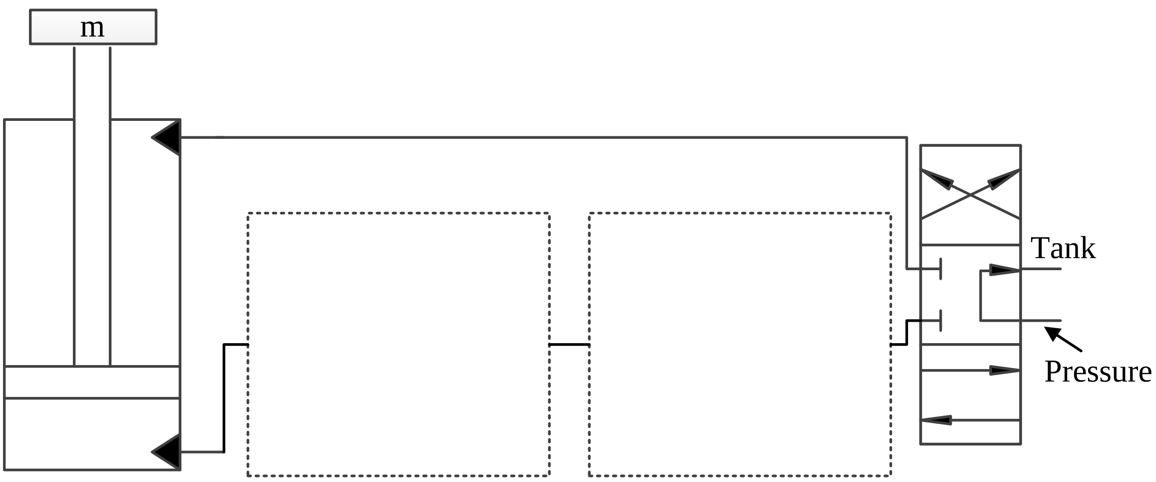
2.1 Draw the valve spool of the pictured valve in middle position into the pictured housing and name the ports (A, B, P, T). How do you call this kind of valve (exact denomination)? What is the use of the middle position? (2 Points)



Complete denomination: ____

Function of the middle position: ____

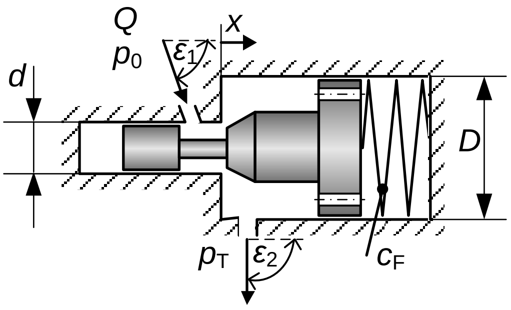
2.2 The pictured hydraulic cylinder shall retract with a constant, adjustable velocity. The move-out velocity shall depend on the supplied flow rate. Furthermore a descent of the cylinder due to pipeline breaking, pump deadlock etc. needs to be prohibited. Draw the switch symbols and – if necessary – the pipes of the necessary valves into the boxes and name them completely. (2 Points)



Name: ______________ ______________

2.3 In order to protect a pump the pictured pressure relief valve shall be used. Calculate the necessary spring pre-tension for the valve to open at a pressure of 200 bar. Friction can be neglected. (1 Point)

Given: $p_o = 200\,\mathrm{bar}$; $p_T = 5\,\mathrm{bar}$; $c_F = 40\,\mathrm{N/mm}$; $d = 7\,\mathrm{mm}$; $D = 20\,\mathrm{mm}$



2.4 What is the system pressure p_o, if the pressure relief valve is opened by 1 mm? (0.5 Points)

Given: $\alpha_D = 0.7$; $Q = 220\,\frac{\mathrm{l}}{\mathrm{min}}$; $\rho = 890\,\frac{\mathrm{kg}}{\mathrm{m}^3}$; $x = 1\,\mathrm{mm}$

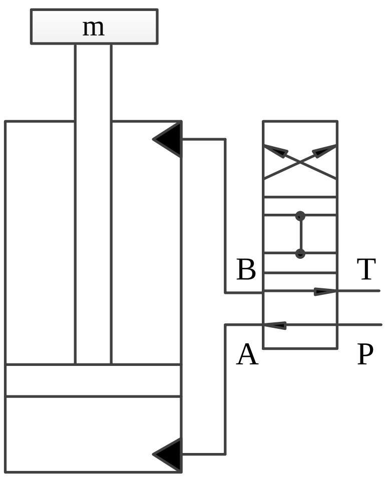
2.5 How far would the pressure relief valve be opened, if in comparison to the former point no flow force occurs? Assume that the pressure forces at the slide and the flow rate stay constant. (1.5 Points)

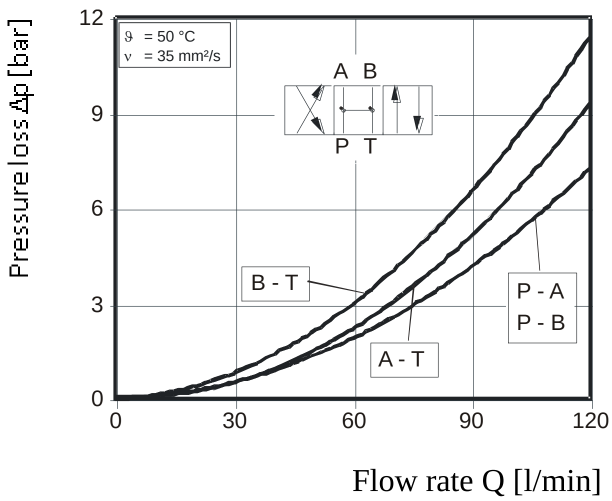
Given: $\varepsilon_1 = 70°$; $\varepsilon_2 = 90°$

2.6 Name two constructive measures to decrease the flow force. (1 Point)

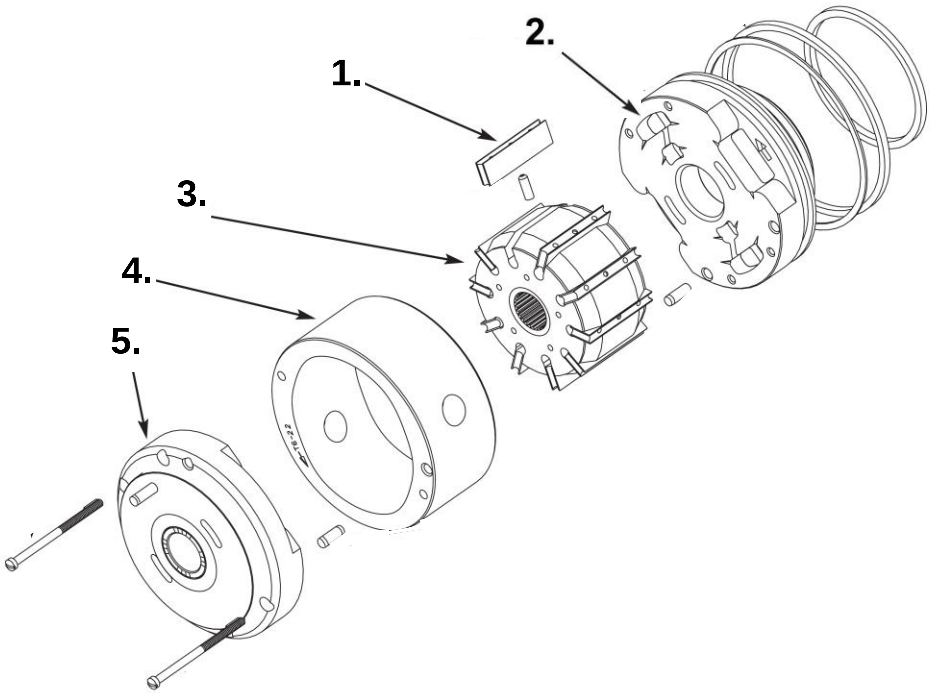
2.7 Calculate the power loss due to the valve if the piston's move-out velocity is 0.8 m/s for the pictured hydraulic system. For your aid the Δp-Q-characteristic curves of the valve are available. (2 Points)

Given: $d_{\text{Piston}} = 54\ \text{mm}$; $d_{\text{rod}} = 26\ \text{mm}$; $v = 0.8\ \text{m/s}$; $m = 50\ \text{kg}$





Exercise 3: Pumps and Motors (10 Points)



3.1 In the picture a hydraulic pump is illustrated. Give the appellation of this kind of pump. (0.5 Points)

___

3.2 Name the marked elements 1 – 5. (2.5 Points)

1.___

2.___

3.___

4.___

5.___

3.3 Name the three most important designs of axial piston machines as well as an advantage and a disadvantage each (only the mention of the design inclusive advantage and disadvantage result in 0.5 points per configuration). (1.5 Points)

____

Advantage: ______________________________

Disadvantage: ______________________________

____

Advantage: ______________________________

Disadvantage: ______________________________

____

Advantage: ______________________________

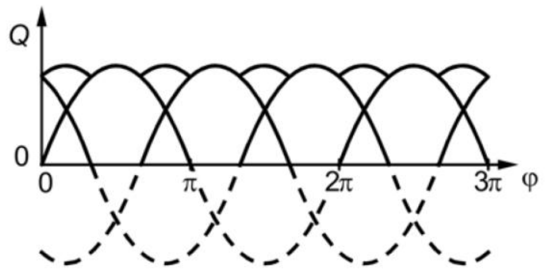
Disadvantage: ______________________________

3.4 Give a reason why motors in general achieve higher efficiency factors than pumps. (1 Point)

In the following a piston pump in swash plate design with 3 pistons and a rotational speed of 1500 rpm is given. The cross-section area of a piston is 6 cm^2 and the circle diameter of the cylinder block 10 cm. The swash plate angle can vary between 0° - 15°. The reversing process happens ideal and pressure less.

3.5 Calculate the maximal theoretical flow rate per minute? (1 Point)

At swash plate pumps with 3 pistons kinematic pulsation due to the configuration occurs as shown below.



3.6 Calculate the kinematic flow rate pulsation approximately. (0.5 Points)

3.7 How high is the deviation between the real pulsation and the approximation? For this, first calculate the kinematic flow rate with the help of the equations below. (3 Points)

$$\delta = \frac{\left[\sum \frac{dV_P}{d\varphi}\right]_{\max} - \left[\sum \frac{dV_P}{d\varphi}\right]_{\min}}{\left[\sum \frac{dV_P}{d\varphi}\right]_{avg}} \cdot 100\% = \frac{\Delta Q}{Q_{avg}} \cdot 100\%$$

$$\sum \frac{dV_P}{d\varphi} = \frac{h_{\max}}{2} \cdot A_P \left[\sin\varphi + \sin\left(\varphi + \frac{2 \cdot \pi}{z}\right) + \sin\left(\varphi + \frac{4 \cdot \pi}{z}\right) + \ldots + \sin\left(\varphi + \frac{n \cdot \pi}{z}\right) \right]$$

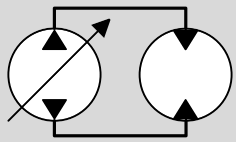
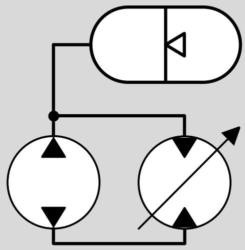
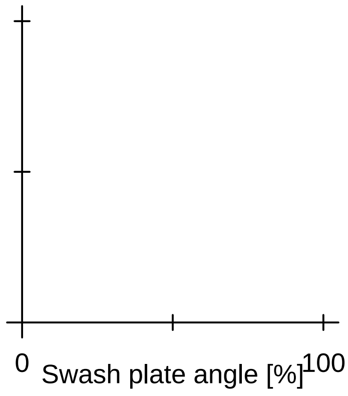
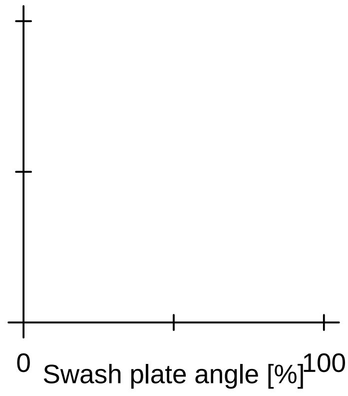
with $n = 2 \cdot (z - 1)$

Exercise 4 (10 Points)

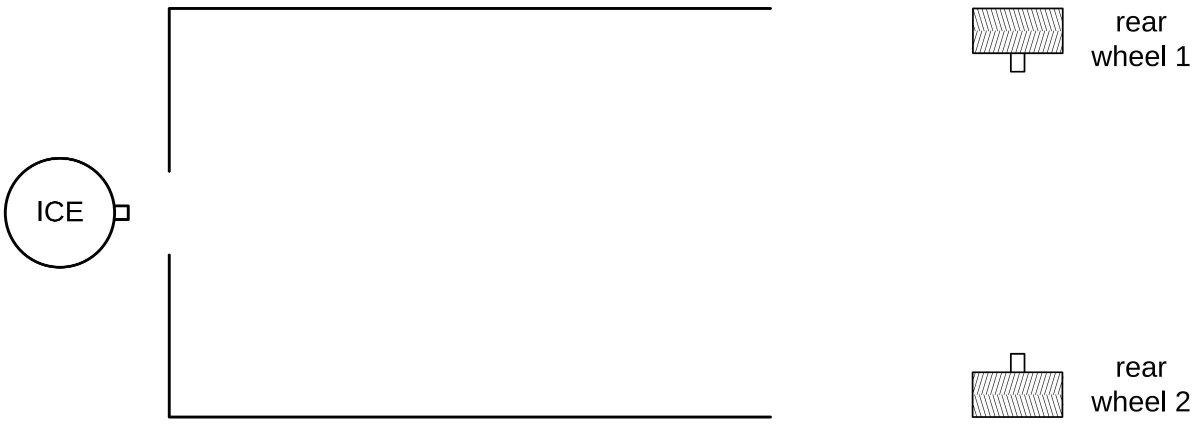
Hydrostatic transmissions show very different topologies and are designed individually for each usage. In the following, different variants of transmissions should be analysed.

4.1 Allocate the following terms to the two circuits. Respectively sketch the output rotational speed or the output torque over the swash plate angle (2.5 Points):

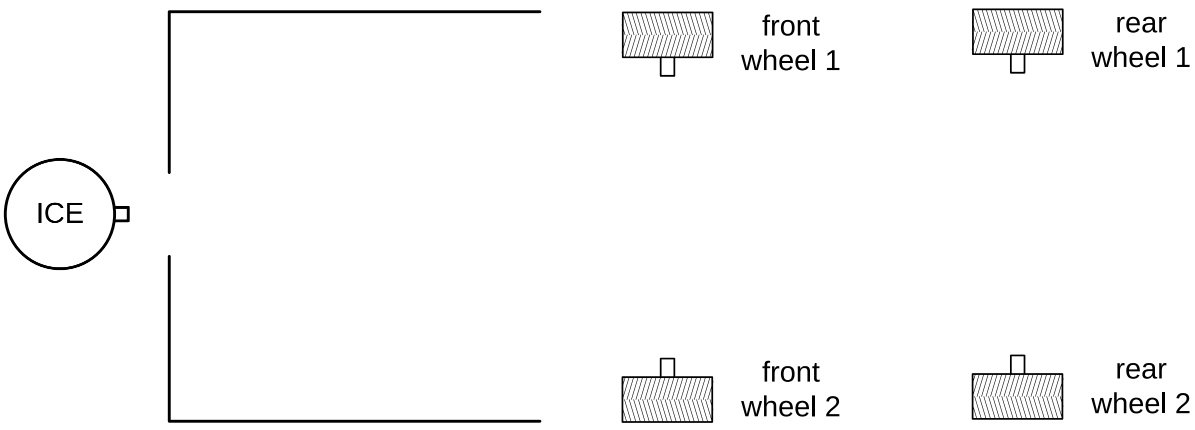
Rotational speed - controlled, impressing of pressure, torque - controlled, primary adjustment, secondary adjustment, impressing of flow rate

		
adjustment		
impressing		
output control		
		

4.2 Complete the hydraulic schema to an operative, reliable and efficient closed transmission. Provide a compound control of the transmission and a mechanic power-output distribution of both rear wheels. (2.5 Points)



4.3 The hydrostatic transmission shall now be changed and completed so that the front axis is also driven hydrostatically. The output power is split by a mechanical construction element to both wheels of the front axis. Take into consideration that for driving bends a hydraulic differential between the axes is required. Draw (only) the essential changes into the circuit. (1 Point)



In the following, the components of the generatoric part of a hydrostatic transmission with a primary adjustment should be designed. Use the following data.

Required output torque $M_{out.}$	800 Nm	Required output speed $n_{out.}$	1200 rpm
Drive Speed n_{in}	2100 rpm	Swash plate angle relation α_2	0.6
Max. operating pressure p_{HD}	350 bar	Low pressure level p_{ND}	20 bar
H-m efficiency $\eta_{hmMotor1}$	98%	Vol. efficiency $\eta_{volMotor1}$	93%
H-m efficiency $\eta_{hmPumpe1}$	97%	Vol. efficiency $\eta_{volPumpe1}$	94%

For the case with minimal swash plate angle (state 2) the particular efficiency factor at this operating point can be approached through the values at maximal swash plate angle (state 1) with the following formula: $\eta_2 = \eta_1 \cdot \left(e^{\alpha 2} - 1\right)$

4.4 Calculate the required flow rate for the motor in state 1. (1 Point)

4.5 Determine the pump displacement volume in state 1. (1 Point)

[alternatively to 4.4: $Q_{requ.}$ = 300 l/min]

4.6 Which input power can the pump use in state 2. (2 Points)

[alternatively to 4.5: V_{pump} = 75 cm³]

Exercise 5 (15 Points)

5.1 Cylinder Selection: For the assembly in a machine you need to choose a pneumatic cylinder. At the extending-stroke an injecting procedure is realized. The return stroke is initiated through external forces by the machine. Which cylinder do you use? (0,5 Points)

Single Acting Cylinder	Double Acting Cylinder

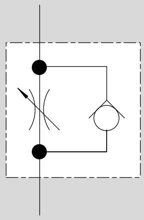
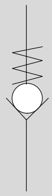
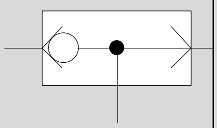
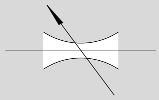
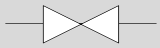
5.2 Name a benefit and a disadvantage each for the use of air in technical applications concerning to the given characteristics. (3 Points)

	Benefit	**Disadvantage**
Low Operating Pressure		
Low Viscosity		
High Compressibility		

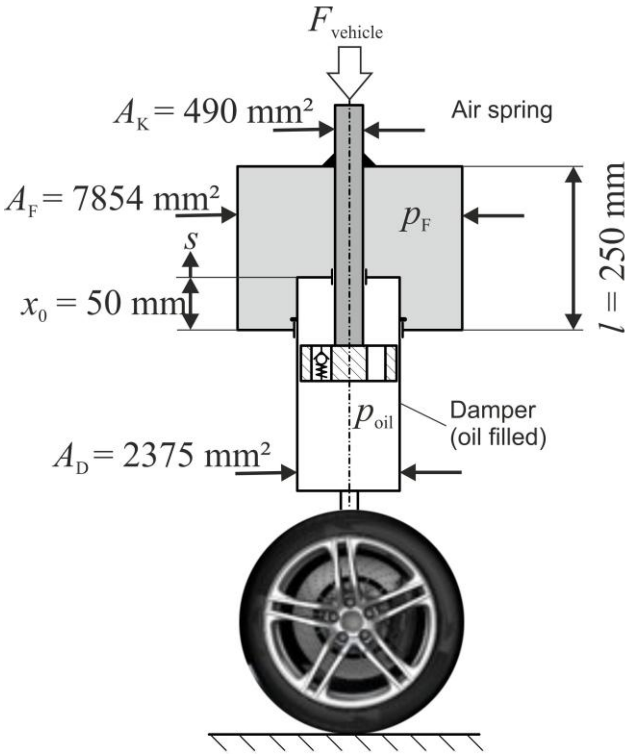
5.3 Some pneumatic rotary drives can use the expansion work due to their principle. Divide the drives into the corresponding groups. (2 Points)

Rotary Drive	Use of Expansion Work Possible Due to Principle	Use of Expansion Work Not Possible Due to Principle
Vane Motor		
Geared Motor		
Turbines		
Piston Motors		

5.4 Name the pictured valves. (2,5 Points)

You would like to equip your passenger car with a dead weight of m_{PKW} with an air cushioning. You contemplate the model pictured in Fig. 5-1 and now want to prove if the spring damper is suitable for your vehicle. Therefore you make some calculations. In the upper part of the spring damper the air spring is arranged. In the unloaded case it is pre-stressed with p_{F0} against a mechanical stop position with x_0. On this the force $F_{vehicle}$, which is the force the vehicle holds on the wheels, affects. The damper arranged in the bottom part is filled with oil. The pressure p_{oil} can be considered as constant throughout the whole stroke. The pressure compensating room is not pictured.



Given are the following hints and parameter:

P_{oil} = 20 bar	p_{F0} = 20 bar	m_{PKW} = 2 t
T_U = 293,15 K	p_U = 1 bar	g = 9,81 m/s²

All pressures are and need to be indicated as absolute pressures. The mass of the shock absorber can be neglected. The cross-sectional areas are full sections.

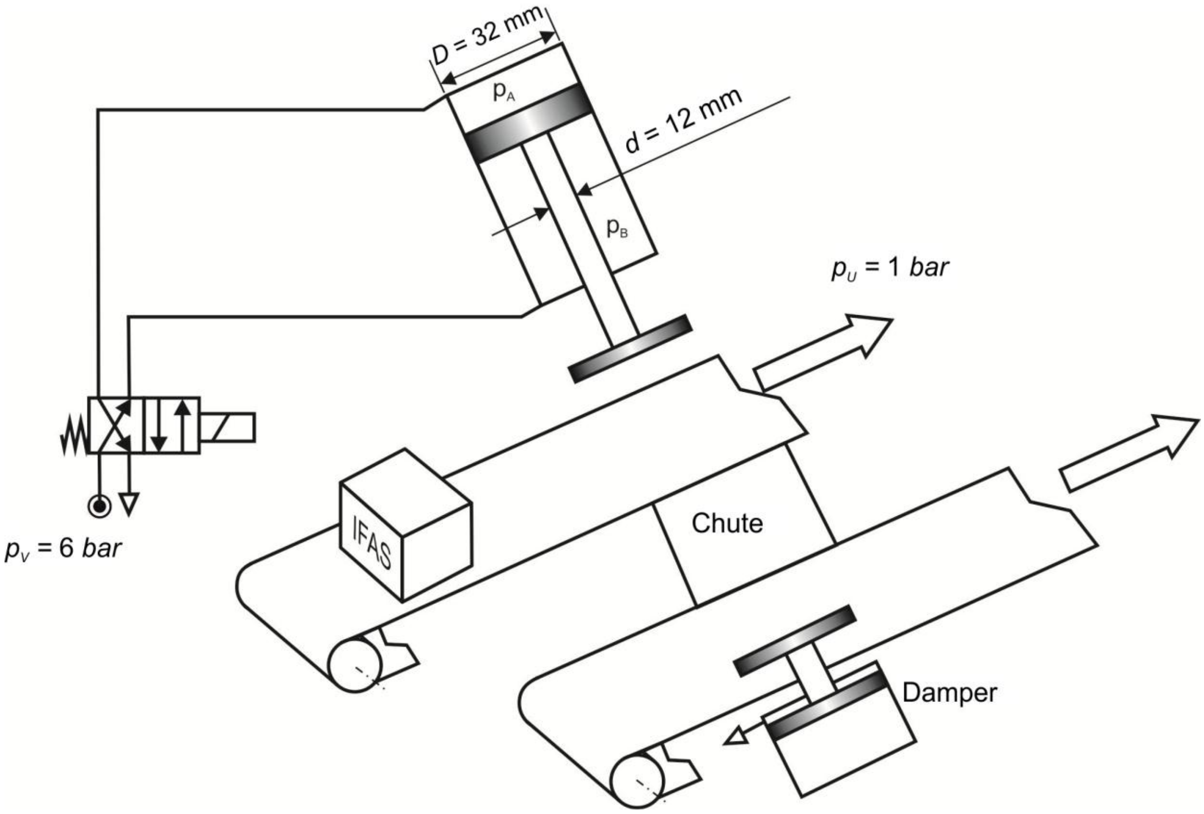
5.5 Calculate the compression path s if you set your unloaded passenger car from the lifting ramp on its own four wheels. Consider an equal load spreading on all four wheels. Consider a very slowly running lifting ramp. (3 Points)

5.6 Giddy with pleasure that your passenger car finally stands on its own wheels you and your friends jump in simultaneously so the pressure p_F = 30 bar occurs abruptly in the air spring. Calculate the temperature T_F that appears in the air spring and the energy that is stored in the spring. Consider a spring pressure of $p_{F,unloaded}$ = 24 bar and a spring volume of $V_{F,unloaded}$ = 1700 cm³ for the unloaded vehicle. (2 Points)

5.7 From the attached gas spring the air exhausts over a sealing gap with a sonic conductance of C = 0,5 Nl /(min bar) to the environment. How long does it take until the spring runs in the upper mechanical stop? Consider a constant temperature T_F = 300 K and a constant pressure p_F = 24 bar. At the beginning the spring is compressed with s = 20 mm. (2 Points)

6th Exercise (10 Points)

Boxes with different masses are pushed from one conveyor belt over a chute to a second one and thereby moved with a constant velocity of v = 1 m/s. On the second conveyor belt they are retarded by a damper.



Given are the additional parameters and hints:

All pressures are and need to be indicated as absolute pressures!

The weight can be neglected.

R_L=288 Nm/(kg K)

κ=1,4

6.1 Indicate the complete appellation of the used switching valve (0,5 Points).

6.2 Complete the circuit diagram towards an exhaust air flow control. Why is this one predestinated for the contemplated task? (1,5 Points).

6.3 Calculate the effective friction force of the exhaust air flow controlled cylinder during the move-out. Act on the assumption that a pressure difference of 0,5 bar is required to overcome the friction force. The valve can be considered as pressure loss-free (1,5 Points).

6.4 Calculate for the move-out of the cylinder the mass flow through the exhaust port, the required sonic conductance C and the smallest cross section of the restriction. (3,0 Points)

Given: T_B = 300 K, α_D = 0,7

6.5 The absorber, for which the technical state at standard conditions can be considered in rest position, has a piston diameter and a stroke of 100 mm each. It is hit by a box with the weight of 50 kg with a velocity of 1 m/s. Calculate with the help of the first law of thermodynamics the temperature T_2 in the absorber chamber for the state in which the kinetic energy was transferred completely in the absorber. The change in state shall be isentropic, changes of the external energy can be neglected and the specific heat capacity at constant volume is $c_v = R/(\kappa - 1)$ (2,5 Points).

6.6 How far does the absorber move under the circumstances described in 6.5? (In case it is not calculated use: T_2 = 327 K) (1 Point).