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: Fundamentals of Fluid Power (15 Points)

Given is the hydraulic circuit shown in Fig. 1-1 that can be used to lift and lower a load.

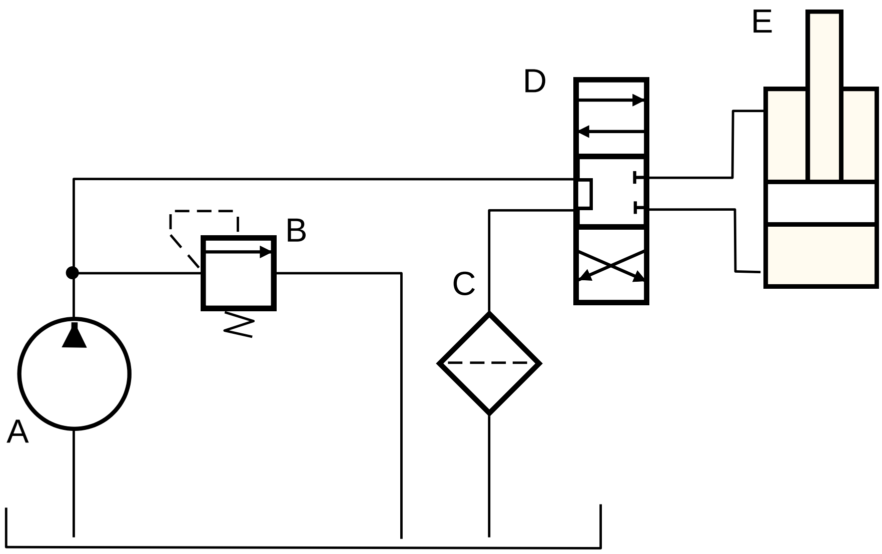


Fig 0-1: Hydraulic circuit

1.1 Name the components according to their marking in the following table (2.5 Points):

A	
B	
C	
D	
E	

1.2 The pump shall be protected through an additional filter against rough particles which can be existent in the tank. Draw the additional filter into the circuit above at the appropriate position using the adequate symbol. (1 Point)

1.3 For the height control over medium distances a barometric level as shown in Fig. 1-2 is used. According to the law of communicating vessels, the water in the sight glass (right) appears as high as in the tank (left). After being brought into service it turns out that the liquid column oscillates after animation. Although the water level in the tank stays nearly constant, in the sight glass it moves up and down. Compile the differential equation for the height x of the water level in the sight glass. Neglect all friction influences and the movement of the water inside the tank. (3 Points)

Given:	pipeline length	l_S	25 m
	density of water	ρ	1000 kg/m³
	Gravitational acceleration	g	9.81 m/s²
	internal diameter hose	d_S	10 mm
	internal diameter sight glass	d_G	10 mm

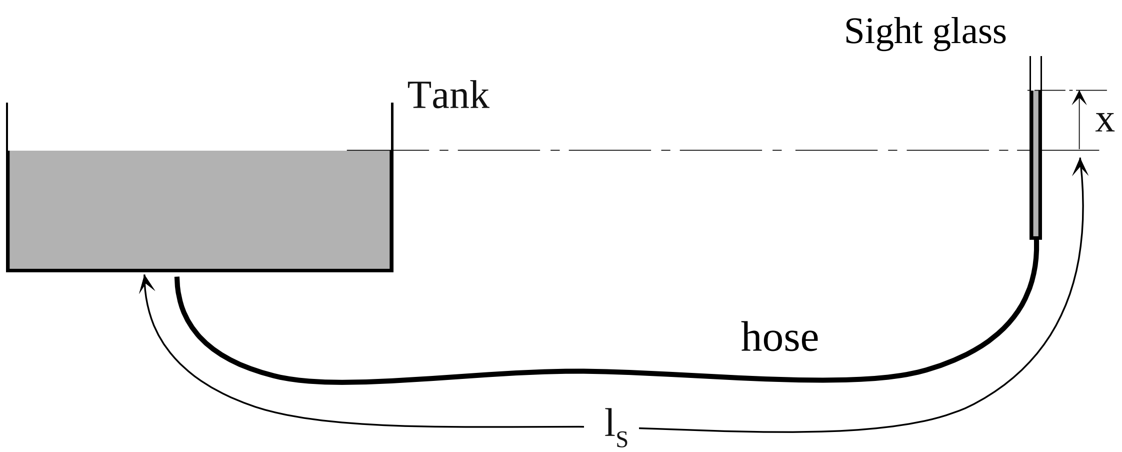


Fig. 0-2: Barometic Level

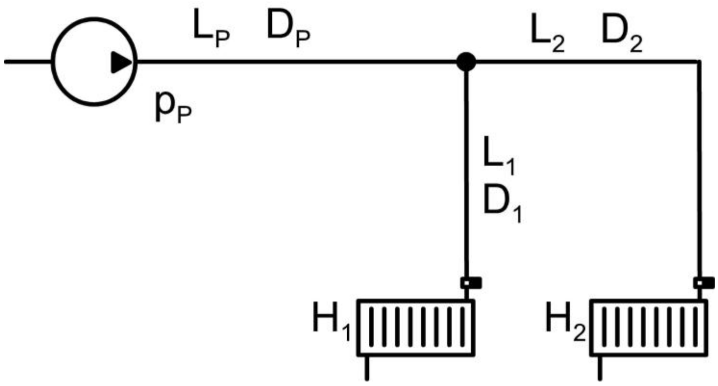
1.4 What is the hydraulic inductance L of the system? (1 Point)

1.5 What is the hydraulic capacity C = dV/dp of the sight glass? (2 Points)

1.6 Calculate the natural frequency f of the system due to the formula $f = 1/(2\pi\sqrt{LC})$ or alternatively through derivation from the differential equation. (1.5 Points)

1.7 In a heating installation, as pictured in the sketch, the centrifugal pump produces a constant pressure of p_P = 1 bar. Two heating radiators are connected. The differences in altitude and the flow resistors of the heating radiators, the radiator valves, the manifolds and the return pipes can be neglected. In all pipelines a turbulent flow state is given. Calculate the flow rate Q_1 through the heating radiator H_1 in case the radiator's valve is open and the other valve at heating radiator H_2 is closed. (2.5 Points)

Given:	Δ_{water} = 1000 kg/m³	8 = 0.04 (pipe resistor coefficient)
	L_P = 16 m	D_P = 16 mm
	L_1 = 10 m	D_1 = 10 mm
	L_2 = 20 m	D_2 = 10 mm



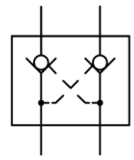
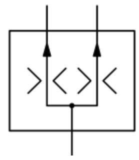
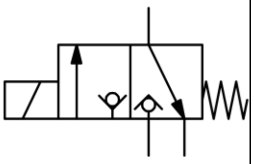
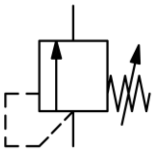
1.8 Mark if and how the flow rate Q_P of the pump changes when the second valve is opened in addition to the first one in the table below. (0.5 Points)

	Q_P decreases
	Q_P stays constant
	Q_P increases

1.9 Due to different flow rates one of the heating radiators heats worse than the other. Suggest one procedure to achieve the same water supply without using a flow divider at both radiators while the lengths of the pipes stay constant and the valves are fully opened. (1 Point)

Exercise 2: Valves (10 Points)

2.1 Name the pictured valves completely and relate them to one of the four main valve groups (check, directional control, pressure control or flow control valve). (2 Points)

2.2 Name two reasons and one counteraction for each reason why the valve spool of a directional control valve can be stuck. (1 Point)

2.3 Mark the orifice and the pressure compensator of the valve pictured in Fig. 2-1 exactly and give its concrete denomination. (1 Point)

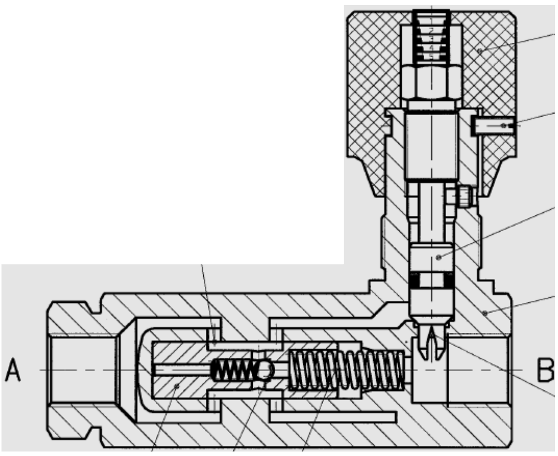


Fig. 0-1: Valve

denomination:____

2.4 Calculate the opening width of this valves pressure compensator. (1.5 Points)

Given: $\Delta_{oil} = 890\ kg/m^3$ $Q = 180\ l/min$ $\alpha_{D,pc} = 0.7$

$d_{pc} = 18\ mm$ $p_A = 230\ bar$ $p_B = 160\ bar$

$\Delta p_{orifice} = 5\ bar$

2.5 Calculate the spring force at the pressure compensator. Act on the assumption that the system in its current state is in balance. Neglect the flow force and the forces due to friction. (1 Point)

2.6 Calculate the required axial force to keep the valve spool shown in Fig. 2-2 in its position. No external pressure forces affect the valve spool. Act on the assumption of a stationary flow. (1 Point)

Given: Δ_{oil} = 890 kg/m³ Q = 120 l/min d = 10 mm

x = 2 mm ε_1 = 30°

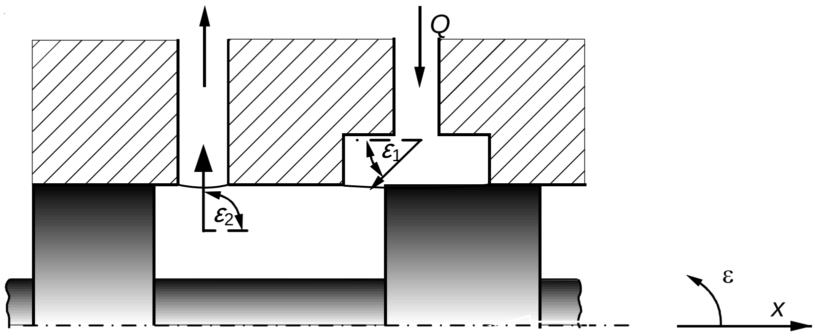


Fig 0-2: Valve Spool

2.7 Calculate the pressure loss through the valve. (0.5 Points)

Given: Δ_{oil} = 890 kg/m³ Q = 120 l/min d = 10 mm

x = 2 mm ε_1 = 30° α_D = 0.6

2.8 To compensate the flow forces, the out flow geometry is changed as in Fig. 2-3 ($\varepsilon_2 = 120°$). Calculate the value difference of the flow force (2.0 Points)

Given: Δ_{oil} = 890 kg/m³ Q = 120 l/min d = 10 mm

x = 2 mm ε_1 = 30° ε_2 = 120°

A_2 = 300 mm²

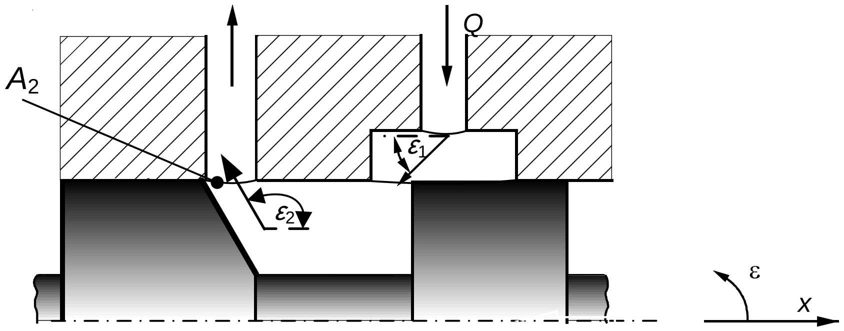


Fig. 0-3: Valve Spool with Flow Force Compensation

Exercise 3: Pumps and Motors (10 Points)

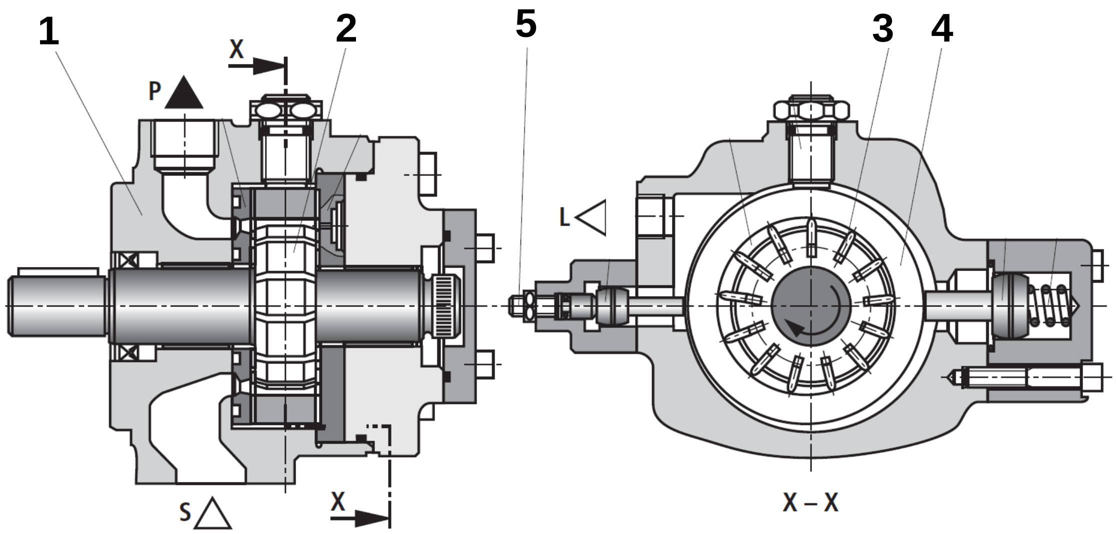


Fig. 0-1: Hydraulic Pump

3.1 In Fig. 3-1 a hydraulic pump is pictured. Give the explicit appellation of this pump design. (0.5 Points)

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

1.____

2.____

3.____

4.____

5.____

3.3 Which pump design is most suitable if the pressure fluid is polluted heavily with particles and the displacement volume should be big? (0.5 Points)

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To improve the reversal of a fixed displacement pump in swash plate design (swash plate angle = 15°) the pre-compression should be considered in detail. For the exercise the following values are given:

The pump works at an operating pressure of 350 bar and a rotational frequency of 1500 min^{-1}. The 9 pistons have a cross-section area of 4 cm^2 apiece and a dead volume of 5 cm^3 apiece. They are ordered on a pitch circle diameter of 10 cm. The effective compression module of the oil can be taken into consideration with 14000 bar.

3.4 Calculate the stroke a piston needs to move to pre-compress the oil onto the operating pressure. (2.5 Points)

If you are not able to answer this exercise then (and only then!) calculate in the following with 2 mm.

3.5 How large is the work that needs to be dedicated for the compression of the volume in one displacement chamber? Please give the answer in Joule. (1 Point)

3.6 Calculate the ratio of compression work and dispensed work per piston. (1 Point)

3.7 Calculate the optimum angle at which the displacement changer should be connected to high pressure. The stroke movement of the piston can be described by $h(\varphi) = \frac{h_{\max}}{2}(1 - \cos\varphi)$. (2 Points)

Exercise 4: Hydrostatic Drives (10 Points)

In landscape contracting and in municipal field of operation, lawn mowers with a tough construction type are used for landscape preservation. Therefore a continuously adjustable transmission is inserted in manually shuffled automotive lawn mowers to adjust the adequate driving speed for the different application areas. All subexercises can be answered separately. Solutions from other subtasks are not relevant. Declare all numerical values with three positions after decimal point.

Fig. 0-1: Manual Lawn Mower with Hydrostatic Drive

4.1 Write down the two options for the control and supply mode of hydraulic circuits and underline the best option in each case for this mobile case of operation. (1.5 Points)

	Control Mode	Supply Mode
Option 1		
Option 2		

4.2 Complete the hydraulic circuit (Fig. 4-2) to a functional, operationally reliable and efficient transmission. Plan a primary control of the transmission and a hydraulic output separation for both wheels. (2.5 Punkte)

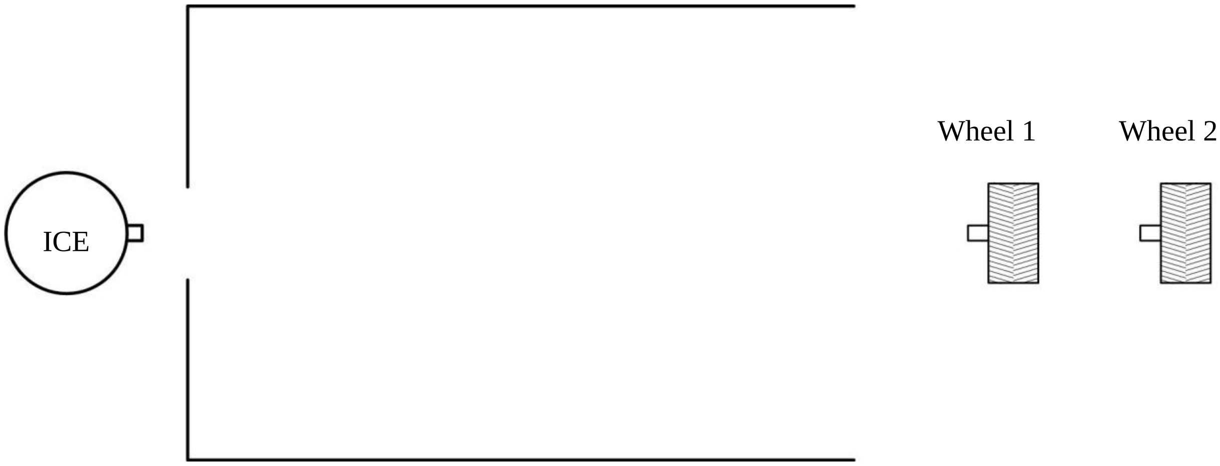

Fig. 0-2: Hydraulic Circuit Lawn Mower Drive

4.3 In operation, the lawn mower drives into a rabbit burrow so that the wheel loses road adherence. Which deficient behaviour can occur at the drive (0.5 Points) and through which addition this deficit can be eliminated? (0.5 Points)

4.4 Calculate in the following the construction size of both hydromotors with the given data. (1.5 Points)

Given: m_G = 100 kg | g = 9.811 m/s² | D_{wheel} = 200 mm

$\eta_{hmMotor}$ = 98% | $\eta_{volMotor}$ = 93% | p_{zul} = 350 bar

α_{ST} = 30° (inclination) | X = 100% (driving resistance addition)

4.5 Which flow rate is necessary to achieve the given velocity? Use the given data. (1.5 Points)

Given: v = 2 m/s | V_{Motor} = 6 cm³ | D_{wheel} = 230 mm

$\eta_{hmMotor}$ = 97% | $\eta_{volMotor}$ = 94%

4.6 Calculate the maximum displacement volume of the pump with the help of the given values and the diagram of the volumetric efficiency factor (Fig. 4-3). (2 Points)

Given: n_{VKM} = 1200 U/min $P_{operation}$ = 220 bar $Q_{nec.}$ = 3 l/min

$A_{adjustable}$ = 0,8 (swash plate angle relation)

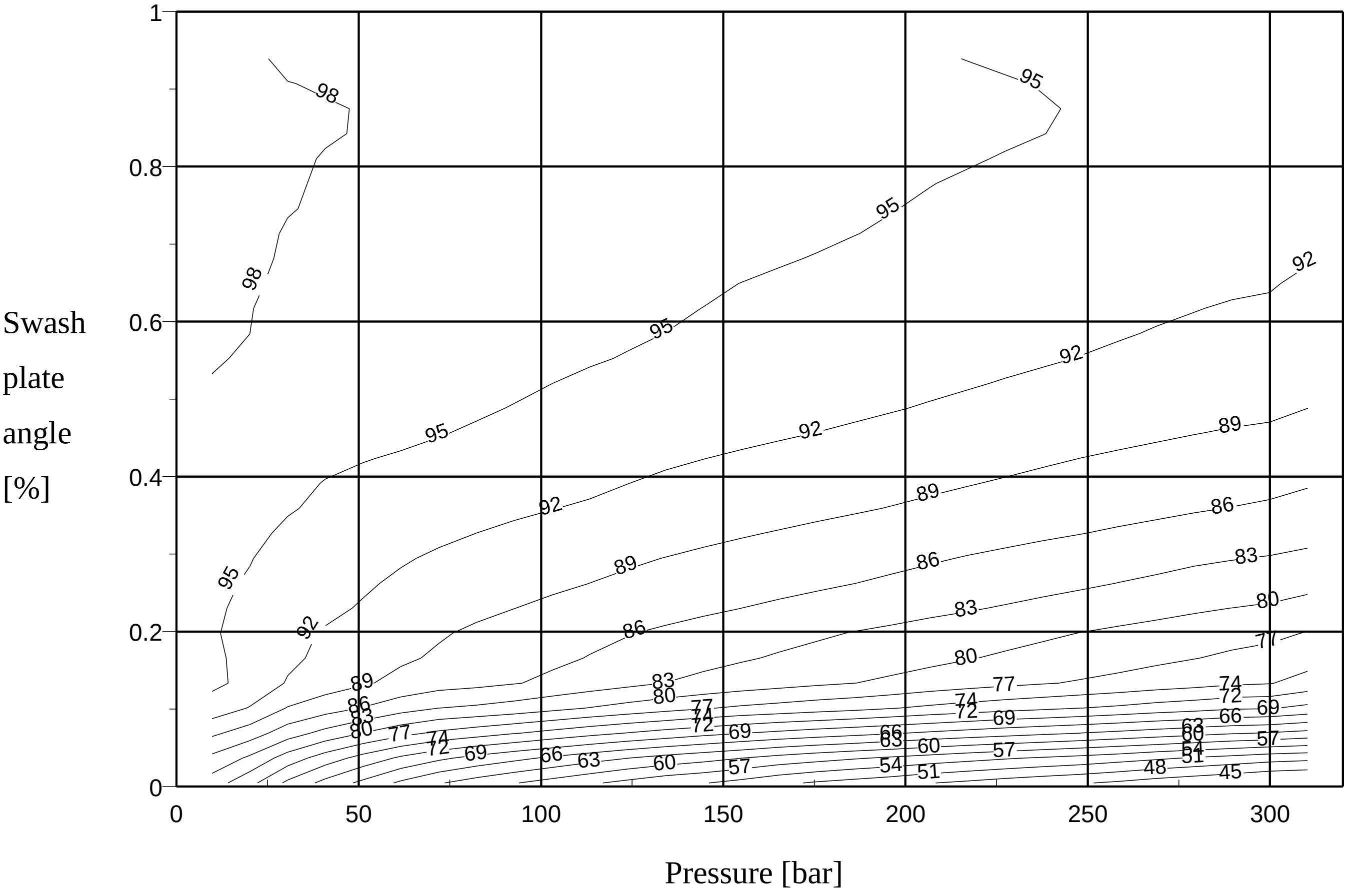

Fig. 0-3: Volumetric Efficiency Factor of the Adjusting Unit [%]

Exercise 5: Fundamentals of Pneumatics (15 Points)

5.1 In pneumatic constructions so called service units are used. From which three components are these composed? (1,5 Points)

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5.2 In a pneumatic resistor a “hypercritical flow“ occurs. Explain through which characteristics this kind of flow is physically distinguished. (0,5 Points)

____

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5.3 Name 3 possible solutions to avoid the hard impact of the piston at the cylinder ground during the movement of the cylinder in the final position. (1,5 Points)

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5.4 Which benefit do cylinders without a piston rod have in comparison to cylinder drives with piston rods? (0,5 Points)

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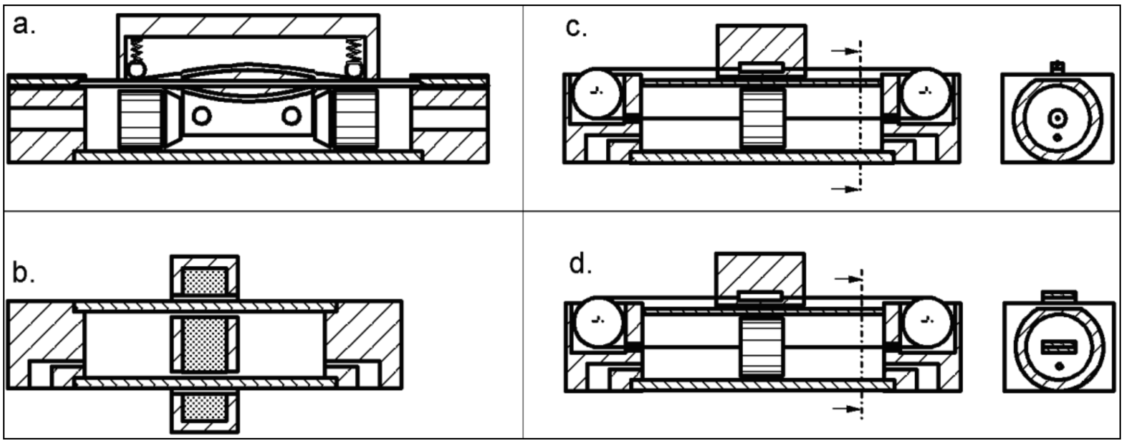
5.5 Double acting cylinders without a piston rod can be divided into different construction types. Name the different construction types for the pictured cylinders. (2 Points)



a: ______________________________ c: ______________________________

b: ______________________________ d: ______________________________

5.6 Pneumatic rotary motors can be divided into the construction types “rotary drive“ and “semi-rotary drive“. Distribute the drives to the corresponding group. (2 Points)

Rotary Drive	Rotary Drive	Semi-rotary Drive
Axial Piston Motor		
Toothed Belt Drive		
Stepping Drive		
Vane Motor		

As a responsible student you would like to realize your lately acquired knowledge in pneumatics in a practical project: You develop a pneumatic spud gun as pictured in Fig. 5-1. The accumulator is filled through a compressor with the flow rate Q_N until the pressure $p_{accumulato,full}$ is reached and a temperature $T_{accumulator,full}$ is given at the filled state. The potato is shot from a PVC-pipe with an internal diameter d. To speed up the potato the accumulator is connected with the end of the pipe through a valve. From your research on the internet you know that the pressure $p_{pipe,muzzle}$ shall occur in the pipe while passing the muzzle.

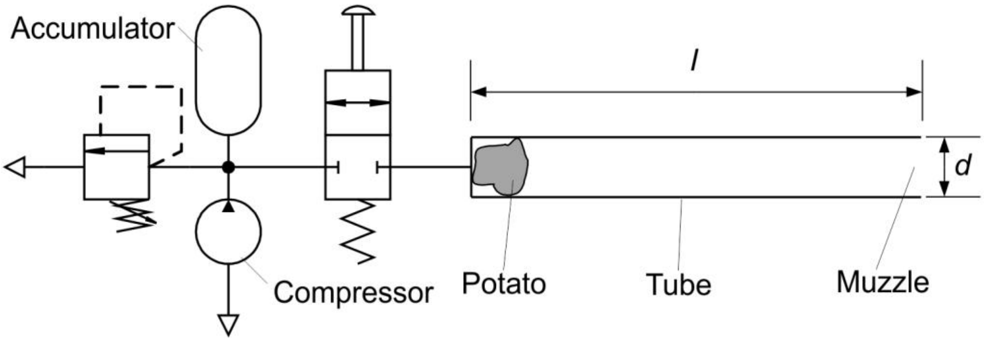


Fig. 0-1: Spud Gun

Given:	d = 40 mm	E_{kin} = -250 J	p_U = 1 bar
	$P_{pipe,muzzle}$ = 2 bar	$Q_{N,comp.}$ = 4,6 l/min	$P_{accumulator,full}$ = 10 bar
	$T_{accumulator,full}$ = 30°C		

All pressures are given and need to be given as absolute pressures. Dead volumes and friction can be neglected. The valve cross section is chosen so big that the connection between accumulator and pipe can be considered as lossfree. No leakage throughout the potato occurs. The expansion of the potato alongside the pipe can be neglected. Because the firing act of the potato is very short you can neglect the mass flow which is boosted during the firing.

5.7 Calculate the accumulator volume $V_{accumulator}$ so the potato receives the kinetic energy E_{kin} from the accumulator during the acceleration procedure. Consider an isentropic change in state. (2 Points)

5.8 Calculate the length of the pipe so the pressure $p_{pipe,muzzle}$ is reached when the potato passes. Calculate with the accumulator volume $V_{accumulator}$ = 0,3 l. (2 Points)

5.9 How long do you need between the single shots until the gun can be fired again at the full accumulator pressure? Assume that the valve closes as soon as the accumulator pressure declines under 2 bar. Calculate with $V_{accumulator}$ = 0,3 l. (3 Points)

Exercise 6: Practice in Pneumatics (10 Points)

You should establish a new work station in your company where at poured cable sheaves (Fig. 6-1) the inclusion of the rolling-element bearing shall be drilled onto the correct diameter. To reduce the accident hazard and to avoid waste it is necessary to clamp the component part first before it can be drilled. Therefore pneumatic energy shall be used.

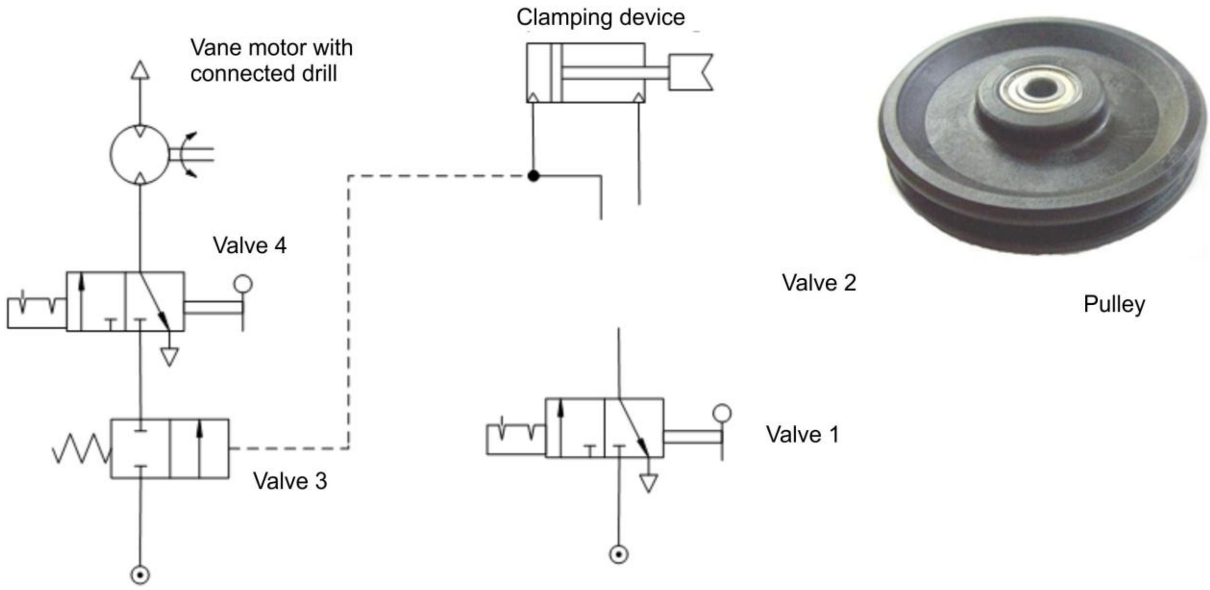


Fig. 0-1: Circuit of the Combined Clamping and Drilling Device

Given:	$R = 287$ J/kg K	$T_U = 293$ K	$p_U = 1$ bar
	$H_{vane} = 3$ mm	$b_{vane} = 100$ mm	$R_{motor;rotor} = 13$ mm
	$D_{cyl.-piston} = 0{,}06$ m	$D_{cyl.-rod} = 0{,}02$ m	

Friction and heat transfer can be neglected in general.

6.1 Draw in valve 2. It needs to open and close the clamping device and shall stay in the activated position after actuation. The actuation energy shall be brought up through the operator. (2 Points)

6.2 What is the name of the kind of sequence control pictured in Fig. 6-1? (1 Point)

6.3 At which pressure does valve 3 open if the clamping device needs to bring up a clamping force of at least 1500 N. Consider environmental pressure inside of the piston rod-sided chamber. (2 Points)

6.4 Calculate the sonic conductance of valve 4 (b_{crit} = 0,4) in Nl/min/bar so the vane motor of the pneumatic drill can move with maximum 8000 rpm if a pressure of 2 bar operates in front of the motor (T_{front} = 293 K). The vane motor has two connections. Calculate with a pressure of 6 bar in front of valve 4. (4 Points)

6.5 Does the danger of icing exist at the vane motor from exercise 6.4? Give a reason for your answer. (1 Point)