RWTH AACHEN UNIVERSITY
IFAS Institut für fluidtechnische Antriebe und Steuerungen
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Written Examination „Fundamentals of Fluid Power“

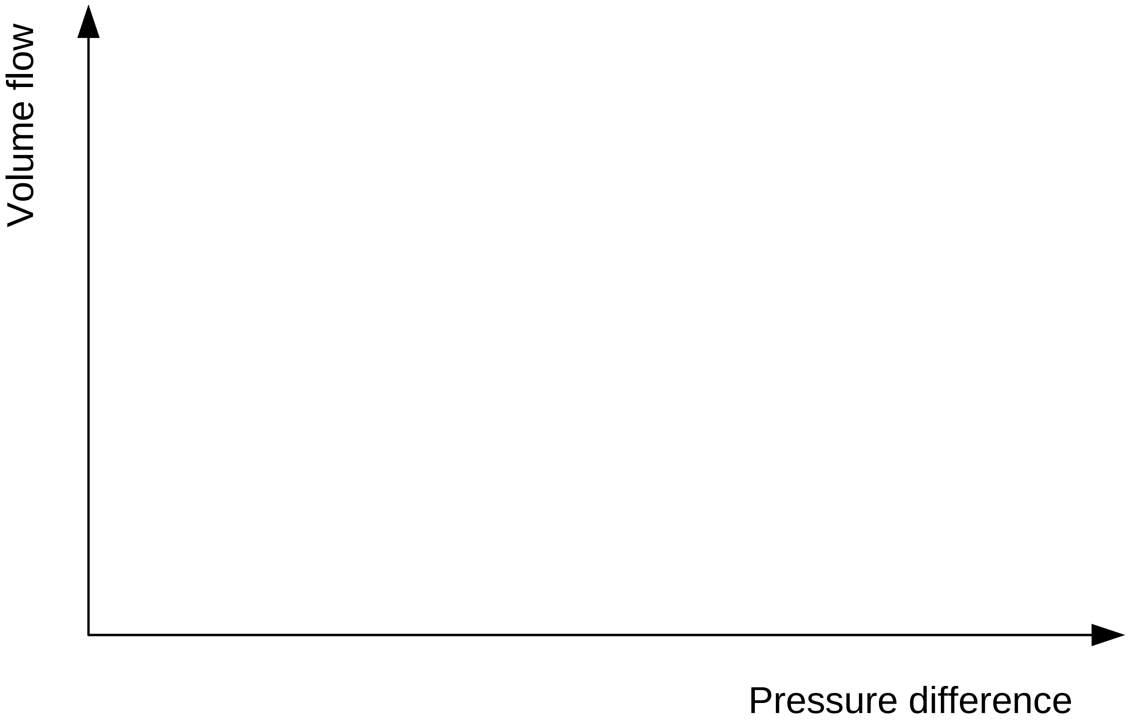
February, 19^{th} 2015

1. Exercise / 15 Points

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

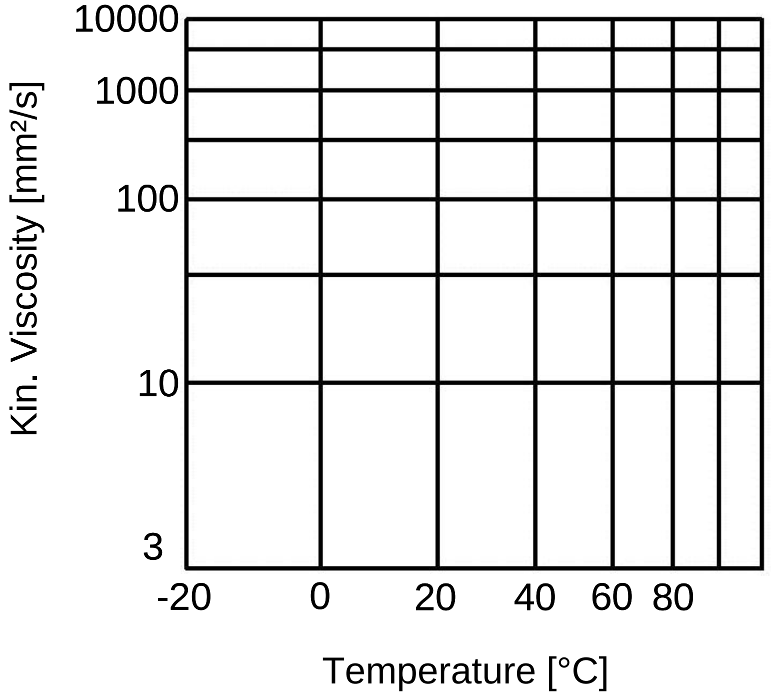
Advantage ☺	Disadvantage ☹

1.2 Plot the characteristic curve of a throttle and an orifice into the graph shown below. Mark the curves clearly and state the corresponding flow law for each resistor. (1.5 Points)



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

1.4 Plot the qualitative course of the kinematic viscosity of HLP10 and HVLP46 into the graph shown below. Mark the curves clearly. (1.5 Points)



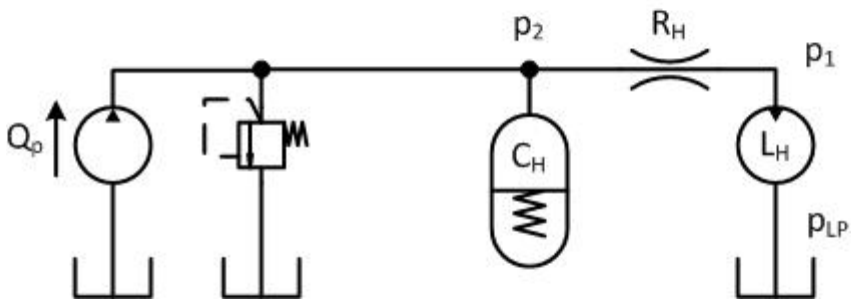
1.5 In an axial piston machine, amongst others, the viscose friction force acts against the piston movement. Calculate the maximal viscose force needed for the piston movement. The gap between piston and bushing is filled with mineral oil at a temperature of 60°C. (2.5 Points)

Name	Value
Gap height h	5 µm
Density mineral oil ρ	860 kg/m³
Kinematic viscosity ν at 60 °C	52 mm²/s
Piston skin surface A	340 mm²
Maximal piston speed $\dot{x}$	1 m/s

1.6 What is the dynamic viscosity of the oil (see assignment 1.5) at 350 bar? (Hint: $b = 1.7 \cdot 10^{-3}\ bar^{-1}$) (1 Point)

1.7 A hydraulic cylinder shall provide a force of 22 kN at a speed of 1.5 m/s. Calculate the necessary volume flow in l/min, if the supply pressure is 300 bar. All losses can be neglected. (1.5 Points)

1.8 The following hydraulic network is given. Compile the differential equation for the pressure p_1. A constant volume flow is provided by the pump and the pressure relief valve is closed. The low pressure is pre-stressed. (4 Points)



2. Exercise / 10 Points

2.1 Which four basic types of valves (related to the function) do you know? (2 points)

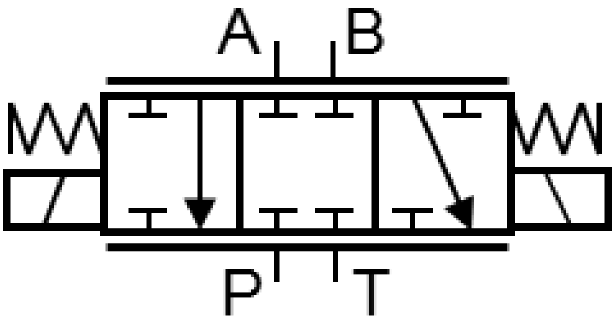
1) ______________________________

2) ______________________________

3) ______________________________

4) ______________________________

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



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2.3 Name the two main valve construction types and one characteristic advantage for each. (2 points)

1) ______________________________

Advantage: ______________________________

2) ______________________________

Advantage: ______________________________

2.4 Name one advantage and one disadvantage for a 3-way flow control valve in comparison to a 2-way flow control valve. (1 point)

Advantage: ______________________________

Disadvantage: ______________________________

You are designing a test rig for a “high striker”. A cylinder is connected to the high pressure and compresses a spring (see following picture). In the second phase the valve is opened fast, the pressure chamber decompresses, the piston is accelerated by the spring and hits the plate of the “high striker”.

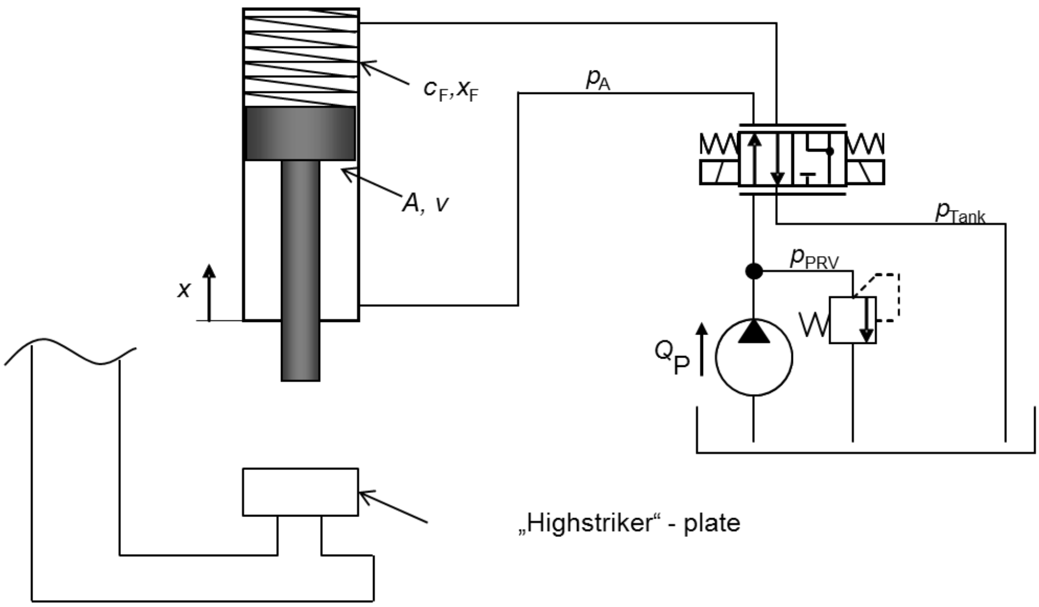
As an encouraged Fundamentals-of-fluid-Power valve-expert you are stepping into action.

<u>Note</u>: All parts of the exercise can be solved separately!

A 4/2-way valve is used to control a differential cylinder. In the considered operating point the cylinder moves with a constant speed. The seals of the cylinder can be considered as frictionless and leakage-less. The plunger mass and gravitation can be neglected. The pressure at the piston side is equal to the tank pressure.

The following data of cylinder and valve are known:

effective piston area	A	150 mm²
piston speed	v	*1 m/s*
spring rate	c_F	30 N/mm
spring displacement	x_F	50 mm
adjusted pressure at PRV	p_{PRV}	105 bar
tank pressure	p_{tank}	0 bar
pump flow rate	Q_P	2 l/min
flow coefficient	α_D	0,6
oil density	ρ	850 kg/m³
diameter of the spool	d	2 mm



2.5 Calculate the pressure loss Δp_1 between the pump (p_{PRV}) and the cylinder (p_A) in the point of time when the spring is displaced by x_F = 50 mm? Dynamic effects shall be neglected.

Note: Write down each step which is necessary to solve the exercise and specify the final result in the corresponding unit [bar]. (1.5 points)

2.6 Calculate the representing spool displacement *x*?

If you couldn't solve 2.5, you can go on with Δp_1 = 10 bar.

Note: Write down each step which is necessary to solve the exercise and specify the final result in the corresponding unit [mm]. (1 point)

2.7 The valve is opened and the piston moves with a velocity of $v = 1$ m/s in negative x-direction. Calculate the pressure loss at the valve Δp_2 between the cylinder (p_A)and the tank (p_{Tank}) at the point of time, as the valve's opening stroke is equal to x = 0.8 mm?

Note: Write down each step which is necessary to solve the exercise and specify the final result in the corresponding unit [bar]. (1.5 points)

3. Exercise 3 / 10 Points

3.1 Draw the symbol for the named components. (1.5 Points)

Hydraulic linear motor	
Adjustable hydro motor with two directions of flow	
Constant displacement pump with one direction of flow	

3.2 Name the three different displacement principles for hydraulic pumps and motors. Give an example for each principle. (3 Points)

Principles of displacement	Example

There are two causes for pulsation: kinematic and compression-induced pulsation.

3.3 Briefly describe the cause for kinematic pulsation. Also give the formula for estimating the kinematic pulsation for an odd number of pistons. (1 Point)

Formula: ___________________________

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You are confronted with the task to choose a hydro motor for a hydrostatic transmission. You are looking for a constant displacement hydro motor, since the transmission uses a primary adjustment. Without load the rotational speed is 3000 rpm and the pressure differential over the motor is 5 bar. The motor requires 0.42 kW under these circumstances. Consider the volumetric efficiency η_{vol} = 95%. Neglect the hydraulic-mechanic efficiency.

3.4 Calculate the volume of displacement per revolution. Give your results in cm³ per turn.

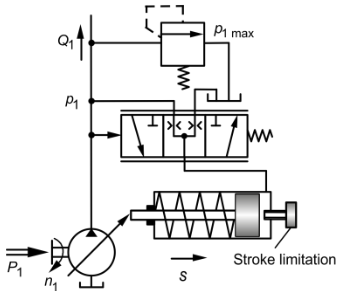
Hint: Start off by calculating the effective flow rate. Then calculate the theoretical flow rate. (2 Points)

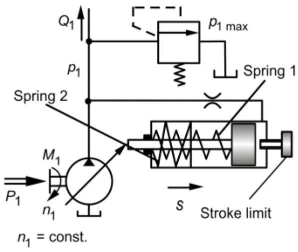
3.5 You want to give a demonstration of your knowledge and calculate the total volume of a swash plate pump V_0. That is the sum of the displacement and the dead volume of a piston times the number of pistons. Also state the dead volume of a single piston. Give your results with two decimal places. Use cm³ per turn as unit for your results. (2.5 Points)

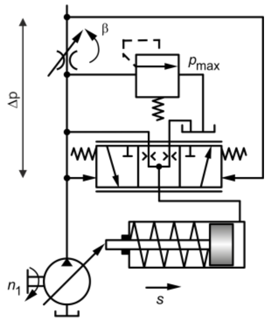
Given:	Volume of displacement of a single piston	V_{Disp} = 10.01 cm³
	Pressure difference at hydro motor	Δp = 250 bar
	Bulk modulus of liquid	E'_{Fl} = 16.000 bar
	Pre-compression angle	φ_{VK} = 14.66°
	Number of pistons	z = 7

4. Exercise 4 / 10 Points

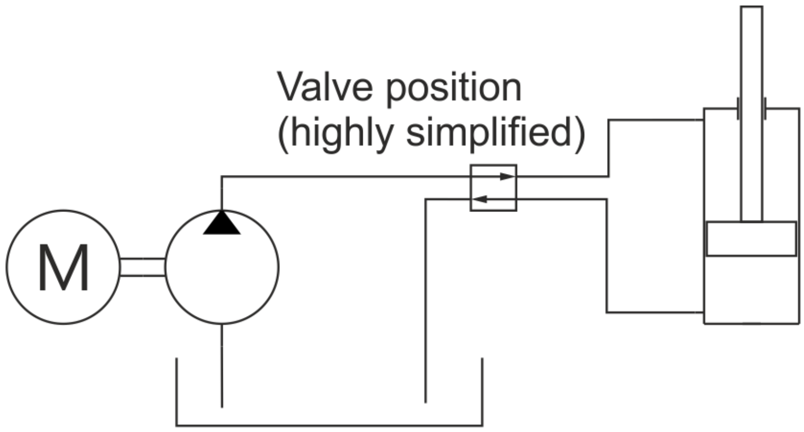
4.1 Assign the systems below to the following control types: pressure control, flow control, power control! (1 point)







In the following a cylinder drive is considered, as shown in the circuit below. The valve controlling the cylinder is shown only in the used switching position.



Given:	Cylinder bore diameter	$D = 320$ mm
	Cylinder rod diameter	$d = 220$ mm
	Cylinder friction	$F_{Cylinder,Friction} = 0$ N
	Hydro mechanic efficiency of pump	$\eta_{hm,\ Pump} = 0.9$
	Volumetric efficiency of pump	$\eta_{vol,\ Pump} = 0.85$
	Pressure drop function of valve for each direction	$\Delta p_{Valve} = (Q_{Valve}\ k_{Valve})^2$
	Valve constant	$k_{Valve} = 0.005\frac{\sqrt{bar}}{l/_{min}}$
	Pump displacement	$V_{Pump} = 500\ cm^3$

4.2 Which rotational speed of the pump is required to provide a retracting velocity of $v = 0.2$ m/s? (1.5 points)

4.3 Which external cylinder force in extending direction is required to apply a driving torque of $M = 500$ Nm to the motor, while moving the cylinder with the same speed as above? (2.5 points)

4.4 Draw a circuit diagram for a hydrostatic system meeting the following requirements: (4 points)

Two hydraulic motors are to be driven by a hydrostatic system. The first one has a resistive control, the second a positive displacement control. Both motors need to be controlled independently.

A constant displacement pump shall be used for driving the motors in an open circuit. Since the required volume flow might vary strongly and the constant displacement pump is driven at a constant speed an accumulator shall be charged to provide varying volume flows. Because the pump can provide a higher power than needed by the motors it shall be switched into hydraulic idle run mode when reaching a maximum operation pressure. When the pump is in idling mode, the accumulator shall supply the operating power for the motors. Furthermore the system needs to be designed for a long lasting and safe operation.

4.5 How do the provided power and the actually used power differ, when the pressure needed for the positive displacement control motor is higher than the power needed for the resistive control motor? Note: The higher pressure is always the pressure provided by the pump. Explain! (1 point)

5. Exercise / 15 Points

5.1 Name four kinds of changes of state and the corresponding state equations (2 points)

Change of state	**State equation**

5.2 Name one advantage and one disadvantage of pneumatic drives with supply air throttling towards drives with exhaust air throttling. (1 point)

Advantage	**Disadvantage**

5.3 Plot the typical power and torque-characteristic of a pneumatic motor over rotational speed. Mark nominal power, nominal speed and nominal torque. (1.5 points)

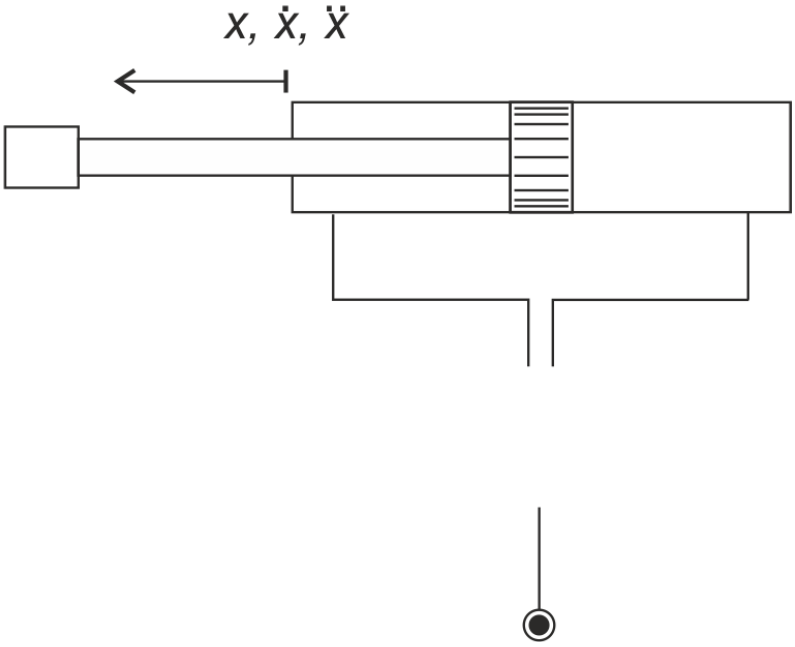
5.4 Pneumatic maintenance units are usually made of three components. Name all three! (1.5 points)

1) ______________________________

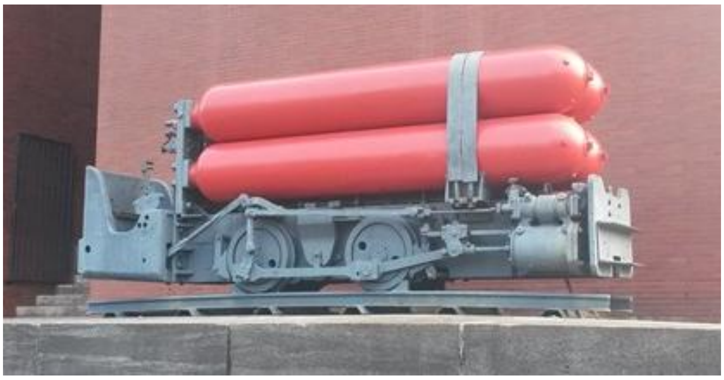
2) ______________________________

3) ______________________________

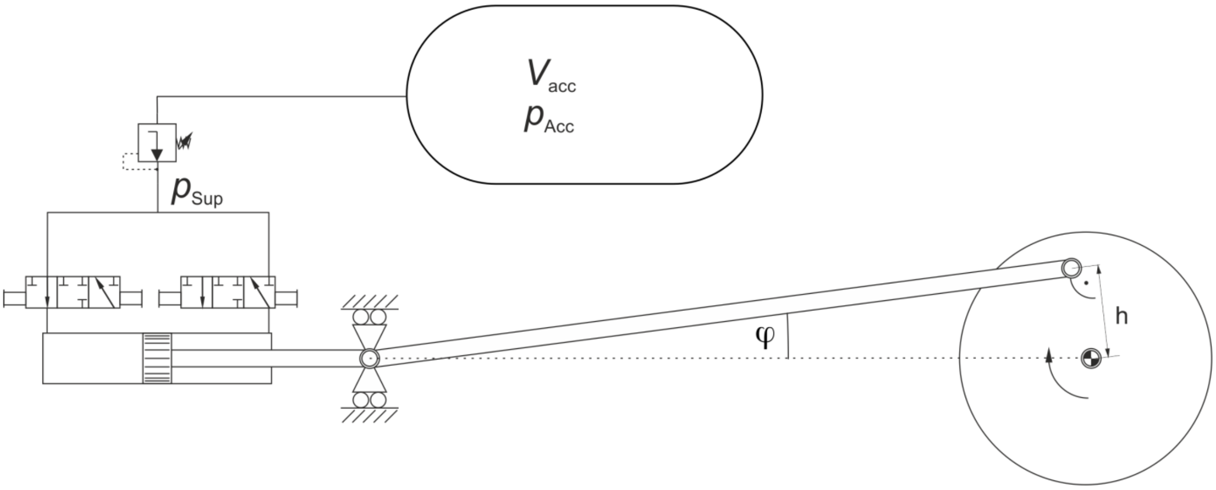
5.5 The cylinder shown in the figure shall be controlled with one valve. The cylinder shall be moved in and out by electric control signals. If no signal is applied, the cylinder shall be completely cut off the environment and the air supply. Draw the symbol for the necessary valve according to DIN ISO 1219. (1 point)



Due to the danger of explosions in coal mining, trains driven by pressurized air locomotives were used for transport in the past. The wheels of the locomotive are driven by one or two cylinders using a mechanical gear. The pressurized air needed for the drive is carried on the locomotive in pneumatic accumulators. To move large parts at IFAS this idea shall be carried out again. A locomotive driven by air shall be constructed and afterwards build at the IFAS mechanical workshop.



Pressurized air locomotive at the german museum for mining in Bochum



Sketch of the drive for one wheel using a cylinder and a drive rod

Given: d_{Wheel} = 500 mm h = 200 mm φ = 7°

p_{Sup} = 7 bar p_{Amb} = 1 bar $\Delta p_{Acc,max}$ = 7 bar

$R_0 = 288 \frac{Nm}{kg\ K}$ $T_U = T_{Sup} = T_{Acc} = 293{,}15$ K

η_{pm} = 0,3 η_{vol} = 0,8

Available cylinder sizes:

Name	Piston diameter d_{Piston} [mm]	Rod diameter d_{Rod} [mm]
Cylinder 1	16	6
Cylinder 2	25	10
Cylinder 3	32	12
Cylinder 4	50	20
Cylinder 5	63	20
Cylinder 6	80	25

All pressures are and must be given as absolute pressures

Hint: Assume that **one** cylinder drives **one** wheel

5.6 Calculate the diameter necessary to deliver a maximal torque of 20 Nm at the position shown in the figure and pick the appropriate cylinder from the table above. Assume that 90 % of the theoretical cylinder force can be used. (2 points)

5.7 Calculate the necessary volume of the pneumatic accumulators (pressure loss in the accumulator $\Delta p_{\mathrm{Acc,max}} = 7$ bar) for driving the locomotive for 10 km. The supply valves to the cylinder are switched so that the pressure in the cylinder chamber at end position is 4 bar. (4 points)

Hints:

- Dead volumes which have to be filled can be neglected for the estimation of the accumulator volume.
- The expansion in the cylinder can be seen as isothermal.

5.8 The cylinder drive is now exchanged with a pneumatic motor. Calculate the necessary displacement volume of the motor, if there is a transmission of $i = 4$ between motor and wheel. The torque at the wheel is the same as in exercise 5.6. (1 point)

5.9 Calculate the pressurized air flow in Nl/min at a rotational speed of the wheel of 1/s. (1 point)

6. Exercise / 10 Points

Figure 6.1 is an incomplete circuit diagram of an automated process sequence.

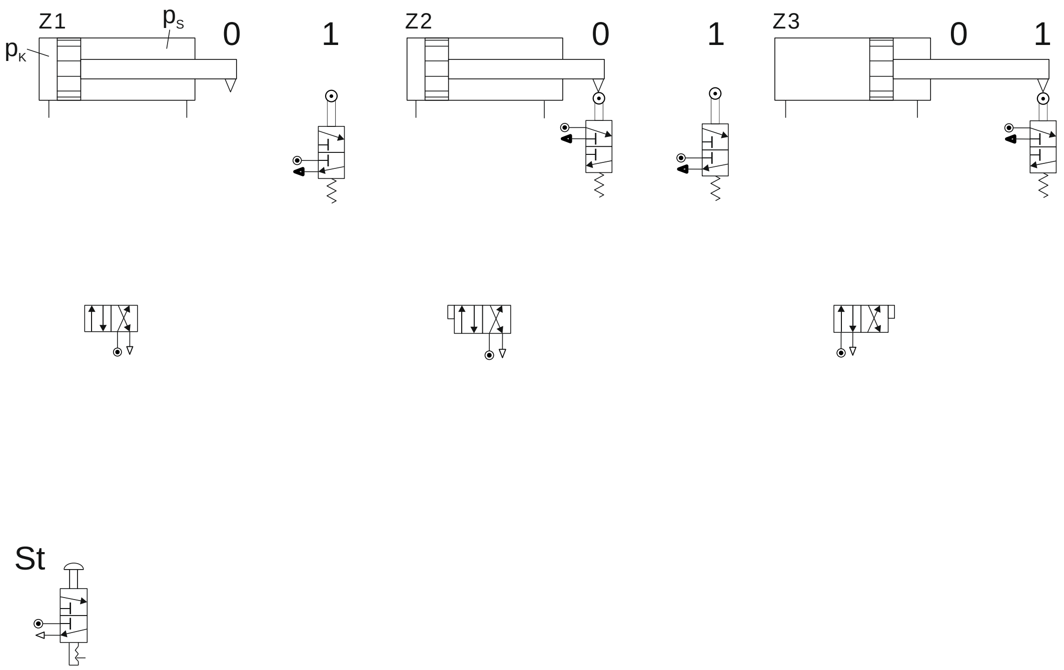


Figure 6.1: circuit diagram - automated process sequence

The function chart of Figure 6.2 belongs to the circuit diagram. The process starts with the activation of the start valve St at the time step 0 and the process should realize the cylinder states corresponding to the function chart at every time step.

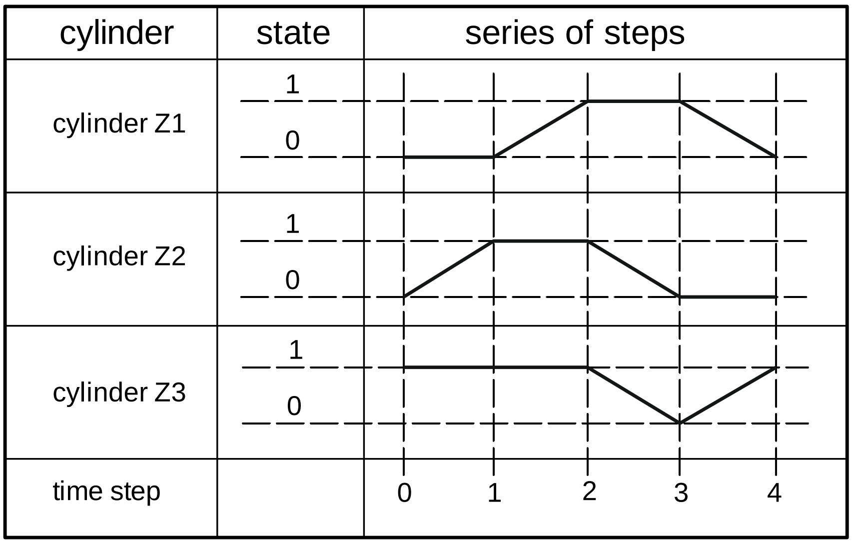


Figure 6.2: function chart - automated process sequence

The process shall be realized using only pneumatic components. The depicted valves in the scheme shall be connected reasonably. If necessary, further pneumatic components can be added.

Please read the entire exercise **before** working on the solution!

Hints:

a) All push buttons, valves and cylinders in **Figure 6.1** are shown at time step 0.

b) Pulse valves with identical actuation areas rest in their actual position, if pressurized bilateral.

c) All pressure sources have the same supply pressure. Consider the given effective actuation area of some valves.

d) Insert your solution on the answer sheet on the next page of the exercise.
Don't use Figure 6.1 !

Realize the following requirements in the circuit diagram:

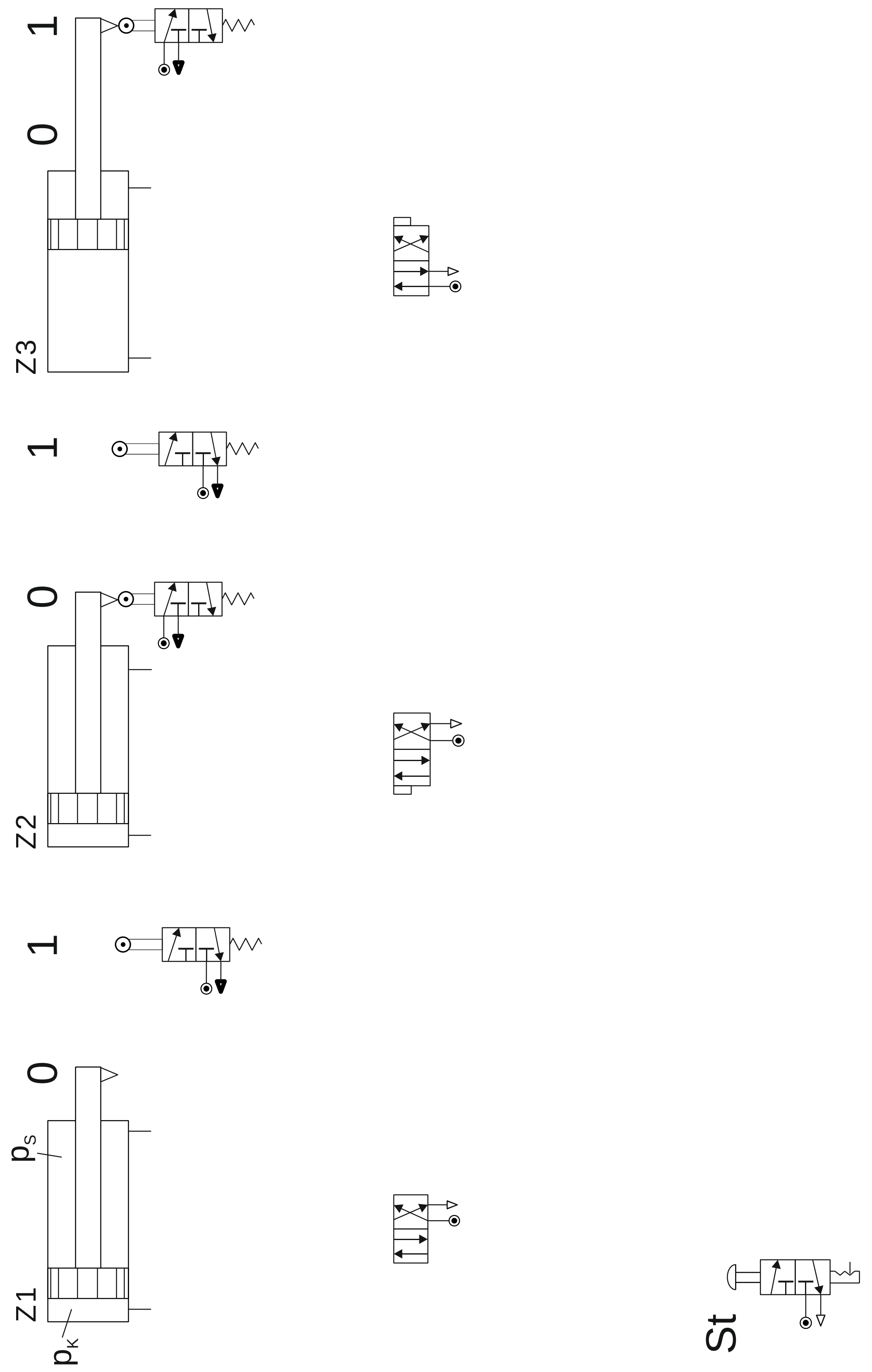
6.1 Complete the circuit diagram so that all functions of the function chart are considered. Please regard that the process restarts automatically after time step 4 with time step 0 as long as the start valve St is activated. (3.5 Points)

6.2 As the process reaches time step 4, an adjustable period of time should be integrated, before the process restarts in time step 0. Expand the circuit diagram with the necessary components. (1 Point)

6.3 Cylinder Z1 should move load-independent from state 1 to state 0 with constant piston velocity. Complete the circuit diagram with the needed components. (0.5 Points)

Matr.-Nr.:

Answersheet A 6.1-3:



6.4 A compressor is needed to supply the automation process. It delivers compressed air with a constant volume flow Q_0 at an outlet pressure p from ambient condition. How high is the compressor's power? (1.5 Points)

Given:			
	$Q_0 = 1300$ Nl/min	$n = 1.2$	$R_0 = 288$ Nm/kgK
	$p_u = p_0 = 1\ \text{bar}_{abs}$	$p = 9\ \text{bar}_{abs}$	$T_U = T_0 = 293.15$ K

6.5 To deliver the compressed air at ambient temperature, the air is cooled after compression. Which heat flow is discharged by the cooler? (2 Points)

Hints: Neglect technical work and external energy.

6.6 The load-independent movement of cylinder Z1 from state 1 to state 0 should be realized with the maximum piston velocity v. Determine the necessary sonic conductance C! (1 Point)

Given: $v = 0.5$ m/s $T = T_0 = 293.15$ K (isothermal) $p_U = p_0 = 1$ bar

piston diameter: $d_K = 40$ mm

piston rod diameter: $d_S = 15$ mm

6.7 Which minimal pressure is needed in the cylinder chamber p_S, to guarantee a load-independent movement? (0.5 Points)

Regard the critical pressure relation $b = 0.25$ and neglect friction forces.