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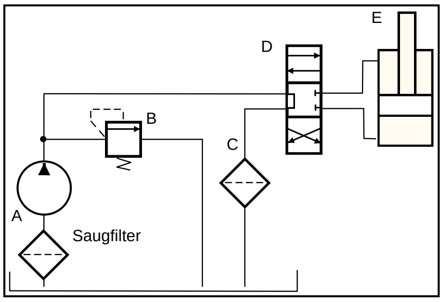
Sample Solution for Exercise: 1   Total Score: 15

Subtask	Th	**Points**
1.1	A – pump B – pressure relief valve C – (return) filter D – 4/3-port valve E – cylinder (0,5 Point each)  	**2.5**
1.2	suction filter (cf. sketch)	**1.0**
1.3	$\rho g\pi\frac{d^2}{4}\cdot x+\rho l\pi\frac{d^2}{4}\cdot\ddot{x}=0 \quad \Rightarrow \quad \frac{g}{l}\cdot x+\ddot{x}=0 \qquad (\Rightarrow \omega^2=\frac{g}{l})$	**3.0**
1.4	$L=\frac{l_S\cdot\rho\cdot 4}{\pi\cdot d_S^2}=\frac{25m\cdot 1000kg/m^3\cdot 4}{\pi\cdot 10^{-4}m^2}=0.318\cdot 10^9 kg/m^4$ $L=0.318\cdot 10^9\,\frac{Pa}{m^3/s^2}=3.18\frac{bar}{l/s^2}$	**1.0**
1.5	$C=\frac{\pi\cdot d_G^2\cdot x}{4\rho\cdot g\cdot x}=\frac{\pi\cdot 10^{-4}m^2}{4\cdot 10^3 kg/m^3\cdot 9.81m/s^2}$ $C=0.801\cdot 10^{-8}m^3/Pa=0.801 l/bar$	**2.0**
1.6	solution a: $f=\frac{1}{2\pi\cdot\sqrt{L\cdot C}}==\frac{1}{2\pi\cdot\sqrt{3.18\cdot 0.801}}s^{-1}=0.0997Hz$ solution b: $f=\frac{\omega}{2\pi}=\frac{1}{2\pi}\cdot\sqrt{\frac{g}{l}}=\frac{\sqrt{9.81/25}}{2\pi}s^{-1}=0.0997Hz$	**1.5**
1.7	Bernoulli: (kin. energy can here be neglected exeptionally) $p_P=\frac{\rho\cdot\lambda}{2}\cdot\left(\frac{L_P}{D_P}\cdot v_P^2+\frac{L_1}{D_1}\cdot v_1^2\right)=\frac{\rho\cdot\lambda\cdot v_1^2}{2}\cdot\left(0.1526\cdot\frac{L_P}{D_P}+\frac{L_1}{D_1}\right)$ 1.5 $v_1=2.083m/s\Rightarrow Q_1=0.164\cdot 10^{-3}m^3/s=9.82l/\min$ 1.0	**2.5**
1.8	Q_P increases	**0.5**
1.9	Attachment of a flow resistor in front of or behind H1; or alternatively: minimise D1 and maximise D2; WRONG: flow divider, flow control valve => unrealistic because temperature regulation is not possible anymore => no point!	**1.0**
	Summation:	**15**

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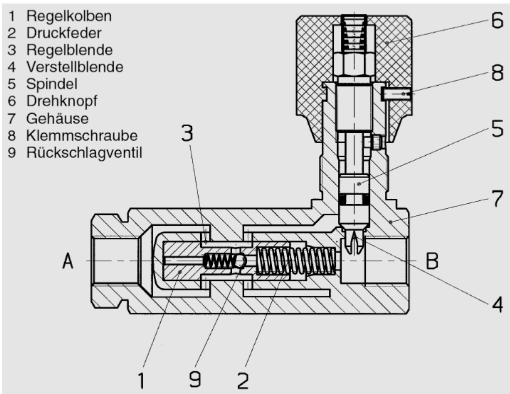
Sample Solution for Exercise: 2 Total Score: 10

Subtask	Ro	Points
2.1	twin check valve or piloted double check valve (check valve) flow devider (flow control valve) spring return, electrically actuated 3/2-port seated valve (directional control valve) adjustable pressure relif valve (pressure control valve)	**2.0**
2.2	i) asymmetrical incoming flow: symmetrical design of entrance and exit bore or peripheral grooves ii) Form error of the valve spool: chose smaller tolerance class for the cylindricity iii) dirt particles in the oil: increase level of purity or attach protection filter	**1.0**
2.3	 1) Pressure compensator 4) orifice Source: Hydac GmbH Denomination: 2-port flow control valve with preceding pressure compensator (and bypass check valve)	**1.0**
2.4	$\Delta p_{DW} = p_A - (p_B + \Delta p_{MB}) = 65\,\text{bar}$ $x_{DW} = \frac{Q}{\alpha_{DW}\, d_{DW}\, \pi}\sqrt{\frac{\rho}{2\,\Delta p_{DW}}} = \frac{180\,\frac{\text{l}}{\text{min}}}{0.7 \cdot 0.018 \cdot \pi\,\text{m}}\sqrt{\frac{890\,\frac{\text{kg}}{\text{m}^3}}{2 \cdot 65\,\text{bar}}}$ $x_{DW} = 0.627\,\text{mm}$	**1.5**
2.5	$\Sigma F = 0 = F_F + (p_B - p_1) \cdot A$ $F_F = (p_1 - p_B) \cdot A = p_{MB} \cdot A = 5\,\text{bar} \cdot \frac{\pi}{4}\, 0.018^2\,\text{m}^2 = 127.235\,\text{N}$	**1,0**
	Summation:	**6,5**

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Sample Solution for Exercise: 2   Total Score: 10

Subtask	Ro	**Points**
	carry:	**6.5**
2.6	$F_{\mathrm{Str}} = \frac{\rho\, Q^2}{d\ \pi\ x}\ \frac{\cos \varepsilon_1}{\sin \varepsilon_1} = \frac{890\ \mathrm{kg}\left(120\,\frac{\mathrm{l}}{\mathrm{min}}\right)^2}{0.01\ \mathrm{m}\ \pi\ 0.002\ \mathrm{m\ m^3}}\ \frac{\cos 30°}{\sin 30°} = 98.137\ \mathrm{N}$	**1.0**
2.7	$\Delta p = \left(\frac{Q}{\alpha_D\ A}\right)^2 \frac{\rho}{2} = \left(\frac{120\ \mathrm{l}}{0.6\ \pi\ 0.01\ \mathrm{m}\cdot 0.002\ \mathrm{m\ min}}\right)^2 \frac{890\ \mathrm{kg}}{2\ \mathrm{m^3}} = 12.524\ \mathrm{bar}$	**0.5**
2.8	$v_2 = \frac{Q}{A_2\ \sin(180° - \varepsilon_2)} = \frac{Q}{A_2\ \cos(\varepsilon_2 - 90°)}$ $F_{\mathrm{Str}} = \frac{\rho\, Q^2}{A_2}\ \frac{\cos \varepsilon_2}{\sin(180° - \varepsilon_2)} = \frac{890\ \mathrm{kg}\left(120\,\frac{\mathrm{l}}{\mathrm{min}}\right)^2}{300\ \mathrm{m\ m^2}}\ \frac{\cos 120°}{\sin 60°} = -6.85\ \mathrm{N}$	**2.0**
	Summation:	**10**

Sample Solution for Exercise: 3 Total Score: 10

Subtask	Sk	**Points**
3.1	adjustable vane pump (single-stroke, pre-controlled)	**0.5**
3.2	1. housing, 2. rotor, 3. vane, 4. stator, 5. adjusting screw	**2.5**
3.3	In-line piston pump	**0.5**
3.4	$V_K = A_k \cdot D_k \cdot \tan\alpha = 10.72 cm^3$ $E_{Fl} = V_0 \dfrac{\Delta p}{\Delta V_K}$ $V_0 = (V_K + V_{tot}) = 15.72 cm^3$ $\Delta V_K = V_0 \dfrac{\Delta p}{E_{Fl}} = 0{,}39 cm^3$ $h = \dfrac{\Delta V_K}{A_K} = 0{,}098 cm$	**2.5**
3.5	$W_K = \dfrac{V_0 \cdot \Delta p^2}{2 \cdot E_{Fl}} = 68.78 cm^3 bar = 6.88 J$	**1**
3.6	$\dfrac{W_K}{W_A} = \dfrac{\Delta p}{2 \cdot E_{Fl} \cdot \left(\dfrac{V_K}{V_{UT}} - \dfrac{\Delta p}{E_{Fl}}\right)} = \dfrac{350 bar}{2 \cdot 14000 bar \cdot \left(\dfrac{10.72 cm^3}{15.72 cm^3} - \dfrac{350 bar}{14000 bar}\right)}$ $\dfrac{W_K}{W_A} = 1.9\%$	**1**
3.7	$h(\varphi) = \dfrac{h_{\max}}{2}(1 - \cos(\varphi)) = 0.098 cm$ $h_{\max} = \dfrac{V_K}{A_K} = D_k \cdot \tan\alpha = 2.68 cm$ $\cos(\varphi_{NF}) = 1 - \dfrac{2 \cdot h(\varphi)}{h_{\max}} \Rightarrow \varphi_{NF} = 22.08°$	**2**
	Summation:	**10**

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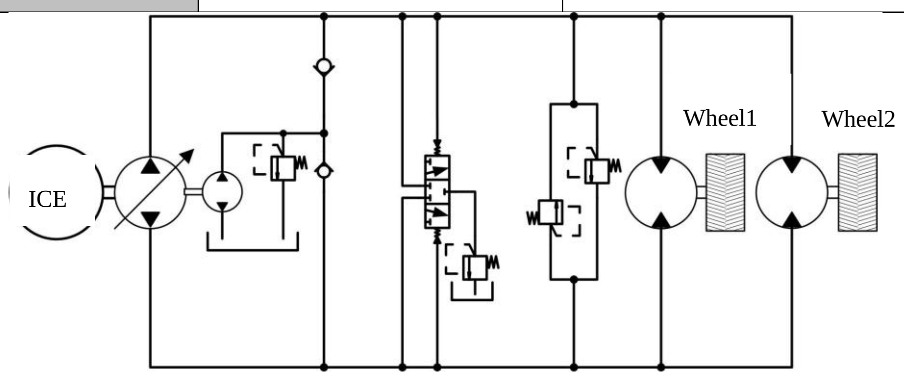
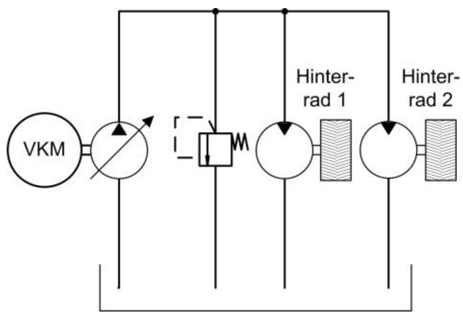
Sample Solution for Exercise: 4 Total Score: 10

<table>
<tr><th>Subtask</th><th>Va</th><th>Points</th></tr>
<tr><td>4.1</td><td>
<table>
<tr><th></th><th>Control Mode</th><th>Supply Mode</th></tr>
<tr><td>Option 1</td><td>Resistive Control</td><td>Pressure supply</td></tr>
<tr><td>Option 2</td><td><u>Displacement Control</u></td><td><u>Volume flow supply</u></td></tr>
</table>
</td><td>1.5</td></tr>
<tr><td>4.2</td><td>




or
</td><td>2.5</td></tr>
<tr><td>4.3</td><td>The free wheel races, there is no load torque at this wheel so „no“ pressure can occur in the system. The other wheel therefore stops.
Through two flow control valves in front of one motor each the maximum revolution speed of the free wheel is limited, pressure rises in the system and the second wheel thereby gets a new drive torque.
(Alternative: series connection of the motors)</td><td>0.5
0.5</td></tr>
</table>

Sample Solution for Exercise: 4 Total Score: 10

Subtask	Va	**Points**
4.4	$M_{req} = m_G \cdot g \cdot \sin\alpha_{St} \cdot \frac{d_{wheel}}{2} \cdot 200\% = 100\,kg \cdot 9.811\frac{m}{s^2} \cdot \sin 30° \cdot \frac{200\,mm}{2} \cdot 200\%$	**0.5**
	$M_{req} = 98.11\,Nm$	
	$M_{eff,ein\,Motor} = \frac{\Delta p \cdot V \cdot \eta_{hm}}{2 \cdot \pi} \Rightarrow V = \frac{M_{erf} \cdot 2 \cdot \pi}{\Delta p \cdot \eta_{hm}} = \frac{49.055\,Nm \cdot 2 \cdot \pi}{35\,MPa \cdot 0.98} = 8.986\,ccm$	**1.0**
4.5	$v = U \cdot n \Rightarrow n = \frac{v}{U} = \frac{2\frac{m}{s}}{\pi \cdot 0.23\,m} = 2.768\frac{1}{s} = 166.074\,rpm$	**0.5**
	$Q_{req} = \frac{V \cdot n}{\eta_{vol}} \cdot 2 = \frac{6\,ccm \cdot 166{,}074\frac{U}{\min}}{0{,}94} \cdot 2 = 2.12\frac{l}{\min}$	**1.0**
4.6	$\eta_{vol} = 0.95\,(in\,Diagramm\,abgelesen)$	**0.5**
	$Q_{eff} = \alpha \cdot V_{\max} \cdot n \cdot \eta_{vol} \Rightarrow V_{\max} = \frac{Q_{req}}{\alpha \cdot n \cdot \eta_{vol}} = \frac{3\frac{l}{\min}}{0{,}8 \cdot 1200\,rpm \cdot 0.95} = 3.289\,ccm$	**1+0,5**
	Summation:	**10**

Sample Solution for Exercise: 5 Total Score: 15

Subtask	vG	**Points**
5.1	lubricator, pressure control valve, filter of compressed air	**1,5**
5.2	At the smallest point of the resistor sonic velocity occurs.	**0,5**
5.3	- cushioning by elastic material - cylinder-integrated pneumatic damping - external damping e.g. through hydraulic shock absorbers - counter ventilation through an external circuit	**1,5**
5.4	smaller constructional length than cylinder with piston rod	**0,5**
5.5	a: slotted cylinder b: magnet cylinder c: rope cylinder d: belt cylinder	**2**
5.6	see table below	**2**
5.7	isentropic change in state (closed system)	**2**

5.6

Rotary Drive	**Rotary Drive**	**Semi-rotary Drive**
Axial Piston Motor	x	
Toothed Belt Drive		x
Geared Motor	x	
Vane Motor	x	

5.7 isentropic change in state (closed system)

$$E_{kin} = \frac{p_{accumulator} \cdot V_{accumulator}}{n-1} \left(\left(\frac{p_{pipe,muzzle}}{p_{accumulator}} \right)^{\frac{n-1}{n}} - 1 \right)$$

$$\Leftrightarrow V_{accumulator} = \frac{(n-1) \cdot E_{kin}}{p_{accumulator} \left(\left(\frac{p_{pipe,muzzle}}{p_{accumulator}} \right)^{\frac{n-1}{n}} - 1 \right)}$$

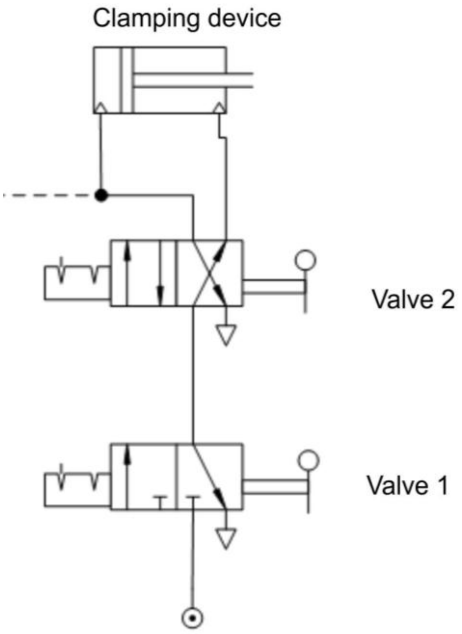
$$\Leftrightarrow V_{accumulator} = \frac{(1{,}4-1) \cdot (-250J)}{10bar \left(\left(\frac{2bar}{10bar} \right)^{\frac{1{,}4-1}{1{,}4}} - 1 \right)} = 0{,}2713l$$

Summation: 10

Sample Solution for Exercise: 5 Total Score: 15

Subtask	vG	Points
	add carry:	**10**
5.8	Isentropic change of state $\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n$ $\Leftrightarrow \frac{p_{accumulator}}{p_{pipe,muzzle}} = \left(\frac{V_{pipe} + V_{accumulator}}{V_{accumulator}}\right)^n$ $\Leftrightarrow V_{pipe} + V_{accumulator} = \left(\frac{p_{accumulator}}{p_{pipe,muzzle}}\right)^{\frac{1}{n}} \cdot V_{accumulator} = 0{,}947l$ $V_{pipe} = 0{,}947l - V_{acumulator} = 0{,}647l$ $l = \frac{V_{pipe}}{\pi \frac{d^2}{4}} = \frac{0{,}647l}{\pi \frac{(40mm)^2}{4}} = 51{,}49cm$	**2**
5.9	$Q_{N,compressor} = 4{,}6 \frac{l}{\min}$ $\dot{m}_{compressor} = Q_{N,compressor} \cdot \rho_N = 0{,}0991 \frac{g}{s}$ calculation of the air mass in the filled accumulator $m_{accumulator,full} = \frac{p_{accumulator,full} \cdot V_{accumulator}}{R \cdot T_{accumulator}} = \frac{10bar \cdot 0{,}3l}{287 \frac{Nm}{KgK} \cdot 303{,}15K} = 3{,}448g$ calculation of the air mass in the exhausted accumulator $T_{accumulator,empty} = T_{accumulator,full} \cdot \left(\frac{p_{accumulator,empty}}{p_{accumulator,full}}\right)^{\frac{n-1}{n}} = 303{,}15K \cdot \left(\frac{2bar}{10bar}\right)^{\frac{1{,}4-1}{1{,}4}} = 191{,}404K$ $m_{accumulator,empty} = \frac{p_{accumulator,empty} \cdot V_{accumulator}}{RT_{accumulator,empty}} = \frac{2bar \cdot 0{,}3l}{287 \frac{Nm}{KgK} \cdot 191{,}404K} = 1{,}092g$ $\Delta m = m_{accumulator,full} - m_{accumulator,empty} = 2{,}356g$ length of time between the shots $T = \frac{\Delta m}{\dot{m}_{compressor}} = 23{,}78s$	**3**
	Summe:	**15**

Sample Solution for Exercise: 6 Total Score: 10

Subtask	vG	Points
6.1		**2**
6.2	pressure dependent sequence control	**1**
6.3	balance of forces, piston rod side deaerated to environmental pressure	
	$F = p_{PRV} \cdot A_{AC} - p_U \cdot A_{PR} - p_{PR} \cdot (A_{AC} - A_{PR})$	**0,5**
	$F = A_{AC} \cdot \left(p_{PRV} - p_U\right)$	
	$p_{PRV} = \dfrac{F}{A_{AC}} + p_U$	**0,5**
	$p_{PRV} = \dfrac{1500N}{\frac{\pi}{4}(0{,}06m)^2} + 100000\dfrac{N}{m^2}$	**0,5**
	$p_{PRV} = 6{,}31 bar$	**0,5**
	Summation:	**5**

Sample Solution for Exercise: 6 Total Score: 10

Subtask	Ev	**Points**
	transfer:	**5**
6.4	swallowing capacity vane motor with two connections	
	$V = \pi \cdot b \cdot h\left(r + \frac{h}{4}\right)$	**0,5**
	$V = \pi \cdot 0{,}1m \cdot 0{,}003m \cdot \left(0{,}013m + \frac{0{,}003m}{4}\right) =$	
	$V = 1{,}296 \cdot 10^{-5} m^3$	**0,5**
	$Q_{ad} = n \cdot V = 1{,}728 \cdot 10^{-3} \frac{m^3}{s}$	**0,5**
	$\dot{m} = Q \cdot \rho = Q \frac{p}{R \cdot T}$	
	$\dot{m} = 1{,}728 \cdot 10^{-3} \frac{m^3}{s} \cdot \frac{200000 \frac{N}{m^2}}{287 \frac{J}{kg \cdot K} \cdot 293K}$	
	$\dot{m} = 4{,}11 \cdot 10^{-3} \frac{kg}{s}$	**0,5**
	$b = \frac{2bar}{6bar} = 0{,}33 \Rightarrow b < b_{crit} \Rightarrow \sup ercritical$	**0,5**
	$C = \frac{\dot{m}}{p_{before} \cdot \rho_0} \cdot \sqrt{\frac{T_{before}}{T_0}}$	**0,5**
	$= \frac{4{,}11 \cdot 10^{-3} \frac{kg}{s}}{6bar \cdot 1{,}1845 \frac{kg}{m^3}} \cdot 1$	**0,5**
	$= 5{,}783 \cdot 10^{-4} \frac{m^3}{bar \cdot s} = 34{,}7 \frac{Nl}{bar \cdot \min}$	**0,5**
6.5	No because no expansion work is taken from the air.	**1**
	Summation:	**10**