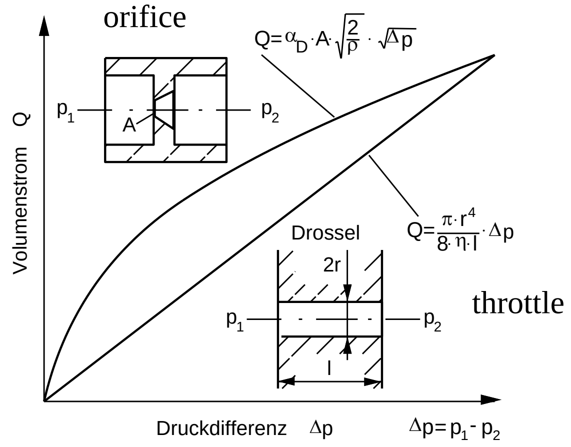
Sample Solution for Exercise: 1 Total Score: 15

Subtask	Sh	**Points**
1.1	+ high power density	0.5
	+ simple realization of linear movements	
	+ good controlability and regulation	0.5
	+ good time response due to low mass inertia	
	+ simple and reliable overload protection	
	+ good lubrication and removal of heat losses through the fluid	
	- energy consumption (losses through friction and internal leakage)	0.5
	- maintenance of the pressure medium (contamination and abrasion of the components)	
	- environment (noise, leakage …)	0.5
1.2	power transfer / pressure transfer, lubricant / friction reduction, corossion prevention, removal of heat energy…	1.5
1.3	fire resistant liquids	0.5
1.4	classes: ISO 4406: 17 / 14 / 10	3 x 0.5
	ISO 4406: number of particles / 1 ml (devide the number of particles through 17)	0.5
		0.5
	ISO 4406: cumulative add up of the classes: < 4; < 6; < 14	
1.5	$p = \frac{F}{A} \quad => \quad A = \frac{F}{p} \qquad Q = v \cdot A$	1.0
	$Q = v \cdot \frac{F}{p} = 1\frac{m}{s} \cdot \frac{15\ kN}{200\ bar} = 7.5 \cdot 10^{-4}\frac{m^3}{s} = 45\ \frac{l}{min}$	0.5

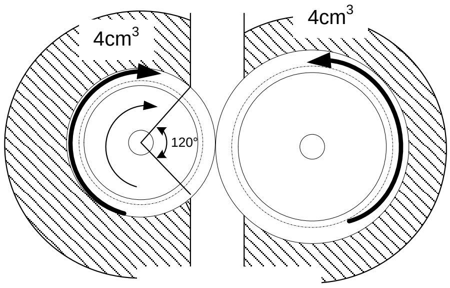
Subtask	Sh	Points
1.6	orifice: $Q = \alpha_D \cdot A \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{\Delta p}$ throttle: $Q = \frac{\pi \cdot r^4}{8 \cdot \eta \cdot l} \cdot \Delta p$ characteristic curve with correct caption  	0.5 0.5 0.5
1.7	**Orifices,** because the flow law is predominantly independend of viscosity and temperature.	0.5 0.5
1.8	$p = \frac{F}{A_Z} \;\; => \;\; F = \Delta p \cdot A_Z$ $A_Z = \frac{\pi}{4}(d_K^2 - d_Z^2) = 765.76\, mm^2$ $F = (p_P - p_{ND}) \cdot A_Z = 345\, bar \cdot 7.6576 \cdot 10^{-4}\, m^2 = 26.42\, kN$	0.5 0.5 0.5
1.9	$C_H = \frac{Q}{\dot{p}}$ balance of forces in the accumulator $p \cdot \left(\frac{{d_K}^2}{4} \cdot \pi\right) = c_F \cdot (x + x_0) \;\; => \;\; \dot{p} = \frac{c_F \cdot \dot{x}}{\left(\frac{{d_K}^2}{4} \cdot \pi\right)}$ flow rate accumulator $Q = \dot{x} \cdot \left(\frac{{d_K}^2}{4} \cdot \pi\right)$ fill in and simplify: $C_H = \frac{\dot{x} \cdot \left(\frac{{d_K}^2}{4} \cdot \pi\right)}{\frac{c_F \cdot \dot{x}}{\left(\frac{{d_K}^2}{4} \cdot \pi\right)}} = \frac{\left(\frac{{d_K}^2}{4} \cdot \pi\right)^2}{c_F} = \frac{A^2}{c_F}$	0.5 1.0 1.0 0.5
	Summation:	**15**

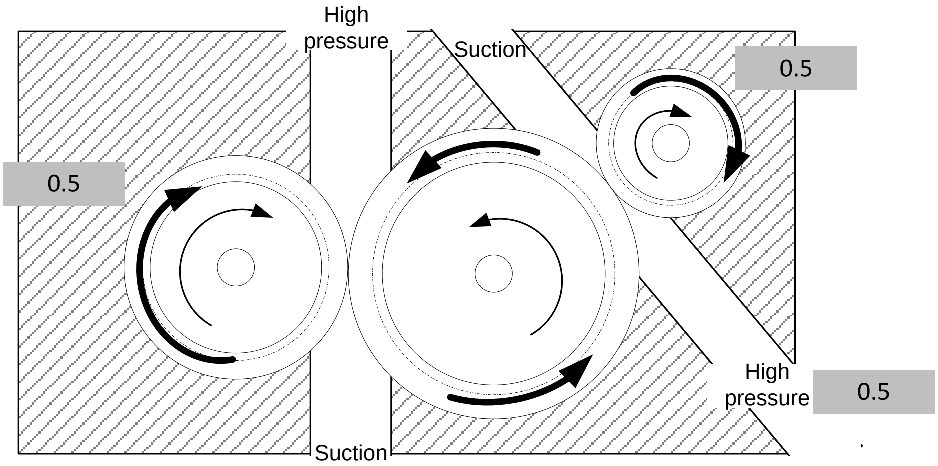
Sample Solution of Exercise: 2 Total Score: 10

<table>
<tr><th>Subtask</th><th>Ro</th><th>Points</th></tr>
<tr><td>2.1</td><td>i. group: check valve: flow in just one direction
ii. group: directional control valve: one or more flow paths open/partially open/closed
iii. group: pressure control valve: control/regulation of pressure
iv. group: flow control valve: control/regulation of flow rate</td><td>2</td></tr>
<tr><td>2.2</td><td>a) housing / cage
b) control edge
c) spool
d) control groove</td><td>1</td></tr>
<tr><td>2.3</td><td><table>
<tr><th>Field of Operation</th><th>Benefit</th><th>Disadvantage</th></tr>
<tr><td>Mechanic</td><td>easy to realise
no auxuliary energy necessary</td><td>actuation force limited
relatively imprecise and slow</td></tr>
<tr><td>Electric</td><td>high precision possible
high dynamic possible
easy integration in the regulation/control</td><td>Auxiliary energy necessary (danger in case of power blackout)</td></tr>
<tr><td>Hydraulic</td><td>high actuation forces possible
remote transmission possible</td><td>additional sealing
losses through leakage</td></tr>
</table></td><td>1.5</td></tr>
<tr><td>2.4</td><td>Type: 2-port flow control valve with downstream pressure compensator because of good responsiveness to pressure changes of the upstream equipment
Installation place: in front of the motor to react fast towards changes of the supply pressure</td><td>1</td></tr>
</table>

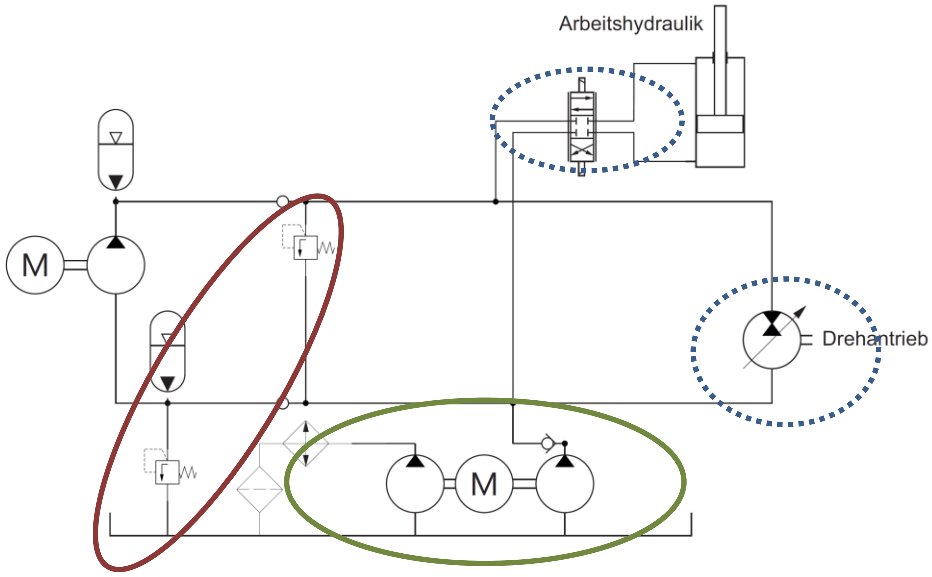
Subtask	Ro	**Points**
2.5	$Q_A = \alpha_D \cdot A \sqrt{\frac{2 \cdot \Delta p}{\rho}} = 12.51 \frac{\mathrm{l}}{\mathrm{min}}$ $Q_E = Q_A + Q_T = 30.01 \frac{\mathrm{l}}{\mathrm{min}}$	1.5
2.6	$x = \frac{Q_T}{\alpha_D \cdot \pi \cdot d_{DW}} \sqrt{\frac{\delta}{2 \cdot \Delta p}} = 0.125\ \mathrm{mm}$	1
2.7	$F_{Str} = \rho \cdot \frac{Q_T^2}{\pi \cdot d \cdot x} \frac{\cos 60°}{\sin 60°} = 22.24\ \mathrm{N}$ $[F_{Str} = 27.83\ \mathrm{N};\ F_{Str} = 17.78\ \mathrm{N}]$ The flow force operates in closing direction, because it operates contrary to the impulse in axial direction.	1
2.8	$F_F = (p_E - p_A) \cdot A_K - F_{Str} = 56.3\ \mathrm{N}$ $[F_F(mit\ F_{Str} = 27.83\ \mathrm{N}) = 50.71\ \mathrm{N}]$ $[F_F(mit\ F_{Str} = 25\ \mathrm{N}) = 58.54\ \mathrm{N}]$	1
	Summation:	10

Sample Solution for Exercise: 3 Total Score: 10

Subtask	Sk	**Points**
3.1	variable radial piston pump	0.5
3.2	1. piston, 2. cylinder star, 3. slipper,4. stroke ring, 5. actuating piston	2.5
3.3	compression caused pulsation and kinetic pulsation	0.5
3.4	adjust pre-compression angle, throtteling grooves	0.5
3.5	external gear pump	0.5
3.6	$V = (\pi \cdot m^2) \cdot b \cdot 2 \cdot z_{driving-wheel}$ $V = \pi \cdot 8^2 mm^2 \cdot 2mm \cdot 2 \cdot 10 = 8042.5 mm^3 = 8ccm$	1
3.7	Pressure port  Suction port	1
3.8	$V = (\pi \cdot m^2) \cdot b \cdot z_{displacementchambers-right} = \pi \cdot 8^2 mm^2 \cdot 2mm \cdot 20 = 8042.5 mm^3$ $Q_{leckage} = \Delta V \cdot n$ $\Delta V = V \cdot \frac{\Delta p}{E}$ $\Delta V = 8042.5 mm^3 \cdot \frac{100 bar}{16000 bar} = 50.3 mm^3$ $Q_{leckage} = 50.3 mm^3 \cdot 800 \frac{1}{\min} = 40.2 \frac{cm^3}{\min}$	2

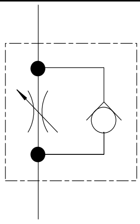
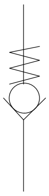
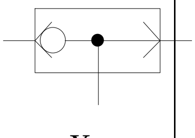
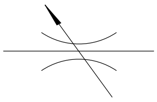
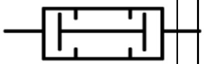
Subtask	Sk	**Points**
3.9	 The displacement volume of the unit increases from 100% to 200%.	1.5
	Summation:	10

Sample Solution for Exercise: 4 Total Score: 10

Subtask	Di	**Points**
4.1	Circuit system: closed circuit	0.5
	to enable the hydraulic braking of the motors and thereby transfer kinetic energy into hydraulic energy	0.5
	adjustment: motor adjustment	
	because a pump adjustment with multiple consumers is not possible	0.5
	power output : parallel power output	0.5
	to control all consumers independently from each other	0.5
		0.5
4.2		blue (dotted) 1 Point each the other two colours 0.5 each
4.3	Through so called load-sensing the pump only conveys as much as required. Hereby the flow rate that is conveyed by the pump and draines by the pressure relief valve is avoided. Hence less energy is lost through the pressure relief valve and less energy is needed for the pressure supply unit.	1

Subtask	Di	**Points**
4.4	$n\_wheel = v/(2\pi\ r) = 39.79$ U/min	0.5
	$Q = n\ V\ i\ /\ \eta\_vol\_motor = 88.43$ l/min	0.5
	$Q\_total = 4\ Q = 353.7$ l/min	0.5
	$\alpha = Q\_total\ /\ (\eta\_vol\_pump\ n\_pump\ V\_max\_pump)$ $\alpha^2 = Q\_total\ /\ n\_pump\ V\_max\_pump = 0.5607$	0.5
4.5	$M\_required = m\ g\ \sin(\alpha)\ r = 40884$ Nm	0.5
	$Delta\_p = 2\pi\ M\_required\ /\ (V\_motor\ \eta\_hm\_motor\ i) = 338$ bar	0.5
	Summation:	10

Sample Solution for Exercise: 5 Total Score: 15

<table>
<tr><th>Subtask</th><th>vG</th><th>Points</th></tr>
<tr><td>5.1</td><td>
<table>
<tr><td></td><td></td><td>
X</td><td></td><td></td></tr>
<tr><td></td><td></td><td>OR-element</td><td></td><td></td></tr>
</table>
</td><td>1</td></tr>
<tr><td>5.2</td><td>semi-rotary drive with linear axis
semi-rotary vane drive
rotary motor, geared belt drive, stepping motor</td><td>1,5</td></tr>
<tr><td>5.3</td><td>O-ring
quad ring
groove ring</td><td>1,5</td></tr>
<tr><td>5.4</td><td>$m \sim D^2 \cdot p_{before}$, from the equation for supercritical flow through a nozzle.
with m = const, D_1 = 6 mm, $p_{1,\text{before}}$ = 6 mm, D_2 = 3 mm, $p_{2,\text{before}}$ = ?,
$D_1^2 \cdot p_{1,before} = D_2^2 \cdot p_{2,before} \Leftrightarrow p_{2,before} = \frac{D_1^2 \cdot p_{1,before}}{D_2^2} = 12 bar$</td><td>1</td></tr>
<tr><td>5.5</td><td>increase piston area
inrease supply pressure</td><td>1</td></tr>
<tr><td>5.6</td><td>pneumatically actuated 5/2-port switching valve</td><td>1,5</td></tr>
</table>

Subtask	vG	Points
5.7	chamber: 1 / 2 / 3 / 4 pressure: p_{U} / p_{Vers} / p_{HD} / p_{Vers}	2
5.8	Balance of forces around the piston: $\sum F = 0: p_{Vers} \cdot \left(A_{piston} + A_{piston} - A_{rod}\right) - p_{HD} \cdot \left(A_{piston} - A_{rod}\right) - p_{U} \cdot A_{piston}$ $\Leftrightarrow p_{HD} = \frac{p_{Vers} \cdot \left(2 \cdot A_{piston} - A_{rod}\right) - p_{U} \cdot A_{piston}}{A_{piston} - A_{rod}}$ $\Rightarrow p_{HD} = \frac{6bar \cdot \left(2 \cdot 2400mm^2 - 80mm^2\right) - 1bar \cdot 2400mm^2}{2400mm^2 - 80mm^2} = 11{,}17bar$	2
5.9	At the beginning of a cycle the volume in the high pressure chamber (3) is at its maximum and filled with the supply pressure p_{Vers}. Hereby the mass at the high pressure connection is provided. In the course of time the high pressure volume decreases and the chambers 2 and 4 also increase in their volume from zero to the maximum volume at supply volume. Because in all chambers the same pressure is given the accounting can be carried out through the volume. Same pressure in all chambers to accounting → volume ratio $V_{c1,\max} = A_{piston} \cdot \left(l_{chamber} - l_{piston}\right) = 216cm^3$ $V_{c3,\max} = V_{c2,\max} = \left(A_{piston} - A_{rod}\right) \cdot \left(l_{chamber} - l_{piston}\right) = 208{,}8cm^3$ $\frac{\dot{m}_{HD}}{\dot{m}_{Vers}} = \frac{\dot{m}_{c2,pVers}}{\dot{m}_{c1,pVers} + \dot{m}_{c3,pVers}} = \frac{V_{c2,\max}}{V_{c1,\max} + V_{c3,\max}} = 0{,}49$ Alternatively also an acounting through the masses is possible.	2
5.10	polytropic change of state with n = 1,2: $\frac{p_1}{p_2} = \left(\frac{T_1}{T_2}\right)^{\frac{n}{n-1}}$ $\frac{p_{Vers}}{p_{HD}} = \left(\frac{T_{Vers}}{T_{HD}}\right)^{\frac{n}{n-1}} \Leftrightarrow p_{HD} = T_{Vers} \cdot \left(\frac{p_{Vers}}{p_{HD}}\right)^{\frac{1-n}{n}} = 319{,}2K$	1,5
	Summation:	15

Sample Solution for Exercise: 6 Total Score: 10

Subtask	Rn	**Points**
6.1	0,5 Points each for exhaust air throttle and valve	1,5
6.2	p2: pressure at the rod side	
	exhaust air flow control valve: $b = p_U / p_2 \;\; => \;\; p_2 = p_U / b = \underline{2{,}5\ bar}$	0,5
	balance of forces:	
	$p_1 A_1 - p_2 A_2 - p_U (A_1 - A_2) = F$	0,5
	$=> p_1 = (F + p_2 A_2 + p_U (A_1 - A_2)) / A_1 = \underline{5{,}75\ bar}$	0,5
6.3	mass flow rate: $dm/dt = p_1 v A_1 /(R_0 T_1)$	0,5
	flow state: subcritical case because 6 bar / 10 bar > 0,4	
	$=> p_{\text{operation}} / p_{\text{bottle}} > b$	0,5
	C-value: $\rho_0 = p_0 /(R_0 T_0) = 1{,}1845\ kg/m^3$	0,5
	$C = p_1 v A_1 / (p_F\, p_0\, \psi)$ with ψ = sqrt(8/9)	0,5
	=> $\underline{0{,}019092066\ \text{Nl/min bar}}$	0,5
6.4	Determine air mass consumption from cylinder volumes (at operating pressure and T_U)	
	$dm = dV\,(p/RT)$	
	$= (50\ mm^2 + 25\ mm^2) * 30\ mm * 6\ bar / (288\ Nm/kgK * 293K)$	
	$=> dm = 0{,}0159983\ g / cycle$	0,5
	Determine air content of nitrogen bottle from 200 bar to 10 bar at T_U	
	$m_{start} = p_{start} V/RT = 50\ bar * 0{,}5\ l / (288\ Nm/kgK * 293K) = 29{,}626469\ g$	
	$m_{end} = p_{end} V/RT = 10\ bar * 0{,}5\ l / (288\ Nm/kgK * 293K) = 5{,}9252938\ g$	0,5
	quantity of cycle: $n = (m_{start} - m_{end}) / dm = 1481\ cycles$	0,5
6.5	$V_1 = 10\ cm^3$	
	$V_2 = 50\ mm^2 * 30\ mm = 1{,}5\ cm^3$	0,5
	$p_U V_1^{\kappa} = p_2 V_2^{\kappa} \;\; => p_2 = p_U (V_1 / V_2)^{\kappa} = \underline{14{,}24\ bar}$	0,5

Subtask	Rn	**Points**
6.6	Mechanical energy from compression work $W = m * R/(\kappa-1) * (T2-T1)$ $T2 = T1 * (p2/p1)^{((\kappa-1)/\kappa)} = 626,130\ K$ $m = pV/RT = 1bar * 10\ cm^3 / (288\ Nm/kgK *293K) = 1,1845e-5\ kg$ $\underline{W = 2,840\ J}$	 0,5 0,5 0,5 0,5
	Summation:	10