



Lecture Notes

Fundamentals of

Fluid Power

Part 2: Pneumatics

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Table of Contents

Formula Symbols.....	7
1 Introduction	11
1.1 Definition of the field.....	11
1.2 Historical Survey	12
1.3 Pneumatics today	15
1.4 Fundamental terms.....	16
1.4.1 Pressure	16
1.4.2 Temperature.....	17
1.4.3 Flow rate.....	17
1.4.4 Standard conditions	18
2 Fundamentals	21
2.1 State equations	21
2.1.1 Ideal gases	22
2.1.2 Thermal state equation of ideal gases	22
2.1.3 Caloric state equations	23
2.1.4 Real gases	25
2.2 First law.....	27
2.2.1 First law for a closed system	27
2.2.2 First law for an open system	28
2.3 Changes of state	31
2.3.1 Isothermal state change	31
2.3.2 Isochoric state change	32
2.3.3 Isobaric change of state	32
2.3.4 Isentropic change of state	32

2.3.5	Polytropic change of state	33
2.4	Calculation of the technical work	33
2.4.1	Closed system.....	34
2.4.2	Technical work during a steady flow process	36
2.5	Properties of air as a pressure medium	39
2.5.1	Composition	39
2.5.2	Compressibility	40
2.5.3	Viscosity	43
2.5.4	Humidity.....	45
2.5.5	Features during technical application.....	49
2.5.6	Material values	50
2.6	Flow laws	52
2.6.1	Flow through ideal nozzles	52
2.6.2	Flow through orifices	57
2.6.3	Flow through gaps.....	58
2.6.4	Valves and throttles	62
2.6.5	Series connection of pneumatic resistors	68
2.6.6	Pressure losses in pipings	72
3	Components.....	75
3.1	Compressors.....	75
3.1.1	Compressor Based on the Displacement Device Principle.....	81
3.1.2	Dynamic Compressors	94
3.1.3	Power Ranges of the Different Compressor Types.....	96
3.1.4	Delivery Flow Rate Control for Compressors	97
3.2	Drives	105
3.2.1	Linear drives.....	106
3.2.2	Rotary drives, pneumatic motors	139

3.2.3	Semi-rotary drives	152
3.3	Valves.....	157
3.3.1	Types of valves.....	158
3.3.2	Types of actuation of valves	163
3.3.3	Pilot-Controlled Valves.....	176
3.3.4	Function of Valves	180
3.4	Compressed air conditioning	202
3.4.1	Dryers	205
3.4.2	Maintenance unit	208
3.5	Other components	214
3.5.1	Vacuum technology.....	214
3.5.2	Pressure vessel (accumulator)	218
3.5.3	Pipes, hoses and fittings	221
3.5.4	Seals.....	226
4	Open and Closed Loop Control of Systems.....	229
4.1	Controls.....	230
4.1.1	Fundamentals	231
4.1.2	Pneumatic Controls	238
4.1.3	Electro-pneumatic Controls.....	246
4.1.4	Sensors.....	246
4.1.5	Control Units	260
4.1.6	Communication	262
4.2	Closed Loop Control.....	271
4.2.1	Continuous Control	274
4.2.2	Discontinuous Control Processes	284
5	Simulation	289

5.1	System Simulation	289
5.1.1	Fundamentals of Pneumatic System Simulation.....	291
5.1.2	Simulation examples	292
5.2	Flow Simulation.....	300
5.3	Component Simulation	302
6	Applications	303
6.1	Automation Engineering / Industrial Handling	303
6.1.1	Axes.....	303
6.1.2	Grippers	305
6.2	Mobile Pneumatics.....	308
6.2.1	Pneumatics in Motor Vehicles	308
6.2.2	Pneumatics in Rail Vehicles.....	310
6.3	Hand Tools.....	312
6.4	Medical Engineering.....	317
7	Appendix	319
7.1	Literature References	319
7.2	Conversion Factors	323
7.3	Symbols.....	325
7.4	Index.....	328

Formula Symbols

Abbrev.	Description	Unit
τ	shear stress	N mm ⁻²
ψ	discharge function	-
$\bar{\psi}$	saturation level	-
A	area, piston area, flow cross section	cm ²
b	width	m
b	critical pressure ratio	-
b_{tot}	critical total pressure ratio	-
C	conductance	Nl (s bar) ⁻¹
c_F	spring stiffness	N m ⁻¹
C_{tot}	total conductance	Nl (s bar) ⁻¹
c_{air}	spring stiffness of air	N m ⁻¹
c_p	specific heat capacity at constant pressure	N m kg ⁻¹ K ⁻¹
c_v	specific heat capacity at constant volume	N m kg ⁻¹ K ⁻¹
D, d	diameter	m
d_{friction}	coefficient of Newtonian friction	Ns m ⁻¹
E	bulk modulus	N m ⁻² ; bar
E_a	external energy	N m
e_a	specific external energy	N m kg ⁻¹
E_{air}	bulk modulus of air	N mm ⁻²
E_{oil}	bulk modulus of oil	N mm ⁻²
F	force	N
F_{spring}	spring force	N
F_{load}	load force	N
f_p	pulse frequency	Hz
F_{friction}	friction force	N
g	gravity acceleration	m s ⁻²
h	height	m
h	specific enthalpy	N m kg ⁻¹
H	Enthalpy	N m
I_{control}	electric current of controller	A
l	length	m
m	mass	kg
m_{out}	exiting mass	kg
m_D	mass of steam	kg

m_{in}	incoming mass	kg
m_{L}	mass of air	kg
M_{load}	load torque	Nm
M_{Pnmot}	torque of pneumatic motor	Nm
n	polytropic index	-
n_{Pnmot}	rotational speed of pneumatic motor	s ⁻¹
p	pressure	N m ⁻² ; bar
p_0	technical standard pressure	bar
p_{out}	pressure of exiting flow	bar
P_{exhaust}	power of exhaust air	W
$p_{\text{operation}}$	operational pressure	bar
p_{C}	critical pressure	bar
p_{vap}	vapour pressure	bar
Δp_{nozzle}	pressure drop over nozzle	bar
P_{peak}	peak power	W
P_{supply}	pneumatic supply power	W
$P_{\text{el.tot.}}$	required electric performance	W
p_{air}	air pressure	bar
p_{measure}	measured pressure	bar
p_{N}	pressure at physical standard condition	bar
p_{R}	scaled pressure	bar
p_{ref}	reference pressure	bar
$\Delta p_{\text{friction}}$	pressure difference equivalent to friction force	bar
p_{S}	saturation vapour pressure	bar
P_{t}	technical power	W
$P_{\text{compressor}}$	provided pneumatic power of compressor	W
Δp_{he}	pressure caused by heat exchange	bar
p_{in}	pressure of incoming flow	bar
P_{cyl}	power output of cylinder	W
Q	volume flow rate	m ³ s ⁻¹ ; l min ⁻¹
Q_0	volume flow rate at standard condition	Nl min ⁻¹
Q_{12}	heat	J
q_{12}	specific heat	J kg ⁻¹
Q_{suction}	sucked in volume flow rate	l min ⁻¹
Q_{out}	exiting volume flow rate	l min ⁻¹
$Q_{\text{operation}}$	volume flow rate of compressor at operating pressure	l min ⁻¹
Q_{in}	incoming volume flow rate	l min ⁻¹

Q_{deliver}	volume flow rate of compressor	l min^{-1}
Q_{measure}	measured volume flow rate	l min^{-1}
Q_{N}	volume flow rate at standard condition	Nl min^{-1}
Q_{S}	volume flow rate of supply	l min^{-1}
R	gas constant	$\text{N m kg}^{-1} \text{K}^{-1}$
R_0	gas constant at technical standard condition	$\text{N m kg}^{-1} \text{K}^{-1}$
R_{D}	gas constant of steam	$\text{N m kg}^{-1} \text{K}^{-1}$
Re	Reynolds number	-
R_{L}	gas constant of air	$\text{N m kg}^{-1} \text{K}^{-1}$
R_{N}	gas constant at physical standard condition	$\text{N m kg}^{-1} \text{K}^{-1}$
s	displacement	m
S_{R}	control signal	-
T	temperature	K
t	time	s
T_0	technical standard temperature	K
T_{out}	temperature of outlet flow	K
T_{exhaust}	exhaust air temperature	K
T_{C}	critical temperature	K
t_{E}	pulse width	s
T_{supply}	supply air temperature	K
T_{crit}	critical temperature	K
T_{cool}	inlet temperature of cooling water	K
T_{meas}	measured temperature	K
T_{N}	temperature at physical standard condition	K
T_{P}	period, cycle time	s
T_{R}	scaled temperature	K
T_{ref}	reference temperature	K
T_{in}	temperature of incoming mass	K
U	internal energy	J
u	flow rate	m s^{-1}
u	specific internal energy	N m kg^{-1}
U_{actual}	voltage signal of actual value	V
U_{set}	voltage signal of set value	V
v	velocity	m s^{-1}
v	specific volume	$\text{m}^3 \text{kg}^{-1}$
V	volume	m^3
v_0	specific volume at technical standard condition	$\text{m}^3 \text{kg}^{-1}$

V_0	volume at technical standard condition	m^3
v_{crit}	critical flow velocity	m s^{-1}
V_{disp}	displacement volume	cm^3
$V_{\text{disp,p}}$	displacement volume of piston motor	cm^3
$V_{\text{disp,v,2con}}$	displacement volume of vane motor	cm^3
$V_{\text{disp,g}}$	displacement volume of gear motor	cm^3
W	technical work	J
w	specific technical work	J kg^{-1}
W_a	external work	J
W_R	friction work	J
w_f	specific friction work	J kg^{-1}
W_V	volume change work	J
x	piston position	m
x_D	moisture content	-
Z	compressibility factor	-
α	angle	°
α	heat exchange coefficient	$\text{W m}^{-2}\text{K}^{-1}$
α_F	Flow rate coefficient	-
α_C	contraction coefficient	-
γ_{air}	coefficient for air	-
γ_{oil}	coefficient for oil	-
Δp	pressure difference	bar
η	dynamic viscosity	Ns m^{-2}
η	standard dynamic viscosity	Ns m^{-2}
η_{pm}	pneumatic-mechanical efficiency	-
$\eta_{\text{compressor}}$	efficiency factor of compressor	-
$\eta_{\text{vol.}}$	volumetric efficiency factor	-
κ	heat capacity ratio (isentropic expansion factor)	-
ν	kinematic viscosity	$\text{m}^2 \text{s}^{-1}$
ρ	density	kg m^{-3}
ρ_0	density at technical standard condition	kg m^{-3}
ρ_K	density inside cylinder	kg m^{-3}
ρ_{air}	density of air	kg m^{-3}
ρ_N	density at physical standard condition	kg m^{-3}
φ	relative humidity	-
ω	specific power requirement	W l min^{-1}