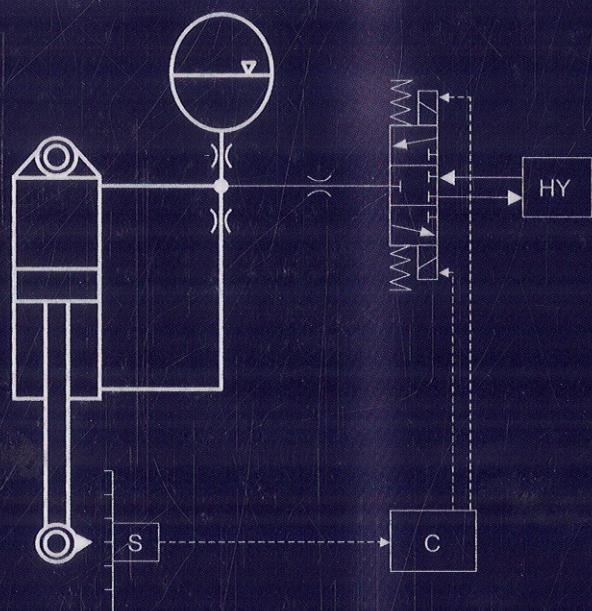


Wolfgang Bauer

Hydropneumatic Suspension Systems



Contents

1	Suspension Systems Basics	1
1.1	Requirements for Suspension Systems	1
1.1.1	Minimize Accelerations on the Isolated Side	2
1.1.2	Equalize Variations of Vertical Wheel Forces	4
1.2	General Setup of a Suspension System	5
1.3	Hydropneumatic Suspensions Compared to Other Suspension Methods	7
1.3.1	Comparison of Spring Characteristics	7
1.3.2	Comparison of Damping Characteristics	11
1.3.3	Level Control	12
1.3.4	Non-functional Requirements	13
1.4	Applications for Hydropneumatic Suspensions	15
2	Spring and Damping Characteristics of Hydropneumatic Suspension Systems	19
2.1	General Setup and Working Principle	19
2.2	Spring Characteristics	21
2.2.1	Thermodynamic Background	21
2.2.2	Calculation Predeterminations	25
2.2.3	Non-preloaded Hydropneumatic Suspensions	25
2.2.4	Systems with Mechanical Preload	35
2.2.5	Systems with Constant Hydraulic Preload	41
2.2.6	Systems with Variable Hydraulic Preload	48
2.3	Damping Characteristics	50
2.3.1	Boundary Friction Damping	51
2.3.2	Fluid Friction Damping	55
2.3.3	End-of-Stroke Damping	62
2.4	Combined Operation of Spring and Damper	64
3	Dimensioning of the Hydropneumatic Suspension Hardware	67
3.1	Dimensioning of the Hydraulic Spring Components	67
3.1.1	Cylinder	69
3.1.2	Accumulator Gas Precharge	71
3.1.3	Detailed Calculation of p_0 and V_0	73

3.2	Dimensioning of the Hydraulic Damping Elements	85
3.2.1	Single-Acting Cylinder in a System Without Hydraulic Preload	85
3.2.2	Double-Acting Cylinder in a System Without Hydraulic Preload	88
3.2.3	Double-Acting Cylinder in a System with Hydraulic Preload	91
3.2.4	End-of-Stroke Damping	91
4	Hydraulic Components Design	95
4.1	Cylinders	95
4.1.1	Function and Requirements	95
4.1.2	Types of Cylinders	96
4.1.3	Sealing Elements	101
4.1.4	End-of-Stroke Damping	106
4.1.5	Types of Support Elements	109
4.2	Accumulators	111
4.2.1	Function and Requirements	111
4.2.2	Types of Accumulators	113
4.2.3	Methods to Reduce Diffusion Pressure Loss	116
4.2.4	Integration into Available Design Space	118
4.3	Flow Resistors	120
4.3.1	Non adjustable Orifices and Throttles	120
4.3.2	Flow Direction Depending Resistors	122
4.3.3	Adjustable Flow Resistors	126
4.4	Hydraulic Lines and Fittings	130
4.4.1	Function and Requirements	130
4.4.2	Required Flow Cross Section	132
4.4.3	Tubes	133
4.4.4	Hoses	135
4.4.5	Fittings	138
5	Level Control	141
5.1	Self-Pumping Suspension Elements	141
5.2	Mechanical Level Control with External Hydraulic Power Supply	144
5.3	Electronic Level Control with External Hydraulic Power Supply	147
5.3.1	Function	147
5.3.2	Hydraulic Circuits	148
5.3.3	Control Algorithms	150
6	Special Functions of Hydropneumatic Suspension Systems	157
6.1	Suspension Lockout	157
6.1.1	Lockout by Blocking the Hydraulic Circuit	158
6.1.2	Lockout at the Compression End Stop	160
6.1.3	“Quasi-Lockout” Through High Spring Stiffness	161

6.2	Adjustment of the Zero Position	162
6.3	Alteration of Roll and Pitch Behavior	163
6.3.1	Coupling Cylinders on Corresponding Sides	163
6.3.2	Decoupling Cylinders	164
6.3.3	Coupling Double-Action Cylinders on Opposite Sides	166
6.4	Spring Rate Adjustment by Selective Connection of Accumulators	169
7	Design Examples	173
7.1	Tractor Front Axle Suspension TLS by John Deere	173
7.2	Passenger Car Axle Suspension by Citroen	180
7.2.1	Citroens First Hydropneumatic Suspension	181
7.2.2	Hydractiv Suspension	183
7.2.3	Activa Suspension	188
8	Important Patents	193
8.1	Improvement of Suspension Characteristics	193
8.1.1	DE1755095	194
8.1.2	DE19719076	195
8.1.3	DE10107631	196
8.1.4	DE10337600	196
8.1.5	DE4221126	198
8.1.6	DE4234217	198
8.1.7	DE4223783	200
8.1.8	US6167701	201
8.1.9	DE19949152	201
8.1.10	US6398227	203
8.1.11	DE102008012704	203
8.2	Roll Stabilization and Slope Compensation	205
8.2.1	GB890089	205
8.2.2	DE3427508	206
8.2.3	DE10112082	207
8.2.4	US4411447	208
8.2.5	US6923453	209
8.3	Suspension Lockout	210
8.3.1	US3953040	211
8.3.2	DE4308460	211
8.3.3	DE4032893	212
9	Looking into the Future	215
Index of Symbols and Abbreviations		219
References		223
Index		229