Edited by Bert Breuer Karlheinz H. Bill

Brake Technology Handbook

i

First English Edition

A International"

Warrendale, Pennsylvania, USA

Contents

. • .

Sy	mbols,	Indices, and Acronyms	xxi
1	1.1 1.2 1.3 1.4 1.5 1.6 1.7	History of Automobile Brakes Mechanically Operated Vehicle Brakes The Hydraulically Operated Four-Wheel Brake Brakes with Internal Amplification Multi-Circuit Braking Systems From Muscle Power to Full Power Brakes The Hydraulically Operated Disc Brake Electronic Brake Control Systems	1 1 2 4 4 5 7 8
2		Elements of the Braking Process	10
	2.1 2.2 2.3 2.4 2.5	Braking as Driving Task Characteristics of the Braking Process Stopping Distance Braking Stability and Braking Force Distribution Reliability	10 11 12 14 16
3		notive Engineering Requirements	18
	3.1	Performance	18
		3.1.1 Braking Distance	18
		3.1.2 Stability	19
		3.1.3 Road Irregularities 3.1.4 Dependence on Friction Value	20 21
	3.2	Vehicle Performance	21
	5.2	3.2.1 Stability	22
		3.2.2 Body Pitch	25
	3.3	Actuation/Control	27
		3.3.1 Responsiveness and Controllability	27
		3.3.2 Forces, Travels, Characteristics	28
	3.4	Package/Installation Situation	29
		3.4.1 Installation Sizes and Relations	29
		3.4.2 Masses	30
	3.5	Brake Boost Energy Supply	30
	3.6	Thermal Marginal Conditions	32
	3.7	Environmental Conditions	33
	3.8	Noises and Vibrations	33
		3.8.1 Vibrations	34
	2.0	3.8.2 Noises	35
	3.9	Crash Requirements Environmental Protection	36 37
	3.10	3.10.1 Brake Linings	37
		3.10.2 Corrosion Protection	37
		3.10.3 Brake Fluid	37
	3.11	Energy Recuperation	37
		Related Requirements	
4		-	39 39
	4.1 4.2	IntroductionBraking Situation	39 39
	4.2	4.2.1 Information Reception	41
		4.2.2 Cognition (Information Processing in the Narrower Sense)	41
		4.2.3 Reaction	42
		4.2.4 Time Sequence of Information Processing in Braking Situations	42
	4.3	Braking Action	43
		4.3.1 Foot Movement	43
		4.3.2 Actuation of Brake Pedal	44

			•
	4.4	e	mic Brake Design
		4.4.1	Geometry
		4.4.2	Key Features of Brake Pedal
		4.4.3	Alternative Concepts
		4.4.4	Braking Assistants
5	Inter	action A	mong the Road Surface, Tire, and Brake
5	5.1		ction
	5.1		ission of Forces Between the Tire and the Road Surface
	5.2	5.2.1	The Friction of Rubber
		5.2.1	Interaction Between the Tire and the Road Surface
		5.2.3	
		3.2.3	Buildup of Tire Forces 5.2.3.1 Braking Forces/Tangential Forces
	<i>с</i> 2	Tatana	5.2.3.2 Side Slip: Forces and Moments
	5.3		tion Between Tire and Brake
		5.3.1	Tire Models
		5.3.2	Dynamic Tangential Force/Slip Characteristics of a Tire During Braking
		5.3.3	Tangential Forces During Braking with ABS
		5.3.4	Combined Tangential and Lateral Forces, Braking When Lateral Force
	<i></i>	Interio	Is Required
	5.4	-	tion of the Tire into the Overall Vehicle System
		5.4.1	Product Optimization of the Tire and the ABS Controller Using the
		5 4 0	Example of Winter Tires
		5.4.2	The Role of Skid Marks in Accident Reconstruction
	5.5	Outlook	۲ · · · · · · · · · · · · · · · · · · ·
5	Decia	n and Si	mulation of Automobile Brake Systems
,	6.1		les of the Brake Dynamics
	0.1	6.1.1	Lines of Equal Deceleration
		6.1.2	Lines of Constant Coefficient of Friction Between the Tire and the
		0.1.2	Road Surface
	6.2	Princip	les of the Brake Calculation
	0.2	6.2.1	Pedal Unit
		6.2.2	Vacuum Booster with Master Cylinder
		6.2.3	Brake
		0.2.5	6.2.3.1 Disc Brake
			6.2.3.2 Drum Brake
	6.3	Broke S	System Design
	0.5	6.3.1	Brake-Split Configuration
		0.5.1	6.3.1.1 Front Axle/Rear Axle Configuration (II-Configuration)
			6.3.1.2 Diagonal Configuration (X-Configuration)
			6.3.1.2 Diagonal Configuration (X-Configuration) 6.3.1.3 Other Brake-Circuit Configurations (HI-, LL-, HH-Configuration)
		6.3.2	• • • •
		0.3.2	Sizing Criteria for Brake Systems
			6.3.2.2 Requirements of the Actuation Unit and the Transmission
			Mechanism
		622	6.3.2.3 Thermal Sizing Criteria
		6.3.3	Design of Wheel Brakes
			6.3.3.1 Brake Power
			6.3.3.2 Thermal Design
			6.3.3.3 Component Life/Wear
			6.3.3.4 Comfort
			6.3.3.5 Costs
			6.3.3.6 Weight
		6.3.4	Design of Brake Control Systems
			6.3.4.1 Design Criteria for ABS Systems
			6.3.4.2 Design Criteria for the Traction Control System
			6.3.4.3 Design Criteria for the Electronic Stability Control
		6.3.5	Design Criteria for Electrohydraulic Brake Systems

vii

	6.4	Simulat	tion of Brake Systems	81
		6.4.1	Brake System Design	82
		6.4.2	Analysis of the Brake System Components Using the Finite	
			Elements Method	83
		6.4.3	Simulation of Brake-System Components	84
		6.4.4	Overall System Simulation	85
		0.4.4		05
7	Const	mustion	and Components of Passenger Car Braking Systems	87
1				87
	7.1		ction	
		7.1.1	The Underlying Physics	87
		7.1.2	Braking System Types	89
		7.1.3	Construction of Braking Systems in Passenger Cars	90
			7.1.3.1 Front-Rear Split	90
			7.1.3.2 Diagonal Split ("X Split")	90
			7.1.3.3 Other Hydraulic Brake Circuit Splits	91
	7.2	Genera	tion of the Braking Force	91
		7.2.1	Disc Brakes	92
		1.2.1	7.2.1.1 Fixed Calipers	95
			-	95
			7.2.1.2 Frame Calipers	
			7.2.1.3 Fist Caliper	95
			7.2.1.4 FN Fist Caliper	96
			7.2.1.5 FNR Fist Frame Caliper	97
			7.2.1.6 Combined Fist Caliper	97
			7.2.1.7 Brake Discs	98
			7.2.1.8 Brake Linings	100
		7.2.2	Drum Brakes	100
			7.2.2.1 Simplex Drum Brake	100
			7.2.2.2 Duplex Drum Brake	101
			7.2.2.3 Duo-Servo Drum Brake	101
		7 7 7		
		7.2.3	Electric Generator	102
		-	7.2.3.1 Crankshaft Starter Alternator	102
	7.3		er and Modulation of Braking Energy	103
		7.3.1	Mechanical-Hydraulic Modulation of Brake Pressure	103
		7.3.2	Electrohydraulic Brake Pressure Modulation	104
			7.3.2.1 Hydraulic-Electronic Control Unit (HCU)	106
			7.3.2.2 Electronic Control Unit (ECU)	108
			7.3.2.3 Electronic Control Functions	108
			7.3.2.4 Sensors for Electronic Brake Control Systems	113
		7.3.3	Transmission Elements	117
		7.5.5	7.3.3.1 Brake Fluid	117
		D 1		117
	7.4		Actuation	117
		7.4.1	Brake Booster	117
			7.4.1.1 Vacuum Brake Boosters	117
			7.4.1.2 Hydraulic Brake Boosters	120
		7.4.2	Tandem Master Cylinder	120
			7.4.2.1 Compensating Bore TMc	121
			7.4.2.2 Central Valve TMc	121
			7.4.2.3 Plunger TMc	122
			7.4.2.4 Reservoir	123
				143
	75	Uuma-	Machine Interface (HMI)	102
	7.5		-Machine Interface (HMI)	123
	7.5	7.5.1	Service Brake HMI	123
	7.5	7.5.1 7.5.2	Service Brake HMI Parking Brake HMI	123 123
	7.5	7.5.1	Service Brake HMI Parking Brake HMI Pedal Characteristics (Ergonomics)	123 123 125
	7.5	7.5.1 7.5.2	Service Brake HMI Parking Brake HMI Pedal Characteristics (Ergonomics) 7.5.3.1 Adjustable Pedals	123 123
	7.5	7.5.1 7.5.2	Service Brake HMI Parking Brake HMI Pedal Characteristics (Ergonomics)	123 123 125
	7.5	7.5.1 7.5.2 7.5.3	Service Brake HMI Parking Brake HMI Pedal Characteristics (Ergonomics) 7.5.3.1 Adjustable Pedals	123 123 125 125

.

•

Contents

10.00

8	Brak		8	128
	8.1	Evaluat		128
		8.1.1		128
		8.1.2	Distribution of the Braking Forces to the Axles	128
		8.1.3	Brake Application in the Braking Force Distribution Diagram	131
·		8.1.4	Load-Sensitive Braking Force Distribution (ALB)	131
		•	8.1.4.1 Braking Force Limiters	132
			8.1.4.2 Braking Force Reducers	132
		8.1.5	Influence of Engine Drag Torques, Inertia Masses and Braking Torques of	
				33
		8.1.6	Determination of Brake Factor Fluctuations and Their Influence on	
		0.1.0		34
		8.1.7		34
	8.2			36
	0.2	8.2.1		136
		8.2.1		138
	0.7		1	40
	8.3			40
		8.3.1	8	41
		8.3.2		
	8.4			43
		8.4.1		43
		8.4.2		44
	8.5		8 8 8 8	44
		8.5.1		47
		8.5.2	8	47
		8.5.3	Optimization of the Compatibility Between Tractor Vehicle and	
				49
		8.5.4	5	50
		8.5.5	Hill Holder 1	50
		8.5.6	Lining/Pad Wear Control 1	150
		8.5.7	Distance Monitoring	150
		8.5.8	Systems for Automatic Vehicle Guidance	51
	8.6	System	Integration and Electronic Networking	52
	8.7			52
9	Brak	es for Co	mmercial Vehicles	154
	9.1			54
		9.1.1		54
		9.1.2		154
	9.2	Design	and Operation of the Pneumatically Operated Floating Caliper	
	<i>y</i> .=			155
		9.2.1		155
		····· 1		155
				155
		9.2.2		156
		9.2.3	5	157
		9.2.4	6	57
		9.2.5		158
			6	158
	o -		5	159
	9.3			60
		9.3.1	0	60
				60
			9.3.1.2 Long-Term Braking Performance	60
	9.4	Friction	n Elements 1	61
		9.4.1	Brake Pads 1	61
		9.4.2	Brake Disc	62
			9.4.2.1 Brake Disc Designs 1	62
			5	

ix

			9.4.2.2 Brake Disc Material	163
			9.4.2.3 Causes for Heat Cracks	164
			9.4.2.4 Causes for Brake Vibrations	164
			9.4.2.5 Dimensioning of the Friction Partners	164
			9.4.2.6 The Specific Braking Performance	164
	9.5	Develop	pment and Testing of Brake and Friction Partners	166
	9.6	Trailer	Brakes	168
		9.6.1	Trailer-Specific Characteristics	168
			9.6.1.1 Wheel Brakes	169
			9.6.1.2 Adjustment	170
		9.6.2	Trailer-Specific Requirements	171
	,		9.6.2.1 Trailer Homologation	171
			9.6.2.2 Trailer Brake Certificates	172
		9.6.3	Trailer-Specific Brake Systems	172
			9.6.3.1 Brake Calculations for Vehicle Homologation	172
			9.6.3.2 Parking Brake Effect	173
	9.7	Compa	tibility in Tractor/Trailer Units	173
		9.7.1	Legislation	173
		9.7.2	Matching of Tractor/Trailer Combinations	174
		9.7.3	Causes and Consequences of Inadequate Matching	174
			1 1 5	
10	Braki	ng Beha	avior of Single-Track Vehicles	175
	10.1		ycles	175
		10.1.1	Riding Dynamics of Single-Track Vehicles	175
			10.1.1.1 Stationary Straight-Ahead Motion and Stability	175
			10.1.1.2 Stationary Motion in Bends	175
			10.1.1.3 Balance of Forces and Roll Angle	176
		10.1.2	Braking Behavior of Single-Track Vehicles	176
			10.1.2.1 Fundamental Aspects of Riding Dynamics in the Braking Process	176
			10.1.2.2 Brake Behavior on Slopes	177
			10.1.2.3 Influence of Tire-Road Friction	177
			10.1.2.4 Ideal and Real Distribution of Brake Forces	178
			10.1.2.5 Influence of Suspension Geometry	178
			10.1.2.6 Braking Dive Compensation	178
			10.1.2.7 Application of the Brakes in a Bend	180
		10.1.3	Typical Riding Errors While Braking	181
			10.1.3.1 Over-Braking	-181
			10.1.3.2 Errors When Braking in an Emergency	181
		10.1.4	Brake Systems of Single-Track Vehicles	182
			10.1.4.1 The Brake Caliper	183
			10.1.4.2 Brake Discs	186
			10.1.4.3 Brake Pads	188
		10.1.5	Configuration of the Brake System	189
			10.1.5.1 Transformation of Lever Force Into Deceleration	189
			10.1.5.2 Thermal Stability	191
			10.1.5.3 Brake Noise	192
			10.1.5.4 Long-Term Behavior of Brake Components	193
		10.1.6	Integral Brake Systems and Brake Control Systems	194
			10.1.6.1 Antilock Systems (ABS)	194
			10.1.6.2 ABS Components	194
			10.1.6.3 The ABS Braking Process	195
			10.1.6.4 Operating Principles	196
		10.1.7	Integral Brake Systems	200
			10.1.7.1 Combined Brake System by Honda	200
			10.1.7.2 Integral Brake System by BMW	202
		10.1.8	Brake-by-Wire	202
	10.2	Bicycle	-	203
	10.2	10.2.1	Introduction	204
	•	10.2.1	Braking Behavior of Bicycles	204
				404

		10.2.3	Typical Braking Faults	204
,			10.2.3.1 Over-Braking of the Front Wheel	204
			10.2.3.2 Locking of the Rear Wheel	204
		10.2.4	Bicycle Braking Systems	204
			10.2.4.1 Basic Demands for Bicycle Braking Systems	204
			10.2.4.2 Rim Brakes	204
			10.2.4.3 Hub Brakes	206
			10.2.4.4 Disc Brakes	207
11	Over	run Brak	ing Systems	211
11	11.1		tion	211
	11.1		ction and Function of the Braking System	211
	11.2		Components	211
		11.2.1	11.2.1.1 Overrun Coupling	211
			11.2.1.2 Transmission System	211
			11.2.1.2 Wheel Brakes	214
		1122		214
		11.2.2	Functions	215
			11.2.2.1 Service Brake, Forward Travel	
			11.2.2.2 Automatic Reversing System, Reverse Travel	215
			11.2.2.3 Parking Brake	215
			11.2.2.4 Breakaway Braking Function	217
	11.3		System Layout	217
			Brake Compatibility Calculation as per Directive 71/320/EEC	217
			Brake Force Utilization	217
			ABS Compatibility	218
	11.4		ance and Care	218
			Maintenance	219
			Readjustment	219
	11.5	New De	velopments	219
12	Brake	es of Off-	Road Vehicles	221
12	Brak 12.1		Road Vehicles	221 221
12		Historic		
12	12.1	Historic Survey o	al Development of Brakes in Off-Road Vehicles	
12	12.1	Historic Survey o Brake S	al Development of Brakes in Off-Road Vehicles	221
12	12.1	Historic Survey o Brake S 12.2.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany	221 221
12	12.1	Historic Survey of Brake S 12.2.1 12.2.2	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC)	221 221 221
12	12.1	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe	221 221 221 222 222
12	12.1	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers	221 221 221 222
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic:	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design	221 221 221 222 222 222
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1	al Development of Brakes in Off-Road Vehicles	221 221 221 222 222 222 222 222 222 223
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake	221 221 221 222 222 222 222 222 223 224
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake)	221 221 222 222 222 222 222 223 224 224
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake	221 221 222 222 222 222 222 223 224 224 224 224
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2	al Development of Brakes in Off-Road Vehicles	221 221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics	221 221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technica 12.3.1 12.3.2 12.3.3	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.4 Power Loss and Efficiency	221 221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technica 12.3.1 12.3.2 12.3.3 Brake T	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.4 Power Loss and Efficiency esting and Braking Effect	221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technica 12.3.1 12.3.2 12.3.3 Brake T	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing	221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technica 12.3.1 12.3.2 12.3.3 Brake T	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications	221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.1.2 Durability and Wetr Testing	221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.1.2 Durability and Wear Testing Vehicle Testing	221 221 222 222 222 222 222 223 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.2 Durability and Wear Testing Vehicle Testing 12.4.2.1 Cold Performance Test (Type 0)	221 221 222 222 222 222 222 223 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.1.2 Durability and Wear Testing Vehicle Testing 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.2 Heat Fading Test	221 221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technica 12.3.1 12.3.2 12.3.3 Brake T 12.4.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.2.2 Urability and Wear Testing Vehicle Testing 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.3 Comparison of the Standards	221 221 222 222 222 222 222 223 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1 12.4.2 Prospec:	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.3 Comparison of the Standards ts and Tendencies	221 221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1 12.4.2 Prospec: 12.5.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.3 Comparison of the Standards ts and Tendencies Interaction Between Wheel Brake and Other Brake Systems in	221 221 222 222 222 222 223 224 224 224 224 224
12	12.1 12.2 12.3	Historic Survey of Brake S 12.2.1 12.2.2 12.2.3 12.2.4 Technic: 12.3.1 12.3.2 12.3.3 Brake T 12.4.1 12.4.2 Prospec: 12.5.1	al Development of Brakes in Off-Road Vehicles of National and International Legal Specifications for ystems Transport Laws in the Federal Republic of Germany Guidelines of the European Community (EC) Regulations of the Economic Commission for Europe Standards of the Society of Automotive Engineers al Versions and Design Drum Brake Disc Brake Multiple-Disc Brake (Wet Brake) 12.3.3.1 Design of a Multiple-Disc Brake 12.3.3.2 Calculation of the Brake Torque 12.3.3.3 Friction Characteristics 12.3.3.4 Power Loss and Efficiency esting and Braking Effect Laboratory Testing 12.4.1.1 Proof of Compliance with Legal Specifications 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.1 Cold Performance Test (Type 0) 12.4.2.3 Comparison of the Standards ts and Tendencies	221 221 222 222 222 222 222 223 224 224 224 224

13	Brake	es for Tracked Vehicles	232
	13.1	Introduction	232
	13.2	Special Requirements for Brakes of Tracked Vehicles	232
	13.3	Mechanical Brakes for Tracked Vehicles	233
		13.3.1 Mechanical Friction Brakes	234
		13.3.2 Multiple Wet Plate Brakes	234
		13.3.3 Dry-Type Single and Multiple-Disc Brakes	235
		13.3.4 Control of Mechanical Brakes	237
	13.4	Combination Brake Systems	237
		13.4.1 Combination with a Primary Retarder	237
		13.4.2 Combination with a Hydrodynamic Service Brake	238
		13.4.3 Other Brake Combinations	238
	13.5	Approval of Tracked Vehicle Brakes	239
	13.6	Summary and Outlook	239
	10.0		
14	A !	A Destro	241
14		aft Brakes	241
	14.1	General Description of an Aircraft Braking System	241
		14.1.1 Hydromechanical Brake Control	242
		14.1.2 Electronic Brake Control (Brake-by-Wire)	243
		14.1.3 Subsystems	244
		14.1.3.1 Anti-Skid System	244
		14.1.3.2 Auto-Braking System	245
		14.1.3.3 Parking Brake System	245
		14.1.3.4 Emergency Braking System	245
		14.1.3.5 Brake Cooling System	245
		14.1.3.6 Indicating and Monitoring System	245
	14.2	Design Criteria for Military and Civil Aircraft	246
		14.2.1 Qualification Directions	246
		14.2.1.1 Civil Aviation Requirements	246
		14.2.1.2 Military Aviation Requirements	247
		14.2.2 Simulation Procedures	247
	14.3	Layout of a Modern BBW System and its Components	248
		14.3.1 Brake Pedal Assembly	248
		14.3.2 Brake Control Unit (BCU)	249
		14.3.3 Valves	250
		14.3.3.1 Brake Control Valves	250
		14.3.3.2 Shutoff Valves	250
		14.3.3.3 Hydraulic Fuses	250
		14.3.4 System Sensors	250
		14.3.4.1 Thermocouples (Optional)	250
		14.3.4.2 Brake Torque Transducer	250
		14.3.4.3 Wheel Speed Sensor	250
		14.3.5 Wheel Brakes	250
	14.4	Friction Materials	252
		Cooling and Temperature Monitoring	252
	14.5	14.5.1 Thermal Loads	252
		14.5.2 Cooling Features	252
		14.5.3 Temperature Monitoring	253
	14.6	Future Aspects	255
	14.0	Tume Aspects	404
			0
15		Car Brake Systems	255
	15.1	Introduction	255
	15.2	Race Car Performances	255
	15.3	Racing Car Straight-Line Braking	257
	15.4	Brake System	258
		15.4.1 Brake Caliper	259
		15.4.2 Master Cylinder	260

i

· · ·

		16.8.3.2 Electrodynamic Brake	276
		16.8.3.3 Electrohydraulic Brake	276
		16.8.4 Brake Matrix	276
		16.8.5 Schematic Tram Brake System	278
		16.8.6 Main Components of a Hydraulic Brake System	278
		16.8.6.1 Brake Force Actuator, Brake Disc, Brake Pad	278
		16.8.6.2 Electrohydraulic Supply and Control Units	278
		16.8.6.3 Brake Control Electronics	278
			210
17	Maab	atrania Systems. A Shart Introduction	279
11		atronic Systems: A Short Introduction	
	17.1	From Mechanical to Mechatronic Systems	279
	17.2	Mechanical Systems and Mechatronic Developments	280
	17.3	Functions of Mechatronic Systems	282
		17.3.1 Basic Mechanical Design	282
		17.3.2 Distribution of Mechanical and Electronic Functions	282
		17.3.3 Operating Properties	283
		17.3.4 New Functions	283
		17.3.5 Other Developments	283
	17.4	Integration Forms of Processes and Electronics	283
	17.5	Design Procedures for Mechatronic Systems	286
	17.6	Computer-Aided Design of Mechatronic Systems	287
18	Basic	s of Electrically Actuated Braking Systems for Passenger Cars	290
	18.1	Introduction	290
	18.2	Definition of Brake-by-Wire	291
	18.3	Structure of Electrically Actuated Braking Systems	292
	18.4	Design of the Actuation Device	293
	10.4	18.4.1 Control Element	293
		18.4.2 Basic Attributes	293
	10 <i>5</i>		294
	18.5	Electrohydraulic Braking Systems	294
		18.5.1 EHB Systems with Pressure Modulator and Pressure Accumulator	294
	10.6	18.5.2 EHB Systems with Electrohydraulic Converter	295
	18.6	Electromechanical Braking System	296
		18.6.1 Electrically Actuated Vehicle Brake	297
•		18.6.1.1 Components	297
		18.6.1.2 Modes of Operation: Interaction of the Components	298
		18.6.2 Energy Demand	300
		18.6.3 Operation of Electrically Actuated Wheel Brakes	302
		18.6.4 Braking System Design	305
		18.6.5 Failsafe Concept	306
	18.7	Mechatronic Interventions in the Self-Reinforcement of the Brake	306
		18.7.1 Active Guidance of the Brake Pad	307
		18.7.2 Active Intervention in the Brake Factor Mechanism	308
	18.8	Comparisons of the Concepts	308
	18.9	Hybrid Electric Brake Systems	309
		Perspectives	311
		1	
19	Elect	rohydraulically Actuated Brakes	313
	19.1	Conflicts of Goals and Limitations of Conventional Brake Systems	313
	19.2	Comparison of Operating Principles of Various Brake Systems	313
	19.2	Characteristics of Electrohydraulically Actuated Brake Systems	315
	19.5	System and Component Description	315
	12.4	19.4.1 Actuator Unit	
			316
	-		318
	10 5	19.4.3 Control Units and Sensors	319
	19.5	Functional System Characteristics	319
		19.5.1 Pedal Feel	319
		19.5.2 Stopping Distance	319

20	The E	Jectromechanically Actuated Brake	321
	20.1	Objective	321
	20.2	System Structure: Interaction of the Components	321
		20.2.1 Actuation Unit	321
		20.2.2 The Electromechanical Wheel Brake	322
		20.2.2.1 Converter	322
		20.2.2.2 Gearing Systems	322
		20.2.2.3 Sensors	323
		20.2.3 Control Concepts	323
		•	323
		20.2.4 Power Supply	
		20.2.5 Passive Safety Aspects	324
	20.3	Electric Parking Brake (EPB) and Active Parking Brake (APB)	324
	20.4	Electric Hydraulic Combi (EHC) Brake	325
	20.5	Utilization of Self-Energizing Brakes	326
	20.6	Electronically Actuated Wedge Brake	327
		20.6.1 Summary	327
		20.6.2 History	327
		20.6.3 Principles	328
		20.6.4 Embodiments	329
		20.6.5 Control Theory	330
		20.6.6 Selected Measurement Results	331
		20.6.6.1 General Test Profile	331
		20.6.6.2 Response Dynamics	331
		20.6.6.3 Sinusoidal Excitation	332
			332
		20.6.7 Outlook	332
• •	an D	the Senten in Deiner Assistence Sentence	224
21		rake System in Driver Assistance Systems	334
	21.1	Overview, Function, and Requirements of Driver Assistance Systems for Cars	334
		21.1.1 Antilock Brake System (ABS)	334
		21.1.2 Traction Control System (TCS)	337
		21.1.3 Electronic Stability Control (ESC)	339
		21.1.3.1 Vehicle Dynamics Controller	342
		21.1.3.2 Brake Slip Controller	344
		21.1.3.3 Drive Slip Controller	346
		21.1.4 Electronic Brake Force Distribution (EBV)	348
		21.1.5 Electronically Controlled Deceleration (ECD)	348
		21.1.6 Hill Descent Control (HDC)	348
		21.1.7 Brake Assistant (BA)	349
		21.1.8 Active Trailer Stabilization	350
	21.2	Function of the Brake System in Driver Assistance Systems	351
	21.2		352
		Requirements of the Brake System for Driver Assistance Systems	352
	21.4	Brake System Designs for Driver Assistance Systems	
	21.5	Monitoring the Brake System for Driver Assistance Systems	356
	21.6	Outlook and Perspective	356
••	m -		0-0
22		Brake in the Mechatronic Chassis	358
	22.1	Introduction	358
	22.2	Chassis Mechanics	358
		22.2.1 Function Structure and Suspension Interfaces	358
		22.2.2 Interaction Between Brakes and Suspension	358
		22.2.3 Representation of Chassis Parameters	359
	22.3	Limitations of Passive Chassis Systems	360
	-	22.3.1 Constraints of Conventional Hydraulically Actuated Wheel Brakes	360
		22.3.2 Dynamics	360
		22.3.3 Braking Comfort	361
			361
	<u></u> ₄	· · · · · · · · · · · · · · · · · · ·	
	22.4	Solution Potential Using Mechatronics	362
		22.4.1 Opportunities Through Mechatronics	362
		22.4.2 Mechatronics in the Brake System	362

		22.4.3 Mechatronics in the Suspension	364
		22.4.4 Interaction Between Steering System and Brake	367
		22.4.5 Interaction Between Tires and Brakes	368
	22.5	Outlook	370
23	Fricti	on Linings	372
	23.1	Introduction	372
	23.2	Friction Lining Requirements	372
	23.3	Material Concepts	373
	40.0	23.3.1 Semimetallic Friction Linings	373
		23.3.2 Low Steel Friction Materials	375
		23.3.3 Non-Asbestos Organic Friction Linings	375
		23.3.4 Nonmetallic Linings	375
		-	375
		23.3.6 Friction Linings for Ceramic Discs	376
		23.3.7 Underlayer	377
	23.4	Ecology	378
	23.5	Raw Materials and Their Characteristics in Friction Linings	380
	23.6	Test Methods for Raw Materials	382
		23.6.1 Analytical Equipment Test Methods	382
	23.7	Manufacturing Procedures	384
	23.8	Outlook	385
		· · · · · · · · · · · · · · · · · · ·	
24	Funct	tion Mechanism and Properties of Friction Couplings in Brake Processes	387
	24.1	Introduction	387
	24.2	Test Devices, Characteristic Load Values, and Assessment Criteria	387
		24.2.1 Test Methods, Testing Opportunities, and Measurement Systems	387
		24.2.2 Characteristic Parameters of Load	389
		24.2.3 Criteria for Assessment of Friction and Wear Properties	389
		24.2.4 Friction Surface Temperature	391
	24.3	Running-In Process	391
	24.4	The Function Mechanism in the Contact Surface	392
	24.5	Local Friction Lining Wear	393
	24.6	Local Friction Coefficients	394
	24.7	Explanation of the Function Mechanism in the Contact Surface	395
	24.8	Parameters that Influence Friction and Wear Properties	395
	24.0		575
25	Mach	anical Brakes in Stationary Industrial Plants	399
10	25.1	Introduction	399
	25.2		399
	23.2	Industrial Brakes	399 399
			401
		25.2.2 The Interaction of Energy Between Drive Gear and Brake	
		25.2.3 Friction and Wear Properties of the Friction Couples	402
		25.2.4 Dimensioning of Friction Couples for Industrial Brakes	405
	,25.3	Friction Disc Brakes	407
	~		
26		tion and Noise	410
	26.1	Definition	410
	26.2	Forms of Vibration and Noise	410
		26.2.1 Low-Frequency Vibrations and Noise	410
		26.2.2 High-Frequency Noises	410
	26.3	Sources of Excitation	410
		26.3.1 Causes of Low-Frequency Noises and Vibrations	410
		26.3.2 Causes of High-Frequency Noise	412
	26.4	Effects	412
		26.4.1 Vibrations	412
		26.4.2 Acoustic Effects	412
•	26.5	Test and Evaluation Methods	412
		26.5.1 Simulation	412

المراجع من المراجع المر

		26.5.2	Test Setup Investigations	413
		26.5.3	Road Tests	414
	26.6	Measur	es to Reduce or Avoid Vibrations and Noise	414
		26.6.1	Measures at the Excitation Sources	414
		26.6.2	Measures at the Transfer System	415
		26.6.3	Secondary Measures	415
	26.7	Outlook	and Prospects	416
27			Ionmetallic Brake Discs	417
	27.1		ction	417
		27.1.1	History	417
		27.1.2	Carbon Brake Discs	417
	27.2	Materia	ıl	417
			Definition, Properties, Applications	417
		27.2.2	Manufacture of a Carbon-Ceramic Brake Disc	417
			27.2.2.1 Manufacturing Process	417
		27.2.3	Quality Assurance	419
			27.2.3.1 Tests During Manufacture	419
			27.2.3.2 Random Sample Tests	419
	27.3	Applica	stion	419
		27.3.1	Design of Ceramic Brakes	419
			27.3.1.1 Dimensioning of the Brake System	419
			27.3.1.2 Brake Disc Ring	419
			27.3.1.3 Brake Disc Chamber	420
			27.3.1.4 Brake Linings	421
		27.3.2	Influence of Ceramic Brakes on Vehicle Properties	421
			27.3.2.1 Influence on Braking Performance	421
			27.3.2.2 Influence on Driving Performances, Driving Properties,	
			and Comfort	421
		27.3.3	Wear Behavior	421
			27.3.3.1 Abrasive Wear	421
			27.3.3.2 Cracking Due to Thermal Stresses	422
			27.3.3.3 Thermal Wear (Fiber Erosion)	422
			27.3.3.4 Wear Assessment	422
	27.4	Further	Development of the Carbon-Ceramic Brake Disc Technology	422
20	Dusles	The state		424
28	вгаке 28.1		Turid Three	424
	20.1	28.1.1	Fluid Types	424
		28.1.2	Silicone Ester-Based Brake Fluids	424
		28.1.2	Mineral Oil-Based Brake Fluids	424
	28.2		al and International Standards	425
	28.3		Fluid Properties	425
	20.5	28.3.1	Vehicle-Specific Suitability	425
		28.3.2	Compatibility with Other Brake Fluids	426
			Physical Properties	426
	28.4		Fluid Handling and Storage	427
	20.4	28.4.1	Handling	427
		28.4.2	Storage	427
		28.4.3	Disposal	428
		20.7.5	\$	720
29	Brake	Testino		429
	29.1		Brake	429
		29.1.1	Laboratory Tests	429
			29.1.1.1 Functional Behavior	429
			29.1.1.2 Tightness	430
			29.1.1.3 Strength	430
			29.1.1.4 Vibration	431
			29.1.1.5 Corrosion	431

.

		29.1.2	Dynamometer Tests	431
			29.1.2.1 Brake Dynamometers	432
			29.1.2.2 Strength and Brake Disc Testing	438
			29.1.2.3 Function of the Wheel Brake	439
			29.1.2.4 Performance	439
			29.1.2.5 Comfort	440
		29.1.3	Road Tests	442
			29.1.3.1 Static/Dynamic Basic Measurements	442
			29.1.3.2 Brake Lining Coefficient of Friction Tests	443
			29.1.3.3 Performance Tests	443
			29.1.3.4 Comfort Tests	444
			29.1.3.5 Endurance Tests	444
			29.1.3.6 Statutory Requirements	445
	29.2	Electro	nic Brake Systems (EBS)	445
	27.0	29.2.1	Laboratory Tests	445
		27.2.1	29.2.1.1 Environmental Simulations	446
			29.2.1.2 Resistance to Media	446
			29.2.1.3 Testing in Corrosive Gas Atmospheres	446
			29.2.1.4 Corrosion Tests	446
		2022	Dynamometer Tests	447
		47.4.4	29.2.2.1 Functional Developments on the Overall System Test Rig	447
			29.2.2.2 Endurance Testing of the Overall EBS System	447
			29.2.2.3 Vibration Resistance	449
		29.2.3	Vehicle Tests	449
		29.4.5		
30	Safety	and Re	liability of Brake Systems	455
	30.1		as Sources of Trouble	455
	50.1	30.1.1	Safety Considerations on Conventional Braking Devices	455
		30.1.2	Safety Considerations for Braking Systems Incorporating Newer	
			Technologies	456
			30.1.2.1 System Reliability	457
			30.1.2.2 System Availability	458
			30.1.2.3 Requirements Pertaining to Electronic Safety Systems	458
	30.2	Lean Te	esting in Automotive Industry	460
	50.2	30.2.1	Support in the Design and Development Phase	460
		30.2.2	Homologation	460
			Field Experience	460
	30.3		ping the Basic Principles of Testing and Inspection	461
	50.5	30.3.1	· · · · ·	461
			Future Homologation	463
		50.5.2		405
31	Leniel	ation ar	nd Testing Procedures	465
	31.1		ogation Procedure in Europe and the United States	465
	31.2		pment Processes of Regulations in Europe and the United States	466
	51.4		Development Process for Regulations in Europe and the Onited States	466
		31.2.2	Development Process for Regulations at the UN ECE	466
		31.2.3	Development Process for Regulations in the United States	467
	31.3		an Regulations for Road Vehicles	467
	51.5	31.3.1	General Regulations, ECE Regulation 13, and EU Directive 71/320/EEC	467
		31.3.2	Performance Regulations	469
		31.3.2	The Distribution of Braking Forces and Compatibility Between	707
		51.3.3	Tractor and Trailer	471
		21 2 4		471
		31.3.4	Regulations for ABS Systems	
		31.3.5	Regulations for Complex Electronic Systems Testing Aftermarket Friction Linings	473
	214	31.3.6		473
	31.4		States Braking Regulations	473
		31.4.1	FMVSS 105—Hydraulic Braking Systems	473 473
		1 4 /	ENVERSE FOR THE PRETURATION OF A CONTRACTOR OF	4/1

		31.4.3 FMVSS 106—Brake Hose Assemblies	473			
		31.4.4 FMVSS 116—Brake Fluids for Motor Vehicles	474			
	31.5	Worldwide Harmonization	474			
		31.5.1 FMVSS 135 and ECE R.13H	474			
		31.5.2 Harmonization: A Look into the Future	474			
32	Maint	tenance and Diagnosis of Brake Systems	476			
	32.1	Influence of Standards, Regulations, and Laws in Practice	476			
	32.2	Brake Diagnosis	477			
		32.2.1 Noise and Vibrations	477			
		32.2.2 Pedal Box	477			
		32.2.3 Booster	478			
		32.2.4 Master Cylinder	478			
		32.2.5 Supply Pipes and Brake Hoses	479			
			479			
		32.2.6.1 Disc Brakes	479			
		32.2.6.2 Drum Brakes	481			
		32.2.7 Pressure Control Devices	482			
		32.2.8 Brake Fluid	482			
		32.2.9 ABS, BA, EHB, VSC, and Other Components and Their Inspection	483			
	32.3	Environment, Repair, and Maintenance at Fair Market Value	483			
	32.4	Test Devices	483			
33	Devel	opment Trends and Future Aspects	485			
	33.1	Social and Economic Trends	485			
	33.2	The Driver's Task—Today and Tomorrow	485			
	33.3	Quantum Leaps in New Technology	487			
	33.4	Limits of Power-Assisted Systems—Potential of By-Wire Systems	487			
	33.5	The Human-Machine Interface	488			
	33.6	Examples of By-Wire Technologies and Assistance Systems in the Chassis Sector	488			
	55.0	33.6.1 Throttle-by-Wire (E-Gas)	488			
			490			
		33.6.3 Steer-by-Wire	491			
		33.6.4 Brake-by-Wire (EHB and EMB)	491			
		33.6.5 Energy Management in the Car of the Future: The 42-Volt Onboard Network	492			
	33.7	Global Chassis Control with Networked Assistance and Chassis Systems	493			
		33.7.1 ESC II—Networking with Externally Controlled Lead Steering	493			
		33.7.2 Electronic Air Suspension; Damper and Stabilizer Adjustment	494			
		33.7.3 Technical and Economic Necessities	495			
		33.7.4 APIA—The All-Encompassing Approach to Safety	496			
		33.7.5 The Long-Term Goal of Accident Prevention	496			
		ů –				
Ch	apters.	, Contributions, and Authors	499			
	- F ,	,				
Au	thor In	ndex	501			
Inc	lex of (Companies and Universities	506			
TD						
IIR	istratio	on Credits	509			
Ab	out the	e Editors	510			
			210			
		·	_			
Inc	lex		511			
Color Section 52						