

# Contents

<b>Terms and Symbols .....</b>	<b>XVII</b>
--------------------------------	-------------

<b>1 Introduction .....</b>	<b>1</b>
1.1 Preface .....	1
1.2 History of Automotive Transmissions .....	7
1.2.1 Basic Innovations .....	7
1.2.2 Development of Vehicles and Drive Units .....	9
1.2.3 Stages in the Development of Automotive Transmissions .....	10
1.2.4 Development of Gear-Tooth Systems and other Transmission Components .....	20
1.2.5 Development of Torque Converters and Clutches .....	23
1.2.6 Investigation of Phenomena: Transmission Losses and Efficiency .....	24
1.2.7 Historical Overview .....	26
<b>2 Overview of the Traffic – Vehicle – Transmission System .....</b>	<b>28</b>
2.1 Fundamental Principles of Traffic and Vehicle Engineering .....	28
2.1.1 The Significance of Motor Vehicles in our Mobile World .....	30
2.1.2 Trends in Traffic Engineering .....	34
2.1.3 Passenger and Goods Transport Systems .....	36
2.1.4 Alternative Transport Concepts .....	40
2.2 The Market and Development Situation for Vehicles, Gearboxes and Components .....	41
2.2.1 Market Situation and Production Figures .....	41
2.2.2 Development Situation .....	46
2.3 Basic Elements of Vehicle and Transmission Engineering .....	46
2.3.1 Systematic Classification of Vehicles and Vehicle Use .....	47
2.3.2 Why do Vehicles Need Gearboxes? .....	49
2.3.3 Main and Auxiliary Functions of Vehicle Transmissions, Requirements Profile .....	51
2.3.4 Interrelations: Direction of Rotation, Transmission Ratio, Torque .....	52
2.3.5 Road Profiles, Load Profiles, Typical Vehicle Use and Driver Types .....	56
2.4 Fundamental Performance Features of Vehicle Transmissions .....	58
2.4.1 Service Life and Reliability of Transmissions .....	58
2.4.2 Centre Distance Characteristic Value .....	60

2.4.3	Gearbox Mass Characteristic Value .....	62
2.4.4	Gearbox Cost Characteristic Value .....	64
2.4.5	Gearbox Noise .....	65
2.4.6	Gearbox Losses and Efficiency .....	66
2.5	Trends in Transmission Design .....	67
<b>3</b>	<b>Mediating the Power Flow .....</b>	<b>73</b>
3.1	Power Requirement .....	73
3.1.1	Wheel Resistance .....	73
3.1.2	Adhesion, Dynamic Wheel Radius and Slip .....	75
3.1.3	Air Resistance .....	77
3.1.4	Gradient Resistance .....	79
3.1.5	Acceleration Resistance .....	80
3.1.6	Total Driving Resistance .....	81
3.1.7	Efficiency Map .....	82
3.2	Diversity of Prime Movers .....	85
3.2.1	Overview .....	86
3.2.2	Electric Drive with Electric Energy Accumulator .....	87
3.2.3	Electric Drive with Fuel Cell .....	87
3.2.4	Hybrid Drive .....	89
3.3	Power Output, Combustion Engine Characteristic .....	93
3.3.1	Torque/Engine Speed Characteristic .....	95
3.3.2	Engine Spread, Throttle Map .....	97
3.3.3	Consumption Map .....	98
<b>4</b>	<b>Power Conversion: Selecting the Ratios .....</b>	<b>100</b>
4.1	Powertrain .....	101
4.2	Total Ratio and Overall Gear Ratio .....	102
4.2.1	Overall Gear Ratio $i_{G,tot}$ .....	103
4.2.2	Selecting the Largest Powertrain Ratio $i_{A,max}$ .....	104
4.2.3	Selecting the Smallest Powertrain Ratio $i_{A,min}$ .....	105
4.2.4	Final Ratio .....	109
4.3	Selecting the Intermediate Gears .....	109
4.3.1	Velocity/Engine-Speed Diagram .....	110
4.3.2	Geometrical Gear Steps .....	111
4.3.3	Progressive Gear Steps .....	111
4.4	Ratio Variation in Continuously Variable Transmissions .....	113
<b>5</b>	<b>Matching Engine and Transmission .....</b>	<b>115</b>
5.1	Traction Diagram .....	117
5.1.1	Deriving a Traction Diagram (Example) .....	119
5.1.2	Engine Braking Force .....	120
5.1.3	Geared Transmission with Dry Clutch .....	123
5.1.4	Geared Transmission with Torque Converter .....	123
5.2	Vehicle Performance .....	126
5.2.1	Maximum Speed .....	126

5.2.2	Climbing Performance .....	127
5.2.3	Acceleration Performance .....	128
5.3	Fuel Consumption.....	128
5.3.1	Calculating Fuel Consumption (Example) .....	129
5.3.2	Determining Fuel Consumption by Measurement.....	131
5.3.3	Reducing Fuel Consumption .....	133
5.3.4	Continuously Variable Transmissions.....	134
5.4	Emissions.....	134
5.5	Dynamic Behaviour of the Powertrain, Comfort .....	138
<b>6</b>	<b>Vehicle Transmission Systems: Basic Design Principles .....</b>	<b>140</b>
6.1	Arrangement of the Transmission in the Vehicle .....	140
6.1.1	Passenger Cars .....	140
6.1.2	Commercial Vehicles .....	143
6.1.3	All-Wheel Drive Passenger Cars.....	146
6.1.4	Transverse and Longitudinal Dynamics with All-Wheel Drive.....	150
6.2	Transmission Formats and Designs .....	151
6.2.1	Transmission Format.....	152
6.2.2	Transmission Design .....	153
6.3	Basic Gearbox Concept .....	154
6.3.1	Shifting with Power Interruption.....	155
6.3.2	Shifting without Power Interruption.....	156
6.3.3	Continuously Variable Transmissions without Power Interruption.....	157
6.4	Gear Sets with Fixed Axles, Countershaft Transmissions and Epicyclic Gears.....	158
6.5	Solution Principles for Part Functions, Evaluation.....	160
6.5.1	Reverse Gear as Example.....	161
6.6	Passenger Car Transmissions.....	163
6.6.1	Manual Passenger Car Transmissions (MT) .....	164
6.6.2	Automated Manual Passenger Car Transmissions (AMT).....	169
6.6.3	Dual Clutch Passenger Car Transmissions (DCT) .....	172
6.6.4	Automatic Passenger Car Transmissions (AT) .....	174
6.6.5	Passenger Car Hybrid Drives .....	182
6.6.6	Continuously Variable Passenger Car Transmissions (CVT).....	186
6.7	Commercial Vehicle Transmissions .....	189
6.7.1	Manual Commercial Vehicle Transmissions (MT) .....	192
6.7.2	Automated Manual Commercial Vehicle Transmissions (AMT) .....	207
6.7.3	Commercial Vehicle Torque Converter Clutch Transmissions (TCCT).....	213
6.7.4	Automatic Commercial Vehicle Transmissions (AT) .....	215
6.7.5	Commercial Vehicle Hybrid Drives .....	216
6.7.6	Continuously Variable Commercial Vehicle Transmissions (CVT).....	219

6.8	Final Drives .....	222
6.8.1	Axle Drives for Passenger Cars .....	223
6.8.2	Axle Drives for Commercial Vehicles .....	225
6.8.3	Differential Gears and Locking Differentials .....	227
6.8.4	Hub Drives for Commercial Vehicles .....	232
6.8.5	Transfer Gearboxes .....	233
6.9	Power Take-Offs .....	234
<b>7</b>	<b>Design of Gearwheel Transmissions for Vehicles .....</b>	<b>237</b>
7.1	Gearwheel Performance Limits .....	237
7.1.1	Causes and Types of Damage .....	239
7.1.2	Calculating the Tooth Root Load Capacity .....	243
7.1.3	Calculating the Pitting Load Capacity .....	245
7.1.4	Calculating the Scuffing Load Capacity .....	246
7.2	Estimating Centre Distance .....	247
7.3	Estimating Face Widths .....	249
7.4	Operational Fatigue Strength and Service Life .....	250
7.4.1	The Wöhler Curve .....	252
7.4.2	Load Profile and Counting Procedure .....	254
7.4.3	Damage Accumulation Hypothesis .....	257
7.5	Developing Low-Noise Transmissions .....	264
7.5.1	Transmission Noise and Its Causes .....	265
7.5.2	How Noise Reaches the Ear .....	269
7.5.3	Assessment Criteria .....	270
7.5.4	Countermeasures .....	274
<b>8</b>	<b>Specification and Design of Shafts .....</b>	<b>278</b>
8.1	Typical Requirements in Vehicle Transmissions .....	278
8.1.1	Configuration of Shafts in Vehicle Transmissions .....	278
8.1.2	Designing for Stress and Strength .....	279
8.1.3	Deflection .....	280
8.1.4	Vibration Problems .....	280
8.2	General Design Guidelines .....	281
8.3	Transmission Drive Shaft Strength Design .....	283
8.3.1	Loading .....	283
8.3.2	Bearing Reactions .....	286
8.3.3	Spatial Beam Deflection .....	286
8.3.4	Shear Force and Bending Moment Diagrams .....	287
8.3.5	Critical Cross-Section .....	289
8.3.6	Stresses .....	290
8.3.7	Preliminary Specification of the Shaft Diameter .....	293
8.3.8	Designing for Endurance Strength .....	294
8.3.9	Designing for Operational Fatigue Strength .....	294
8.3.10	Common Shaft Materials .....	296
8.4	Calculating Deformation .....	296
8.5	Flow Chart for Designing Transmission Shafts .....	297

<b>9</b>	<b>Gearshifting Mechanisms .....</b>	<b>300</b>
9.1	Systematic Classification of Shifting Elements .....	302
9.1.1	Shifting Elements for Transmissions with Power Interruption.....	303
9.1.2	Shifting Elements for Transmissions without Power Interruption.....	306
9.1.3	Shift-by-Wire .....	309
9.2	Layout and Design of Synchronizers.....	310
9.2.1	Synchronizer Functional Requirements .....	310
9.2.2	The Synchronizing Process .....	316
9.2.3	Design of Synchronizers .....	321
9.2.4	The Tribological System of Synchronizers .....	334
9.2.5	Engineering Designs .....	336
9.2.6	Alternative Transmission Synchronizers.....	342
9.2.7	Detail Questions .....	343
9.3	Layout and Design of Multi-Plate Clutches.....	344
9.3.1	Multi-Plate Clutch Requirements .....	346
9.3.2	The Shifting Process.....	346
9.3.3	Design of Multi-Plate Clutches .....	350
9.3.4	Tribological System of Multi-Plate Clutches .....	355
9.3.5	Engineering Designs .....	358
9.3.6	Detail Questions .....	363
9.4	Parking Locks.....	365
9.4.1	Mechanically Activated Parking Locks.....	366
9.4.2	Electrically Activated Parking Locks .....	368
9.4.3	Detail questions .....	369
<b>10</b>	<b>Moving-Off Elements .....</b>	<b>371</b>
10.1	Dry Clutches.....	374
10.1.1	Structure of Dry Clutches.....	374
10.1.2	Design of Dry Clutches .....	385
10.1.3	Dry Multi-Plate Clutches.....	387
10.2	Wet Clutches.....	388
10.3	Dual Clutches .....	390
10.4	Hydrodynamic Clutches and Torque Converters.....	393
10.4.1	Principles.....	394
10.4.2	Hydrodynamic Clutches and their Characteristic Curves.....	397
10.4.3	Torque Converters and their Characteristic Curves.....	399
10.4.4	Engine and Torque Converter Working Together .....	401
10.4.5	Practical Design of Torque Converters .....	406
10.4.6	Engineering Designs .....	406
10.4.7	Design Principles for Increasing Efficiency .....	410
<b>11</b>	<b>Design and Configuration of Further Design Elements .....</b>	<b>420</b>
11.1	Bearings.....	420
11.1.1	Selecting Rolling Bearings.....	421

11.1.2	Rolling Bearing Design.....	423
11.1.3	Design of Rolling Bearings.....	426
11.1.4	Plain Bearings – Bearing Bushes and Thrust Washers.....	428
11.2	Lubrication of Gearboxes, Gearbox Lubricants .....	431
11.2.1	Bearing Lubrication .....	432
11.2.2	Principles of Lubricating Gearwheel Mechanisms.....	432
11.2.3	Selecting the Lubricant .....	435
11.2.4	Selecting Lubricant Characteristics.....	436
11.2.5	Lifetime Lubrication in Vehicle Gearboxes.....	440
11.2.6	Testing the Scuffing Resistance of Gearbox Lubricants .....	440
11.3	Oil Supply and Oil Pumps.....	442
11.3.1	Oil Supply .....	442
11.3.2	Oil Pumps.....	445
11.3.3	Detail Questions.....	451
11.4	Gearbox Housing.....	453
11.4.1	Gearbox Housing Design .....	453
11.4.2	Venting Gearboxes.....	456
11.5	Gearbox Sealing .....	460
11.5.1	Seals for Static Components .....	460
11.5.2	Seals for Rotating Components.....	464
11.5.3	Seals for Reciprocating Round Components.....	466
11.5.4	Practical Examples.....	467
11.5.5	Final Inspection for Detecting Leakage .....	468
11.6	Vehicle Continuous Service Brakes .....	469
11.6.1	Definitions.....	470
11.6.2	Engine Braking Systems .....	471
11.6.3	Retarders .....	472
11.6.4	Actuation and Use.....	478
<b>12</b>	<b>Typical Designs of Vehicle Transmissions.....</b>	<b>479</b>
12.1	Passenger Car Transmissions .....	479
12.1.1	Manual Passenger Car Transmissions (MT) .....	481
12.1.2	Automated Manual Passenger Car Transmissions (AMT).....	494
12.1.3	Dual Clutch Passenger Car Transmissions (DCT) .....	498
12.1.4	Automatic Passenger Car Transmissions (AT) .....	503
12.1.5	Passenger Car Hybrid Drives .....	511
12.1.6	Continuously Variable Passenger Car Transmissions (CVT) ..	514
12.2	Commercial Vehicle Transmissions .....	520
12.2.1	Manual Commercial Vehicle Transmissions (MT).....	521
12.2.2	Automated Manual Commercial Vehicle Transmissions (AMT) .....	530
12.2.3	Commercial Vehicle Torque Converter Clutch Transmissions (TCCT).....	538
12.2.4	Automatic Commercial Vehicle Transmissions (AT).....	542
12.2.5	Commercial Vehicle Hybrid Drives.....	546

12.2.6	Continuously Variable Commercial Vehicle Transmissions (CVT).....	547
12.3	Final Drives .....	548
12.3.1	Axle Drives for Passenger Cars.....	549
12.3.2	Axle and Hub Drives for Commercial Vehicles.....	551
12.3.3	Differential Gears and Locking Differentials.....	555
12.4	All-Wheel Drives, Transfer Gearboxes .....	560
<b>13</b>	<b>Electronic Transmission Control .....</b>	<b>573</b>
13.1	Networked Systems .....	573
13.2	Electronic Transmission Control Unit (TCU).....	574
13.2.1	TCU Structure .....	575
13.2.2	Operating Conditions and Construction Technologies.....	576
13.3	Control Systems.....	577
13.3.1	Transmission Actuator .....	579
13.3.2	Clutch Actuator .....	579
13.3.3	Transmission Control Functions .....	580
13.3.4	Software .....	584
13.3.5	Further Examples of Transmission Control Systems .....	585
13.4	Transmission Calibration with Vehicle-Specific Software Data Input.....	587
<b>14</b>	<b>Computer-Aided Transmission Development .....</b>	<b>589</b>
14.1	Principles and Tools .....	590
14.2	Driving Simulation .....	594
14.2.1	Simulation of Vehicle Longitudinal Dynamics .....	595
14.2.2	Route Data Set, Route Data Acquisition .....	599
<b>15</b>	<b>The Automotive Transmission Development Process.....</b>	<b>600</b>
15.1	Product Life Cycle.....	601
15.2	Product Strategy, Product Planning .....	603
15.3	Release Stages in the Product Development Process.....	604
15.4	The Design Process and Systematic Design .....	606
<b>16</b>	<b>Transmission Manufacturing Technology.....</b>	<b>615</b>
16.1	Process Chains for Steel Part Processing.....	616
16.1.1	Soft Machining Methods .....	617
16.1.2	Heat Treatment Methods .....	617
16.1.3	Hard Machining Methods.....	617
16.2	Process Chains for Cast Part Processing.....	618
16.2.1	Casting Methods.....	619
16.2.2	Machining Cast Parts .....	620
16.3	Process Chains for Gear Machining .....	621
16.3.1	Soft Machining Methods .....	621
16.3.2	Hard Machining Methods.....	623
16.4	Process Chains for Sheet Metal Machining .....	623

16.4.1	Sheet Separation.....	624
16.4.2	Sheet Forming.....	625
16.5	Manufacturing and Factory Management.....	626
16.5.1	Work Preparation and Planning.....	626
16.5.2	Production Systems.....	626
16.5.3	Statistical Process Control in Manufacture.....	627
<b>17</b>	<b>Reliability and Testing of Automotive Transmissions.....</b>	<b>631</b>
17.1	Principles of Reliability Theory.....	632
17.1.1	Definition of Reliability.....	632
17.1.2	Statistical Description and Representation of the Failure Behaviour of Components.....	633
17.1.3	Mathematical Description of Failure Behaviour using the Weibull Distribution.....	636
17.1.4	Reliability with Systems.....	641
17.1.5	Availability of Systems.....	642
17.2	Reliability Analysis of Vehicle Transmissions.....	643
17.2.1	System Analysis.....	644
17.2.2	Qualitative Reliability Analysis.....	646
17.2.3	Quantitative Reliability Analysis.....	648
17.3	Testing to Ensure Reliability.....	651
17.3.1	Classifying Vehicle Transmission Test Programs.....	653
17.3.2	Test Benches for the Test Programs.....	656
17.3.3	Simulation during Bench Testing.....	658
	<b>References.....</b>	<b>661</b>
	<b>Index of Companies/Transmissions.....</b>	<b>695</b>
	<b>Index of Names.....</b>	<b>698</b>
	<b>Subject Index.....</b>	<b>699</b>
	<b>About the Authors.....</b>	<b>717</b>



**Automotive Transmissions**

Fundamentals, Selection, Design and Application

Naunheimer, H.; Bertsche, B.; Ryborz, J.; Novak, W.

2011, XXIV, 717 p., Hardcover

ISBN: 978-3-642-16213-8