

# Contents

<b>Terms and Symbols</b> .....	XVII
<b>1 Introduction</b> .....	1
1.1 Preface .....	1
1.2 History of Vehicle Transmissions .....	6
1.2.1 Fundamental Innovations .....	6
1.2.2 Development of Vehicles and Drive Units.....	8
1.2.3 Stages in the Development of Vehicle Transmissions .....	9
1.2.4 Development of Gear-Tooth Systems and other Transmission Components .....	17
1.2.5 Development of Torque Converters and Clutches .....	19
1.2.6 Investigation of Phenomena: Transmission Losses and Efficiency .....	20
1.2.7 Overview .....	21
<b>2 Overview of the Traffic – Vehicle – Transmission System</b> .....	23
2.1 Fundamental Principles of Traffic and Vehicle Engineering .....	23
2.1.1 The Significance of Motor Vehicles in our Mobile World .....	24
2.1.2 Trends in Transport Engineering .....	28
2.1.3 Passenger and Goods Transport Systems .....	30
2.1.4 Alternative Transport Concepts.....	33
2.2 The Market and Development Situation for Vehicles, Gearboxes and Components .....	35
2.2.1 Market Situation and Production Figures .....	36
2.2.2 Development Situation .....	39
2.3 Basic Elements of Vehicle and Transmission Engineering .....	41
2.3.1 Systematic Classification of Vehicles and Vehicle Use .....	41
2.3.2 Why do Vehicles Need Gearboxes? .....	42
2.3.3 Main and Auxiliary Functions of Vehicle Transmissions, Requirements Profile .....	44
2.3.4 Interrelations: Direction of Rotation, Transmission Ratio, Torque .....	45
2.3.5 Road Profiles, Load Profiles, Typical Vehicle Use and Driver Types .....	49
2.4 Fundamental Performance Features of Vehicle Transmissions.....	49
2.4.1 Service Life and Reliability of Transmissions .....	50

2.4.2	Centre Distance Characteristic Value.....	51
2.4.3	Gearbox Mass Characteristic Value .....	52
2.4.4	Gearbox Cost Characteristic Value .....	53
2.4.5	Transmission Noise .....	54
2.4.6	Gearbox Losses and Efficiency .....	54
2.5	Transmission Design Trends .....	56
<b>3</b>	<b>Mediating the Power Flow .....</b>	<b>58</b>
3.1	Power Requirement .....	58
3.1.1	Wheel Resistance.....	58
3.1.2	Adhesion, Dynamic Wheel Radius and Slip .....	60
3.1.3	Air Resistance.....	61
3.1.4	Gradient Resistance .....	63
3.1.5	Acceleration Resistance.....	63
3.1.6	Total Driving Resistance .....	64
3.1.7	Efficiency Map .....	65
3.2	Diversity of Prime Movers .....	68
3.2.1	Overview .....	68
3.2.2	Electric Drive.....	69
3.2.3	Hybrid Drive.....	70
3.3	Power Output, Combustion Engine Characteristic.....	71
3.3.1	Torque/Engine Speed Characteristic .....	72
3.3.2	Engine Spread, Throttle Map.....	74
3.3.3	Consumption Map .....	75
<b>4</b>	<b>Power Conversion: Selecting the Ratios.....</b>	<b>77</b>
4.1	Power Train .....	78
4.2	Speed Converter for Moving Off.....	79
4.3	Total Ratio and Overall Gear Ratio.....	81
4.3.1	Overall Gear Ratio.....	82
4.3.2	Selecting the Largest Power-Train Ratio.....	83
4.3.3	Selecting the Smallest Power-Train Ratio.....	84
4.3.4	Final Ratio .....	87
4.4	Selecting the Intermediate Gears.....	87
4.4.1	Saw Profile Diagram .....	88
4.4.2	Geometrical Gear Steps .....	88
4.4.3	Progressive Gear Steps .....	89
4.5	Continuously Variable Transmissions .....	90
<b>5</b>	<b>Matching Engine and Transmission .....</b>	<b>92</b>
5.1	Traction Diagram.....	94
5.1.1	Deriving a Traction Diagram (Example).....	95

- 5.1.2 Engine Braking Force ..... 97
- 5.1.3 Geared Transmission with Dry Clutch ..... 98
- 5.1.4 Geared Transmission with Trilok Converter ..... 98
- 5.2 Vehicle Performance ..... 101
  - 5.2.1 Maximum Speed ..... 102
  - 5.2.2 Climbing Performance ..... 103
  - 5.2.3 Acceleration Performance ..... 103
- 5.3 Fuel Consumption ..... 104
  - 5.3.1 Calculating Fuel Consumption (Example) ..... 104
  - 5.3.2 Determining Fuel Consumption by Measurement ..... 106
  - 5.3.3 Reducing Fuel Consumption ..... 107
  - 5.3.4 Continuously Variable Transmissions ..... 107
- 5.4 Emissions ..... 108
- 5.5 Dynamic Behaviour of the Power Train, Comfort ..... 109
  
- 6 Vehicle Transmission Systems: Basic Design Principles ..... 111**
  - 6.1 Arrangement of the Transmission in the Vehicle ..... 111
    - 6.1.1 Passenger Cars ..... 111
    - 6.1.2 Trucks and Buses ..... 114
    - 6.1.3 Four-Wheel Drive Passenger Cars ..... 114
    - 6.1.4 Transverse and Longitudinal Dynamics with All-Wheel Drive ..... 119
  - 6.2 Transmission Formats and Designs ..... 120
    - 6.2.1 Transmission Format ..... 120
    - 6.2.2 Transmission Design ..... 121
  - 6.3 Basic Gearbox Construction ..... 123
    - 6.3.1 Shifting with Power Interruption ..... 124
    - 6.3.2 Shifting without Power Interruption ..... 124
    - 6.3.3 Continuously Variable Transmissions without Power Interruption ... 125
  - 6.4 Gear-Sets with Fixed Axles, Countershaft Transmissions and Epicyclic Gears ..... 126
  - 6.5 Fundamental Approaches for Part Functions, Evaluation ..... 128
    - 6.5.1 Reverse Gear ..... 129
  - 6.6 Passenger Car Transmissions ..... 130
    - 6.6.1 Manual Passenger Car Transmissions ..... 130
    - 6.6.2 Semi-Automatic Manual Passenger Car Transmissions ..... 133
    - 6.6.3 Fully Automatic Passenger Car Transmissions ..... 134
    - 6.6.4 Continuously Variable Passenger Car Transmissions ..... 141
  - 6.7 Commercial Vehicle Transmissions ..... 145
    - 6.7.1 Single-Range Transmissions ..... 146
    - 6.7.2 Multi-Range Transmissions ..... 147
    - 6.7.3 Practical Design of Two- and Three-Range Transmissions ..... 154
    - 6.7.4 Semi-Automatic Manual Commercial Vehicle Transmissions ..... 157
    - 6.7.5 Fully Automatic Commercial Vehicle Transmissions ..... 158
    - 6.7.6 Continuously Variable Transmissions for Commercial Vehicles ..... 159

6.8	Transfer Gearboxes and Power Take-Offs .....	160
6.9	Final Drives: Formats, Performance Limits, Transmission Ratios.....	162
6.9.1	Final Drive Systems for Passenger Cars.....	163
6.9.2	Final Drive Systems for Commercial Vehicles .....	164
6.10	Differential Gears, Differential Locks and Locking Differentials.....	167
6.10.1	Principles of Differential Gears .....	168
6.10.2	The Need for Locking.....	169
6.10.3	The Interlock Value .....	170
6.10.4	Alternatives to Self-Locking Differentials .....	171
<b>7</b>	<b>Design of Gearwheel Transmissions for Vehicles.....</b>	<b>173</b>
7.1	Gearwheel Performance Limits .....	173
7.1.1	Causes and Types of Damage.....	174
7.1.2	Calculating the “Tooth Failure” Performance Limit .....	178
7.1.3	Calculating the “Pitting” Performance Limit .....	178
7.1.4	Calculating the “Gear Scuffing” Performance Limit .....	180
7.2	Estimating Centre Distance .....	180
7.3	Estimating Face Widths.....	183
7.4	Operational Integrity and Service Life .....	184
7.4.1	The Wöhler Curve .....	185
7.4.2	Load Profile and Enumeration.....	187
7.4.3	Damage Accumulation Hypothesis .....	189
7.5	Developing Low-Noise Transmissions.....	195
7.5.1	Transmission Noise and Its Causes .....	195
7.5.2	How Noise Reaches the Ear .....	199
7.5.3	Assessment Criteria .....	199
7.5.4	Countermeasures .....	202
<b>8</b>	<b>Specification and Design of Shafts.....</b>	<b>204</b>
8.1	Typical Problems in Vehicle Transmissions .....	204
8.1.1	Configuration of Shafts in Vehicle Transmissions .....	204
8.1.2	Designing for Stress and Strength .....	204
8.1.3	Deflection .....	206
8.1.4	Vibration Problems.....	206
8.2	General Design Guidelines.....	207
8.3	Transmission Drive-Shaft Strength Design .....	208
8.3.1	Loading .....	208
8.3.2	Bearing Reactions.....	211
8.3.3	Spatial Beam Deflection .....	211
8.3.4	Power and Torque Profiles .....	212
8.3.5	Critical Cross-Section.....	214
8.3.6	Stresses .....	215
8.3.7	Preliminary Specification of the Shaft Diameter.....	218

8.3.8	Designing for Fatigue Strength.....	218
8.3.9	Designing for Operational Integrity .....	219
8.3.10	Normal Shaft Materials .....	220
8.4	Calculating Deformation .....	220
8.5	Flow Chart for Designing Transmission Shafts.....	221
<b>9</b>	<b>Gear Shifting Mechanisms, Layout and Design of Synchronisers.....</b>	<b>224</b>
9.1	Systematic Classification of Shifting Elements.....	226
9.1.1	Shifting Elements for Geared Transmissions with Power Interruption.....	226
9.1.2	Shifting Elements for Geared Transmissions without Power Interruption.....	229
9.1.3	Parking Lock.....	230
9.2	Synchroniser Functional Requirements.....	231
9.2.1	Changing Gear.....	233
9.2.2	Main Functions and Ancillary Functions .....	234
9.2.3	Speed Synchronisation with Slipping Clutch .....	234
9.2.4	Synchroniser Dimensions .....	236
9.3	The Synchronising Process.....	237
9.3.1	Ease of Use .....	239
9.4	Design of Synchronisers .....	241
9.4.1	Synchroniser Performance Limits .....	241
9.4.2	Basis for Design Calculation .....	244
9.4.3	Practical Design for Acceptable Thermal Stress .....	245
9.4.4	Designing Locking Toothing for Locking Effect .....	249
9.5	The Tribological System.....	253
9.5.1	Materials .....	253
9.6	Engineering Designs.....	254
9.6.1	Detail Questions .....	258
9.7	Alternative Transmission Synchronisers .....	259
<b>10</b>	<b>Hydrodynamic Clutches and Torque Converters .....</b>	<b>261</b>
10.1	Principles .....	262
10.2	Hydrodynamic Clutches and their Characteristic Curves.....	265
10.3	Torque Converters and their Characteristic Curves.....	266
10.3.1	The Trilok Converter .....	267
10.4	Engine and Torque Converter Working Together .....	268
10.4.1	Torque Converter Test Diagram, Interaction of Engine and Trilok Converter .....	270
10.5	Practical Design of Torque Converters.....	272
10.6	Engineering Designs.....	272
10.7	Design Principles for Increasing Efficiency .....	274
10.7.1	Torque Converter Lock-Up Clutch.....	274
10.7.2	Power Split Transmission.....	275

<b>11</b>	<b>Notes on the Design and Configuration of Further Vehicle Transmission Design Elements.....</b>	<b>279</b>
11.1	Bearings .....	279
11.1.1	Selecting Bearings .....	280
11.1.2	Bearing Design .....	280
11.1.3	Design of Roller Bearings .....	284
11.2	Lubrication of Gearboxes, Gearbox Lubricants .....	286
11.2.1	Bearing Lubrication .....	287
11.2.2	Principles of Lubricating Gearwheel Mechanisms.....	287
11.2.3	Selecting the Lubricant .....	290
11.2.4	Selecting Lubricant Characteristics .....	290
11.2.5	Lifetime Lubrication in Vehicle Gearboxes .....	293
11.2.6	Testing the Scuffing Resistance of Gearbox Lubricants .....	294
11.3	Gearbox Housing .....	295
11.3.1	Gearbox Housing Design.....	295
11.3.2	Venting Gearboxes .....	297
11.4	Gearbox Sealing.....	301
11.4.1	Seals for Static Components.....	301
11.4.2	Seals for Rotating Components .....	304
11.4.3	Seals for Reciprocating Round Components.....	305
11.4.4	Practical Examples .....	306
11.5	Vehicle Continuous Service Brakes .....	307
11.5.1	Definitions .....	308
11.5.2	Engine Braking Systems.....	309
11.5.3	Retarders .....	309
11.5.4	Actuation and Use .....	313
<b>12</b>	<b>Typical Designs of Vehicle Transmissions .....</b>	<b>314</b>
12.1	Manual Gearboxes .....	315
12.1.1	Manual Passenger Car Gearboxes .....	315
12.1.2	Manual Commercial Vehicle Gearboxes.....	322
12.2	Semi-Automatic Manual Gearboxes.....	326
12.2.1	Semi-Automatic Manual Passenger Car Gearboxes.....	326
12.2.2	Semi-Automatic Manual Commercial Vehicle Gearboxes .....	326
12.3	Fully Automatic Gearboxes .....	328
12.3.1	Fully Automatic Passenger Car Gearboxes .....	329
12.3.2	Fully Automatic Commercial Vehicle Gearboxes.....	332
12.4	Further Examples.....	333
12.5	Final Drives .....	340
12.5.1	Typical Designs, Passenger Cars.....	340
12.5.2	Typical Designs, Commercial Vehicles .....	343
12.6	Differential Gears, Locking Differentials.....	346
12.7	Four-Wheel Drives, Transfer Gearboxes.....	352

- 13 Engine and Transmission Management, Electronics and Information Networking..... 359**
  - 13.1 Overview of Electronic Systems in Current Use..... 359
  - 13.2 Engine Management ..... 361
  - 13.3 Transmission Control..... 361
    - 13.3.1 Automatic Master/Gearshifting Clutch ..... 361
    - 13.3.2 Semi-Automatic Manual Transmissions, Automatic Gear Selection. 362
    - 13.3.3 Fully Automatic Transmissions, Adaptive Gearshift Strategy ..... 362
    - 13.3.4 Continuously Variable Transmissions..... 364
  - 13.4 Electronically Controlled Braking and Traction Systems ..... 364
  - 13.5 Safety Concepts ..... 364
  
- 14 Overview of the Development Process, Product Planning and Systematic Engineering Design..... 365**
  - 14.1 Product Life Cycles ..... 366
  - 14.2 Product Planning..... 368
  - 14.3 The Development Process ..... 371
  - 14.4 Systematic Engineering ..... 373
  - 14.5 Linking Development and Production..... 380
  
- 15 Computer-Aided Transmission Development, Driving Simulation..... 381**
  - 15.1 Driving Simulation ..... 383
    - 15.1.1 Extraneous Factors ..... 384
    - 15.1.2 Route Data Set, Route Data Acquisition ..... 385
  - 15.2 Driving Simulation Programs ..... 386
    - 15.2.1 Classification ..... 386
    - 15.2.2 Modular Construction..... 387
  - 15.3 Applications of Driving Simulation..... 388
  
- 16 Reliability and Testing of Vehicle Transmissions..... 391**
  - 16.1 Principles of Reliability Theory..... 392
    - 16.1.1 Definition of Reliability..... 392
    - 16.1.2 Statistical Description and Representation of the Failure Behaviour of Components ..... 392
    - 16.1.3 Mathematical Description of the Failure Behaviour Using the Weibull Distribution ..... 395
    - 16.1.4 Reliability with Systems ..... 400
    - 16.1.5 Availability of Systems ..... 402
  - 16.2 Reliability Analysis of Vehicle Transmissions..... 403
    - 16.2.1 System Analysis ..... 403
    - 16.2.2 Qualitative Reliability Analysis..... 406

- 16.2.3 Quantitative Reliability Analysis..... 408
- 16.3 Testing to Ensure Reliability ..... 411
  - 16.3.1 Classifying Vehicle Transmission Test Programs ..... 412
  - 16.3.2 Test Stands for the Test Programs ..... 415
  
- References** ..... 419
  
- Index of Companies/Transmissions** ..... 439
  
- Index of Names** ..... 441
  
- Subject Index** ..... 442