Automotive Transmissions

Second Edition

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Joachim Ryborz · Wolfgang Novak

Automotive Transmissions

Fundamentals, Selection, Design and Application

In Collaboration with Peter Fietkau

Second Edition

With 487 Figures and 85 Tables

Springer

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Preface to the Second Revised and Expanded Edition

"Automotive Transmissions" was first published in Germany in May 1994. It was so well received that we decided to publish the book in English in 1999. Since then much has happened in the automotive and transmission sectors.

Imperatives imposed upon the development of automotive transmissions are improving driving performance, increasing driving comfort and ease of use, increasing reliability and service life, reducing weight and installation space, raising efficiency levels, profiling the brand image, reducing costs and, above all, reducing fuel consumption and pollutant emissions. Markets and market mechanisms for passenger cars and commercial vehicles differ and the emphasis placed on these requirements differs in turn. Common to all cases is that a variety of requirements leads by necessity to a conflict of goals. Approaches that can help to solve the goal conflicts are individual usage-optimised transmission solutions, higher integration of submodules, introducing more functionality and generating superordinate functions by means of networking with other vehicle components.

In the case of passenger cars, the trend toward individualised designs has caused strong segmentation with numerous vehicle classes. This has also lead to a massive diversification among transmission designs, with individual solutions and competing concepts: manual transmissions (MT), automated manual transmissions (AMT), dual clutch transmissions (DCT), conventional automatic transmissions (AT), continuously variable transmissions (CVT) and hybrid drives. The "black and white", manual vs. automatic situation existing back in 1990 no longer applies. In the case of commercial vehicle transmissions, the mechanical geared transmission with 6 to 16 speeds of either single-range or multi-range design are standard. In the heavy-duty truck segment, AMT have become successful in Europe. Their path led from semi-automatic designs right up to fully automated transmissions. Increasing integration of peripheral parts and submodules into the transmission has led to lighter, more compact and more reliable aggregates.

Electrics and electronics, actuator technology and sensor technology have played a defining role in many innovations in the area of automotive transmissions. Software is responsible for many of the functions of transmission systems, and thus for much of their customer benefit. The increase in function content and networking with other components of the vehicle leads to changes in the chain of responsibility between vehicle and transmission manufacturers.

The correct evaluation of trends in the market, in engineering and technology has taken on greater importance. The tasks now are to recognize and evaluate future demands early on, to derive new strategies and products from this basis and to develop and finally to produce these products for the market cost-effectively while maintaining a high level of quality. The goal of this book is to provide some of the tools required to do this. It intends to show the process of product development for automotive transmissions in its entirety.

The second edition integrates innovations in automotive transmissions into the systematic framework established in the first edition. Approximately 40% of the content of the second edition is either entirely new or revised with new data. As with the first edition, however, the goal is not to introduce the most current developments or to be exhaustive in details, but to provide the reader with lines of reasoning and to demonstrate approaches. Theoretical principles and concepts are explained that are of general validity and hence of enduring relevance. Therefore beside current designs, transmission systems that are no longer in production are also presented.

In order to strengthen the relation to praxis, the second edition has consolidated the knowledge of experts from different sub-disciplines. Our thanks go to them: *history*: Hans-Jörg Dach (ZF); *passenger car MT/AMT*: Christian Hoffmann (Getrag); *passenger car DCT*: Michael Schäfer (VW), Michael Kislat (VW), Michael Ebenhoch (ZF); *passenger car AT*: Christoph Dörr (Mercedes-Benz); *passenger car/commercial vehicle hybrid*: Stefan Kilian (ZF); *passenger car CVT*: Peter Schiberna (Audi); *commercial vehicle AMT*: Carsten Gitt (Mercedes-Benz); *commercial vehicle CVT*: Karl Grad (ZF); *gearing*: Franz Joachim (ZF); *operational fatigue strength*: Karl-Heinz Hirschmann (Uni Rostock); *acoustics*: Martin Hildebrand (Ford); *external gearshift system*: Andreas Giefer (ZF); *multi-plate clutches*: Dietmar Frey (ZF); *dry clutches*: Benedikt Schauder (ZF Sachs); *wet dual clutches*: Johannes Heinrich (BorgWarner); *bearings*: Oskar Zwirlein (FAG); *seals*: Werner Haas (Uni Stuttgart); *retarders*: Reinhold Pittius (Voith); *all-wheel drive*: Dieter Schmidl (Magna Powertrain), Andreas Allgöwer (Getrag), Hubert Gröhlich (VW); *electronic transmission control*: Josef Schwarz (ZF); *calculation tools*: Marco Plieske (ZF); *driving simulation*: Friedemann Jauch (ZF); *manufacturing*: Christian Wagner (ZF); *testing*: Peter Brodbeck (Porsche) – and many others who supported us with their advice and expertise.

We would like to thank the following companies for up-to-date and realistic illustrations: Allison, Audi, BMW, BorgWarner, Eaton, Ford, Getrag, Honda, LuK, Magna Powertrain, Mercedes-Benz, Opel, Porsche, Toyota, Voith and VW. Special thanks are due to ZF for all their support during the development of this book.

This English language edition could not have come to fruition without the assistance of many contributors. We are particularly indebted to Dipl.-Ing. Peter Fietkau as the manager and co-ordinator of the project, and to his assistants at the Institute of Machine Components (IMA), University of Stuttgart. We thank Springer-Verlag for their good cooperation. Our special thanks go to our families for their great patience, understanding and support during the three years spent preparing this book.

In 2002, Professor Dr.-Ing. Gisbert Lechner passed away. He was the initiator and author of the first English edition of “Automotive Transmissions”. We see the second edition as a continuation of his excellent work.

Friedrichshafen
and Stuttgart, May 2010

Harald Naunheimer, Joachim Ryborz
Bernd Bertsche, Wolfgang Novak

Preface

It was in 1953 that H. Reichenbächer wrote the first book on motor vehicle transmission engineering. At that time, the German motor industry produced 490 581 vehicles including cars, vans, trucks, busses and tractor-trailer units. In 1992, production had reached 5.2 million. The technology at that time only required coverage of certain aspects, and Mr Reichenbächer's book accordingly restricted itself to basic types of gearbox, gear step selection, gear sets with fixed axles, epicyclic systems, Föttinger clutches and hydrodynamic transmissions.

Automotive engineering and the technology of mechanism design have always been subject to evolution. The current state of the art is characterised by the following interrelations:

Environment - Traffic - Vehicle - Transmission.

Questions such as economy, environment and ease of use are paramount. The utility of a transmission is characterised by its impact on the traction available, on fuel consumption and reliability, service life, noise levels and the user-friendliness of the vehicle.

There are new techniques which now have to be taken into account, relating to development methodology, materials technology and notably strength calculation. Examples include operational fatigue strength calculations, the introduction of specific flank corrections, taking account of housing deformation, and the need for light-weight construction.

Transmission design engineering bas been enriched by numerous variants. The manual two-stage countershaft transmission, preferred for longitudinal engines, and the single-stage countershaft transmission preferred for transverse engines now have many sub-variants, e.g. automatic transmissions, continuously variable transmissions, torque converter clutch transmissions, dual clutch transmissions, and transmissions for all-wheel drive.

The engine and transmission must increasingly be considered as one functional unit. The terms used are "powertrain matching" and "engine/transmission management". This can only be achieved by an integrated electronic management system covering the mechanical components in both engine and transmission.

The technique of systematic design developed in the 1960s, and the increasing use of computers for design, simulation and engineering (CAD) are resulting in ever-reducing development cycles. This trend is reinforced by competitive pressures. Systematic product planning is another significant factor in this regard.

It was therefore necessary to create an entirely new structure for the present book "Automotive Transmissions". Modern developments have to be taken into account. The great diversity and range of issues in developing transmissions made it difficult to select the material for this completely new version of "Automotive Transmissions", especially within the prevailing constraints. Not every topic could be covered in detail. In those places where there is an established literature, the authors have chosen to rely on it in the interests of brevity.

The purpose of this book is to describe the development of motor vehicle transmissions as an ongoing part of the vehicle development system. Only by actively taking this interaction into account is it possible to arrive at a fully viable transmission design. The aim is to highlight the basic interrelations between the drive unit, the vehicle and the transmission on the one hand, and their functional features such as appropriate gear selection, correct gear step, traction diagram, fuel consumption, service life and reliability on the other. Of course, another major concern was to represent the various engineering designs of modern vehicle transmissions in suitable design drawings.

The book is addressed to all engineers and students of automotive engineering, but especially to practitioners and senior engineers working in the field of transmission development. It is intended as a reference work for all information of importance to transmission development, and is also intended as a guide to further literature in the field.

Without the assistance of numerous people this book would not have been written. We would like to thank Dr Heidrun Schröpel, Mr Wolfgang Elser, Dr Ekkehard Krieg, Dr Winfried Richter, Mr Thomas Spörl, Mr Thilo Wagner, Dr Georg Weidner and Professor Lothar Winkler for researching and revising chapters. We also wish to acknowledge the contribution of numerous assistants and postgraduates for important work on specific aspects.

We wish to thank Christine Häbich for her professional editing. We would like to thank many employees and scientific assistants of the IMA (Institute of Machine Components) for reviewing and checking various parts of the text.

Such a book cannot be published without current practical illustrations. The publishers wish to acknowledge their gratitude to numerous companies for making illustrations available: Audi AG, BMW AG, Eaton GmbH, Fichtel & Sachs AG, Ford Werke AG, GETRAG, Mercedes-Benz AG, Adam Opel AG, Dr.-Ing. h.c. Porsche AG, and Volkswagen AG. We are particularly indebted to ZF Friedrichshafen AG who have always been most forthcoming in responding to our numerous requests for graphic material.

We are also indebted to Springer-Verlag for publishing this book. We would particularly like to thank Mr M Hofmann, whose faith in our project never wavered, and whose gentle but firm persistence ensured that the book did indeed reach completion. Dr Merkle then prepared the work for printing. We must also thank the publisher of the "Design Engineering Books" series, Professor Gerhard Pahl for his patience and advice. Our thanks especially to our families for their understanding and support.

Stuttgart,
May 1994

Gisbert Lechner
Harald Naunheimer

Contents

Terms and Symbols

A formula you cannot derive is a corpse in the brain /C. Weber/

Physical variables are related by mathematical formulae. These can be expressed in two different ways:

- quantity equations,
- unit equations.

Quantity equations

Quantity equations are independent of the unit used, and are of fundamental application. Every symbol represents a physical quantity, which can have different values:

$$\text{Value of the quantity} = \text{numerical value} \times \text{unit} \, .$$

Example: Power P is generally defined by the formula

$$P = T\,\omega \, , \tag{1}$$

where T stands for torque and ω stands for angular velocity.

Unit equations

If an equation recurs frequently or if it contains constants and material values, it is convenient to combine the units, in which case they are no longer freely selectable.

In unit equations, the symbols incorporate only the numerical value of a variable. The units in unit equations must therefore be precisely prescribed.

Example: In order to calculate the effective power P in kW at a given rotational speed n in 1/min, the above equation (1) becomes the unit equation

$$P = \frac{T\,n}{9550} \, . \tag{2}$$

The unit equation (2) applies where the prescript P is expressed in kW, T in Nm and n in 1/min.

Designation system for steels

In several sections of this book, particular steels have been referred to according to German standard DIN EN 10027. Often there is no exact English equivalent. However it seemed important to provide an explanation of the type of steel being referred to. Therefore the basics of the specification will be explained.

The main symbol is the carbon content multiplied by 100 followed by the chemical composition of the material. The alloying elements are sorted by their alloy content, whereby the percentage of content is multiplied by a multiplier according to the following table. If there is no percentage of an element given in the specification, this means that there is just a small content of this element.

Multiplier	Alloying element
4	Mn, Si, Ni, W, Cr, Co
10	Al, Cu, Mo, Ta, Ti, V, Pb, Zr, Nb, Be
100	P, S, N, C
1000	B

Examples:

16MnCr5	0.16% carbon, 1.25% Cr, small content of Cr
42CrNiMo4-4	0.42% carbon, 1% Cr, 1% Ni, small content of Mo

Terms and Symbols

(Only those which occur frequently; otherwise see text)

A	Surface area, vehicle cross-section = projection of vehicle frontal area
A_R	Friction surface area
$A(t)$	Availability
B_{10}	System service life for a failure probability of 10%
B_x	System service life for a failure probability of x%
C	Basic dynamic load rating, constant
CG	Constant gear
CG_H	Front-mounted splitter unit constant high
CG_L	Front-mounted splitter unit constant low
CG_{main}	Main gearbox constant gear
CG_R	Range-change unit constant gear
D	Diameter, damage
D_{act}	Actual damage sum

D_{prof}	Damage sum of a load profile
D_{th}	Theoretical damage sum
E	Modulus of elasticity
F	Force
F_B	Braking force
F_H	Manual effort, slope descending force
F_L	Air resistance, bearing force
F_Q	Shear force (transverse force)
F_R	Wheel resistance
F_S	Lateral force
F_{St}	Gradient resistance
F_U	Circumferential force
F_Z	Traction
$F_{Z,A}$	Available traction
$F_{Z,B}$	Required traction
F_a	Acceleration resistance, axial force
F_{ax}	Pressure force of the pressure plate
F_n	Normal force
F_r	Radial force
F_t	Tangential force
$F(t)$	Distribution function, failure probability
G_R	Wheel load
J	Moment of inertia
K_G	Transmission characteristic value
L	Service life, sound level
M_b	Bending moment
M_t	Torsional moment
M_v	Reference moment
N	Number of load cycles, number of oscillation cycles to failure, component service life
P	Power, equivalent bearing load
P_A	Frictional power related to surface area
$P_{Z,B}$	Power requirement at wheel
P_m	Mean frictional power during synchronizer slipping
Q	Shear force (transverse force), flow rate
R	Reaction force, stress ratio
R_e	Yield strength
R_m	Tensile strength
$R_{p0.2}$	0.2% offset yield strength
$R(t)$	Survival probability, reliability
S	Safety factor, locking safety factor of synchronizers, slip, interlock value, taper disc radius
S_B	Brake slip
S_H	Rear-mounted splitter unit high
S_L	Rear-mounted splitter unit low
S_T	Drive slip

T	Torque, temperature, characteristic service life
T_B	Acceleration torque (synchronizer), locking torque (differential)
T_C	Clutch torque
T_D	Drag torque
T_L	Load torque
T_M	Engine torque
T_R	Friction torque, slip torque
T_Z	Opening torque (synchronizer)
U	Revolutions
V	Displacement volume (oil pump)
V_H	Total swept volume
W	Section modulus, work, absorbable work, frictional work
W_A	Frictional work related to surface area (specific frictional work)
W_b	Section modulus under bending
W_t	Section modulus under torsion
a	Acceleration, centre distance
b	Shape parameter, failure slope, pack length, width, fuel consumption
b_0	Size factor
b_e	Specific fuel consumption
b_s	Fuel consumption per unit of distance, surface factor
c	Rigidity, absolute speed
c_W	Drag coefficient
c_m	Machine capability index
c_p	Process capability index
c_s	Tooth rigidity
c_u	Circumferential component of absolute speed
c_γ	Meshing rigidity (average value of tooth rigidity over time)
d	Diameter
e	Eccentricity
f	Deflection, frequency
f_R	Rolling resistance coefficient
$f(t)$	Density function
g	Gravitational acceleration
h_i	Number of stress oscillation cycles
i	Ratio
i_A	Powertrain ratio (from engine to wheels)
i_{CG}	Constant gear ratio
i_E	Final ratio
$i_{E,A}$	Ratio of the axle drive
$i_{E,N}$	Ratio of the hub drive
$i_{E,V}$	Ratio of the transfer box
i_G	Transmission ratio
$i_{G,tot}$	Overall gear ratio, range of ratios
i_S	Moving-off element ratio

i_V	Variator ratio
j	Number of friction surfaces
k	Wöhler curve equation exponent
$k(v)$	Characteristic value of a torque converter
m	Gear module, mass, linear scale (converter)
m_F	Vehicle mass
m_n	Standard module
n	Rotational speed, number, number of load cycles, number of bearings
n_M	Engine speed
p	Contact pressure, pressure, number of gear pairs, service life exponent
p_{me}	Effective average pressure in the cylinder of a combustion engine
q	Gradient
q'	Gradient in %
r	Radius, redundancy level of a system
r_{dyn}	Dynamic wheel radius
s	Travel, shift movement at the gearshift sleeve
s_{Fn}	Root thickness chord
t	Statistical variable, time
t_0	Failure free time
t_R	Slipping time, friction time
t_S	Shifting time
u	Gear ratio, circumferential speed
v	Speed, flow rate
v_F	Vehicle speed
v_W	Wind speed
v_{th}	Theoretical speed with slip $S = 0$
w	Absorbed work
x	Addendum modification coefficient
x, y, z	Co-ordinates
z	Number of speeds, number of friction surfaces, number of teeth, number of load cycle passes
z_i	Number of teeth gear i
Δ	Interval, difference
ΔS	Wear path (synchronizer)
ΔV	Wear (synchronizer)
α	Meshing angle, cone angle of a cone synchronizer, viscosity-pressure coefficient
α_0	Effort ratio
α_{St}	Gradient angle
α_k	Stress concentration factor
α_n	Normal meshing angle
β	Helix angle at reference circle, opening angle of dogs

β_k	Fatigue notch factor
δ	Reference cone angle, degree of pump irregularity (volumetric flow pulsation)
ε	Total contact ratio
ε_α	Transverse contact ratio
ε_β	Overlap ratio
η	Efficiency, dynamic viscosity
ϑ	Temperature
λ	Performance coefficient (converter, retarder), rotational inertia coefficient
$\lambda(t)$	Failure rate
μ	Torque ratio, torque conversion, coefficient of friction
μ_{stall}	Stall torque ratio
μ_H	Static coefficient of friction
ν	Speed ratio, speed conversion, kinematic viscosity
ρ	Density, radius of curvature
σ	Normal stress
σ_D	Endurance strength
σ_H	Hertzian stress
σ_b	Bending stress
σ_v	Reference stress
τ	Torsional stress, torque increase of a combustion engine
φ	Gear step, bending angle
φ_1	Base ratio change with progressive stepping
φ_2	Progression factor with progressive stepping
φ_{th}	Gear step with geometrical stepping
ω	Angular velocity

Subscripts

0	Nominal or initial state
1	Pinion (= small gearwheel), input
2	Wheel (= large gearwheel), output
3	Frame
1, 2, 3, ...	At point 1, 2, 3, ...
A	Available, related to area, powertrain, axle
AM	Angular momentum
B	Required, brake, acceleration
C	Clutch
CC	Converter lock-up clutch
CG	Constant gear
CS	Countershaft
D	Endurance, endurance strength, deficit, direct, drag

E	Final ratio
Ex	Excess
F	Vehicle, tooth root
G	Gearbox, propeller shaft
H	Static friction, main, main gearbox, ring gear, high (= fast), Hertzian, displacement, manual
IS	Input shaft
L	Air, load, low (= slow)
L, L1, L2	At bearing point, at bearing point 1, 2
M	Engine, model
MS	Main shaft
MSW	Main shaft wheel
N	Hub, rear-mounted range unit
OS	Output shaft
P	Pump, pump wheel, planetary gear
PV	Pump test
Q	Transverse
R	Reverse gear, roll, slip, friction, wheel, range-change unit, reactor, rotor (retarder)
Roll	Roll
Rot	Rotation
S	Sun gear, splitter unit, stator (retarder), system, lateral, shifting, moving-off element
Sch	Pulsating (strength)
St	Gradient
T	Turbine, drive
TC	Torque converter
U	Circumferential
V	Front-mounted range unit, loss, test, variator, transfer box
W	Alternating (strength), wind
Z	Traction, opening

a	Acceleration, axial, values at tip circle
abs	Absolute
act	Actual
ax	Axial
b	Bending
calc	Calculated
dyn	Dynamic
e	Effective
exper	Experimental
f	Values at root circle
i	Inner, input, control variable $i = 1, 2, 3, ..., n$
i, j	At point i, j
id	Ideal
in	Input

j	Control variable
k	Control variable, notching effect
m	Mean, machine, number of stress classes
main	Main
max	Maximum
min	Minimum
n	Nominal, normal, n-th gear, standard
o	Outer, output
out	Output
p	Process
perm	Permissible
r	Radial
red	Reduced
ref	Reference
rel	Relative
res	Resultant
s	Surface, distance
spec	Specific
stat	Static
t	Torsion, time, tangential
th	Theoretical
tot	Total
trans	Transverse
u	Circumferential
v	Reference
w	Pitch circle
x, y, z	In x, y, z direction, around x, y, z axis
z	Highest gear, number of speeds

1 Introduction

Every vehicle needs a transmission!

1.1 Preface

All vehicles, aircraft and watercraft included, require transmissions in order to convert torque and engine speed. Transmissions are distinguished in accordance with their function and purpose – e.g. selector gearboxes, steering boxes and power take-offs. This book deals exclusively with transmissions for road vehicles as well as for vehicles designed for both on-road and off-road use (Figure 1.1).

Figure 1.2 provides an overview of common transmission designs and their systematic classification. Further details can be found in Chapter 6 "Vehicle Transmission Systems". Dual clutch transmissions are assigned to automatic transmissions with various gear ratios due to their similarity with respect to control and functionality.

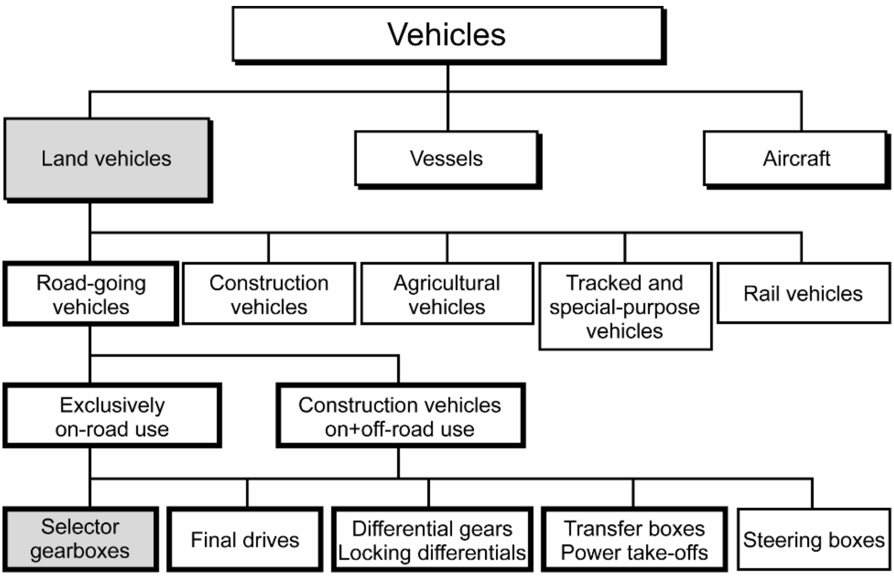


Fig. 1.1. Definition of the term "automotive transmission" as this book uses it

H. Naunheimer et al., *Automotive Transmissions*, 2nd ed.,
DOI 10.1007/978-3-642-16214-5_1, © Springer-Verlag Berlin Heidelberg 2011

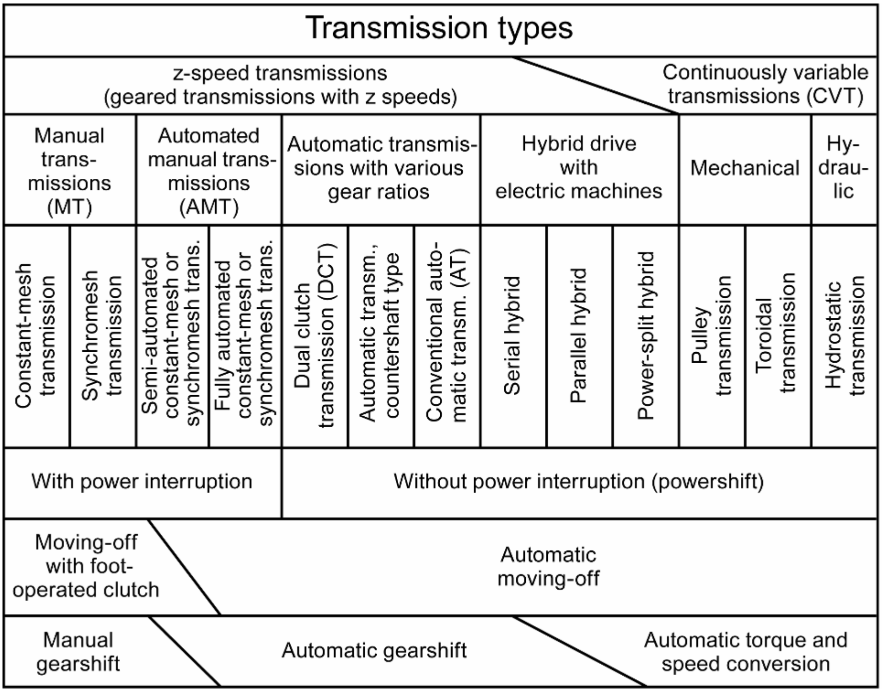


Fig. 1.2. Systematic classification of automotive transmission types

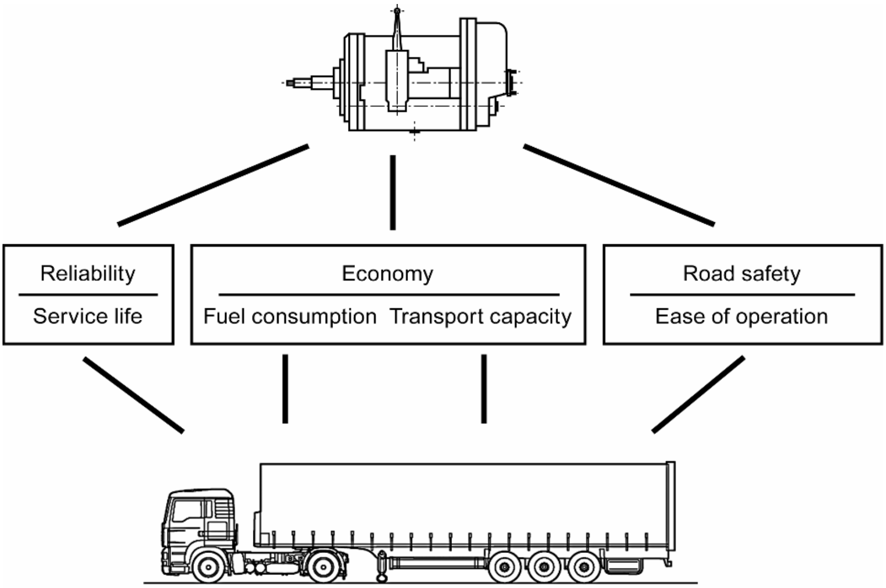


Fig. 1.3. The effect of the transmission on basic attributes of a vehicle

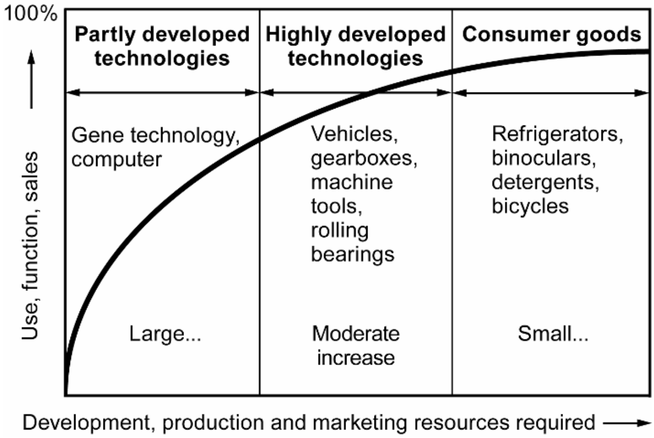
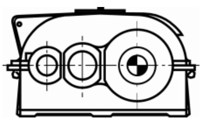
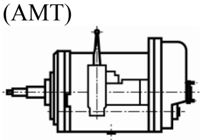
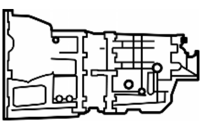


Fig. 1.4. Achievable increase in the practical value of a product by additional development effort

The task of a transmission is to convert the traction available from the drive unit, satisfying requirements placed on it by the vehicle, the road, the driver and the environment. Technical and economical competitiveness are essential here. In addition to the driving and transport performance of passenger and commercial vehicles, transmissions are of central importance with respect to reliability, fuel consumption, ease of operation and road safety (Figure 1.3).

Table 1.1. Comparison between industrial and automotive transmissions

Transmission	Number of speeds (forward)	Ratio 1st gear/overall gear ratio	Power (kW)	Input torque (Nm)	Mass (kg)	Specific power (kW/kg)
Industrial 	1	12.5 –	330	2100	680	0.48 100%
Commercial vehicle (AMT) 	16	14.1 17.0	397	2600	266	1.49 300%
Passenger car (MT) 	6	4.2 5.1	294	500	46	6.39 1300%

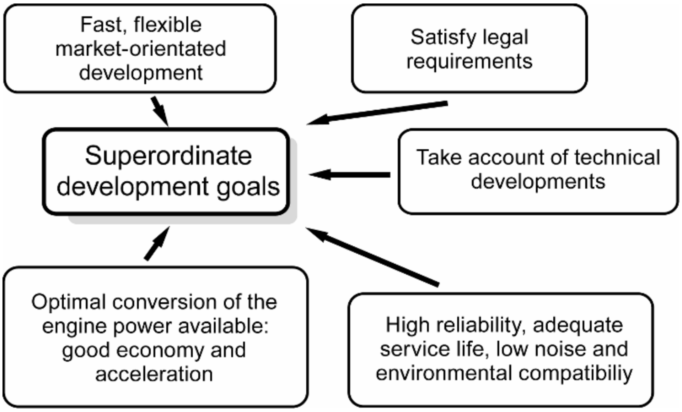


Fig. 1.5. Superordinate development goals for vehicle transmissions

Automotive transmissions are mass-produced products of a high technical and technological order. They are classified as highly developed technologies (Figure 1.4). What is remarkable is the specific power P_{spec} in kW/kg of commercial vehicle transmissions, which is more than three times more than that of industrial transmissions (Table 1.1), despite the fact that automotive transmissions have more speeds. On the other hand, industrial transmissions have to be designed for a longer service life.

Basic innovations in the field of automotive transmissions are no longer to be expected. Instead, we are witnessing a process of gradual evolution. This process is characterized by system thinking focused on the factors Environment ⇔ Traffic ⇔ Vehicle ⇔ Engine/Transmission and by the use of electronics for operational, control and monitoring processes. The superordinate design objectives for automotive transmissions resulting from these tendencies are shown in Figure 1.5.

Vehicle transmission development must be fast and market-oriented. Customers' preferences, especially in the case of commercial vehicles, must be accommodated flexibly. Legal conditions, kW/t-regulation or emission policies for example, must be met. Furthermore, emotional aspects like driving pleasure must also be taken into consideration.

The main goal when designing an automotive transmission is an optimal conversion of the traction available from the engine into the traction force of the vehicle over a wide range of road speeds. This must be done such that there is a favorable compromise between the number of speeds, the climbing and acceleration performance and fuel consumption. Further technical and technological developments should obviously be considered – reliability and service life as well. It is also essential to have regard for environmental and social considerations.

The design of vehicle transmissions should always stay within the planning horizon for new vehicles (Figure 1.6). During the developmental phase of a vehicle, a corresponding transmission must also be created or further developed. To this end, new manufacturing technologies for mass production must also be prepared and introduced.

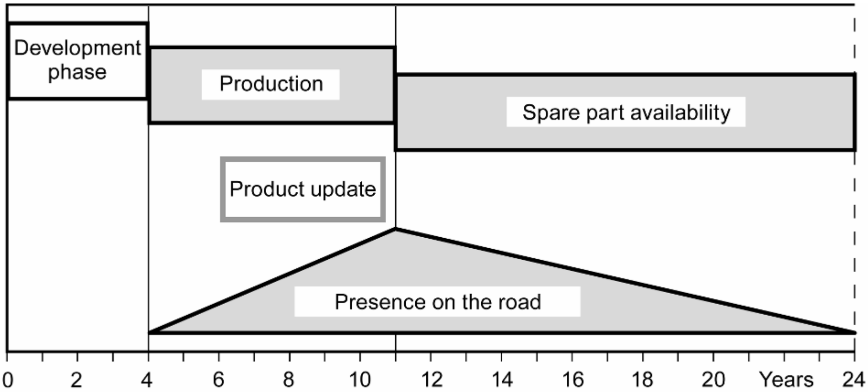


Fig. 1.6. Time dimensions and planning horizons in the automotive industry, from [1.1]

After the end of the production phase, it should be guaranteed that spare parts are available. For this purpose, the life cycles of additional components, including semiconductor components, have to be taken into consideration.

This book seeks to present the automotive transmission development process as a whole (Figure 1.7). It should show ways of thinking that go beyond mere component design. Regardless of which product is at hand, it is always necessary to assess the total system in which that product will later be employed. Such a system overview is indispensable and will be presented in Chapter 2.

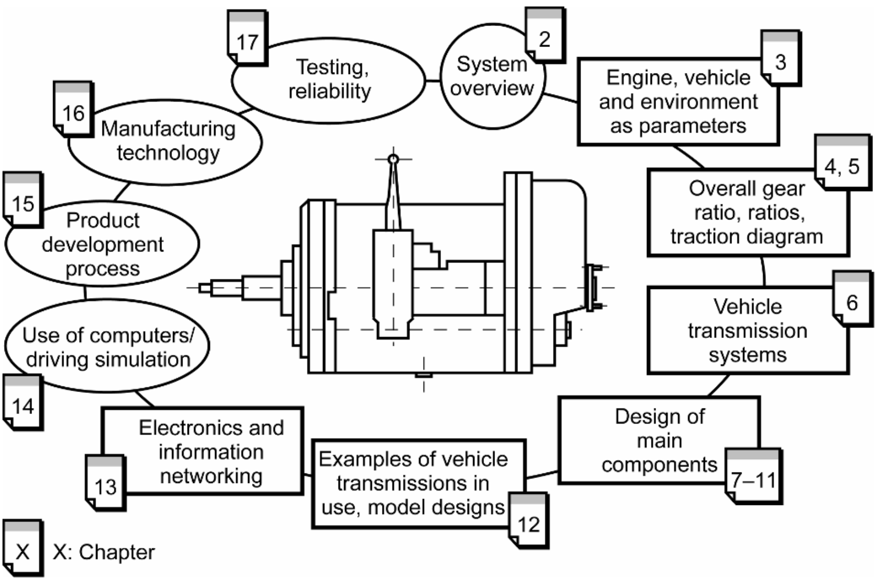


Fig. 1.7. The tasks involved in developing automotive transmissions, overview of chapters

Automotive transmissions are decisively influenced by the vehicle, the engine and the road profile. Without basic knowledge of these factors, meaningful developments are impossible.

Chapter 3 shows the interaction between power required and power available. The first development task focused directly on vehicle transmission is then selecting the range of ratios to be covered, the "overall gear ratio". In conjunction with selecting the number of speeds z, the gear ratio of the individual speeds, the resultant gear steps and the gear ratio of the final drive, the interaction of the vehicle and its transmission system can be evaluated and defined. Observing the road profile, it must be decided whether the vehicle is being sufficiently accelerated and whether the required climbing power and the specified maximum speed v_{max} are reached. We can then establish at the same time whether the transmission unit also permits economical driving – driving with low amounts of fuel consumption in particular. This is dealt with extensively in Chapters 4 and 5.

Creative design, which is indispensable, is complemented by systematic design. Here, a functional analysis is carried out during the conceptual phase. Solutions for individual functions must be found, evaluated and joined together to make an overall solution, i.e. the transmission design. Chapter 6 provides the information regarding the vehicle transmission systems necessary for this.

Following this in Chapters 7 to 11 are the layout and design of the most important components of a transmission: gearwheels, shafts, bearings, synchronizers, clutches, parking locks, pumps as well as hydrodynamic clutches and converters. A treatment of all the details involved in highly developed computation and simulation methods would go beyond the scope of this book. We have instead confined ourselves to the basics of calculation methodology and operations.

In Chapter 12, the structure of various transmission designs and important detailed solutions are explained with the help of a plentiful amount of design examples. Electronic transmission controls built with microprocessors have been the standard in automatic transmissions since 1982. They are among the most complex electronic components in the vehicle and are undergoing a very dynamic development with respect to both hardware and software. Chapter 13 explores this topic and deals with their integration and interconnection with other control devices in the vehicle.

Tools and parameters for the development of automotive transmissions are handled in the latter part of the book. Chapter 14 is dedicated to calculation and simulation tools. In Chapter 15, we take a look at the product development process. Manufacturing technology has a large influence on transmission design, competitiveness and quality. Chapter 16 provides insight into the broad and innovative field of machining, assembly and final inspection.

Quality is a decisive competitive factor. The final customers are interested above all in the reliability and service life of the overall system. Methods for planning and guaranteeing quality as well as corresponding testing programs and test stations are described in Chapter 17.

Of particular concern in this book is to show the reader different approaches and to supply data as amply as possible regarding practical development work on automotive transmissions. As Dudeck put it, "The task of engineering science is, among other things, to refine complicated models to the point of simplicity". This book strives towards that aim.

1.2 History of Automotive Transmissions

Knowledge of the past and of the state of the Earth adorns and nourishes the human spirit /*Leonardo da Vinci*/

Learn from the past for the future! Development engineers and designers should have a grasp of the historical development of their products. Then they can estimate what progress is still possible and what technological potential the current product development has already realized. Such knowledge compliments that of systematic design (see Chapter 15).

1.2.1 Basic Innovations

Basic innovations are discoveries, inventions and new developments, without which products of today could not have been developed. They lead in turn to further discoveries, inventions, new developments and designs that culminate inevitably in new products (Figure 1.8).

In the course of such developments, certain phenomena should be explained and researched in order to guarantee that the product will function reliably.

Table 1.2. Examples of fundamental innovations in automotives and automotive transmissions

4000 BC	Mesopotamian vase with a picture of a cart
2500 BC	Wheels made of two semicircular wooden discs, presumably with leather tyres
2000–1000 BC	Spur gears with pin wheel gear as drive element for water scoops (Sakie, Figure 1.10), worm gears for cotton gins
500 BC	Greek scholars discover the principles of mechanics
200 BC	Lever, crank, roller, wheel, hoist, worm gear and gearwheel are in use
1754	*Euler's* law of gears for gearwheels, involute toothing
1769	*Watt* Patent for steam engine
1784	*Watt* Gearbox with constant-mesh engagement
1829	*Stephenson* Rail vehicle, steam locomotive
1877	*Otto* Patent for four-stroke gas engine with compression
1885	*Benz* Three-wheeler with internal combustion engine
1897	*Bosch* Magneto-electric ignition
1905	*Föttinger* Hydrodynamic torque converter
1907	*Ford* Mass production of model T; the passenger car becomes a mass-produced item
1923	*Bosch* Injection pump
1925	*Rieseler* Automatic passenger car transmission with torque converter and planetary gear set