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Automotive Transmissions

Fundamentals, Selection,
Design and Application

Second Edition

 Springer

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Joachim Ryborz · Wolfgang Novak

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Fundamentals, Selection, Design
and Application

In Collaboration with Peter Fietkau

Second Edition

With 487 Figures and 85 Tables



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ISBN 978-3-642-16213-8 e-ISBN 978-3-642-16214-5
DOI 10.1007/978-3-642-16214-5
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2010937846

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Cover design: eStudio Calamar S.L.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

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 led 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 Kislal (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 has 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

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