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Foreword

One of the greatest innovations in automotive technology was the automatic transmission. Automatic transmissions have allowed both the vehicle driver and builder to optimize the driving experience and efficiency. The automatic transmission permits the driver to have full enjoyment of the vehicle without the worry and effort of shifting gears, with one hand and two feet, for the desired acceleration and deceleration—similar to a manual transmission except with fewer manipulations of the controls. No more worries about missing a gear and losing power! Meanwhile, the automatic transmission gives automotive manufacturers the ability to maximize gear-shift timing for better vehicle fuel economy, thus allowing for increased U.S. Corporate Average Fuel Economy miles per gallon, which is crucial for EPA requirements.

Automatic transmissions are the most fascinating, complicated, and ever-changing piece of equipment used in a transportation vehicle, be it a passenger car or commercial vehicle. Globally, original equipment manufacturers have focused on further enhancing transmission efficiency for better fuel economy performance, while striving to maintain durability for their extended warranties.

Since the turn of the new century, there has been a move toward a higher number of gear ratios (six, seven, eight, nine, and ten speeds) in automatic transmissions from the traditional three- and four-speed automatic transmissions, and a move from manual transmissions to dual-clutch transmissions (DCT), another form of automatic transmission. Continuously variable transmissions (CVT) are also being introduced to the global market for smaller passenger vehicles as an alternative to stepped-ratio transmissions.

Along with these changes, significant advances in design specifics have occurred, with a concentration on reduced energy losses (greater efficiency) and lighter equipment. One of these design changes includes the reduction of the number of clutch plates in the clutch pack; reducing the number of clutch plates reduces the spin losses, which, in turn, helps vehicle fuel economy. However, this adjustment requires more thermally stable friction plate materials such as higher carbon-containing composites, graphitic materials, and/or woven carbon fiber to handle the higher energy shifts.

One might ask why The Lubrizol Corporation, the world's number-one lubricant additive company and a subsidiary of Berkshire Hathaway, would be interested in being a primary sponsor for the updating of this book. All of these design changes, which continue to evolve, have influenced the development of new and more-sophisticated transmission lubricants. These new fluids must have better friction durability and anti-shudder protection across many types of friction materials, especially the newer carbon-containing and woven carbon fiber materials. These fluids also must have more thermally stable additive chemistry for longer OEM warranties and higher sump temperatures.

Dual-clutch transmission fluids specifically must provide excellent synchronizer friction durability in addition to paper-on-steel friction durability for the startup clutch, as in a stepped (speed) automatic transmission. Continuously variable transmission fluids have a major challenge in providing a frictional balance; these fluids must have a high metal-to-metal friction coefficient for good belt-pulley or chain-pulley contact to handle the varying vehicle speeds effectively, as well as have a lower paper-on-steel static friction coefficient to prevent anti-shudder within the CVT startup assembly when the vehicle begins motion.

An additional change in automatic transmission fluids by the OEMs in the past ten years has been the lowering of the kinematic viscosity of their factory fill automatic transmission fluids for improved fuel economy benefits; lower fluid viscosity reduces churning losses within the transmission. This significant lowering of kinematic viscosity places a greater emphasis on having better gear and bearing wear protection.

Lubrizol's latest commercialized automatic transmission, CVT, and DCT fluids accomplish this need of superior wear performance through the balanced use of additives containing phosphorus, boron, and sulfur. Finally, many of
these automatic transmission design changes have caused an increased need for improved oxidation and thermal stability in ATFs due to observed higher operating sump temperatures and the introduction of smaller transmission sump sizes.

Anyone involved in the passenger car industry, even remotely, should take the time to learn how the automatic transmission operates and, most importantly, become more familiar with the latest advances in automatic transmission technology. We highly recommend this new, 4th Edition of AE-29 Design Practices: Passenger Car Automatic Transmissions, to be the lead reference of use, especially for those working in and supporting the area of automatic transmissions.

William D. Abraham, Ph.D.
Driveline Technology Manager, Senior Fellow
Automatic Transmission & Farm Tractor Fluids
The Lubrizol Corp.
Design Practices: Passenger Car Automatic Transmissions has a long history—nearly half a century—as the “go-to” handbook of current and relevant design considerations for automatic transmission industry engineers of all levels of experience.

This edition represents a major overhaul from the prior edition and is arguably the most significant update in its long history. Virtually all existing chapters have been updated and improved with the latest state-of-the-art information. Many previously existing chapters have been significantly expanded with more detail and design consideration updates; most notably:

- Torque Converters and Start Devices
- Gears/Spline/Chain
- Bearings
- Wet Friction
- One Way Clutch
- Automatic Transmission Controls
- Pumps
- Seals and Gaskets

Additionally, all new chapters have been added, including state-of-the-art information on:

- Lubrication
- Transmission Fluids
- Filtration and Contamination Control

Finally, details about the latest transmission technologies have been added, including Dual Clutch Transmissions and Continuously Variable Transmissions.

This complete overhaul was an exhaustive effort by many of our industry’s most knowledgeable experts, developed over a significant period of time. This required major commitment from both individual chapter authors (whose credits are shown at the introduction to each chapter) and also the members of the Automatic Transmission & Transaxle Technical Standards Committee, who provided invaluable material development oversight. Those colleagues include:

- Ernest J. DeVincent (Chairman), Getrag Transmissions Corporation, and Ford Motor Company (retired)
- Michael T. Berhan, Ford Motor Company
- Susan M. Bothe, Freudenberg-NOK General Partnership
- Thomas Brand, BorgWarner Corporation
- Gang (George) Chen, Chrysler Group LLC
- Louis Crocco, Greening Associates
- Mark R. Dobson, Ford Motor Company
- Hussein A. Dourra, Chrysler Group LLC
- Charles (Chip) Hartinger, Ford Motor Company
- James D. Hendrickson, General Motors Company
- Harry A. Hildebrandt, Oakland Community College
- Andrew F. Joseph, Freudenberg-NOK General Partnership
- Ibrahim A. Khalil, SPX Filtran
- John M. Kremer, BorgWarner Corporation (retired)
- Larry Larkin, Filtertek Corporation (retired)
- Maurice B. Leising, Chrysler Corporation (retired)
- Glenn Mann, Nichols Portland Corporation
- Gregory Mordukhovich, General Motors Company
- Michael D. Myers, Otis Elevator Corp, and Timken Corporation (retired)
- Thomas M. O’Brien, Chrysler Group LLC
- Lev Pekarsky, Ford Motor Company
- John Titlow, Conxall Corporation, and Honeywell Corporation (retired)

It should be noted that the manual itself is not intended as a design requirements document, but rather a compilation of the latest design practices in the industry. Therefore, it should
Preface to Fourth Edition

not be considered a basis for legal regulation or administrative ruling.

In summary, this team has put together the most definitive handbook for Automatic Transmission Design Practices available today. There are many to sincerely thank for this: the chapter authors, the members of the Auto Trans Technical Standards Committee, the SAE Staff, and—very importantly—the OEM and supplier companies who allowed their expert employees to contribute their valuable time to this effort.

Ernest J. DeVincent, Chairman
SAE Automatic Transmission & Transaxle
Technical Standards Committee
Preface to the Third Edition

The Automatic Transmission Design Practices Manual has a long and distinguished history of technical contribution to the automotive engineer dating back to the first published manual in 1962. This manual is a compendium of the latest current practices of transmission engineering sponsored and compiled by the SAE Transmission/Axle/Driveline Forum Committee of the SAE Power Train Systems Group. It retains some of the original papers from the previous manual wherein the technical material is still valid. Design calculations are included wherever possible to enhance the usefulness of this document for the design engineer.

Special credit for coordinating the planning of this Herculean work goes to Co-Chairmen Kevin L. Wicks and Carl E. Shellman (detailed credit below). It is evident that many people have contributed toward the preparation, writing and editing of the Automatic Transmission Design Practices Manual. The task was divided into sections, many of them championed by the chairperson of the applicable standards committee of the Forum Committee as credited below in alphabetical order:

- Martin G. Gabriel (Chairman), Senior Reliability Engineer, Power Train Reliability and Quality Office, Ford Motor Company
- John E. Mahoney (Vice-Chairman), General Motors Corp. (retired)
- Edward L. Clary, Buick Motor Div., General Motors Corp. (retired)
- Merrill L. Haviland, Sr. Automotive Dev. Specialist, Exxon Chemical
- Karl Schneider, Vice President, Advanced Transmission Technology, Automatic Transmission Systems, Borg Warner Automotive
- Carl E. Shellman, Chief Design Engineer, F F Developments
- Leo G. Steinl, Staff Project Engineer, Advance Engineering Staff, General Motors Corp.
- John R. Tanzer, Ford Motor Company (retired)
- Kevin L. Wicks, Mgr. Mechanical Components, Power Train Division, General Motors Corp.
- Stanley N. Smith, Director of Technical Dev., Chassis Products Operations, Federal Mogul Corp.

There has been no attempt to cite applicable patents covering any section of the art contained in the material presented. Neither SAE nor the authors wish to imply that discussion of a topic indicates there are no patent rights involved. The reader is responsible for his own investigation to establish his right to use any device or principle described herein.

No material presented in this manual is to be construed as a design standard or a recommended practice by the Society of Automotive Engineers. It is a compilation of existing design practices as interpreted by the Transmission/Axle/Driveline Forum Committee and individual authors. It is not intended to be a basis for legal regulation litigation or administrative ruling by a regulatory body.

The many contributors including the members of the committees and the authors of the papers are recognized for their many hours of effort to make this latest reference manual available to the automotive engineer.

Martin G. Gabriel, Chairman SAE Transmission/Axle/Driveline Forum Committee
Preface to the Revised Second Edition

The original editions of this handbook were an indispensable tool for both the experienced and the novice transmission design engineer and have become classics. To improve upon these was considered a Herculean task, and so it was decided to split the task in two. This revised edition of the design practices handbook is a corrected version of the second edition. A new version of the handbook will be written in the next few years.

The corrections are to the obvious errors and omissions, and you will find that most of the typographical errors are corrected. There have been minor changes to update the information along with certain rewriting of phrases to clarify and assist in understanding. Added to this volume is a copy of the SAE metric standards (1916) so that conversion of any of the information contained herein can be done from one reference source rather than needing to look elsewhere for conversion factors. There is also a listing of the SAE papers that were considered relevant to the topics in this volume.

There are many areas of design that have become increasingly important since the original publication of this volume, but we have been unable to include them. The application of electronics on what was essentially a mechanical device is not covered; neither are the design alterations driven by the need to improve fuel economy of passenger car vehicles equipped with automatic transmissions. Problems of designing four-wheel-drive automatic transmissions and Continuously Variable Transmissions (CTV) are not included. For the reader interested in the CVT, a separate SAE publication is available (PT-30).

The revision required to produce this edition has required much time by many people. Those who volunteered to bring this edition to print include:

- M.G. Gabriel (Chairman, Transmission & Drivetrain Technical Committee), Supervisor of Product Reliability, Ford Motor Company
- W.E. McCarthy, Staff Research Engineer, General Motors Corporation
- J.H. Tanzer, Supervisor, Transmission & Axle Engineering, Ford Motor Company
- K.L. Wicks, Senior Project Engineer, Hydra-Matic Division, General Motors Corporation
- L.G. Steinl, Staff Project Engineer, General Motors Corporation
- D.L. Otto, Product Development Specialist, Timken Company
- S.N. Smith, Manager, Engineering & Research, Federal Mogul Corporation
- E.L. Clary, General Motors Corporation (retired)
- M.C. Sefcik, Advanced Engineering Staff, General Motors Corporation
- J.R. Grady (Sponsor), Vice President, North American Sales, Borg-Warner Automotive, Inc.
- A.R. Fisher, Ford Motor Company (retired)
- E.W. Upton, Staff Engineer, General Motors Corporation

Many others helped to produce this edition including many of the original authors who reviewed and corrected their own work, plus practitioners in the field who had used the previous editions and were able to offer constructive criticism. These efforts to clarify and update this volume were sincerely appreciated.

N.F. Avery
Chief Engineer
Long Manufacturing
The automatic transmission is one of the most complex components in the automobile. The design reflects knowledge from almost every branch of the field of mechanical engineering. Its more than 600 parts are expected to be so well designed and fabricated that the assembled unit is not only lightweight, compact, and durable, but also easy to service, quiet in operation, and smooth shifting under all driving conditions. The goal of every automatic transmission engineer is to design a unit that has all of these qualities at a low competitive cost.

The need for a manual of design practices to aid transmission engineers in achieving their goals was recognized as early as 1955, when a Design Standards Subcommittee was established within the SAE Hydrodynamic Drive and Transmission Committee—renamed the Transmission Committee in 1957. In 1959, the Subcommittee under the chairmanship of Charles S. Chapman undertook to fill a void in design information on passenger car automatic transmissions. Recognizing that an invaluable wealth of knowledge was possessed by many transmission experts with widely varying experience and background, the Subcommittee set out to get this information documented, compiled, and published in a form that would be useful to both the experienced and the novice transmission design engineer. To achieve its goal, the Subcommittee sponsored a number of Transmission Workshop Meetings at which papers on the various aspects of automatic transmissions were presented by many authors of considerable experience. These papers were later edited and compiled into two hardbound volumes that sold over 2,000 copies each.

The preface appearing in each of those two volumes—now recognized as the first edition of this reference work—is reproduced in this revised edition for two reasons: first, to recognize the members of the group responsible for getting that valuable first edition published, and second, to capture and retain some of that group's thinking and philosophy with regard to the purpose, scope, and format of the publication. The revised edition of *Design Practices: Passenger Car Automatic Transmissions* represents both an updating and an expansion of the information contained in the original two-volume edition. Most of the papers included in the original edition are retained, with many of them edited to reflect current practices. Several papers presented since 1962 have been included to add new subject matter. The papers have been grouped in sections identified by subject, material, or component—for example, seals, friction material, lubrication, etc. Each section is subdivided into chapters to cover the various categories of information within that section.

The task of producing this volume was assigned to a new Editorial & Publication Subcommittee established within the SAE Transmission and Drivetrain Committee. The members of this Subcommittee who participated in the organization of this material are:

- Harold Fischer (Chairman), Senior Staff Engineer, Buick Motor Div., General Motors Corp.
- M.G. Gabriel (Section Chairman), Automatic Transmission Engineering, Transmissions and Chassis Div., Ford Motor Co.
- E.L. Jones, Managing Editor, Axle Engineering, Chrysler Corp.
- T.F. Ristau, Director of Advanced Engineering, Saginaw Steering Gear Div., General Motors Corp.
- G.R. Smith, Engineering Staff, General Motors Corp.
- R.W. Wayman, Vice President, Advance Transmission Engineering, Borg-Warner Corp.
- E.L. Clary, Research and Development Engineering, Buick Motor Div., General Motors Corp.

The members of this Subcommittee, the authors of the papers, and several members of the SAE Transmission and Drivetrain Committee have unselfishly devoted many hours of personal effort to make this a truly useful reference manual.

Bert W. Cartwright
*Engineering & Research Office*
*Chrysler Corp.*
Preface to the First Edition

The material printed in this volume has been gathered and published as a result of the activities of the Design Standards Subcommittee of the SAE Transmission Committee. The members of this Subcommittee who participated in the organization of this material are:

- Charles S. Chapman (Chairman), Staff Engineer, New Transmission Design, Buick Motor Div., General Motors Corp.
- Bert W. Cartwright, Manager, Product Engineering, Axle and Transmission Div., Chrysler Corp.
- Jack R. Doidge, Chief Engineer, Detroit Transmission Div., General Motors Corp.
- Harold Fischer, Section Engineer, Current Transmission Design, Buick Motor Div., General Motors Corp.
- John W. Holdeman, Vice-President, Engineering, Warner Automotive Div., Borg-Warner Corp.
- Frank J. Winchell, Assistant Chief Engineer, Research and Development Section, Chevrolet Motor Div., General Motors Corp.

Several years ago, this Subcommittee undertook to fill a void in design information on passenger car automatic transmissions. The means and format for accomplishing this have changed as the effort progressed. The textbook and recommended practice approaches have given way to a form in which the current practices of the industry are tabulated or analyzed for the information of designers without any recommendation telling designers what they should or should not do specifically. This does not exclude comments on what is considered poor design by current standards, but does avoid dogmatic recommendations in a field where the number of design variables is too large and the differences in environment and application have too large a bearing to make any specific recommendations. It is the feeling of the Subcommittee that the use of a device at a known design level in millions of automatic transmissions in customer service is information of the highest utility. In addition to this information, the methods of design calculation are included as an attempt to consolidate this information in order to make a useful reference for the design engineer.

There are members of this Subcommittee from every transmission manufacturing organization now producing passenger car automatic transmissions in large volume in the United States. These Subcommittee members and their engineering organizations have made available to the Subcommittee the design and dimensional information on all of the components of the transmission currently in production. Of course, no proprietary information on new designs not yet in production was given nor was it requested. Most of the information on the production units is available to anyone who wishes to purchase a unit and measure and calculate these design stresses or other information. Normally, except in cases of detailed interest, this is too time-consuming and costly a procedure to carry out for all production units by an individual organization, and, for this reason, the data are of considerable interest to most engineers.

The material was broken down into sections according to the function of the components for presentation. Members of the Subcommittee were assigned various subjects and were made session chairman for SAE meetings to present the material. Authors who had considerable experience with the subject material were invited to present papers at these Transmission Workshop sessions. The time and arrangements for these sessions were made available by the Passenger Car Activity Committee, which gave our efforts enthusiastic support as part of a general effort to improve constantly the technical content of SAE papers and presentations.

These papers have been edited and revised by the Subcommittee where necessary to make them more compatible with the Subcommittee’s objectives. This is particularly true of the earlier papers that were presented while the objectives were being formulated. The papers presented later benefited from...
Preface to the First Edition

there has been no attempt to cite current or expired patents covering any section of the art contained in the material discussed. Neither SAE nor the authors wish to imply that discussion of an item indicates that there are no patent rights involved, and the reader is responsible for making his own investigation to determine his right to use any device or principle described herein.

As stated previously, no material presented in this volume is to be construed as a design standard or a recommended practice of the Society of Automotive Engineers. It is a compilation of existing design practices as interpreted by the Transmission Design Standards Subcommittee and individual authors. It is intended in no way to be a basis for legal regulation, litigation, or administrative ruling by a legally constituted regulatory body.

C.S. Chapman
Buick Motor Div.
General Motors Corp.

these earlier efforts and needed less revision for incorporation into this volume.

The effort put into the papers by the authors and the Subcommittee members can be well appreciated only by those involved in similar undertakings. These men have given a great deal of their personal time and effort very unselfishly and have made a substantial contribution to this profession. The fact that no one involved will ever be completely satisfied with the results is testimony to the high professional standards of those participating in the presentation of this material.

The encouragement and active sponsorship of this activity by other members of the SAE Transmission Committee has greatly aided this program. The cooperation of the Passenger Car Activity Committee and the help of Forest McFarland in presenting the program to the Committee to arrange for the Transmission Workshop sessions has been very much appreciated.