Ground Vehicle Engineering Series

Driveline Systems of Ground Vehicles

Theory and Design

Alexandr F. Andreev

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Driveline Systems of Ground Vehicles

Theory and Design

Dedication

In fond and respectful memory of Dr. Anatoliy Kh. Lefarov,
engineer, scientist, and educator

My father, Anatoliy Khristoforovich Lefarov, was born on February 2, 1913, in a rural family of intellectuals. His father was an accountant and his mother was a teacher. From a young age, my father devoted his life to education and work. He graduated from a peasant's youth school in 1929 and from a technical school of agriculture in 1932. From 1934 onward, he worked as a grain-harvesting combine operator and as a driver of Caterpillar and International Harvester Farmall Tractors, first at the Evpatoria, and then at Simferopol farms that specialized in grain growing.

In recognition of the high quality of his professional work, the People's Agriculture Commissariat of the Crimean Autonomous Soviet Socialist Republic sent my father to Leningrad Industrial Institute (subsequently renamed as Leningrad Polytechnic Institute) in 1935, where he was successfully admitted.

Upon his admission to the institute, my father immediately devoted all his time and energy to his studies. His diligence, which consisted of studying 12–14 hour daily, did not fail to bear fruit. During the third year of his school, he became one of the best students in the institute and was awarded a higher-level stipend; he was later awarded the highest student honor at the time—the Stalin grantee.

Having graduated from the institute with honors in 1940, my father was assigned to work at the design department of the Gor'kiy Automotive Company (GAZ). He started his work under the guidance of one of the U.S.S.R. founders of the school of off-road equipment design—Vitaliy Andreyevich Grachev. It was precisely at this time that the direction of his scientific activity, which subsequently became his entire life purpose, germinated. Using his knowledge and through diligent work, he rapidly gained the respect of his coworkers and the leadership of the design office.

After Nazi Germany attacked the U.S.S.R. in 1941, my father was drafted and sent to the front. But he was soon recalled, as his engineering expertise was needed by the military, and he was returned to the GAZ design office. He continued working in this office donning the role of a senior designer. During the war, he designed and refined a number of mechanisms and assemblies of off-road wheeled and tracked vehicles for the military.

With the end of the war in 1945, my father, who was now a fully established expert, was transferred by the order of the Secretary of Automotive Industry of the U.S.S.R. to the Dnepropetrovsk Automobile Company (DAZ) as a deputy chief designer. Here fate again brought father together with his superior at the Gor'kiy Automotive Company, Vitaliy Andreyevich Grachev, who had been appointed as the chief designer of DAZ the previous year.

In DAZ, the following vehicles were designed under the guidance of V.A. Grachev with the direct participation of my father: the DAZ-150 4 ton self-loader, the DAZ-485 3-axle amphibian truck (LAT, large amphibian truck) for the military, the Ukraina passenger car, and other vehicles. But soon, by decree of the Soviet government the DAZ was switched to other manufacturing tasks and my father was sent to Minsk, the capital of Belarus, and appointed as the deputy chief design engineer at the Minsk Automotive Company (MAZ). In Minsk, he resumed his work with heavy-duty trucks, in particular, high-mobility trucks and tractors.

This was the time when the MAZ had just established a special design office (SKB-1 as further mentioned in the preface) for designing multiaxle rocket tractors. This office consisted of a large scientific, engineering, and manufacturing task force that subsequently not only established an entirely new direction in the design of military and civilian multi-wheel heavy-duty trucks but also became a prominent scientific and engineering school of the Soviet Union. This office was headed by Boris L'vovich Shaposhnik, a leading design engineer, and my father became his first deputy. The SKB-1 was established in 1954; the project of the base four-axis chassis MAZ-535 was already completed by 1955, and just a year later, the MAZ-537 tractor with a hydraulic gearbox, locked by a torque converter, lockable differentials, and independent suspension of all the wheels was also completed. In 1962, under the leadership and direct participation of my father, gear-type free-running differentials for heavy-duty MAZ tractors were designed. These differentials became an integral part of the driveline system of the well-known four-axle MAZ-543 chassis that went into production in 1962. The design of the differentials was so successful that they are still used on tractors that serve as carriers of various rocket launchers. Drs. Otto Ya. Zaslavskiy and Lev Kh. Gileles, who worked for many years with my father, write in their memoirs that my father had a sharp intellect, tact, and exceptional precision. This he most probably acquired from the old Russian engineering community and professors, some of whom remained in the Stalin years at Leningrad Polytechnic Institute, which was his alma mater. His colleagues made mention of the fact that he was the first one to point to the organic link between engineering developments and scientific studies, and was the first to call attention to the importance of intellectual property in modern society. He was the first staff member in the SKB-1 who was issued a certificate (Soviet equivalent of patent) for an invention. It is most likely that for these reasons my father performed experimental and analytic studies and wrote scientific works while being engaged in designing new vehicles. He authored articles and books and was the first in the SKB-1 to defend a PhD dissertation.

But father did not devote himself exclusively to military vehicles. He also worked actively on designing MAZ trucks, MAZ-501 and MAZ-509, and various modifications of the MAZ-537, for civil use. For example, he developed and put into production an original lightweight front axle for an all-wheel-drive timber carrier. The MAZ-501 automobile was the first automobile in the U.S.S.R. to employ a differential in the transfer case. This was a significant achievement for Dr. Lefarov as a designer. The locking differential designed and tested by my father under actual operating conditions started coming into use on MTZ-52 and MTZ-82 tractors of the Minsk Tractor Works, and also on the K-700 tractor of the Leningrad Tractor Company named after Kirov.

While working at the MAZ, my father, on the invitation of the administration of the College of Automobile and Tractor Engineering of Belarusian National Technical University (previously Belarusian Polytechnic Institute, BPI), Minsk, Belarus, became involved in teaching students—future experts in automobile and tractor engineering. He left his company in 1963 for the chair of the tractor engineering department of BPI.

In this institute, my father acquired students; he then established a school of study—a research group on multiwheel drive vehicles and driveline systems. His school investigated power distribution among the wheels connected with different types of driveline systems, and developed techniques of calculating the torque bias of self-locking differentials of different types. He also investigated the effect of many factors on the properties of locking and self-locking differentials.

The studies performed by father and his students were not restricted to two-axle automobiles and tractors, but concerned themselves with all multiaxle, many-wheel-drive vehicles. The main purpose of my father's school was, and still is, to find methods of optimizing the properties of systems of power distribution among the wheels and, in the final analysis, improving the overall mobility and other operational properties of wheeled vehicles operating under various road and off-road conditions.

As a result of the large volume of work performed at the SKB-1 and at the institute, my father defended his DSc dissertation (the highest degree in the U.S.S.R.) in 1976, and in 1977 he was conferred the rank of professor. For his contributions to the national machine-building industry, he was conferred the honorary title of Deserving Machine Builder of Belarus.

My father devoted all his life to work; more precisely, work was his entire life. He passed away on February 10, 1992, but left behind his scientific works, the automobiles and tractors that he designed, and, most importantly, his students who continue his work.

Dr. Victor A. Lefarov
Minsk, Belarus

Series Preface

Ground-vehicle engineering took shape as an engineering discipline in the twentieth century, and became the foundation for significant advancements and achievements, from personal transportation and agriculture machinery to lunar and planetary exploration. As we step into the twenty-first century faced with global economic challenges, there is a need to develop fundamentally novel vehicle engineering technologies, and effectively train future generations of engineers. The Ground Vehicle Engineering Series will unite high-caliber professionals from the industry and academia to produce top-quality professional/reference books and graduate-level textbooks on the engineering of various types of vehicles, including conventional and autonomous mobile machines, terrain and highway vehicles, and ground vehicles with novel concepts of motion.

The Ground Vehicle Engineering Series concentrates on conceptually new methodologies of vehicle dynamics and operation performance analysis and control, advanced vehicle and system design, experimental research and testing, and manufacturing technologies. Applications include, but are not limited to, heavy-duty multilink and pickup trucks; farm tractors and agriculture machinery; earthmoving machines; passenger cars; human-assist robotic vehicles; planetary rovers; military conventional and unmanned wheeled and track vehicles; and reconnaissance vehicles.

Dr. Vladimir V. Vantsevich
Series Editor

Preface

The dynamics and performance of a vehicle manifest themselves in the interaction of the vehicle with the surroundings and result from its properties such as energy/fuel efficiency, terrain mobility, tractive and velocity properties, vehicle turnability, stability of motion and handling, braking properties, and smoothness of ride. A distinctive feature in the design of vehicles with four or more driving wheels that is of great significance is that many of their properties depend markedly not only on the total power applied to all the driving wheels but also on the distribution of the total power among the wheels. Under given road or terrain conditions, the same vehicle with a constant total power at all the driving wheels, but with different power distributions among the driving axles and the left and right wheels of each axle, will perform differently; that is, the criteria of the above-mentioned vehicle properties will have different quantitative values. In practical engineering terms, this means that due to different power distributions among the driving wheels, a given vehicle will demonstrate variable fuel consumption, terrain mobility, and traction, and will accelerate differently and turn at different radii. Depending on the wheel power split, the vehicle can "unexpectedly" run into either understeering or oversteering and can sometimes become unstable, skidding in a lateral direction and eventually rolling over.

The power distribution among the driving wheels is largely determined by the vehicle's driveline system, which is generally defined as a part of the power train, located between the transmission and the driving wheels. A driveline system includes a set of mechanisms and subsystems which have been referred to in this book as power-dividing units (PDUs). Typically, a PDU has one input and two outputs. These units are employed in transfer cases, interaxle reduction gears, and driving axles. For a vehicle with one engine and with a conventional axle-type driveline system layout (which differs from the left–right side layout), the number of PDUs is equal to the number of the driving wheels less one. For example, a vehicle with four driving wheels will have three PDUs and a vehicle with eight driving wheels will have seven PDUs (see Figure 1).

It should be obvious to the reader that the number of combinations of mechanisms and subsystems that can be employed even in three PDUs of a vehicle with two driving axles is virtually limitless. In fact, a list of such mechanisms and subsystems may be compiled of open differentials and positively locked units, limited slip differentials with all kinds of torque biases, mechanically and electronically locked differentials, viscous couplings, NoSPINs, and also most current developments that are commonly referred to as torque-vectoring or torque-management systems.

This gives rise to two fundamental engineering problems: First, how to investigate the effect of different driveline systems on the properties of vehicles, their dynamics, and performance? Second, how to determine the optimal characteristics of the driveline system and its PDUs and then design them for a specific vehicle in a manner that would ensure a high level of dynamics and performance, mobility and fuel efficiency, traction and acceleration, and stability of motion and turnability?

Probably the first study of the effect of a driveline system on vehicle motion was the research paper of Prof. Nikolay E. Zhukovskiy, titled "The theory of the instrument of engineer Romeyko-Gurko," published in 1903. The developments in the theory, design, and manufacture of vehicles with four or more driving wheels—all-wheel drive and multiwheel drive vehicles (see Section 1.2)—were to a large extent facilitated by

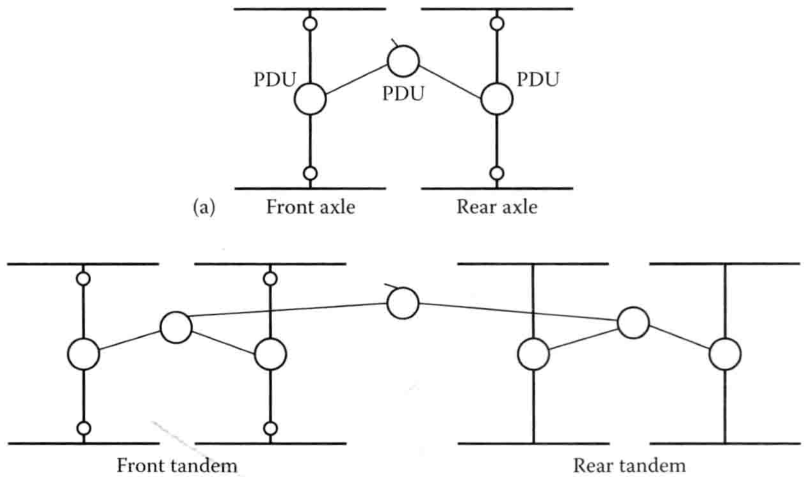


FIGURE 1
Driveline system layouts of (a) 4 × 4 and (b) 8 × 8 vehicles.

experience gathered during World War II: The shortage of arterial and high-type roads and the poor terrain mobility of vehicles determined how military applications progressed for many postwar years. After World War II, with the development of hard-surface roads, multiwheel drive vehicle layouts were actively designed and employed in the agriculture sector, and in construction, forestry, and the petroleum industry. At a later stage when space research and space flights began, planet rovers were also designed with all the wheels driven by torque. From the 1980s onward, passenger cars and sport-utility vehicles with four driving wheels became very popular. The twentieth century thus saw the emergence of multiwheel-drive vehicles of all types. In conjunction with this, the names of many engineers, researchers, and professors, who developed the theory of motion of vehicles and the practice of driveline system design, should be mentioned here. This is a very difficult task and I fully realize that I could fail to mention many of them. However, the following persons deserve special mention: Yakov S. Ageykin, Alexander S. Antonov, Dmitriy A. Antonov, Pavel V. Aksenov, Mieczyslaw G. Bekker, Nikolay F. Bocharov, G. Broulhiet, Colin Chapman, Evgeniy A. Chudakov, Keith Duckworth, J. R. Ellis, Yaroslav E. Farobin, Thomas G. Gillespie, Wunibald Kamm, Frederick W. Lanchester, Andrey S. Litvinov, William F. Milliken and Douglas L. Milliken, M. Mitschke, Tatsuro Muro, Maurice Olley, Hans B. Pacejka, Vladimir A. Petrushov, Yuliy V. Pirkovskiy, Vladimir F. Platonov, A.R. Reece, Robin Sharp, Anatoliy T. Skoybeda, Gleb A. Smirnov, Sergei B. Shukhman, Jaroslav J. Taborek, Igor S. Tsitovich, Jo Y. Wong, and Georgiy V. Zimelev.

Engineering designers and their design developments are now part of history; notable engineers among them include N.A. Astrov, Marius Berliet, William Besserdich, Carl Borgward, Henry Bussing, Carlo Cavalli, John W. Christie, V.E. Chvyalev, Wesley M. Dick, G.A. Fest, V.A. Grachev, Nikolay I. Korotonoshko, A.M. Kriger, I.P. Ksenevich, Nils Magnus, Alfred Masury, A.A. Lipgart, Ralf Nash, Ferdinand Porsche, Wilfredo Ricart, Delmar B. Roos, B.L. Shaposhnik, and M.S. Vysotskij. Vitali A. Grachev, chief design engineer, who has designed many forms of multiwheel drive vehicles, became legendary in the former U.S.S.R. among experts who designed military vehicles. Boris L. Shaposhnik established the Special Design Office, known by its Russian-language acronym, SKB-1, in Minsk, Belarus, where new-generation vehicles, such as multiwheel drive missile carriers, were designed. Vladimir E. Chvyalev followed in the footsteps of B.L. Shaposhnik. He headed the design department of the Minsk Wheeled Tractors Company that grew out of SKB-1. Dr. Mikhail S. Vysotskij, academician at the National Academy of Sciences of Belarus and chief design engineer of automotive vehicles in Belarus led the design of heavy-duty vehicular trains. Even now, in spite of advancing years, he directs a scientific research institute of the National Academy of Sciences.

Another eminent individual in the field, Professor Anatoliy Kh. Lefarov, a design engineer, subsequently became a professor of Belarusian National Technical University (the current name), Minsk, Belarus; Dr. Lefarov was the deputy of chief design engineer, V.A. Grachev, and the first deputy of chief design engineer, B.L. Shaposhnik. During the 1960s, Dr. Lefarov established a research group in the field of multiwheel drive vehicles that designed various driveline systems and PDUs and performed analytic and experimental studies on the effect of driveline systems on the properties of vehicles.

We have been associated with Dr. Lefarov's research group for our entire professional lives. Dr. Kabanau was his first postgraduate student and then became the principal design engineer, who has to his credit designed many mechanisms and systems. Dr. Andreev is concerned with simulating the motion of vehicles and designing PDUs. Seventeen professionally fortunate years, which have rapidly slipped away, with our leader united me not only in a common endeavor but also in a binding friendship. Dr. Lefarov has shaped me not only as an expert but also as a human being. It so happened that after he passed away in 1992, I became the leader of our group.

The culmination of all of this has led to this book. This book comprehensively covers the subject matter from a historic overview, classification, and the nature of driveline influence on vehicle dynamics and performance (Chapter 1), through analytical fundamentals (Chapters 2 through 5) and optimization and control of wheel power distributions (Chapters 6 and 7), to mechanical and mechatronic design of advanced systems (Chapters 2 through 7) and experimental research and tests (Chapter 8). Also, I believe the readers will thoroughly enjoy the illustrations, hand-drawn by Dr. Kabanau.

In many ways, this book is unique; it is probably the only book that deals with the solution of the two fundamental engineering problems that were formulated earlier in the preface. Therefore, the reader can see that the book presents an analytical treatment of driveline systems research, design, and tests based on vehicle dynamics and performance requirements. Methodologically, this is described in two ways. First, the book introduces analytical tools for studying the driveline effects on power distribution among the driving wheels and then on the dynamics and performance of vehicles. Engineering applications of these tools, for instance, include the comparative analysis of several driveline systems with the purpose of selecting a driveline system that provides a given vehicle with better performance and also to evaluate same-class vehicles with different driveline systems. Additionally, the developed techniques adequately supplement the mathematical modeling of vehicle dynamics. Chapters 1 through 5 and Chapter 7 present the necessary material for such mathematical modeling of driveline systems that can be compiled of different types of PDUs. All analytical techniques were built based on the so-called generalized vehicle parameters, which integrate characteristics of PDUs with tire (or combined tire/soil) characteristics and, implicitly, suspension characteristics.

Second, the book develops methodologies for the synthesis of optimal characteristics of PDUs that can be applied to different types of vehicles. Thus, a researcher would not need to run a comparative analysis of hundreds of potential driveline systems to try to find a better one for the vehicle under design. Instead, optimal characteristics can be directly achieved and then optimal PDUs can be designed. Respective analytical techniques were based on the principles of driveline system designs that were developed on the inverse vehicle dynamics approach and first introduced in this book. To learn more about the inverse vehicle dynamics approach and the optimization of power distribution among the driving wheels, the reader should start with Sections 1.5 and 1.6, then go through Sections 2.9 and 3.6, and finally to Chapters 6 and 7. The mechanical design of PDUs and control development issues are covered in Chapters 2 through 5, and also in Chapter 7.

The book is also unique in the sense that it was written virtually entirely on the basis of the results of investigations by its authors. All analytical tools, and computational, design, and test methods were verified through many engineering projects; some of the projects are presented in this book as illustrative examples to prove the applicability of the developed theories. The material in this book will provide the reader with answers to intriguing engineering problems such as achieving higher energy/fuel efficiency of a vehicle by driving either all the wheels or not all the wheels, obtaining oversteering characteristics by increasing the torque at the front-steered wheels, and many other such technical problems. Engineering workers will find interesting methods of design and experimental studies of new driveline systems that provide for optimal/specified vehicle properties. The presented methodologies and results on the optimization of wheel power distributions among the driving wheels can also be of interest to engineers working on vehicles with individual wheel drives and vehicles with hybrid driveline systems.

The reader will find only some of the references in the text to the detailed bibliography at the end of the book. The bibliography reflects that, to a large degree, the history of investigations in driveline system engineering and vehicle dynamics during the twentieth century and the start of the twenty-first century was compiled by studying a large number of publications and it should be regarded as a source of additional engineering data; after all, the experience of each expert is unique. We have conscientiously investigated publications on the theory of motion of all-wheel-drive vehicles and on driveline system design for many years and, if we missed some important investigations and did not include them in the bibliography, we apologize to the authors. We have also included some of our own publications in the bibliography that reflect not only the results of investigations but also, by representing a sequence, give an idea about the development of our scientific and engineering approaches to, and methods of, solutions for engineering problems.

The volume of the scientific and engineering information and the structure of its arrangement within the book are such that it could be used both by beginning design and test engineers as well as engineers with experience in the design and experimental studies of various PDUs, driveline systems, and multiwheel drive ground vehicles as a whole. The book will also be useful to research engineers involved in simulating motion and in testing multiwheel drive vehicles, because it illuminates many aspects of the mathematical simulation of the different driveline systems and dynamics of such vehicles, something that is usually not examined in classical textbooks on vehicle dynamics. The simulation of vehicle dynamics on the basis of the inverse dynamics approach is also a topic that is examined in this book for the first time. This method is also used for working out algorithms for the control of mechatronic driveline systems.

For many years, we developed and delivered university-level courses on the theory of vehicle motion and on the design of driveline systems. This book was written with reference to these courses and can therefore also be used as a textbook on advanced vehicle dynamics and on the design of driveline systems in master of science and PhD courses. Thereby, all the mathematical formulae in the book have been derived together with the necessary detailed explanations, something that makes the material easily comprehensible and convenient both for the student and the lecturer. The analytical results are illustrated by quantitative examples (illustrative problems) and examples of developing driveline systems and PDUs. Using our experience, we devised engineering problems associated with the dynamics of vehicular motion, design, and testing of driveline systems. These problems developed for each chapter can be used in the course of studies as examination problems or homework assignments, and also by practicing engineers for better familiarization with the material in the book and for illustrating its underlying theoretical principles.

Dr. Vladimir V. Vantsevich
Southfield, Michigan

Acknowledgments

We regard it as a pleasure to express our appreciation to our colleagues whom we invited to participate and write sections of the book. More than 30 years of friendship and mutual work link me with Dr. Sergei I. Strigunov and Dr. Vladimir S. Voiteshonok. We studied together in the university and then worked with Dr. Lefarov. Dr. Strigunov presented the results of his studies and participated in writing Sections 3.1, 3.2, 3.3.1, 3.4, and 8.5. Dr. Voiteshonok contributed the results of his studies and participated in writing Sections 2.5.1, 3.6, and 8.5.

In the course of writing this book, we had the pleasure of continuing cooperation with my first PhD student and currently chief design engineer, Front Driving Axles and Wheel Systems at P/A Minsk Tractor Works, Belarus—Dr. Valeriy Yermalionak. Dr. Yermalionak participated in writing Sections 2.5.1, 2.6.1, and 2.7. He also supplied some material for Sections 1.2 and 4.4.

Dr. Siarhei V. Kharytonchyk, also my PhD student and currently the head of the computer center at the Joint Institute of Mechanical Engineering, National Academy of Sciences of Belarus, participated in the investigations that are jointly described in Section 7.6. Together with another PhD student, Dr. Gennady Valyuzhenich, we tested the differential lubrication systems, which we have described in Section 8.3.

I collaborated with Dr. Arkadij D. Zakrevskij, corresponding member of the National Academy of Sciences of Belarus, who works in the field of parallel logical control algorithms. Some of the results of his studies and their application to the design of mechatronic systems have been included in Section 7.6.2, which was jointly written.

It has been almost 15 years since I first collaborated with Dr. Gemunu S. Happawana, professor at California State University at Fresno, Fresno, California. Dr. Happawana participated in writing Sections 2.1, 6.5, and 7.6.1.

For many years, I was lucky to enjoy the friendship and professional collaboration of Dr. Yuliy V. Pirkovskiy, and, after his passing, of his successor Dr. Sergei B. Shukhman. I am glad that the book includes Sections 7.7.1 and 7.7.2, written by Dr. Shukhman and his colleague Dr. Evgenij I. Prochko.

We would like to express our gratitude to the heads of Lawrence Technological University, Southfield, Michigan—President Dr. Lewis N. Walker, Provost Dr. Maria J. Vaz, and Associate Provost Dr. Steven K. Howell—for their financial support for the translation of the manuscript.

This book was written during a transitional period of my life, when I was taking up work at Lawrence Technological University.

I wish to express my heartfelt gratitude for professional collaboration and friendship, technical and personal advice, and fruitful discussions to Dr. William Begell, Professor Eugene I. Rivin, Dr. Joseph and Mrs. Sally Wolf, Dr. Moisey and Mrs. Vera Shkolnikov, Dr. Lev Gileles and Dr. Otto Zaslavskiy, Dr. Simon and Mrs. Larisa Itskovich, Dr. Guennadi Koulechov and Svetlana Skalskaya, Robert Edmonson, Mr. John and Mrs. Carol Erickson, Mr. James and Mrs. Sandra Fisher, Mr. Patric and Mrs. Maryann Hermes, Joanne Kowalenok, Mr. Ephim and Mrs. Anna Schmidt, Mr. Volodymyr and Mrs. Lyubov Shesiuk, Dr. Jan and Mrs. Nadzia Zaprudnik, Dr. Vitaut Kipiel, Mr. Allen M. Krass, and many colleagues and friends in academia and industry, and my church.

We would like to express our gratitude to Dr. Mircea Gradu, Chrysler LLC; Celso Fratta, Eaton Corp.; Dr. Sankar Mohan, Magna Powertrain; and Dr. Alexandre F. Opeiko, Chrysler LLC, for their professional and constructive comments and suggestions.

The publication of this book owes a great deal to the painstaking labor of Dov Lederman, BME, interpreter, to whom we express our gratitude and appreciation.

The time spent in writing the book was irreversibly taken away from family time. We are immeasurably grateful to our spouses and children for their understanding of the importance of our contribution to the profession, and for their unwavering love and support.

When I was still a student, I once asked Dr. Lefarov why he had not written his autobiography. His reply was surprising and it took me years to understand and accept it. He said that his life as a person is not of much interest—after all it is very similar to the lives of millions of people in the country where we live. Dr. Lefarov added that it would be much more interesting to read our engineering books, which reflect not only the progress made in the field of engineering, but also, frequently, give insight about the lives of the authors at a professional, social, and sometimes even personal level. He did not leave any remarks concerning his life. These were written for this book by his son, Dr. Victor A. Lefarov.

As for engineering books, our new book is now held by the readers. The authors hope that this book will be useful. As Dr. Lefarov once said, the engineer must remember that any redundant line on the blueprint of an design may require an additional machine tool and maybe even an entire automatic production line. If the publication of this book reduces the number of "redundant lines," that is, mistakes, and results in the appearance of more advanced driveline systems and causes more young engineering experts to become professionally associated with multiwheel drive vehicle engineering, the authors will have the satisfaction of having achieved their goal. Any remarks and comments will be gratefully received.

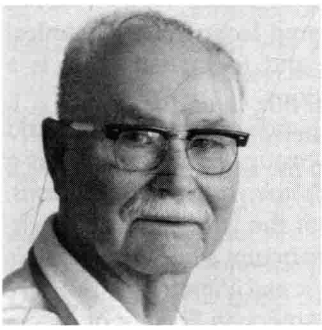
Dr. Vladimir V. Vantsevich
Southfield, Michigan

Authors

Alexandr F. Andreev has been an associate professor in tractor engineering at the College of Automobile and Tractor Engineering, Belarusian National Technical University, since 1975. He received his PhD in automobile and tractor engineering in 1972. Dr. Andreev has also worked as a leading researcher in vehicle dynamics and vehicle performance analysis of the Research and Design Group on Multi-Wheel Drive Vehicles since the founding of the group in 1963. His research concentrates on motion modeling, design, and computation of ground transport and tractive vehicles, and vehicle systems. Dr. Andreev served as the principal investigator to 11 research programs and projects, and contributed to 57 more projects with his innovative analytical models of vehicles in motion, driveline systems, and tire–ground interaction models. His designs of limited slip differentials have been employed in 4×4 farm tractors and multiwheel drive terrain trucks.

Dr. Andreev has written 19 internal research reports, and has published 4 technical books and graduate level texts on vehicle driveline system design and computation, hydraulic and pneumatic control systems, and hydro-drive design and engineering. He has authorized 22 research papers published in journals and conference proceedings, and has received 8 certified inventions.

Professor Andreev developed standards and curricula for MSc programs in tractor engineering, mobile track and wheeled vehicle engineering, and urban electric vehicle engineering. He served at the Higher Education Publishing House of Belarus for 15 years, and as the executive editor of two major research journals in Belarus: *Automobile and Tractor Engineering* and *Design, Computation and Operation of Automobiles and Tractors*.



Dr. Viachaslau I. Kabanau has been an associate professor at the College of Automobile and Tractor Engineering, Belarusian National Technical University, ever since he received his PhD in automobile and tractor engineering in 1966. He also served as the associate dean of the college for 10 years. Dr. Kabanau has worked as a leading researcher and the principal design engineer of the Research and Design Group on Multiwheel Drive Vehicles since the founding of the group in 1963. His research and design work focuses on vehicle driveline systems and mechanism design, and vehicle experimental research. Dr. Kabanau participated in and contributed with his original designs of transfer cases, differentials with lubrication systems, locking and free-running differentials to more than 20 R&D programs and projects on terrain and highway truck and farm tractor engineering. Dr. Kabanau has authorized 6 technical books, graduate level texts, and brochures; he has published 40 reviewed papers in research journals and conference proceedings, and has received 11 certified inventions. He has also delivered a number of presentations and invited lectures to industry and universities.

Professor Kabanau actively developed innovative academic programs and courses in tractor engineering. His lecture courses on hydro dynamic drive engineering, vehicle experimental research and tests, vehicle art design, and ergonomics have been of immeasurable service to the College of Automobile and Tractor Engineering and also established him as an outstanding teacher and student project advisor.

Vladimir V. Vantsevich is a professor in mechanical engineering and the founding director of the MSc in Mechatronic Systems Engineering Program and the Laboratory of Mechatronic Systems at Lawrence Technological University, Michigan. He is also a cofounder and associate director of the Automotive Engineering Institute. Before joining Lawrence Tech, Dr. Vantsevich was a professor and the head of the Research and Design Group on Multiwheel Drive Vehicles that designed and developed a number of mechatronic and mechanical driveline systems for multipurpose vehicles in Belarus. He received his PhD and DSc (the highest degree in the former U.S.S.R.) in automobile and tractor engineering from the Belarusian National Technical University approved by the Higher Awarding Committee of the Russian Federation.

Professor Vantsevich's research area is inverse and direct dynamics of mechanical and mechatronic systems, and system modeling, design, and control. Applications include conventional and autonomous, multiwheel ground vehicles, and vehicle locomotion and driveline systems. He developed a novel research avenue—*inverse ground vehicle dynamics*—which is the basis of his optimization of power distribution among the driving wheels and control of vehicle performance including vehicle mobility, energy/fuel consumption, traction and acceleration performance, and stability of motion.

He is the author of 5 technical books and more than 100 research papers on inverse dynamics, vehicle performance and energy efficiency optimization and control, and design of driveline and autonomous wheel power management systems. Professor Vantsevich has participated in more than 110 science seminars, and has delivered lectures and technical presentations at academic institutions, professional societies, and to industry. He is a registered inventor of the U.S.S.R. and holds 30 certified inventions.

Professor Vantsevich is the founder and editor of a series of handbooks, textbooks, and references on ground vehicle engineering at Taylor & Francis Group/CRC Press. He is a member of the editorial boards of the *International Journal of Vehicle Autonomous Systems*, the *Journal of Multi-Body Dynamics* (Part K of the Proceedings of the Institution of Mechanical Engineers), and the *International Journal of Advanced Mechatronics and Robotics*. He is also an associate editor of the *International Journal of Vehicle Noise and Vibration*.

Professor Vantsevich was honored with a fellowship of the American Society of Mechanical Engineers and of the Belarusan Institute of Arts and Sciences, New Jersey. He is a member of the Association of Vehicle Autonomous Systems International, the Society of Automotive Engineers, the International Society for Terrain-Vehicle Systems, and the International Association for Vehicle System Dynamics.