Brake Design and Safety

Third Edition

Rudolf Limpert



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Third Edition

By Rudolf Limpert

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Dedication

To Dr. Hans Strien,
at Alfred Teves, Co. in Frankfurt, Germany,
who took into his brake department a young engineering trainee.
16. April 1963.

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Preface to the Third Edition



While writing the third edition, I have carefully considered the comments received from readers all over the world. One engineer remarked that whenever he has new trainees in his brake department, they must read Limpert's brake book. Following that mandate I have added explanations and examples to the theoretical analysis of braking and brake temperature while retaining the practical aspects of brake system design.

Electronic system controls have significantly increased the potential of braking systems. Notwithstanding the advances made in applying brakes by mechanical, hydraulic, or electrical means, vehicles are slowed and stopped by friction between pad and rotor. Only when the underlying brake system is properly engineered will automatic controls perform effectively and vehicles brake safely under all foreseeable operating conditions.

The third edition provides the fundamental tools necessary to design efficient braking systems that will comply with safety standards, minimize consumer complaints, and perform safely and efficiently long before and while electronic brake controls become active. New to the readers is the brake design software, developed by the author as an effective companion tool to this edition. The efficient design of automotive brake systems, including trucks and trailers, with PC-BRAKE software is demonstrated with detailed examples. Automotive engineering students, brake engineers, and forensic experts will benefit greatly from the third edition in conjunction with the computer programs and brake design workshop available from the author's website www.pcbrakeinc.com.

Rudy Limpert

Preface to the Second Edition



The Second Edition continues to provide a systems approach to designing safer brakes. Consulting experts will find it a single reference in determining the involvement of brakes in accident causation.

Brake system technology has attained a high standard of quality over the last two decades. Nearly all automobiles are now equipped with antilock brakes. Federal braking standards require commercial vehicles to use antilock brakes. Revolutionary innovative brake designs are not expected. Improvements in brake systems will only be achieved through basic research, the application of sound engineering concepts, and testing, resulting in small, yet important, design changes.

The objective of the Second Edition is to assist the brake engineer in accomplishing his task to design safer brakes that can be operated and maintained safely. The brake expert will find all the analytical tools to study and determine the potential causes of brake failures. The Second Edition is expanded to cover all essential subjects, including the mechanical and thermal analysis of disk brakes. Mistakes found in the First Edition were corrected.

I thank all those who have made valuable suggestions and comments and helped me to understand brakes better, in particular the many individuals who attended my Brake Design and Safety seminars.

Preface to the First Edition



The purpose of this book is to provide a systems approach to designing safer brakes. Much of the material presented was developed during my work as a brake design engineer, conducting automotive research, consulting as a brake expert, and teaching brake design.

The book is written for automotive engineers, technical consultants, accident reconstruction experts, and lawyers involved with the design of brake systems, the analysis of braking performance, and product liability issues. Junior engineers will benefit from the book by finding in one single source all essential concepts, guidelines, and design checks required for designing safer brakes.

Chapter 1 reviews basic stopping distance performance, design rules, and product liability factors.

In Chapter 2, drum and disc brakes are discussed. Brake torque computations are shown for different drum and disc brake designs.

Temperature and thermal stresses are analyzed in Chapter 3. Practical temperature equations are shown whenever possible.

Chapter 4 briefly reviews basic concepts involved in analyzing mechanical brake systems.

The operation and design of hydraulic brakes are discussed in Chapter 5.

Air brake systems and their components are discussed and analyzed in Chapter 6.

Brake force distribution, braking efficiency, optimum brake force distribution, and vehicle stability during braking for the single vehicle are analyzed in Chapter 7.

Car-trailer and commercial truck-trailer braking is discussed in Chapter 8.

Important elements of antilock braking performance and design are introduced in Chapter 9.

Brake failures are discussed in Chapter 10.

Chapter 1



Fundamentals of Braking Performance, Design, and Safety

1.1 The Functions of a Brake System

A vehicle is connected to the roadway by the normal and traction forces produced by the tires. Braking, steering, or accelerating forces must be generated by the small tire tread area contacting the ground. Only forces equal to or less than the product of tire normal force and tire-road coefficient of friction can be transmitted between vehicle and ground. Even the ideal braking and stability control system cannot utilize more traction than provided by the tires and road.

The safe operation of a motor vehicle requires continuous adjustment of its speed to changing traffic conditions. The brakes and tires along with the steering system are the most safety-critical accident avoidance components of a motor vehicle. Brakes must perform safely under all reasonably foreseeable operating conditions, including slippery, wet, and dry roads; with a lightly or fully laden vehicle; when braking straight or while turning; with new or worn brakes; when applied by the novice or experienced driver; on smooth or rough roads; or when pulling a trailer.

The basic functions of a brake system must be provided under foreseeable circumstances, at reasonable cost and brake wear life, while providing directional stability and acceptable tire-road friction utilization.

The braking system must comply will all applicable safety standards. Under most conditions, safety standards are considered minimum performance requirements.

1.1.1 Slowing and/or Stopping

Decelerating a vehicle to a lower speed or to a complete stop is the function most often performed by the service brakes of a vehicle. Safety standards and industry practices place stringent requirements on effectiveness of stops including repeated braking under a variety of operating conditions. Critical design parameters include proper brake balance front-to-rear to ensure directional stability while braking at, or near, the limit of tire-road friction,