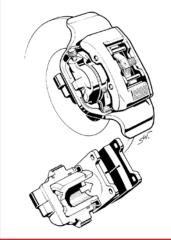
Brake Technology Handbook First English Edition



List of Chapters:

Symbols, Indices, and Acronyms 1 The History of Automobile Brakes

- 1.1 Mechanically Operated Vehicle Brakes
- 1.2 The Hydraulically Operated Four-Wheel Brake
- 1.3 Brakes with Internal Amplification
- 1.4 Multi-Circuit Braking Systems
- 1.5 From Muscle Power to Full Power Brakes
- 1.6 The Hydraulically Operated Disc Brake
- 1.7 Electronic Brake Control Systems

2 Basic Elements of the Braking Process

- 2.1 Braking as Driving Task
- 2.2 Characteristics of the Braking Process
- 2.3 Stopping Distance
- 2.4 Braking Stability and Braking Force Distribution
- 2.5 Reliability

3 Automotive Engineering Requirements

- 3.1 Performance
 - 3.1.1 Braking Distance
 - 3.1.2 Stability
 - 3.1.3 Road Irregularities
 - 3.1.4 Dependence on Friction Value
- 3.2 Vehicle Performance
 - 3.2.1 Stability
 - 3.2.2 Body Pitch
- 3.3 Actuation/Control
 - 3.3.1 Responsiveness and Controllability
 - 3.3.2 Forces, Travels, Characteristics
- 3.4 Package/Installation Situation
 - 3.4.1 Installation Sizes and Relations
 - 3.4.2 Masses
- 3.5 Brake Boost Energy Supply
- 3.6 Thermal Marginal Conditions
- 3.7 Environmental Conditions
- 3.8 Noises and Vibrations
 - 3.8.1 Vibrations
 - 3.8.2 Noises
- 3.9 Crash Requirements
- 3.10 Environmental Protection

- 3.10.1 Brake Linings
- 3.10.2 Corrosion Protection
- 3.10.3 Brake Fluid
- 3.11 Energy Recuperation

4 User-Related Requirements

- 4.1 Introduction
- 4.2 Braking Situation
 - 4.2.1 Information Reception
 - 4.2.2 Cognition (Information Processing in the Narrower Sense)
 - 4.2.3 Reaction
 - 4.2.4 Time Sequence of Information
 Processing in Braking Situations
- 4.3 Braking Action
 - 4.3.1 Foot Movement
 - 4.3.2 Actuation of Brake Pedal
- 4.4 Ergonomic Brake Design
 - 4.4.1 Geometry
 - 4.4.2 Key Features of Brake Pedal
 - 4.4.3 Alternative Concepts
 - 4.4.4 Braking Assistants

5 Interaction Among the Road Surface, Tire, and Brake

- 5.1 Introduction
- 5.2 Transmission of Forces Between the Tire and the Road Surface
 - 5.2.1 The Friction of Rubber
 - 5.2.2 Interaction Between the Tire and the Road Surface
 - 5.2.3 Buildup of Tire Forces
 - 5.2.3.1 Braking Forces/Tangential Forces
 - 5.2.3.2 Side Slip: Forces and Moments
- 5.3 Interaction Between Tire and Brake
 - 5.3.1 Tire Models
 - 5.3.2 Dynamic Tangential Force/Slip Characteristics of a Tire During Braking
 - 5.3.3 Tangential Forces During Braking with ABS

First English Edition



- 5.3.4 Combined Tangential and Lateral Forces, Braking When Lateral Force Is Required
- 5.4 Integration of the Tire into the Overall Vehicle System
 - 5.4.1 Product Optimization of the Tire and the ABS Controller Using the Example of Winter Tires
 - 5.4.2 The Role of Skid Marks in Accident Reconstruction
- 5.5 Outlook

6 Design and Simulation of Automobile Brake Systems

- 6.1 Principles of the Brake Dynamics
 - 6.1.1 Lines of Equal Deceleration
 - 6.1.2 Lines of Constant Coefficient of Friction Between the Tire and the Road Surface
- 6.2 Principles of the Brake Calculation
 - 6.2.1 Pedal Unit
 - 6.2.2 Vacuum Booster with Master Cylinder
 - 6.2.3 Brake
 - 6.2.3.1 Disc Brake
 - 6.2.3.2 Drum Brake
- 6.3 Brake System Design
 - 6.3.1 Brake-Split Configuration
 - 6.3.1.1 Front Axle/Rear Axle
 Configuration (II-Configuration)
 - 6.3.1.2 Diagonal Configuration (X-Configuration)
 - 6.3.1.3 Other Brake-Circuit Configurations (HI-, LL-, HH-Configuration)
 - 6.3.2 Sizing Criteria for Brake Systems
 - 6.3.2.1 Requirements of the Brake Dynamics
 - 6.3.2.2 Requirements of the Actuation Unit and the Transmission Mechanism
 - 6.3.2.3 Thermal Sizing Criteria
 - 6.3.3 Design of Wheel Brakes
 - 6.3.3.1 Brake Power
 - 6.3.3.2 Thermal Design
 - 6.3.3.3 Component Life/Wear
 - 6.3.3.4 Comfort
 - 6.3.3.5 Costs
 - 6.3.3.6 Weight
 - 6.3.4 Design of Brake Control Systems
 - 6.3.4.1 Design Criteria for ABS Systems
 - 6.3.4.2 Design Criteria for the Traction Control System

- 6.3.4.3 Design Criteria for the Electronic Stability Control
- 6.3.5 Design Criteria for Electrohydraulic Brake Systems
- 6.4 Simulation of Brake Systems
 - 6.4.1 Brake System Design
 - 6.4.2 Analysis of the Brake System Components Using the Finite Elements Method
 - 6.4.3 Simulation of Brake-System Components
 - 6.4.4 Overall System Simulation

7 Construction and Components of Passenger Car Braking Systems

- 7.1 Introduction
 - 7.1.1 The Underlying Physics
 - 7.1.2 Braking System Types
 - 7.1.3 Construction of Braking Systems in Passenger Cars
 - 7.1.3.1 Front-Rear Split
 - 7.1.3.2 Diagonal Split ("X Split")
 - 7.1.3.3 Other Hydraulic Brake Circuit Splits
- 7.2 Generation of the Braking Force
 - 7.2.1 Disc Brakes
 - 7.2.1.1 Fixed Calipers
 - 7.2.1.2 Frame Calipers
 - 7.2.1.3 Fist Caliper
 - 7.2.1.4 FN Fist Caliper
 - 7.2.1.5 FNR Fist Frame Caliper
 - 7.2.1.6 Combined Fist Caliper
 - 7.2.1.7 Brake Discs
 - 7.2.1.8 Brake Linings
 - 7.2.2 Drum Brakes
 - 7.2.2.1 Simplex Drum Brake
 - 7.2.2.2 Duplex Drum Brake
 - 7.2.2.3 Duo-Servo Drum Brake
 - 7.2.3 Electric Generator
 - 7.2.3.1 Crankshaft Starter Alternator
- 7.3 Transfer and Modulation of Braking Energy
 - 7.3.1 Mechanical-Hydraulic Modulation of Brake Pressure
 - 7.3.2 Electrohydraulic Brake Pressure Modulation
 - 7.3.2.1 Hydraulic-Electronic Control Unit (HCU)
 - 7.3.2.2 Electronic Control Unit (ECU)
 - 7.3.2.3 Electronic Control Functions

First English Edition



- 7.3.2.4 Sensors for Electronic Brake Control Systems
- 7.3.3 Transmission Elements
 - 7.3.3.1 Brake Fluid
 - 7.3.3.2 Brake Tubes and Hoses
- 7.4 Brake Actuation
 - 7.4.1 Brake Booster
 - 7.4.1.1 Vacuum Brake Boosters
 - 7.4.1.2 Hydraulic Brake Boosters
 - 7.4.2 Tandem Master Cylinder
 - 7.4.2.1 Compensating Bore TMc
 - 7.4.2.2 Central Valve TMc
 - 7.4.2.3 Plunger TMc
 - 7.4.2.4 Reservoir
- 7.5 Human-Machine Interface (HMI)
 - 7.5.1 Service Brake HMI
 - 7.5.2 Parking Brake HMI
 - 7.5.3 Pedal Characteristics (Ergonomics)
 - 7.5.3.1 Adjustable Pedals
 - 7.5.3.2 Crash Compatibility
- 7.6 New and Future System Architectures
 - 7.6.1 Electric Hydraulic Combi Brake EHC

8 Braking Systems and Braking Performance of Commercial Vehicles and Buses

- 8.1 Evaluation of a Braking System
 - 8.1.1 Vehicle StabilityWhen Braking
 - 8.1.2 Distribution of the Braking Forces to the Axles
 - 8.1.3 Brake Application in the Braking Force Distribution Diagram
 - 8.1.4 Load-Sensitive Braking Force Distribution (ALB)
 - 8.1.4.1 Braking Force Limiters
 - 8.1.4.2 Braking Force Reducers
 - 8.1.5 Influence of Engine Drag Torques, Inertia Masses and Braking Torques of Continuous Braking Systems
 - 8.1.6 Determination of Brake Factor
 Fluctuations and Their Influence on
 the Braking Force Distribution
 - 8.1.7 Brake Circuits and Brake Circuit Failure
- 8.2 Braking Systems for Medium and Heavy Commercial Vehicles
 - 8.2.1 Structure of a Braking System
 - 8.2.2 Wheel Brakes and Components
- 8.3 Continuous Braking Systems
 - 8.3.1 Engine Braking Systems
 - 8.3.2 Retarders

- 8.4 Conventional Braking- and Driving-Slip Control Systems
 - 8.4.1 Antilock Braking Systems (ABS)
 - 8.4.2 Traction Control
- 8.5 Electronic Braking Management (EBS)
 - 8.5.1 Integration of Continuous Braking Systems
 - 8.5.2 Vehicle Stability Control with Integrated Roll-Over Protection
 - 8.5.3 Optimization of the Compatibility Between Tractor Vehicle and Semitrailer/Full Trailer
 - 8.5.4 Braking Assistant
 - 8.5.5 Hill Holder
 - 8.5.6 Lining/PadWear Control
 - 8.5.7 Distance Monitoring
 - 8.5.8 Systems for Automatic Vehicle Guidance
- 8.6 System Integration and Electronic Networking
- 8.7 Concluding View on X-by-Wire Systems

9 Brakes for Commercial Vehicles

- 9.1 Types of Pneumatically Operated CV Brakes
 - 9.1.1 Drum Brakes
 - 9.1.2 Disc Brakes
- 9.2 Design and Operation of the Pneumatically Operated Floating Caliper Disc Brake
 - 9.2.1 Actuating System
 - 9.2.1.1 Service Brake
 - 9.2.1.2 Parking Brake and Secondary Braking System
 - 9.2.2 AutomaticWear-Adjusting System
 - 9.2.3 Adjustment Behavior
 - 9.2.4 Significance of the Clearance
 - 9.2.5 Interaction Brake/Wheel Hub
 - 9.2.5.1 Forces Resulting at the Brake
 - 9.2.5.2 Thermal Load of the Wheel Bearing
- 9.3 Performance and Service Life Behavior
 - 9.3.1 Design Data
 - 9.3.1.1 Durability
 - 9.3.1.2 Long-Term Braking Performance
- 9.4 Friction Elements
 - 9.4.1 Brake Pads
 - 9.4.2 Brake Disc
 - 9.4.2.1 Brake Disc Designs
 - 9.4.2.2 Brake Disc Material

First English Edition



| α, | 12 | 3 | Causes | for I | Haat | Cracks |
|------|-----|-----|--------|-------|-------|--------|
| IJ.' | +.~ | . U | Causes | IUI I | ιıσαι | Olauno |

9.4.2.4 Causes for Brake Vibrations

9.4.2.5 Dimensioning of the Friction Partners

9.4.2.6 The Specific Braking Performance

9.5 Development and Testing of Brake and Friction Partners

9.6 Trailer Brakes

9.6.1 Trailer-Specific Characteristics

9.6.1.1 Wheel Brakes

9.6.1.2 Adjustment

9.6.2 Trailer-Specific Requirements

9.6.2.1 Trailer Homologation

9.6.2.2 Trailer Brake Certificates

9.6.3 Trailer-Specific Brake Systems

9.6.3.1 Brake Calculations for Vehicle Homologation

9.6.3.2 Parking Brake Effect

9.7 Compatibility in Tractor/Trailer Units

9.7.1 Legislation

9.7.2 Matching of Tractor/Trailer Combinations

9.7.3 Causes and Consequences of Inadequate Matching

10 Braking Behavior of Single-Track Vehicles

10.1 Motorcycles

10.1.1 Riding Dynamics of Single-Track Vehicles

10.1.1.1 Stationary Straight-Ahead Motion and Stability

10.1.1.2 Stationary Motion in Bends

10.1.1.3 Balance of Forces and Roll Angle

10.1.2 Braking Behavior of Single-Track Vehicles

10.1.2.1 Fundamental Aspects of Riding Dynamics in the Braking Process

10.1.2.2 Brake Behavior on Slopes

10.1.2.3 Influence of Tire-Road Friction

10.1.2.4 Ideal and Real

Distribution of Brake Forces

10.1.2.5 Influence of Suspension Geometry

10.1.2.6 Braking Dive Compensation

10.1.2.7 Application of the Brakes in a Bend

10.1.3 Typical Riding Errors While Braking

10.1.3.1 Over-Braking

10.1.3.2 ErrorsWhen Braking in an Emergency 10.1.4 Brake Systems of Single-Track Vehicles

10.1.4.1 The Brake Caliper

10.1.4.2 Brake Discs

10.1.4.3 Brake Pads

10.1.5 Configuration of the Brake System

10.1.5.1 Transformation of Lever Force Into Deceleration

10.1.5.2 Thermal Stability

10.1.5.3 Brake Noise

10.1.5.4 Long-Term Behavior of Brake Components

10.1.6 Integral Brake Systems and Brake Control Systems

10.1.6.1 Antilock Systems (ABS)

10.1.6.2 ABS Components

10.1.6.3 The ABS Braking Process

10.1.6.4 Operating Principles

10.1.7 Integral Brake Systems

10.1.7.1 Combined Brake System by Honda

10.1.7.2 Integral Brake System by BMW

10.1.8 Brake-by-Wire

10.2 Bicycles

10.2.1 Introduction

10.2.2 Braking Behavior of Bicycles

10.2.3 Typical Braking Faults

10.2.3.1 Over-Braking of the Front Wheel

10.2.3.2 Locking of the RearWheel

10.2.4 Bicycle Braking Systems

10.2.4.1 Basic Demands for Bicycle Braking Systems

10.2.4.2 Rim Brakes

10.2.4.3 Hub Brakes

10.2.4.4 Disc Brakes

11 Overrun Braking Systems

11.1 Introduction

11.2 Construction and Function of the Braking System

11.2.1 Components

11.2.1.1 Overrun Coupling

11.2.1.2 Transmission System

11.2.1.3 Wheel Brakes

11.2.2 Functions

11.2.2.1 Service Brake, Forward Travel

11.2.2.2 Automatic Reversing System, Reverse Travel

11.2.2.3 Parking Brake

First English Edition



- 11.2.2.4 Breakaway Braking Function
 - 11.3 Braking System Layout
 - 11.3.1 Brake Compatibility Calculation as per Directive 71/320/EEC
 - 11.3.2 Brake Force Utilization
 - 11.3.3 ABS Compatibility
 - 11.4 Maintenance and Care
 - 11.4.1 Maintenance
 - 11.4.2 Readjustment
 - 11.5 New Developments

12 Brakes of Off-Road Vehicles

- 12.1 Historical Development of Brakes in Off-Road Vehicles
- 12.2 Survey of National and International Legal Specifications for Brake Systems
- 12.2.1 Transport Laws in the Federal Republic of Germany
- 12.2.2 Guidelines of the European Community (EC)
- 12.2.3 Regulations of the Economic Commission for Europe
- 12.2.4 Standards of the Society of Automotive Engineers
- 12.3 Technical Versions and Design
 - 12.3.1 Drum Brake
 - 12.3.2 Disc Brake
 - 12.3.3 Multiple-Disc Brake (Wet Brake)
 - 12.3.3.1 Design of a Multiple-Disc Brake
 - 12.3.3.2 Calculation of the Brake Torque
 - 12.3.3.3 Friction Characteristics
 - 12.3.3.4 Power Loss and Efficiency
- 12.4 Brake Testing and Braking Effect
 - 12.4.1 Laboratory Testing
 - 12.4.1.1 Proof of Compliance with Legal Specifications
 - 12.4.1.2 Durability and Wear Testing
 - 12.4.2 Vehicle Testing
 - 12.4.2.1 Cold Performance Test (Type 0)
 - 12.4.2.2 Heat Fading Test
 - 12.4.2.3 Comparison of the Standards
- 12.5 Prospects and Tendencies
 - 12.5.1 Interaction Between Wheel Brake and Other Brake Systems in the Vehicle (Brake Management)
 - 12.5.2 Environmental Protection
 Thanks to New Brake Concepts

13 Brakes for Tracked Vehicles

13.1 Introduction

- 13.2 Special Requirements for Brakes of Tracked Vehicles
- 13.3 Mechanical Brakes for Tracked Vehicles
 - 13.3.1 Mechanical Friction Brakes
 - 13.3.2 MultipleWet Plate Brakes
 - 13.3.3 Dry-Type Single and Multiple-Disc Brakes
 - 13.3.4 Control of Mechanical Brakes
- 13.4 Combination Brake Systems
 - 13.4.1 Combination with a Primary Retarder
 - 13.4.2 Combination with a Hydrodynamic Service Brake
 - 13.4.3 Other Brake Combinations
- 13.5 Approval of Tracked Vehicle Brakes
- 13.6 Summary and Outlook

14 Aircraft Brakes

- 14.1 General Description of an Aircraft Braking System
 - 14.1.1 Hydromechanical Brake Control
 - 14.1.2 Electronic Brake Control (Brake-by-Wire)
 - 14.1.3 Subsystems
 - 14.1.3.1 Anti-Skid System
 - 14.1.3.2 Auto-Braking System
 - 14.1.3.3 Parking Brake System
 - 14.1.3.4 Emergency Braking System
 - 14.1.3.5 Brake Cooling System
 - 14.1.3.6 Indicating and Monitoring System
- 14.2 Design Criteria for Military and Civil Aircraft
 - 14.2.1 Qualification Directions
 - 14.2.1.1 Civil Aviation Requirements
 - 14.2.1.2 Military Aviation Requirements
 - 14.2.2 Simulation Procedures
- 14.3 Layout of a Modern BBWSystem and its Components
 - 14.3.1 Brake Pedal Assembly
 - 14.3.2 Brake Control Unit (BCU)
 - 14.3.3 Valves
 - 14.3.3.1 Brake Control Valves
 - 14.3.3.2 Shutoff Valves
 - 14.3.3.3 Hydraulic Fuses
 - 14.3.4 System Sensors
 - 14.3.4.1 Thermocouples (Optional)
 - 14.3.4.2 Brake Torque Transducer
 - 14.3.4.3 Wheel Speed Sensor
 - 14.3.5 Wheel Brakes

First English Edition



| 4 4 4 | | | |
|-------|----------|-----------|--|
| 7/1/ | Friction | Natoriale | |
| 14.4 | LUCUOII | Materials | |

14.5 Cooling and Temperature Monitoring

14.5.1 Thermal Loads

14.5.2 Cooling Features

14.5.3 Temperature Monitoring

14.6 Future Aspects

15 Race Car Brake Systems

15.1 Introduction

15.2 Race Car Performances

15.3 Racing Car Straight-Line Braking

15.4 Brake System

15.4.1 Brake Caliper

15.4.2 Master Cylinder

15.5 Brake System Cooling

15.6 Friction Materials

15.6.1 Carbon Manufacturing Process

16 Brake Systems of Rail Vehicles

16.1 Introduction

16.2 Requirements on Rail Vehicle Brakes

16.2.1 High-Speed Trains

16.2.2 Locomotives

16.2.3 Passenger Carriages

16.2.4 GoodsWagons

16.2.5 Multiple Units

16.2.6 Metros

16.3 Brake Operation and Safety Requirements

16.3.1 Basic Safety Requirements

16.3.2 Requirements for Signaling

16.3.3 Requirements for Maintenance and Service Life

16.3.4 Requirements for AAR Railways

16.4 Authorization and Regulations

16.4.1 UIC Leaflets

16.4.2 EU Directives and TSI

16.4.3 European Standards

16.4.4 Approval Authorities

16.4.5 Operator-Specific Standards and Guidelines

16.5 Engineering of Rail Vehicle Brakes

16.5.1 Adhesion of Wheel/Rail-Contact

16.5.2 Performance

16.5.3 BrakeWeight

16.6 Brake Systems

16.6.1 Types of Brake Application

16.6.2 Indirect Pneumatic Brake

16.6.2.1 Brake Positions

16.6.2.2 Load-Controlled Braking

16.6.2.3 Direct Pneumatic Brake

16.6.2.4 Dual-Line Brake System

16.6.3 Direct Electropneumatic Brake

16.6.4 Brake Management

16.6.4.1 Retarder

16.6.4.2 ED Brake

16.6.4.3 Interaction of Brake Systems

16.7 Components and Subsystems

16.7.1 Air Supply

16.7.2 Air Stopcocks and Brake Pipe Couplings

16.7.3 Distributor Valves

16.7.4 Driver's Brake Valve

16.7.5 Brake Module

16.7.6 Mechatronic Module

16.7.7 Wheel Slip Prevention

16.7.8 Tread Brakes

16.7.9 Disc Brakes

16.7.10 Parking Brake

16.7.11 Magnetic Track Brake

16.7.12 Eddy Current Brake

16.8 Hydraulic Brake Systems in Trams

16.8.1 Rules and Regulations for Tram Brakes

16.8.2 Vehicle Structure

16.8.3 Brake Systems

16.8.3.1 Magnetic Track Brake

16.8.3.2 Electrodynamic Brake

16.8.3.3 Electrohydraulic Brake

16.8.4 Brake Matrix

16.8.5 Schematic Tram Brake System

16.8.6 Main Components of a Hydraulic Brake System

16.8.6.1 Brake Force Actuator, Brake Disc, Brake Pad

16.8.6.2 Electrohydraulic Supply and Control Units

16.8.6.3 Brake Control Electronics

17 Mechatronic Systems: A Short Introduction

17.1 From Mechanical to Mechatronic Systems

17.2 Mechanical Systems and Mechatronic Developments

17.3 Functions of Mechatronic Systems

17.3.1 Basic Mechanical Design

17.3.2 Distribution of Mechanical and Electronic Functions

17.3.3 Operating Properties

17.3.4 New Functions

17.3.5 Other Developments

17.4 Integration Forms of Processes and Electronics

First English Edition



- 17.5 Design Procedures for Mechatronic Systems
- 17.6 Computer-Aided Design of Mechatronic Systems

18 Basics of Electrically Actuated Braking Systems for Passenger Cars

- 18.1 Introduction
- 18.2 Definition of Brake-by-Wire
- 18.3 Structure of Electrically Actuated Braking Systems
- 18.4 Design of the Actuation Device
 - 18.4.1 Control Element
 - 18.4.2 Basic Attributes
 - 18.4.3 Information Feedback
- 18.5 Electrohydraulic Braking Systems
 - 18.5.1 EHB Systems with Pressure Modulator and Pressure Accumulator
 - 18.5.2 EHB Systems with
 - Electrohydraulic Converter
- 18.6 Electromechanical Braking System
 - 18.6.1 Electrically Actuated Vehicle Brake
 - 18.6.1.1 Components
 - 18.6.1.2 Modes of Operation: Interaction of the Components
 - 18.6.2 Energy Demand
 - 18.6.3 Operation of Electrically ActuatedWheel Brakes
 - 18.6.4 Braking System Design
 - 18.6.5 Failsafe Concept
- 18.7 Mechatronic Interventions in the Self-Reinforcement of the Brake
 - 18.7.1 Active Guidance of the Brake Pad
 - 18.7.2 Active Intervention in the Brake Factor Mechanism
- 18.8 Comparisons of the Concepts
- 18.9 Hybrid Electric Brake Systems
- 18.10 Perspectives

19 Electrohydraulically Actuated Brakes

- 19.1 Conflicts of Goals and Limitations of Conventional Brake Systems
- 19.2 Comparison of Operating Principles of Various Brake Systems
- 19.3 Characteristics of Electrohydraulically Actuated Brake Systems
- 19.4 System and Component Description
 - 19.4.1 Actuator Unit
 - 19.4.2 Hydraulic Unit
 - 19.4.3 Control Units and Sensors
- 19.5 Functional System Characteristics
 - 19.5.1 Pedal Feel

19.5.2 Stopping Distance

20 The Electromechanically Actuated Brake

- 20.1 Objective
- 20.2 System Structure: Interaction of the Components
 - 20.2.1 Actuation Unit
 - 20.2.2 The ElectromechanicalWheel Brake
 - 20.2.2.1 Converter
 - 20.2.2.2 Gearing Systems
 - 20.2.2.3 Sensors
 - 20.2.3 Control Concepts
 - 20.2.4 Power Supply
 - 20.2.5 Passive Safety Aspects
- 20.3 Electric Parking Brake (EPB) and Active Parking Brake (APB)
- 20.4 Electric Hydraulic Combi (EHC) Brake
- 20.5 Utilization of Self-Energizing Brakes
- 20.6 Electronically ActuatedWedge Brake
 - 20.6.1 Summary
 - 20.6.2 History
 - 20.6.3 Principles
 - 20.6.4 Embodiments
 - 20.6.5 Control Theory
 - 20.6.6 Selected Measurement Results
 - 20.6.6.1 General Test Profile
 - 20.6.6.2 Response Dynamics
 - 20.6.6.3 Sinusoidal Excitation
 - 20.6.7 Outlook

21 The Brake System in Driver Assistance Systems

- 21.1 Overview, Function, and Requirements of Driver Assistance Systems for Cars
 - 21.1.1 Antilock Brake System (ABS)
 - 21.1.2 Traction Control System (TCS)
 - 21.1.3 Electronic Stability Control (ESC)
 - 21.1.3.1 Vehicle Dynamics Controller
 - 21.1.3.2 Brake Slip Controller
 - 21.1.3.3 Drive Slip Controller
 - 21.1.4 Electronic Brake Force Distribution (EBV)
 - 21.1.5 Electronically Controlled Deceleration (ECD)
 - 21.1.6 Hill Descent Control (HDC)
 - 21.1.7 Brake Assistant (BA)
 - 21.1.8 Active Trailer Stabilization
- 21.2 Function of the Brake System in Driver Assistance Systems
- 21.3 Requirements of the Brake System for Driver Assistance Systems

First English Edition



- 21.4 Brake System Designs for Driver Assistance Systems
- 21.5 Monitoring the Brake System for Driver Assistance Systems
- 21.6 Outlook and Perspective

22 The Brake in the Mechatronic Chassis

- 22.1 Introduction
- 22.2 Chassis Mechanics
 - 22.2.1 Function Structure and Suspension Interfaces
 - 22.2.2 Interaction Between Brakes and Suspension
- 22.2.3 Representation of Chassis Parameters
- 22.3 Limitations of Passive Chassis Systems
 - 22.3.1 Constraints of Conventional Hydraulically ActuatedWheel Brakes
 - 22.3.2 Dynamics
 - 22.3.3 Braking Comfort
 - 22.3.4 Conflict of Objectives Between Handling and Ride
- 22.4 Solution Potential Using Mechatronics
 - 22.4.1 Opportunities Through Mechatronics
 - 22.4.2 Mechatronics in the Brake System
 - 22.4.3 Mechatronics in the Suspension
 - 22.4.4 Interaction Between Steering System and Brake
 - 22.4.5 Interaction Between Tires and Brakes
- 22.5 Outlook

23 Friction Linings

- 23.1 Introduction
- 23.2 Friction Lining Requirements
- 23.3 Material Concepts
 - 23.3.1 Semimetallic Friction Linings
 - 23.3.2 Low Steel Friction Materials
 - 23.3.3 Non-Asbestos Organic Friction Linings
 - 23.3.4 Nonmetallic Linings
 - 23.3.5 Hybrid Linings
 - 23.3.6 Friction Linings for Ceramic Discs
 - 23.3.7 Underlayer
- 23.4 Ecology
- 23.5 Raw Materials and Their Characteristics in Friction Linings
- 23.6 Test Methods for Raw Materials
 - 23.6.1 Analytical Equipment Test Methods
- 23.7 Manufacturing Procedures
- 23.8 Outlook

24 Function Mechanism and Properties of Friction Couplings in Brake Processes

- 24.1 Introduction
- 24.2 Test Devices, Characteristic Load Values, and Assessment Criteria
 - 24.2.1 Test Methods, Testing Opportunities, and Measurement Systems
 - 24.2.2 Characteristic Parameters of Load
 - 24.2.3 Criteria for Assessment of Friction and Wear Properties
 - 24.2.4 Friction Surface Temperature
- 24.3 Running-In Process
- 24.4 The Function Mechanism in the Contact Surface
- 24.5 Local Friction LiningWear
- 24.6 Local Friction Coefficients
- 24.7 Explanation of the Function Mechanism in the Contact Surface
- 24.8 Parameters that Influence Friction and Wear Properties

25 Mechanical Brakes in Stationary Industrial Plants

- 25.1 Introduction
- 25.2 Industrial Brakes
 - 25.2.1 Preferred Types of Mechanical Brakes
 - 25.2.2 The Interaction of Energy Between Drive Gear and Brake
 - 25.2.3 Friction and Wear Properties of the Friction Couples
 - 25.2.4 Dimensioning of Friction Couples for Industrial Brakes
- 25.3 Friction Disc Brakes

26 Vibration and Noise

- 26.1 Definition
- 26.2 Forms of Vibration and Noise
 - 26.2.1 Low-Frequency Vibrations and Noise
 - 26.2.2 High-Frequency Noises
- 26.3 Sources of Excitation
 - 26.3.1 Causes of Low-Frequency Noises and Vibrations
 - 26.3.2 Causes of High-Frequency Noise
- 26.4 Effects
 - 26.4.1 Vibrations
 - 26.4.2 Acoustic Effects
- 26.5 Test and Evaluation Methods
 - 26.5.1 Simulation
 - 26.5.2 Test Setup Investigations
 - 26.5.3 Road Tests
- 26.6 Measures to Reduce or Avoid Vibrations and Noise
 - 26.6.1 Measures at the Excitation Sources
 - 26.6.2 Measures at the Transfer System

First English Edition



| 26.6.3 Secondary Measures |
|--|
| 26.7 Outlook and Prospects |
| 27 Brakes with Nonmetallic Brake Discs |
| 27.1 Introduction |

27.1.1 History

27.1.2 Carbon Brake Discs

27.2 Material

27.2.1 Definition, Properties, Applications

27.2.2 Manufacture of a Carbon-Ceramic Brake Disc

27.2.2.1 Manufacturing Process

27.2.3 Quality Assurance

27.2.3.1 Tests During Manufacture

27.2.3.2 Random Sample Tests

27.3 Application

27.3.1 Design of Ceramic Brakes

27.3.1.1 Dimensioning of the Brake System

27.3.1.2 Brake Disc Ring

27.3.1.3 Brake Disc Chamber

27.3.1.4 Brake Linings

27.3.2 Influence of Ceramic Brakes on Vehicle Properties

27.3.2.1 Influence on Braking Performance

27.3.2.2 Influence on Driving Performances, Driving Properties, and Comfort

27.3.3 Wear Behavior

27.3.3.1 AbrasiveWear

27.3.3.2 Cracking Due to Thermal Stresses

27.3.3.3 ThermalWear (Fiber Erosion)

27.3.3.4 Wear Assessment

27.4 Further Development of the Carbon-Ceramic Brake Disc Technology

28 Brake Fluid

28.1 Brake Fluid Types

28.1.1 Glycol-, Glycol Ether-, and Borate Ester-Based Brake Fluids

28.1.2 Silicone Ester-Based Brake Fluids

28.1.3 Mineral Oil-Based Brake Fluids

28.2 National and International Standards

28.3 Brake Fluid Properties

28.3.1 Vehicle-Specific Suitability

28.3.2 Compatibility with Other Brake Fluids

28.3.3 Physical Properties

28.4 Brake Fluid Handling and Storage

28.4.1 Handling

28.4.2 Storage

28.4.3 Disposal

29 Brake Testing

29.1 Wheel Brake

29.1.1 Laboratory Tests

29.1.1.1 Functional Behavior

29.1.1.2 Tightness

29.1.1.3 Strength

29.1.1.4 Vibration

29.1.1.5 Corrosion

29.1.2 Dynamometer Tests

29.1.2.1 Brake Dynamometers

29.1.2.2 Strength and Brake Disc Testing

29.1.2.3 Function of theWheel Brake

29.1.2.4 Performance

29.1.2.5 Comfort

29.1.3 Road Tests

29.1.3.1 Static/Dynamic Basic

Measurements

29.1.3.2 Brake Lining Coefficient of Friction Tests

29.1.3.3 Performance Tests

29.1.3.4 Comfort Tests

29.1.3.5 Endurance Tests

29.1.3.6 Statutory Requirements

29.2 Electronic Brake Systems (EBS)

29.2.1 Laboratory Tests

29.2.1.1 Environmental Simulations

29.2.1.2 Resistance to Media

29.2.1.3 Testing in Corrosive Gas Atmospheres

29.2.1.4 Corrosion Tests

29.2.2 Dynamometer Tests

29.2.2.1 Functional Developments on the Overall System Test Rig

29.2.2.2 Endurance Testing of the Overall EBS System

29.2.2.3 Vibration Resistance

29.2.3 Vehicle Tests

30 Safety and Reliability of Brake Systems

30.1 Brakes as Sources of Trouble

30.1.1 Safety Considerations on

Conventional Braking Devices

30.1.2 Safety Considerations for Braking Systems Incorporating Newer Technologies

30.1.2.1 System Reliability

30.1.2.2 System Availability

30.1.2.3 Requirements Pertaining to Electronic Safety Systems

30.2 Lean Testing in Automotive Industry

30.2.1 Support in the Design and Development Phase

30.2.2 Homologation

First English Edition



- 30.2.3 Field Experience
- 30.3 Developing the Basic Principles of Testing and Inspection
 - 30.3.1 Continuous Improvement of the Main Roadworthiness Inspection
 - 30.3.2 Future Homologation

31 Legislation and Testing Procedures

- 31.1 Homologation Procedure in Europe and the United States
- 31.2 Development Processes of Regulations in Europe and the United States
 - 31.2.1 Development Process for Regulations in the EU
 - 31.2.2 Development Process for Regulations at the UN ECE
 - 31.2.3 Development Process for Regulations in the United States
- 31.3 European Regulations for Road Vehicles
 - 31.3.1 General Regulations, ECE Regulation 13, and EU Directive 71/320/EEC
 - 31.3.2 Performance Regulations
 - 31.3.3 The Distribution of Braking Forces and Compatibility Between Tractor and Trailer
 - 31.3.4 Regulations for ABS Systems
 - 31.3.5 Regulations for Complex Electronic Systems
 - 31.3.6 Testing Aftermarket Friction Linings
- 31.4 United States Braking Regulation
 - 31.4.1 FMVSS 105—Hydraulic Braking Systems
 - 31.4.2 FMVSS 121—Pneumatic Braking Systems
 - 31.4.3 FMVSS 106—Brake Hose Assemblies
 - 31.4.4 FMVSS 116—Brake Fluids for Motor Vehicles
- 31.5 Worldwide Harmonization
 - 31.5.1 FMVSS 135 and ECE R.13H
 - 31.5.2 Harmonization: A Look into the Future

32 Maintenance and Diagnosis of Brake Systems

- 32.1 Influence of Standards, Regulations, and Laws in Practice
- 32.2 Brake Diagnosis
 - 32.2.1 Noise and Vibrations
 - 32.2.2 Pedal Box

- 32.2.3 Booster
- 32.2.4 Master Cylinder
- 32.2.5 Supply Pipes and Brake Hoses
- 32.2.6 Brakes
 - 32.2.6.1 Disc Brakes
 - 32.2.6.2 Drum Brakes
- 32.2.7 Pressure Control Devices
- 32.2.8 Brake Fluid
- 32.2.9 ABS, BA, EHB, VSC, and Other Components and Their Inspection
- 32.3 Environment, Repair, and Maintenance at Fair Market Value
- 32.4 Test Devices

33 Development Trends and Future Aspects

- 33.1 Social and Economic Trends
- 33.2 The Driver's Task—Today and Tomorrow
- 33.3 Quantum Leaps in New Technology
- 33.4 Limits of Power-Assisted Systems— Potential of By-Wire Systems
- 33.5 The Human-Machine Interface
- 33.6 Examples of By-Wire Technologies and Assistance Systems in the Chassis Sector
 - 33.6.1 Throttle-by-Wire (E-Gas)
 - 33.6.2 Shift-by-Wire
 - 33.6.3 Steer-by-Wire
 - 33.6.4 Brake-by-Wire (EHB and EMB)
 - 33.6.5 Energy Management in the Car of the Future: The 42-Volt Onboard Network
- 33.7 Global Chassis Control with Networked Assistance and Chassis Systems
 - 33.7.1 ESC II—Networking with Externally Controlled Lead Steering
 - 33.7.2 Electronic Air Suspension;
 Damper and Stabilizer Adjustment
 - 33.7.3 Technical and Economic Necessities
 - 33.7.4 APIA—The All-Encompassing Approach to Safety
 - 33.7.5 The Long-Term Goal of Accident Prevention

Chapters, Contributions, and Authors Author Index Index of Companies and Universities Illustration Credits About the Editors Index Color Section

First English Edition

