MECA0063 : Braking systems

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Bibliography

- T. Gillespie. «Fundamentals of vehicle Dynamics», 1992, Society of Automotive Engineers (SAE)
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    - Drum brakes
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    - Optimal braking distribution
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  - Non ideal braking
INTRODUCTION
Introduction

- Brakes are primarily used to decelerate a vehicle beyond its road resistance and the braking drag of the engine.

- Brakes generally transform the kinetic energy of the vehicle into heat.

- Brakes can also be used to:
  - Keep a constant speed
  - Keep the vehicle at standstill
Introduction

- One distinguishes the different categories of braking systems
  - Service brake system: generally decreases the speed while driving
  - Emergency brake system: has to take over the function of the service brake system when failing
  - Parking brake system: prevents unwanted motion of the vehicle when parked
  - Continuous service braking systems: for longer uninterrupted braking and frequent stops for instance in urban heavy vehicles

- The service, emergency and parking brake systems directly work on the wheels
- The brake elements of the continuous service generally act on the driveline
Introduction

- A common brake system includes:
  - **Control device**: pedals / hand-brake lever
  - An **energy source** which generates, stores and releases the energy required by the braking system
  - **Transmission device**: components between the control device and the brake
  - **The wheel brake or foundation brakes** generating the forces opposed to the vehicle motion
BRAKE DEVICES
Types of brakes

- Drum brakes
  - They used to be the usual brakes some time ago because of their high mechanical advantage and because of their ability to include parking brakes

- Disk brakes
  - Their mechanical advantage is lower and they require higher actuation forces
  - They require also additional developments to introduce parking brakes
  - They yield more constant braking forces
Drum brakes

The drum spins with the wheel

The flange is fixed with respect to the chassis

http://auto.howstuffworks.com/auto-parts/brakes/brake-types/drum-brake1.htm
Drum brakes

Brake shoe

Drum (inside view)
Drum brake

- **Braking factor** is the mechanical advantage between the actuating force (input) and the braking force (output).

\[
\sum M_A = e P_a + n \mu N_A - m N_A = 0
\]

\[
F_A = \mu N_A \\
F_B = \mu N_B
\]

- It comes:

\[
\frac{F_A}{P_a} = \frac{\mu e}{(m - \mu n)} \\
\frac{F_B}{P_a} = \frac{\mu e}{(m + \mu n)}
\]
Drum brake

- The leading shoe A.
  - The friction force creates a moment that applies the shoe against the drum and the lining pad and thus increases the friction force.
  - The system is self-actuated so it yields a high mechanical advantage.
  - This may lead to a brake locking.

- The trailing shoe B.
  - The friction force tends to create a repulsive moment thus reducing the contact force.
  - The mechanical advantage is lower.
  - It requires a higher actuation force.
  - It is not subject to self locking.

Smart combination of trailing and leading shoes and their lining materials may lead to on demand braking factors.
Drum brakes

- The conventional design consists in an internal brake shoe that is applied on the inner surface of the drum.
- The usual drum brake includes two shoes in one drum.
- According to the type of the clamping force and of the shoe support, the drum brakes are classified in different categories:
  - Simplex-brake
  - Duplex-brake
  - Servo brake
  - Duo-duplex-brake
  - Duo-servo-brake
Drum brakes
Drum brakes

**Drum brake simplex**
- Double brake cylinder
- Axle fixed rotation point
- One leading shoe and one trailing shoe
- Independent of rotation direction

**Drum brake duplex**
- Braking with two leading brake shoes or, when backing-up, with two trailing brake shoes
Drum brakes

**Drum brake servo**
- Actuation by a single double brake cylinder
- Supporting force of the primary shoe is the application force of the secondary shoe
- Transmission of the frictional forces of one brake shoe to the other

**Drum brake with parking brake**
- Operation of the brake shoes via the wheel brake cylinder
- Function of the leading and trailing shoes (the leading shoe is pulled onto the drum, the trailing shoe is pushed away)
- Operation of the service brake via the pistons in the wheel cylinder
- Operation of the parking brake via a linkage
Drum brakes

FIGURE 10–32 The operation of a typical self-adjuster. Notice that the adjuster actually moves the starwheel.
Drum brakes
Disk brakes

Car

Motorbike
Disk brakes: definitions

Diagram showing disk brake components:
- Brake pads
- Brake rotor / disc
- Caliper
- Piston
- Wheel attaches here
- Brake Pads
- Hub
- Rotor
Disk brakes

- The disk brakes include
  - A disk that is connected to the wheel and so it is spinning
  - A calliper that supports one or several pistons on which are mounted the friction pad. The calliper is fixed with respect to the chassis
  - There can be one or several pistons
  - Friction pads made of high friction materials

- One can distinguish between
  - The fixed calliper
  - The floating calliper or self-adjusting brakes
Disk brakes

Ventilated disk brakes

Disk brakes
Self adjusting/floating and fixed callipers

Floating calliper disk brake

Fixed calliper disk brake
Self adjusting and fixed callipers

Floating calliper disk brake

Fixed calliper disk brake
Self adjusting callipers

Operating principle of floating calliper
Floating calliper with adjustment

Adjustment mechanism for a floating calliper
Brake pads

- The pads must resist to high temperature (about 600°C to 700°C) and to important efforts.
- The pads are made of high friction materials with friction coefficient in between 0.25 and 0.5.
- The pads must:
  - Preserve their high friction coefficient independently of the speed, of the contact pressure, and of the temperature.
  - Resist to the wear without attacking the disk.
  - Do not produce stick-slip behaviour and noise.
  - Recover their friction properties after being wet.
- The reduction of the efficiency of pad materials with the temperature is known as the fading. It can conduct to the loss of braking.
Disk braking factor

- The braking factor of a disk brake

\[ T_b = F_b R_e = R_b \mu_b A_b p_b = R_e k_b p_b \]

\[ k_b = \mu_b A_b R_b / R_e \]
Drum brakes v.s. disk brakes

DRUM BRAKES
- High braking factor and so low braking actuation effort
- Drawback of the high braking factor: sensitivity of the friction coefficient of pads can lead to chattering and vibrations
- Braking torque variation with time
- Difficulty to maintain a good braking balance
- Stopping distance can be longer

DISK BRAKES
- Lower braking factor and so higher braking effort
- More constant brake torque
- Braking torque rather constant
- Better braking distribution
- Stopping distance is lower
Drum brakes v.s. disk brakes

\[ T_b = f(P_a, \text{speed, temperature}) \]

Gillespie: Fig. 3.3 : Measurement of brake torque for drum brakes and disk brakes on a braking dynamometer
BRAKING SYSTEM
Command and actuation of the braking system

- In a braking system, one must distinguish:
  - The braking device itself that is the drum and disk brakes
  - The command and actuation system that encompasses all the actuation components of the brakes and their command devices

- Specifications of the braking system:
  - Short response time
  - Smooth and precise control force by the driver
  - Requires a moderate actuation effort from the driver
  - Braking distribution between the two wheels of a same axle, whatever could be the orientation and the motion of the wheels
  - Distribution of the braking forces between front and rear axles as a function of the vertical loads
  - To be able to stop the vehicle even in case of mal function of the braking circuit
Command and actuation of the braking system

- Types of a actuation for a braking system:
  - Mechanical actuation using rigid rods or soft cables (Bowden cables)
  - Hydraulic actuation
  - Pneumatic actuation (mostly used on industrial vehicles)

- For all vehicles, the ECE regulation prescribes to have two different braking actuation systems on board. The must work independently.

- For passenger cars, we have generally:
  - A mechanical actuation system for the emergency brake and the parking brake called hand brake
  - A hydraulic braking system for the main braking system
Command and actuation of the braking system

Emergency and parking brakes of the Ford Focus 2000
Command and actuation of the braking system

- Object of the emergency and parking brake
  - In case of malfunction, it must be able to stop the vehicle within good conditions (to be defined)
  - When stopped, the system must be able to maintain the permanent rest conditions

- The parking system acts only on a single axle

- The emergency and parking braking system can (not mandatory):
  - Be integrated to the drum brakes
  - Be integrated in the calipers
  - Include some independent calipers with their proper set of pads
  - Be present as a small drum brake system integrated in the disk bowl
Command and actuation of the braking system

Mémeteau Fig. 9.3
Parking brake integrated in a disk brake

Mémeteau Fig. 9.4
Drum parking brake in a disk brake
Parking brake systems

- Generally the mechanical actuation is sufficient for emergency and parking brakes:
  - The system is independent of the main brake system (hydraulic or pneumatic)
  - Keep a constant effectiveness even for long parking periods
- The drawbacks of the mechanical actuation systems are:
  - Bad distribution of the braking force on the axles or even between different axles
  - Bad braking stability during suspension jounce/bounce, wheel steering because the system is based on straight lines mechanical components (cables, rods)
  - Low efficiency because of the various internal frictions
  - Risks of seizure
  - Wear and elongation of the cables
  - Progressive failure of the cables by progressive failure of the filaments
Hydraulic actuation system

An hydraulic command system includes:

- A reservoir of hydraulic liquid
- A power source or the master cylinder that transforms the brake pedal pressure in hydraulic energy
- Receivers: that convert the hydraulic energy into actuating force of the shoes or of friction pads.
- Un network of hydraulic pipes connecting the source to the receivers.
Basic hydraulic system

Mémeteau Fig. 9.3 Basic hydraulic command system
Hydraulic actuation system

- Advantages of hydraulic systems:
  - Perfect repartition of the braking force to the wheels of an axle (the pressure is equal everywhere because of Pascal’s principle)
  - Possible amplification of the force when using with different piston sections in the master cylinder and in the brake pistons
  - The pipes can bend and adapt easily the tortuous links
  - The frictions are very weak

- The force amplification mechanism in the braking system results from:
  - Mechanical amplification, by a system of levers
  - Hydraulic amplification by using different section ratio
Force amplification mechanisms

Lever systems

Hydraulic system with different pistons surfaces
Master cylinder
Master cylinder

Mèmeteau Fig. 9.9
Master cylinder

Components of the master cylinder:

- A **cylindrical body** communicating with the **reservoir** by an opening in which there is fit slotted elastic pin
- At the front end, **one or several holes** communicating with the pipes to the receiving brake cylinders
- A **valve for the residual pressure** for the drum disks hydraulic circuits
- A **piston** sliding in the cylinder bore
- A second ring that insure the **sealing** with respect to outer
- A **spring for the recall of the piston** that keeps the pressure valve and the primary cups
Double braking circuits

- Requirement for a double braking circuit:
  - If the four receiving pistons are connected to a single network of pipes and to the master cylinder,
  - In case of leakage, the pressure drops everywhere in the pipe network coming to a total failure of the braking system
  - With a double braking circuit, one increases the safety and the reliability of the system because some braking capability is preserved.

- Double braking circuit:
  - A tandem master cylinder
  - Two reservoirs
  - Two pistons (primary and secondary ones)
  - Two independent networks of pipes
Double braking circuits

One circuit for two wheels: Parallel or cross lay-out

Front circuit is doubled: Parallel or triangular lay-out

Completely doubled circuit
Tandem master cylinder
Tandem master cylinder

- Normal operation of a tandem master cylinder
  - When the brake pedal is depressed, the rod is pushed and then pushes the primary piston
  - The pressure grows in the primary cylinder and the fluid is pushed in the primary circuit.
  - The pressure in the first cylinder acts on the wall of the second piston, and the pressure grows as well in the secondary cylinder and the fluid is also sent into the secondary circuit.
  - In case of normal operation, the pressure is the same in the two circuits.
- In case of leakage, the system continues working but with a longer displacement of the brake pedal
Tandem master cylinder

Working principle of a tandem master cylinder
**Tandem master cylinder**

- In case of a leakage, the tandem master cylinder works as following:
  - Let a leakage in circuit 1. The pressure drops between 1 and 2.
  - The piston 1 is pushed without any resistance until coming into contact with the face of the piston 2.
  - When the two pistons are in contact, the system works as a single piston.
  - The circuit 2 continues working but the driver feels a longer displacement of the brake pedal to be actuated. This gives a warning feedback signal to the driver.
Hydraulic circuit in case of a leakage
Combination valve

- The combination valve has three separate functions:
  - Pressure metering valve
  - Pressure differential switch
  - Proportioning valve
Pressure metering valve

- The pressure metering valve is required for vehicles with both disk brakes in front and drum brakes on the rear axles.
- The brake pads of brake disks are remaining nearly in contact with the disks whereas the shoes in drum brakes are extracted from the drum by a spring elements. Thus the time responses of drum brakes is longer than disk brakes.
- For braking stability, one has to delay the actuation of the disk brakes on front wheels.
- The metering valve is a calibrated valve that allows only a actuation of the front brake disks over a given threshold of pressure.
The pressure differential switch is a device devoted to warn the driver when there is a pressure drop in one of the circuits.

It is made of a small piston whose faces are in contact with the pressure in the two circuits.

A pressure difference conducts to a displacement of the piston which insures a electrical contact to switch on a light for the driver.
The proportioning valve is a valve that reduces the pressure in the rear brake pistons to prevent the rear wheel locking.
Braking assistance
Braking assistance

- Braking assistance = device that enables to develop a high pressure in the hydraulic braking circuit with a low or moderate pedal force.

- Devices enabling the braking efforts:
  - Mechanical systems: lever arms
  - Hydraulic systems: different cross sections of the pistons

- Brake assist systems:
  - Magnification of the effort developed without using mechanisms that requires a increase in the pedal displacement.
Braking assistance

Mèmeteau Fig 10.1
Braking assistance

- **Source of braking assistance:**
  - Create a **low pressure** using the pressure loss in the admission manifold (for SI engines) and a vacuum pump (for CI engines)
  - Create a **high pressure** in the hydraulic fluid developed by a hydraulic pump
  - Create a **high pressure** of air developed by a compressor (as in industrial and heavy utility vehicles)

- Assistance is obtained by the action of the difference of pressure across the two faces of a membrane

- The modulus of the actuating force is the sum of
  - The braking force on the pedal multiplied by the *mechanical advantage* of the pedal
  - The additional force of the assistance device
Braking assistance

Mèmeteau Fig 10.4
Braking assistance

Mèmoteau Fig 10.6
Braking assistance

- System of braking assistance
  - Hydrovac
  - Master vac
Vacuum assist unit

- The vacuum assist unit is inserted between the brake pedal and the master cylinder.
Vacuum assist unit

- It includes:
  - A cylinder a large diameter (in green)
  - The two chambers are separated by a sliding piston
  - The piston pushes the actuation rod of the master cylinder
Master Vac – working principle

- The device uses the low pressure available from engine admission pipes.
- When the strut is pressed, the air at atmospheric pressure can come into contact with the diaphragm in the right hand side part.
- The pressure difference between the two sides of the diagram pushes the strut of the master cylinder.
- As the pressure difference is rather limited, the diameter of the piston must be large to create a significant force.
Master Vac – working principle

- When the pressure on the braking pedal is relaxed, the atmospheric pressure valve is released.
- The right hand side of the diaphragm is set under depression.
- The assistance force is cancelled by returning to initial position.
The check-valve

- The check-valve is a one-way valve that allows the low pressure air to leave the master vac low pressure chamber but not to enter into the master vac.

- So in case of pressure leakage or engine stop, or in case of a pressure leakage not to admit atmospheric air into the chamber.

- This allows to guarantee that the master is able to work several times and operate safely an assistance force whereas the engine has stopped working.
Summary
Summary: the braking system