BRAKE SYSTEMS 101

Topics To Be Presented

- The Basic Concepts
- Hydraulic layouts
- Component functions
- Brake Balance
- Stopping Distance and Fade
- Formula SAE vs. Mini Baja
- Lessons Learned
- The Rules
- Questions
The Basic Concepts

Kinetic energy = heat
F = ma
Newton is always right!
Do the calculations first
When all else fails see rule 3.
Energy Conversion

The brake system converts the kinetic energy of vehicle motion into heat.
Energy Conversion

A vehicle weighing 290 kg. (639 lbs.)

At 90 kph (55.9 mph) has kinetic energy of:

\[
\frac{MV^2}{2G} \quad \text{OR} \quad 90,770 \text{ N-M.}
\]

Stopping the vehicle at .9G takes 2.9 Seconds

This is equal to 31 kilowatts (42 HP).
Kinetic Energy as a Function of Speed and Mass

- Mass:
  - 200 kg
  - 250 kg
  - 290 kg

- Speed (kph):
  - 30
  - 60
  - 90
  - 120

Energy (N-M):
- 0
- 20,000
- 40,000
- 60,000
- 80,000
- 100,000
- 120,000
- 140,000
- 160,000
- 180,000
$F = ma$

The Key Question!

How do you calculate $F$?
BRAKE SYSTEMS 101

Basic System Model

Brake Force

\[ F \propto \frac{r}{R} \times 2 \times \mu \times \frac{A_w}{A_m} \times (R_p \times f + F_b) \]
Hydraulic System Configurations

There are two layouts of hydraulic brake systems used in cars and light trucks.

**Front/Rear hydraulic split:**
Also called axle by axle, vertical, and sometimes “black and white”.

**Diagonal Split:**
Also called criss-cross.

*The type of split is only significant in the event of a hydraulic system failure.*
BRAKE SYSTEMS 101

Front/rear Hydraulic Split

Front Axle

Primary System

Secondary System

Rear Axle
Diagonal Split System

In a diagonal split system, one brake line is run to each rear brake and one to each front brake.

The connections are such that the left front and the right rear brake are on one circuit and the right front and left rear are on the other circuit.
Typical Diagonal Split System
Brake Component Function
Four Sub-systems

- Actuation sub-system
- Foundation sub-system
- Parking brake sub-system
- ABS & ESP (electronic stability program) sub-system
Actuation Sub-system

- Brake Pedal
- Master Cylinder
- Proportioning Valves
- Brake Lines
The Brake Pedal

Output to master cylinder:
400 N and 36 mm

Driver Input:
100 N and 144 mm

4:1 Nominal Pedal Ratio
A master cylinder is just a simple piston inside a cylinder.
M/C Unapplied

RESERVOIR

COMPENSATING PORTS OPEN

RESERVOIR

PISTON CUP

PISTON CUP
BRAKE SYSTEMS 101

M/C Applied

COMPENSATING PORTS BLOCKED

SECONDARY

PRIMARY PISTON
Primary System Failure

Pressure for Normal Secondary System Function

Operated Mechanically

Bottoms Against Secondary Piston
Secondary System Failure

Bottoms at End of Cylinder Bore

Pressure for Normal Primary System Function
Proportioning Valves

- Reduce the pressure to the rear brakes
- Diagonal systems require two
- Split and slope are changed to create proper balance
BRAKE SYSTEMS 101

Adjustable Proportioning valves

Wilwood

Tilton

Only the split points are adjustable
Brake Lines

- Double wall steel tubing (Bundy Tubing) is industry standard.
- 3/16” o.d. is standard size.
- Very robust, can take a lot of abuse
- Use SAE 45° inverted flare (J533 and J512) joints if you can.
Foundation Brake Sub-system

- Disc Brakes
- Linings
Front Disc Brake

- Knuckle
- Brake hose and housing
- Bolt and washer
- Bleeder screw
- Caliper assembly
- Gasket
- Drive hub
- Disc assembly
- Shield
- Wheel stud nut
BRAKE SYSTEMS 101

Front Disc Brake
Brake Linings

Brake linings are probably the most mis-understood part of a brake system.

The output of any brake is directly related to the coefficient of friction ($\mu$) between the lining and the disc or drum.

The challenge is knowing what the instantaneous value of $\mu$ is during any given stop.

Any design calculations you do, go right out the window if the lining you use does not have the $\mu$ value you assumed.
Brake Linings

Remember the equation for a disc brake

\[ F \propto \frac{r}{R} \times 2 \times \mu \times \frac{A_w}{A_m} \times (R_p \times f) \]

The best method for determining the actual value of \( \mu \) for a given lining is from a dynamometer test.
Brake Balance
Both Front Wheels Locked:

- You can’t steer
- The vehicle goes straight
- OK, if you must hit something
- Not good if you are on a curved road
Both Rear Wheels Locked:

- The front wheels track straight ahead.
- Then the rear wheels deviate to the side.
- Until the vehicle can’t track straight any longer and the rear starts to spin around the front.
μ vs. % Wheel Slip

Typical Dry Surface

Braking

Steering
If there is more front brake torque than dynamic front weight, the front wheels will lock up before the rears.
If there is more *rear* brake torque than dynamic *rear* weight;

![Diagram showing brake torque distribution and dynamic weight distribution.]

The *rear* wheels will lock up before the fronts.
Optimum Braking

Optimum braking is achieved when brake torque distribution matches dynamic weight distribution.

**No Braking**
- Weight Distribution: 40% - 60%

**Hard Braking**
- Weight Distribution: 20% - 80%
Calculating Dynamic Weight Transfer

\[ W_{df} = \frac{W_t \times H_t}{W_b} \times D + W_{fs} \]
Ideal Vs Actual Torque

With a prop valve
BRAKE SYSTEMS 101

Stopping Distance

Does **not** Depend on:

- Type of brakes
- Size of brakes

Does **Depend on**:

- Tire to road friction
- Vehicle balance
- Skill of driver
- System Reaction Time
$\mu$ vs. % Wheel Slip

Typical Dry Surface

Braking
Brake fade is the loss of performance resulting from the lining friction decreasing as the lining and rotor or drum rises in temperature.
The brake system design must match the vehicle objectives

Formula SAE vs. Mini Baja
BRAKE SYSTEMS 101

Formula SAE
- Absolute reliability
- High Speeds
- Maximum possible decel without locking
- Consistent balance with changing temperatures

Mini Baja
- Absolute reliability
- Low Speeds
- Very hostile environment
- Brake must work when wet and muddy
Mini Baja, Hostile Environment

Will your master cylinder fill up with water?
How does your brake lining work when it is wet?
Lessons Learned
Don’t Do Something Because:

- The other guys do it.
- All the race cars have it.
- It looks really cool
Design to a Specific Objective:

- Do the math first
- Verify your assumptions
- Take the easy solution (KISS)
Lessons Learned

Lesson Number 1 - Keep it SIMPLE
BRAKE SYSTEMS 101

**Lessons Learned**

Lesson Number 2 - Keep it light; but not too light.

- 90% of the braking energy goes into the rotor
- If the rotor is **too** light it gets very hot
- If the temperatures get too high **very nasty** things can happen.
Too light

- 2006 DCAE program involved a Hemi powered Grand Cherokee.

- One team used much smaller rear brakes and rotors to save a few pounds on a 3200 lb vehicle with 500 hp.

- The vehicle went off the end of the main straight at over 100 mph on the third lap because of brake failure.
Lessons Learned

Lesson Number 3 - Packaging and Integration drive 90% of design

Lesson Number 4 - Read the rules

Lesson Number 5 - Allow enough time for details and testing
Brake rules

- The car must have four wheel brakes operated by a single control.

- It must have two independent hydraulic circuits with independent fluid reserves.

- The brake system must be capable of locking all four (4) wheels, and stopping the vehicle in a straight line.

The braking systems must be protected with scatter shields from failure of the drive train (FSAE only)

- A brake pedal over-travel switch must be installed. This switch must kill the ignition and cut the power to any electrical fuel pumps. (FSAE only)

- The car must be equipped with a red brake light that illuminates when ever the brakes are applied.
Copyright © 2011 Paul S. Gritt.
All rights reserved.