Hydraulic Brake Systems

Remember races are won more by having consistent & efficient braking, not just cornering & acceleration.

This article delivers really useful information about Race Car braking and understanding how the braking system works and what elements are involved that impact on Race Car brake performance.

History of Fluid Mechanics

Fluid Mechanics is the study of Fluids. There are several branches, fluid at rest is commonly known as Fluid Statics, while Fluid in motion is known as Fluid Dynamics.

The study of pressurised systems also have several branches, the study of pressurised air systems is known as Pneumatics, while the study of pressurised fluid systems is known as Hydraulics.

The term Hydraulics originates from a Greek term hydraulikos, which originated from 2 words referring to water and pipe. Pascal (1623–1662) studied fluid hydrodynamics and hydrostatics, centered on the principles of hydraulic fluids.

Pascal established Pascal's Law and is the namesake of the SI unit for pressure, the Pascal (Pa), being a force on an area, specifically 1Pa is equal to 1 Newton force per Square Metre in area (or $Pa=N/m^2$). Mathematically, Pascal found the amount of pressure resulting from a column of fluid would be a function of the height of the column and the density of the fluid. Later experiments with U-tubes filled with water with varying size pistons and tube diameter's led to the invention of the Hydraulic press.
The hydraulic press, multiplied a smaller force acting on a smaller area, to a larger force totalled over a larger area. This was a great example of leverage or mechanical advantage while using a fluid, and typical of many hydraulic systems today.

Brake System Hydraulics

The mechanical lever, known as the brake pedal, accepts the mechanical force input from the driver's foot. The hydraulic brake system on a vehicle starts at the fluid reservoir, then master cylinder, hydraulic lines and ends at the callipers. The master cylinder converts a pedal force to a fluid pressure, and is responsible for the amount of pressure in a brake line feeding a brake calliper.

The fluid pressure at the calliper pushes the piston/s to squeeze the brake pads to the rotors. Via friction between the brake pads & rotors, you have a given resistance known as braking.

Any portion of a brake system that acts on the fluid, or carries fluid is part of the braking system. This includes the pedal, lever, linkages, pushrods, reservoirs, master cylinders, hard brake lines, proportional valves, flexible brake lines, brake bias bars, callipers, pads & rotors.

Race Car Hydraulic System Performance

If you have ever changed a master cylinder, brake line or calliper on a vehicle, you are probably quite familiar with how air trapped in the brake's hydraulic system affects its performance. A spongy pedal or brakes that simply don't work are usually the result of air getting into the hydraulic system. Proper bleeding of the system to remove the air from the system restores the functionality of the hydraulics.

While brake fluid is considered incompressible, naturally does an excellent job of transferring a pressure increase across the entire system, air simply compresses and fails to transmit the effort put in at the pedal.

Since most of today's vehicles incorporate an ABS system into the hydraulics, it's important to follow the vehicle manufacturers' recommendation's for bleeding the system. In most cases, bleeding is started at the calliper furthest from the master cylinder. Using a suction type bleeder can be helpful in removing stubborn air pockets from the brake system.

Hydraulic Ratios

On a factory vehicle, a group of engineers determine the exact amount of pedal travel and pedal resistance they desire for the driver. By varying the bore size of the master cylinder, the pedal ratio and the total piston area of the calliper's pistons, engineers establish total pedal travel and pedal effort.

The amount of travel that OEM's set generally pretty long with ABS system activation occurring a couple inches off the floor in a properly working system. A long pedal travel minimises effort while maximising modulation (the ability to vary the degree of braking applied).

For a racing application, there may be a desire to shorten the pedal travel to allow full braking power to come sooner. One way to accomplish this is to increase the master cylinder bore. While this will reduce the pedal travel, it will come at the cost of reduced modulation and increased effort.

Of course braking systems feature some type of assist (vacuum or electric), may not reveal the increase in pedal effort in full. Conversely changing to a master cylinder with a smaller bore will result in increased pedal travel, decreased effort and improved modulation.

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Pedal effort is directly proportional to the amount of pressure created in the hydraulic braking system peak pressure will reach between 600 and 1200 psi.

A stroke of about 25 – 35 mm at the pedal is all that should be typically needed to reach the peak pressure.

The bore diameter of the master cylinder, the pedal ratio, the total area of all the callipers pistons and the pressure in the brake system all influence the pedal effort.

These also influence the amount of travel required to reach the peak pressure.

TO INCREASE PEDAL EFFORT:

- Increase Master Cylinder Diameter
- Choose Lower Pedal Ratio
- Remove or Decrease Brake Assist

TO DECREASE PEDAL EFFORT:

- Decrease Master Cylinder Diameter
- Choose Higher Pedal Ratio
- Add or Increase Brake Assist.

LINE PRESSURE

Three factors influence the line pressure in the brake system:

- The pedal force,
- The pedal ratio and
- The master cylinder bore sizes.

About 100 to 150 pounds of force from the leg to the pedal is a good working range.

The pedal ratio multiplies this effort.

For example

A 5:1 pedal ratio would multiply a 100-pound pedal force to 500 pounds force going into the master cylinder. With a 13/16" bore (area=0.5185) the pressure in the system would be 500/0.5185 or 964 psi.

Also, a 4:1 pedal ratio would multiply a 100-pound pedal force to 400 pounds force going into the master cylinder. With a 5/8" bore (area=0.3068) the pressure in the system would be 400/0.3068 or 1304 psi.

IF YOU INCREASE MASTER CYLINDER BORE DIAMETER:

- Increase Pedal Effort
- Decreases Total Pedal Travel
- Reduced Push-rod Stroke to Master Cylinder
- Decreases Line Pressure for a Given Pedal Force

IF YOU DECREASE MASTER CYLINDER BORE DIAMETER:

- Decrease Pedal Effort
- Increases Total Pedal Travel
- Increases Push-rod Stroke to Master Cylinder
- Increases Line Pressure for a Given Pedal Force

If you have any questions, free to ask our friendly PE staff