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CHAPTER 3

Brake System Design

If you skipped over the first two chapters, you missed the big news: brakes don't stop your car. If you didn't skip them, well, now you have heard it again. In case you have not caught on by now, this is a point that needs to be driven home.

Yet you know that when you press on the brake pedal the vehicle will, in most cases, slow down. Usually, the more you push on the pedal, the more deceleration you feel. Heck, the vehicle might even stop. Eventually, anyway.

Chapter 1 taught you that between the effects of tire rolling resistance, driveline frictional losses, and aerodynamic drag, the kinetic energy of the vehicle in motion can be absorbed without the need for a separate vehicle brake system. However, there are often times when the *rate* of energy conversion is not sufficient enough to produce an acceptable rate of deceleration (such as driving around town, let alone on a race track). This is where the brake system steps in, and certain modifications may prove useful to the casual driver, high-performance enthusiast, and pro racer alike.

Now, before analyzing the benefits (and tradeoffs!) of adjustable proportioning valves, 6-piston calipers, floating rotors, DOT 5.1 brake fluid, and stainless steel braided brake lines, it's necessary to take a high-level look at a typical brake system. Knowing the roles of the individual components will better prepare you for the detailed discussions to come.

Driver Applied Force

Brake systems are fitted to vehicles in order to increase their deceleration capability. They accomplish this task by converting energy at a higher rate than the aforementioned passive mechanisms. In fact, the rate of energy conversion is limited only by the tractive capability of the tires and the thermal capacity of the brake system components.

None of this matters one bit, however, if the driver does not press on the pedal in the first place. If you neglect the effects of tire rolling resistance, driveline frictional losses, and aerodynamic drag for the rest of this chapter, it's only the force exerted by the driver on the brake pedal that creates slip (and hopefully force) at the contact patch. It's not quite like Fred Flintstone, but all of the force the brake system generates ultimately comes from the driver's leg.

Of course, most people are not strong enough to decelerate a 3,000-pound vehicle at a reasonable rate from even 20 mph using only their leg muscles. The brake system is therefore designed to amplify the leg force generated by the driver (while of course still converting kinetic energy into heat). This brings forward the concept of brake system *gain*.

Gain

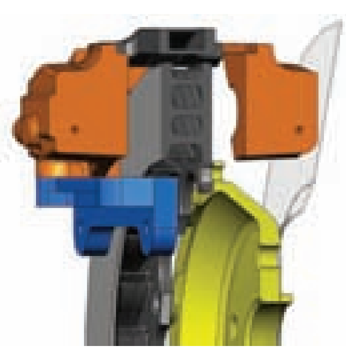
Gain is really nothing more than a fancy way of saying multiplication. The brake system gain relates the amount of brake system force input to brake system force output. In equation form:

Brake system gain (unitless) =
total brake force (lb) ÷
driver's leg force (lb)

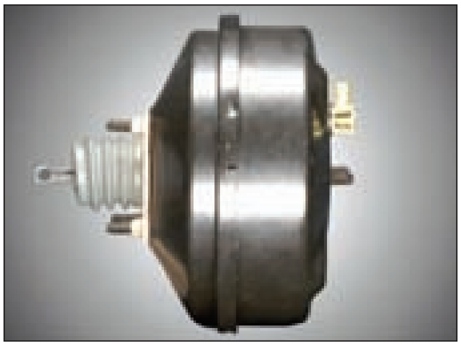
For example, if a leg force of 50 pounds on the brake pedal nets a total brake force of 2,000 pounds at the four contact patches, the brake system gain is 40. You could also say that the system increased force at a 40-to-1 ratio, or that the gain was 40:1.

So where does the brake system gain come from? In brief, each of the brake system components is designed to provide its own gain through some type of mechanical advantage. The overall brake system gain is therefore equal to the individual brake system component gains all multiplied together.

If a brake system is designed properly, even the very weakest driver should be capable of generating enough leg force to decelerate the vehicle at the limit defined by the tire-to-road interface. This dictates that every vehicle has a unique gain requirement. As a result, much of the art of brake system design revolves simply around developing the appropriate amount of gain.



Although the tire ultimately stops the car, it's the combined contributions of the brake system components that multiply the driver's leg force to stop the car. For this reason, methodical brake system design is required to ensure that all performance expectations are met. (StopTech)



The gain of a brake system component is simply the relationship between the force coming in and the force going out. In the case of a brake booster, the ratio of these two forces is called the boost gain. (Randall Shafer)

Force Distribution

In addition to amplifying the driver's leg force, the brake system must also distribute all of this amplified force to the four corners of the car, ultimately directing it to the four tire contact patches. It may also need to modify the brake force distribution as a function of deceleration, speed, or vehicle loading.

While brake force distribution is a critical responsibility of the brake system, you'll need to wait until Chapter 4 to learn more. For the remainder of this chapter, the focus is on brake system gain.

Brake System Overview

It's now time to analyze the mechanical attributes, the functional responsibilities, and gain characteristics of each individual brake system component. Note that this is required reading before jumping to Chapters 5 through 10 which go into much deeper detail!

The Brake Pedal

Most people are already familiar with the brake pedal *pad*—it's where you press to make the your vehicle stop. But while most of you are aware of the part of the pedal that makes contact with your foot, two equally important components of the pedal assembly, the *output rod* and *fulcrum*, are generally out of sight. Together, these three separate parts define the brake pedal assembly.

The primary function of the brake pedal assembly is to harness and multiply the force exerted by the driver's leg. The amount of amplification, or gain, is a function of the brake pedal *leverage*.

You probably learned the concept of leverage on a teeter-totter—the farther you sit from the middle (the pivot point, or fulcrum), the more weight you can lift on the other end. In the case of the brake pedal assembly, the fulcrum is at the top of the brake pedal arm, the brake pedal pad is on the opposite end, and the output rod is somewhere in between. Based on the distance between these features, the pedal ratio can be defined as:

Pedal ratio (unitless) =
distance, pad to fulcrum (in) ÷
distance, output rod to fulcrum (in)

Because the distance from the pad to the fulcrum is longer than the distance

How Much Gain is Enough?

To illustrate the variability in gain from vehicle to vehicle, the following table demonstrates how brake system gain can be influenced by just vehicle weight alone. Note that this analysis assumes a maximum driver leg force of 50 pounds and a deceleration limit of 0.9g for each vehicle.

	Gain Required
400-lb race kart	7.2:1
1,900-lb formula car	34.2:1
3,000-lb passenger car	54:1
80,000-lb tractor-trailer	1,440:1

Even though the assumptions listed might not be perfectly accurate for each vehicle, it becomes quite clear that there is not one optimum value for brake system gain. A brake system designed to generate 0.9g on a 1,900-pound formula car would only generate 0.02g if installed on an 80,000-pound tractor-trailer.

The overall brake system gain is a function of how much absolute force is required to stop the vehicle. Due to its weight, this 60,000-pound airport snowplow requires much more brake system gain than a typical passenger car. (Randall Shafer)

Conversely, if the 3,000-pound passenger car brake system were installed on the 400-pound race kart, only 6.7 pounds of driver leg effort would be required to achieve maximum deceleration. This would make the brake system response less progressive than desirable. In fact, with a gain this high, the brake pedal would be so sensitive that it could probably be replaced with an on-off switch to achieve the same result.

In summary, if the gain is too low the vehicle will be difficult to stop with reasonable leg efforts. If the gain is too high, the brake system response may be touchy or grabby. Determining the proper gain comes down to driver preference, and the careful selection of components will allow you to tailor it to meet your needs.