HIGH-PERFORMANCE BRAKE SYSTEMS

DESIGN, SELECTION AND INSTALLATION

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Front Cover:
There is more to upgrading your brake system than just shopping for the best looking parts. While aesthetics certainly are important, consideration must also be given to system-level performance. Picking the right parts is usually more complicated than physically bolting them on–they have to work together. (Randall Shafer)

Title Page:
During track use, rotors are squeezed with thousands of pounds of clamp force, twisted by thousands of foot-pounds of torque, and heated to over 1,200 degrees F. Heavy cars with large engines such as these only make the demands that much more intense. (Wayne Flynn/pdxsports.com)

Back Cover, Top:
Designing a hot rod brake system from scratch may seem intimidating at first, but the fundamental concepts of gain and balance still apply. What really differentiates these brake systems are unique design and operating requirements that may require different compromises than would be appropriate for an all-out racecar. (Randall Shafer)

Middle:
Because experience is the best teacher, the final four chapters of this book are dedicated to sharing our years of upgrade know-how with you. Whether you are upsizing your front rotors for track use or converting your muscle car from rear drum brakes to rear disc brakes, grab your wrenches and head out to the garage with us. Just be sure to wear your safety glasses! (Randall Shafer)

Bottom:
Motorsports can place extreme demands on your brake system, and if your hardware is not up to the task, performance can suffer dramatically. A solid understanding of brake system fundamentals greatly increases your likelihood of ending up in the winner's circle on race day. (Wayne Flynn/pdxsports.com)

CHAPTER 2

TIRES STOP THE CAR

As you just learned in Chapter 1, brakes do not stop the car—they simply convert energy from one form into another. The responsibility of stopping the car falls solely on the tires, or more specifically the tire-to-road interface. Only these four palm-sized patches of rubber that are in contact with the road below (the contact patches) govern how quickly a car will stop.

Of course, a poorly designed or malfunctioning brake system can certainly *prevent* a vehicle from achieving its maximum deceleration rate, but the best stopping performance each and every time is dictated by the tire-to-road interface. A few simple equations are used later in this chapter to illustrate this point, but for the next few pages sit back and hang tight. It's now time to talk about another law.

The brakes don't stop the car—that's the tires' job! For this reason, tires come in a wide variety of shapes, sizes, and designs to optimize the available brake force. The lack of a tread pattern on this tire makes it a poor choice for wet-weather performance, but a great choice for racing when the track is dry. (Hoosier Racing Tire)

The First Law of Motion

You may recognize Sir Isaac Newton as the guy who allegedly defined the concept of gravity when an apple fell on his head one afternoon. However, for a few paragraphs you should look past that rather major accomplishment and focus on the first of his three stated Laws of Motion.

(Note that Newton's First Law of Motion is not to be confused with the First Law of Thermodynamics from Chapter 1. Apparently, every physicist wants to be known for discovering the first law of something or other.)

Paraphrasing Newton with a reasonable degree of accuracy, the First Law of Motion states that an object at rest will stay at rest unless it is acted upon by an external force. Conversely, it also states that an object in motion will stay in motion unless it too is acted upon by an external force. In other words, things sitting still will just sit still until you push them and things that are moving continue to move until you do something to stop them.

Brake Forces

Applying Newton's First Law of Motion to vehicle brake systems is relatively straightforward. It goes something like this: Once in motion, a vehicle essentially will not slow down or stop unless it is acted upon by an external force, or what can now be called a *brake force*.

So where do these brake forces come from? Essentially, they result from any mechanism that absorbs a vehicle's kinetic energy (they are one and the same). Consequently, this merits a brief revisit of

Brake forces can come from a variety of sources other than the brake system. For example, if a mischievous co-driver were to force a car traveling at highway speeds into first gear, the resulting driveline friction forces would be transmitted immediately back to the driven wheels. Not that we speak from experience here…

energy transformation factors from Chapter 1, now adding in the resulting brake force contributions for each mechanism:

1. *Rolling resistance brake forces* result from the body and tread of the tire resisting deformation at the contact patch. As the tire flattens out against the road, a force is generated that resists the motion of the vehicle.

2. *Axle, differential, bearing, and engine brake forces* result from rotating and reciprocating friction. As these components mesh and rub together, they resist any motion between themselves, which is then mechanically transferred to the tire-to-road interface.

3. *Aerodynamic brake forces* result from the vehicle simply traveling through the air. As the vehicle attempts to push the air out of its path, the air molecules react by resisting the motion. In other words, the air is not happy with the situation and it pushes back (the sensation you get from holding your hand out of the car window).

4. *Mechanical deformation brake forces* result from running the vehicle into a fixed object. Again, this is a highly undesirable, yet highly effective, way of stopping a vehicle. Turn 3 at Martinsville pushes back pretty hard, as do trees and telephone poles.

So, while it is nice to be aware of these secondary brake force mechanisms, the whole point of this book is to understand the contribution of the brake system components. Consequently, the rest of this chapter leaves these factors behind and focuses on brake forces occurring at the tire-to-road interface as a result of brake system operation.

Tire Slip

Tire slip, or simply slip, is the single most important concept in understanding any aspect of vehicle performance (at least in my humble opinion). Without slip, vehicles could neither accelerate, nor decelerate, nor turn, as a tire can only generate force when it is slipping. As you'll learn in a few moments, a tire that is not slipping is free rolling, or coasting, and a free-rolling tire does not generate any force at all (except for the small amount of brake force due to its internal rolling resistance).

Before going any further, let's clarify one important point: A tire does not need to be spinning wildly or skidding out of control to be slipping. Although these conditions are a result of a significant amount of slip, there are many other times where a slipping tire does not actually *look* like it's slipping at all. Yet for all practical purposes, any time your vehicle is in motion, its tires are slipping, even though you can't see it with the naked eye.

Applying this concept to brake system performance is relatively straightforward. In order for a tire to generate a brake force, it must be slipping relative to the road surface in the direction of travel (normally to a very small level, but it is slipping nonetheless). If a tire is not slipping, it is not generating any brake force (again, ignoring the brake force due to its internal rolling resistance).

Although that may sound odd, it makes more sense by taking a moment to formally define slip. Tire slip can be quantified mathematically by the following equation:

Tire Slip Calculations

The data in the table below illustrates how much tire slip would be present for given combinations of tire speed and vehicle speed.

	Tire speed	Vehicle speed	Tire slip
Condition 1	50 mph	50 mph	0%
Condition 2	45 mph	50 mph	10%
Condition 3	0 mph	50 mph	100%

So, what do these numbers mean? Well, a few observations can quickly be made:

1. Condition 1 indicates that when the tire speed (50 mph) is the same as the vehicle speed (50 mph), there is zero slip present. Because this is a free-rolling condition, there is no brake force present between the tire and the road. The vehicle will be coasting.

2. Condition 2 indicates that when the tire slows down (45 mph) relative to the vehicle (50 mph), the slip level increases (10 percent in this case). This is the slip range where most normal braking occurs.

3. Condition 3 represents a tire that has stopped spinning (0 mph) although the vehicle continues to speed along (50 mph), resulting in 100-percent slip. This is the classic "brakes locked up" situation, which is usually accompanied by screeching sounds and billowing tire smoke. Note that this condition is also commonly referred to as sliding or skidding and is generally an undesirable way to slow down a vehicle.

100 percent tire slip, also known as wheel lock, occurs if a vehicle is still moving yet the tire is no longer rotating. This may be amusing for the spectators, but it's not the most effective way to achieve the best possible stopping distance. (Wayne Flynn/pdxsports.com)