Pascal's Legacy
Mercedes-Benz Hydraulic Systems

Core principles, evolution, flushing, bleeding, and service tips.

When you think about it, it's pretty hard to believe that a teeny tiny column of fluid can transmit enough force to stop a ton or two of hurtling automobile, but that's the magic of hydraulics. Early cars used mechanical apply set ups – cams, cables, and levers. No matter how clever the design, however, they were almost impossible to equalize perfectly, and required constant adjustment, so the idea of using hydraulics to do the job intrigued engineers from the 1890s onward. But it took many years to develop reasonably dependable systems, so the first production cars with fluid pressure actuated brakes didn't appear until the early 1920s.

With refinements, hydraulic systems essentially the same as those originals got us through four decades. But in the mid 1960s the changes and complications started. First there were disc brake calipers and dual circuits with metering, proportioning, and a warning light, then came combination valves, diagonally split systems, low drag calipers, step bore masters, load sensitive proportioning, etc. ABS started another whole ball game that was to include the most important safety advances ever seen.

French genius and prodigy Blaise Pascal, who lived a short life in the 17th century, defined the law of physics upon which all hydraulic systems are based. ABS and its derivatives mess with it, but they can't violate it.

Opposite Page: You might be surprised when you first see the twin calipers on an electro-hydraulic brake system, but you can handle it.

A firm grasp of the modern Mercedes-Benz hydraulic system and the service procedures it requires is about as important to anybody doing brake work as knowing which way to turn a wrench. Unfortunately, we've found that lots of techs out there still have some fuzzy areas in that essential understanding and also harbor a few misconceptions and prejudices. So, we figured we'd better lay it all out for you, including some important service tips.

We've run many articles on the incredible advancements that Mercedes-Benz has made to control the hydraulic systems of its cars for the benefit of human safety, from ABS to ASR, ASC, ABR, etc., but here we're going to look at the core: how brake actuating pressure is generated and applied to the calipers, Pascal's Law, evolution, fluids, and real-world information involving calipers, lines, hoses, and potential problems.

Although he was also a mathematician, Christian philosopher, inventor, and writer, French scientist Blaise Pascal (1623-1662, a short, productive life) is mostly remembered for formulating Pascal's Law, also known in fluid mechanics as the principle of transmission of fluid pressure. It's simple, but profoundly important: Pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere. Just think of the implications!

You can extrapolate it to many practical uses, and combined with conservation of energy you get an understanding of why a small piston moved a long distance pushes a big piston a short distance, and how its force is multiplied – master and slave.

While ABS and related systems with their pumps and solenoid valves may seem to mess with Pascal's Law, they can never violate it.

Fail safe

The prime mover in brakes is the dual, split, or tandem master cylinder, which has been used on every car sold in this country since 1967. Believe it or not, plenty of people still aren't comfortably familiar with its construction and operation.

A typical modern specimen will be of the composite variety (in other words, aluminum with a plastic reservoir), but iron one piece units are still around in vintage vehicles. Two pistons ride in the bore, the rear piston being the primary, and the front the secondary.

Each piston has a primary cup at its front and a secondary at its rear, so you'll be hearing such combinations as

primary piston secondary seal, secondary piston secondary seal, etc. The primary seals are the most important because they trap the fluid that's about to be squeezed into the lines. The primary piston's secondary seal keeps fluid from escaping out of the back of the cylinder, and the secondary piston's secondary seal acts as a barrier to make two essentially separate cylinders out of one.

In normal braking, the pushrod from the pedal or booster forces the primary piston forward. No pressure is created until the primary seal covers the compensating, replenishing, or vent port from the reservoir, but once it does fluid is trapped in the chamber between the pistons and becomes, for all intents and purposes, a solid column. Pressure is routed from this chamber to two wheels. A combination of the trapped fluid and the primary piston coil spring bears on the secondary piston, moving it forward also and creating pressure in the chamber ahead of the secondary piston's primary seal, to which the line to the other two wheels is attached.

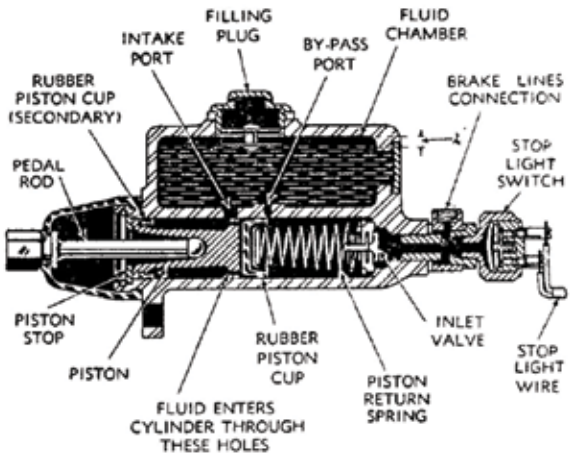
When the pedal is released, a partial vacuum occurs in both pressure chambers because the fluid is too lazy to return from the lines fast enough. So, in order to re arm the brakes instantaneously, the primary seals are designed to allow fluid to flow one way (forward) from behind each seal into the pressure chambers.

The replenishing ports allow fluid to move freely between the chambers behind both pistons' primary cups and the reservoir according to demand and expansion and contraction from temperature changes.

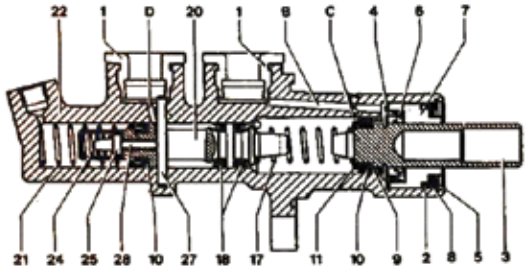
Blown

If a hose lets go or a saboteur has sawed through one of the brake lines so there's a catastrophic loss of fluid in half the system, the other half will still provide a means of decelerating the vehicle, albeit with a lower pedal and reduced stopping power. Both pistons have extensions which project out in front of their primary seals. A failure in the circuit that's connected to the primary piston's pressure chamber will allow the piston to move forward enough so the extension will bear on the secondary piston, push it ahead, and generate pressure in the other circuit. If, on the other hand, the circuit that gets its juice from the secondary chamber blows, the extension on the secondary piston will bottom out on the front of the cylinder and the fluid trapped between the pistons will operate the alternate set of brakes.

But a master cylinder alone does not an integrated brake system make. Means of fine tuning the pressure for the situation and warning the driver of a partial failure are equally important. All kinds of individual and combination valves have been used to perform the metering, proportioning, and warning light activation functions, but that's all ancient history now, especially with discs all around and ABS.



For two generations, this simple master cylinder design ruled vehicular deceleration. The whole function became much more complicated from the 1960s onward. The only place you'll see one of these today is on an antique, or a trailer surge brake.



1. Reservoir busing (rubber)
2. O-ring
3. Primary piston (primary circuit)
4. Stop washer
5. Snap ring
6. Secondary sleeve
7. Plastic Bushing
8. Stop washer
9. Filler washer
10. Primary sleeve
11. Supporting ring
12. Compression spring
13. Separating sleeve
14. Secondary piston (secondary circuit)
15. Compression spring
16. Housing
17. Valve spring
18. Valve seal
19. Cylinder pin
20. Valve pin

A. Filling bore
B. Compensating bore
C. Filing and compensating bore

Although it's been around for 50 years, many people still don't understand how the dual or tandem master cylinder works. We're sure the universal adoption of the idea may have saved lives.

Tubes

We've always been particularly concerned with the metal brake lines that route pressure to the wheels. Since we live near salt water, we often get cars in that have been partially dunked at a boat ramp, so much so that the double wall steel lines rust out, resulting in a complete loss of stopping power in that circuit. The same is true where lots of salt is used on the roads in winter.

If a line runs up over the chassis so that it's hard to see, use a mirror and your sense of touch to examine it. Replace lines if the rust has reached the scaly stage. When installing replacements, follow the original routing as closely as possible. We've heard of fade or low pedal problems because of a line being mounted too close to an exhaust pipe, or has a hump or loop in it that traps air.

All Mercedes-Benz vehicles use brake lines with the ISO (International Standards Organization) flare, which is not compatible with traditional domestic double flare tube seat connections. Because the shoulder of the nut bottoms in the fitting, sealing pressure is uniform and over tightening isn't a problem. Also, only one simple die is required to form the flare.

Standard double-wall steel brake lines serve us well, but be careful of corrosion. Note that this is the ISO flare that's used on all Mercedes-Benz vehicles.

It was once considered smart to isolate wheels using clamps like these. Not anymore. You'll crush the plastic lining.

Liquid link

Then there's brake fluid, the stuff that makes everything happen. Mercedes-Benz specifies DOT 4 glycol because of its high boiling point and its ability to hold a lot of moisture so that slugs of water don't form in the system. But in the past, that hygroscopic characteristic made another type seem attractive: silicone, rated DOT 5 and color coded purple. It doesn't absorb H_2O (so it was expected to practically eliminate corrosion), has a 500 deg. F. boiling point, and won't dissolve paint the way ordinary glycol does.

There were, however, unintended consequences in the use of DOT 5 that spelled its demise. First, as a brake engineer told us years ago, he had trouble getting cylinder and caliper seals to make it through the SAE longevity test with silicone because they got hard and wore out. Worse, any moisture that found its way into the system collected in slugs. When elevated temperatures were encountered, especially at high altitudes, these boiled into bubbles resulting in a total loss of stopping power. By the way, this stuff is in no way related to DOT 5.1, which is a glycol fluid. Regardless, your choice should always be Mercedes-Benz-branded DOT 4.

Misconceptions and profitable service

Now for some service tips that'll help you avoid problems. First, there's the myth that you should always clamp off the hose before bottoming out caliper pistons to keep from backflushing nasty sediment up into the works. That may have been fine in the old days of plain rubber hoses with braided reinforcement, but today's hoses have stiff plastic linings that may be crushed if clamped and stay that way. Just open the bleeder.

Then there's flushing and refilling the system with fresh fluid. In the old days, some brake experts said it wasn't worth the effort because you can't get all the old stuff out unless you disassemble the calipers. True, you won't be able to eliminate every drop of the contaminated liquid, but you can get most of it, and that will effectively reduce the amount of moisture in the circuits.

This has always been important for corrosion prevention, but now higher operating temperatures make maintaining

a high boiling point critical to safety even for the average motorist. Besides water, there's sediment, which is a combination of rust and the ashy residue of burned glycol. Expensive and intricate ABS and related hardware is further justification for this maintenance. Most systems are vented to the atmosphere, and there's also contamination from under hood vapors in some layouts. Fluid changes are cheap insurance against big bucks repairs.

For generations, Mercedes-Benz has recommended a two-year interval for this service, which you should recommend to your customers.

When the hose goes ...

Whenever you've got a car up in the air, take a careful look at the rubber hoses. In our shop, we've seen total circuit failures due to blown hoses several times. They're so well made they often last for the life of the car, but why push your luck? A related item is the high-pressure ABS hose between the pump and the accumulator, which sometimes carries a replacement interval of 60,000 miles.

Bubbles

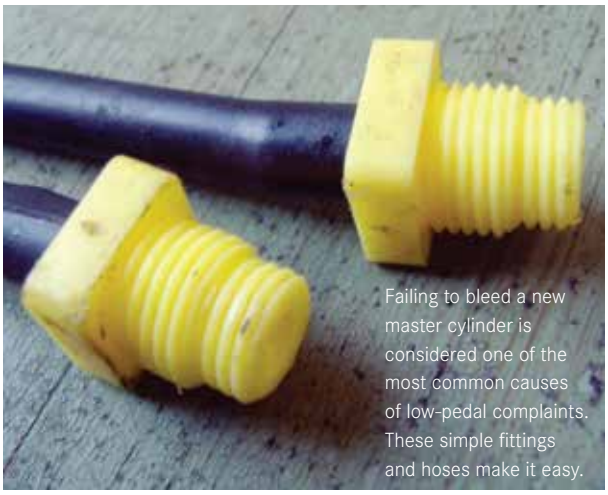
Air expulsion definitely deserves some space because there's more to it than just observing the proper sequence (Right rear, LR, RF, LF). Bench bleeding master cylinders, for instance. Brake experts have told us that neglecting this is the number one reason for spongy pedal complaints.

One way to block off a caliper for diagnosis is to use two copper washers and a nut and bolt on a banjo connection.

You can do this job by just holding your fingers over the outlet tubes to keep air from being drawn in on the return stroke, but that's pretty messy, so use tubes and fittings. Clamp one of the master's mounting ears in a vice so the unit is level. Position the tube tips well below the level of fluid in the reservoir, then use a rod or drift to stroke the piston SLOWLY. Wait at least 15 seconds between strokes to allow the chambers to release all their bubbles and fill completely. Keep stroking until there's no more evidence of air at the tube tips and ports.

Should you get a car with a replacement cylinder that some other tech didn't bench bleed, you might be able to do it with the master in place providing you can jack the rear of the vehicle high enough to get the cylinder level. Surge bleeding where you pound the pedal violently a bunch of times to get the bubbles mixed up with the fluid, then crack the line is frowned upon by experts who don't think aeration is ever a good idea.

While over the long history of hydraulic brakes numerous means of flushing and bleeding the system have been used, with a conventional brake system (master cylinder, ABS/



Failing to bleed a new master cylinder is considered one of the most common causes of low-pedal complaints. These simple fittings and hoses make it easy.

For a couple of decades, a scan tool has been required for proper bleeding and flushing. XENTRY handles the process.

ASR control unit, and calipers), the only procedure approved by Mercedes-Benz is the use of a pressure bleeding unit installed on the master cylinder reservoir, which keeps the reservoir full while the bleeders are opened.

As all of you know by now, proper bleeding requires the use of a scan tool. XENTRY, for example, will walk you through the procedure. We know seasoned technicians who say they do it "the old-fashioned way" without a scan tool on Mercedes-Benz systems and don't have problems. Personally, we wouldn't take the chance that entrained air might impair stopping in a panic situation.

Process of elimination

When you get a low-pedal complaint, you can find out all you need to know about the master cylinder by removing the lines, screwing brass or plastic plugs into the outlets, then applying the brakes. If the pedal's high and hard now, the master's properly bled and its seals are okay because the pedal would sink gradually if it were bypassing (that is, fluid is finding its way around the sliding seals).

Over the years, various testers have been available for finding out how much water the brake fluid has absorbed.

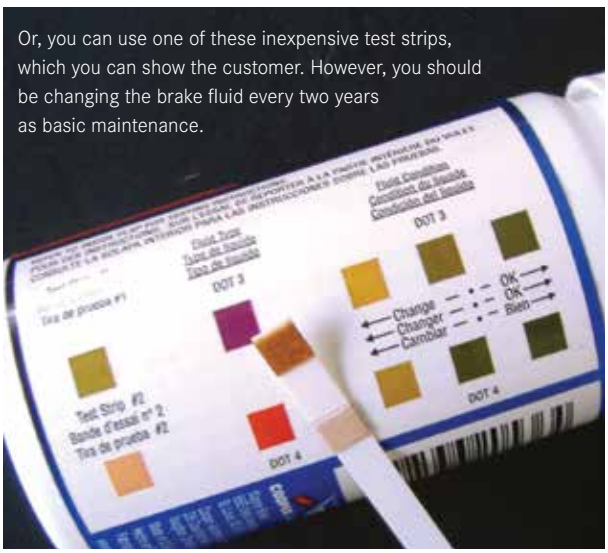
Continue in this investigation by blocking off hoses to isolate each wheel. As already mentioned, don't use clamps at the hoses. Instead, remove them from their calipers and cap them in whatever way you deem practical.

Seized!

Then there are the bleeder screws themselves. You haven't worked on cars very long if you haven't encountered a frozen one that wants to break off before opening. You can use the rather drastic and primitive method of clamping Vise Grips to the screw and shaking it while you heat the caliper around the port with a propane torch until it moves, but what's all that heat doing to the piston seals? Buying a pair of new calipers from your local Mercedes-Benz dealer's parts department is the professional alternative.

By the way, whenever you get a vehicle in that hasn't yet developed the problem, unscrew the bleeders and coat their threads with just a touch of anti seize compound. If you get it back later for brake work, you'll be glad you took the time.

In an ideal world, every caliper would be overhauled during a reline to insure against piston seizure and seal failure. That's what most authorities recommend. But when was the last time you encountered a leaky caliper? They last and last in most cases, especially if brake fluid changes are done regularly. So, if you're under time or cost pressure, you could just push those pistons back for a reline. One caveat: If you feel any roughness or binding as you force a piston home, you'd better get a genuine Mercedes-Benz replacement.



Or, you can use one of these inexpensive test strips, which you can show the customer. However, you should be changing the brake fluid every two years as basic maintenance.