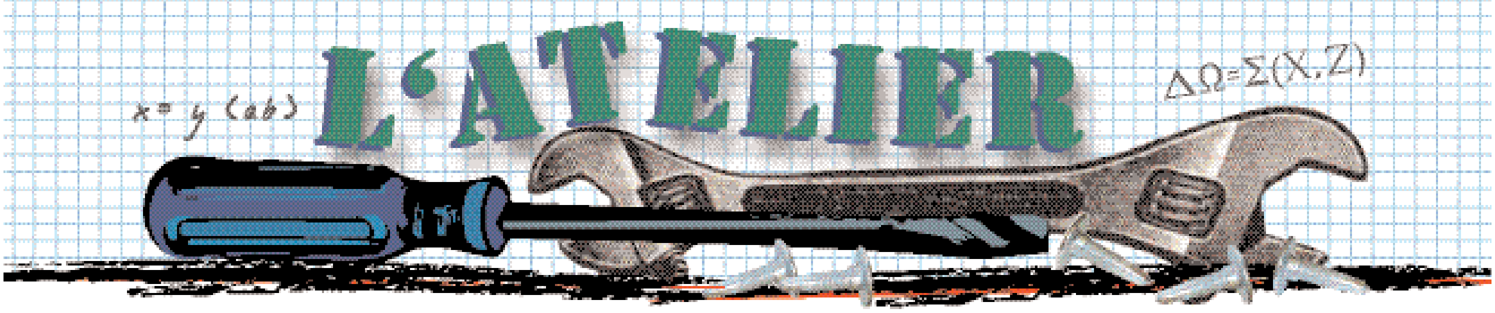


ABOUT BRAKES

To paraphrase a popular saying, what speeds up must slow down. With so much time, energy and effort expended on learning more about what makes snowmobiles go, we felt it appropriate to shift the focus on learning more about what makes them slow down and stop safely. We are pleased to present this overview on braking systems by technical wizard Kevin Cameron as he sheds light on this critical component that many of use take too much for granted. Enjoy the read.

Cars (and snowmobiles) today have generally capable brakes, but I am old enough to remember when it wasn't so. Tourists descending Whiteface Mountain in NY State sometimes arrived at the toll station with their brakes smoking from all the energy they had absorbed.

Clearly, a vehicle descending a mountain needs brakes capable of dissipating the energy released in the descent. Drum brakes went out of automotive use around 1970 because it was easier and cheaper to build capable, durable brakes in disc form. When a brake drum expands from braking heat, it not only expands away from the internal friction shoes, it also "bells", or expands more at its open than at its closed side. This makes it doubly hard to maintain full friction shoe contact. A properly mounted brake disc, on the other hand, does not deform as heat expands it, and it cannot get away from the pads as they are pressed against it from both sides by the caliper. Both disc surfaces are exposed to ambient air, so cooling is also superior to that of a drum.

NATURE OF FRICTION

When two surfaces are in contact – even surfaces that appear highly polished – only a very small percentage of their surface area is actually in contact. As the two solid surfaces are forced together, this area of true surface contact increases in more or less direct proportion to the applied force.

Because area of true contact is so small, local pressures within it are very high. As one surface slides on the other, frictional resistance to motion arises from micro-welding at these intense areas of contact. The welded regions are elastically stretched as sliding continues, producing a force that opposes the sliding. Friction is the sum of these forces. Ultimately the welded regions reach their elastic limits and the welds are broken – only to re-form farther on. Some material is plucked from the two surfaces by this process. These wear particles take the form of dust, which acts to further limit the area of true surface contact. The constant elastic stretching, breaking, and vibration of bonds in the material by this weld/fracture process is heat – molecular vibration. In this way, dry solid friction transforms mechanical energy – the force acting through a distance required to produce sliding between the brake surfaces – into heat energy.

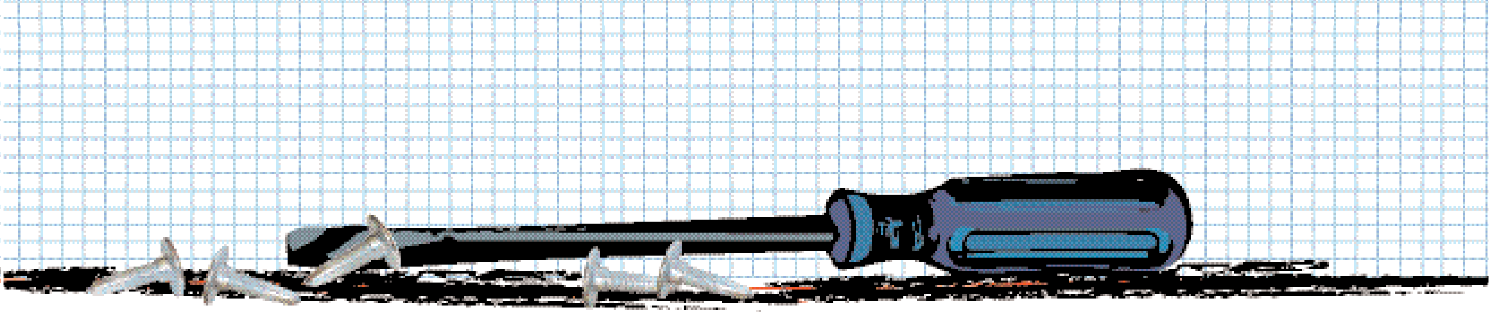
HYDRAULICS 101

Simple disc brakes have been made using a mechanical scissors mechanism, operated by cable, to press friction pads against the rotating disc. Slightly more sophisticated are mechanical calipers that use a low-friction ball-screw, operated by a lever and cable, to apply the clamping force. Modern snowmobiles, however, utilize hydraulic braking systems due to their smoother and more progressive operation.

A hydraulic system works by transforming the hydraulic pressure generated by the master cylinder piston (and carried via the brake line) into a mechanical force which presses the friction pad against the rotor. The actual force generated by the piston is equal to the line pressure multiplied by the surface of the moveable piston. In the case of a multiple piston design, the total force is equal to that of all the cylinders combined.

THE MASTER CYLINDER

The master cylinder consists of a small piston pump, operated by the brake lever, and connected to a small fluid reservoir. The reservoir is necessary to keep the system full as pad wear causes the caliper pistons to advance toward the disc. Releasing the brake lever allows the master cylinder piston to retract against its stop. In this position, it exposes a small hole connecting the master cylinder piston bore to the reservoir. This "return port" not only allows the system to take fluid as needed from the reservoir, but also permits heat-expanded fluid to return to the reservoir, preventing an overheated brake system



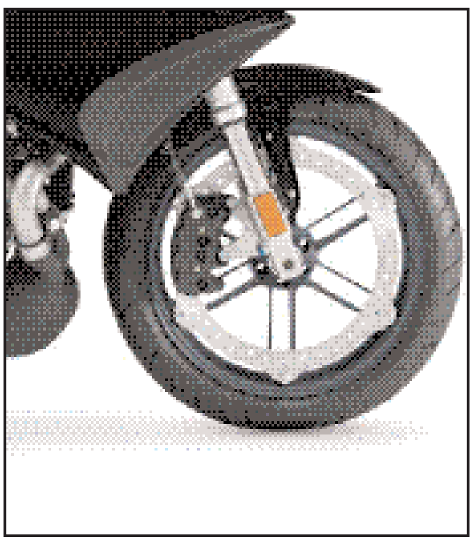
AND BRAKING

By Kevin Cameron

from applying itself. In the rare cases in which I have heard of disc brakes applying themselves, it has resulted from something preventing the master cylinder piston from fully returning to its stop. Then, with the return port blocked, fluid expansion can pressurize the system, applying the brake. This is the only way in which the system can remain under pressure without the brake being applied, that is, when the operator has released the brake lever. Always be sure the brake lever can return fully when released.

The master cylinder piston assembly has two seals on it. The second seal – located some distance back from the end seal, or "cup", is there to prevent fluid from leaking from the reservoir when application of the brake pushes the cup past the return port.

CALIPER TYPES



The simplest hydraulic caliper has a single piston on one side, and the whole caliper floats laterally on its mount to permit the caliper to move as its fixed pad wears. Two-piston calipers can be rigidly mounted because both pistons can move to compensate for wear.

The demand for increased braking performance over the years has resulted in the more widespread use of multiple-piston designs. For example, the new Buell 1125R sportbike uses an eight-piston caliper on its front wheel while four-piston designs are now commonplace.

CALIPER CONSTRUCTION

Low cost brake calipers are cast from aluminum in two pieces, which makes the machining of their piston bores easy. They are then assembled by bolts, with an internal or external line to balance pressures between the two sides.

A stronger construction begins with a single piece – no bolts – and the piston bores are finished through holes in one side, later closed with screw plugs. More recently so-called "monobloc" calipers are milled from solid wrought stock for added stiffness, and the piston bores are finished by a special device from within the pad space. No bore plugs are required.

PAD RETRACTION AND ADVANCE

When you apply the brakes, hydraulic pressure pushes the caliper pistons against the backs of the friction pads, advancing them about a tenth of a millimeter to press against the disc. When you release the brake, the elasticity of the elastomer caliper piston seals, gripping the pistons, retracts them very slightly, allowing the disc to spin without friction. When the pad wears enough to permit it, the caliper piston breaks this grip just enough to slide through its seal slightly, taking up a new position closer to the disc.

FRICTION MATERIALS

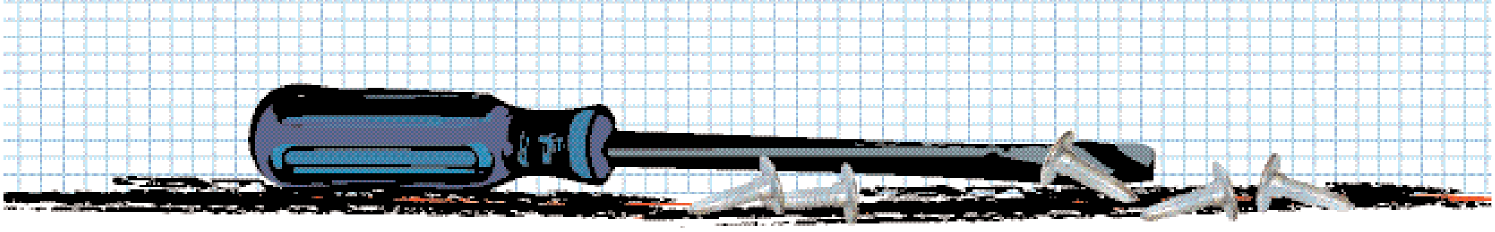
The common organic-based friction material, used for both brake shoe facing and for disc brake pads, generates gas at high temperature, reducing braking friction. Constituents of the friction material may also melt to form a "glaze" – a slick surface layer with poor friction. Organic friction materials can have poor grip when the friction surface is wet, making brakes weak initially in such conditions. As rising temperature boils off the water, friction increases rapidly, making brakes "grabby".

Providing superior performance in such conditions are pads containing metallic or ceramic constituents. These materials also, in general, provide higher friction than organics. Pad friction is expressed as "mu", which is the braking force at the pad, divided by the force pressing the pad against the disc. Typical mu for organic pads is 0.3-0.4, but with metallics or ceramics this can rise to 0.6 or so.

As you'd expect, such more aggressive materials can scratch or score the disc surface over time, but this isn't a beauty contest. We want good brake performance! Metallic pads conduct heat better than do organics, and so in some cases heat insulation or a ventilated spacer is placed between the pad and the caliper's operating piston to prevent brake heat from boiling the brake fluid inside the caliper.

WEDGE WEAR OF FRICTION PADS

If you use disc brakes hard you will notice that the leading edge regions of pads wear faster than trailing edges. Over time, this effect wears the pad into a wedge shape. This causes cocking of the caliper piston(s), possibly leading to jamming, poor retraction, or excessive motion at the brake lever. Various means are employed to prevent this. Discs may be grooved or drilled to provide escape for the brake pad dust and gas that causes this, or the pad surfaces may be interrupted by grooves. In the case of four- or six-piston calipers, multiple pads are used to avoid "wedge-wear" that would occur if just two long pads were used.



ROTOR MATERIALS

The ventilated disc (left) used on the new Yamaha FX Nytro, and the " wave" rotor as found on the Ski-Doo REV-XP sleds.

Plain discs of 400-series stainless or cast iron are in the majority but interesting variants exist. Ventilated discs are made with radial cooling air passages, as seen on certain Yamaha snowmobiles. Another style has extensive fluting of its OD, with oddly-shaped slots or holes through the disc material. Such "wave rotors" are claimed by makers to cool more rapidly than plain discs.

For the most severe braking, discs made of carbon-carbon may be used. Carbon discs were originally developed for aircraft (carbon is much lighter than iron or steel), was adopted in Formula One, and then about 1989 moved into GP motorcycles. The very high melting point of carbon keeps it functioning normally at temperatures that would melt iron discs into a glowing puddle. A cheaper alternative is a new material, still reinforced by carbon fibers, but mainly made of the very hard and temperature-tolerant ceramic silicon carbide. Carbon-carbon discs are black, while carbon-ceramic discs look like gray stone.

DISC WEIGHT VS OPERATING TEMPERATURE

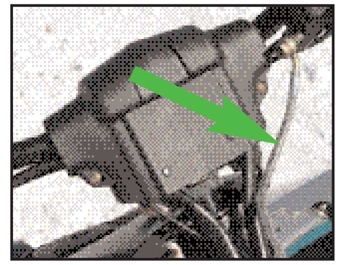
All brakes can fade, or become less effective, as their temperature rises. The smaller the mass of the brake disc, the hotter it will get in operation. As the brake is air-cooled, it is desirable that air circulation be provided around the disc – we have all seen the large flex hoses that carry air to cool the discs and calipers of racing cars.

In 1988 Honda decided to pare the considerable weight of the iron discs on its NSR500 GP bike to the minimum. They were rewarded at the Laguna Seca race by having their discs turn black from severe overheating. Pad wear was so accelerated that the friction pads were gone before the end of the race. If your brake disc is turning dark blue or black in use, you may need more disc mass.

BRAKE LEVERAGE

Common sense rules – the larger the diameter of the brake disc, the more leverage the caliper has. You can change the lever effort by changing the diameter of the master cylinder bore, and a small bore change causes a large change at the lever. The smaller the master cylinder bore, the smaller the effort required at the lever (or, conversely, the greater the line pressure for the same effort) – but there is a limit. As master cylinder bore is made smaller, lever travel increases – until eventually the lever comes in too far for safety.

PLUMBING



A braided-steel brake line as used on a late-model Arctic Cat.

Many options for hydraulic plumbing exist. Solid steel lines, as used on cars and trucks, are durable but long unsupported spans of such line should be supported to prevent vibration which has been known to crack such lines. Aftermarket suppliers offer aircraft-type flexible tube with braided stainless steel jacketing, joined by threaded compression fittings.

BRAKE FLUID

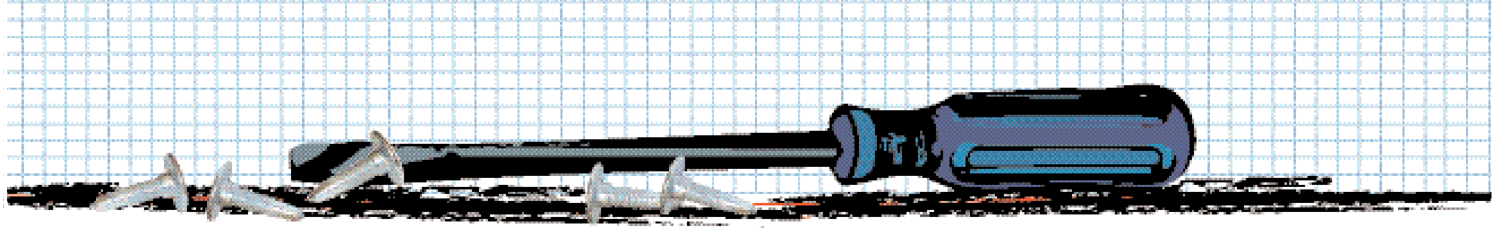
Brake fluids DOT-3, DOT-4, and DOT-5 are the choices. DOT-3 works well but must be kept from atmospheric moisture, which it absorbs with a resulting drop in its boiling point. DOT-4 is similar but with a higher boiling point. DOT-5 is a silicone fluid best avoided. It is a good idea to periodically disassemble and clean these brake systems, which are not as well weather-protected as those on cars and trucks. When you open up brake systems that have been in service for some time, crystals and gummy deposits are often found – neither of which is helpful to operation.

Do not use hydrocarbon solvents around brake system seals! As a cleaning solvent, use only brake fluid itself or isopropyl alcohol. Many have ignored this simple rule, and many have suffered swelling and/or failure of seals, with brakes stuck on when seals absorbed hydrocarbon solvents and swelled in place.

BRAKE SYSTEM BLEEDING

Bleeding of brake systems is necessary, periodically or after service and assembly, to remove trapped air that makes the lever springy or even prevents operation completely. I have usually found it best to remove the master cylinder, caliper, and line as a unit, then set them up for bleeding with the master cylinder lowest and the caliper above it. Place a piece of metal stock of disc thickness between the brake pads. Build up a slight pressure on the lever (being sure there is always plenty of fluid in the reservoir!) and have a helper crack open the bleed screw on the caliper, then close it. If repeating this process does not flush through the air bubbles to produce a firm lever, try tapping the line, especially at screwed fittings. Air loves to cling inside the banjo fittings common in brake systems, so it may even be necessary to loosen such fittings as if they were bleed screws, to let this air out. Sometimes I have wished I had a swimming pool full of DOT-3 so I could assemble the whole system there!

Occasionally you will encounter a system that will not hold pressure – the lever slowly goes down as you press against it. If the system is not leaking externally, it is leaking internally. The usual cause is corrosion on the bore of the master cylinder, letting fluid leak past the lip of the master cylinder piston seal. Because I have run into this more than once, I now examine the master cylinder bore in strong light before beginning to assemble it. All that's needed to produce this kind of corrosion is water absorbed into the brake fluid.



Take care with brake fluid because it removes many kinds of paint, and its avidity for moisture dries out any skin exposed to it for long. Protect especially your eyes!

Brakes are usually the last system to receive attention on a high-performance vehicle, but they deserve better.

DISC CONING

When brakes are used hard, the discs expand from the heat. If they are bolted rigidly to an aluminum disc carrier, hard use may result in disc coning. To check for this, lay a straightedge across the disc surface; there should be no gap between a flat disc and the straightedge.

To prevent such coning, brake manufacturers employ floating mounting. This transmits brake torque from disc to carrier, but allows the disc to freely expand/contract radially.

As brakes have worked harder and harder over the years, coning has occurred even with floating mounting. The cause is faster heating of the disc at its OD than at its ID – which is a result of the difference in sliding velocity and therefore frictional heating rate, between the two. The outside of the disc, being hotter, expands enough to permanently stretch the inner part of the disc. When the disc cools, its stretched inner portion is too big for the outer part, so the disc must assume a slight cone shape.

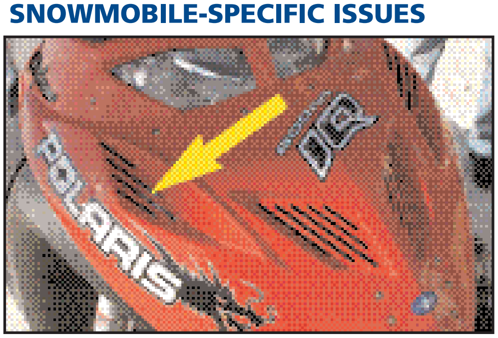
The cure for this has been to make the friction pads' track quite narrow radially, so that maximum and minimum sliding velocities are little different. To achieve this, pads have become longer around the disc, and narrower radially. To achieve uniform loading on such a pad (or pad array), each side of the disc must have two or three pistons.

WOBBLE, KNOCK-OFF

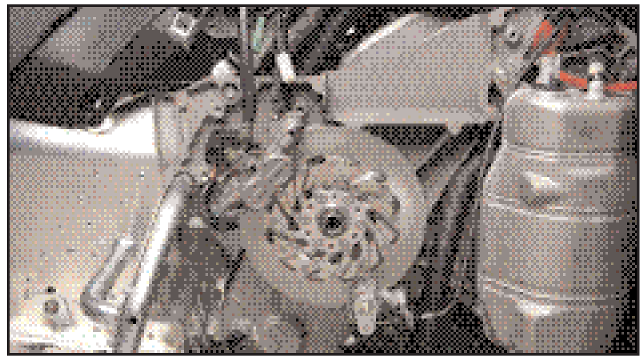
If brake rotors wobble more than about 0.10-mm you will feel it in the lever. If flex of the disc or caliper supports takes place in use, any motion of the disc between the caliper pistons may push the pistons back, resulting in a low or non-existent lever height the next time you go for the brakes. The car people call this "pad knock-off", and it can make life unnecessarily exciting. I mention it because it can be puzzling when you first encounter it.

Occasionally iron discs used hard will develop surface "hard spots", which also cause thumping at the lever. These are zones in which the metal has undergone a change of atomic stacking that causes a slight local increase in volume. Sometimes hard spots can be sanded off.

SNOWMOBILE-SPECIFIC ISSUES



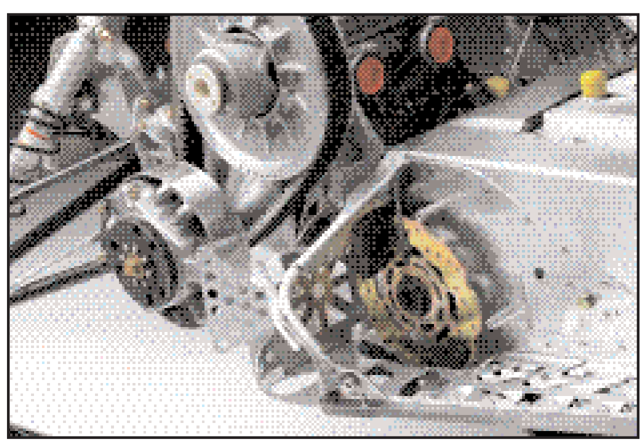
The cab on the new Polaris 600 RR comes with built-in air ducts designed to help cool the braking system.



The rotor on the FX Nytro is positioned outside the chaincase helping to improve access to cooling air.

Ironically, you may surprised to know that in spite of the fact that snowmobiles generally operate in cold temperatures, a sled's braking system must operate in one of the demanding environments of any vehicle, largely due to a lack of cooling. Unlike automobile or motorcycle applications in which calipers and rotors, the items most affected by heat build-up, are exposed to cooling air, these components are generally located inside the cab, well isolated from outside cooling air. Snowmobile designers try to alleviate this issue by numerous ways, ranging from integrating air ducts into the cab, to incorporating a cooling system into the caliper (as Polaris has done for years), or more recently, by re-locating the rotor and caliper assembly altogether (as Ski-Doo has done on the latest XP chassis).

The typical location of the brake system on the jackshaft presents another unique problem, this one even more critical as it involves safety. In a traditional chaincase design, braking forces are directed through the chain and gear assembly. In normal circumstances this is non-problematic (although it does result in premature wear of these parts) but in the event of a chain breakage, the rider can find himself in a dangerous situation where there is no braking whatsoever. Some newer designs (notably the Arctic Cat ACT system and Ski-Doo's XP chassis) position the brake assembly on the driveshaft itself, thereby circumventing the chaincase altogether and eliminating this possibility.



The placement of the brake rotor on the driveshaft on REV-XP models helps eliminate braking issues related to drive chain failure.