Brake Tech #01

The final word on brake judder and "warped" discs

In simple terms brake judder is experienced by the driver of a car as a pulsation through the brake pedal and/or side-to-side vibration of the steering wheel under braking. The above symptoms can be frustrating, disconcerting and result in driver complaints about "warped" brake discs. The phrase "warped brake discs" is used almost universally by uninformed vehicle owners to describe the cause of brake judder. The actual underlying causes of brake judder are, without a doubt, the most misunderstood aspect of automotive braking.

While it is possible for a brake disc to "warp" or distort (i.e. change shape) - disc distortion is responsible for relatively few brake judder complaints in our experience. **The overwhelming cause of brake judder is a condition called Disc Thickness Variation – period!** In other words the disc develops a lack of parallelism between its inboard and outboard friction surfaces. I say, "develops" because even discs that are machined to the very tightest tolerances during production can easily develop Disc Thickness Variation (hereafter referred to as: DTV) due to incorrect fitment or driver abuse.

When the brake pads are pressed up against a disc that has developed DTV they will pass over a series of thinner and thicker areas on the braking surface of the disc in rapid succession. Considering that the brake pads are being pushed together with substantial force they will be forced down into the 'cavities' or thinner areas only to be kicked back violently when reaching the bumps or 'thicker' areas. The frequency of this 'bouncing' action is typically over 100 Hertz when braking from highway speeds of around 130kph. This results in pulses that are transmitted through the caliper pistons, via the brake fluid to the driver, who experiences them as brake judder..

Causes of DTV

Once you understand the causes of DTV it becomes clear that brake judder problems can be almost completely eradicated by following a few simple rules. So, what causes DTV? DTV can be caused by a number of factors including disc fitment errors, driver abuse and poor manufacturing processes. The causes above are mentioned in order of their likelihood of occurrence.

DTV Cause No. 1: Failure to ensure that the mounting surface of the brake disc and hub are perfectly clean prior to disc fitment.

One of the most common causes of DTV is the failure of the fitter to properly clean the mounting surface of the disc and the vehicle's hub. The smallest fragment of dirt or rust scale caught between the mating surface of the disc and hub is magnified as you move towards the outside diameter of the disc. This results in an unacceptable amount of axial run-out (inboard-outboard movement) at the friction surfaces of the brake disc (the areas of the disc that come into contact with the brake pads). To put this into perspective, the maximum axial run-out measurement that Powerbrake™ will accept on a newly fitted disc is 0.08mm (measured in the centre of the friction surface of the disc). A single spec of rust scale measuring only 0.05mm (50 microns) in thickness trapped between the mounting surface of the disc and the hub can easily cause the axial run-out value to exceed this tolerance!

Once you have a brake disc that is fitted with unacceptable run-out you have entered a downward spiral that will lead to brake judder and irreversible disc damage over time. Every time you apply your brakes the pads will first come into contact with the disc at the point of maximum run-out. In fact, due to the fact that your brake pads retract only fractionally when you release your brakes, excessive run-out often causes a light, continuous rubbing of the disc against the pads at the point of maximum run-out. This is happening when you are off the brakes completely!

To understand what happens next we need to briefly discuss two broad categories of brake pads. The first category of pads relies more heavily on the concept of **abrasion** to slow your car down. In simple terms this involves the mechanical gripping and breaking off of opposing pad and disc materials at a molecular level. The materials literally wear each other away in the process. The harder material (typically the disc) will wear slower than the softer friction material of the brake pad.

The second category of pads relies more heavily on the concept of **adhesion**. In this case some of the pad friction material is transferred to across to the contact surface of the disc, where it forms a thin, uniform layer of friction material. Essentially you now have the friction material of the pad coming into contact with identical friction material that has been deposited on the surface of the disc. Under braking, the bonds between the friction material of the brake pad and the friction material deposited on the disc are constantly breaking and reforming. Material crosses the pad/disc interface in both directions as the molecular bonds continually break and reform.

All pad formulations use a combination of both abrasion and adhesion but some pads (such as common semi-metallic formulations) rely more heavily on abrasion and others (such as many high temperature 'Ferro-Carbon' fast-road and race formulations) rely far more heavily on adhesion. Abrasive and adhesive pads affect the formation of DTV in different ways.

Back to our brake disc that was fitted without the hub and mounting surface of the disc being carefully cleaned. Let's assume that the rust scale on the hub caused the disc to have a run-out of 0.1mm. On many vehicles this will NOT be felt as brake judder by the vehicle owner when he collects his vehicle from the fitment centre. He drives off a happy customer. However, after a period of between 1000 and 6000 kilometres of driving the brakes begin to develop a judder, which gets progressively worse. The vehicle owner complains to the fitment centre, who assumes that the discs have "warped"…right…wrong!

Even the best quality discs money could buy would have developed the same brake judder. Here's why…. As explained above, the disc was continually coming into contact with the pads at the point of maximum run-out first. If **abrasive** pads were being used this area of the disc would wear down quicker than the rest of the disc surface causing DTV, which is felt as an intrusive judder. If **adhesive** pads were being run then the pads would have deposited more material on the initial contact point (the area of max. run-out) than on the rest of the disc surface. Again this leads to DTV and brake judder. (See Figure 1 and 2)

Figure 1

Figure 2

It gets worse! Once you have the development of DTV the surface of the disc will begin to heat unevenly. The high spots will get extremely hot compared to the rest of the disc. When the temperature around these high spots reaches 650 – 700°C. the cast iron in that area will change structurally and transform into a material called Cementite. Cementite is far harder than the cast iron of the unaffected parts of the disc and will therefore wear considerably less as the disc wears down with use. Cementite also has very poor heat sink properties and will therefore continue to run extremely hot resulting in the rapid spread of the Cementite formation deeper and deeper into the disc. As a result the DTV will get progressively worse with time until it becomes literally unbearable to use the brakes. Depending on the pads used and the driving style of the vehicle owner this process could take 1000 – 6000 kilometres to develop and, NO, the initial run-out will not necessarily be felt by the driver. Hence the confusion and clinging to the concept of brake discs "warping".

The disc has now entered as self-defeating spiral that will very quickly become irreversible. Disc 'skimming' will only help if the formation of Cementite has just begun on the disc surface. Once the formation of the Cementite has spread deeper into the disc material, skimming will only remove the surface layer but the DTV (and judder) will return as the Cementite wears less than the surrounding cast iron. If you consider that VERY few mechanics ever bother to clean the disc mounting surface or the inevitable rust scale from the surface of the hub when fitting new brake discs, the magnitude of the problem becomes clear. Of course, the exact same thing will occur if a new disc is fitting to a distorted hub that is not running true. Distorted hubs are a reasonably common occurrence after a vehicle has been in an accident but we find that the overwhelming cause is a dirty hub!

DTV Cause No. 2: Improper bedding-in of new discs and pads.

After fitting a new set of discs and pads (or when running a set of used pads on new discs) it is ABSOLUTELY CRITICAL that the correct bed-in procedure be followed! It is important that an even, consistent layer of friction material is transferred from the pads to the disc surface before the brakes are run at very high temperatures. This material transfer is normally best achieved under moderate braking at low to medium brake temperatures. Most pad manufacturers issue clear bed-in instructions. If not, you need to read our Brake Tech article #2: Correct bedding-in of new brake discs and pads. If the flashpoint temperature (the temperature at the interface between the discs and pads) gets too hot, before an even layer of friction material has been established, material transfer will become random and erratic resulting in uneven, spot material transfer and the formation of DTV. (See Figure 3). We've already established what happens after that…

Figure 3

Apart from causing uneven friction material transfer, failure to follow the correct bed-in procedure can also lead to distortion (change in shape) of new discs. The distortion will once again result in axial run-out, the formation of DTV and brake judder (see article on Distortion). Understand this – brake pads and discs are not like a new performance exhaust system that you can fit to your vehicle and then go out and drive hard

immediately to test your new modification. With new brake discs and pads you have a very simple choice - Bed them in correctly or you WILL destroy them and cost yourself money!

DTV Cause No. 3: Fitting the wrong brake pad compound for your driving style.

All brake pads have a temperature range that they are designed to operate within. If you exceed that temperature range, you will set into motion a chain of events that can ruin your pads AND discs in no time. Even if you took the time to bed your new discs and pads in correctly and establish an even, consistent layer of friction material transfer on the disc surface, you still need to keep flashpoint temperatures within the operating limits of the friction material that you are using.

If you exceed the pads maximum temperature limit the pad will again begin to transfer friction material in a random and uneven pattern (See Figure 3) leading to formation of DTV and all the resulting long term hassles. Although this will happen at a far higher temperature than it would have before the pads and discs were bedded-in, it will happen nevertheless. The solution is to run a pad compound that is designed to work optimally at the temperatures that your driving style produces. In other words - Match your brake pads to your driving style.

I don't want to get into a lengthy discussion about pad compounds, which can get extremely complex. What I do want to point out is that there is no miracle "All round brake pad" that will offer perfect friction, no noise and smooth braking for all tasks ranging from taking the kids to school to doing hard laps at a weekend track day! If your driving needs are that diverse you will have to either compromise or get more than one set of brake pads and change them before club events or track days.

Generally speaking, pads that are designed for everyday commuting will offer good friction from cold up to disc temperatures of around 350°C. They should offer a smooth comfortable brake action and be relatively noise free. Pads designed for high temperature use (over 350°C) will generally offer reasonably poor cold friction and be noisier, less comfortable and often dust terribly. Some fast-road pads will offer acceptable cold-friction and remain consistent to about 500 – 550°C. These pads tend to offer acceptable, rather than good, comfort and noise characteristics. In many cases they will not withstand the temperatures associated with serious club events, track days or even extreme road driving.

Beware of scenarios where you fit standard road pads to your wife's car, not taking into account that your 18-year-old son has just got his driver's license and thinks he is Michael Schumacher. Also beware of fitting high temperature pads to your sports car and not telling your wife about the reasonably low cold-friction characteristics. If you decide to have two sets of pads, then be sure to fit the high-temperature pads a week or two before an upcoming club event or track day in order to re-bed the discs and replace the old friction deposits with a transfer layer from the performance pads. Failure to do this will result in poor brake performance on the day and can damage your discs.

Please don't choose a brake pad because your friend says it works well when it's hot. You would not believe the amount of misinformation and urban legend that we hear on a daily basis with regards to pad compounds. Find out from the manufacturer of the pads whether they suite your intended application!! As far as price is concerned, you get what you pay for. Performance pads cost more to produce than standard road pads do. We strongly suggest spending the money and getting the right pads for the job but it's your life at the end of the day…

Disc temperatures - rough guidelines:

- Normal urban commuting: 80 - 250°C.
- Braking from highway speeds: 200 - 350°C.
- Consecutive heavy braking: 300 - 550°C.

- Continuous consecutive heavy braking without cooling periods (abuse): 550 - 800°C.
- Closed circuit racing with OE brake systems (Production Car Racing): 500 - 900°C.

DTV Cause No. 4: Severe overheating of your brake discs

As discussed above, cast iron will transform into super-hard material called Cementite at temperatures of around 650 – 700°C. We've established that Cementite will wear slower than the surrounding cast iron and will therefore lead to DTV as the disc wears. What we see in discs that are run regularly at temperatures exceeding 610°C is that Cementite formations typically first start to appear in the areas of the disc that fall between the underlying cooling vanes of the rotor. This makes perfect sense, as there is less material in contact with these areas of the disc to absorb and distribute the heat. As a result the areas between vanes run hotter and will start to transform earlier than the areas that have vanes directly beneath them. Cementite formations are normally visible as blue/black areas on the disc surface. (See Figure 4)

Figure 4

What are the causes of severe disc overheating? First and foremost - driving style. We have worked with numerous car enthusiasts and racecar drivers that are fast but do not destroy brakes. On the other hand we come across people regularly who manage to reach disc temperatures of 800°C on urban roads. This is absolutely nothing to be proud of!

It is very simple to destroy any set of brake discs. Your brakes convert kinetic energy into heat in order to slow your vehicle. A medium size sedan will produce enough heat when stopping from 80km/h to boil 2 litres of water in 3 seconds. A typical driver will apply their brakes about once every kilometer, which means that an average brake disc is expected to go through this extreme heating and cooling cycle around 100 000 times in its life. If the driver knows how to use their brakes correctly this will not be a problem.

Discs are designed to cool rapidly between brake applications. Typically, after severe (emergency) applications the discs will be allowed to cool. The problem arises when the brakes are used hard in rapid and continuous succession without allowing the discs enough cooling time between applications. This creates a compounding of excess heat that will quickly run over the crucial 610°C mark.

So the message is simple – By all means, use your brakes hard when you need to but you MUST allow enough cooling time between applications for the disc to cool.

All Powerbrake™ discs feature our unique Max Temp Recording (MTR) heat sensitive paint system that allows our customers to establish the maximum temperature that their discs are reaching. (See Figure 5)

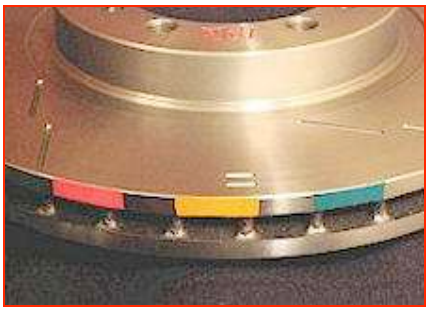

Figure 5

The other common cause for severe overheating is sticking (unlubricated or rusted) guidebolts or pins on calipers. It is ABSOLUTELY ESSENTIAL to lubricate caliper guide bolts and pins when changing brake pads. If the guide bolts are damaged or badly rusted they MUST be replaced. Sticking guide bolts will cause your brake pads to drag constantly on the disc, even when you are off the brakes. Even a light dragging action WILL overheat and destroy a brake disc.

DTV Cause No. 5: Pad Etching

Whenever possible you should try not to come to a complete stop and leave your foot on the brake pedal when your discs are very hot. Of course it is no problem to leave the brakes applied at intersections etc. during normal urban driving because the brakes are not excessively hot under these conditions. Discs will be very hot after heavy consecutive braking or a long brake application from high speed. Leaving the brake pads clamped to a very hot disc will lead to 'pad etching' or 'pad welding' in which friction material from the pads will be unevenly deposited on the disc surface at the point of contact. This can lead to DTV and will often be visible to the eye as the outline of a brake pad on the surface of the disc.

Bear in mind that when you stop the discs no longer have air flowing over them, which means that they will cool far slower than if you were moving! People who do track days need to pay particular attention to pad etching. DO NOT pull into the pits and stop with your foot on the brake pedal after a fast lap! This will lead to pad etching, among other problems. The reason that racecar drivers have cool down laps is to allow their brakes (and other components) to cool to more moderate temperatures before parking the vehicle. So, if you have been indulging in some fast-road driving or have braked from high speed on a highway off-ramp it is not a bad idea to let your car roll back slightly (if there is no traffic behind you) or gently edge forwards rather than leaving the brakes applied at the intersection. Also, try to slow down and allow your brakes to cool slightly before arriving home and parking your car.

DTV Cause No. 6 – Manufacturing errors

Up to this point all of the causes of DTV that we have covered have been a result of fitment or driver error. Can DTV be caused by poor manufacturing practices? Yes, manufacturing errors can lead to DTV. We regularly buy OE and aftermarket discs and inspect them for manufacturing quality. Although we do come across discs that have unacceptable DTV measurements (a lack of parallelism) from the factory, it is more common to find discs leave the factory with excessive run-out measurements. A new disc with DTV will result in judder being felt almost immediately after fitment and getting progressively worse. A new disc with run-out may only develop DTV and judder at mileages of between 1000 and 6000 kilometres.

The other common manufacturing fault is severe mass imbalance due to core-shift in the casting process. Of course this leads to balance problems but more importantly it can lead to differing operating temperatures on the surface of the disc due to differences in material thickness and therefore heat sink. This can lead to disc distortion and uneven friction material deposits. All Powerbrake™ discs are inspected for core shift and machine balanced prior to packaging and shipment. (See Figure 6)

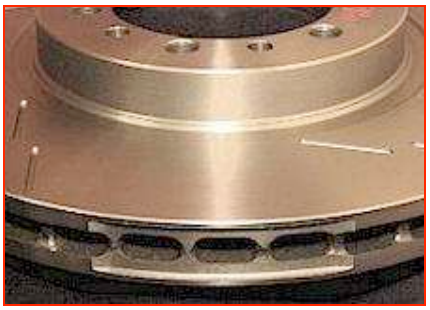

Figure 6

Powerbrake™ discs are machined to tolerances up to 3 times tighter than the norm in order to ensure perfect brake function. In addition to this EVERY SINGLE Powerbrake™ disc is measured in all critical dimensions prior to packaging and shipment. Measuring is performed using equipment capable of measuring accurately in increments of 0.005mm (5 microns).

We will NEVER ship a disc that has unacceptable run-out or DTV – period! This 100% inspection policy is extremely rare from disc manufacturers and is just one of the reasons that we are extremely confident in our finished product.

Rules for avoiding DTV

As mentioned earlier the development of DTV can be almost completely eradicated by following a few simple rules. Here they are:

- Ensure that BOTH the mounting surface of the disc (normally the inside of the hat) and the vehicle's hub are PERFECTLY CLEAN and free from rust scale or any other form of dirt. The disc can be cleaned using a cloth and suitable solvent. The hub should be cleaned using a soft wire brush or emery paper followed by wiping with a cloth and solvent until perfectly silver.

- Insist that the fitter measures disc run-out with a dial gauge after fitting each new disc. This takes no longer than 5 minutes per side and is definitely worth the effort! If the run-out value exceeds 0.08mm the disc must be removed and the hub re-cleaned. If the problem persists then the hub should be measured for run-out using the dial gauge. A hub run-out in excess of 0.04mm is problematic.

- Always bed-in new brake discs and pads according to manufacturer's recommendations. This allows for an even, uniform layer of friction material to be deposited on the disc surface, creates a proper wear pattern and avoids disc distortion. For more information see the Brake Tech article #2: Correct bedding-in of new brake discs and pads.

- Select the correct pad compound for your driving style. If necessary have two sets of pads. One for road use and one for club events and track days. Always bed-in your high-temperature pads for a week prior to a track day or club event.

- Avoid running your discs at temperatures over 610°C. This can be achieved by allowing the discs sufficient time to cool between brake applications. Continuous, consecutive heavy braking in rapid succession destroys discs and pads. Ensure that the guide bolts and pins in your calipers are well lubricated, free of rust and moving freely.

- Do not leave your foot on the brake pedal when you stop with extremely hot brake discs. Slow down and allow the passing air to cool your brakes to a moderate temperature before parking the vehicle.

- Buy brake discs from a manufacturer that checks every single disc for DTV and run-out prior to shipment.

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