

New Developments of an On-Vehicle Brake Pad Waste Collection System

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ABSTRACT

The design of a braking system involves a delicate balance between the friction pair, the disc and pad, where the pad is a complex blend of constituents to provide predictable characteristics, typically, a known and consistent friction level. In its base form the brake has to absorb the vehicle kinetic energy by converting it into heat. This heat absorption by the friction pair can result in chemical and physical interactions with the release of debris about which we know little. Other than environmental concerns, brake dust causes unnecessary problems with wear, thermal gradients (hot banding) and NVH. This paper is concerned with the removal and collection of brake debris from the friction interface - the debris being regarded as solids and airborne particles, the latter less than 10µm in size. The test procedure consisted of a Burnish program followed by 8 different drive cycles. The overall effects of debris removal is then reported for each test. It will be shown that, by careful design of air circulation within a collection system, over 92% of dust generated may be removed and collected. It will also be shown that debris collection results in reduced rotor and pad wear and that the brake temperatures during the braking event are not significantly affected. The impact on brake cooling and brake operating temperatures during a customer usage-based braking schedule are under study. The implementation of providing a solution "at source" may provide the automotive industry with a system to meet current U.S. legislative requirements. It will also help to satisfy future costly global legislation. In addition the module will serve as a "real life" mobile laboratory where the OEMs may gather data from the filters to gain a greater understanding of the characteristics of the debris generated during braking - saving time and money on research. This is the first paper in a series which introduces the benefits of using the on-vehicle CBPModular brake wear debris collection system.

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INTRODUCTION

Emissions from road vehicles has so far concentrated on exhaust gases and as such regulation has been limited/focused in that direction. Following increasing global concerns regarding environmental issues there is some move towards extending regulations to "whole vehicle emissions", which will include tyre and brake debris. This concern is exemplified by the demand for low copper pads following the discovery of high concentrations of copper in San Francisco Bay in part as a result of copper-containing brake debris being washed into the bay with each rainfall. It is difficult to confirm or contradict such claims because effective dust collection has never been considered necessary, or viable.

In 2015 the number of vehicles on the road exceeded 1.25 billion, 0.32 billion in the USA. In the same year global production exceeded 90.6 million, 68.6 million being cars (4.2 million USA) and 22 million commercial (8 million USA). The production numbers (OICA) do not include 2-wheelers or trailers. The numbers suggest that there are a minimum of 5 billion brake heads or 10 billion friction interfaces - all sources of brake debris emissions.

The launch of new models often involve the design of new brake systems, or at least, modified designs that take account of new legislation, as issued by appropriate bodies. It is the case that all OEM suppliers need to meet the approval of all countries so, although the regulations may not apply to their regional base, the destination country "rules" must be satisfied. It is also the case that if one country, or region, imposes a new regulation then it may be adopted in more regions - and the OEM and lower tier suppliers need to be in a position to meet such changes.

The primary function of a brake system is to decelerate a vehicle in a controlled manner. In addition to this basic function the brake designer has to satisfy ever increasing constraints and challenges, typically, weight reduction, smaller envelope, enhanced rigidity, improved response, better "feel", thermal issues, improved NVH demands it goes on. Focal to many of these issues involve the friction material formulation. In this regard the designer works closely with the formulator to ensure reliable, predictable and consistent characteristics over its lifetime of use. In this regard the interface friction level is paramount, yet reliable measurement of its magnitude is difficult to determine over the range of parameters of concern - temperatures, pressures and speed.

features such as wear, compressibility and strength. In general, if a parameter can be measured it is. Others such as dynamic shear of the interface μ /velocity slope are difficult to measure so are not readily available for use by the brake engineer. Last in line is dust generation - it only being of concern if warranty claims regarding appearance (dirty brakes) or wheel-hub corrosion become significant. Such is the problem that JD Power [1] now list it as a quality issue and an annoyance to customers "because it simply does not go away". This concern led to the "Sustainable Conservation" bringing together representatives of brake manufacturers and other interested stakeholders under the banner "Brake Pad Partnership" [2]. The investigations stated that some 50% of brake dust becomes airborne, about 12% falls to the road and 38 % sticks to the car, to be washed off eventually. The Partnership estimated that in 2010 some 580tons of copper found its way into the California waterways. A principal recommendation was "source control" rather than water treatment. In 2010 the "Partnership" research led to the signing of Senate Bill (SB) 346 [3] - legislation to phase out copper from vehicle brake pads. In brief it limits copper in pads to 5% by 2021 and 0.5% by 2025. Initially this only covered the State of California but has since been adopted by Washington State.

Within the last decade brake dust has become more of a concern with regard to health issues. With regard to human health it is the airborne particles that are of concern, particles less than $10\mu\text{m}$ (PM10) - the 50% proportion of generated brake dust. Driven by concerns of exhaust emissions, the European Environment Agency [4] has completed research regarding airborne emissions of PM 10 and PM 2.5 to establish the source of such particles. This led to a European Commission [5] which identified non-exhaust emissions to be as significant as exhaust emissions. With the anticipated reduction of exhaust emissions it was estimated that non-exhaust air pollution from vehicles will consist of brake wear 16 - 55%, tyre wear 5-30% and resuspension 28-59%. It is suggested that future legislation will be extended to total vehicle emissions that will include tyre and brake debris. To continue this work the EU has funded "ReBrake" [6] - industry/academic research studies to better understand particle generation mechanisms and to evaluate the possibility of reducing particle generation. The airborne particles are being studied extensively with some research concluding "*the identified compounds are known to have adverse effects even with mutagenic and carcinogenic potency to humans*" [7].

THE BRAKE PAD WASTE COLLECTION MODULE

Although the definition of emitting no copper or other debris must be defined, the module as defined below potentially satisfies the Senate Bill, "SB-346 Hazardous materials: motor vehicle brake friction materials SEC. 2" exemption rule which states:

"25250.55. Brake friction materials for the following motor vehicle classes are exempt from this article:

- (b). **Vehicles employing internal closed oil immersed brakes, or a similar brake system that is fully contained and emits no copper, other debris, or fluids under normal operating conditions".**

General Design of the BPWCS

The Brake Pad Waste Collection System (BPWCS) is designed to have no moving parts and to have no contact with any moving part of the brake. It comprises 2 halves, clamped together such that the pair nearly totally encloses the rotor and caliper. The assembly encapsulates the brake using existing mounts and existing fixings. The 2 halves are assembled in such a manner to allow for clean airflow through the vented disc and so ensure continued cooling of the rotor. The gap between the 2 halves is adjustable and airflow through the vented disc is adjustable to optimize cooling and debris collection. The module is generally as shown in [Figure 1](#).

A feature of the design is that the caliper is still visible so vehicle manufacturers that wish to use their view is still maintained. In addition the outer surface of the casing may be personalized to emphasise the character of the vehicle. As such the outer casing may be constructed of carbon fiber, glass fiber or anodized aluminium alloy.



Figure 1. The Brake Pad Waste Collection System as mounted to the knuckle assembly. Left - general view, Right - side view.

[Figure 2](#) shows a wheel rim with and without the module fitted.



Figure 2. Left - Wheel rim with the module fitted, Right - Wheel rim without the module fitted.

Operating Principle of the BPWCS

A vented disc acts as a centrifugal pump impeller with air flowing from the inner rim of the blades to the outer rim of the disc. Airflow is through the vents and along the outsides of the blades. The module design takes advantage of this process. [Figure 3](#) shows the general airflow about and within the vented disc and also within the module.

Clean air flows in at the bottom and flows radially outwards through the vents and along the outside of the blades. At the outer edge of the disc the module employs 2 lipped members to “tap-off” a given amount of the vent airflow. This “tapped-off” portion of airflow (Module airflow) is dictated by the degree of lip overhang into the vent outlet area. The module airflow is directed into a bypass channel formed by the module outer casing and a middle “C” shaped guide ring to an outer high pressure region. Because of the lower pressure at the inner radius of the disc the air flows downwards and back towards the disc surface. At the disc surface the module airflow is joined by the disc surface airflow which is driven outwards to the outer rim of the disc. At this point a second lip then guides the total airflow around and into a filter channel and is then forced through the filters and back towards the disc surface where it “scrubs” the disc surface of dust, to return it back to the filter.

Some air will “leak” from the recirculating airflow at the outer ring of the disc but it is then met by the “tapped-off” airflow and guided back into the bypass duct and filter duct. The air is thus constantly recycled and filtered. Once the recycling process has been established (whenever the wheel is rotating) the majority of air will pass through the disc vent so maximizing cooling.

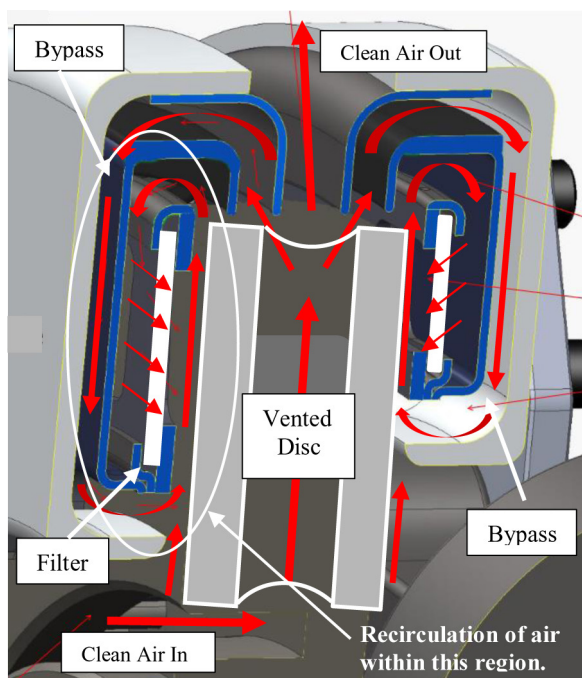


Figure 3. Airflow through the vented disc and within the module.

The module being tested is the prototype version. Further design developments have been completed which will enhance the performance of the module significantly. Additional testing of the new design is currently being initiated. Regardless of the unit being a prototype, it will be shown (within the test results section) that the temperature of the disc during the braking event is not elevated by the presence of the module and in many cases it reduces. It is appropriate

to answer this observation at this point in order to explain this temperature reduction. Because the air is to some degree restricted from flowing around the outer sides of the disc then more air is encouraged to pass through the disc vents which in turn increases the turbulence of the air. This reduces the surface heat transfer coefficient and this, combined with the increased airflow, results in a lower overall disc temperature.

TEST PROCEDURES FOR THE BPWCS

To undertake an independent and professional appraisal of the performance of the module, the test procedure was completed by LINK Engineering within their North American Laboratory in Detroit. It complied with test procedure SAE J2707 METHOD B, 1 SHIFT. The SAE J2707 procedure was used for tests with and without the use of the CBPModule so that this was an apples to apples comparison. The present series of dynamometer tests is designed to confirm the collection of wear debris as well as consider cooling more closely but within the limits of this screening procedure. An industry standard temperature/wear procedure will be used eventually to quantify the cooling capabilities of the CBPModule and accompanying impact to life of the friction material and rotor. Wear and other potential performance characteristics such as noise damping properties will be evaluated separately for each application using the appropriate testing procedures for both dynamometers and vehicles. The procedure is also used by the European Commission Programme [8]. The platform was a 2005 Dodge Caravan front brake. The Dynamometer was 17 - model 3599. Measurements included the interface friction coefficient, original and final temperatures of disc and both the inner & outer pad. The testing procedure established a baseline test (brake without the module) and then the same testing procedure with the module fitted. The stop list details are as listed in Table 1.

Table 1. Details of individual tests.

TEST		Speed (kph)		Average Decel ⁿ (g)	Average Torque (Nm)	Target Disc Temp °C
		Max	Min			
	BURNISH	50	4	0.25	675	100
1	Town (#1)	50	4	0.25	675	150
2	Highway (#1)	149	80	0.4	1072	150
3	Country Road (#1)	80	4	0.35	952	200
4	Town (#2)	80	4	0.25	679	125
5	Highway (#2)	180	80	0.5	1339	100
6	Country Road (#2)	100	4	0.4	1083	150
7	Country Road (#3)	100	4	0.4	1088	125
8	Hill descent	80	4	0.35	938	345