Understanding Motorcycle **Crankcase Breathing**

by Rex Bunn

MOTORCYCLE CRANKCASE BREATHING remains under-researched and poorly understood. Yet it causes daily problems with oil leaks, poor running and fouled air cleaners.

The classic engine designers such as Ricardo and Irving overlooked this aspect of engine design. This oversight persisted into the 1960s, when emissions laws further obscured the subject. When I started researching crankcase breathing a decade ago, global patent searches showed little research activity. Only in the last couple of years has it become a priority with race engineers like A. Graham Bell.

For road-bike riders, little has changed with today's marques. Current engines feature the same breathing problems as vintage engines. Our research suggests that significant improvements can be made to oil-tightness, power and service-life by making simple improvements to crankcase breathing.

How Do Crankcases Breathe?

In four-stroke singles, parallel twins, V-twins and boxer designs (but not triples) air is drawn into the crankcase as pistons rise. On the power stroke, combustion gas also escapes past the piston rings into the sump as "blow-by vapor." As the pistons fall, this crankcase air mixture compresses and its pressure rises because the crankcase is a nearly closed vessel. During daily riding, over millions of engine strokes, these crankcase "pressure spikes" alternately suck and blow at gaskets and seals. Air is forced through joints, unions and porous castings. And although the crankcase is vented, at least in theory, to let some of this gas escape via a breather, what happens in practice is often different.

Early Factory Breathers

Classic US and British manufacturers vented their engines with open tubes, flapper valves and timed breathers. Early check valves were hampered by materials technology, such as fibrous seals, which were heavy with high stiction. The timed breathers, as used by Harley-Davidson, were successful at cutting return flow, but they weren't as good at passing large volumes of air like an open breather. A timed shaft breather may only be open for 8% of shaft rotation, which results in little blow-by gas getting out.

In older modified engines with different cams and valve timing, the original breather settings may no longer apply.

Daimler's Einspur engine may have had the first crankcase breather in 1885.

And in competition engines, blow-by volumes can ramp up at peak revs due to ring flutter, and a timed breather can be found insufficient to deal with the flow.

Classic designers often engineered crankcases to operate with a small vacuum as they tried to control oil leaks. As the conservation of vintage bikes has been a personal priority, I have learned how one can improve on these early systems with new breather technology in order to keep these classic engines working more efficiently, while also purging blow-by and cutting oil leaks.

What Drives Today's Engine Breather Design?

Since 1980, EPA requirements partly explain why little crankcase breathing research has been done in the US and elsewhere. The EPA set a zero emission of crankcase gas for motorcycle engines. There was no quantitative test for this, only a visual test that prohibited breather tubes venting to the atmosphere. As automotive-style PCV valves aren't appropriate for motorcycle engines, manufacturers were obliged to recycle blow-by into the air intakes with sometimes damaging engine effects. This was unfortunate, given that the EPA's argument was flawed: Motorcycle emissions in the USA comprise just 0.001-0.006 of vehicle emissions, ("Control of Emissions From Highway Motorcycles") [Federal Register: 1/15/04 (Vol. 69, Number 10)].

For crankcase breathing systems, we can break down crankcase emissions vs. exhaust pipe emissions. Thus, a 1000cc engine at 3000 rpm pumps out a little under 1500 quarts of exhaust gas per minute. Riders sometimes incorrectly assume a similar gas volume is displaced from the crankcase. This never happens. Bikes of 250–1400cc equipped with an efficient breather will pass 1–10 quarts/minute of blow-by from the crankcase. At an average of 5 quarts/minute, this is just 0.003 of exhaust pipe volume. At cruising speeds, when blow-by volume drops, the figure averages just 0.001.

The US motorcycle fleet puts out 0.001–0.006 of total US vehicle emissions. If released into the atmosphere, motorcycle crankcase emissions would be 0.0000035 of total US vehicle emissions. This is statistically and practically insignificant—a tiny number on which to base legislation. Interestingly, the same motorcycle engines installed in ultralight airplanes in the US have no emission controls and can vent their crankcases directly to the atmosphere.

What's Wrong With Today's Crankcase Breathing?

New motorcycles sold in the US and elsewhere often experience poor breathing. Fortunately, this can be remedied without a significant effect on greenhouse gases or planetary health. The ban on crankcase emissions since 1980 discouraged research and technical innovation in crankcase breathing. My own research started outside the US and was concerned primarily with classic and vintage bikes. These are exempt from EPA emission requirements. Other exemptions enable riders to legally rectify their bike breathing. It's worth recalling many automotive engineers disagreed with PCV (Positive Crankcase Ventilation valve) technology in the 1960's. They saw PCV breathing as a backward step. For motorcycles, I believe this remains true. A useful reference for this debate is Russell; *"PCV...real advance or just another headache for the motorist."* Mechanix Illustrated, 5/1964, pp. 118-124.

The problems with breather systems start with the composition of blow-by gas. Many riders equate this with exhaust gas, as blow-by gas comes from the combustion chamber. Typically exhaust gas comprises 72% Nitrogen, 14% CO_2, 13% water and 1% acids, soot and hydrocarbons (Hillier, 2006). Apart from the water, we might think this sounds pretty harmless. However, Murakami and Moritani show us that blow-by gas and crankcase gas are different animals. The vapor venting a crankcase breather has two phases; exhaust gas and oil spray. At idle, the vapor composition is typically 67% oil, 22% fuel, 10% water and <1% solids by weight. At wide open throttle (WOT) this changes to 58% oil, 30% fuel, 12% water and <1% solids. If that oil mist passes into our air intakes, it will burn to form soot and carbon deposits that one day will need to be scraped out. More or less oil is carried out the breather depending on crankcase conditions, engine wear and crankcase breather design.

Of particular interest is the non-oil portion. This comprises unburned fuel at 68–71%. The remainder is largely water at 28-31% and carrying $NO_2/NO_3/SO_4$. The water fraction has an acid ph of 4.6-3.85 at WOT, roughly that of red wine. Fuel follows two pathways into the crankcase to become the major constituent. First, on induction and compression strokes it dilutes the oil around the piston and flows down the barrel. During combustion and exhaust strokes, it is forced past the rings into the crankcase along with combustion gas. There is always unburned fuel in combustion gas, as bike engines run at less than the ideal or stoichiometric air/fuel ratio of 14.7:1. Bikes often run instead at 12–13:1. This helps stabilize engine temperature and avoids detonation, but at the expense of boosting blow-by.

Unburned fuel sounds harmless until we consider its effect on lubricating oil. As Irving showed in his classic book, *Motorcycling Technicalities*, 5% fuel dilution can cut oil viscosity by <25%. This means SAE20-50 oil may degrade to SAE15-40 viscosity, resulting in increased engine noise and wear. Water, the other main constituent of blow-by gas, is a serious problem. It forms sludge that blocks oil passages and corrodes engine springs, bearings and shafts.

The challenge for crankcase breathing is to maintain engine oil quality by averting dilution by fuel and contamination by water. We need also consider the acids and solids found in crankcase gas. Feeding these back into the engine makes no sense to me when the pollution concerns about crankcase emissions are unconvincing. On the other hand, the increased servicing costs on bikes with bad breathing are clear. We need a better way forward.

Power Gain & Crankcase Breathing

This is a contentious aspect of crankcase breathing. Claims have been made for power increases by various breathers, yet independent testing sometimes fails to show significant gains from these breathers. Are riders right to be skeptical? As a crankcase breathing specialist, I must report only the empirical evidence and the engineering theory.

For the record, my research derives from classic bikes where the emphasis is on engine conservation and oil leaks. With vintage bikes of 20–30 hp, there's little interest in power. Instead, bad crankcase breathing means accelerated wear and corrosion. There may be only 300,000 classic bikes left in the world and protecting them from deterioration by acid blow-by and moisture is a laudable goal. Many oil leaks are caused by bad breathing, and with improved breathing riders can once again park without embarrassment.

The result of poor breathing on a Royal Enfield.

The well-known US motorcyclist Charles Falco interested me in the power question with his 1996 views on piston drag, pumping losses and wasted work. He noted "… the piston, which has a surface area of ~9 sq. in. in the case of a 500cc, would have to travel the entire length of its stroke against a force of ~130 pounds (9 x 14.7 = 132lbs.)…". He predicted an extra 10%, or three hp, might be gained if pumping losses could be reduced with optimal crankcase breathing. By 2006, our research had cut pumping losses and realized Falco's prediction during an independent dyno test with a Vincent 1000cc V2 engine fitted with our breather design. Subsequent Chicago testing on the Harley-Davidson engine showed similar gains. However, a later Denver test failed to replicate this result. This last finding puzzled us until we spoke to aviation engineers. They explained the mile-high-city's altitude inactivates pneumatic breather valves. Bikes in Denver effectively breathe openly like aircraft engines.

Such dyno findings followed years of client reports that their bikes ran better, faster, more responsively and/or louder with one of our kits. We considered the theoretical explanations for reported power increases. Crankcase vacuum is an obvious one. AHRMA experience shows cutting crankcase air pressure translates into power gains of 15%+ at the cost of reduced TBO (time between overhauls). In motorcycle engines, power gains from cutting crankcase air pressure have been reported by Bell. The mechanism is straightforward. The high-speed components in the engine such as the crankshaft, flywheel and conrods cause a local drop in air pressure via the Bernoulli effect. The pressure drop causes more oil to cling to the components and this causes oil drag and the resulting power loss. If crankcase pressure can be reduced, then gravity can remove the oil and power losses diminish. Bell cites power increases of up to 5% from cutting oil drag. This effect plus Falco's pumping losses seem capable of explaining power gains up to the observed 10% level. So we have some theoretical explanation for what has been measured.

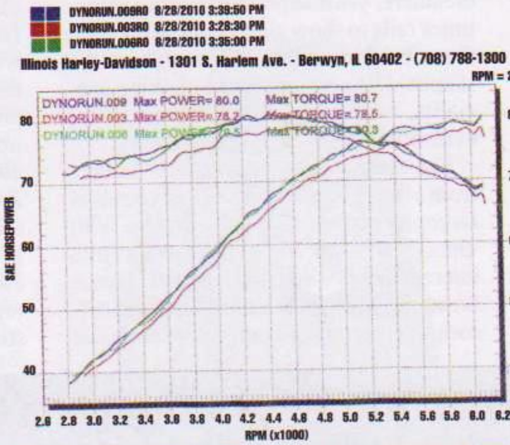
Why then is there controversy? I think for several reasons. First, the kind of AHRMA power gains have not been seen on bikes. For reasons of power consumption and bike longevity; powered vacuum pumps have not entered service on road bikes. Instead, riders are offered a range of simple check valves. These differ from what was used 50 years ago largely in their casing manufacture. They are valves our grandfathers would recognize. Such valves can be of limited usefulness for controlling crankcase air volume and pressure. Other breathers are simply air filters or catch-cans which mask the symptoms of breathing problems but do nothing about the causes. Secondly, there have been perhaps overly enthusiastic claims made by some suppliers for their products, often with little empirical evidence. Third, realistically, the maximum power gains from optimizing breathing is going to be <10%. In this range, it is hard to distinguish power gains from measurement errors and normal variation in engine performance. It's worth recalling the <24% variation in cylinder pressures occurring in any engine on consecutive power strokes as reported by Rototest. Fourth, in the US it's customary to look for evidence via dyno tests. This is not always the right way to test crankcase breathing effects. As we found in Denver when dealing with pneumatic valves and air flows the altitude effects must be considered. While dyno makers scale power reports for the 18% loss of power at Denver's altitude there's no practical way of scaling up a breather test there. Fifth, our breathers are designed to exploit the aerodynamics of a bike moving through air at speed. It's difficult to account for such aerodynamic factors with the bike stationary in the artificial environment of a dyno room. Sixth, breather effects on an engine vary with load, engine rpm, acceleration and bike speed. There are at least three different breathing mechanisms operating between 1000–6000 rpm, hence dyno printouts need to be broken down into sections before interpreting the findings. As well it is probably unrealistic to expect a consistent power gain over the entire rev range. Furthermore engine response to breather function can lag by up to a minute. It's difficult to replicate these road and engine conditions with the ordinary short engine test procedures employed in a dyno room.

For these reasons we're skeptical of dyno testing as the sole research tool and are extending testing to speed trials. It's possible to devise speed-trap tests that address these issues with dyno testing. However, speed-traps are not a complete answer either. We are turning to crankcase mapping and simulation studies to try and overcome these test issues.

Motorcycle Breather Faults

All crankcase breathers are compromises. Open breathers waste power and contaminate engine components by sucking in dirt. Breather valves can stick and malfunction in dirty conditions. Hoses can clog with blow-by emulsion leading to pressurizing, oil venting and ultimately an engine seizure. Later British designs worsened blow-by problems so that bikes could pass emission tests. They re-cycled blow-by into the oil tank, timing chest or chaincase... anywhere but outside the engine where it could be detected. This contained the emissions but spread corrosive blow-by over the ignition, alternator, clutch and chain. It denatured engine oil and pressurized oil tanks. These problems afflict Triumphs, Nortons, Vincents and BSA's even now.

On today's bikes the same problems are seen in Moto-Guzzis, Triumphs, Royal Enfields and Harley-Davidsons. Their recycling breathers also sacrifice engine function and service life to satisfy emission requirements. From the viewpoint of crankcase breathing, this is poor design but, fortunately, classic engines face no emission requirements.



A Harley-Davidson shows a statistically significant power gain near sea level with a breather kit.

Auto PCV [Positive Crankcase Ventilation] Breathers-

It's not surprising that riders attempt to fit automobile PCV valves to their motorcycles. However, the applications are quite different, and for this reason auto PCV valves have no place on air-cooled, dry-sump bike engines. There are perhaps three reasons for this.

1) Valve Design- PCV valves fail on bikes because of their weight, inertia, cycling speed, pressure/ flow range, servicing and installation. When we compare the engines for which they're designed the reasons for this become clear.

2) Engine Design- Auto PCV valves are designed to operate in multi-cylinder, water-cooled, large wet-sump engines without significant air displacement. Motorcycle engines have fewer cylinders, small dry sumps, are often air-cooled and typically displace a lot of air. From the crankcase breathing point of view, the only thing auto and bike engines have in common is they're Otto-cycle engines.

3) Valve Operation- Auto PCV valves are designed for smooth changes in intake manifold vacuum. On a motorcycle, they face aggressive crankcase pumping action, high pressures and severe pressure oscillations. PCV valves are only designed to stop blow-by gas escaping to atmosphere, negative impacts on engine function are ignored. Auto PCV valves are operated by vacuum from the intake manifold in a car. In a bike, they face the oscillating wind under the pistons. A valve designed to respond to vacuum may respond differently to high-pressure flows. When we force air through a PCV valve, instead of sucking on it, the valve is outside its design parameters. We should not be surprised if odd things happen as a result.

Fire Risk With Breathers

Many riders are unaware of potential fire hazards created by some breather installations. When breathers recycle blow-by into the inlet tract, a potential flame path opens to the crankcase. Motorcycle crankcases sometimes fill with flammable gas for reasons discussed above. Recycling blow-by gas without a flame barrier invites a crankcase fire if the engine backfires.

New Breather Technology

After 10 years of research and several patents in motorcycle crankcase breathing, we have a growing understanding of how bike engines breathe under road and race conditions. There's a long way to go, and this year we teamed with a leading university engineering school to broaden the research.

Every motorcycle engine old-and-new can benefit from improved crankcase breathing. Flushing blow-by vapor from our engines before it condenses into sumpwater can increase the time between overhauls and reduce engine wear. If engine oil develops a moisture content of even 0.5% then crankcase breathing is suspect, and we are in "accelerated wear and tear" territory.

The first stage of a breather solution is to redirect vapors from the crankcase, timing case, head or oil tank. This cuts carbon build-up in the combustion chamber and aids engine longevity. For riders who don't wish to purge even tiny amounts of blow-by vapor to atmosphere, a catch-can will store any condensation until you dig a hole and bury it. The second stage is to fit a breather that controls crankcase conditions like air volume, air pressure and air flow velocity. Do you agree?

The Author

Rex Bunn is an Australian restorer, inventor and author of *Classic Motorcycling: A Guide for the 21st Century*. He has been working on the problems of engine breathing for more than a decade. His patented Bunn Breather Kits are designed to extend the life of classic engines and H-Ds and are distributed by britcycle.com. Readers are welcomed to contact him at www.bunn.co.nz on crankcase breathing issues. His blog is bunnbreather.bigblog.co.au