

AIR RESISTANCE TESTS FOR R1100S INTAKE COMPONENTS

with comments about intake duct size

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CAN ANYBODY LOAN ME A POWERFILTER, PLEASE?

***NEW!!! CHECK OF FOAM FILTER AFTER 18,000 MILES – PAGE 5
HAVE A PEEK AT BMW ATLANTA'S DYNO TESTS BELOW***

Method

I built an air resistance tester using a cardboard box, 5.6 amp ShopVac with HEPA filter, and a modified carb airflow meter (Schleyer Carb Synchronizer) with a dial face non-linearly scribed to “50.” The ShopVac evacuates the box and draws air through the rectangular test hole (the same size as the filter sits on the R1100S). The meter supplies a bit of make-up air to the evacuated box in relation to the vacuum inside the box; the volume of that air is scaled somehow to the meter face.

The ShopVac draws maybe half-again as much air as a 5-inch muffin fan and purely as a guess, I'd say about the same as a liter engine at 3000 rpm. My guess is a liter bike draws about 130 cfm at WOT — that may seem small for something claiming 100 HP and is comparable to a stove exhaust fan. On the other hand, I've never been knocked over by an exhaust blast; we're not talking about hurricanes here.

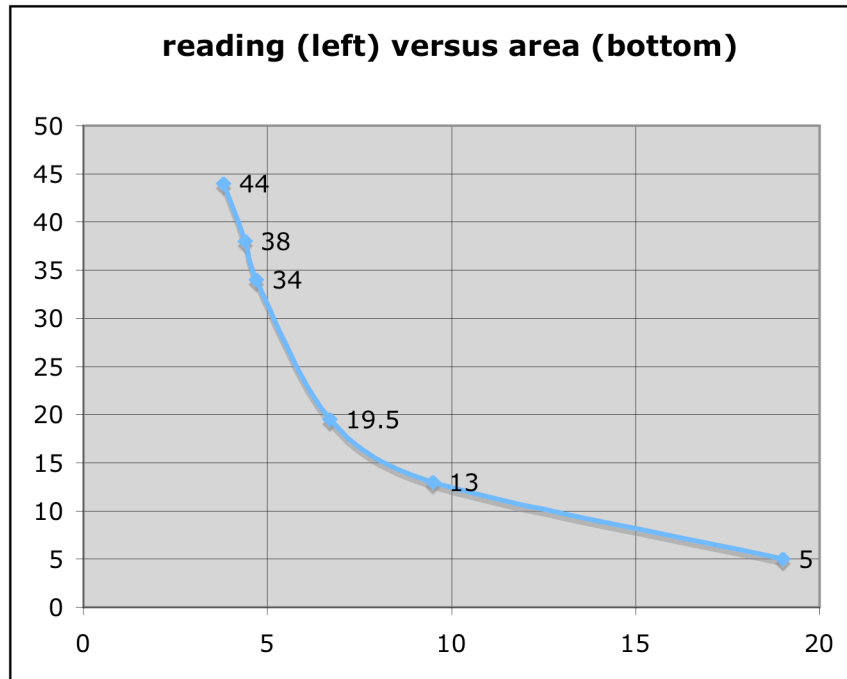
While the numbers I am reading from my gauge and reported in this write-up have no absolute meaning, they should be clear enough as reliable relative (if not proportional) measures of resistance to air flow, the higher the number the more vacuum in the box arising from resistance to air entering the box through the filter or whatever. While I can't tell you just what any given meter number means, I do report the size of an equivalent plain open hole (with no filter installed in the hole) that corresponds to that meter number. To be absolutely clear: after each filter test, I removed the filter and covered over the hole with a piece of cardboard until the meter read exactly the same; then I measured the size of the opening remaining.

Some of my “technique” may seem as casual as Watts' lab work with horses and their power, but again, the numbers should speak for themselves. A chart appears at the end of this report; these make the numbers a lot clearer and going right there may save you the trouble of reading the whole thing.

Resistance of the test set-up (or an S motorcycle) with no filter at all

With no filter or other obstruction over the intake hole in my test set-up (3.75 x 5 inches or 19 sq in), the meter reads “5”. In other words, “5” on the scale is the same as an open hole of 19 sq inches. Putting the oval-hole filter-retainer piece in place, the reading is 7.5

(on the bike, the oval adds no resistance because the entry size of the filter is smaller anyway). Covering half the hole (9.5 sq in) gives a reading of 13. With no filter in place but adding the hideously narrow R1100S intake duct, resistance rises to a reading of 23 (which is like 6 sq in). To convert meter scale figures to sq inches, use the chart near the end of this report.



The chart above shows the calibration of the meter scale reading (y-axis) versus the equivalent size open hole of the filter test mounting plate (which is identical to the hole in the air box for mounting the filter), in square inches (x-axis). No kidding, this chart is not doctored in any way: I work carefully and get orderly results the odd time.

Still with no filter in place, but substituting a homemade enlarged duct similar if not really as good as Lennie's respected Induct (or the similar SJ model) resistance still rises nearly as far to 19.0 (about 7 sq in, which still seems pretty constipated for a passive duct... see below). But adding the flex pipe, which is upstream of the duct on the bike, it increases a mere .5 or 1.0 to about 20. My homebrew Bennie intake duct may not be as large as Lennie's or SJ's, not sure. See the comments about how big an intake duct is needed at the end of this paper.

There may be some ram-air effect from the air intake scoop located at the front of the R1100S and this might compensate for the tight intake duct. But that seems like bad engineering since ram-effect obviously changes a lot with wind speed and wind direction and provides no stable basis for pressure under 100 mph (when wind speed is less important). The front scoop has more to do with inhaling cool air, I'd say. Prolly it is a reasonable move to simply ditch the intake pipes on the R1100S.

Considering adding some window screen to the intake scoop to keep leaves and bugs out? That of course wouldn't be necessary with the big sock homemade Uni filter described below because it can hold a lot of bugs with no deterioration in performance. But you should know that the added resistance of the window screen is barely detectable when the screen is covering a plain hole (the loss is equivalent to less than 2 sq in from 19 sq in hole for a net resistance with screen of 17 sq in) and the presence of the screen is certainly undetectable when the duct leads to a K&N.

Some paper filters loosely fitted over the hole

Sitting a middle-aged R80 flat paper filter on the hole, the gauge reads 28 and a tired, clogged, old Subaru filter maybe twice the size, 24, which are equivalent to an unobstructed hole about 5 sq in.

Stock paper filter (and now for some bad news)

A kind buddy sent me a stock paper filter for testing. It was run for two miles (dealer to home where he slipped in a K&N) and then he stored the paper filter for a few years. Looks pretty clean to me but I am uncertain if the medium loses or gains flow capacity in storage. Amidst a dispute about filters, one defender-of-the-stock estimated the paper size as 800 sq inches (and my estimate is roughly the same). On the other hand, even with that entire vast filter surface to work with, you still can't stuff that much paper into the small intake hole and expect good flow. And you don't find good flow.

This stock paper filter was close to the end of the meter scale at 42, which is equivalent to a plain old hole a mere 3.3 sq in. Adding the stock duct brought it to very roughly the meter-pointer bump-stop at 50 or so (2.3 sq in) — yuck. Readings near the limits of a meter are often of diminished trustworthiness, but I think the general drift is clear enough. If these numbers can be trusted, the stock breathing equivalent is smaller than one TB bore which seems pretty lousy.

But the good news is that "42" is exactly the same resistance as a large, brand-new Honeywell HEPA filter with carbon pre-filter. So if you want a really clean engine with no (further) cost to performance than the stock paper filter, you can substitute a Honeywell HEPA filter for the stock and keep your TBs and intake manifold hospital clean! Only kiddin' of course, you'd have to give up half your gas tank to make room.

Assuming my test filter is representative of nearly stock filters. Then after a thousand miles, the filter pores start getting clogged and resistance to flow would increase to a yet more unhappy state of interference.

K&N cotton gauze

A dry K&N reads about 37; after light oiling the gauze with K&N red stuff, 38 (which is equal to a hole just 4.4 sq in)... which doesn't sound as good as I think flow for an R1100S should be. With the two ducts, 46 and 43 total (although reading the meter can't

be any too precise at that range, that's in a ballpark roughly equal to a very small 3.8 sq in open hole). I'd be glad to borrow a PowerFilter (a very large K&N-type oiled cotton gauze filter that went to Harvard) for testing if anybody has one to spare briefly.

Ben's sticky foam filter

Putting a flat piece of dry green Uni foam over the hole (19 sq in) moves resistance from open-hole-5 to 36 (equivalent to a hole about 4.6 sq in). This conforms to Uni practice of using filters with the same "face" area as paper or oiled gauze; that seems much too small to me. But as a design short cut, it is a very direct way to fabricate a foam filter to substitute for a paper filter. Never the less, this is still better than the stock filter and about as good as a K&N... except the sticky foam would also do some filtering (which would distinguish it from a K&N). It makes more sense to fabricate a foam filter when you have a cylindrical filter shape (like the other Oilheads) rather than a flat-but-deep paper filter (like on the S) because you'll have lots of foam surface. However, if you have the room for a bigger foam filter — as you have inside the large S plenum, or if you are clever about making space for accordion pleats enlarging the foam surface, read on.



Now *that's* a big filter.

I made a big Uni-like filter of roughly 85 sq in (made from half of the green sheet Uni supplies as a "universal" kit – Pliobond is the ideal construction adhesive... piece of cake). I spritzed it with proly too much hideous flypaper goo (not falsely named "Fab 1") on the inside and outside. With a surface of 85 sq in, it is between 4X and 5X the size of the unadorned hole.

Not shown in the photo, the filter was "puckered" a bit with cord to ensure that the bike's TB intake venturis horns had the least possible obstruction. The entry hole to my Uni-like filter is 9.3 sq in which is about the same as the stock paper and K&N net openings.

I know you are wondering what the meter said when I sat the big sticky sock into the hole: 19.5 (that is equivalent to an open hole 6.7 sq in). With the stock or Bennie ducts added on top, 35 or 31 (equivalent to an open hole 4.8 sq in)... lots less resistance than the K&N and far less than stock paper. See charts at end.

Filtering ability

I haven't developed the means of testing filtering ability. But I believe that many people greatly overestimate the filtering strength of paper just because it looks kind of solid and underestimate the filtering ability of half-inch thick sticky foam sprayed inside and out just because it breathes so well even when it is moderately dirty. BTW, after 5,000 miles, my Uni filter is hardly soiled at all and my guess is that it would be in reasonable fighting trim at 24,000 miles. See the 18,000-mile tests described below.

There seems to be no argument that the small R1100S K&N does not filter well, clean or dirty, or even flow well. Likewise, the PowerFilter, although much larger and better designed than the K&N, must pass even more dirt because it takes longer for the smaller pores to clog (as with too-often replaced paper media).

Tom Cutter, a highly respected authority on BMW maintenance writes, "I have seen the damage to engines running foam filters. Remember when the Uni Filters were all the rage for "hot-rodding"? I rebuilt a LOT of Triumph and BSA motors that were wiped out in rings and valve guides from dirt entry. The telltale marks are obvious, even to a novice tuner." But others are not as critical of sticky foam filtering or at the present stage.

Re-test of giant sticky foam filter after 18,000 miles

After 18,000 miles and about two years, I had a look at the giant foam filter. It was filthy black inside with a few spoonfuls of crud sitting on the bottom of the sock. But the outside — which had been given a sticky coating too — looked like new. This indicates that little dirt penetrated the foam.

Weight before cleaning was about 125 grams and after cleaning but before spraying it was about the same or within 15 grams, as close as I could measure on my mail scale. This proves that grime doesn't weigh or I can't weigh well.

To test the increase in flow resistance when dirty, I first validated the benchmarks of my tester. The open hole resistance was within about 4% of earlier readings, as were the repeat tests with the K&N, the stock filter, and the foam filter after cleaning (and even when still damp from its bath). This level of repeat reliability would have made me suspicious if anybody else had reported it! Real-world measurements just ain't too stable.

The dirty air resistance after 18,000 miles was equivalent to a hole of 6 square inches (as compared to the new resistance equivalent to 6.7 square inches). Far worse, the stock paper filter is equivalent to 3.3 square inches and the K&N is 4.4 square inches.

From this it may be concluded that even a real old and dirty foam filter works really well and can probably be ignored within the hard-to-reach recesses of the R1100S for 30,000 miles without unacceptable loss of flow. In fact, to reach levels of flow as poor as the

stock paper or the K&N filter, I suspect you could simply leave it in place indefinitely. I do not plan on conducting that test, unless I get any lazier about cleaning filters.

However, I don't know how long the sticky goo remains potent; it may be "used up" by 12,000 miles. My impression is that the filter, filthy at it is at 18,000 miles, still has lots of dirt catching power and stickiness left.

Final thought on performance

Sizing the resistance of an air intake system requires an assessment of the peak demand (which recognizes valve duration and quality of breathing both into and out-of), not by just looking at the engine displacement or at average demand. On this basis, it is instructive to note that a twin like the S has twice the peak of an equivalent displacement four-cylinder engine, cams and other things equal.

The resistance of the intake system upstream of the plenum needs to be considered in relation to the engine design and the size of the plenum. A large plenum helps average out the peak demand for air. On a large, high-performance, high compression-ratio twin, the cylinders take big, brief gulps of air. Therefore, an R1100S might need as responsive a filtering system as a two-gallon (7600 cc) lazy old Cadillac V8.

Other things congruent, the better your bike inhales, the more horses it will produce. But simply slipping in a trick filter may not be beneficial in the absence of other changes, as Eilenberger has sort of demonstrated. This is particularly true of Oilhead EFI that is an especially ignorant brute-force and runs along with little knowledge of how the engine is running or of power demand. Moreover, in a moment of unconscionable cost cutting, BMW opted for an Alpha-n EFI with, horrors, a wasted-spritz cycle.

As best as anybody knows, the O2 sensor in Motronic EFI 2.4 is polled only during certain kinds of operation – just in case you thought the O2 sensor did anything beneficial (it is generally accepted that it causes surging during cruising by leaning the mixture... cyclically). In other words, if you are going to enhance breathing, you need a Techlusion to provide a broad enrichment to the mixture (I tend to feel a Power Commander III is an appealing if costly way to economize on gas). My impression is that the R1100S uses too much gas due to the Alpha-n EFI character, wasted spritz, and weaknesses in cylinder design. But despite consuming more gas, I am sure The Factory saw to it that the bike runs on about the right mixture it requires most of the time; it goes too-lean when the O2 sensor is polled. In consequence, it is best not to go additionally lean even if the bike seems a bit piggish at the fuel pump.

But once you have gone rich, the 98%-HP power band is quite wide and certainly does not need the nit-picking fine-grained mapping of a PC III. But not good to be seriously rich if you have a catalytic converter. A/F (that is, reading the corresponding O2 voltage) can be accessed with a DVM wired to the black lead of the O2 sensor — simple as that.

These issues are discussed in greater detail — and with A/F findings — in another report of mine.

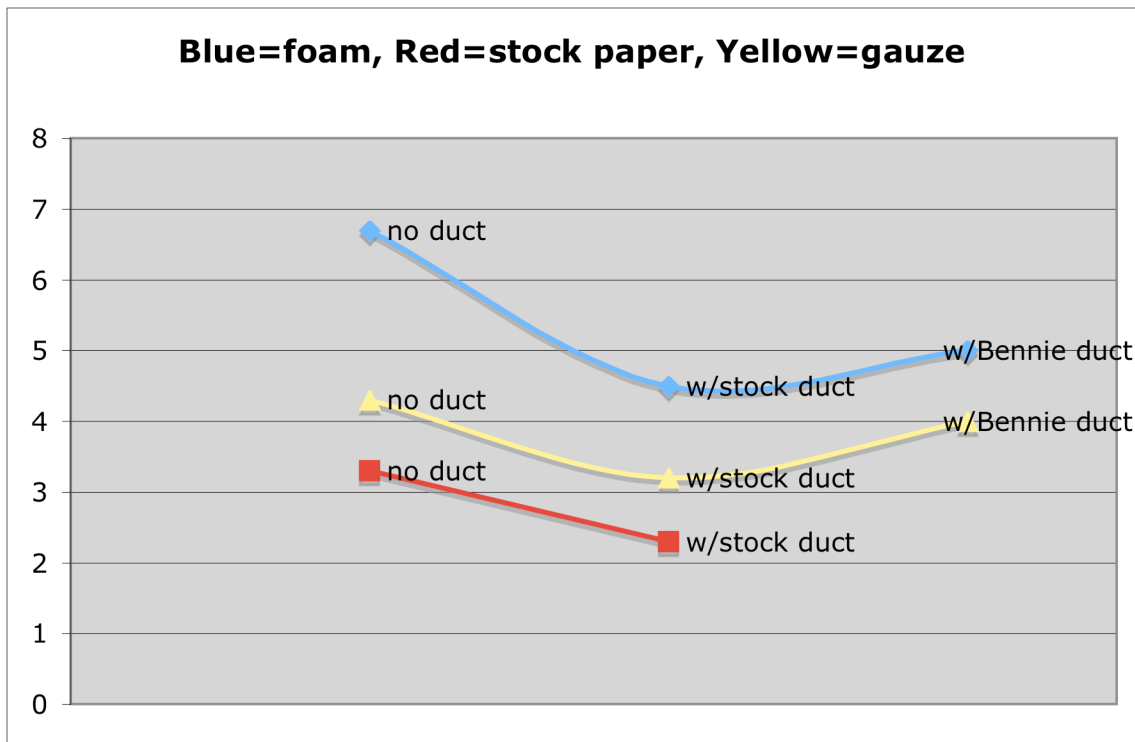
BMW Atlanta's foam filter for the R1200S

Bobby Woolridge, guiding spirit of BMW Atlanta, is now selling a foam filter for the R1200S bikes. Dyno testing of an R1200S with a PowerCommander shows an increase of 4 rear-wheel HP mid-band and 2.5 at the top. He previously said you get the same results without a PC and that makes sense since a PC doesn't "invent" any power other than marketing power (see my report on A/F). With no filter, he says you get just one more horsepower but then you get filtering for nothing smaller than a small bird. Sure vindicates the tests reported here.

Conclusions

The stock set-up is like feeding the TBs from a single hole that is 2.4 square inches. With a foam filter and slight modifications to the duct, you can double that to about 5 square inches – which I'd say is just honky-dory. Anything more puts you into diminishing returns and breathing dirty or pre-warmed air. Installing a K&N barely helps breathing.

I welcome any comments and I'm glad to try to answer any questions.



The various filters with and without the final duct versus the equivalent open hole size in square inches (y-axis). The larger the equivalent hole size the better. Again, orderly chart behaviour without cooking the data!

Here's how to read the chart above. If you had no filter in your air filter space and no duct at all, that would be like the engine breathing through a hole 19 sq inches (in fact, we are just talking about a hole that *is* 19 sq inches and that is the size of the hole in the airbox which accepts the filter). But if you had a K&N and used the stock plumbing, it would be like breathing through a hole about 3¼ sq inches... not too impressive, eh. And if you had the stock paper filter with the stock duct, even 30% less satisfactory although you'd have some filtering.

For additional reports on various bike topics (esp. related to R1100S and Oilheads), please see:

<http://tinyurl.com/6bvt23>

Appendix: how big does the intake pipe have to be?

When the cylinders are drawing mixture into their interiors, they are sucking on a pipeline that extends out to the intake bell of the intake pipe. The more mixture in the cylinders, the more power, at least until the engine self-destructs. The lower the resistance along the way, the more mixture that enters the cylinder, up to the point of diminished improvement. As far as diminishing returns for inhaling a maximum of about 120 cfm at max rpm into the engine in a minute, keep in mind that the intake valves do not open a whole lot (or very long) and the throttle bodies have roughly 2 sq inches of cross-section each. And the mighty Vincents had one-inch carbs!

You'd be amazed how small is the opening formed by the butterfly or carb slide valve most of the time. Once in a blue moon open my throttle fully wide open. I can run 90 mph two-up on maybe a 30% opening although a bike needs a whole lot more headroom for accelerating. Of course, when the butterfly is wide open, it may be that the poppet intake valve(s) opening that is the limiting condition on flow.

Modern intake designs such as fuel injection don't depend on vacuum to draw the fuel up from jets in a carb. These designs have increasingly large "tidal basins" or plenums. The air box volume serves as a plenum, particularly the volume on the downstream side of the filter. This volume holds a mass of air so that when the cylinders are sucking, the air can come from the nearby plenum rather than all be sucked all the way from the ambient air at the entrance to the intake duct. On the R1100S, the air box is exceedingly large.

Through the butterfly valve opening, all the air needed by each cylinder flows and it flows into the intake poppet valve(s) about 1/8 of the time or less because the sucking isn't going on for longer. For a boxer, the two sides alternate and so air is being drawn through some fraction of one or the other throttle throat about a total of 1/4 of the time. As I said, the nearby plenum (the air box) supplies the first quick breath and then the intake duct makes up the rest. Then the intake duct continues to re-fill the plenum.

Picture this: the intake poppet valve(s) open and the cylinder begins to draw mixture in. The butterfly is open a wee bit, the plenum supplies air, and the remainder of the air

comes down the duct for the valve(s) and the intake duct continues to draw air ready to re-fill the plenum for the other side of the engine 100% of the time. That small butterfly opening about 1/4 of the time (both cylinders together) is fed by the large intake duct 100% of the time.

Coarsely considered, for the intake duct to be as big as the max opening of ONE of the butterflies (working 1/4 of the time) it only needs to be 1/4 the diameter of the butterfly max opening or 1/4 of the poppet(s) throat, whichever is less. When you think about it that way, the intake duct sure does not need to be excessively big or even perfectly straight and I guess that is why BMW didn't fret over the size.

To my eyes, the intake duct on the S seems small and it has two 90 degree bends. With no trouble at all and maybe \$2 in fiberglass materials, you can enlarge say, the three most constricted points, as I did, in about 2 hours. I promise you, the first time you get back on the bike, you will sense a great improvement and will detect a wonderful free-breathing quality you never noticed before, albeit only at the fastest speeds and risky accelerations and that will be largely illusion. And if you had access to a dynamometer, you just might be able to objectively measure some tiny improvement, if you are using the stock paper filter of K&N gauze filter. Maybe.

If you choose to use a gauze SJ PowerFilter or large oiled foam filter, the improvement is likely to be measurable objectively as well as subjectively. But if you use an SJ PowerFilter, then when you go to sell your bike years later, you need to be able to explain to the purchaser why you felt it was unimportant to filter clean the air all those millions of crank cycles and accelerate the maintenance cycle.

To summarize, it is fine to enlarge the air intake plumbing, maybe up to some small multiple of the size of the TBs. But going overboard is not helpful.