GFB Discussion Paper

Diverter valve leaks & the effects on engine performance and TMS solutions

Introduction

Diverter valves often leak, it's common knowledge. Regardless of the amount of air that escapes a valve, if *any* air escapes it is correct to say there is a leak.

Common tests used to detect a diverter valve leak include smoke testing the intake tract (read more on this here), removing the valve and pressurising the ports (usually in conjunction with a bucket of water or some soap to find a leak), a vacuum pump on the top port or any combination of these.

When such tests are applied and indicate a leak coming from a GFB TMS valve however, what is often not understood is the *scale* of a leak, where it originates from, and whether or not it is detrimental to engine performance.

GFB TMS valve design criteria

GFB TMS valves are designed with maximum throttle response in mind first, followed by the ability to vent to atmosphere for noise (if desired) on cars that typically don't allow atmosphere venting.

The piston-type valve design used by GFB satisfies the broadest range of design requirements and applications, which is why it continues to be used. For example, the dual outlet Hybrid design pioneered by GFB back in 1999 is only possible with a piston-type valve – dual outlets and 50/50 venting simply cannot be done with a factory poppet type valve.

Sealing a piston in a bore is simple, right? Use an O-ring and no air will be able to leak past – this is how hydraulic and pneumatic pistons and rams work. GFB TMS valves however, do not use an O-ring on the piston as is sometimes found on other brands, for two important reasons:

1. Minimum sliding friction is a key requirement for both optimum performance and successful atmosphere-venting operation. Friction in the piston travel can cause undesirable side-effects such as poor throttle response, compressor surge, idling problems, stalling and backfiring.

   For optimum throttle response, the piston must be able to move freely in reaction to very small changes in pressure (the forces involved can actually be very small). O-rings create significant friction, no matter how loosely compressed, and worse still, the amount of friction varies greatly depending on the amount of lubrication, temperature, and how long the O-ring has been stationary (they tend to take a "set" after a while of not moving, and require significantly more force to get moving again).

It is simply not possible for a piston-type valve to operate properly with even the smallest amount of friction added by an O-ring.

2. O-rings in sliding operation require frequent replacement and/or lubrication.

Instead of O-rings, GFB TMS valves have multiple design features that offer the best balance between lowest friction, longest service life and minimal leak. These features are:

Tolerance:
GFB products are manufactured exclusively on CNC machines capable of holding tolerances to +/- 0.01mm. This is essential since the piston-to-bore clearance is critical to ensure good sealing and low friction.

Material choice:
The piston is made from brass, which offers good corrosion resistance and machining properties for tight tolerances, and relatively low friction as it is often used in bearings and bushings. The bore is anodised aluminium, which also offers good machining properties and therefore tight tolerances, whilst the anodising results in an extremely hard and smooth finished surface that resists wear.

Piston ring:
In lieu of an O-ring, GFB's pistons use a low-friction Ertalyte™ piston ring, designed much like the rings used on high performance engine pistons to spring outwards against the bore to aid sealing.

Of course, like the pistons in an engine, a small amount of air under pressure will be able to "leak-down" from the top chamber between the piston and bore, and through the split in the piston ring, where it will exit through the valve's venting outlet/s. This is unavoidable if the piston is to remain able to move freely.

If further proof of our argument against the use of O-rings is required, consider that the cost of O-rings in bulk is minimal – usually cents per piece. GFB's piston design already features a groove into which the piston ring fits, so no design change would be required to swap to an O-ring. Yet we choose the best performance by design, even though the Ertalyte™ piston ring and tight tolerances cost more to produce that O-rings.

What about a diaphragm? Diaphragm-type valve designs (as most factory valves are) boast the ability to completely seal the upper chamber, but they do not satisfy our performance design criteria. This is a topic entirely unto itself, and will be covered elsewhere.

So a GFB valve will always show a minor "leak" through the vacuum nipple on the top chamber, but the ***size*** of this leak however and its effect on the engine is the topic of this discussion.

So how big a "leak" are we talking?

To put a number on it, a simple series of tests were performed. The test apparatus consists of a GFB TMS valve, with its vacuum nipple and boost inlet port connected to a pressure regulator with a gauge. This simulates WOT (wide open throttle) conditions (where the intercooler and manifold are effectively at the same pressure), and the simulated boost pressure can be varied via the regulator.

Since capturing and accurately measuring the volume of air leaking from the valve is a little difficult, the measuring apparatus uses the leaked air to displace water, which is simple to measure. The measuring apparatus consists of a water-filled sealed plastic container with two hose fittings. One fitting is connected to the TMS valve's recirc outlet where the leak occurs, the other feeds into a measuring jug via a hose.

As air leaks from the TMS valve's outlet, it will displace water from the plastic container into the measuring jug. Timing how long it takes to displace a fixed amount of water will give us a numerical indication of the size of the leak which we can calculate in CFM. Of course, a small amount of pressure is required to displace the water, but at approximately 0.1psi it can be considered negligible compared to the supply pressure.

Procedure

A GFB Mach 1 TMS valve was used for this test. It is important to note that all GFB TMS valves use the exact same piston and spring (except the race-use SV45), and the same piston seat type, so the results can be effectively transferred across different GFB valves.

The valve was disassembled and wiped dry so no oil or grease could affect the results. The Mach 1's bore was measured at 30.01mm, and two pistons were selected to represent a tight and loose piston-to-bore clearance, even though in practice the piston tolerance is kept tighter than the range selected. The two pistons measured 29.94mm (loose) and 29.98mm (tight).

The Mach 1 was then set up on the test apparatus and tests were run at pressures of 10, 15, 20, 25 & 30psi, and the time to displace 500mL (500cc) of water in each case was recorded.

Results

Test 1	10psi	15psi	20psi	25psi	30psi
Tight tolerance	136 sec	119 sec	97 sec	71 sec	58 sec
Loose tolerance	93 sec	84 sec	60 sec	37 sec	35 sec

A further two tests were performed at 30psi, both with pressure fed only to the top of the valve.

Test 2	30psi
Tight tolerance	58 sec
Loose tolerance	35 sec

The purpose of test 2 is to demonstrate that the leak is confined only to the amount of air that can leak through the piston-to-bore clearance, and that no leak occurs on the piston seat side. The importance of this will become apparent in the discussion to follow.

Calculations:

To work out the size of the leak in CFM, a few simple conversion formulae are applied:

Displacement volume = 500mL = 500cc

1 cubic foot = 28,316cc

Therefore displacement volume = 500 / 28,316 = 0.0176 cubic feet (CF)

To convert the test results to CFM:

CFM = (displacement volume (CF) / time (s)) x 60

So the leak results table from test 1 converted to CFM becomes:

Test 1	10psi	15psi	20psi	25psi	30psi
Tight tolerance	0.0077	0.0089	0.0108	0.0149	0.0182
Loose tolerance	0.0114	0.0126	0.0176	0.0286	0.0302

Analysis

If we take an example of a 2.5L engine at 7000RPM and 10psi boost, using an engine airflow calculator the maximum airflow is approximately 386 CFM.

With an airflow of 386 CFM into the engine, the GFB valve with the loose tolerance on leaks 0.00295% of the total airflow.

If the same engine were modified and running high boost, at 7000RPM and 25psi it will be flowing approximately 621 CFM, of which the loosest GFB valve would be leaking 0.00461% of the total airflow.

Other boost leak sources

As an interesting comparison, there is a device fitted to almost every turbo car that produces a leak far larger than the results shown above, but is often overlooked.

The boost control solenoid, or in fact any boost control device, must leak air in order to function. This leak is almost never noticed however, as a factory boost control solenoid is a closed system that won't show a leak during a smoke test, nor will it even operate until the engine is running and on boost.

A common boost control solenoid valve was connected to the test apparatus and driven at 50% duty cycle. The actual duty cycle depends entirely on the turbo system and boost level, but 50% is a common figure for a mild boost increase on a stock car.

Test 3	10psi	15psi	20psi	25psi	30psi
Boost control	0.0960	0.151	0.176	0.211	0.264

From these results we can see that at 50% duty cycle the boost control solenoid is leaking up to 17 times more air than the GFB TMS valve.

Discussion

From the results above, it can be seen that the expected leak from a GFB TMS valve represents such a tiny percentage of an engine's total airflow that it would be impossible to for any engine performance measuring equipment (such as a dyno, boost or air/fuel ratio gauge) to detect the slightest change in boost level, torque or air/fuel ratio.

When boost leaks are suspected and tested for on a car, this is usually because a loss of boost pressure or performance has been noted. Smoke testing or pressure testing the intake tract will often discover a leak from the BOV, but the size of the leak is not taken into consideration by such testing. More can be read on this topic in the "Turbo lag" discussion paper available from GFB and reference sites

What if…?

As surely as the results of this test will answer many questions and put things into perspective, it will also undoubtedly raise a few more questions such as “What if my valve is old and worn”, or “what if my valve is leaking more than the tests results above”?

The results from test 2 show that the leak measured is all coming from the top chamber of the GFB TMS valve. The air source to the top chamber is via a nipple connected to the intake manifold, usually using a length of 3/16” or similar vacuum hose.

It makes sense than, that the largest leak possible from the top chamber of a TMS valve is limited by the vacuum hose – i.e. the vacuum hose will only flow up to a certain amount at a given pressure, even if the leak at the valve were larger. Even though a leak this large would render the GFB valve ineffective and would be immediately noticeable, it’s worth performing the test for perspective.

The pressure regulator was connected directly to the test apparatus using a 400mm length of 3/16” vacuum hose.

The vacuum hose displaced the 500cc of water in an average of 0.21 seconds at 10psi, which was difficult to measure accurately but is still indicative nonetheless. Since the time was so rapid and the test equipment not big enough to test a larger volume of water, higher boost pressures were not tested.

So a 400mm length of 3/16” vacuum hose at 10psi leaks at a rate of approximately 5 CFM. Again, using the example of the 2L engine at 10psi, this represents 1.29% of maximum airflow.

So although this amount of air loss is a grossly exaggerated example and would not actually occur, it is still not large enough to be noticeable when driving, and would be difficult if not impossible to measure at the engine.

Further testing

As stated initially, any amount of air escaping from a TMS valve can be correctly referred to as a leak. However, from the results above it can be safely concluded that even the theoretical maximum leak at the top of a GFB TMS valve will not cause a drop in boost pressure or engine power large enough to be noticeable, let alone reliably measurable.

So the top of the valve can be eliminated as a potential source of power loss. The only way it can leak enough air to cause a power loss is if the piston were to actually open under boost.

The test procedure used in test 1 simulates WOT conditions up to 30psi, and test 2 proves that no leak from the bottom of the valve occurs under these conditions.

It is often thought that BOVs will eventually begin to open given enough pressure. This is true in many factory fitted valves as they are actually designed to do this to limit boost pressure. However, a GFB valve's design means that the opposing pressures on the piston cancel each other out, meaning that no amount of pressure at WOT will open the valve.

In fact, because the diameter of the Mach 1's piston seat is slightly smaller than the outside diameter of the piston, there is a slightly larger area on top for the pressure to push down than there is on the bottom pushing up. Therefore the spring pre-load is irrelevant – it is not possible for the GFB valve to open under boost.

As final proof of this, test 4 was a repeat of test 1 at 30psi with the spring ***removed entirely*** from the Mach 1 valve. The piston did not open and the results were again exactly the same.

Conclusion

So technically, GFB TMS valves can be said to "leak". Importantly however, when put into context the following has been demonstrated:

- on a 2L engine at 10psi the leak would represent 0.00295% of the maximum engine airflow
- the largest expected leak at 30psi is 0.0302 CFM
- all boost control devices also leak air, and at an average setting of 50% duty cycle a boost control solenoid leaks up to 17 times more air than a GFB TMS valve
- The amount of air lost to these leaks is so small that it would not be possible to detect or measure a performance loss as a result
- It is a simple matter to prevent the leak altogether with the use of an O-ring, but we choose not to (even though it would be cheaper) for valve performance reasons

To summarise, a GFB TMS valve shown to leak as per the tests above indicate that it is not large enough to cause a performance drop or even be measurable at the engine.

The only way a GFB valve can cause a loss of air large enough to be felt as a drop in performance, or measured as a lower boost reading, power drop or AFR change would be for the valve to open under boost.

However, as all of the tests demonstrate (in particular test 4), the GFB valve remains shut regardless of the boost pressure or the spring pre-load, so the possibility of a GFB TMS opening under boost pressure can also be safely eliminated as a source of power loss.