THE EXPERT STEWART SANDERSON

Having worked as a tuner for 17 years, Stewart 'Stu' Sanderson is one of the most-respected names in the business.

A Level 5-trained fuel-injection technician, Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.

Eight years ago he joined forces with Kenny Walker and opened up Motorsport Developments near Blackpool (01253 508400, www.remapping.co.uk), specialising in engine management live remapping, as well as developing a range of Evolution chips which are now sold all over the world.

He is the creator and administrator of www.passionford.com, which he started in 2003. It has grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web.

Stu's enviable knowledge of the workings of modern-day Ford performance engines means that every month he's just the man to explain how and why things work, and importantly how they can be improved.

FUEL SYSTEMS

WHAT YOU NEED TO KNOW TO SIZE YOUR FUEL SYSTEM FROM SCRATCH.

Words: Stewart Sanderson and Will Pedley

Imagine you are building a new powerful engine and have the task of designing the fuel system. What size fuel injectors would you use? What fuel pump would you fit? How big do the fuel lines need to be? Can you go too big? Well, simply read on for some answers...

The ultimate role of any vehicle's fuel system is to ensure that there is sufficient fuel available to the engine to meet its maximum power demands. As the fuel injectors are the exit point of the fuel, we will start with those and work backwards. Even with the best fuel delivery system in the world, if the fuel injectors fitted are too small then there will be insufficient fuel available to the engine and it will either under perform due to running lean, or worse still, be damaged or totally destroyed.

MEASURING FUEL EFFICIENCY

Before we go any further, we need to talk about Brake Specific Fuel Consumption (BSFC). BSFC is a measurement of the engine's fuel efficiency, calculated using the rate of fuel consumption divided by the power produced. Using the imperial measuring system (the industry standard) we're talking about the weight of fuel used in pounds and the amount of power in bhp.

Let's say that we are going to install an engine very similar to a known design and that you researched that design and discovered it produces 400bhp. When run for an hour at that power level it consumes 200lb of fuel. We can now calculate the BSFC by dividing the weight of fuel used by the power produced. The calculation would be:

Fuel Used/Power Produced = BSFC

With our figures: 200/400 = 0.50 BSFC

With forced induction engines it's quite common to find BSFC figures of between 0.6 and 0.7

Each engine will produce different BSFC figures, some are inherently more efficient than others, so if you are unable to get exact values for your particular engine type and power, it would be wise to ensure some headroom in your injector choice. It's usually wise to factor in quite a lot of headroom anyway to take into consideration any future modifications.

INJECTOR SELECTION

Once we've obtained the BSFC we can choose our injectors. We need to know how many fuel injectors we'll be using, we will assume four. We also need to know what duty cycle we are going to run them at – 80% is the maximum safe value for most injectors so let's use that. Also note that the industry standard for quoted fuel flow rates is 43.5psi (3bar).

Using the following example:
Engine BSFC = 0.50
Target bhp = 400
Number of injectors = 4
Target duty cycle = 0.8

We are now three simple calculations away from our required injector size.

1. Multiply the target bhp (400) by the BSFC (0.5) - **400x0.5 = 200**

2. Multiply the number of injectors (4) by the max duty cycle (0.80) - **4x0.80 = 3.2**

3. Divide the first answer (200) by the second answer (3.2) to give the fuel required per hour in lb - **200 divided by 3.2 = 62.5 lb/ph per hour of fuel**

Some injector manufacturers quote flow rate in lb/hr, others in cc/min. To convert from lb/hr to cc/min there is a simple calculation:

CC/min = lb/ph x 10.5

(For our example - 62.5x10.5 = 656.25cc injectors)

To achieve 400bhp on four injectors at 80% duty cycle running 3bar fuel pressure on an engine with 0.5 BSFC, we would need to use the next available size injector up from 62.5lb/hr or 656.25cc/min. You never intentionally design a fuel system that has its injectors anywhere near maximum capacity from day one. You always give the injectors an easy time, and in an ideal world will plan with a maximum injector duration of 60% to allow for tuning headroom and engine efficiency being lower than expected.

INJECTOR POWER RATINGS

If you already have a set of injectors and want to know what power they are capable of in an engine whose BSFC you know, multiply injector size (in lb/ph) by duty cycle and then divide your answer by the BSFC.

Using our earlier answer let's assume the fuel injector is 62.5lb/hr

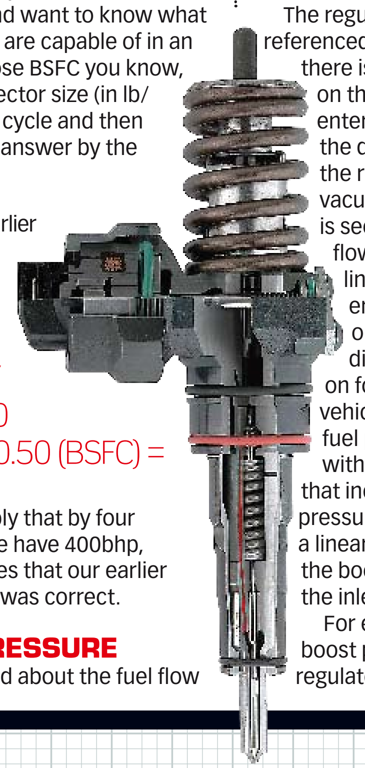
62.5 (lb/hr) x 0.80 (duty) / 0.50 (BSFC) = 100bhp.

If we multiply that by four injectors we have 400bhp, which proves that our earlier calculation was correct.

FUEL PRESSURE

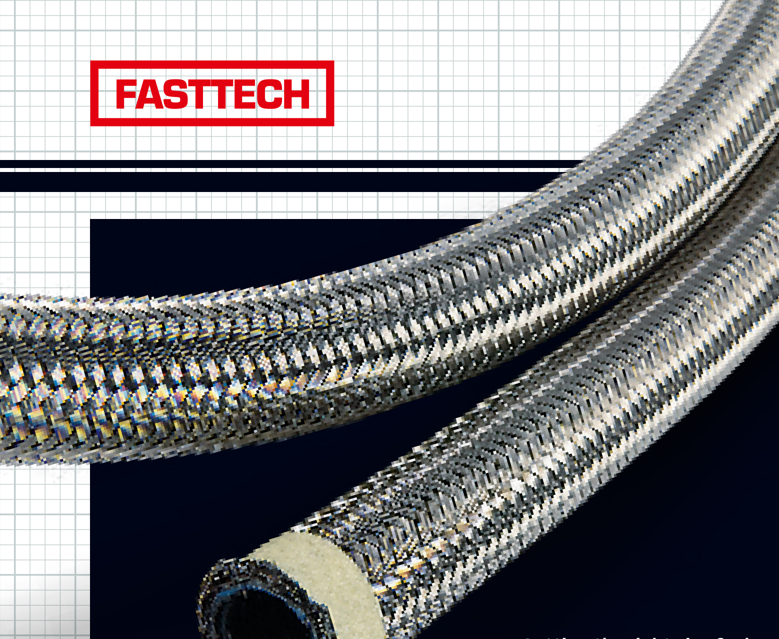
We've talked about the fuel flow ratings of injectors normally being quoted at 3bar or 43.5psi. This is because most fuel injection systems run fuel pressure of around 3-3.5bar. We maintain this pressure with a fuel pressure regulator.

This is present in the fuel system to ensure that the fuel pressure within the rail is constantly maintained even when exposed to a differential pressure. If we have atmospheric pressure in the inlet manifold and 3bar of fuel pressure in the rail, the fuel exiting the injector is meeting no resistance and so is exiting at 3bar. On a turbocharged vehicle running 2bar of boost pressure, there is 2bar of resisting pressure trying to stop that fuel coming out of the injector, so the fuel is only coming out at 1bar of fuel pressure.



The regulator is vacuum referenced meaning that there is a port/nipple on the regulator that enters the area above the diaphragm within the regulator. As vacuum or pressure is seen here the fuel flow down the return line is restricted or encouraged. So, in order to overcome differential pressure on forced-induction vehicles we can use fuel pressure regulators with a 'rising pressure' that increase the fuel pressure in the fuel rail in a linear way in relation to the boost pressure inside the inlet plenum.

For every 0.1bar of boost pressure the regulator increases



Getting the right size fuel lines is crucial to getting an engine running correctly

FUEL RAIL AND LINES

The fuel rail needs to be of larger internal diameter (ID) than the internal diameter of the fuel feed line to ensure that it isn't restrictive and offers a head of fuel to feed the injectors. Sometimes the fuel rail is changed purely to allow for the use of different fittings/attachments.

Another benefit of moving to a larger ID fuel rail is that the greater volume of fuel within the rail helps to smooth out pulses created by the injectors opening and shutting and ensures even fuel delivery at all times.

Pulse dampeners can be found on many factory fuel rails and are now often found on vehicle specific aftermarket items too. Another feature of pulse dampeners in the fuel rail is to reduce the operating noise of the injectors.

Even if everything else in the fuel system is suitable, there will be problems if the fuel lines to and from the fuel rail aren't sufficient. If the fuel feed line is too small, there will not be the volume of fuel required in the fuel rail under load. If the return line is too small then there will be a build up of pressure in the fuel rail and the fuel pressure will rise.

There are a couple of different fuel line options available depending on your requirements and budget, the first being rubber hose, the second being steel braided (Aeroquip). Whichever one you choose, they shouldn't be run through the interior of the car! When lines are run under the car, they should be secured at least every 18in apart and kept away from the exhaust and any low spots that may result in road contact. It's also worth checking to make sure that your fuel lines are routed away from any battery cables too.

If you choose rubber hose, make sure the hose is rated to at least twice the operating pressure your vehicle will see at peak fuel pressure. If we are expecting to see 5.5bar fuel pressure under load, the hose will need to be rated to at least 11bar operating pressure. Aeroquip hose has considerably higher operating and burst pressures than rubber hose.

Here's a rough guide of hose size suitability for your intended power outputs, for petrol/race fuel-powered engines:

Up to 500bhp - 8.6mm ID hose or -6AN

500-800bph - 11mm ID hose or -8AN

800-1000bhp - 14mm ID hose or -10AN

If the vehicle runs on an oxygenated or alcohol-based fuel such as methanol, the hose size will need to be upgraded to at least the next AN size, as a far greater flow is required on these fuels.

The fuel return hose should be one size smaller than the supply hose, so if a -10AN supply feed is entering the fuel rail, then a -8AN hose should be used to return back to the tank from the regulator.

the fuel pressure by 0.1bar. With a fuel pressure of 3bar and 2bar of boost pressure entering the inlet plenum, the fuel pressure is raised to 5bar within the fuel rail, maintaining a 3bar fuel pressure out of the injectors throughout. We can fit a regulator with a rising rate if we need to, maybe 1.2:1 instead of 1:1, but that's another topic and only really required if your injectors are too small.

The regulator helps to overcome differential pressure, but for greater control aftermarket items are available. The standard one might be a sealed item without the facility for adjustment, however most aftermarket fuel pressure regulators are easily adjusted to your desired pressure.

Also, if a higher flowing fuel pump is used to ensure sufficient fuel supply at high engine loads, the flow may be too much at low engine speeds for the standard regulator to bypass away from the fuel rail down the return line. This will ultimately lead to the fuel pressure increasing within the rail at times of low fuel demand from the injectors. It can also be uprated if more secure fittings are needed, compared to the usual Jubilee clip offered as standard on some engines.

"MOST PRODUCTION VEHICLES RUN A SIMPLE, EASILY REPLACED EXTERNAL FUEL FILTER."

FUEL FILTERS

Making sure that clean fuel enters both the fuel injectors and the engine is vital. It is frighteningly easy to damage fuel injectors with debris so filtration is needed.

Most production vehicles run a single, easily replaced external fuel filter between the fuel pump and fuel rail. However, vehicles that run 'in-tank' fuel pumps generally have a small 'bag' filter to ensure any debris in the tank is not drawn through the fuel pump. This also forms the basis for any performance fuel system.

Running a pre-pump and pre-rail fuel filter will ensure that any large bits of debris are removed prior to entering the pump and any smaller bits removed prior to entering the fuel rail. As a guide, a 100micron filter before the fuel pump and a 10micron filter before the fuel rail are normally sufficient.

FUEL PUMP

As we start to tune the engine and fuel demand is increased, it's not uncommon to find that the standard fuel pump is no longer up to the job.

It's not just a simple case of fitting the biggest one you can afford though. If the fuel pump is too big, fuel will circulate rapidly around the system. The friction created by the fuel travelling down the fuel lines will heat it up. Hot fuel is less efficient and will reduce power, very hot fuel can actually start to vaporize and lead to misfires.

We need to know a few facts before we can establish what size to go for:

Weight of fuel
1 litre of Super Unleaded weighs approximately 0.737kg. As most fuel pumps are rated in gallons per hour, we need to convert that. There are 4.546litres to a gallon so

0.737kgx4.546 = 3.35kg.

So, 1 gallon of Super Unleaded weighs 3.35kg or 7.385lb.

Brake Specific Fuel Consumption
We used a Brake Specific Fuel Consumption figure of 0.5 for our hypothetical engine earlier, so we'll use that again.

Restrictions/losses in the fuel lines
Depending on the fuel system and the number of restrictions within it (restrictions include any bends greater than 45 degrees), it's worth factoring a 5-10psi restriction factor in to ensure sufficient headroom in the fuel pump selection. We'll go midway with this hypothetical engine and allow 7psi.

Target bhp
We spoke of 400bhp (flywheel power) as our earlier target bhp, so we'll use that again.

Target Boost
We'll use a target boost figure of 2bar or 30psi.

First we need to calculate total fuel pressure:

Base Fuel Pressure + Target Boost + Restriction Losses = Total Fuel Pressure

43.5 + 30 + 7 = 80.5PSI

Now we have the total fuel pressure figure, we can calculate the fuel required:

Target bhp x BSFC = Fuel required in lb/hr

400 x 0.5 = 200lb/hr

Now we know the fuel required we can calculate the fuel pump flow requirement in gallons or litres per hour (the rating most fuel pumps are listed by).

Lb per hour / fuel weight per gallon = gallons per hour

200 / 7.385 = 27.08 gallons per hour.

(To convert to litres multiply your result by 4.546)

FUEL SWIRL POT

We need to look at where the pump gets its fuel. Depending on the vehicle, this will either be the fuel swirl pot or the fuel tank. Let's assume the vehicle has a swirl pot, this is designed to ensure that there is a constant supply of fuel to the pump's inlet. It's not uncommon for fuel to 'slosh' around within the fuel tank under hard cornering, acceleration and braking, meaning that there is a strong possibility of the fuel pump drawing air in. The solution is a swirl pot, which can be plumbed into an existing system. There are normally four ports on a fuel swirl pot:

Fuel in: Found on the top half of the swirl pot, fuel is fed in from the fuel tank via a lift pump or the original vehicle in-tank fuel pump.

Return in: Found on the top half of the swirl pot, the return line from the fuel pressure regulator no longer needs to go back into the fuel tank. It can be fed into the fuel swirl pot to ensure maximum fuel content within.

Overflow out: Found at the very top of the swirl pot, this allows any air or excess fuel to return to the fuel tank. The original return line into the fuel tank can be used for that purpose.

Fuel out: Found at the bottom of the swirl pot, this is the point the fuel pump can draw from.

Swirl pots help eliminate fuel starvation under heavy cornering

To achieve 400bhp at the flywheel at 2bar/30psi of boost pressure we need a fuel pump that can supply a minimum of 27.08gallons per hour (123.10) at 80.5psi of fuel pressure.

A pump rated in excess of these figures is acceptable, however we have established what is required and the unit chosen should be selected with this information in mind.

Fuel Pump Voltage
Fuel pumps are normally rated at 13.50volts. Depending on the age of your vehicle, there is a chance that the wiring may have deteriorated. It's worth checking the fuel pump voltage under full load and checking to see if it drops below 12.50volts. If so, it's look at rewiring it to ensure suitable fuel supply. If it does need rewiring, a common practice is to use the original fuel pump wiring to switch a relay, with fresh wiring run through the relay.

Uprated pumps and more fuel pressure to pump against will mean more current draw, so often the standard sized, factory fitted cable as fitted from the factory is insufficient.

FUEL TANK

The final part to consider is the fuel tank. Depending on the vehicle and the application, this can come in a number of formats. The original tank is suitable for a lot of vehicles, however, where it isn't there are aluminium fuel cells and bag tanks available.

Aftermarket fuel tanks can be used to aid weight distribution as part of the relocation process and some can be made with integral fuel swirl pots. One thing to make sure of with an aftermarket item is that the vent port is fitted with a one-way valve. This will allow air in to normalize the vacuum created by fuel being drawn out, but without releasing fuel vapour out.

Some fuel tanks feature integral swirl pots to prevent surge

NEXT MONTH
CONVERTING A ROAD ENGINE TO A RACE ENGINE.