Author | Topic: Fuel Injector Sizeing and their relationship to Power Adders Chapter 1 (Read 793 times)

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Fuel Injector Sizeing and their relationship to Power Adders Chapter 1

« **on:** March 18, 2010, 01:38:17 AM »

Everyone,

First I wish to apologize. The length of this paper is ridiculous, as it grew it gained momentum and there was so many aspects to this subject it wasn't possible to stop with out getting some kind of closure. Sorry ! Since it is so large it will not fit as one post. My plan is to break it into five pieces. It will eventually be in the manual that Carl is creating for such things, so they can be easily referenced later.

This has become one of the most important discussions I've come across in a long time.
Every gear head that contemplates adding something to their engine to make more HP needs to consider the fuel system limitations, and what needs to be done to be sure the fuel system is capable of maintaining the correct AFR for whatever power adders they install.

One thought to keep in mind, this entire discussion assumes that we are talking about WOT operation only. i.e., when the engine is operating open loop, we are not going to consider closed loop operation when the O2's are in control.

The consequences for picking the wrong size injectors or for that matter the wrong power adders, could cause sever detonation, that in spite of the knock sensors, that can damage engine parts in les than a second.

The typical parts, most commonly damaged by detonation are: burned off spark pug electrodes, spark plug insulators coated with metallic flakes, broken ring lands, spun bearings, holes in pistons, destroyed cranks, broken rods, and holes in the side of blocks. I've been there and done all of those things. You may be tempted to say "The Knock

Sensors will protect me from those problems" and that's true to a degree. But in-spite of the knock sensors, these failures continue to happen, - just not as frequently. I speak from personal experience. Since learning how detonation manifests it's self, and the probable causes, I have not had a failure, so apparently I have learned some very expensive lessons that I will try and share with you.

In addition, throughout this discussion I have been consulting with a very knowledgeable mentor that is intimately familiar with the tune of our Super Charged AJ16 engines. Andy has been a valuable source of information, some of which has not been previously shared outside Jaguar. He has also added his own personal experience with power adders like replacing the M90 with an M112 supercharger as well as his current project. He is in the process of installing two blowers on one of his AJ16 engines. My kind of guy. "Horse Power is one of the three things in life you never have enough of."

Dale started this thread by mentioning his twin screw compressor project. That led to my thoughts about how interested I was in his project and the need for him to consider upgrading the entire intake system including the air cleaner, MAF, plumbing, throttle body, intercooler water pump, injectors, and EMS programming.

Andy, aka XJRengineer, added some very pertinent information.
The flow rate of the stock injectors is 5.125grams/sec
The MAF is flowing 1019kg of air per hour at max HP of 322
The EMS is programmed to provide an AFR of 12.5:1 at WOT.
He added that 12.5:1 produced the most power our engines could produce given the stock components.
And the need to protect the engine from its self.
In addition he mentioned that in most cases power fell off very rapidly as you increase the AFR above 12.5:1
BTW those numbers are spot on for most well designed systems using Roots Blowers.

The important bit of information you need to be aware of is at 12.5:1 the combustion chamber temperature and exhaust gasses are so hot, you will damage exhaust headers and exhaust valves if you try to maintain WOT at 3500 to 5000 RPM for very long.

If that is your goal, some additional thought may need to be given to methods of reducing combustion chamber temperatures like water/alcohol injection or other means of significantly cooling the intake charge temperatures. Water/alcohol works very nicely as long as you don't over do it But I have not personally noticed much change in exhaust gas temperature from water injection, I wonder why . Hmmmmm

Some time in a different paper I will share my experience with water/alcohol injection. Most of the commercially available systems are poorly designed, inject far too much water and in some cases reduce HP, and damage engines. Don't waste your money. Do not believe their advertising. Water/alcohol does not make HP. It oools the charge controlling detonation so that additional HP can be made through various means. My own recommendation is; if you have a detonation problem, use racing gas up to 116 octane, or mix your own using stuff from the local paint store. If additional detonation control is necessary then water /alcohol is a reasonable solution.

Andy also provided some basic data that is very difficult to come by and is usually guessed at with unfavorable results at times.
So we thank him for that.

Due to the poor thermodynamic efficiency of Roots Blowers, the Brake Specific Air Consumption (BSAC) for our AJ16SC engines, at wide open throttle, is 4.2kg of air per kw per hr. Converted to my habit of thinking, that's 6.9lbs of air per hp per hr . If we consider that the AFR at WOT is 12.5:1 then we can convert the BSAC to the more familiar Brake Specific Fuel Consumption (BSFC) by dividing 6.9 lbs of air by 12.5 and end up with 0.552 BSFC. That is about as good as you will ever get with a Roots Blower on your engine, by the way.

I built two engines with Roots Blowers, neither was even close to the BSFC of our XJR's….The worst had a BSFC of .72 That was in 1955-56 and the 671 GMC Blower was almost ½ the size of my 1940 flat head Ford engine. Fully ½ of the additional HP the engine made from boost, went to spinning the blower. I had to use 6 V belts on custom pulleys to drive the monster.

To be continued
look for chapter 2

Pete

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Re: Fuel Injector Sizeing & Power Adders Chapter 2
« **Reply #1 on:** March 18, 2010, 01:47:12 AM »

Chapter 2

This thread continues to interest me and believe there is much to be offered. I believe the goal is to continue to grow the knowledge base and provide additional information applying current and emerging technology to the art of making more power! Join me!

I will add my own experiences and I hope you do the same.
To a large extent, successful experiences making more power were always accompanied by the application of measuring equipment like Wide Band AFR meters, and remote Fuel Pressure Gauges. In addition a good USB2 interface from the OBDII connector to your lap top PC is a must. If you start to get on the ragged edge of risky HP production i.e., 150HP per liter, you should also consider exhaust gas temperature measuring devices for each individual cylinder because the distribution of fuel air mixture becomes critical at that level. And EGT is an excellent way to measure that.

As important as measuring devices are, you will also need a very good understanding of how to calculate fuel injector sizes. Confucius the founder of the Ru School of Chinese Thought said: “The closer you are to where you need to be, the easier it is to get there.”. Pete’s interpretation; "tuning will be a lot easier if you’ve done your homework first."

Andy added his thoughts on the importance of using a Wide Band AFR meter. He also mentioned how difficult it was to get the relationship of boost, timing, and AFR correct even when you had the engine on a dyno let alone “on the road”.

Having the ability to record the output of 20 different sensors from the OBDII while driving is invaluable. Analyze it later and decide what needs to be done.

Find a dyno hill that is more than 1/4 mile long, steep and is safe to drive 80 or more MPH on. Almost as good as a dyno. Well that’s an exaggeration!

That is a recap, with a few additions, of what has been discussed so far.
Hopefully we can continue this discussion, eventually providing most of the metrics and calculations needed to get the right size injectors the first time.

For the moment I will try and limit this discussion to sizing fuel injectors and related components. Once that discussion is out of the way, we can talk about what you might consider in-terms of power adders that would create the need for more fuel.

We will also discuss running different fuel pressures, how to use adjustable fuel pressure regulators, the potential need for larger fuel lines, larger fuel rails, and selecting the right size fuel pumps

Review
Before calculating some injector sizes, lets review what we know about our AJ16SC engine characteristics and its stock fueling system.

- The engine makes 322 Horse Power @ 5,000RPM
- The engine makes 367 ft/lbs of Torque @ 3050 RPM
- The MAF flows 1019kg of air /hr or 2,246.48 lbs of air /hr at 322HP
- The rail of the MAF’s A to D converter is 1024 kg/hr Good to know!!
- The Brake Specific Air Consumption is 4.2kg/kw/hr or 6.9 lbs/hp/hr
- The AFR at WOT is 12.5:1 and that happen to make max power.
- Efficiency in terms of fuel consumption, measured at WOT
  is measured as Break Specific Fuel Consumption (BSFC) = 0.552 lbs/hp/hr
- Our engines can make 1.812 HP for an hour from one pound of fuel
- Our Injectors are specked to flow 5.125g of fuel per sec
  Or 18.45kg/hr at 100% duty cycle. That is equivalent to 40.67lbs/hr

  @ 43.5PSI (3Bar) or 427.04 cc/min
- 40 pound injectors are a very common size and can be purchased

new for
less than $30 on e-bay. That's about the cost of cleaning.
Why not buy new ones?

- Answer. New ones are not matched, and you don't really know what they
flow until they are tested. In addition their spray patterns could be ugly.
And they could dribble and leak when off.

- My stock injectors measured 38.05 lb/hr, or 400 cc/min after cleaning.
Since they have been tested, and are not a theoretical size, I will use them
in my examples when appropriate.

- At WOT our superchargers make max boost at about 3000 RPM in 5th gear. Forth for you gys with automatics.
The peak boost is 7.8PSI and it falls off to 6.88PSI by 4000 RPM
In 2nd gear the boost has fallen off to 5.5PSI by 4500RPM
Since our blowers are not compressors the only reason they make any boost is because the engine can not use all of the air being delivered.

Modify the engine to make more HP i.e., use more air, and the boost will drop. An interesting concept, eh?

- An interesting measure that is very important that never gets any attention is Volumetric efficiency. Ours occures at 4000 RPM
and we will discuss it more later on.

- At WOT our torque curve is very flat (that's good)
It starts at 1500RPM and is close to 400 Nm
The peak occurs at 3000 RPM close to 450Nm – no surprise there
By the time the RPM reachs 5500 it has fallen to 400Nm again
400 Nm = 295ft lb of torque 450Nm = 331 ft lb of torque
That my friends is called drivability. Very desirable

- At WOT our HP peaks at 5000 RPM and remains quite flat until 5500

An interesting observation
HP is calculated by multiplying measured Torque in ft lb X RPM and dividing the result by 5252. Therefore at 5252RPM, ft lb of torque and HP are equal. See, there is at least one an advantage to SAE measures.

For example,
If you had a 2 liter engine that made 200ft lb of torque at 19,000 RPM it would be making 734HP at that RPM. A real life example!

If you had a 10liter engine that made 1,000ftlb of torque at 4000 RPM you would be making 762 HP at that RPM.

If you had a 500 CC motorcycle that made 50 ft lb of torque at 32,000 RPM you would be making 305 HP – experimental Honda race bike

- Our intercoolers, when compared to supercharged AJ16's without intercoolers increase torque by about 20% at 3000 RPM.
  By the time the engine reaches 5500 RPM the additional torque is down to 10%. Lots of room for improvement there.
  Start with a bigger pump! Then chill the water.

Things to keep in mind when sizing injectors.
- All injectors are not created equal. Most are measured at 3 bar or 43.5 PSI
- Ford injectors are specked and run at 39 PSI. I run them at 58PSI
- GM LSx injectors are specked at 43.5 PSI but are used at 58PSI
- Ford and GM injectors will interchange and physically fit our engines.
- Both Ford and GM injectors come in many different flow rates.
- Determining what flow rate you need is up to you.

Purchasing new injectors.
- I buy my injectors on ebay, they are very inexpensive that way.
  But only from people that sell new ones and sell a lot of them.

- There is only one way to find out what your injectors flow, and that is to
  have them cleaned and measured.

- For size calculation purposes the world has decided to use an injector duty
  cycle of 80%. Some people prefer 90% but no one recommends using
  100%. A little head room is a very good idea.

Thoughts about Sequential Port Fuel Injection.
Interesting, at WOT, 3000 RPM and higher, each injector is squirting fuel at a closed intake valve most of the time. Each complete cycle, or 100% duty cycle is 720 degrees of crank rotation. At 80% duty cycle the injector is squirting for 570 degrees. The intake valve is most likely open for only 220 degrees or so. Interesting thought eh?? No wonder the next generation of gas engines will use direct injection, somewhat like diesels.

Also when the intake valve opens, the pistons downward movement is trying to suck 666cc or 40.66 cu in - that's a very large 22.5 fluid oz bottle of pop or fuel air mixture into the cylinder. Since we pressurize the manifold at roughly 7 PSI you can add 50%. That would say the actual volume of air at atmospheric pressure would be 60cu in per cylinder, but it's all relative and we are actually looking for 41 cu in at 7PSI to stuff into the cylinder while the intake is open.

By the way at 5000RPM the intake valve is only open for 5ms
So we are trying to find well over ½ a liter of fuel air mixture to stuff into the cylinder in about 5ms. That's a neat trick. Where does it all come from ?? Not that little port with the injector in it that's way too small.

Heck no, our cylinder is going to steal mixture from the plenum behind the intercooler matrix, but it doesn't have any fuel in it yet. In addition all of the other 5 ports will contribute some fuel air mixture to the cause.

So much for sequential port injection.
At idle when most of the cylinder is vacuum and not fuel air, sequential port injection is a good way to control pollution. And the intake valve will be open for 46ms So there is plenty of time to sip a little air and fuel

At operating speeds there is little advantage to sequential port injection. The air in the manifold is moving around at the speed of sound, so there is a lot of activity going on. Smooth gentle radiuses are good to maintain dynamic cross sectional area in the turns.
Dimpled walls in the port and manifold, like a golf ball surface, are good to kick fuel that has fallen out of suspension due to changes in pressure., and now trapped in the boundary layer back into the air stream, this is also a very good technique to help burn all of the fuel in the combustion chamber, which some times responds to dimpling. around the intake valve Small drops get burned, big ones end up in the exhaust manifold. Fuel drops are burned in layers, like pealing an onion, and large drops have too many layers to get completely burned in the time allotted.

Common Conversions
What follows is a list of common conversions needed for these calculations.
Sorry, my mind doesn't automatically think in metric, so it is impossible for me to spot a nonsense error when the measures are in metric notation. When possible, I will provide the metric equivalent of my SAE numbers.

Convert cc/min to lbs/hr
divide the cc/min by 10.5 - answer is lbs/hr

Convert lbs/hr to US gal./hr
divide the lbs/hr by 6.25 - answer is gal/hr

Convert cc/min to US gal/hr
multiply cc/min by 0.015873 - answer is in gal/hr

Convert kilograms to pounds
multiply kilograms by 2.2046 - answer will be in pounds

Convert lbs/hr to g/sec
multiply lbs/hr by 0.125998 - answer will be in g/sec

Convert KPa to PSI
1 atmosphere = 14.69 PSI = 101.3KPa

Convert KPa to Bar
100KPa = 14.5PSI = 1Bar That explains a lot.

Convert Kw to BTU to HP
1KW = 3413 BTU = 1.341HP

One US gallon of gasoline at 72F weighs 6.25lbs

What follows are some formulas that I have found useful during the past 30 years of using fuel injection on modified engines.

How to calculate injector flow rate to produce desired HP
How to calculate potential HP from a known injector flow rate.
How to figure out the flow rate and HP potential of an injector if you increase the fuel pressures.
How to size a furl pump.
How to adjust an adjustable fuel pressure regulator
And other stuff that can't be ignored.

1) How to calculate injector flow rate to produce desired HP

We will use my injectors for this example because they have been measured, Allowing us to create an example using real numbers. – not advertised flow rates.

What pertinent facts do we know?

My injectors flowed 38.05 lbs/hr or 400cc/min when measured
We have 6 injectors in our engines.
We will use an injector duty cycle of 80% for calculation.
Our engines have a BSFC 0.552lb of fuel /hr at WOT

Other Examples of BSFC and related facts
- If our engines were NA with 10:1 static compression, the BSFC would be closer to .5 and if turbo charged closer to .6

- The most efficient reciprocating engine measured, is a 10 liter aircraft engine that has a BSFC of close to .4 .

- 351CU/in NASCAR Cup engines making over 800HP and have a BSFC of less than .5! Fuel economy is important to them

At partial throttle, the BSFC of an Otto Cycle engines gets very high. The reason is simple, the efficiently of an engine is proportional to the dynamic compression ratio – or more accurately the combustion chamber pressure before the fire is lit. At partial throttle, the cylinder is mostly filled by vacuum, nothing, and the combustion chamber pressure is very low.

Rule of thumb, for each increase in static compression ratio of one full point i.e., 8:1 to 9:1, the efficiency of the engine will increase by 3% But that's an old wives tail, so it isn't necessarily so.

2) How to calculate amount of HP that can be provided by a specific injector flow rate.

(Injector flow rate) X (duty cycle) divided by (BSFC) X (number of injectors). = HP

39.05 lb injector Example (Using my stock injectors)
38.05 X .80 = 30.44 divided by .552 = 55.14 X 6 = 330.86 HP

That's a very interesting piece of information to keep in mind isn't it. Our stock injectors can produce 330.86HP at 34.5 PSI and 80% duty cycle

How much HP can our injectors make if we decided to get a little closer to the danger zone and calculate at 90% duty cycle.
38.05 X .90 = 32.245 divided by .552 = 62.038 X 6 = 372.23HP
An interesting thought, but be careful.

60Lb injector example
60 X .80 = 48 divided by .552 = 86.95 X 6 = 521.71HP

Examples.

322 HP Example
Lets do the calculations for our stock engine making 322 HP
(HP X BSFC) divided by (number of injectors X 80%) = Flow Rate
(322 X .552) divided by (6 X .80) = Flow Rate in lb/hr
(177.744) divided by (4. = 37.03lbs/hr/injector.

They don't make a 37.03 lb injector so Jaguar used a 40lb/hr injector
The 40# in my car flow 38.05 --- not unusual !
And are more than big enough to make the 322HP we get from our engines.

400 HP Example
100hp/liter engines are just barley getting into the high performance league these days. So that's very reasonable.

Same calculation just change the HP number
(HP X BSFC) divided by (number of injectors X 80%) = flow rate
(400 X .552) divided by (6 X .80)
220.8 divided by 4.8 = 46Lb/hr injectors
I found some great looking Siemens 575cc/min injectors on e-bay but when I looked up their spec they were low impedance about 3 ohms. We need high impedance injectors about 15 ohms. So they won't work. But I'm sure something close is available. They should cost about $40 each.

500 HP Example
This is a great power level. And is entirely possible from 4 liters.
2 HP per cu in is very achievable NASCAR Cup engines make 2.3 HP per cu in from two valve per cylinder, pushrod engines., designed in the 50's

But they are spinning those things at close to 9.000 RPM these days. We don't want to do that. We want to make more torque and the 2nd best way to make more torque is with a supercharger. The supercharger you choose will need to force 3,450lbs of air into our engines per hour. Or 1565kg of air /hr To do that we will need to run 18 PSI of boost. That's doable!

What size injectors will we need?
(500 X .552) divided by (6 X .80) = Flow Rate per injector
276 divided by 4.8 = 57.5 lb/hr injectors

60 lb/hr injectors will set you back $49 each on e-bay these days
When I bought mine, 7 years ago, they were over $600 for a set of 8

The supercharger kit to do this will cost over $5,000. By the time you are done you should also consider: a bigger throttle body, larger or more efficient intercooler, larger plumbing, larger MAF, and unless you can reprogram the stock EMS, you will need to replace that also.
Pro Charger makes a well designed Centrifugal Super Charger Kit that will fit very nicely in our engine bays. Plus you will definitely need a hand made set of headers and exhaust system. That's a lot of air to move around.

To be continued
Look for Chapter 3

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Re: Fuel Injector Sizeing & Power Adders Chapter 3

« **Reply #2 on:** March 18, 2010, 01:49:21 AM »

3) How to figure out the flow rate and HP potential an injector can make at different fuel pressures.

Lets first take a look at how to calculate the amount of fuel your injectors would flow if you were to increase the fuel pressure.

This is a very common practice, among tuners looking for more HP inexpensively. This technique allows you to increase the flow rate of your stock injectors, and use them to cover the additional HP made by a power adder or two. It is also a way to tweak the AFR in fine increments.

Be aware that exceeding 60PSI is counter productive and should be avoided. At that pressure some injectors can get unpredictable. Also I will be using 80% duty cycle in all of these calculations. Feel free to recalculate any of them using 90% . If you are careful in your calculations, 90% will provide enough safety factor, but be careful.

What we are discussing here, is how to insure that when you open the throttle, there is sufficient capacity in the injectors to allow the EMS to maintain the AFR at 12.5:1 Any power adder requires more fuel, and it is your responsibility to be sure your system can supply it in the right amounts. The vendor of the power adder assumes you know what you are doing!

Changing fuel pressure. What is the effect of changing fuel pressure? We will assume you know what the 43.5 PSI injector flow rate is for the injectors you intend to use.

There is one conversion factor that we will be using that we haven't used before. We will be using the flow rate of the injectors expressed in cc/min. To arrive at that. Simply multiply the flow rate in lb/hr X 10.5 = flow rate in cc/min.

When choosing a higher fuel pressure, make it easy to remember. I like to use 3 Bar = 43.5PSI or 3.5 Bar = 50.75 PSI or 4 Bar = 58 PSI.
It can be adjusted as part of the tuning process later but do not exceed 4 BAR

Formula:
Divide the new pressure by the old pressure calculate the square root.

Multiply the square root, times the old flow rate in cc/min.
The answer is the flow rate of the injector in cc/min using the new pressure.
Convert that to lb/hr by dividing by 10.5
Convert that to lb/hr at 80% duty cycle X the number of cylinders
Convert that to HP by multiplying by the BSFC Reciprocal = to 1.812
Example:
(new pressure) divided by (old pressure)
58-PSI divided by 43.5-PSI = 1.31034

The Sq. Root of 1.3333 is 1.15470

Multiply that times the flow rate of the injectors with the old pressure,
Lets use 400cc/min ---- that's the flow rate of my injectors at 43.5 PSI.
Therefore 1.15470 X 400 = 461.88 cc/min

Convert cc/min into lbs/hr at 100% per injector
461.88 divided by 10.5 = 43.99lb/hr

Convert that to lb/hr at 80% x number of cylinders
lb/hr X 80% X number of cylinders
43.99 X .80 X 6 = 211.145 lb/hr

Convert that to HP -- multiply by 1.812 the reciprocal of .552 BSFC
211.145 X 1.812 = 382.60 HP

At the stock pressure, the injectors maxed out at 331HP
But the engine is rev limited to 5500RPM so in reality we can only make

322HP. We will be conservative and claim a gain of 51 HP

That's a lot of additional HP, on a supercharged engine
Install a nice set of SS tube headers and big tubes will get you 15 HP.
Cooling the air charge by 30 degrees C will get you another 15HP.
Port matching and pocket porting the head with a 5 angle valve job may get you an additional 15HP .

With a stock engine, spinning the M90 10% faster will net you some additional HP. Considering everything represented by the gain in peak HP compared to a NA AJ16, as well as the available boost graphs and the available torque at peak volumetric efficiency, it looks like the bigger crank pulley will net an additional 13.41 HP. When added to the other power adders mentioned it will be more. Added together, this collection of hypothetical power adders will add more HP than our fuel injectors running at 58PSI can deliver. But remember we were calculating at 80% duty cycle and if you are willing to take a small risk recalculating at 90% there will be more than enough to cover the requirement. Or don't do one of the modifications.

I know you have been lead to believe some of these things will provide much more HP. Be very suspicious of marketing hype. For instance, just this morning I ran across an advertisement for an air filter. Wolf Technology claims their "Velocity Stack Air Cleaner " will add 15 HP and by god two of them will add 30 HP. That must be a very restricted stock air cleaner they are replacing. Don't believe it!!!

We will get back to some really good ideas in-terms of power adders shortly

Manifold referenced adjustable fuel pressure regulators
Setting adjustable regulators can be confusing because they are referenced to the intake manifold absolute pressure. It the engine is sealed really well, the manifold vacuum can be as low as 25.5 inches going down a hill at 70MPH with your foot off the gas, or close to 10PSI of pressure at WOT at peak torque near 3000 RPM in high gear.

The important thing to remember is at idle, if your engine is in good shape, it will be pulling about 20 inches of Hg (20 inches of vacuum). For each 2.040 inches of Hg (vacuum) in the manifold your regulator will reduce the fuel pressure by 1 PSI. Therefore, at idle, when pulling 20 inches of vacuum, the fuel pressure gauge should be set to read 33.7PSI.

Here are some useful vacuum equivalents that may be helpful
18 in/Hg is equal to -8.82PSI
19.5 in/Hg is equal to -9.56 PSI
21.0 in/Hg is equal to -10.29 PSI

The pressure gauge is always referenced to atmosphere.
The regulator is referenced to the absolute pressure in the manifold.
The fuel pressure across the injector needs to be 43.5PSI all the time Unless you decide it needs to be something different.
So the pressure gauge is not reading across the injector and you must interpolate the reading to set it correctly.

One other point to remember many gauges are not compensated for atmospheric pressure and if you are not aware of that, you can get some really unbelievable readings if the barometric pressure is low or high that day. I've often seen my vacuum/boost gauge read 30 inches of vacuum at idle when a big storm was headed our way.

Selecting the right size Fuel Pump
Lets talk about fuel pumps for a moment. The pumps we have in our XJR's are big enough to supply a 500+HP engine.
- Each pump is rated at 90litres /hr. 90litres is = to 23 US gal.
- One gallon of gasoline weighs 6.25lbs at 72degrees F.
- Therefore 23 gallons weighs 143.75 Lbs.
- We know the BSFC is .552 and the reciprocal of that is 1.812
- Thus our engines can make 1.812hp for an hr from 1 lb of fuel.
- Therefore from 143.75 lbs of fuel we can make 260.475 Hp for an hour
- With two pumps we can make 520HP

Should you ever feel the need for a much larger pump, my favorite is from a 1998 Turbocharged Supra. They are the most reliable and the quietest pump I have ever used. The Denso part number is NP9500155 and they cost $200. They flow 60GPH at 87PSI so each one could fuel a 680 HP engine. One would probably flood the regulator return line in our Jaguars, so they are really too big for our application I'll try and find something more appropriate.

Andy asked about the Supra and how much HP they made. At the time I had no idea. I have since found out they were 6 cylinder engines and used
60 lb injectors so they were pretty stout.

To be continued
Look for chapter 4

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Re: Fuel Injector Sizeing & Power Adders Chapter 4
« **Reply #3 on:** March 18, 2010, 01:53:04 AM »

Section 4

Adding Power
But there is one little item I have been ignoring.
Looking at the graph of the superchargers output pressure vs engine RPM, there is an anomaly that indicates something is close to being maxed out.
So we need to understand what is going on, before considering any power adders.

Remember everything is interrelated so it's very important that you see and understand the whole picture. I'll give you a really great example, everyone knows that increasing static compression ratio will increase output efficiency and result in more torque, better throttle response, more HP, and less heat in the engine.

But in actual practice, carefully monitored experiments on a dyno, when our engines static compression ratio was increased from 8.5:1 to 9.0:1 there was some additional torque produced around 2000 RPM but the peak was way down, and the area under the curve was much worse.

On the other hand when the Static compression ratio was decreased to 8.0:1 the peak torque was significantly higher and it occurred at 4500 RPM, but again the area under the curve was less. Although it would be the way to go for a road race engine. Keeping the RPM between 3800 and 4800 would not be a problem. That's very interesting. But normal drivability would not have been as good.

At 8.5:1 the torque peaks at 3000 RPM and is greater than the other choices. In addition the area under the curve is a bit fatter and that's the key to drivability. Good choice Jaguar.

To be sure, every thing we do to make more power will require more air and fuel. Reciprocating engines have been referred to as heat pumps, that's true, but I like to think of them as air pumps. Every thing you do to make more torque requires that more air is brought into the engine. When you add headers and big pipes what you are really doing is getting more of the residual exhaust gasses out of the way to make room for more fresh air and fuel. In fact, make no mistake, every thing you do to the engine to make more torque will lower the boost pressure because you are making it easier for the engine to use additional air relieving the boost pressure.

So lets talk about this wonderful air mover we call a blower. It is not a compressor there is no compression taking place inside the blower. Pressure or boost occurs because the engine can't use it as fast as the blower delivers it. That is obvious when you look at the boost graph.

Consider this, at 5000 crank shaft RPM the blower is turning at 12,500 RPM
Since it displaces 90cu in it will be trying to move 1,125,000 cu in of air per min. Our engines displace 240cu in but it only consumes air on every other rotation so it in effect displaces 129 cu in per RPM so at 5000 RPM it is trying to consume 600,000 cu in of air. That leave 525,000 unaccounted for. Interesting the volumetric efficiency of a roots blower in actual practice isn't very good.

Note: Peak engine Volumetric Efficiency occurs when the cylinders are being filled with the greatest % of fresh air and fuel. It's measured in terms of % of cylinder displacement. In SC engines that % is usually above 100% at WOT

The stock engine's peak volumetric efficiency occurs at 4000RPM. At that RPM all of the planets are aligned and every part is working in harmony to help our engines to take their deepest breath. And that's where we see a major drop in boost pressure. The peak VE occurs at that rpm because of a combination of things like: port design, camshaft profiles and timing, connecting rod length to stroke ratio, basically every part of the engine contributes. And it is very fortunate that it occurs at such a convenient RPM for drivers like us.

In addition to getting our engines to breath deeper, and use more of the air provided by the blower, there is one other thing we need to consider.

Our blowers can only create a finite amount of vacuum. In essence they are poor vacuum pumps. I don't know what the amount of vacuum is at this moment but I will measure that in the next couple of days.
Unfortunately there are all kinds of things between the inlet of the supercharger and the atmospheric pressure that will be doing its best to fill the depression made by the combination of the engine and blower.

My suspicion is that there are several restrictions to the measly 14.7 PSI that is pushing air through the air cleaner toward the blower, and any thing we can do to reduce those restrictions will be of incredible help in making more air available to the engine.

Starting with the air cleaner. We need to find something really big from a large displacement car or truck that we can fit into the space behind the grill or maybe where those pesky brake air ducts are sitting. I don't use the brake that much anyhow!

Next would be the MAF! The MAF is designed to work with the EMS and screwing with that is not out of bounds as long as we can reprogram the tables in the EMS. That is a complex issue but it needs to be solved. We will work on that. There have been some discussions on how to overcome the volume limitations of the MAF . I'll touch on those later in this paper.

Third would be all of the plumbing, from the new air cleaner to the Throttle Body. It needs to have a cross sectional area of 9.5 Square Inches.

Then we get to the Throttle Body it needs to be bigger. 90mm would be great but anything over 85 would be an improvement.

And finally the adapter that mounts the TB to the super charger.
It needs to be larger, and the changes in air flow direction need to be very gentle. Any time the air can't go straight it gets separated from the surface as it goes around a corner and effectively reduces the cross sectional area and restricts the flow.

There is a company that sells a housing for our M90's. Their castings have an intake that is almost twice the size where the adapter mounts,

They understand the problem.

The real difficulty in this is where does all that big plumbing fit.
I think we need to think out-of-the-box. The air cleaner doesn't need

to be where it is. It could be sucking air from the base of the windshield. Or from the left hand inner fender. Or from a very discreet scoop in the hood. We need to get our cold outside air closer to the throttle body. All that plumbing has got to be very restrictive.

One of the things we need to do is to figure out how much air / HP the MAF can cope with. Then discuss what can be done about it.

This should be relatively easy even though we are assuming a few critical details. The assumption is that the output from the MAF is a voltage between 0 and 5 volts. That's based on the presence of several other sensors in the system that operate on a regulated 5V source.
The second assumption is that the Analog to Digital converter in the EMS is a 10bit device that can resolve 1024 increments of data. Since the max HP of 322 is produced with 1019 kg of air flowing thought the MAF it seams reasonable to assume that the MAX flow that the MAF can measure is 1024 kg of air per hour.

If that is true the max HP that the MAF can cope with can be calculated like this.
1024kg x 2.2046 =-2257.51lb of air
2257.51 divided by 12.5 AFR = 180.60 lb of fuel per hr
180.60 lb/hr X 1.812 = 327.24HP
And that's very disappointing,

In order to support any additional HP we will need to do something to deal with that problem. Some people have suggested that we block off a percentage of the hot wire sensor opening in the MAF and increase the flow rate of the injectors a proportional amount. Sounds logical except there are two problems with that approach.

1) Fooling with air flows usually results in non linear changes.

2) Since the ignition advance is partially determined by load and load is derived from the amount of air being consumed, and the throttle position it
is likely that the timing would end up being advanced further than it should if the MAF were reporting the true amount of air flow.

Since the knock sensors would detect the resulting detonation and the EMS would retard the ignition killing HP. All of that is hypothetical – I don't know what is going to happen with the timing but it certainly deserves some caution.

You could also bypass 20% of the air around the MAF with a butterfly valve so the bypass could be tuned. But that is problematic for the same timing issue.

I don't like any of those ideas. If you must have a MAF then get a bigger one. I have a Granatelli Big Air it is rated at o to 2800Kg/hr
That's big.

But the real problem is we can't reprogram the EMS to recognize that 5 volts is now = to 2800kg instead of the 1024kg it was originally

programmed for.
As the Apollo 13 crew said – "Huston we have a problem"

As a temporary fix you could fool coolant temperature signal going to the EMS, in effect telling the EMS to switch to its cold start fuel enrichment tables. Personally I wouldn't even think about doing something like that without a well calibrated Wide Band AFR meter. And then I would be very cautious and progress slowly through the tuning process.

To be Continued
Look for Chapter 5

Pete

Logged

Pete Lord
95 XJR

Pete Lord
Moderator
Sr. Member
Online

Posts: 406

Re: Fuel Injector Sizeing & Power Adders Chapter 5

« **Reply #4 on:** March 18, 2010, 01:55:21 AM »

Chapter 5

At the moment there is only one solution.
But I add caution, this is only for those looking for a great adventure
Because you can not purchase a custom programming solution for the stock EMS. The only reasonable solution is to replace all of its engine management capabilities. I have done that only once, it was very successful and easy to program and tune. In addition you won't be giving up anything in terms of features or functions. It even includes it's own logging feature and the ability to store two separate tunes that can be switched from the cabin.

I would not recommend something like this if I had not used it myself and been very satisfied with its performance. They have been building these things since fuel injectors first became available. Check out the Haltech Platinum Sport 2000 Engine Management System.

Haltech is located in Sidney, at 61 29729 0999 My experience with a different unit in the early 90's was very good. Their web site address is haltech.com.au There is a better site - easier to navigate, but I do not remember the url

The Sport 2000 replaces all of the engine management functions currently provided by our stock EMS. And it totally eliminates the restrictive and expensive MAF with a MAP interface that can handle from 1 to 5 BAR.
They are not cheep, costing well over $1,000 US I used one of their earlier models for a very complex application, controlling a 10liter 1,100 HP Fuel Injected engine running on gasoline and alcohol. The current EMS from Haltech looks even more comprehensive and the programming interface looks even easier to use. Check it out!!!

You could reduce the cost of a programmable EMS a little by using a Megasquirt but you will be giving up some of the functionally you are familiar with. If it were me, I would stick with what I know works, and check with my friends in Au. But there are plenty of others on the market now.
Although slightly less comprehensive the OMEX 710 looks very attractive and I think its made in the UK.

There will be a lot more information about the use of these and the interesting challenges encountered in the Modifications Forum.

If 475 HP is enough here is the easiest and cheapest solution.
Pick up a good N2O wet kit that includes 6 port nozzles with pills for an additional 150HP total Add a few goodies like a window switch, WOT switch, Remote bottle shut off valve. Bottle heater, Remote bottle pressure gauge, Free standing ½ gal fuel cell, Fuel pressure regulator, and high pressure low volume Fuel pump. And anything else you feel makes sense in-terms of safety.

Why use a separate ½ gal fuel tank?
I buy VP race gas to run in the ½ gal fuel cell. It's 116 Octane and adds a little insurance to control detonation. It's enough fuel to last all night long at the drag strip or where ever. I use 10lb tanks of N2O and carry two of them.
By the way the AFR for N20 is 9:1 so for every 10lb bottle of N2O you will burn one pound of fuel and as we know by now, a gal of fuel weighs 6.25 lbs. 3 lb of fuel is enough for (3) 10lb bottles of nitrous.

One other item.
I fill my own bottles. I rent a large bottle by the month for 10 years. Let it get warm in my garage. I put the small 10lb bottle in a small freezer, I bought used for the purpose, and get 10 lb bottle as cold as possible. I then connect the big bottle to the little one and let them equalize for a half hour. Disconnect, and put the little one back in the freezer. Plug in the heating blanket that is wrapped around the big tank and let the little tank get real cold again. Then hook the tanks together, again, and let the little tank fill. That's all there is to it. N2O costs me less than $3 a pound. Thats½ the price of having them filled with a compressor at the local speed shop.

So to answer your question, how long does 9lb of N2O last at the 150 HP level. It's been a while since I ran small a bottles but my best guess would be about 43 seconds. But you should be able to figure out how long 1 lb of fuel will last at 150 hp. 43 seconds will get you down the road 4 times, and in reality that's all you can expect to do in one night of fun. On the street it's rare that you spray for more than 4 or 5 seconds. After all 475 HP gets you going very quickly and you won't be jetted to make a significant difference above 130 MPH anyhow.
Remember we are injecting a constant volume of Oxygen and Fuel, it is not proportional to engine RPM or Road speed.

BTW unless you have SS exhaust headers you don't want to run this stuff for more than 10sec without letting every thing cool down.

And you never ever want to spray at less than 2500 RPM and never at any throttle position except WOT. It's also a good idea to shut the N2O and fuel off for a very short time when shifting. That's easy, simply lift your right foot for an instant. If drag racing, get a purge valve to vent the gaseous N2O from the lines so that when the "noids" open you are getting liquid into the cylinders. Liquid takes up much less space than the gaseous form. And makes the run more consistent.

Also very important at the 150HP level you will need to come up with some method of retarding the timing up to a max of 10 degrees. The N2O is burning a lot of extra fuel and that equates to extra heat. The amount of retard is dependant on the engine and the quality of the fuel you are using. This cannot be emphasized too much. Start at 10 degrees retard when the solenoids open, make a pass, pull the plugs, and look for signs of detonation. Pull the recording from the ODBII / PC and look for timing being pulled by the knock sensor. It will start with one cylinder and a bad situation will have timing pulled from all cylinders. If no signs of detonation, back the retard off to 8 degrees and try it again. After 4 passes you will have found the point where it begins to detonate. Retard it 2 degrees from that point and be safe.

I have not researched what retard box is the right one for our engines I will do that and report later. The Haltech Sport 2000 provides integrated features for controlling N2O window operations as well as timing retard functions. But it is a bit expensive if that is the only reason for using it.

Keep the rest of the engine stock, no need to change anything except the tires on the back. Get the stickiest tires that will fit your wheels. If you really must spend money get some SS headers.

Change the oil in the engine to Redline 20W 50. If automatic transmission, change the ATF to Red Line D6 and by all means change the rear end lube to Red Line 75W 90 with modifier. Or some of their light weight Shock Proof differential lube. Change the engine oil every 6 months, unless you put more than 25,000 miles on it in 6 months then change it sooner. If you can't get Red Line use Motul. It's made from the same Group V stock.

The bottle of N2O provides the oxygen to burn the fuel. And the separate fuel system provides high octane fuel to control detonation. Both dispensed in the proper proportions without the EMS knowing about it In addition if done correctly the N2O goes into the cylinder as a collection of small liquid droplets that boil to a vapor inside the cylinder.

To repeat, Nitrous Oxide does not burn.
It supports combustion just like air.
30% of N2O is Oxygen, 21% of air is Oxygen.
When the N2O reaches 400degrees F the Oxygen is separated from the Nitrogen and the oxygen can oxidizes the fuel.

So N2O is simply good air.
But if miss used it can be very destructive.
If there isn't enough fuel the N2O will cause the fuel that's there to burn so hot, parts will fail, holes will form in pistons, and stuff like that.

Regardless of what you may hear, do not inject N2O into the air stream in front of the supercharger or the intercooler. There is simply too much volume in those places and a random, lean backfire ,of the smallest size will ignite the fuel and N2O mixture causing an explosion of epic proportions. So don't even think about it. Superchargers and cast intercoolers and intake manifolds become little pieces of shrapnel. Very bad for public relations.

Dry systems are safer because they rely on the engines fuel injectors to provide the additional fuel They spray the N2O in front of the MAF relying on the heat of expansion of the N2O to make the MAF think the amount of air is very great, and the MAF tells the EMS to make the mixture richer.
Problem is our stock MAF is up against it's rail and the injectors are close to theirs. The perfect recipe for disaster.

I will be installing a NOS 02462 Pro Shot Fogger this summer. I do not recommend this kit it is designed to provide 150 to 500HP and the components are too big for a 150 HP application.

If I didn't have it sitting in my garage I would get the Sportsman Fogger Kit from NOS # 05040-FINOS. It has a range of 50 to 150HP with the components supplied. But be sure to run the nozzle fuel pressure at 58 PSI you don't want the manifold pressure effecting the nozzle pressure very much. NOS has jets to do that sort of thing. and will understand the need when you talk to them. Camaros and Firebirds and Cadillac's and any GM V8 using the LSx series of engines run fuel pressures of 58PSI so there is no problem

Also I will buy a new 2 stage WOT/ RPM Activated Window Switch # 13982NOS these are about 100 times better than the collection of junk I have been using to do the same job and they are only $163. An absolute must for anything except the 50HP level.

A bottle pressure gauge is a nice thing to have # 5914NOS.
Also do not forget the independent fuel system allowing you to mix your own go juice or buy it at a race track. I'd rather mix my own unless there is a guy selling VP Racing Fuels. You can trust them to be what they say they are.

And eventually, you will want a remote bottle valve, a bottle blanket, and a bottle heater but they are not necessary immediately.
As I remember there is a good book on the subject available free on the NOS site.

All together, you'll spend $1500 for 150HP That's $10 a HP
There isn't anything you can do that will come close to that . My rule of thumb is; today it costs $40 per HP for power adders. And always use caution when reading about the amount of HP the trick of the month will add.
N2O HP obeys the laws of physics we have been using in this paper and you can count on it.

Time to quit talking and start doing!

I have gone way beyond where I thought this would go initially
And we haven't touched on DIY fuel mixing
Or Building a water /alcohol injection system

If you have any questions or suggestions let me know
I'll be glad to answer to the best of my experience.
Pete

Logged

Pete Lord
95 XJR

Carl
Administrator
Sr. Member
Offline

Posts: 410

Mechanical and computer engineer/ Research and Des

Re: Fuel Injector Sizeing and their relationship to Power Adders Chapter 1

« **Reply #5 on:** March 18, 2010, 05:15:09 PM »

Jesus Pete, Thats an impressive piece of work, thanks for the time and effort.

Most apreciated.

Logged

1995 Jaguar XJR6, Ice Blue.

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