HEAT - THE KEY TO POWER

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MAKING POWER?

Ask a group of people what an engine does and 9 out of 10 will say, “It makes power.” But does an engine really “make” power? The answer is no, an engine does not make anything. An engine’s job is to take one form of energy and convert it into another. Simply put, it converts heat energy into mechanical energy. All engines work on a simple principal, pressure differential. What actually goes on in a running engine is anything but simple, but the idea itself, is very simple. If there is higher pressure on one side of something than the other, a force is applied to it. This principal is what old time steam engines were based on as well. A fire (usually coal) heated water to make steam pressure. It is that steam pressure that applied the force to the pistons. Jet engines, diesels, rocket engines, they all work on the simple principal of pressure differential.

In this process, quite a bit of energy is lost; today’s engines are very inefficient machines. As a matter of fact, they are only 25-30% efficient. That means that the average 250 horsepower engine is actually burning enough fuel to make closer to 1000 horsepower, but 70-75% of that energy is lost in the conversion process. Where does this heat go you ask? Some is radiated from the engine itself, some is sucked out by the cooling system and the rest is blown out your tail pipes. Some is turned right back into heat through friction before it gets a chance to make power.

I will not talk about specific engines or mechanical efficiencies here, or what’s better or worse in piston, head design, etc. What I want to get across is the function of an engine, not exactly how it all works, but what it actually does. There is a lot of info out there on the mechanical aspects of engines, but few people really understand the actual function.

HEAT IS POWER

When a fuel is ignited, the stored energy in that fuel is released as heat. Heat is the key to getting power from an engine and heat will be mentioned many times in this article. The first step is to burn a fuel to make heat. The engines job is then to convert that heat energy into mechanical energy. So when it comes to building horsepower, think heat. You want to retain as much heat energy in the chamber as you can, the more heat you can get, the more potential cylinder pressure you will have.

It is the expansion of the gasses that the engine uses to push the pistons down the bores. With a piston at the top of a cylinder, heat expansion (cylinder pressure) forces it down. That is how heat is changed into mechanical energy. More heat equals more force and the result is more power potential.

The most efficient engines today run hotter, which increases thermal efficiency. The ultimate limit of engines operating temperature is going to be detonation. Parts reliability is also a concern, but with materials getting better, building an engine capable of dealing with extremely high temperatures is not too far fetched. It’s detonation that will be a problem.

COOLING SYSTEMS

Knowing that heat is the key to getting power from an engine, you should also realize that anything that takes heat from the engine takes away power potential as well. The cooling system is no exception; it pulls heat out of the engine and power potential along with it. A cooling system is a necessary evil. It takes away power to make the engine reliable and keep it out of detonation.

How much power does a cooling system take away? Considering that today’s engines lose about 25% of the heat generated to the cooling system, it can be substantial. If we could design an engine that would survive at temperatures that would not require a cooling system and we had a fuel that would not detonate in such conditions, we could expect a ~25% boost in efficiency. That would double the power of most engines today with no additional fuel and double the fuel economy as well.

In reality, running an engine at those temperatures (if it could live), would increase the amount of heat radiated off the engine itself as well as increase exhaust temperatures. So we would not get back 100% of the power lost by the cooling system. However, A ~20% increase is a conservative estimate.

DETONATION

It is a common misconception that when the ignition system ignites the air / fuel mixture, it explodes and forces the piston down, this isn't true at all. It is a controlled burn, not an explosion. Detonation is an explosion, which is very damaging to an engine. The speed of the burn has a large effect on power output. It is desirable to have a fast burn rate to limit the amount of ignition advance required, which will also reduce the chances of detonation.

Do not confuse detonation and pre-ignition, they are two different things. Pre-ignition is simply when to much heat or pressure ignites the charge before the spark plug fires. This may or may not cause detonation. Often the early ignition will cause an excess of cylinder pressure near top dead center that will cause detonation, just like too much ignition advance, but not always.

There are 3 things to be concerned with when dealing with detonation, the octane rating of the fuel, heat and pressure. The octane rating is another subject altogether, so to keep it simple; I'll just say that it is a rating of a fuels resistance to ignite. It has nothing to do with the power potential of that fuel, a higher-octane fuel is harder to ignite and therefore will resist pre-ignition and detonation to a higher degree.

Heat is the next thing that must be dealt with to limit the chances of detonation. In a cooling system (any cooling system), coolant boils around the combustion chambers. As a coolant turns from a liquid to a gas (boils), it absorbs a lot of heat. If all goes as planned, the bubbles get drawn from the surface of the combustion chambers by the flow of coolant allowing liquid coolant to contact the surface and the process continues. This process is normal in any engine and called the Nucleate Cooling Phase.

When the engine gets too hot, the coolant will boil faster than the flow and pull it away from the surface. The gaseous coolant bubbles start to combine and form a gaseous curtain, which blocks liquid coolant from contacting the surface. When this happens, the combustion chamber temperatures rise rapidly. The added heat can (and often does) cause detonation. This is why engines often ping when they overheat. The goal on a cooling system should not be to reduce temperatures, which would hurt thermal efficiency. You want to reduce combustion chamber temperatures, which are the hottest part of any engine, but it pays to raise the temperatures of the rest of the engine. The goal is to try and even out the temperatures better.

Pressure is the big one. If all else is running good, pressure will be the most likely cause of detonation. If too much pressure causes detonation, the problem is usually too much compression, not a high enough octane rating, or too much ignition advance. All are common problems.

Most people tent to lean toward the heat problem. If the engine is pinging, they think that lowering the temperature is the fix. In most race engines that have detonation problems, on tear down, the detonation was on the intake side of the combustion chamber, which is the coolest side of the chamber. This leaves use to lean toward pressure being the thing to look at, not heat. The flame front will travel the fastest toward the exhaust valve because it is the hottest part of the chamber. This most likely means that when the pressure has risen high enough to cause detonation, there is no charge left on the exhaust side to detonate.

BURN RATE & IGNITION ADVANCE

The term fast burn combustion chamber is becoming popular and for good reason. A fast burn rate not only makes more power, it reduces the chances of detonation.

Peak power is achieved when peak cylinder pressure occurs at the optimum point to get the most from the burn. This generally is about 20 degrees after top dead center. You do not want to compromise this to stay out of detonation. That will only make an even less efficient package.

Most people know that peak power is had with 30-36 degrees total advance BTDC. Lets say that for a particular engine, we tune it in on a dyno and peak power is achieved at 34 degree BTDC. That means that from the point of ignition it took about 54 crank degrees to reach peak cylinder pressure, 34 of that was resisting the piston on the way up the bore.

Now lets say that we redesign the combustion chamber and use a better quench to get a faster burn rate. Now we tune it in and we get peak power with only 30 degrees advance. What we did was eliminate 4 degrees of resistance and some of the pressure before top dead center.

We also have to keep in mind that dynamic compression ratios are very low at cruising speeds and light throttle. This drastically reduces the burn rate. Some engines run close to 50 degrees total advance at light throttle to keep the point of peak cylinder pressure at 20 degrees ATDC. That is about 70 degrees burn time to reach peak!

Any engine that must run with the ignition advance retarded from optimum to avoid detonation is a poorly put together combination. Don't get yourself in that situation. Never build an engine with a high compression ratio and tell yourself that you can always bump back the timing if it pings. You will get more power with the right compression and right timing.

EGR SYSTEMS

Running at higher operating temperatures sounds like a good direction to go in search of better economy and power, but the reason it will probably never happen is NOx emissions (oxides of nitrogen). NOx emissions are what brought about the EGR (exhaust gas recalculation) systems, used on all cars now. NOx emissions are a by-product of high combustion temperatures.

Rather than run cooling systems that will reduce operating temperatures and loose a lot of efficiency, engine manufacturers came up with EGR systems. Put simply, the EGR puts exhaust gas in the intake to contaminate it, which limits the amount of air (oxygen being the big factor) the engine can inhale. This is a good way to reduce combustion temperatures without losing dynamic compression. The engine is still taking the same volume, or CFM (cubic feet per minute), so dynamic compression does not change. Dynamic compression is important to the burn rate at part throttle. The throttling effect of a gasoline engine is a big downfall in this area; most engines only run with around a 3:1 dynamic compression ratio at cruising speeds. Low compression slows the burn rate and makes for a less efficient package. Believe it or not, an EGR system is a step in the right direction for a more efficient engine, at least for cruising speeds.

The goal, which is a tough one, is to limit the air and fuel entering an engine to the point where there is no more usable cylinder pressure left at the end of the power stoke. In reality, there is a lot of useful cylinder pressure left at the end of the power stroke, which gives us no choice but to dump it out the exhaust and waste it. Not only to we have to open the exhaust valve while there is still useable cylinder pressure, we must open it before the power stroke is complete to allow enough time for that pressure to escape before it becomes a resistance.

It is many peoples first impulse to yank and plug the EGR valve (as well as other emissions systems) in search of more power. The truth is, not only is it illegal, the EGR will not rob you of power. The EGR is closed on hard throttle and does nothing to hurt power.

EGR systems are also being tested on diesel engines. Diesel's work a bit different that gasoline engines and the EGR may actually prove to be a bad thing as far as economy goes. Diesel's, not having a throttle valve; always run at the highest volumetric efficiency they can for a given rpm. This means that the dynamic compression is significantly higher in diesels. An EGR system will serve its intended purpose, which is to reduce combustion temperatures to bring down NOx emissions, but it will do nothing to gain dynamic compression.

Initial testing wasn't as bad as diesel engine manufacturers projected, but they did see slight reductions in fuel economy so far. More testing and development may help the matter.

EXHAUST HEAT

Quite a bit of energy is dumped out the exhaust. The design of a reciprocating engine makes this a very difficult situation to deal with and there haven't been any real developments that have significantly cut this heat loss. The problem is there is still a lot of heat energy at the end of the power stroke. The piston must change direction and go back up the bore; any pressure left in the cylinder must be dumped before this happens.

Good low lift exhaust flow helps this situation to some extent. If the exhaust valve flows well at low-lifts, it allows the valve to open later, increasing the duration of the power stroke. This very limited, it simply dumps what's left faster, the ideal situation would be to have nothing left to dump, but that is way ahead of current technology.

It has been argued (by a very few) that not a lot of power is lost out the exhaust system. To answer that, ask yourself a simple question. Is your exhaust hot? What purpose does heating your headers to 1200-1300 degrees have? Anyone who's been burned by a header tube while trying to check a plug betweens rounds would, love to make use of that heat before it gets to the header. I know I would. There is a huge amount of heat loss through the exhaust system.

INTAKE HEAT

The intake air is one thing that you do not want hot in a performance engine. You want it as cold as possible. Cold air is denser air, which contains more oxygen molecules per cubic foot. More oxygen allows us to burn more fuel to create more heat energy. This is why cold air induction kits are so popular. You want to intake air from the coldest point, not the heated under hood air.

Efficiency is also a factor, creating more heat to make more power also creates more heat that is wasted in the cooling system, exhaust and radiated off the engine. Looking at it from an economy and emissions standpoint, cool intake air is not the direction to go.

Heating the intake has proven to increase combustion efficiency by better fuel atomization resulting in a more complete burn. This reduces hydrocarbon emissions and lightens the load on the catalytic converter. Some engines heat the intake through an exhaust port, a coolant passage to the throttle body, or both.

TURBOCHARGING

The turbocharger has been used for many years. It is a wonderful device that increases the density of the intake charge just as a supercharger does. The downfall of a supercharger is the power required to drive it. Driving a blower directly from a belt takes power directly from the crankshaft. I recall one test on an 800 hp big block Chevy that proved that the blower took over 200 hp to drive. This means that the engine was actually a 1000 hp engine and experienced all the internal loadings of 1000 hp, but never delivered it; 200hp was absorbed driving the blower.

Compare a turbocharger to an equally adiabatic efficient centrifugal blower and it will not take any less power to drive the turbo, the big difference is where the power comes from. The turbo charger is driven from heat and velocity of the exhaust gasses, basically using the heat that had to be dumped out of the exhaust.

A turbo will rob some power; there is no free lunch with a turbo, just a cheaper one. A turbo does put a flow restriction in the exhaust, which does cost power. Tests comparing bowers to turbos in the 800 hp area showed that ~200 hp is the norm to drive a blower. A well-matched turbo took under 50 hp from the engine.

The test was basically driving the compressors with a separate engine to maintain the boost and CFM as it would if the test engine itself were driving it. They then noted the power increases without the drag of the compressors.

Turbochargers do have the efficiency advantage when it comes to all out power, but will they help economy? That depends on a lot of factors. If you simply add a turbocharger to an engine, it will reduce economy. No matter how you slice it, a turbo is an exhaust restriction. The same goes for blowers, if it turns, it takes power to turn it.

One way forced induction engines can help economy is that sufficient power can be had from a much smaller engine. When Ford first introduced the 2.3l Turbo engine in the Thunderbirds, people laughed at a 4 cylinder is such a big car. It turns out that the 4-cylinder engine was faster than the V6 option, yet got 26 mpg, which isn't bad for a 4000 lb car in the mid 80's. I personally did a few modifications to an 88 T-bird and the car ran a 13.75 @ 104 mph and still got about 24 mpg. That is faster than the 5.0l mustangs of those years. The car had an estimated 250 hp to run those numbers.

Turbo's are impressive and do recover some of the heat lost in the exhaust system, but there is no magic there. It would be nice to recover some of that heat energy under normal driving conditions, but that is easier said than done.

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