Exhaust Gas Temperature

More and more serious racers are taking an alternative approach to judging the condition and performance of their engines. By using exhaust gas temperature they have added a powerful diagnostic and tuning tool to their arsenal of racetrack weapons. Exhaust Gas Temperature (EGT) measurement has been a fact of life in other forms of motorsports for years, yet its use in karting has been relatively limited until recently. Here's the skinny.

If combustion was a perfect process, the exhaust gas from an engine would contain only nitrogen, water vapour, and carbon dioxide. But in the real world it also contains carbon monoxide, hydrogen, unburned fuel, other hydrocarbons, plus traces of aldehydes, alcohols, ketones, phenols, acids, nitrogen oxides, carbon, and lots of other stuff. And that's assuming that we're starting with conventional, legal fuel. There has been lots of things written about illegal additives and how dangerous they can be. Please think before you or anybody you know add anything extra to your fuel. Think about the price you or your friends or family might pay, health-wise, just because someone is looking for an edge. But this article is not about what fuel is composed of, but rather about the temperature of the combustion products and how their measurement can be an even bigger edge.

In the temperature measurement industry there are two basic types of measurement devices. The first is called resistance temperature detection or RTD. This type of device is basically a very fine wire encased in a container, or bulb. As the temperature of the bulb changes, the electrical resistance of the wire changes. By passing a small current through this wire and measuring the resistance, the temperature can be determined. This is the method used by your Digatron cylinder head temperature gauge. And as any of you know who've used a CHT GAUGE for any length of time, these CHT sensors, while accurate, are relatively delicate. Rough service (like on a kart) is not generally recommended. They also have a temperature limit that makes them unsuitable for use measuring EGT.

The other major means of temperature measurement is the thermocouple. The thermocouple is a unique device. There are several different types of thermocouples, using different materials for different temperature ranges, but they all operate by the same basic means. A thermocouple consists of two wires, of different materials, welded or fused together. For the temperature range we are most interested in, the type K thermocouple is most suitable with a maximum temperature of 1900 degrees Fahrenheit. In a type K device one wire is an alloy called CHROMEL®*, and the other an alloy called ALUMEL®*. A small portion of each wire is exposed and the two are welded or fused together. That assembly is encased in an electrically insulated sheath and the other ends of the wires are connected to a very sensitive voltmeter. Now here's where the thermocouple differs from the RTD. When the fused end of the thermocouple wire is heated, it generates its own current. It's only a matter of millivolts (that's one one-thousandth of a volt), but the voltage generated is an accurate indicator of the temperature of the end of the thermocouple. A real bonus for motorsports is that these thermocouples are remarkably sturdy and reliable. With no delicate parts to break, unless you exceed their maximum temperature, they're pretty hard to damage. In fact, every gas- fired furnace and water heater uses one to tell the gas valve that the pilot flame is lit.

The thermocouple probe is carefully fitted into the exhaust system, relatively close to the engine. For maximum accuracy you want the tip of the thermocouple to be centred in the exhaust gas stream as it comes out of the engine. But there is considerable debate about how close to the engine it needs to be. Digatron's information advises mounting the probe between 3 and 4 inches from the piston face. But many snowmobile racers routinely set their EGT pickups as much as 8 inches from the exhaust port. In fact, it really doesn't matter exactly where the probe is mounted, although the closer to the exhaust port, the less the ambient air temperature will cool the header and affect the readings. One word of caution however. Comparing EGT readings between engines or karts whose EGT probes are not mounted exactly the same distance from the piston will get you in trouble. If you use EGT, mount the pickups in all your headers at the same length. Otherwise you might just misinterpret the readings.

There are lots of myths and questions surrounding EGT and its use. Some folks figure that, if you have a Cylinder Head Temperature gauge (CHT), you already have all the information you need, and that EGT is redundant. While you can certainly get by on just head temp, CHT and EGT each tell you slightly different things, and using them together tells you some things that neither one could tell you alone. EGT has some advantages because of it's basic construction and it's mounting location. A thermocouple responds very quickly. Because the CHT sensor has to respond to the temperature on the outside of the head, it cannot respond to changes in combustion temperature as fast as the EGT probe that is directly in the exhaust gas stream. Secondly, the EGT probe is not exposed to the outside air, it is not affected by changes in outside temperature. By comparison, since the CHT is measuring the temperature of the cylinder head casting itself, and since the cylinder head is one of the engine's primary means of shedding heat to the air, the cooler the air, the cooler the CHT reading and vice versa. For quick, consistent temp readings, EGT is definitely worth a look.

But what exactly are we trying to determine with these temp sensors, anyway? EGT and CHT are simply ways of trying to judge the relative fuel/air ratio. We all know how critical it is to have the carb mixture correct, whether by changing the jet in a 4 cycle, or by adjusting the carb needles on a 2 cycle. And it's generally agreed that the leaner the mixture, the hotter the engine will run. But what is really happening inside there? Does hotter always mean better, or just sometimes?

Well, the truth is, it's mainly a matter of air. Many of you have had the experience of hitting the set-up just right in practice and then waiting excitedly for the race, certain you're going to blow 'em all away this time. But when the time comes for your race to start, suddenly you've lost that wonderful top-end RPM you had in practice, or the clutch just won't pull like it did in practice, or some other problem pops up to spoil your day. You haven't changed a thing, but the air may have changed things for you! As the air temperature goes up, or the humidity goes down, or a storm front blows in, the density of the air changes, and that changes the fuel/air ratio that your carb delivers. If you don't recognize what's happening and adjust accordingly, you’re going to suffer.

So how can you stay on top of the effect that changing air conditions is having without bringing your own weatherman with you to the track? With a EGT gauge you can take a lot of the guesswork out of carb tuning. Remember we said that it was generally agreed that a leaner fuel/air ratio was always hotter. And when we asked if hotter was always better? Well, you guessed it, neither one is true. If you get the fuel/air ratio too lean, the combustion temperature will actually go down! Let's look at another example of this, one that you can actually see with the naked eye. An Oxy-Acetylene torch will burn with a wide variety of fuel/air ratios. Generally when you light the torch the mixture will have too much fuel (acetylene) for the amount of oxygen that's flowing. The flame will be yellow and produce a lot of smoke, and not be very hot, relatively speaking. But as you turn up the oxygen valve, the yellow flame and smoke disappear, the flame turns bright blue, and the flame temperature goes up dramatically. So leaner here is definitely hotter. But as you continue to turn up the oxygen, the flame begins to shrink, and the flame temperature actually goes down, even though it's leaner! Eventually, if you keep turning up the oxygen, the flame will just go out! Believe it or not, the same thing happens inside your engine.

"Wait a minute," you say. "I know that when I lean the engine out it just keeps getting hotter until it sticks!" If all you have to go by is CHT you're absolutely right. When your engine gets too lean, the skyrocketing temperature you see on the CHT is probably not really an indication of hotter combustion. Most likely it's a warning sign of DETONATION. Detonation is the collision of two flame fronts inside the combustion chamber, where there should be just one, and it's the single biggest cause of heat related engine failures. Savvy drivers can often sense that an engine is slowing down and richen up the mixture to control the detonation. But you don't need decades of experience to spot detonation before it puts you on the trailer for the day. Just like with the Oxy-Acetylene torch, when the mixture gets too lean, the flame temperature goes down! Detonation floods the combustion chamber with heat, so the CHT goes up, but with CHT and EGT readings, if you see CHT rising and EGT going down, it's a sure sign of detonation.

A quick adjustment will restore the power and save that expensive rebuild. Even with just EGT, it's a lot easier to get the most out of your engine without burning it down. EGT should climb as the RPMs come up on the straight, then drop when you lift for the corner. If it drops when you're pulling off a hard corner, or under acceleration, you're on the detonation expressway back to the shop for a rebuild. Detonation is a fascinating subject, one that is too complicated to be handled adequately here. We'll save that for another article. But trust that it is something to avoid, and the best way to avoid it is to watch the exhaust gas temperature.

So to summarize, we know we want to run the fuel/air ratio as close to ideal as possible. And we know that the ideal fuel/air ration should produce the hottest combustion flame. While the cylinder head temperature gives us some indication of the combustion temperature, it can be misleading because of air temperature or other weather conditions. Because of the mass of the cylinder head, CHT can take a few seconds to register a change in internal temperature. And CHT alone is not the best indicator of detonation. Exhaust gas temperature does all these things better than CHT; better, faster, and more reliably. So what's holding you back? If someone came up with a clutch that was better, faster, and more reliable, you'd be after it in a second. Why is this any different? Remember, the more you know, the faster you go.