White Paper

Title: Using NOx as a precursor of Detonation – its use in Performance
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Overview of NOx Generation and Measurement:

NOx is formed during the early part of the combustion process, where there are high enough temperatures to cause nitrogen (80% of air) to combine with the oxygen in the intake charge. It is made up almost entirely of NO (Nitric Oxide) – which is a gas measured in the Model 900503 exhaust gas analyzer. In general, it has been viewed as one of the smog emission gases that is controlled by a variety of methods (including EGR and a three way CAT) and measured by tailpipe gas testing under loaded-mode conditions.

It has not been viewed as an 'important' gas for performance tuning applications.

Lately, though, it has come into some favor with performance tuners as a precursor-to-detonation gas. This is because its generation is directly a function of early combustion flame temperature – during the time when there is a good deal of oxygen present to combine with the nitrogen of the intake charge.

Flame Temperature and Detonation:

Detonation occurs due to early combustion initiation. If the combustion process begins too early in the compression stroke, the chemical process releases heat at an ever increasing rate, due to the fact that the combustion chemical process itself increases markedly with temperature. As this process feeds back on itself, the combustion process can run away, resulting in detonation – ranging from loss of power, to pinging, to outright engine damage. The high pressures created by the early combustion process can be interpreted at high flame temperatures – as the pressure of the combustion gases varies directly as their temperature. Thus, flame temperature and detonation are very closely linked. As the flame temperature increases in the combustion chamber, it will naturally lead to detonation – and if it could be measured, it would yield valuable information regarding the detonation margin available in the operating engine.

Difficulties in the measurement of flame temperature:

Flame temperature in the combustion process has been notoriously difficult to measure, due to the speed at which it develops, the high temperatures it achieves, and the low mass

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that hot gases involve. In addition, the process of instrumenting the combustion chamber is difficult, involves modifications to the combustion chamber itself, and causes the combustion process itself to change as a result. Most testing where flame temperature has been of primary importance have used a pressure sensor instead of attempts at direct temperature measurement – with mixed results – as the natural compression pressure has to be first subtracted from the non-combustion compression pressure waveform. In addition, the dynamics of gas flow inside the combustion chamber during actual combustions often make the pressure reading vary with time and position of the sensor itself. Because of this, measurements of flame temperature have been expensive and difficult to achieve, and have often yielded uncertain results.

Use of NOx as a method to gage flame temperature:

It is well known that the NOx generated by an engine is the combined effect of flame temperature and oxygen availability. At combustion initiation, an engine without EGR has combustion gas mix that generally contains a known and constant mix of nitrogen and oxygen (a 10% variation in AFR effects the ratio of nitrogen to oxygen in the combustion charge by less than 0.5%). So – for performance tuned engines, the level of NOx generation can be used to assess the average flame temperature during the initial phases of the combustion process – and therefore can be used to verify ignition timing and detonation margin. As performance engines can be unique in design, and highly modified from production engines (different cams, pistons, porting, carburetion or fuel injection, stroke, bore, etc) a process which is relatively simple to use and does not require engine modifications to implement is highly desirable.

Since NOx gas can be relatively easily measured and is a non-intrusive process, it has merit as an early indicator of flame temperature, and therefore combustion pressure, and therefore detonation margin.

NOx measurement in practice – use it to verify ignition timing and other effects:

NOx measurement is essentially engine independent. It can be viewed as equivalent to a tracer gas being placed in the combustion chamber of a running engine – and then extracted and measured later. It can be done on an individual cylinder basis or combined engine output with ease – and is only dependant on the location of the gas sampling location.

In essence, as NOx gas generation on a particular engine will vary primarily with ignition timing, so it can be used to verify ignition timing and warn of impending detonation of any engine under the real operating conditions. Further, as it also varies with intrinsic combustion rate – which is effected by AFR as well, it can be used as a general guideline

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of the quality of the combustion process – and can even be a good indicator of issues regarding valve timing vs compression ratio, etc.

Remember that it is a neutral and non-intrusive witness of the combustion process – so the level of NOx generated in a performance engine is directly related to the combustion flame temperatures and pressures. Thus, it can be used to optimize a particular engine, guard against conditions which may produce detonation, and validate that the combustion temperatures and pressures are reasonable for a certain configuration.

Remember also, however, that it is an average indication of combustion pressures, not an absolute real-time measurement. If high combustion temperatures and pressures occur late in the combustion process, there may not be enough Oxygen to create a high level of NOx. This relatively unlikely event may cause two engines – one with a substantially lower combustion flame temperature early in the combustion process, but much higher later – to produce the same concentration of NOx as one which produces a lower combustion flame temperature earlier in the process. It is wise to gain some experience with NOx measurement on the types of engines you experience before general conclusions are drawn regarding what level of NOx is 'good' or 'bad'.

Consider NOx measurement to be just one more valuable tool in the performance tuners gas-analysis toolbox.

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