Technical Support Note

Title: High Performance Tuning – Engine Exhaust Gas Levels
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Overview:

Often engine tuners seek to extract the highest performance available from gasoline fueled equipment, leaving fuel economy and emissions levels as secondary issues. Exhaust gas analyzers have been used with great success to aid performance tuners – and this technical support note is intended to serve as a guide for those seeking to performance-tune engines.

The target audiences for this technical support note are motorcycle or other recreational vehicle technicians, 'Hot Rod', 'Muscle Car' or other performance tuners of street vehicles, or off road performance tuners – such as race car engine technicians or ATV tuners, etc. These technicians are often required to tune for high performance, rather than exhaust emissions levels or high fuel economy. The typical exhaust gas emission levels in high performance gasoline-fueled engine exhaust for commonly found cases of equipment tune are discussed below.

The purpose of this document is to provide some general guidelines regarding the expected gas concentrations in the exhaust of high performance gasoline fueled vehicles.

Factory Tuned Equipment – Tuned for Emissions, not Performance:

As equipment comes from the factory, it is manufactured and tested to meet EPA guidelines for exhaust emissions. The first class of equipment discussed here is open loop carbureted or fuel injected equipment, operating without a lambda sensor, or catalytic converter. They meter fuel by means of physical, real-time adjustments, and are factory-tuned to meet EPA emission specifications before shipment to the dealer.

To meet the EPA specifications, they are tuned closer to stoichometric levels than normal performance-tuned engines – and the gas levels in the exhaust reflect these adjustments:

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Factory Tuned Exhaust Gas Levels:

	Idle (~750 RPM @ 20" Hg)		Medium Power (~2000 RPM @ 10" Hg)		High Power (>3000 RPM @ 5" Hg)	
Gas	**Typical Range:**	**Ideal Target**	**Typical Range:**	**Ideal Target**	**Typical Range:**	**Ideal Target**
CO:	1.00% to 2.00%	1.00%	1.50% to 2.50%	1.00%	1.50% to 3.00%	1.50%
HC:	100 to 300 ppm (Hexane)	100 ppm	100 to 250 ppm (Hexane)	100 ppm	150 to 300 ppm (Hexane)	150 ppm
CO2:	13.0% to 14.0%	14.0%	12.5% to 13.5%	13.5%	12.0% to 13.5%	13.0%
O2:	0.5% to 2.0%	0.5%	0.5% to 2.0%	0.5%	0.5% to 2.0%	0.5%
NOx:	500 to 1000 ppm	500 ppm	1500 to 2500 ppm	1500 ppm	2000 to 3000 ppm	2000 ppm
Lambda:	0.900 to 1.000	0.990	0.950 to 1.000	0.980	0.900 to 1.000	0.970
AFR:	13.2 to 14.7	14.6	14.0 to 14.7	14.4	13.2to 14.7	14.3
CE:	93.00% to 96.00%	96.00%	93.00% to 96.00%	96.00%	90.00% to 95.00%	95.0%

Dealer Tuned Equipment – Tuned for Performance, not Emissions:

When equipment is purchased by the user, it becomes subject to modification and tuning by the dealer for user performance requirements. Generally, the technician tunes the equipment more on the rich side than the manufacturer because he is more concerned about customer performance expectations than EPA guidelines, especially if performance-enhancing modifications or aftermarket items are added to it.
Tuning on the rich side is done to assure that the mixture does not go lean, especially under transient conditions, as this may result in lean misfire. This protection against lean misfire is especially important when other performance enhancing changes in the engine which may improve power output but mitigate charge ignition are performed.

Essentially, the engine is tuned to make sure the intake charge ignites under all circumstances, and makes full use of the inducted oxygen in the intake charge, at the

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expense of higher emissions and lower fuel economy. This practice provides the highest performance available from the engine under the variables of real running conditions. The chart below reflects this rich-side performance tuning practice:

Performance Tuned Exhaust Gas Levels:

	Idle (~750 RPM @ 20" Hg)		Medium Power (~2000 RPM @ 10" Hg)		High Power (>3000 RPM @ 5" Hg)	
Gas	**Typical Range:**	**Ideal Target**	**Typical Range:**	**Ideal Target**	**Typical Range:**	**Ideal Target**
CO:	2.00% to 4.00%	3.00%	2.00% to 4.00%	3.00%	2.00% to 4.00%	2.50%
HC:	150 to 400 ppm (Hexane)	200 ppm	150 to 300 ppm (Hexane)	200 ppm	150 to 300 ppm (Hexane)	200 ppm
CO2:	11.0% to 13.0%	12.0%	11.0% to 13.0%	12.0%	11.0% to 13.0%	12.5%
O2:	1.0% to 2.0%	1.0%	0.5% to 1.5%	0.5%	0.5% to 1.5%	0.5%
NOx:	500 to 1000 ppm	500 ppm	1000 to 2000 ppm	1500 ppm	2000 to 3000 ppm	2500 ppm
Lambda:	0.885 to 0.950	0.900	0.885 to 0.950	0.930	0.885 to 0.950	0.940
AFR:	13.0 to 14.0	13.5	13.0 to 14.0	13.2	13.0 to 14.0	13.8
CE:	85.00% to 95.00%	90.00%	85.00% to 95.00%	88.00%	85.00% to 95.00%	91.0%

Performance-Tuned Closed Loop Fuel Injected Equipment:

This class of equipment has computer controlled closed-loop fuel injection using a variety of sensors, with final control given by a lambda sensor in the exhaust stream. This is called 'closed loop' mixture control – and the equipment may also have a catalytic converter to reduce tailpipe CO, HC and NOx emissions. **The gas values given below are for the 'engine-out' exhaust – measured at the exhaust manifold by means of hardseal port extraction – NOT at the exhaust pipe after the catalytic converter.**

In essence, the performance and levels of emissions of this class of equipment is controlled by the on-board computer control of the fuel injectors. Performance tuning is done by Modification of the microprocessor 'Fuel Map', which sets the fuel injection timing (and therefore volume) by a lookup table containing engine RPM and load. The

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resulting tuning provides the same performance enhancement outlined for open loop systems above.

The microprocessor maintains equipment tune by means of this map and a variety of sensors, including a lambda sensor for mixture control. The level of control is potentially better than the open loop systems, and the table below reflects this improvement – as the richness is somewhat reduced, but has the performance of the open-loop systems above.

Closed-Loop Fuel Injection Control Exhaust Gas Levels (Pre-CAT):

	Idle (~750 RPM @ 20" Hg)		**Medium Power (~2000 RPM @ 10" Hg)**		**High Power (>3000 RPM @ 5" Hg)**	
Gas	**Typical Range:**	**Ideal Target**	**Typical Range:**	**Ideal Target**	**Typical Range:**	**Ideal Target**
CO:	1.50% to 3.00%	2.00%	1.50% to 3.00%	2.50%	1.50% to 3.00%	2.00%
HC:	150 to 300 ppm (Hexane)	175 ppm	150 to 300 ppm (Hexane)	175 ppm	150 to 300 ppm (Hexane)	175 ppm
CO2:	12.0% to 13.5%	13.0%	12.0% to 13.5%	12.5%	12.0% to 13.5%	13.0%
O2:	0.5% to 2.0%	1.0%	0.5% to 1.5%	0.5%	0.5% to 1.5%	0.5%
NOx:	500 to 1000 ppm	500 ppm	1000 to 2000 ppm	1500 ppm	2000 to 3000 ppm	2500 ppm
Lambda:	0.920 to 1.000	0.970	0.890 to 0.970	0.940	0.885 to 0.950	0.960
AFR:	13.5 to 14.7	14.3	13.0 to 14.0	13.9	13.0 to 14.0	14.1
CE:	85.00% to 95.00%	93.00%	90.00% to 95.00%	91.00%	90.00% to 95.00%	93.0%

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