HD Tuning Basics 2008-10-08

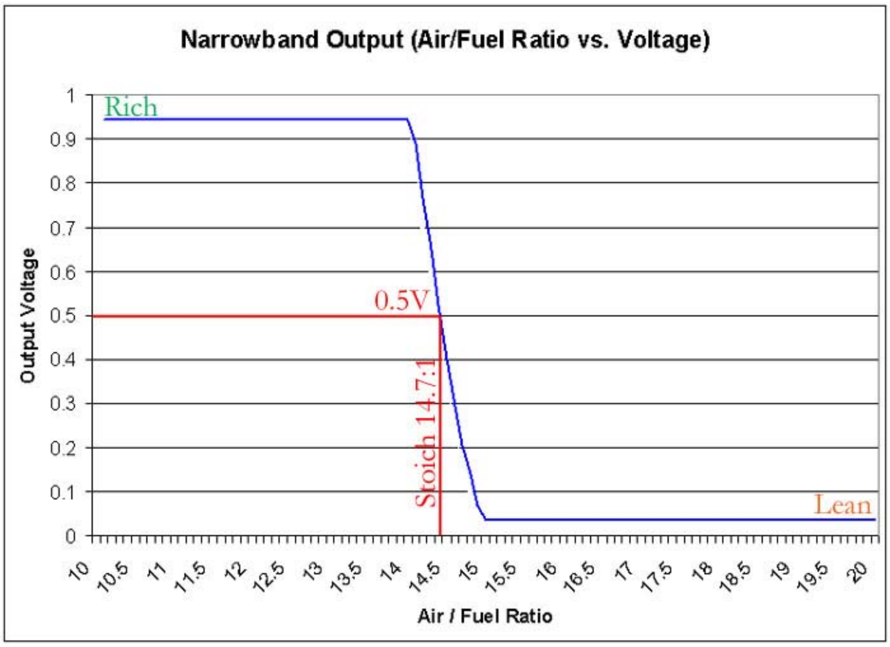
There are a lot of falsehoods and rumours in the area of Harley EFI tuning, in particular relating to 2007 and 2008 models with closed-loop EFI using Lambda sensors. Although EFI tuning is considered complicated by most, it may not be as complicated as you may think if you follow some simple rules.

HD's electronic fuel injection (EFI) system (manufactured by Delphi) is an advanced computer controlled fuel delivery and combustion control system. Tuned in the right way, it can give you excellent results both in power/torque and fuel economy as well as lowering engine operating temperature.

The Electronic Control Unit (ECU) reads a number of sensors and makes continuous real-time decisions of how much fuel to be added or subtracted at any given moment. The ECU, Pulse-Width-Modulates (PWM) the injectors (off and on) in order to squirt the correct air/fuel mix into the engine manifold. The decisions are based on various sensors, an algorithm (program) and a fuel map (look-up table). The sensors such as RPM, engine temperature, exhaust O2 (Lambda), air temperature, throttle position, manifold pressure (vacuum) and crankshaft position provides real-time information on varying operating conditions and the engine load to the ECU.

Closed-loop mode is activated only under steady-state operating conditions like idle or cruising. This means that the ECU gets feedback from the O2 Lambda sensors analyzing the exhaust gases for O2, and correcting the gasoline mix accordingly. Under deceleration, acceleration, high load and Wide Open Throttle (WOT) the ECU runs in open-loop mode with the O2 Lambda sensors deactivated and the ECU is therefore "blind" getting no feedback from the output of the combustion process itself.

All O2 sensor equipped Harleys use narrow-band O2 sensors. Such sensors (also called bang-bang sensors due to their basic on/off functionality) can only detect a narrow band of Air/Fuel ratio mix, actually around the set-point where the chemically perfect combustion takes place (stoichiometry), that is A/F 14.7 (or Lambda 1.0).



However, stochimetry at A/F 14.7 does produce the hottest combustion and the hottest Exhaust Gas Temperature (EGT). Thus there have been complaints that the 2007/2008 Harleys run excessively hot, in particular at idle. The EGT drops at either side of stochimetry (A/F 14.7). A richer A/F ratio at say 13.5 produces less heat and gives maximum power/torque (but less perfect combustion, and more emissions).

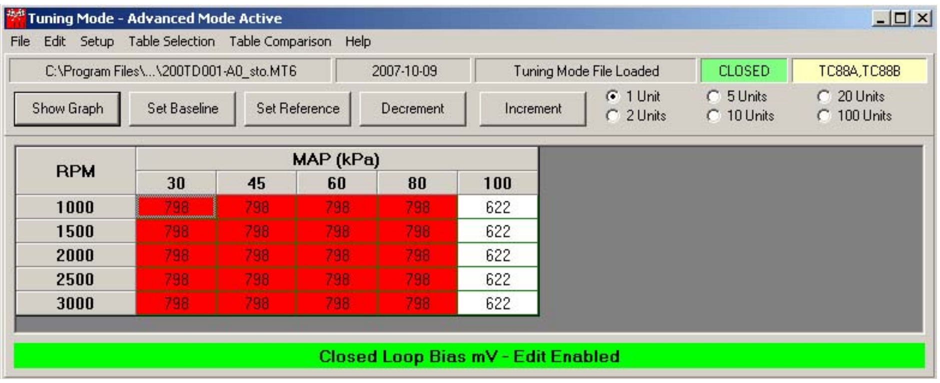
Changing the narrow-band O2 sensors for wide-band adjustable sensors in order to get access to a wide range of A/F ratio settings, is not a simple task as such sensors needs an advanced bias circuitry, due to its different functionality, complexity and range. In addition, going to wide-band sensors and a rich mix will have the engine running continuously rich in closed-loop, giving an inferior fuel economy and creating unnecessary emissions for the environmentally concerned.

A common (non-optimum) alternative practiced by many “tuning specialists” is to bypass the O2-sensors altogether, having the EFI running in a rich open-loop mode. This can be achieved by setting the A/F ratio in the SERT AFR-table to any other value than 14.6. Thus remember; only the AFR-table value of 14.6 gives closed-loop control for that particular cell in the AFR-table! Any other value will force the ECU into open-loop operation! Other ways of converting to open-loop is to use “O2-eliminators” replacing the Lambda sensors with a “dummy-plug”. Again such blunt alternatives give inferior fuel economy and create unnecessary emissions and you will then not benefit from closed-loop operation at all.

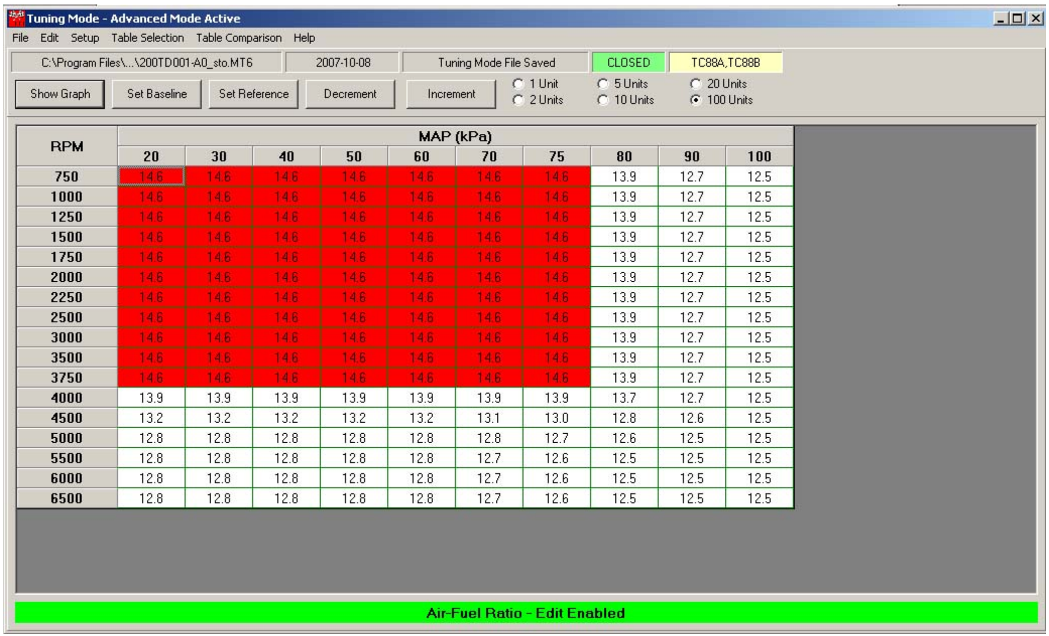
If your Harley has O2 Lambda sensors, use them to get closed loop operation! This will give you better and more consistent overall performance, and in particular under changing environmental conditions like cold damp weather or riding at warm high altitudes and varying fuel quality. However, you may need to perform some simple adjustments in order to fully enjoy the benefits of O2-feedback controlled combustion cruising.

The Screaming Eagle Race Tuner (SERT) together with the recent closed loop HD/Delphi ECU is a rather sophisticated and unsurpassed combination that allows direct access to the ECU programs and their modifications. It is possible to street race tune your HD to get the best of both worlds; lower the combustion/exhaust temperature, and at the same time get max power/torque at high load and wide open throttle (WOT), in combination with good fuel economy when cruising, and this at fairly low emissions.

SERT maps are set to A/F ratio of 14.6 when closed-loop feedback is active and the same goes for the factory stock un-tuned HD. In order to increase reliability, get a better throttle response, reduce cylinder head temperature, and still retaining good fuel economy, a cruising enrichment fix is available. This is made possible by fooling the ECU to think that the O2 sensor is switching at a lower A/F ratio of approx. 14.1, thus obtaining a richer fuel mix. This is achieved by setting most “Closed Loop Bias” cells to max (798 millivolts) instead of the default around 564 millivolts. Note that the MAP 100 cells (for WOT) are left intact as the ECU is in open loop mode at WOT.

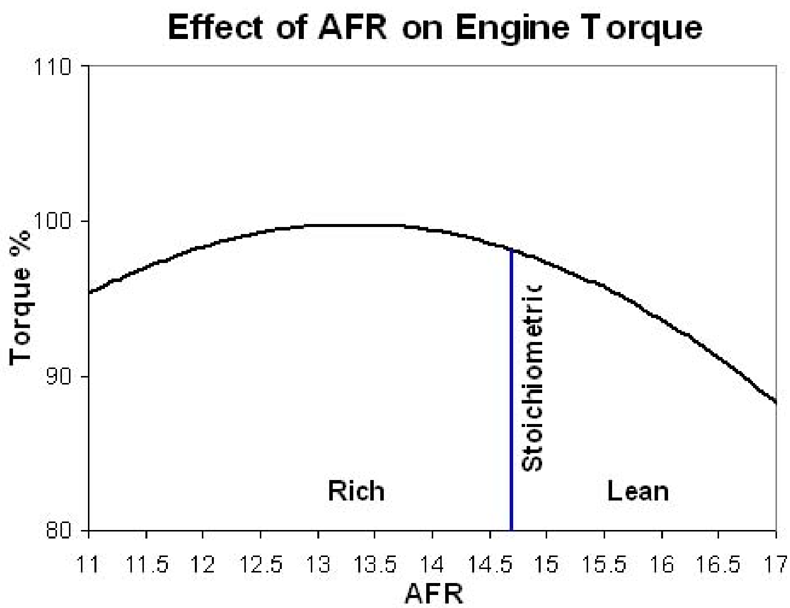


Further, by mapping the AFR cells to A/F ratio of 14.6 in the “milder drive ranges” the ECU will run in closed-loop (red cells) for those ranges (now at a lower A/F of approx 14.1 due to the bias table adjustment). At high load and WOT the cells are mapped to a lower and richer A/F ratio forcing the ECU to run in open-loop mode (white cells).



RPM	MAP (kPa)									
	20	30	40	50	60	70	75	80	90	100
750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
1000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
1250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
1500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
1750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
2000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
2250	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
2500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
3000	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
3500	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
3750	14.6	14.6	14.6	14.6	14.6	14.6	14.6	13.9	12.7	12.5
4000	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.7	12.7	12.5
4500	13.2	13.2	13.2	13.2	13.2	13.1	13.0	12.8	12.6	12.5
5000	12.8	12.8	12.8	12.8	12.8	12.8	12.7	12.6	12.5	12.5
5500	12.8	12.8	12.8	12.8	12.8	12.7	12.6	12.5	12.5	12.5
6000	12.8	12.8	12.8	12.8	12.8	12.7	12.6	12.5	12.5	12.5
6500	12.8	12.8	12.8	12.8	12.8	12.7	12.6	12.5	12.5	12.5

Little additional effect is gained by reducing the A/F ratio any further in the range from from 14.1 down to 13.0 (approx. 14.1 is unfortunately the maximum reduction possible using stock parts). However more is gained reducing A/F ratio in the suggested range from from 14.6 to 14.1 as proposed above. See graph below.

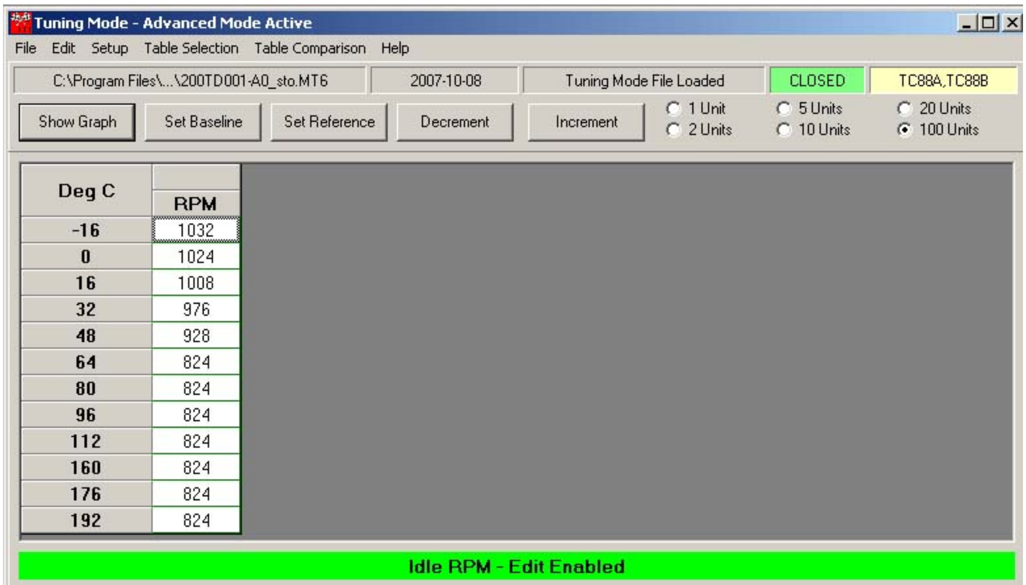


Below is some

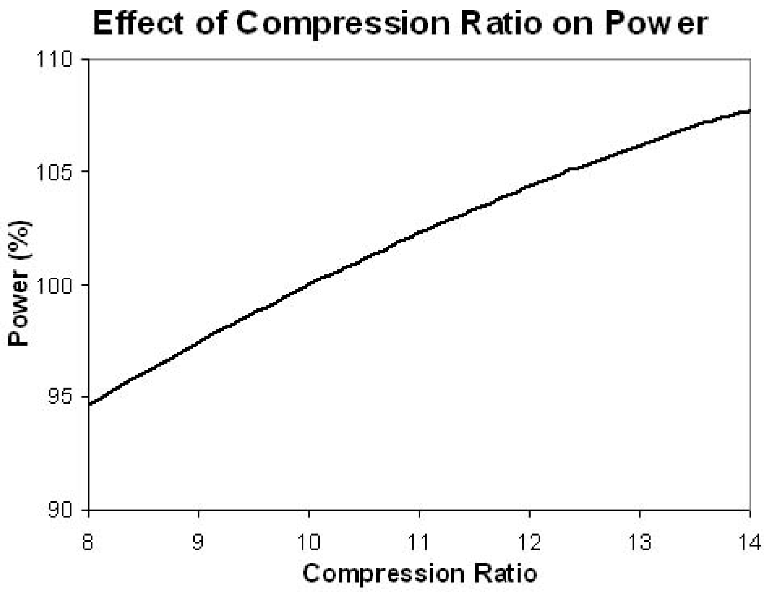
Engine performance relating to A/F ratio

Conditions	Results
Too Lean = High A/F ratio	Poor engine power Misfiring at cruise speeds Burned valves Burned pistons Scored cylinders Spark knock or ping
Slightly Lean = Slightly high A/F ratio	High gas mileage Low exhaust emissions Reduced engine power Slight tendency to knock or ping
Stoichiometric Chemically correct A/F ratio = 14.7	Best all-around performance
Slightly Rich = Slightly low A/F ratio	Maximum engine power Higher emissions Higher fuel consumption Lower tendency to knock or ping
Too Rich = Low A/F ratio	Poor fuel mileage Misfiring Increased air pollution Oil contamination Black exhaust

Further, if you think the idle rpm is a bit too high by default, you can lower the idle rpm to get back the old-fashioned carburated Harley idle style. In addition you will gain less engine heat at idle. Do not go too low, as the engine may occasionally stop after deceleration and in addition you may get less effective lubrication of the cylinder walls at very low idle rpm. A good compromise is shown below that also provides enough rpm for the alternator to charge.



Finally, do not tamper with the engine compression ratio in order to increase power if you are not long-range cruising in cold climates or track racing. Increasing compression ratio will substantially increase cylinder-head temperature and reduce reliability. Stock Twin Cam 96ci is 9.2:1 and stock CVO Twin Cam 110ci is 9.3:1. Increasing compression ratio does comparatively little to engine power improvements. See graph.



Note. In the days of Volkswagen-trike engine tuning it was popular to increase the reliable air-cooled low-compression ratio VW engine to high compression ratio in order to increase power. Due to lack of sufficient air cooling (air cooling system usually dismantled) engine overheat and breakdowns was common. Reducing compression ratios back to 8.5:1 usually cured overheating problems.

There are some alternatives to dyno tuning that gives you control over the tuning process. One alternative is to permanently install an A/F meter on your bike with an A/F ratio display on the handle bar that you can continuously observe while driving. However such units use wide-band O2 sensors that are somewhat sensitive to overheating. Therefore the sensors need to be installed using weld-nuts into the exhaust further down the header pipe, but not too far back as they may pick up exhaust reversion effects, giving erroneous indication in particular at low RPM's. If you have a 2:1 exhaust it is best to install the sensor in the collector. One unit is the RSR air/fuel ratio gauge.
See: http://www.rbracing-rsr.com/rsrgauge.htm

Portable A/F meters exists that makes use of "exhaust-sniffers" that are temporarily inserted into the exhaust outlets. Note, if you have catalytic silencers, this will not work unless you measure before the catalytic converter. Such meter may be borrowed or rented from well equipped tuners. The meter is temporarily taped to the handlebar or tank and the sniffer is inserted in the exhaust and held in place using hose-clamps. Then the bike is run on the road or track and the meter observed. One popular unit is the LM-1 Digital Air-Fuel ratio meter.
See: http://www.innovatemotorsports.com/products/lm1.php

Another cost-efficient and excellent A/F tuning kit (used by the undersigned) is the Daytona Sensors Twin Scan II+ Tuning Aid. This unit uses two wide-band O2 Lambda sensors either as tuning add-ons, tuning replacements or tuning "sniffers", and in addition reads and logs all engine sensor parameters from the internal Harley engine SAE J1850 data bus. This is performed in real-time and graphically presented using a laptop, or logged to a small data logger mounted on the Harley, for subsequent analysis on a laptop. The software also presents a very useful A/F matrix sheet that can easily be copied to the SERT.
See: http://www.daytona-sensors.com/Twin_Scan2.html

As an other nice alternative you can use the "Data Mode" of the SERT to record your track test runs and log all engine sensors and parameters from the internal Harley engine SAE J1850 data bus. This requires a laptop running in one of your saddlebags and connected by the SERT pod to the data test connector on your bike. You set up the data mode at stand-still with the engine running and the SERT in the "monitor mode" (MON). In the "Data Type menu" click the "Engine with O2 Data". Now you can see all engine sensor parameters in real-time displayed on the computer screen including the narrow-band O2 Lambda sensors. If you are in closed-loop mode you can see the O2 sensors continuously toggling between rich/lean conditions. When in open-loop WOT you will see the O2 sensors continuously indicating a rich condition. You can also see the throttle used in % and the currently desired A/F ratio (not necessarily the actual) reflecting the look-up table values. When recording an actual track-run, many parameters can be saved including engine rpm and vehicle speed for later post-analysis. Note that due to the narrow-band O2 sensors you only get an indication when the A/F sensor is toggling. Thus you can not see the actual A/F ratio of the rich fuel mix in open loop.

A nice and powerful feature of the SERT "Data Mode" is the Dyno Graph where you actually can simulate a realistic dyno run in reality with the bike running the track including air resistance and tires friction relating to weight etc. Note that you must input the correct tyre diameter, the primary, gear and belt ratio in order to get realistic results.

Find a good flat race track or runway. Select the highest gear to run that gives you the possibility to run flat-out to max rpm of 6000. Start from the lowest rpm possible, say 1000 – 1500 rpm, then go WOT until 6000 rpm or until the rpm limiter sets in. Do this in the first direction of the track. Then repeat the same procedure in the opposite direction of the track. Then read the data in a properly set up Dyno Graph mode. Calculate the average of the two dyno graphs if they are different. Adjust the corresponding A/F tables for WOT and ignition timing and test with other refinements, test run again to see if you get improvements or not.

Inertia dynos are very popular due to their comparatively low cost and simple design. Provided the dyno tuner knows what he is doing (**beware, not always the case!**) and have the access to a very well functioning air/fuel meter, dyno tuning can be valuable in order to gain those extra HP's and ft/lbs.

However, most tuning experts aren't and sloppy dyno tuning includes:

1. using the wrong tuning-map when flashing the ECU
2. simply swapping closed-loop cells for open-loop in the AFR table
3. as a consequence, not getting the benefits of closed-loop
4. starting dynoing at 2000 or 2500 rpm. Demand dynoing from at least 1500 rpm.
5. not carefully inserting the A/F ratio sensor far enough up in the exhaust
6. as a consequence, get unreliable A/F figures due to exhaust-pulse reversion effects
7. un-calibrated, clogged or worn-out dyno O2 sensor, giving incorrect A/F reading
8. not taking into account air barometric pressure, moisture and temperature
9. not taking care of what gear that is used for the dyno run (5:th common in the US)
10. not having enough capacity cooling fans, thus risking overheating the engine

Please note, many dyno tuners do only measure (or does only care to measure) engine performance at 100% acceleration using WOT, that puts the ECU in open-loop mode and is not representative for part throttle or normal cruising conditions in closed-loop.
Most dynos have provisions to simulate a fixed speed cruising-load at part throttle (using a dyno eddy-current brake) and this should always be performed when dyno tuning. In such condition the ECU is running in closed-loop mode and the A/F ratio should be checked for different loads and speeds. If you have a 2:2 exhaust, check the A/F ratio from both cylinders.

The most popular motorbike dyno is DynoJet. When you dyno tune, demand from the tuner that you get a copy of the SERT fuel-map that he flashed into your ECU (filename.MT6). Demand also that you get a copy of the dyno data file (for DynoJet: filename.drf). You can download the DynoJet browser to view your dyno-file according to different standards.
See: http://www.dynojet.com/downloads/software.aspx

Lars "Stockis" Liljeryd, Stockholm, Sweden
2008 Road King Classic 96ci (including IDS)
SERT + SE A/C + 2:2 Vance Hines original Pro Pipe megaphones (loud!)