ECM ENGINE CONTROL AND MONITORING

AFRecorder 1200A

Fast Air-to-Fuel Ratio Analyzer

Instruction Manual

3/05 Part Number 1210A-5

Information and specifications subject to change without notice.

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Introduction

The AFRecorder Model 1200

The AFRecorder Model 1200 is a highly integrated air-fuel ratio analyzer that packs the following features into a small and easy-to-use package:

- Displays in AFR (air-fuel ratio), λ (Lambda), and $\%O_2$
- Wide range of operation: AFR: 6.0 to 150.0
  λ: 0.4 to 10.0
  $\%O_2$: 0.0 to 22.0
- Can specify any fuel type by composition H:C, O:C, and N:C ratios
- Easy sensor calibration using air
- Programmable 0 to 5 VDC analog output
- Simulated O_2 (SEGO) sensor output with programmable switch point
- Recording capability with built-in statistics
- RS-232 communication interface with PC software supplied
- 95-250 VAC and 11-28 VDC operation

The AFRecorder Model 1200 Components List

The following items are included with the AFRecorder Model 1200 package:

Item No.	Description	Part Number
1.	AFRecorder Model 1200 Display Head	1210A
2.	AFR Sensor	2400E-1
3.	Wiring Adapter[1], 6”	1200A-2
4.	Instrument Wiring Harness[2], 13’	1200A-3A
5.	12 VDC Battery Power Clamp-on Adapter[3], 1.5’	1200A-3B
6.	O_2 Sensor Simulator Cable, 13’	1200A-4
7.	AC/DC Power Supply	1200A-9
8.	Instruction Manual	1210A-5
9.	AFRemote Software	1210A-10
10.	Carrying Case	1210A-6
11.	Sensor Boss and Plug	1200A-8

[1] A right-angled (to the right) Wiring Adapter (P/N 1200A-2R) is available.
[2] An Upload/Download Power Cable (P/N 1210A-11) is available. This allows the AFRecorder’s display head to be powered without the instrument wiring harness.
[3] A 12 VDC Cigarette Lighter Adapter (P/N 1200A-3C), and a 12 VDC Mating Adapter Kit (P/N 1200A-3D) are available.

Important Operation Notes

1. Before installing the AFR sensor, apply a small amount of non-lead containing antiseize compound to its threads. Do not get the compound on the sensor's tip. Do not use teflon tape to seal the treads.

2. Do not operate an engine for more than three minutes with the AFR sensor in the exhaust and the AFRecorder's power off. If the sensor is off in a running engine, soot and water will condense in the sensor and may reduce its sensitivity.

3. Do not use the AFR sensor in exhaust systems in which water is sprayed into the exhaust. Water striking the sensor may cause permanent sensor damage.

4. Do not put the AFR sensor in the exhaust of a heavily sooting or oil-burning engine.

5. Use of the AFR sensor with leaded fuels may reduce the sensitivity of the sensor.

6. Do not put the AFR sensor in exhausts in which the temperature is greater than 950 deg. C (1742 deg. F) or the pressure is not between 0.8 to 1.3 atm.

7. Route and cable-tie the AFRecorder’s wires away from hot or moving objects and ignition wires.

8. Do not remove or attach the AFR sensor from the instrument harness with the AFRecorder on.

9. Do not drop the AFR sensor onto a hard surface.

10. The AFR sensor is self-heated. Do not touch or expose it to flammable substances when the AFRecorder is on.

11. Do not attempt to wash the AFR sensor with any solvent or compressed air.

How to Use

Front Panel and the "SYS" Key

The front panel has 9 keys, pressing them has the following action:

AFR: Displays stoichiometry in air-fuel ratio units

λ: Displays stoichiometry in lambda units

%O2: Displays exhaust $\%O_2$

CAL: Used to calibrate the AFR sensor. Hold sensor in air, press the ↑ and ↓ arrow keys until the $\%O_2$ in air is displayed on the meter, and then press the "ENT" key. It is recommended that the sensor be held in still air for 20 minutes before calibration. To calculate the $\%O_2$ in air when humidity is present, see Appendix C.

SLO: Fast (d.r. F), average (d.r. A), and slow (d.r. S) display

↑ or ↓: Increases or decreases a selection (used when in "SYS" or "CAL")

ENT: Press to select an entry (used when in "SYS" and "CAL")

SYS: Toggles meter in and out of system setup. When pressed, display shows "hc". Pressing ↑ or ↓ rolls through the system setup options list (hc, oc, nc, ...). When the desired option is on the display, press "ENT". Now you can modify the option using the ↑or ↓ key (ie. for "hc" you can change from 1.75 to 1.85). When the option has been suitably modified, press "ENT" to accept the entry and return to the setup options list. Pressing "SYS" will exit system setup.

The setup options list is:

hc: select H:C ratio of the fuel (range: 1.00 to 10.00)
oc: select O:C ratio of the fuel (range: 0.00 to 10.00)
nc: select N:C ratio of the fuel (range: 0.00 to 1.00)
hdro: select hydrogen as the fuel (no or yes)

An U: select units for analog output (AFr, LAb, O2)
An L: select the value of the selected units for an analog output of 0 volts
An H: select the value of the selected units for an analog output of 5 volts
An H must be greater than 1.2 x An L.

EgoU: select the units that trip the SEGO (simulated O_2) sensor output (AFr, LAb)
EgoL: select the value of the selected units for the SEGO output switch point

io2, ico, ih2, i1, i2: AFR sensor calibration numbers
iccr, iccS, iccL: Incomplete combustion compensation for rich, stoichiometric, and lean stoichiometry (range -10 to +10, 5 nominal)

rEcn: select number of data points to record (range: 10 to 2000)
rEci: select interval between data points (range: 0.01 to 60 sec.)
rEcd: displays statistics of previously recorded data
(r A (average), r Lo (minimum), r Hi (maximum), r S.d. (standard deviation))

Power and AFR Sensor Mounting

Power

The AFRecorder can be powered either by AC line power (95-250 VAC) or by a 12 VDC battery. If powered by a 12 VDC battery, it is important that the AFRecorder's power clamp-on adapter (P/N 1200A-3B) is attached directly to the battery. The reason why is because two ground wires are used in the adapter: one for the sensor's heater (high current) and one for the AFRecorder's electronics (low current). The analog output ground (on the analog output BNC connector) uses the electronics (low current) ground. If the sensor's heater and the electronics share a common ground wire then there will be a voltage drop between the analog output ground and the battery ground. Therefore, there must be two separate ground wires and they must join only at the power supply. The power clamp-on adapter is built this way so do not modify it.

The supplied AC/DC power supply (P/N 1200A-9) is a switching power supply. "Switchers", as opposed to linear power supplies are compact, light, but electrically noisy (EMI). Keep the power supply and the AFRecorder separated as far as possible.

AFR Sensor Mounting

The AFR sensor should be located approximately 12" from the exhaust valve(s) of the engine, between the engine and the catalytic converter (if any). A location further from the engine may be used as long as it is at least ten times the exhaust pipe diameter upstream of the end of the exhaust system. For example, with a 2 1/2" diameter exhaust pipe, the sensor should be at least 25" upstream of the end of the exhaust. The problem with locations further downstream than ten diameters is that air may be trapped in the exhaust giving leaner than actual readings. This occurs especially at low exhaust flowrates. AFR sensor mounting locations far from the engine expose the sensor to more liquid water during start-up and should be avoided.

When choosing an AFR sensor location, take into consideration engine movement, ground clearance, and wire routing.

Install the AFR sensor by lightly coating its threads with a non-lead containing antiseize compound and tightening it to 30 ±3 ft-lbf (40 ±4 Nm). Attach the sensor to the instrument wiring harness and route the harness to where the AFRecorder's display head will be located. Use cable ties to keep the harness away from hot or moving objects and ignition wires. The harness is connected to the wiring adapter which in turn is connected to the AFRecorder. The wiring adapter should be left attached to the AFRecorder.

Do not modify the harness or wiring adapter and replace them immediately if they are damaged.

Installation of the Sensor Boss

The AFR sensor is mounted in the engine's exhaust by threading it into a M18X1.5mm boss that is cast, welded, or brazed onto the engine's exhaust pipe. This thread size is identical to that of most exhaust gas oxygen sensors (ie. EGO or O_2 sensors) used in production automobiles with 3-way exhaust catalysts.

The sensor boss provided has a M18X1.5mm thread. To mount the boss, first drill a 3/4" diameter hole in the desired location. Wire-brush the area around the hole and clamp the boss over the hole. Do not mount the sensor on the bottom of the exhaust pipe because liquid inside the pipe may collect on the sensor. Weld or braze the boss to the pipe. After the boss is attached to the pipe, tap the treads to clean them and file the top of the boss to provide a flat surface for sealing. When the AFR sensor is not being used, use the supplied plug (with some anti-seize) to plug the hole. Do not use the AFR sensor to plug the hole when the AFRecorder is not being used.

Calibration

Each AFR sensor supplied by ECM comes with five calibration numbers: io2, ico, ih2, i1, and i2. These numbers should be entered into the AFRecorder before it is used with the sensor.

The calibration can be checked by pressing "CAL" on the keypad and holding the sensor in still air for 20 minutes. After 20 minutes, the AFRecorder should show the $\%O_2$ in air. The $\%O_2$ in dry air is 20.95% and decreases with increasing humidity. Appendix C describes how to calculate the $\%O_2$ in air with humidity. If the AFRecorder does not display the correct $\%O_2$ value, the ↑and ↓ buttons should be pressed until the $\%O_2$ in the air is displayed by the AFRecorder. Then the "ENT" key must be pressed to accept the setting. This will calibrate the system.

How often should the calibration be checked? It depends on how the sensor is being used. A good plan is to check the calibration every day before starting the engine. The sensor's calibration shifts as material condenses on the sensing element behind the shield of the sensor. The material that condenses can be soot, fuel, water, and substances in the fuel such as lead. The richer the engine is operated at and the further the sensor is mounted from the engine, the more often the calibration should be checked. The calibration should also be checked when the barometric pressure changes (either due to weather changes or altitude changes).

Pressure Compensation

All wide-range exhaust sensors have a pressure sensitivity. Errors occur when the sensor is operated at pressures different from the pressure at which it was calibrated. Changes in pressure come about from changes in weather, altitude changes, and engine backpressure. There is no sensitivity to pressure at stoichiometric ($\lambda = 1$) conditions. The sensitivity gets greater the further from stoichiometric the engine is operated. Increases in pressure make the sensor read further from stoichiometric (ie. if lean, reads leaner, if rich, reads richer). For example, an increase in exhaust pressure of 127 mmHg above the calibration pressure (which would result from calibrating at 1 mile above sea level and then driving down to sea level) would make a 12.65 AFR engine read 12.50 or a 16.77 AFR engine read 17.00.

Pressure Compensation Equation for AFR

AFR(corrected) = (AFR(measured) + B x P) / (1 + C x P) [Equation 1a]

where: AFR(corrected) = the AFR corrected for exhaust pressure.
AFR(measured) = the AFR shown on the meter.
B = 0.009140 for AFR < 14.57 (rich).
B = 0.012100 for AFR ≥ 14.57 (lean).
C = 0.000627 for AFR < 14.57 (rich).
C = 0.000830 for AFR ≥ 14.57 (lean).
P = the exhaust pressure in mmHg above the pressure at which the sensor was calibrated. Equation 1a is valid for -152 mmHg < P < 532 mmHg.

Pressure Compensation Equation for Lambda

Lambda(corrected) = (Lambda(measured) + B x P) / (1 + B x P) [Equation 1b]

where: Lambda(corrected) = the Lambda corrected for exhaust pressure.
Lambda(measured) = the Lambda shown on the meter.
B = 0.000627 for Lambda < 1.0 (rich).
B = 0.000830 for Lambda ≥ 1.0 (lean).
P = the exhaust pressure in mmHg above the pressure at which the sensor was calibrated. Equation 1b is valid for -152 mmHg < P < 532 mmHg.

Pressure Compensation Equation for $\%O_2$

$\%O_2$(corrected) = $\%O_2$(measured) / [1.0 + B x P] [Equation 1c]

where: $\%O_2$ (corrected) = the $\%O_2$ corrected for exhaust pressure.
$\%O_2$ (measured) = the $\%O_2$ shown on the meter.
B = See above.
P = the exhaust pressure in mmHg above the pressure at which the sensor was calibrated. Equation 1c is valid for -152 mmHg < P < 532 mmHG.

Analog Output and Simulated O_2 (SEGO) Sensor Output

Analog Output

The analog output range is 0 to 5 VDC, and programmable in AFR, λ, or $\%O_2$. For example, you can select AFR as the units, with a 0 V AFR value of 10, and a 5V AFR value of 15. Then, an output of 4.5V would mean an AFR of 14.5.

After start-up, when the AFRecorder is counting down (AFR sensor is heating up during this period), a steady 1V then a steady 4V value is output. This allows verification of correct hook-up to your data acquisition system.

The bar graph on the AFRecorder shows the analog output value between 0V and 5V during operation.

The analog output is updated every 10 ms.

Using the Production O_2 Sensor Location and the Simulated O_2 (SEGO) Sensor Output

Since the AFR sensor uses the same thread size as most production O_2 sensors, the production mounting hole can be used. However, if the production O_2 sensor is not connected to the powertrain control module (PCM), the PCM may go into "back-up" mode. The AFRecorder avoids this problem by providing a simulated O_2 (SEGO) sensor output that can be fed into the PCM.

The SEGO sensor output is a 0V (lean) to 1V (rich) signal that switches at λ=1.0 (this is the same switch point as the production O_2 sensor) ***or any programmable λ or AFR value***. The SEGO sensor output is available at the red banana plug connector of the instrument wiring harness. Connection between that connector and the vehicle's O_2 sensor signal wire (part of the vehicle's wiring harness) is made with the O_2 sensor simulator cable (P/N 1200A-4). One end of the cable connects to the AFRecorder wiring harness and the other end is used to pierce the O_2 sensor signal wire to the vehicle's PCM. The production O_2 sensor is both electrically and physically disconnected from the vehicle when the SEGO sensor output is being used.

The SEGO feature is a powerful tool to “trick” the PCM into changing the engine’s AFR by programming a non λ=1 switch point.

When using the SEGO feature, three things must be kept in mind:

1. The vehicle's PCM may have a feature to detect if the O_2 sensor's heater is operating properly. If this is the case, the electrical connection between the vehicle’s production O_2 sensor's heater wires and the vehicle's wiring harness must be maintained.

2. The vehicle's PCM may have a routine to detect if the O_2 sensor is operating properly by pumping current into and out of the O_2 sensor. Depending on the sophistication of this routine, using the SEGO feature may cause a trouble code to be set in the vehicle’s PCM.

3. The SEGO feature was designed to match as closely as possible the output of the vehicle's production O_2 sensor. However, the O_2 sensor simulator output cannot be expected to match all vehicle's O_2 sensor outputs under all operating conditions.

AFR Recording and Statistics

The AFRecorder has a built-in, non-volatile, 2000 point recording capability. The recording is initiated by: pressing the red button on the top of the AFRecorder, the shorting of two terminals in the jack on the side of the meter, or via an RS-232 command. The number of points and the time between points are programmable. The "units" LED flashes during the recording. If the recording is terminated before its programmed time (ex. by pressing the red button again), then the data up to that time is recorded. The average, maximum, minimum, and standard deviation of the data are calculated by the AFRecorder and available in the SYS option list. The entire recording can be uploaded to a PC via the supplied PC software program.

PC Software and RS-232 Control

A PC software program (AFRemote) is supplied to communicate with the AFRecorder. AFRemote can run under DOS or a DOS window within Windows. AFRemote allows remote setup, control, uploading of data, plotting of data, storage of data, and recalling of data.

The optional Upload/Download Power Cable (P/N 1210A-11) allows the AFRecorder's display head to be powered without the instrument wiring harness.

The features of AFRemote can be integrated into a user-written program. Appendix D describes the protocol for this communication.

Specifications and Limits

Measurements and Accuracy

Units	Range	Accuracy
Air-to-Fuel Ratio (AFR)	6.0 to 150.0[1]	±0.1 (stoichiometric) ±0.2 (12<AFR<18) ±0.5 (elsewhere)
Lambda (λ)	0.4 to 10.0	±0.006 (stoichiometric) ±0.008 (0.8<λ<1.2) ±0.009 (elsewhere)
$\%O_2$	0 to 22%	±0.2% (0<$\%O_2$<2) ±0.4% (elsewhere)

Response Time: < 150 ms
Calculation Time: 1 ms

[1] AFR range given for gasoline with an H:C ratio of 1.85. For other fuels, AFR range depends on the composition (i.e. H:C ratio, O:C ratio, N:C ratio) of the fuel.

Recording Specifications

Data Recorded: AFR, λ, or $\%O_2$
Number of Data Points: 10 to 2000
Time between Data Points: 0.01 to 60 sec.

Real-Time to Disk and Real-Time Plot to Disk Specifications

These specifications are for the PC software program AFRemote.

Data Recorded: AFR, λ, or $\%O_2$
Number of Data Points: 100 to 100,000
Time between Data Points: 0.1 to 60 sec.

AFR Sensor Specifications

Installation

Thread Size: M18X1.5 mm. Lightly coat with non-lead containing antiseize compound.
Hex Size: 22 mm
Tightening Torque: 30 ±3 ft-lbf, 40 ±4 Nm

The AFR sensor's thread size is identical to that of the exhaust gas oxygen (EGO) sensors used in current production automobiles with 3-way exhaust catalysts.

Use of an AFR sensor cable other than that supplied may affect accuracy and life of the AFR sensor.

Connector on AFR sensor

AMP Series 1, Arrangement 13-9 (Standard Connector)

Pin 1: Heater +
Pin 2: Heater -
Pin 3: Ip cell +
Pin 4: NC
Pin 5: Vs cell +
Pin 6: Ip, Vs cell -
Pin 7: Not connected
Pin 8: Cal resistor
Pin 9: Cal resistor

W.W. Fischer S105A062-60/5.2S (Severe Duty Connector)

Pins 1, 9: Heater +
Pins 2, 10: Heater -
Pin 3: Ip cell +
Pin 4: NC
Pin 5: Vs cell +
Pin 6: Ip, Vs cell -
Pin 7: Cal resistor
Pin 8: Cal resistor

Sanwa SNW-1608-ACM-5 (Optional Connector)

Pin 1: Heater +
Pin 2: Heater -
Pin 3: Ip cell +
Pin 4: Cal Resistor
Pin 5: Ip -, Vs cell -
Pin 6: Vs cell +
Pin 7: Cal resistor
Pin 8: Ip-, Vs cell -

Fuel Composition and Exhaust Operating Conditions

H:C ratio range: 1.00 to 10.00
O:C ratio range: 0.00 to 10.00
N:C ratio range: 0.00 to 1.00

gasoline	(1.70 < H:C < 2.10, O:C=0.0, N:C=0.0)
	(1.75 or 1.85 are commonly used)
methanol	(H:C=4.0, O:C=1.0, N:C=0.0)
ethanol	(H:C=3.0, O:C=0.5, N:C=0.0)
propane	(H:C=2.67, O:C=0.0, N:C=0.0)
methane	(H:C=4.0, O:C=0.0, N:C=0.0)

Maximum allowable levels of fuel "impurities":

Lead: 0.012 gm/gal.
Phosphorous: 0.0008 gm/gal.
Sulfur: 0.035 % by weight

Do not use the AFR sensor with leaded fuel or in a heavily-sooting or crankcase-oil-burning engine because these conditions will severely shorten the life of the sensor.

Exhaust Gas Temperature Range: 0 - 850 deg. C, 32 - 1562 deg. F
Maximum Exhaust Temperature: 950 deg. C, 1742 deg. F
Maximum Rate of Temperature Change: 50 deg. C/sec, 122 deg. F/sec.

Exhaust Gas Pressure Range: 0.8 - 1.3 atm.

Output Specifications

Analog Output

Programmable Ranges for: Air-to-Fuel Ratio (AFR), Lambda (λ), or $\%O_2$
Output Range (linearized in displayed units): 0 - 5 VDC
Output Range Limit: Setup parameter "An H" must be greater than 1.2 x "An L"
Output Current Drive: 20 mA max
Bits Resolution: 12 bits
Update Rate: 0.01 sec.
Output Connector: Female BNC, Signal = Center, Ground = Shell
Output Impedance: 100 Ohm

The output must be measured relative to the signal ground shell on the connector. In the case where the AFRecorder and an external data acquisition system are both powered by the same 12 VDC battery, then the input of the data acquisition system receiving the output from the AFRecorder must be set up in differential mode. If differential mode is not available and single-ended mode is used, be aware that an approximately 5 mV potential exists between the 12 VDC battery ground (measured at the battery) and the signal ground (measured at the output connector of the AFRecorder). Single-ended inputs of some data acquisition systems will tie the signal ground to the power supply ground. This will not cause any problems with the AFRecorder but its effect on the data acquisition system must be considered.

To compensate for differences in voltage references and ground potentials between the AFRecorder and a data acquisition system receiving its output, use Equation A:

$$AFR = \left(AFR_5 - AFR_0\right) \times V/5 + AFR_0 \qquad \text{[Equation A]}$$

where: AFR is the compensated AFR value.
AFR_0 is the programmed AFR for 0 Volts.
AFR_5 is the programmed AFR for 5 Volts.
V is the voltage calculated from Equation B.

Note that the "AFR" in Equation A is replaced by λ, or $\%O_2$ for the chosen analog output units.

$$V = \frac{3V_{ad}}{V_{ad4} - V_{ad1}} + \frac{V_{ad4} - 4V_{ad1}}{V_{ad4} - V_{ad1}} \qquad \text{[Equation B]}$$

where: V is the value calculated and used in Equation A.
V_{ad} is the voltage reported by the data acquisition system when collecting data.
V_{ad1} is the voltage reported by the data acquisition system when the AFRecorder is outputting "1" Volt.
V_{ad4} is the voltage reported by the data acquisition system when the AFRecorder is outputting "4" Volts.

Note that V_{ad1} and V_{ad4} must be measured when the data acquisition system is fully hooked-up and the AFRecorder is fully hooked-up and the AFR sensor is "on".

Simulated Exhaust Gas Oxygen (SEGO) Sensor Output

Programmable Transition at Target: Air-to-Fuel Ratio (AFR) or Lambda (λ)
"High" Output Level (for richer than programmed transition AFR): Approximately 0.8 V
"Low" Output Level (for leaner than programmed transition AFR): Approximately 0.02 V
Output Current Drive: 20 mA max.
Transition Time (10% to 90%): Approximately 25 ms
Update Rate: 0.01 sec.
Output Connector: Red Banana Plug = Positive, Ground via instrument harness
Output Impedance: 100K Ohm

Recording Initiation/Termination Jack

Trigger: Short terminals of jack to initiate or terminate. Shell at power ground.
Mating Plug: Switchcraft 850. Available from Digikey (800-344-4539) as P/N SC1058-ND.

RS-232 Communication

Data Format: Bi-directional, 4800,8,N,1
Connector: Male DB9
Pin 2: Tx from AFRecorder
Pin 3: Rx to AFRecorder
Pin 5: Shield ground and signal ground
All other pins: Not connected
Cable: Use straight-through DB9 cable to computer.
Software: AFRemote software for IBM PC-compatible computer provided on 1.44 Kb (3 1/2") media.

General Information

Power: 11 to 28 VDC at 9.5A (surge at beginning of AFR sensor warm-up), 2A (continuous)
Pins 1, 2: +11 to 28 VDC, Pin 3: Ground (low current), Pin 4: Ground (high current)
Connector: AMP Series 1, Arrangement 11-4
Fuse: Internal, automatically resetable

Dimensions: 7 1/2 " x 4" x 1 1/8",
191mm x 102mm x 29mm (W x H x D)
Weight: 10 oz., 290 gm.

Appendix A: Application Notes

The AFRecorder will give you insight into your engine's fueling system (fuel injection or carburetor) that you may never have had before. Here are some things that you may see:

1. During engine warm-up of an electronically controlled engine, the engine may be fueled rich and oxygen pumped into the exhaust via the air pump. This is for the quick warm-up of the production O_2 sensor and the catalytic converter. When this occurs, the measured AFR will be leaner than the actual AFR because air is entering the exhaust not through the engine but via an external path.

2. During throttle tip-in for engines in which the fuel is injected into the intake manifold (ex. most spark ignition engines), you will see the AFR momentarily go lean and then rich. During throttle tip-out, you will see the AFR momentarily go rich and then lean. The initial lean (for tip-in) and rich (for tip-out) AFRs are due to the fact that the air reaches the cylinder before the fuel. The subsequent rich (for tip-in) and lean (for tip-out) AFRs are due to the carburetor or fuel injection system. For engines in which the fuel is injected into the cylinder (ex. diesels), the AFR transients will be in the opposite direction. This is because the fuel makes it to the cylinder before the air.

3. During a long (approximately 5 seconds or more), foot-off-the-pedal deceleration of a vehicle with a manual transmission, the fuel injection may be turned off by the powertrain control module (PCM). This will result in the AFRecorder displaying a very lean value because just air is being pumped through the engine.

4. For vehicles with 3-way exhaust catalysts, the PCM will vary the fuel pulse duration to oscillate the AFR around $\lambda=1$. This is to maximize the effectiveness of the catalyst in reducing emissions.

5. Most production PCMs operate the engine nominally at stoichiometric ($\lambda=1$). This is because the 3-way exhaust catalyst is most efficient in reducing pollutants at this value. However, when maximum power is requested from the engine (wide-open-throttle), the PCM will change the λ control point to approximately 0.7 (or AFR=10 for gasoline). This is the fueling for maximum power with acceptable engine durability. However it is not the fueling for minimum emissions so you may find that in the future, production PCMs will maintain a stoichiometric mixture ($\lambda=1$) under wide-open-throttle conditions also.

6. After a fuel injected engine is shut off, the AFRecorder will display a very high value (i.e. $\lambda=1.7$). This is because the injection of fuel is stopped with the ignition but the engine pumps a little air before the engine stops rotating, thus diluting the exhaust from its running condition. This is why the AFR sensor should be calibrated outside of the exhaust.

Appendix B: Troubleshooting

The AFRecorder has an error-detecting capability and will display the detected errors. The errors and their descriptions are:

SEnSor Error 1: AFR sensor broken, not connected, or cable is damaged.

bAPr Hi: DC power voltage too low (less than 11 VDC).

bAPr Lo: DC power voltage too high (greater than 28 VDC).

SEnSor Error 4, 5, 6, or 7: AFR sensor broken.

It is important to supply the AFRecorder with clean power at a sufficient voltage (11VDC~28VDC) and with sufficient current capacity (9.5 A (surge), 2 A (continuous)). If the voltage or current is insufficient or the power is noisy, the AFRecorder may not work, may reset, or may give "noisy" data. When it resets, it initializes and then begins the AFR sensor warm-up countdown. During cold cranking, battery voltages can drop below 11 VDC. The AFRecorder will work with battery voltages less than 11 VDC but only for 7 seconds. This is because the AFR sensor cannot be kept at its target temperature at low voltages. During this time, it is hoped that the engine will start and the battery voltage will go over 11VDC. Should the battery voltage be less than 11 VDC for an extended period of time, the AC/DC power supply (P/N 1200A-9) should be used.

Do not run a single ground wire from the ground clamp of the 12 VDC Battery Power Clamp-on Adapter (P/N 1200A-3B) to the vehicle's battery. This will cause the analog output ground to be elevated above battery ground and may put electrical noise into the AFRecorder causing noisy data. Connect the adapter directly to the battery.

The AFRecorder may be reset or give "noisy" data when operated in an electrically noisy environment. In some situations, a timing light might create a noise problem. Keep the AFRecorder and its wiring harness away from the engine's ignition wires and the AC/DC power supply to avoid these problems.

The AFRecorder must be returned to the factory for repair. There are no user-repairable components within the AFRecorder. The warranty is void if the AFRecorder is opened. Contact ECM before returning the AFRecorder to the factory.

When setting up the analog output range, "An H" must be at least 1.2 x "An L".

Appendix C: Calculating the $\%O_2$ in Air

The oxygen concentration in dry air (zero humidity) is 20.95% and decreases with increasing humidity. The $\%O_2$ in air can be calculated from the barometric pressure (Pb), the relative humidity (Rh), and the saturated water vapor pressure (Pws) by using the following formula:

$$\%O_2 = 20.95\% \times (Pb - Pws \times (Rh/100)) / Pb$$

The saturated water vapor pressure (Pws) is a function of the ambient temperature (Ta) and is given in the table below.

Ta (°C)	0	1	2	3	4	5	6	7	8	9
	Pws (mm Hg)									
0	4.579	4.926	5.294	5.685	6.101	6.543	7.013	7.513	8.045	8.609
10	9.209	9.844	10.518	11.231	11.987	12.788	13.634	14.530	15.477	16.477
20	17.535	18.650	19.827	21.068	22.377	23.756	25.209	26.739	28.349	30.043
30	31.824	33.695	35.663	37.729	39.898	42.175	44.563	47.067	49.692	52.442
40	55.324	58.34	61.50	64.8	68.26	71.88	75.65	79.60	83.71	88.02
50	92.51	97.2	102.09	107.2	112.51	118.04	123.80	129.82	136.08	142.60
60	149.38	156.43	163.77	171.38	179.31	187.54	196.09	204.96	214.17	223.73
70	233.7	243.9	254.6	265.7	277.2	289.1	301.4	314.1	327.3	341.0
80	355.1	369.7	384.9	400.6	416.8	433.6	450.9	468.7	487.1	506.1
90	525.76	546.05	566.99	588.60	610.90	633.9	657.62	682.07	707.27	733.24

Appendix D: Protocol for RS-232 Communication

The AFRecorder may be operated under remote control using a standard RS232 serial port. The interface uses text (ASCII) command strings. Current values of the AFR, Lambda or $\%O_2$ can be polled from the unit using simple commands. The interface allows the remote computer to upload or download all AFRecorder setup parameters such as the H:C ratio of the fuel, the analog output range values, and the sensor calibration constants. The interface is bi-directional, 4800 baud, 8 data bits, one stop bit, with no parity.

The external computer may issue commands to the AFRecorder at any time and will always receive a response. The first part of the response is either the downloaded command string or an error string. If a value is being uploaded it will follow the command string. For a command string response without a value or an error string, the string is padded with blanks if necessary so that the response is always seven characters long. For the case of a command string followed by a number, the response will always be 16 characters long, made up of the command string, at least one blank, and a number of the form "1234.567". The number is right justified in the response string, and is always of the same form (with three decimal places) even for an integer value such as the number of recorded data points.

Every command to the AFRecorder must be terminated with a "Z". To set the analog output units to AFR for example, the string "ANAAFRZ" should be downloaded. Lower case characters are allowed. For this command, the AFRecorder would respond with "ANAAFR".

The interface times out in 4 seconds. This is the time between the receipt of the first character and the "Z". The string "TIMEOUT" is uploaded in the event of a timeout.

The other error strings are "BUSY", "ERROR", "LOW", and "HIGH". "BUSY" is sent if the unit is initializing or if a recording is in progress. "ERROR" is sent if the command sequence is not understood. "LOW" and "HIGH" are sent if a downloaded value is out of range.

"Setup Value" commands are used either to download a new parameter value to the AFRecorder or upload the current value. To set a new parameter value, download the command string followed by the value, terminated with a "Z". For example, to set the value of the H:C ratio of the fuel to 1.850, use the string "FUEHC 1.850Z". To upload the current value of the H:C ratio, use the string "FUEHCZ". The AFRecorder would send "FUEHC 1.850" in response to either command. New downloaded parameter values do not take effect until a reset command is issued to the AFRecorder. After downloading all desired setup parameters (fuel type, sensor calibration constants, etc.), issue a reset command ("RESETZ") to the AFRecorder.

Setup Choices Commands

ANAAFR	Set analog output units to AFR
ANALAM	Set analog output units to Lambda
ANAO2	Set analog output units to $\%O_2$
CALSLOW	Set display rate to slow
CALAVG	Set display rate to average

CALFAST	Set display rate to fast
DISAFR	Set display units to AFR
DISLAM	Set display units to Lambda
DISO2	Set display units to $\%O_2$
EGOAFR	Set simulated EGO output units to AFR
EGOLAM	Set simulated EGO output units to Lambda
HYDNO	Set Hydrogen fuel calculation off
HYDYES	Set Hydrogen fuel calculation on

Setup Value Commands (set a new value or upload the current value)

SIMAFR 14.6	Simulated EGO threshold for AFR units
SIMLAM 1.0	Simulated EGO threshold for Lambda units
FUEHC 1.85	Fuel H:C Ratio
FUEOC 1.00	Fuel O:C Ratio
FUENC 1.00	Fuel N:C Ratio
HIVAFR 20.0	AFR analog output value at 5.0V
HIVLAM 1.5	Lambda analog output value at 5.0V
HIVO2 20.0	$\%O_2$ analog output value at 5.0V
LOVAFR 10.0	AFR analog output value at 0.0V
LOVLAM 0.5	Lambda analog output value at 0.0V
LOVO2 -10.0	$\%O_2$ analog output value at 0.0V
RECNUM 1000	Number of recorded data points for future recording
RECINT 0.02	Recorded data interval for future recording
SENO2 0.299	Sensor calibration parameter IO2
SENCO 0.071	Sensor calibration parameter ICO
SENH2 0.434	Sensor calibration parameter IH2
SEN1 4.50	Sensor calibration parameter I1
SEN2 0.041	Sensor calibration parameter I2
ICCRICH 5.00	ICC factor rich
ICCSTOI 5.00	ICC factor stoic
ICCLEAN 5.00	ICC factor lean

Control Commands

RESET	Reset command
RECGO	Start recording
RECSTOP	Stop recording
STATUS	Upload status value. Responses are: 1: Sensor control not active 2,3,4: Sensor warm-up sequence is in progress 5: Normal operation
ERROR	Upload error code value. Responses are: 0: No errors 1: Sensor disconnected or heater broken

2: DC power voltage too low
3: DC power voltage too high
4,5,6,7: Sensor errors

Poll Commands

VALAFR	Upload current value of displayed AFR (poll command)
VALLAM	Upload current value of displayed Lambda (poll command)
VALO2	Upload current value of displayed $\%O_2$ (poll command)

Upload Recorded Data Commands

RECDATA n	Upload recorded data point number "n" (previous recording)	
RECPTS	Upload number of recorded points from previous recording	
RECRATE	Upload recorded data interval (previous recording)	
RECUNIT	Upload recorded data units (previous recording).	
	Responses are:	0: AFR
		1: Lambda
		2: %O2

Safety Warnings

In installation and use of this product, comply with the National Electrical Code and any other applicable Federal, State, or local safety codes.

Always wear eye protection when working near engines, vehicles, or machinery.

During installation, turn off the power and take all other necessary precautions to prevent injury, property loss, and equipment damage. Do not apply power until all wiring is completed.

Never work on a running engine.

When installing the AFRecorder's cabling and sensor on a stopped engine, it is best to think-out your moves before you make them.

Route and cable-tie all cables away from hot, moving, sharp, high energy (spark), and caustic objects.

Take into consideration the movement of the engine, chassis, and wind buffeting when instrumenting the engine.

Clear tools away from the engine before starting.

Operate the engine only in a well ventilated area and never when you or one of your co-workers is tired.

When operating the AFRecorder in a moving vehicle, the operator should keep his or her eyes on the road.

One measure of professionalism is how much you and your co-workers can accomplish without an injury. Always be at your professional best. Think and act with safety in mind.

Warranty and Disclaimers

WARRANTY

The products described in this manual, with the exception of the AFR sensor, are warranted to be free from defects in material and workmanship for a period of 365 days from the date of shipment to the buyer. Within the 365 day warranty period, we shall at our option repair such items or reimburse the customer the original price of such items which are returned to us with shipping charges prepaid and which are determined by us to be defective. This warranty does not apply to any item which has been subjected to misuse, negligence or accident; or misapplied; or modified; or improperly installed.

The AFR sensor is considered an expendable part and as such cannot be covered by a warranty.

This warranty comprises the sole and entire warranty pertaining to the items provided hereunder. Seller makes no other warranty, guarantee, or representation of any kind whatsoever. All other warranties, including but not limited to merchantability and fitness for purpose, whether express, implied, or arising by operation of law, trade usage, or course of dealing are hereby disclaimed.

The warranty is void if the AFRecorder is opened.

LIMITATION OF REMEDY

Seller's liability arising from or in any way connected with the items sold and/or services provided shall be limited exclusively to repair or replacement of the items sold or refund of the purchase price paid by buyer, at seller's sole option. In no event shall seller be liable for any incidental, consequential or special damages of any kind or nature whatsoever, including but not limited to lost profits arising from or in any way connected with items sold and/or services provided to buyer, whether alleged to arise from breach of contract, express or implied warranty, or in tort, including without limitation, negligence, failure to warn or strict liability. In no event shall the company's liability to buyer arising out of or relating to the sale of any product or service exceed the purchase price paid by buyer to the company for such product or service.

PRODUCT CHANGES

We reserve the right to discontinue a particular product or to make technical design changes at any time without notice.

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