AIR-FUEL RATIO

POWERDEX

AFX™

Air-Fuel Monitor

By NGK SPARK PLUGS (U.S.A.), INC.

TUNING MANUAL

Rev.06

<u>WARNINGS</u>

- **The AFR sensor gets very hot when power is applied and it stays hot for a while after power is disconnected. It can burn you and potentially ignite combustible vapors. Be careful when handling the sensor.**
- Do not open or modify the controller.
- Do not apply excessive voltage (more than 28V DC) to the harness.
- Do not modify the wiring harness.
- If the wiring harness is damaged, do not use it. Replace it.
- Do not open or modify the AFR sensor.

Tuning Engines with the AFX

Introduction

The AFX is a tool to measure the air-fuel ratio (AFR) delivered to carbureted and fuel injected performance engines. Its measurement range is 9.00 to 16.00 AFR for gasoline. This range equates to 0.62 to 1.10 λ (Lambda). For maximum AFR sensor life, the sensor must be powered when in the exhaust of a running engine.

AFX Installation

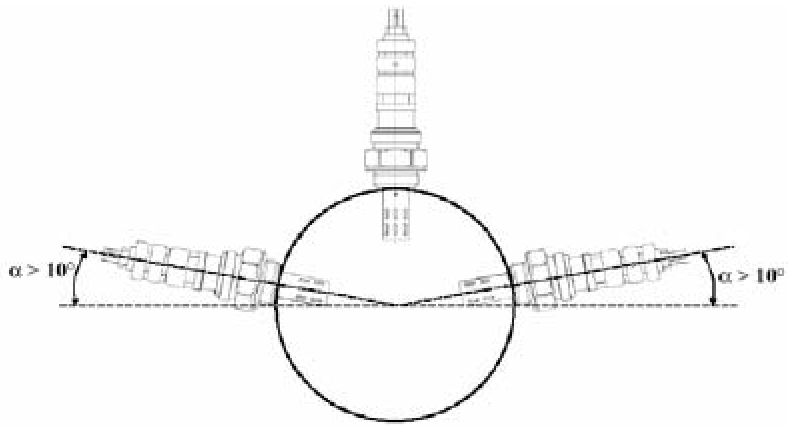
Below are recommended guidelines for installing the AFR sensor. Some exhaust configurations may make it difficult to meet each of the recommendations exactly, and some compromise in mounting may be required. The sensor does not necessarily have to precisely meet every mounting guideline below to operate, but please understand that the better you conform to these rules, the longer the sensor will last and the more accurate the results will be.

The AFR sensor should be located between 12" and 48" from the engine, upstream of any catalyst device if so equipped. The closer the sensor is to the engine, the more likely it will be overheated, possibly shortening its life. The further it is from the engine, the more likely condensed water will get into the sensor and thermally shock it, again possibly shortening its life. The sensor should be mounted at least ten exhaust diameters upstream of the exhaust exit (ex. for a 3" exhaust pipe, that is 30"). If the sensor is mounted between one and ten exhaust diameters from the exhaust exit, the AFR measured will be leaner than the actual AFR by as much as 2 AFR at low engine speeds (i.e. less than 3000 rpm).

Make sure there are no leaks in the exhaust system, as this will create an artificially lean (higher) AFR reading. Also, install the sensor upstream of any factory air-injection if so equipped, as this too will cause a false lean reading.

In turbocharged applications, it is recommended that the sensor be installed downstream of the turbine. This is due to the fact that the high pressures before the turbine can distort the AFR reading. Apply the same installation guidelines as described above, but take into consideration that the sensor needs to be downstream of the turbine.

The sensor boss requires you to drill a hole in the exhaust. A step drill or hole saw may be used. Weld the sensor boss to the exhaust so that it will position the sensor in the upper half of the exhaust, ideally between the 10 o'clock and 2 o'clock locations (see diagram on next page). This is to avoid liquid fuel or condensed water from getting inside the sensor and thermally shocking it.



After welding the sensor boss to the exhaust, run an M18 x 1.5mm tap or thread cleaner (KD Tool P/N 730 or equivalent) through the boss to remove any thread distortion. If this is not done, the sensor's threads may be damaged during installation or removal. Apply a small amount of anti-seize compound to the threads and tighten the sensor to 15~20 lb.-ft. Caution must be taken not to over-tighten the sensor. Unless you are permanently installing the unit as a constant AFR monitoring device, you will be installing and removing the sensor frequently. The more you over-tighten the sensor, the more the threads will deform each time and make it that much more difficult to reinstall the next time. During a reinstallation, if the sensor shows any resistance to being screwed back into the boss, run the tap or thread cleaner through the boss, clean the threads of the sensor with a fine wire brush, and apply a small amount of anti-seize to the threads before installation. If the threads on the sensor are damaged, run the sensor through a die.

The controller has an operating temperature range of -40º to 185º F (-40º to 85º C) and is splash-proof but not 100% water-proof. Mount it accordingly. The controller and the harness should be kept away from ignition systems and the harness should be routed away from the exhaust system and moving engine components.

The quality of the AFR measurement depends on the quality of the power you supply the AFX with. The ground terminal (two BLACK wires) should be connected directly to the battery's negative terminal or the body of the vehicle (if metal). Supplying power and ground through a vehicle's cigarette lighter is not recommended. The power terminal (RED wire) should have 11 to 28V DC attached (via a switch or relay) whenever the engine is running. If the sensor is not powered when the engine is running, sensor life will be shortened. The AFX (including sensor) draws less than 2 amps.

Before the AFX is used for the first time, or for the first time before a new AFR sensor is used, it should be calibrated (see next section).

AFX Calibration

The procedure to calibrate the AFX is as follows:

1. Connect the harness to the control module and the AFR sensor. With power disconnected from the harness and the sensor removed from the exhaust, hold the sensor by its wires letting it hang free in air. You cannot reliably calibrate the AFX with the sensor mounted in the exhaust of an engine, even if the engine has been off for several days.

2. Attach power to the harness. In about 10 seconds, you will start to notice the AFR sensor getting hot. **Use CAUTION, the sensor can burn you**.

3. Wait 3 minutes. This is to allow the sensor to reach operating temperature.

   NOTE: Although 3 minutes is normally sufficient time for pre-calibration warm-up, generally the longer you let the sensor hang in free air before calibration the better. If time permits, we recommend you let the sensor warm up for up to 30 or even 45 minutes for best results. A good method may be to power the system up and attend to other tasks, then come back after 30 or 45 minutes and perform the free air calibration. Keep in mind that this does not mean that performing the shorter warm-ups (3 to 5 minutes) will give bad results. It simply means that the longer warm-up time allows the sensor to acclimate to the atmosphere more thoroughly, and therefore can allow it to yield the most accurate results during on-vehicle use.

4. Turn the calibration knob on the back of the display head until the display reads “CAL-.” If the display reads “Air_” when the sensor is in air, turn the knob clockwise until the display reads “CAL-.” If the display reads “Air¯” when the sensor is in air, turn the knob counterclockwise unit the display reads “CAL-.”

5. Disconnect the power from the harness. When the AFR sensor cools down, install it in the exhaust and do not touch the calibration knob until the next time you calibrate the AFX.

   NOTE: Caution should be taken not to accidentally knock the controller and inadvertently turn the calibration knob after calibration. However, the calibration circuit is designed to have a certain amount of leeway. Accidentally turning the knob a small amount will not affect the results. See the next section for guidelines on calibration intervals.

It is impossible to predict how often the AFX needs to be calibrated without knowing the conditions under which the AFR sensor was used. However, here are some calibration guidelines:

- The first time before a new sensor is used: calibrate.
- For every 3000 ft. change in altitude: calibrate.
- For race engines: calibrate before every tune session.
- For wild, street performance engines: calibrate once every week of use on the street.
- For mild street engines: calibrate once every month of use on the street.
- For continuous use with leaded fuel: calibrate once every hour.

Experience will teach you if you need to shorten or lengthen these times by how much you had to turn the calibration knob to recalibrate. If you did not have to turn the calibration knob at all, try lengthening the time between calibrations.

The AFX has been designed to extend the AFR sensor's life as long as possible. However, since sensor life depends on sensor operating conditions, it impossible to predict sensor life without knowing the conditions under which the AFR sensor was used. Certainly, leaded fuel will shorten the sensor's life. However, there is a statistical component to sensor life. For example, a spark plug may foul and the sensor may be sprayed with raw fuel and thus be thermally shocked. Therefore, the AFR sensor should be considered an expendable part; a cost of tuning, just like gasoline and your time. Some tuners will never kill a sensor. Some tuners will kill two sensors a race season. It all depends.

You may use the AFX as a constant AFR monitoring tool, but keep in mind that this will consume the sensor faster. If you are not using the sensor to tune the engine, we generally recommend you take it out. It may be a good idea to keep a backup sensor on hand if you tune constantly or if you tune at the track.

Replacement AFR sensors are available from your nearest AFX distributor.

Using the AFX to Tune Engines for Racing Applications

People who tune spark ignition engines for racing applications are concerned with decreased lap times, faster e.t.s, and higher speeds. Once an engine is physically built, the fuel delivery (i.e. jetting or fuel pulse duration), and spark timing are the two principle tuning parameters used to optimize the engine for the type of racing it will participate in.

One way to tune the fuel delivery is to do a lot of track testing. However, because the relationship between AFR measurements and maximum horsepower, best throttle response, engine life, and best fuel economy are well known, it is faster to first tune to specific AFRs and then to use actual track performance for final fuel delivery adjustments.

For most spark ignition engines, there is a specific small window of AFR in which maximum horsepower and best throttle response will be found. For gasoline, that range is 12.5 to 13 AFR. For reasons such as engine life and fuel economy, some engines are not operated within that range. Below are some examples. Please note that these are strictly guidelines and will not apply universally to all engines:

- At high load conditions, air-cooled engines are often operated at an AFR as low as 10 in order to reduce engine temperatures that may lead to engine damage.

- At high load conditions, turbocharged engines are often operated at an AFR as low as 10 (sometimes even less) in order to reduce engine and turbocharger temperatures which may lead to engine and turbine damage. When mounting the sensor on a turbocharged application, it is recommended that the sensor be installed downstream of the turbine.

- Engines operated at loads beyond their original design or at their maximum load for periods longer than they were designed for may be operated at an AFR as low as 10 in order to reduce engine temperatures that can lead to engine damage.

- In racing where fuel stops are made, engines can be operated at an AFR greater than 13 at light loads in order to improve fuel economy. Fuel economy is maximized at an AFR of about 16. However, at these leaner AFRs (i.e. higher numbers), internal engine temperatures will increase and can lead to engine damage at high loads.

- With low octane fuels, engines are often operated at an AFR less than 12.5 in order to suppress detonation that can lead to engine damage.

- Engines that have a centralized fuel delivery system (i.e. a carburetor) may have some cylinders operating at an AFR greater or less than the engine average. The fuel delivery and induction should be tuned so that the average of the cylinders is between 12.5 and 13, and to avoid a specific cylinder(s) from operating at a lean AFR that can lead to overheating or detonation.

- For engines equipped with nitrous oxide and/or other chemical intercoolers like water methanol injection systems, the true AFR reading will be altered by these chemicals that have different characteristics than your primary fuel. It is difficult to determine the magnitude of the effect on AFR. A safe starting point is around 12.5 AFR.

- The AFX is designed for 4-stroke cycle engines, and will not accurately perform in a 2-stroke cycle engine. Due to scavenging of 2-stroke engines, the true AFR reading becomes distorted. The nature of 2-strokes is inherently one that is not compatible with exhaust gas sensors.

In summary:

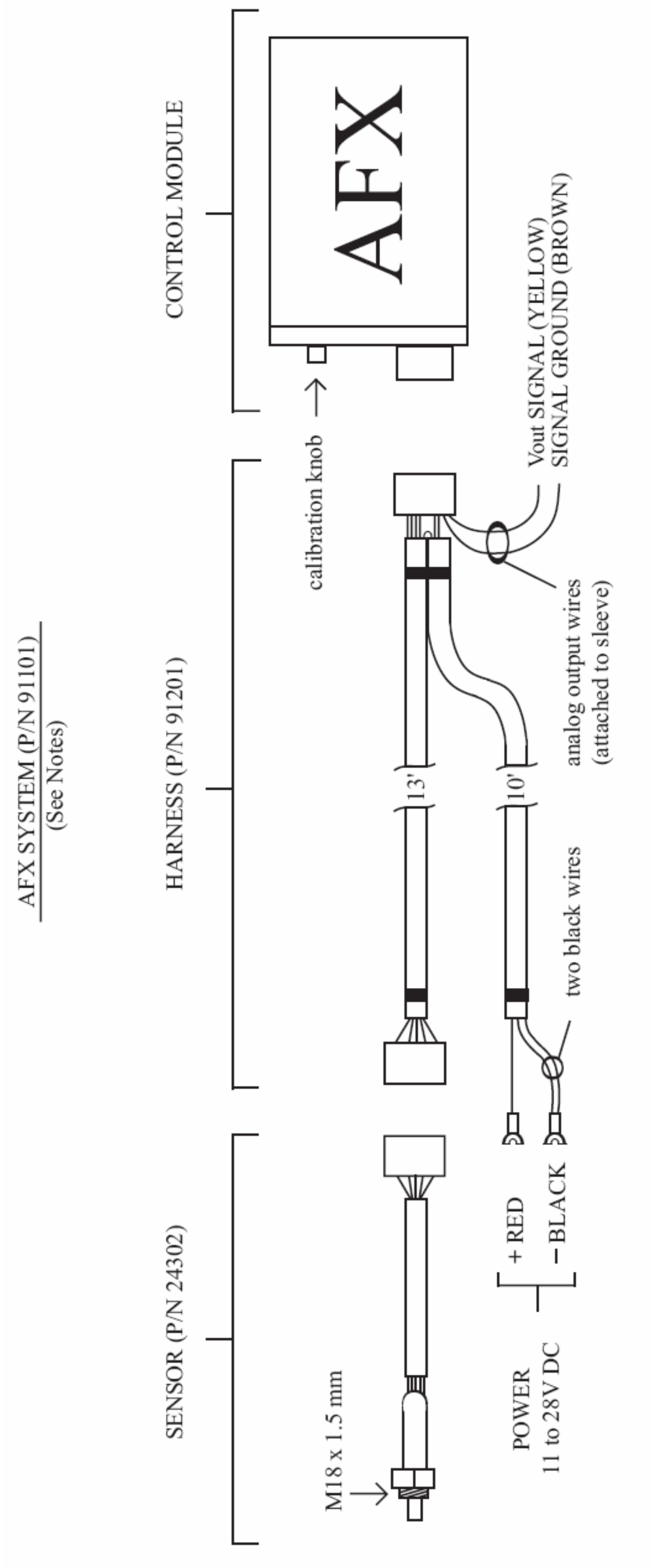
If you have a water-cooled, naturally aspirated engine, start with an AFR of 12.5 and tune from there. For forced induction, start at 10 and tune from there. "Tune from there" means adjusting the AFR and then testing for benefits such as decreased lap times, faster e.t.s, and higher speeds while watching for issues leading to unsatisfactory engine life or fuel economy. Always keep in mind that leaner AFRs (i.e. higher numbers) increase engine temperatures, and if caution is not taken, can lead to engine damage at high engine loads.

The preceding discussion pertains to race engines operating under race conditions. When race engines are idling, an AFR less than 13 can lead to spark plug fouling or unhappy pit neighbors (the smell). Often, increasing the idle AFR will eliminate spark plug fouling. At idle, the engine is operating far below its maximum temperature and pressure limits, so increasing idle AFR is unlikely to lead to engine damage at idle unless the engine is wildly misfiring. With carburetors, idle AFR adjustments will influence off-idle AFR and may cause detonation during initial throttle opening. Therefore and especially with carburetors, the choice of idle AFR will be based on tradeoffs between spark plug fouling, idle smoothness, off-idle AFR, and detonation. The final choice of idle AFR may be between 13 and 16. Often it is closer to 13 than 16.

Using the AFX to Tune Engines for Performance Street Applications

Performance street engines should be tuned the same way as race engines are except during non-WOT (non-wide open throttle) operation, the AFR should be increased. The reasoning here is that it makes no sense to pollute the air and waste fuel unless maximum engine power is required. For non-WOT and non-idle conditions, an AFR of about 14.5 will often give satisfactory performance, will pollute less, and will use less fuel.

AFX System Schematic



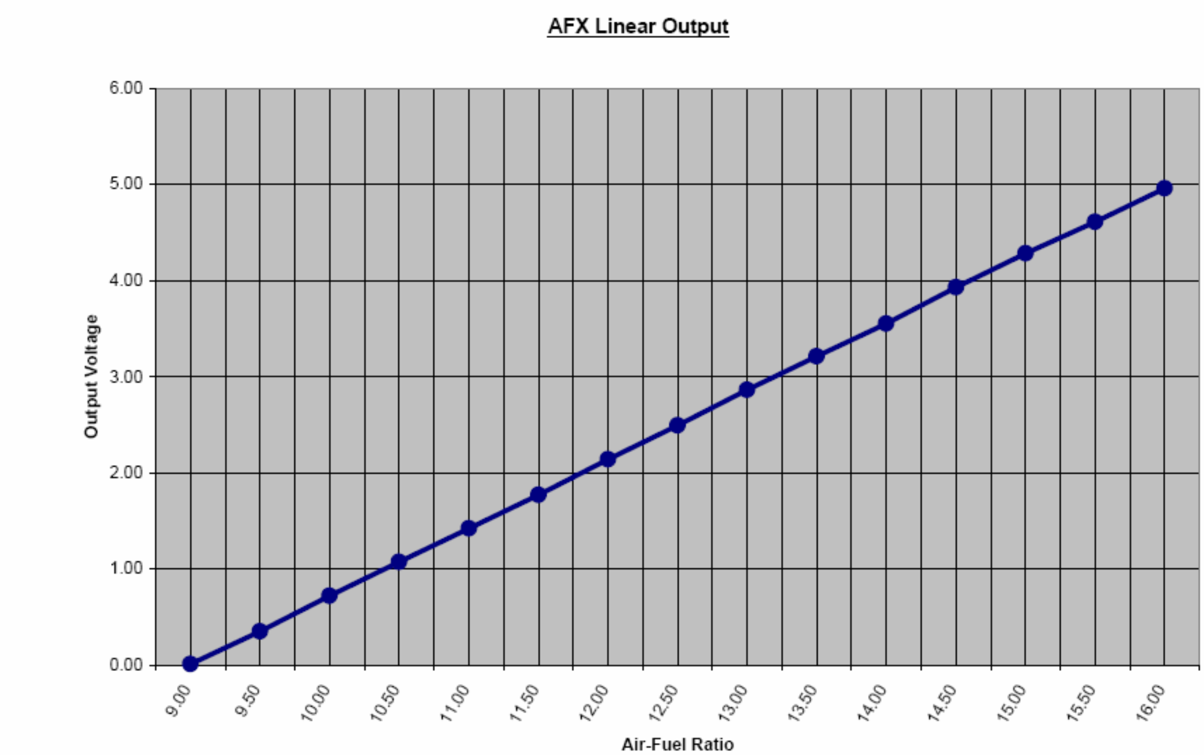
AFX Wiring Notes

1. The AFX considers the point where the two BLACK wires connect to their ground as the 0 (zero) volt reference point.
2. When utilizing the analog output feature of the AFX, always be sure to connect the system ground (two BLACK wires) to the same location as the analog SIGNAL GROUND (BROWN wire). The analog output wires (YELLOW, BROWN) may be lengthened as long as the appropriate gauge wire is used and the connection is solid.
3. It is advised to connect the BLACK wires directly to battery ground or as close to this point as possible. Do not extend the two BLACK wires using a single wire or else this can cause a shift in the ground level of the analog output SIGNAL GROUND (BROWN wire) and any device linked to the analog output (data acquisition or engine controller) will receive an incorrect signal.
4. The RED wire is for system power positive (+). It is acceptable to route this wire through a fuse and/or relay where needed. The wire may be lengthened as long as the appropriate gauge wire is used and the connection is solid.
5. The AFX requires approximately 3A for one minute at start-up and after that, requires less than 1.5A for continuous operation.
6. The AFX can operate on any DC supply voltage between 11V ~ 28V. If the power supply to the AFX drops below 11V for even a short time (i.e. during cranking), the AFX will reset itself. Maintain the supply voltage above 11V; above 13V is ideal.
7. If the AFX system constantly resets itself, the cause is most likely low supply voltage or excessive electrical noise from the ignition system. Use a strong battery and route the wiring harness and controller away from ignition components.

Analog Output

The AFX has a 0 ~ 5V, linear analog output for AFR that can be used as an input to an engine controller or data acquisition system. The analog output signal wire is YELLOW and is attached to terminal position 3 of the connector that plugs into the controller. The analog output ground wire is BROWN and is attached to terminal position 4 of the same connector. The output wires are each 12" long and are attached to the mesh sleeve. To access the wires, gently separate them from the mesh sleeve. An output of 0V means 9.00:1 AFR and an output of 5V means 16.00:1 AFR. When the sensor is in air, the analog output will be pinned at 5V (since the AFR of air is infinity).

Mathematically: **Gasoline AFR = (V_{OUT} x 1.4) + 9.**
V_{OUT} is the analog output voltage of the AFX (0V ~ 5V).



Compatible Fuels

The AFX is compatible with fuels other than gasoline. The AFX's display is designed to show AFR values based on a gasoline scale with 14.57:1 AFR as the stoichiometric ratio. The display will simply show AFR on a gasoline scale even though the fuel used may have different properties (stoichiometry for methanol is approximately 6.5:1). As long as you understand this, interpreting the values should be easy.

The same principle applies to other fuels such as ethanol, propane, CNG, LPG, etc. The display will simply read on a gasoline scale.

The AFX will also work with diesel fuel. However, due to the nature of diesel engines generally running lean by design, you may experience a problem with the limits of range with the AFX. The AFX has a lean limit of 16.00:1 AFR (or approximately 1.10 λ), and many diesel engines run leaner than this.

As long as the engine runs between the range of 9.00:1 ~ 16.00:1 AFR (or 0.62 to 1.10 λ), the AFX will work with almost any fuel type.

Conversion factors for the more commonly used fuels:
Gasoline AFR = (V_{OUT} x 1.4) + 9.
Methanol AFR = (V_{OUT} x 0.616) + 3.96

V_{OUT} is the analog output voltage of the AFX (0V ~ 5V).

Lambda (λ) is a universal unit of measurement for AFR regardless of fuel. A Lambda value of 1 = stoichiometry. Lambda is derived by dividing the actual AFR by the stoichiometric AFR for that specific fuel type. For example, stoichiometry for gasoline is 14.57:1 AFR. A gasoline engine running at 12.5:1 AFR would mean that it is at 0.86 Lambda (divide 12.5 by 14.57).

Lambda = (V_{OUT} x 0.096) + 0.62

Please note that the display on the AFX controller is fixed to read on a gasoline AFR scale. This does not mean that it will not work with other fuels such as methanol. The system still operates on a principle of Lambda, so it is relatively simple to interpret the display values and adapt it to any fuel type you choose.

Contact NGK Spark Plugs (U.S.A.), Inc. for additional information on this topic.

AFX Troubleshooting

- If you cannot calibrate the AFX or if the display shows "Sen#" ("#" is a trouble code number), you should:

1. Check if the sensor is attached
2. Check if the wiring harness is damaged
3. If steps 1. and 2. show no problems, replace the AFR sensor. It has reached its limit for useful life.
4. Contact NGK Spark Plugs (U.S.A.), Inc. for additional information on trouble codes.

- If the display shows "Bat_," the supply voltage is too low (below 11V).

- If the display shows "Bat¯," the supply voltage is too high (above 28V).

- If the display reads "9.00," the AFR is 9.00 or less.

- If the display reads "16.00," the AFR is 16.00 or more.

- When using the AFX on modern fuel injected engines, you may experience occasions where the controller display momentarily goes into calibration mode, where the display will briefly read "Air_," "Air¯," or "CAL-" during deceleration or upon releasing the throttle. This is normal operation and is caused by the fuel injection system cutting off fuel delivery to the engine during deceleration.

AFX Specifications

Product Name	Powerdex AFX Air-Fuel Ratio Monitor
Part #	91101
Function	Linear engine air-fuel ratio (AFR) monitor
Application	4-stroke cycle engines
Measurable AFR Range	9.00:1 ~ 16.00:1 AFR
	Equivalent to 0.62 ~ 1.10 λ (Lambda)
Dimensions	Controller dimensions (excluding protrusions): 86 x 67 x 32 mm
	Controller weight: 120g
	Wiring Harness length: Sensor side 13 ft. Power side 10 ft.
Supply Voltage	DC 11V ~ 28V
Sensor Tightening Torque	15 ~ 20 lb.-ft.
Controller Temperature Tolerance	-40º to 185º F (-40º to 85º C)
Maximum Exhaust Temperature	1650º F (900º C)
Compatible Fuel Types	Gasoline (leaded or unleaded), alcohol (methanol), ethanol, CNG, LPG, propane

AFX Kit Parts

For replacement parts, please contact your nearest AFX distributor.

Distributor Information, Technical Support

1-877-473-6767 Option 2

OR

www.ngksparkplugs.com

NGK Spark Plugs (U.S.A.), Inc.
46929 Magellan Dr.
Wixom, MI 48393

AFX Product Warranty

NGK Spark Plugs warrants that the products, which it sells to the distributor, seller, reseller, or customer, shall be free from defects in workmanship and materials within a period of sixty (60) days from the delivery thereof to the aforementioned parties. This does not apply to products that have been modified, altered, abused, damaged during transit, or subjected to conditions in excess of their intended environment. Due to the nature of the product, there is no warranty on AFR sensor life.

NGK Spark Plugs (U.S.A.), Inc. shall not be liable for any economic damages or losses resulting from the improper use of its products.

This warranty is valid only in the U.S.A.