FirstLook®

DIAGNOSTIC PULSE SENSORS

User's Guide for Diesel Engines

FirstLook® Automotive Engine Diagnostic Sensor
"The Pulse of Your Engine!"

Model ADS ES 100-D

from

SenX TECHNOLOGY

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Midland, MI 48640
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U.S. Patent No. 6,484,589
Made in the U.S.A.

Introduction

Congratulations on your purchase of the FirstLook® diesel engine diagnostic sensor.

This is your first step down a road of easier and more accurate engine diagnostics. The FirstLook® sensor will give you a picture of an engine's performance *while it is running*.

Tests can be set up and run within minutes of parking the vehicle. You simply attach the sensor to the exhaust pipe, the intake manifold and/or to the oil level indicator tube and run the test.

Once you have learned how to "read" the sensor displays, you will be able to find burnt valves, worn rings and other engine performance problems as quickly as you can run the tests.

When a customer says the engine is "acting funny", FirstLook® can help you identify the problem more quickly and complete the job in less time. This helps your bottom line and it can make a happier customer.

You can make FirstLook® part of your routine service work. Then, you can include engine performance when you review your service checklist with your customer:

"*We tested engine operation. Compression across cylinders, valves, rings all seemed to be working normally during the tests*." (Or not.)

You will find FirstLook® to be a valuable addition to your diagnostic tool kit.

Fleet operators will find FirstLook® particularly valuable. Individual diesel engine performance can be monitored and tracked over time. Fleet operators can then schedule engine maintenance when needed based on performance. This avoids costly unnecessary repairs based on engine hours and even more costly engine problems on the road.

Warranty

SenX Technology warranties the products described herein for a period of 1 year under normal use and service from the date of purchase, that the product will be free of defects in material and workmanship. This warranty does not cover ordinary wear and tear, abuse, misuse, overloading, altered products, or damage caused by the purchaser connecting the unit incorrectly.

THERE IS NO WARRANTY OF MERCHANTABILITY. THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION HEREIN. THERE ARE NO WARRANTIES EXPRESSED OR IMPLIED OR ANY AFFIRMATION OF FACT OR REPRESENTATION EXCEPT AS SET FORTH HEREIN.

REMEDY

SenX Technology sole responsibility and liability, and purchaser's exclusive remedy shall be limited to the repair or replacement at SenX Technology option, of a part or parts not conforming to the warranty. All products requiring warranty service shall be returned to SenX Technology within 1 year of purchase, shipping prepaid. SenX Technology will return repaired or replaced products to the purchaser via prepaid ground transportation. In no event shall SenX Technology be liable for damages of any nature, including incidental or consequential damages, including but not limited to any damages resulting from non-conformity, defect in material or workmanship.

Neither SenX Technology nor its affiliates shall be liable to the purchaser of this product or third parties for damages, losses, costs, or expenses incurred by the purchaser or third parties as a result of: accident, misuse, or abuse of this product or unauthorized modifications, repairs, or alterations to this product, or failure to strictly comply with SenX Technology's operating and maintenance instructions.

Table of Contents

Before You Start

Like living creatures, each cylinder of an internal combustion engine breathes in (intakes) and breathes out (exhausts) every cycle. The FirstLook® sensor measures these puffs of air, or air pulses, and displays the 'pulse signature' on your lab scope.

The Offset Diagrams in the Appendix illustrate when the different pulses are created during the firing cycle. The primary purpose of the offset diagrams is to explain how to relate exhaust and crankcase pulses to the same cylinder. Notice that these patterns differ depending on the type of engine and number of cylinders:

- The most common, the 4-stroke, has each cylinder go thru all four strokes (intake, compression, power, and exhaust) in two rotations (720°) of the crankcase.
- Two stroke engines are more common in military vehicles, in stationary equipment (electric generators, for example), and in heavy off-road vehicles. A 2-stroke engine has each cylinder fire during each rotation (360°) of the crankcase.

The main consideration in whether your engine is 2- or 4-stroke is to relate time between cylinders firing to the engine rpm. In 4-stroke engines, an n-cylinder engine has (720°/n) degrees between ignitions; whereas, a 2-stroke n-cylinder engine has (360°/n) degrees between ignitions. So, for a 6-cylinder engine, if 4-stroke, each cylinder fires every (720/6) = 120°; but at (360/6) = 60° in a 2-stroke.

Test Summary

This table shows the tests you may run with your FirstLook® sensor system and the purposes of each test.

Test Condition	**Exhaust**	**Crankcase**
Cold Crank	Use to check: relative compression between cylinders, possible piston blow by; exhaust valve train operation	Use to check: confirm piston blow by
Idle	Use to check: possible misfires; possible head gasket issues or piston blow by; relative compression between cylinders	Use to check: confirm piston blow by
Load (~1500 rpm)	Use to check: same as 'Idle" but for problems that show up under higher pressures or only intermittently	Use to check: confirm piston blow by

We recommend that you run both tests for a given test condition at the same time. For example, run both idle tests (Exhaust and Crankcase) at the same time. This requires two sensors and a 2-channel scope. If both the exhaust and crankcase are tested separately, there will no way to determine if one cylinder has both a 'blow-by' and a weak compression, or if the two observations are for different cylinders. (Even this information can be valuable!)

Basics of Reading Pulse Signatures

Reading pulse signatures is the key to finding and diagnosing engine problems. There are two basic things you need to know about reading pulse signatures:

1. You need to understand what pulse signatures mean.
2. You need to understand separating the pulse signal from the signal noise.

SenX recommends you practice using the sensor by running tests on engines without problems. This will help you learn how to separate pulse signals from the noise and learn how to identify pulses by cylinder. It will also give you a feel for how much pulse deviation is 'OK.' You may even consider creating engine problems just to see what they do to the pulse signatures.

1. Basic Pulse Signature Analysis

The pulses in the pulse signatures for a perfect engine will be very uniform. They will all have the same general size, shape and spacing. You are looking for deviations in the pulses that indicate engine problems.

There are very few perfect engines. Expect to see *some* deviation in the pulses. So, look for non-uniform pulse signatures and LARGE pulse deviations. Accept some pulse deviations and ignore the noise. Especially pay attention to non-uniform patterns and pulses that repeat from cycle to cycle.

Take a minute here to review the example pulses and reference pulse signatures in the Appendix. Remember, pulses can be either positive (peaks) or negative (valleys). The table below describes the two most common pulse deviations and some of the possible causes.

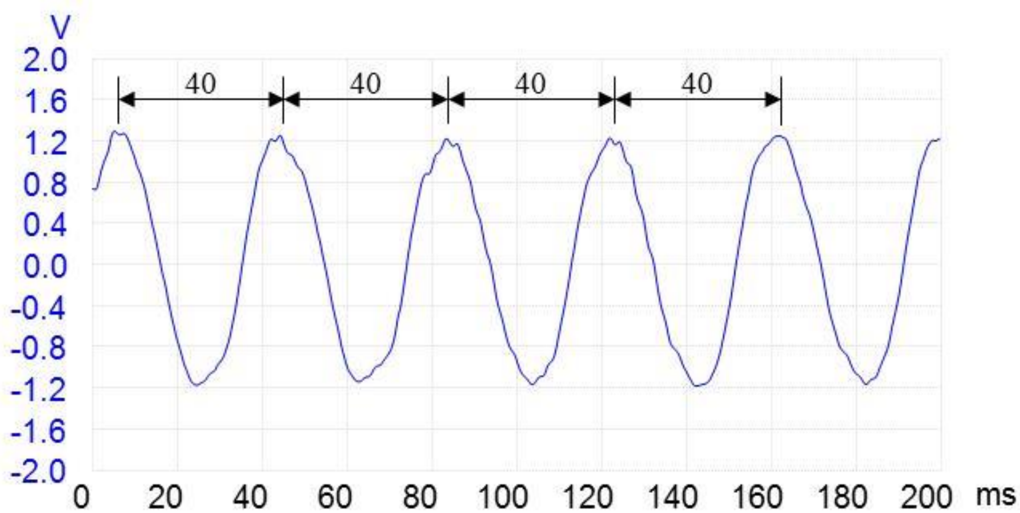
	Exhaust Tests	**Crankcase Tests**
undersize or missing pulses	possible misfire possible head or head gasket issue possible piston blow by	very little compression very tight rings
oversize pulses	probable excess fuel possible head or head gasket issue possibly intentional extra fuel to heat up the catalytic converter	probable piston blow by

1. Basic Pulse Signature Analysis (continued)

You can also see timing problems from deviations in the pulse signatures. The time between pulses should be the same for all cylinders. When the pulse signature is clean, with little noise, you may also be able to see and measure the time between valve openings and closings.

To see timing issues, use your cursor to measure the time between common points on the pulses. You have timing problems when the pulses are not equally spaced. You can use the ES 100 Timing Charts in the Appendix and the time between cylinders to estimate the engine rpm. Notice that there is one timing chart for 4-stroke engines and another for the less common 2-stroke engines.

This is an exhaust pulse signature for a 4-cylinder engine (4-stroke). The time between peaks is about 40 ms.



Using the Timing chart for 4-stroke engines, find the column for the number of cylinders and read down the column until you find the measured time between pulses. Next, read this row across to the left to the Engine RPM column to see the engine RPM.

In this example, find the column for 4-cylinder engines in the Timing Chart and read down the column to 40ms. Now, follow this row across to the left and read the engine RPM in the first column, 750 rpm.

Of course, you *could* calculate the exact engine rpm for the pulse signature displayed:

> Engine rpm = 120,000 / [(# of cylinders) x (the time between pulses in ms)] for 4-stroke engines.
>
> More generally,
> Engine rpm = 30,000 x (#strokes) / [(# of cylinders) x (the time between pulses in ms)] for 2- or 4-stroke engines.

It is generally easier to estimate the rpm using the Timing Chart.

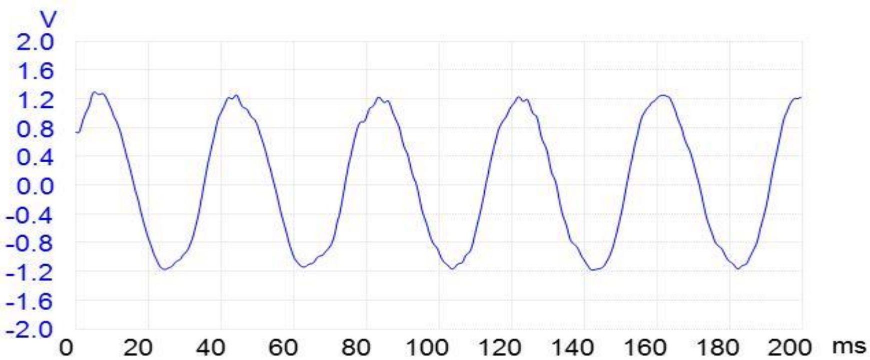
2. Signal and Signal Noise

Generally, it is best to step back and look at the 'big picture' when reading pulse signatures. Air pulses flow smoothly through some engines. In other engines, they seem to ricochet and echo off every elbow and sidewall they can find. This causes signal noise, and you need to ignore it.

The one exception is when you are looking at valve action. At first, valve issues may look like signal noise to you. With experience, you will learn you *can* pick out valve chatter from the background noise. Valve signals will just look different.

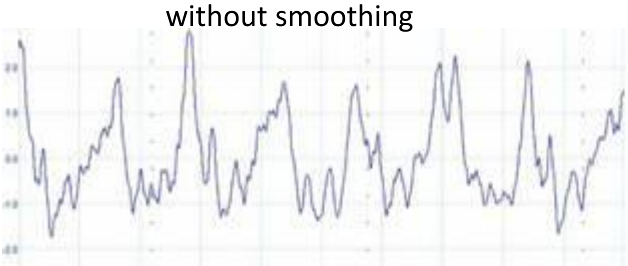
You may consider reducing the noise in Exhaust Test pulse signatures with the vacuum line adapter as described in 'Sensor Set Up for Exhaust Tests.' This, however, can smooth out and hide valve issues.

These exhaust pulse signatures illustrate smooth flow, noisy flow, and noisy flow smoothed by using the vacuum line adapter.



This is a well-running 4-cylinder engine with very smooth exhaust airflow. The uniformity of the pulses suggests the relative compression across the cylinders is also uniform.

without smoothing



with smoothing

These pulse signatures are both from the same 6-cylinder engine and show the effect of using the vacuum line adapter for smoothing. The engine is running reasonably well. The pulse signature is fairly uniform and the pulses are fairly close in size.

Test Plans

There are three very different reasons to obtain your engine's signatures and to analyze them. Your goal for each use suggests a variation on the sequence and which tests you might want to perform.

1. **Diagnosis:**

Mechanics will usually use the FirstLook® sensors to help diagnose an engine that is not running 'right'. The FirstLook® sensor is used in conjunction with the vehicle's OBDII. Begin by reviewing the stored codes in the OBDII and then use FirstLook® to zero in on the problems. As experienced mechanics know, the OBD codes are set assuming that the engine has 'mechanical integrity'; i.e., the pistons, rings, valves, and gaskets are all in 'good shape' – not compromised. **To avoid the time-consuming process of relying only on the OBD codes and, too often, replacing a number of expensive parts to no avail (and irritated customers),** use the described **'Diagnostic Test Plan'** and **'Test Analysis'** described in this document to first confirm mechanical integrity or identify the real problem. With experience, you will develop your own preferred testing strategies. Until then, below is a quick and easy test plan.

2. **Assessment:**

There are times when you want to see if an engine, even if running 'well', might have some mechanical integrity issues. Perhaps you are a buyer for a used-truck lot and want to buy only vehicles that can be warranted to be in good shape - or offer a price commensurate with the compromised components. Or you may want to sell a vehicle with proof that the engine does have mechanical integrity, commanding appropriate price.

Other times you might want to assess the engine's integrity include before you return a vehicle that you have just overhauled/rebuilt to verify that the job was done correctly; or before you send the equipment on an extended mission (beginning of a harvest season, long trip, rent the unit out for use, etc.). Likewise, you might want to verify that the engine returned from a long job or rental is in good condition before you complete the transaction.

3. **Capture for Predictive Analysis:**

A third type of use of FirstLook® sensors is to capture the signatures of an engine and keep a file over time for each engine to watch for changes. With experience, the normal wear with use can be compared against signatures of vehicles that experience faster than normal deterioration/wear of the components to alert you to pending problems to help in 'culling' decisions. You will want to look at and record these signatures after each oil change.

Diagnostic Test Plans:

A diagnostic plan implies that you are aware that the engine has an issue (an OBD code has been 'tripped') and the goal then is to determine if the engine has mechanical integrity, or not. To determine if the engine has mechanical integrity, perform all the tests described below, in the sequence presented:

1. Cold-crank Tests
2. 'Hot' Tests
    a. Idle Tests (Exhaust and Crankcase)
    b. Load Tests (Exhaust and Crankcase)

When analyzing a diesel engine for repair, as with doing anything, it is best to start with step 1. In this case, step 1 is Test 1, the Diesel Cold-crank Test. This tests both the exhaust and crankcase pulses at the same time. Since the fuel system is disabled, the engine is not firing. Only mechanical problems with pistons, rings, valves, heads and head gaskets will show in this test. Use the **Cold-crank Signature Observations vs. Probable Cause Table** to identify possible problems with the engine.

If everything looks fine in Test 1, then proceed to Test 2, the Diesel Hot Test. This is the same as Test 1 except it tests the engine while it is running. Test 2 is a two-part test. First, run Test 2 at idle and then run it at Load. (By "Load", we mean about 1500 rpm.) Increasing the load on the engine can reveal engine problems that do not show at idle. This test will show both mechanical problems and firing problems in engine. However, Test 1 has ruled out mechanical problems, and it is safe to say problems appearing here are fuel system and combustion problems. Use the Diesel Test Analysis Table to identify possible problems with the engine, but only look at firing issues.

If the engine has mechanical integrity, you will want to proceed with the recommendations of the manufacturer based on the OBD codes. Otherwise, you will want to use the **Diesel Test Analysis** (page 27, ff.) of the signatures captured to pin down the probable cause(s).

Assessment Test Plan:

If your goal is to determine if an engine has a significant issue, mechanical or otherwise, you will want to only run the 'hot' engine tests:

1. Idle Tests (Exhaust and Crankcase), and
2. Load Tests (Exhaust and Crankcase)

In this case, it is expected that the engine 'check light' is not on when the engine is running (and that the bulb works correctly during the engine-start process). You will want to use the **Diesel Test Analysis** (later in this document) of the signatures captured to verify that the engine is working properly. If you find issues, you might later decide to repair the engine; if so, then refer to the Diesel Engine Diagnosis section above. If you think repair is a possibility, consider saving the pulse signatures from the Assessment Tests. Then you will not need to repeat step 2 during engine diagnosis.

AVOID costly, unnecessary teardowns by running both tests before starting repair work. Know what needs to be fixed before you start. If you have no OBD code on, the issue is very likely to be mechanical integrity!

Capture Plan for Predictive Analysis

If this is a routine data capture to establish the condition of the engine at a point in time for (later) time-series analysis, you will want to store and catalogue the test results in a database with appropriate identifiers so that all signature tests on this engine over time can be recalled and analyzed together – probably by someone else. Use the spreadsheet, **Signature Log** shown on page 20 & 21. As suggested earlier, this might be done at oil-change intervals. Alternatively, you may use the SenX History Manager (SHM) to store the signatures for later search, retrieval and comparison over time. (See www.senxhistorymanager.com.) The tests to run and save are only the 'hot' engine tests:

1. Idle Tests (Exhaust and Crankcase), and
2. Load Tests (Exhaust and Crankcase)

Test Equipment Setup

Test Equipment Required

You will need the following equipment to run these diagnostic tests:

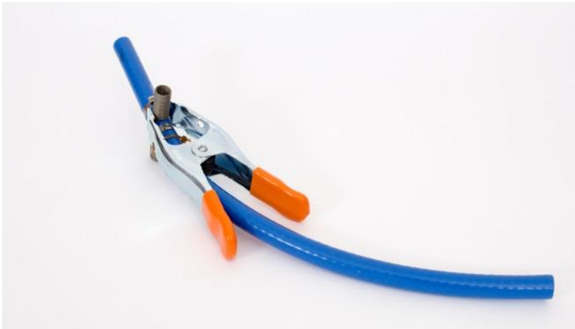
A FirstLook® Diesel Sensor Kit containing: (pictured below)

1. Two threaded FirstLook® Model ADS ES 100 Diagnostic Sensors
2. One silicone rubber exhaust pipe hose with clamp
3. One oil dipstick tube adapter set
4. One 25-foot male BNC to male BNC cable
5. One 15-foot male BNC to male BNC cable
6. One BNC to BNC adapter
7. One “**User’s Guide for Diesel Engines**”
8. Male BNC to Banana Jack Plug with 6' rg58 cable (not shown)
9. Female BNC/BNC Connector (not shown)

You will also need:

1. A SenX diesel shepherd’s hook exhaust collector (shown on next page)
2. A 2-channel (minimum) lab scope
3. Fuse puller to help remove fuel pump fuse for cold crank tests

Kit Contents

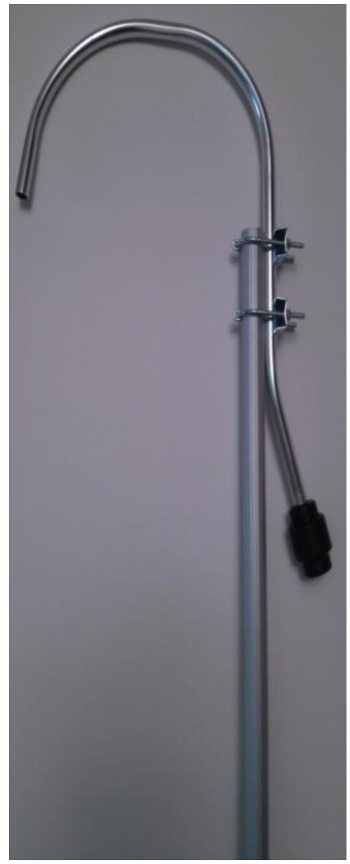


Diesel exhaust hose collector with clamp (above)

Above: Threaded adapter and hose for sampling the crankcase through a typical 3/8” oil dipstick tube.

Below: Oil dipstick tube crankcase adapter (3-sizes for some large trucks and military vehicles with tubes of I.D.):

- 15/16” on right in picture above)
- 1” on left-most section, and
- 1 ¼ centermost section



Shepherds hook exhaust collector with telescopic pole for vertical exhausts

The FirstLook® sensors have a threaded nipple to screw into the silicone rubber hose or into one of the attachments or the Shepherd’s hook. Normally, one sensor is used to test the exhaust pulses and the other will be used for the crankcase through the oil dipstick tube.

Equipment Handling and Care

Your FirstLook® sensor is mounted inside a rigid plastic housing. While reasonably sturdy, use standard care when handling the sensor so as to not crack or break the housing.

The threads on the sensors make it easy to attach the sensors, or remove them, from the various attachments: the exhaust pipe hose, the two crankcase oil dipstick tube adapters, and the shepherd's hook vertical exhaust collector. To avoid causing damage or possible personal injury when changing hoses, grasp them near the open ends that attach to the sensor and **rotate the sensor to attach or remove** them.

Use standard care with the connector cables. Avoid driving or standing on them. Avoid kinking them during use and when coiling for storage.

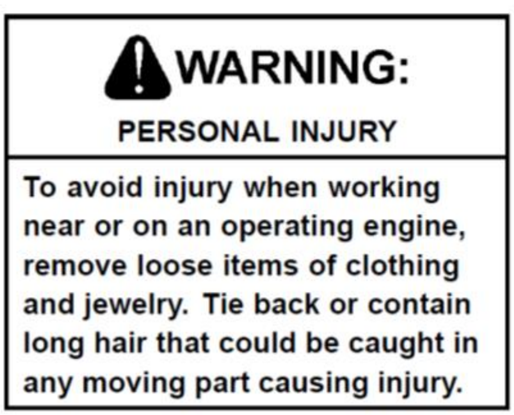
During use in Exhaust Tests, moisture in the exhaust air can condense inside the pulse sensor and exhaust hose. When done with Exhaust tests, store the pulse sensor and exhaust hose so that water can drain out.

ALLOW THE PULSE SENSOR TO AIR DRY NATURALLY! Using an air hose to blow out the sensor can damage it beyond repair.

WARNING: Exhaust gases are hot so handle the sensor apparatus with care, touching rubber parts or parts not directly exposed to the exhaust, wipe off the parts inserted into the exhaust only after they have cooled.

Use gloves while inserting and removing the exhaust hose with clamp (for horizontal exhausts).

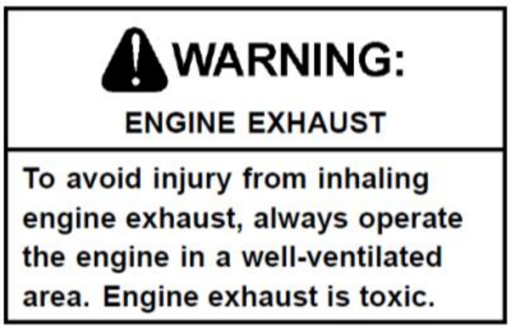
You will be working around engines running at various speeds so **be aware of long hair and clothing hazards**!



Prepare Vehicle / Engine for Testing

WARNING: Be sure to use wheel chocks to block the vehicle from rolling when the engine is running and the brakes are off!

IMPORTANT: The signatures of diesel engines change quite a bit between cold temperature and operating temperature. Warm the engine to above 150˚F to assure that the oil is flowing normally and that metal parts have expanded to be near normal operating conditions.



IMPORTANT: Many diesel engines have computer control modules to optimize the engine performance, especially at idle. The control module will intentionally not provide fuel to random cylinders, causing false misfires. Use your Owner's Manual for the manufacturer's procedures to start the engine in a way that the computer-controlled optimization is turned off. On many vehicles, this is done by starting the engine with the brakes off. **USE WHEEL CHOCKS!**

Use the manufacturer's procedure to capture the odometer mileage for documentation of the vehicle condition at the time of the test. Often, this requires turning the lights on before cranking the engine with the starter.

Keep the fan either OFF or ON during the test. Do not allow it to change while you are taking a pulse signature. The power requirements to run the fan may cause the pulses to change as it cuts in or out.

The turbocharger should not present any problem during the test since there should be no load on the engine to cause it to engage. [If the sensor is employed while the vehicle is pulling a load on the road, the additional airflow provided by the turbocharger would change pulse sizes or shapes in a pulse signature. This can lead to a misdiagnosis of engine problems.]

Sensor Set Up for Exhaust Tests

To install the sensor in the exhaust:

1. Push the rubber exhaust pipe hose onto the sensor.
2. Select the correct sensor cable for your scope and attach the cable to the sensor.
3. Insert the sensor exhaust pipe hose about 4 inches into the exhaust pipe.
4. Use either the clamp or the springs on the hose to secure the sensor hose in the exhaust pipe. The clamp can be attached directly to the end of the exhaust pipe. The springs may be bent so they fit inside the exhaust pipe to hold the sensor hose in place.

   Note: When using a shepherd's hook exhaust collector, attach the sensor to the collector and simply hang the shepherd's hook in exhaust pipe.

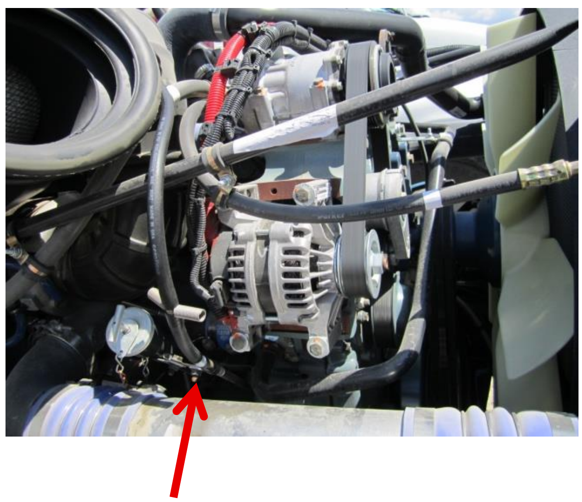
5. Attach the sensor cable to your scope.

Shepherd's hook exhaust sensor on telescopic pole inserted into the vertical exhaust.

Sensor Set Up for Crankcase Tests

To install the sensor in the crankcase:

1. Push the rubber exhaust pipe hose onto the sensor.
2. Select the correct sensor cable for your scope and attach the cable to the sensor.
3. Remove the oil level indicator stick.
4. Insert the sensor exhaust pipe hose into the oil level indicator tube. If the sensor exhaust pipe hose does not fit inside oil level indicator tube, pull it off the sensor. Push the vacuum adapter hose onto the sensor and insert the adapter into the oil level indicator tube. **Note**: Some engines will generate error codes if the oil level indicator tube is not sealed sufficiently. An insufficient seal may also cause a misdiagnosis in the test.
5. Attach the sensor cable to your scope.



Crankcase sensor hose with dipstick adapter inserted into the dipstick tube.

Lab Scope Set Up

Scope Voltage and Time Scales
Set the scope voltage scale to display pulses for easy viewing. Set the time scale so at least one entire firing cycle is displayed on the screen. This means at least six pulses for a 6-cylinder engine or at least eight pulses for an 8-cylinder engine are displayed. Once you have looked at a single firing cycle, adjust the time scale to display two or three firing cycles at the same time to look for repeating patterns. Use a sample rate of 10k Hertz (readings per second).

Use the following settings as starting points and adjust as needed.

Test Condition		**Starting Voltage**	**Starting Time Scale**
Cold-crank Tests		2v AC	1000ms, full scale
Idle Tests		5v AC	300ms, full scale
Load Tests		10v AC	100ms, full scale

Data Capture and Storage for Later Reference

In a busy shop, it is important to keep track of the signatures captured for 'second looks' and comparison for a quality check after repairs have been completed. Most PC oscilloscopes allow you to save the data captured in a file with a default name consisting of date and a sequence number, but also allow you to provide a file name in a directory of your choice. This approach is fine unless there are several PCs with oscilloscopes such that the sequence numbers might be repeated in one day on more than one PC. One can alternatively use the web-based SenX History Manager (SHM) application, www.senxhistorymanager.com, to store the information about a signature and the signature itself for future reference to study the change in the signatures from an engine over time, watching wear and degradation take its toll.

Data that may be important are:

1. Date of the tests being conducted
2. Name of the mechanic doing the tests
3. PC identification and Directory name holding the file

For each test:

4. File sequence number (Seq#)
5. Vehicle identification: either a number assigned to the vehicle when it was brought in, or perhaps the license plate "number"

Engine data:

6. Engine configuration: {In = straight line (in-line), Vn = 2 banks of cylinders, …}, where n = number of cylinders in the engine
7. Number of strokes between cylinder firings (4 usually, or 2 in special engines)
8. Manufacturer: {Detroit™, Paccar, Cummins, Navistar, etc.}
9. Displacement: {CID = cubic inch displacement; cc = cubic cm.; l = liters}
10. Odometer reading in miles or km

Signature data:

11. Engine temperature (°F)
12. Condition: {c-c = cold crank; idle; Load = approximately 1500 rpm}
13. RPM = revolutions per minute from tachometer
14. Scope channel: (for up to 4 channels) {ex = exhaust; in = intake manifold; oil = oil level indicator tube; none = no sensor attached}

We include a sample spreadsheet for you to record your tests on the following page. You may download the spreadsheet from our web site at www.senxtech.com.

SenX History Manager:

An alternative is to subscribe to the web application, SenX History Manager, to store, index, and retrieve your signatures. You can find the application at www.senxhistorymanager.com.

SenX FirstLook® Signature Log

Date (yyyymmdd)	Mechanic	PC + Directory

Seq#	Vehicle	Config./cyls	Stroke	Mfg	Displ.	Odometer	Engine Temp	Condition	RPM	Scope Channel A	Scope Channel B	Scope Channel C	Scope Channel D
nnnnn, or filename	Id# or plates	{I6, V8, ..}	4 (or rarely, 2)	{Detroit, Cummins, Ford, , ...}	{CID, cc, l}	{mi, km}	(°F, C))	{c-c, idle, 1500rpm}	nnnn	{ex, in, oil, trig, none}			

Cold-crank Exhaust Test

Follow the manufacturer's procedure to perform a cold-crank test – or you risk 'throwing a code'! (For many vehicles, removal of the fuel pump fuse is an efficient approach.)

To run this test:

1. Place the pulse sensor in the exhaust pipe and connect it to your scope.
2. Set the time base scale on your scope to 1000ms.
3. Set the voltage scale to 2v AC.
4. **DISABLE the FUEL SYSTEM.** See the Owner's Manual for the correct way to do this.
5. Make sure the fan is set to either OFF or ON. Again, see the Owner's Manual for the correct way to do this.
6. Make sure all cables, hoses fingers, hands, hair and loose clothing are secure and clear of moving or rotating parts before starting the test.
7. Crank the engine until the display pattern stabilizes.
8. Adjust the voltage scale as needed for viewing pulses.
9. Adjust the time base as needed to display both a single firing cycle and then to display several firing cycles.
10. Freeze or Save the patterns.
11. Remember to re-enable the fuel system and fan when the test is done.

Cold-crank Crankcase Test

Follow the manufacturer's procedure to perform a cold-crank test – or you risk 'throwing a code'! (For many vehicles, removal of the fuel pump fuse is an efficient approach.)

To run this test:

1. Place the pulse sensor in the oil level indicator tube and connect it to your scope.
2. Set the time base scale on your scope to 1000ms.
3. Set the voltage scale to 2v AC.
4. **DISABLE the FUEL SYSTEM.** See the Owner's Manual for the correct way to do this.
5. Make sure the fan is set to either OFF or ON. Again, see the Owner's Manual for the correct way to do this.
6. Make sure all cables, hoses fingers, hands, hair and loose clothing are secure and clear of moving or rotating parts before starting the test.
7. Crank the engine until the display pattern stabilizes.
8. Adjust the voltage scale as needed for viewing pulses.
9. Adjust the time base as needed to display both a single firing cycle and then to display several firing cycles.
10. Freeze or Save the patterns.
11. Remember to replace the oil level indicator stick and re-enable the fuel system and fan when the test is done.

Idle Exhaust Test

To run this test:

1. Start the engine and allow it to warm up. When warm, shut it down.
2. Place the pulse sensor in the exhaust pipe and connect it to your scope.
3. Set the time base scale on your scope to 300ms.
4. Set the voltage scale to 5v AC.
5. Make sure all cables, hoses, fingers and hands, hair and loose clothing are secure and clear of moving or rotating parts before starting the test.
6. Make sure the computer-controlled optimization is disabled. See the Owner's Manual for the correct way to do this.
7. Make sure the fan is set to either OFF or ON. Again, see the Owner's Manual for the correct way to do this.
8. Start the engine and allow the idle and the pulse display pattern to stabilize.
9. Adjust the voltage scale as needed for viewing pulses.
10. Adjust the time base as needed to display both a single firing cycle and then to display several firing cycles.
11. Freeze or Save the patterns.
12. Remember to re-enable the computer-controlled optimization and the fan when the test is done.

Idle Crankcase Test

To run this test:

1. Start the engine and allow it to warm up. When warm, shut it down.
2. Place the pulse sensor in the oil level indicator tube and connect it to your scope.
3. Set the time base scale on your scope to 300ms.
4. Set the voltage scale to 5v AC.
5. Make sure all lines, hoses, fingers and hands, hair and loose clothing are secure and clear of moving or rotating parts before starting the test.
6. Make sure the computer-controlled optimization is disabled. See the Owner's Manual for the correct way to do this.
7. Make sure the fan is set to either OFF or ON. Again, see the Owner's Manual for the correct way to do this.
8. Start the engine and allow the idle and the pulse display pattern to stabilize.
9. Adjust the voltage scale as needed for viewing pulses.
10. Adjust the time base as needed to display both a single firing cycle and then to display several firing cycles.
11. Freeze or Save the patterns.
12. Remember to replace the oil level indicator stick when the test is done.
13. Remember to re-enable the computer-controlled optimization and the fan.

Load Exhaust Test

Important Safety Note: Run this test only when the vehicle is on a hoist, or the wheels are blocked, and with two people. One person runs the diagnostic equipment outside the vehicle while the other person operates the vehicle.

To run this test:

1. Start the engine and allow it to warm up. When warm, shut it down.
2. Place the pulse sensor in the exhaust pipe and connect it to your scope.
3. Set the time base scale on your scope to 100ms.
4. Set the voltage scale to 10v AC.
5. Make sure all cables, hoses, fingers and hands, hair and loose clothing are secure and clear of moving or rotating parts before starting the test.
6. Lift the vehicle until the wheels are suspended in the air, or place chocks on the wheels.
7. Make sure the computer-controlled optimization is disabled. See the Owner's Manual for the correct way to do this.
8. Make sure the fan is set to either OFF or ON. Again, see the Owner's Manual for the correct way to do this.
9. Start the engine and allow the idle and the pulse display pattern to stabilize.
10. Press the accelerator and run the engine to about 1500 rpm and hold. Do NOT go over 1600 rpm.
11. Adjust the voltage scale as needed for viewing pulses.
12. Adjust the time base as needed to display both a single firing cycle and then to display several firing cycles.
13. Watch for and Freeze or Save pulse deviation patterns.
14. Return engine to idle and place the transmission in PARK.
15. Remember to re-enable computer-controlled optimization and the fan.

Load Crankcase Test

<u>Important Safety Note</u>: Run this test only when the vehicle is on a hoist, or the wheels are blocked, and with two people. One person runs the diagnostic equipment outside the vehicle while the other person operates the vehicle.

To run this test:

1. Start the engine and allow it to warm up. When warm, shut it down.
2. Place the pulse sensor in the oil level indicator tube and connect it to your scope.
3. Set the time base scale on your scope to 100ms.
4. Set the voltage scale to 10v AC.
5. Make sure all lines, hoses, fingers and hands, hair and loose clothing are secure and clear of moving or rotating parts before starting the test.
6. Lift the vehicle until the wheels are suspended in the air, or place chocks on the wheels.
7. Make sure the computer-controlled optimization is disabled. See the Owner's Manual for the correct way to do this.
8. Make sure the fan is set to either OFF or ON. Again, see the Owner's Manual for the correct way to do this.
9. Start the engine and allow the idle and the pulse display pattern to stabilize.
10. Press the accelerator and run the engine to about 1500 rpm and hold. Do NOT go over 1600 rpm.
11. Adjust the voltage scale as needed for viewing pulses.
12. Adjust the time base as needed to display both a single firing cycle and then to display several firing cycles.
13. Watch for and Freeze or Save pulse deviation patterns.
14. Return the engine to idle and place the transmission in PARK.
15. Remember to replace the oil level indicator stick when the test is done.
16. Remember to re-enable the computer-controlled optimization and the fan.

Diesel Symptoms-Causes Analysis Tables

Each signature is to be reviewed to identify various features indicating probable causes. In the methodology described here, the symptoms are listed in two tables: one for cold-crank conditions and the other for the hot conditions (Idle and Load). When the symptoms for an exhaust signature match a row in the table, a probable cause can be read off. For a **diagnosis**, it is important to review the cold-crank signatures first, then the hot signatures, placing more faith in the observation of the Load signature.

Analyzing the test results is almost as simple as running the tests. Use the Diesel Symptoms-Causes Analysis Tables to identify possible causes.

Look at exhaust pulses first since they will identify more potential problems. Then look at the corresponding crankcase pulses to complete the analysis.

Before using the table it is important to understand how to identify the corresponding crankcase pulse. This is easily understood by knowing how the exhaust pulses and crankcase pulses are aligned.

The exhaust pulse is created during the upward stroke of the piston immediately after the power stroke. So, the corresponding crankcase pulse for a given cylinder is the pulse immediately before the exhaust pulse from that cylinder. This is illustrated in the example signatures below. See 'Offset Diagrams' in the Appendix for a more detailed explanation.

Cold-crank Signature Observations vs. Probable Cause

Exhaust	Crankcase - two strokes before	Cause\Symptom
uniform pulses	uniform pulses	clean cold-crank
jagged, weak pulse	normal/weak pulse	valves not seated (new engine?)
missing pulse	normal/weak pulse	broken valve or valve rocker or pushrod
normal pulse	jagged pulse	rings not seated (new engine?)
normal or weak pulse	weak and/or jagged pulse	carboned/dirty rings
weak pulse	huge pulse in compression and/or 'power' strokes of cyl with weak pulse	very bad rings/ piston
weak pulse	normal or weak pulse	dirty valve (intake or exhaust)
weak pulse	normal or weak pulse	gasket failure to outside or cooling system
similar weak pulses in two adjacent cyls	normal or weak pulse	gasket failure between adjacent cylinders

Hot Signature Observations vs. Probable Cause

Exhaust	Crankcase - previous stroke	Cause\Symptom
reasonably uniform pulses	reasonably uniform pulses	clean hot test
jagged pulse at top or bottom	normal pulse/ undersize pulse	dirty valve
missing pulse	undersize pulse	pluged injector
missing pulse followed by oversize pulse	undersize pulse	ignition did not occur followed by burn of fuel in exhaust manifold
oversize pulse	normal/ slightly larger pulse	excess fuel - fat burn
undersize or no signal (but uniform)	normal pulse	hole in exhaust system
undersize pulse	big pulse	carboned/dirty rings
undersize pulse	huge pulse	broken rings/piston
undersize pulse	normal/ undersize pulse	dirty injector
undersize pulse	normal/ undersize pulse	gasket to outside or cooling system
undersize pulses in two physically adjacent cylinders	normal/ undersize pulses for same cyls	gasket between adjacent cylinders
undersize pulses (but uniform)	normal pulse	very large exhaust port

Using the Diesel Symptoms-Causes Analysis Table

When the pulses appear uniform for both the exhaust pulses and the crankcase pulses, the engine is in good shape. Trust your OBD codes if the check engine light is on; otherwise, there are no observed issues with this engine.

Exhaust Pulses

A missing or undersized exhaust pulse may be either MECHANICAL or a MISFIRE. During a cold-crank test, ONLY mechanical causes are possible.

If it is mechanical, the exhaust air went somewhere else, not out the exhaust system:

- Piston blow by
- Valve blow-by
- Head or head gasket leak
- Exhaust leak

If it is a misfire (hot test), look for:

- Insufficient or no fuel
- Low compression, would not ignite
- Incorrect fuel injection atomization
- Incorrect fuel injection timing

A single oversize exhaust pulse indicates a FAT BURN, and is caused by:

- Excess fuel

A missing or undersized exhaust pulse followed by an oversized exhaust pulse shows a MISFIRE followed by a FAT BURN.

- Fuel delivered to the cylinder did not ignite until in the exhaust of the following cylinder

A jagged or rough outline on the exhaust pulse is an indication of:

- Dirty or sticky exhaust valves
- Some other exhaust valve train issue

Crankcase Pulses

A missing or undersize crankcase pulse means less air than expected entered the crankcase during the combustion (or in the case of a cold-crank test, compression,) stroke:

- (hot test) possible valve or gasket leakage during **combustion**, less blow by than expected
- (cold crank test) possible valve or gasket leakage during **compression**, less blow by than expected
- (hot test) possible misfire, less blow by than expected

An oversize crankcase pulse means extra air entered the crankcase. Look for:

- (hot test) possible piston blow by, cylinder air went past the piston into the crankcase
- (cold crank test) possible piston blow by, cylinder air went past the piston into the crankcase

Diesel Engine Test Analysis Example 1

Recalling that there are various reasons for running the FirstLook® Tests, we walk through the analyses of the results in a similar sequence. The first set of tests described earlier were for Engine Diagnosis under evidence that the engine has issues/problems. We then will discuss the 'Hot Engine' analyses when the intent is only to determine if the engine is running well, but that specific diagnosis is not of interest. (In the case that you determine that the engine does have problems, you might want to go through the diagnosis analysis next.) Last, we will discuss the considerations for looking at a series of signatures for a single engine over time (years/many miles).

I. Diesel Test Analysis for Diagnostics

After the tests have been completed, the files produced by the oscilloscope can be analyzed for determination if the OBD codes should be trusted (if any codes have been tripped.) We will consider a set of signatures from a new (fewer than 100 miles on the engine) DD Series 60 engine, an inline 6 cylinder (4-stroke) engine. The firing sequence for this engine is 1-5-3-6-2-4. We are not diagnosing this engine for any reason except to demonstrate the analysis - there was no OBD code nor other symptoms of concern.

1. First consider the results of the Cold-crank Signatures

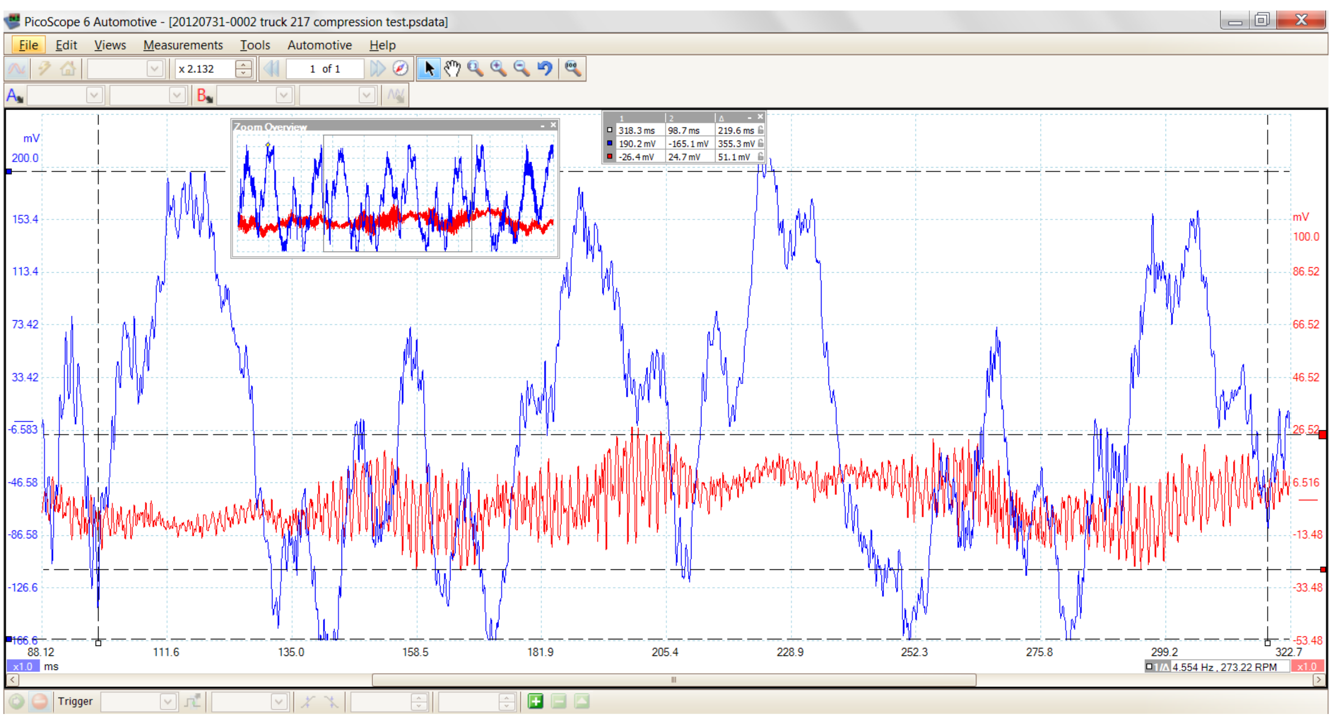
Start with the Cold-crank Test for the exhaust and the crankcase. The exhaust test is a quick test of *relative* compression across all cylinders. There are no misfires in this test because the engine is not firing. A rough or irregular exhaust pulse outline may indicate an exhaust-valve train issue or a head gasket issue. Exhaust gas pulses that are significantly smaller, or different from the others, either did not create adequate compression (valve issue) or the good compression went somewhere else, not through the exhaust system (head gasket or rings/pistons).

The crankcase signature, if recorded simultaneously, shows what is going on – on the other side of the pistons. It is important to realize that the exhaust pulse is generated in the stroke following the 'power' stroke. So, any blow-by from the high pressures associated with the two strokes of the cycle shows on the two strokes prior to the corresponding exhaust pulse – one for its compression stroke and then also from the power stroke. (See the Offset Diagrams in the Appendix.) Significant pulse differences in the crankcase signature represents blow-by when the pressure in the cylinder is higher than normal – during the compression AND power stroke in a cold-crank test and during the power stroke in a hot (running) engine.

Let us review our example. First, let's look at the oscilloscope output. We use the software to select a timeframe to look at in detail. The small window "Zoom Overview" has a movable and expandable box to control the timeframe shown in the larger window. We need to select a timeframe to include at least all 6 cylinders. As suggested in the Cold-crank Test procedure, we have used channel A (the blue curves) to display the exhaust pulses and channel B (red) to display the crankcase pulses.

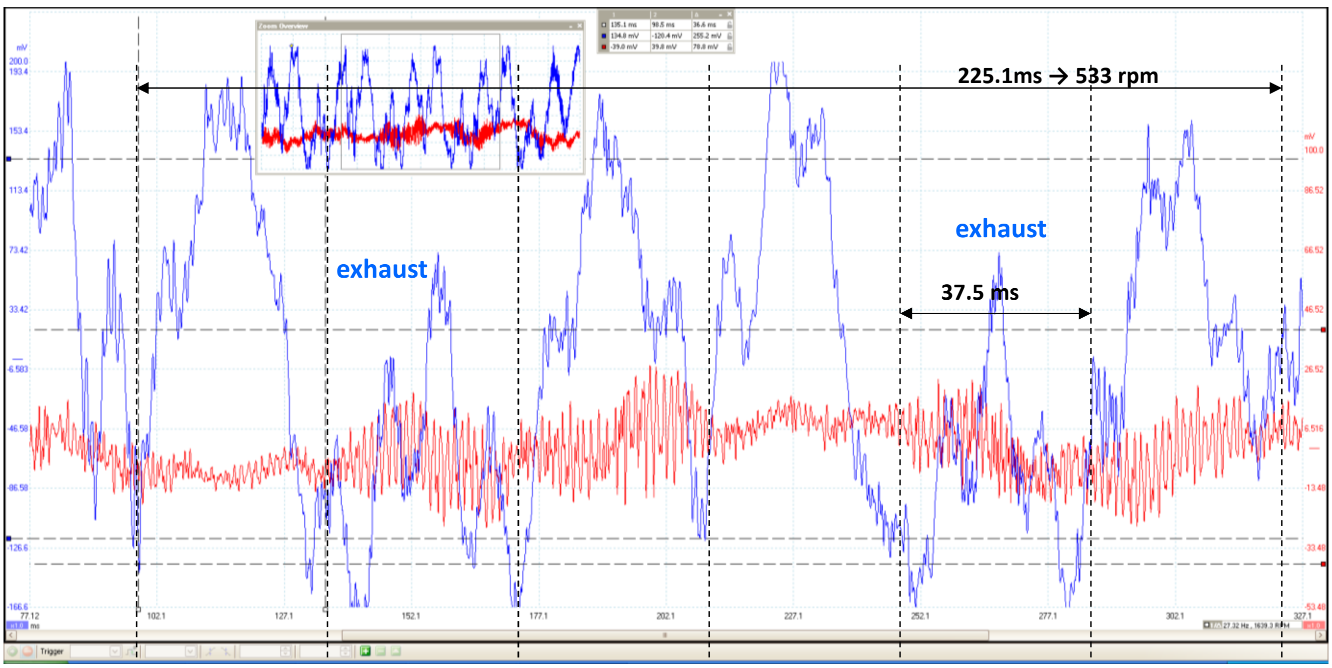
From the Zoom window, we see that every third cylinder has a weak exhaust pulse. Since there is no fuel, a weak pulse in the exhaust stroke suggests that the compression was 'lost' by unseated or dirty valves that allowed the gases to escape during the compression. Then a vacuum was created when the power stroke pulled the piston down; so when the exhaust stroke pushed the gases out the now open exhaust valve, little air was present. A bad head gasket could enable this observation; bad, or unseated rings could also be the culprit (remember this is a new engine); dirty or unseated valves could also be a cause.

You might notice that we also moved the horizontal dashed lines to contain the range of the voltages experienced. The two lines with a blue box on the far left capture the voltage range of the exhaust, .36 volts; the dashed lines with red boxes on the far right show the voltage range of the crankcase sensor, .05 volts. These are very low voltage ranges.



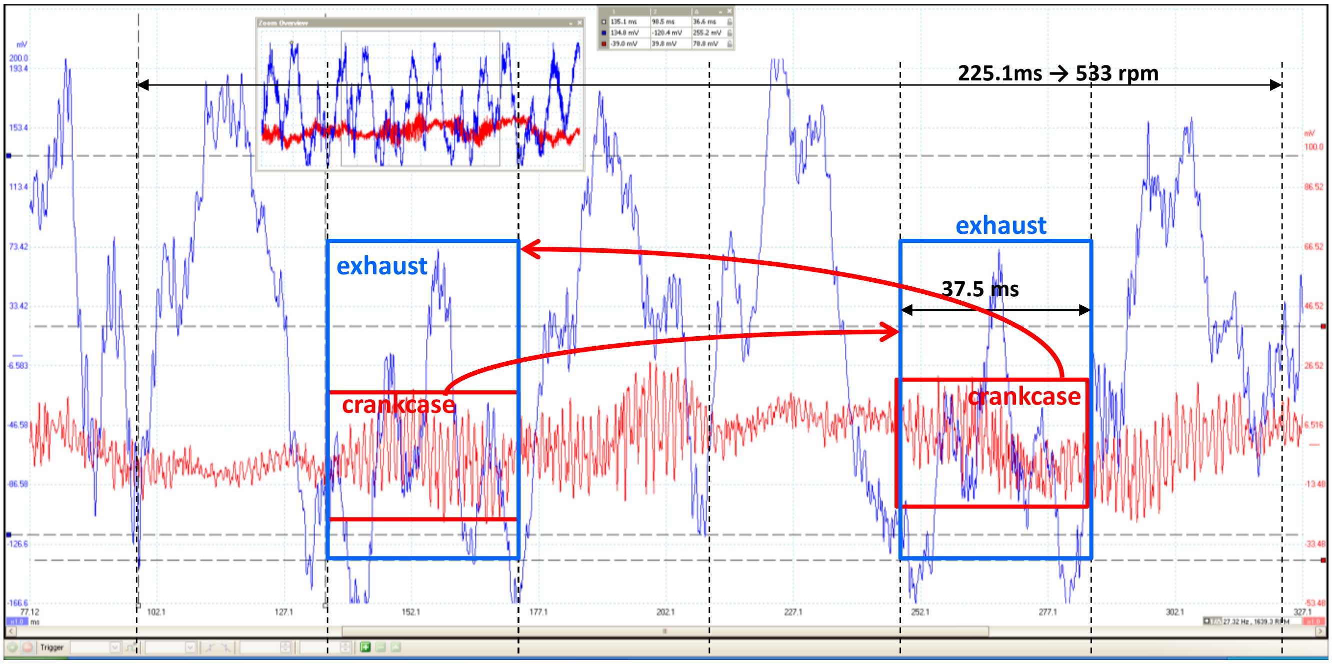
The next diagram shows the same signature with a few other considerations illustrated. Here we have highlighted some of the timing considerations. The crankcase makes its two revolutions in 225.1ms,

corresponding to 533 rpm from our equation earlier. (On the timing table, 225.1ms implies 550rpm – close enough for our work!) Divide the 225.1ms by the 6 cylinders to get 37.5ms per cylinder. Now we can start to look at the exhaust and crankcase readings for the same cylinder – but first notice that the battery cranks the engine at a varying rate, averaging 533rpm. We can see the variation by noticing that the pulses around the weak pulses go faster than when the bigger pulses are being recorded. If this variation were noticed while the engine is running, we would suspect a problem with the valve timing.



Next, we will continue analyzing the cold-crank signature to relate information from different strokes with the same cylinder. Since there are 4 strokes per cylinder of 180° in a 4-stroke engine, the strokes of one cylinder are separated by 225.1ms divided by 4 = 56.3ms. The sequence is: intake, compression, power, and exhaust. Next we assign to each cylinder 225.1ms divided by the number of cylinders (6) to get the 37.5ms 'assigned' to each cylinder as major contributor. (See the Offset Diagrams in the Appendix.) In a cold-crank, we expect the major blow-by comes from the compression stroke, since there is no fuel to burn in the power stroke. The compression stroke is 360° out of phase from the exhaust stroke.

In the following diagram, we add exhaust and crankcase boxes for the two cylinders with low compression. What we see in the red boxes are the pulses from the compression strokes of the corresponding exhaust strokes of those same cylinders. Both show a fair amount of blow-by indicating that the rings are not well seated and is probably contributing to the low voltage (pressure) coming out the exhaust from those cylinders.

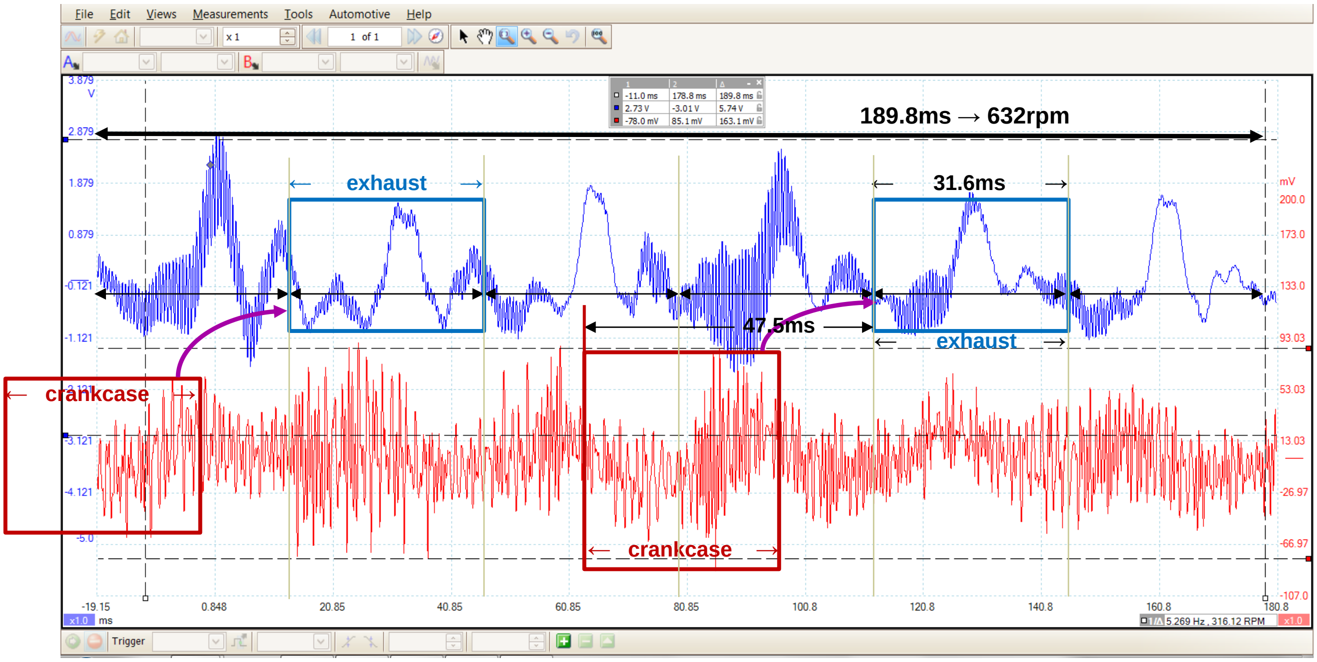


The summary of the cold-crank test is that this engine shows two cylinders that have valves that have not yet seated and that the rings probably will also seat a little more in the next several hundred miles.

2. Idle Engine Signature Analysis

Next, we will analyze the signatures from the same engine, on the same day, running at idle.

We now refer to a table of signature observations with corresponding likely causes. Since we now are looking at the signatures of a running engine, issues of fuel supply and ignition can affect our observations. After the table, we will continue our discussion of the Hot Engine signature analyses. (The same table is used for idle and Load tests because the same observations will have the same causes – the added pressures are just more likely to accentuate real problems.)



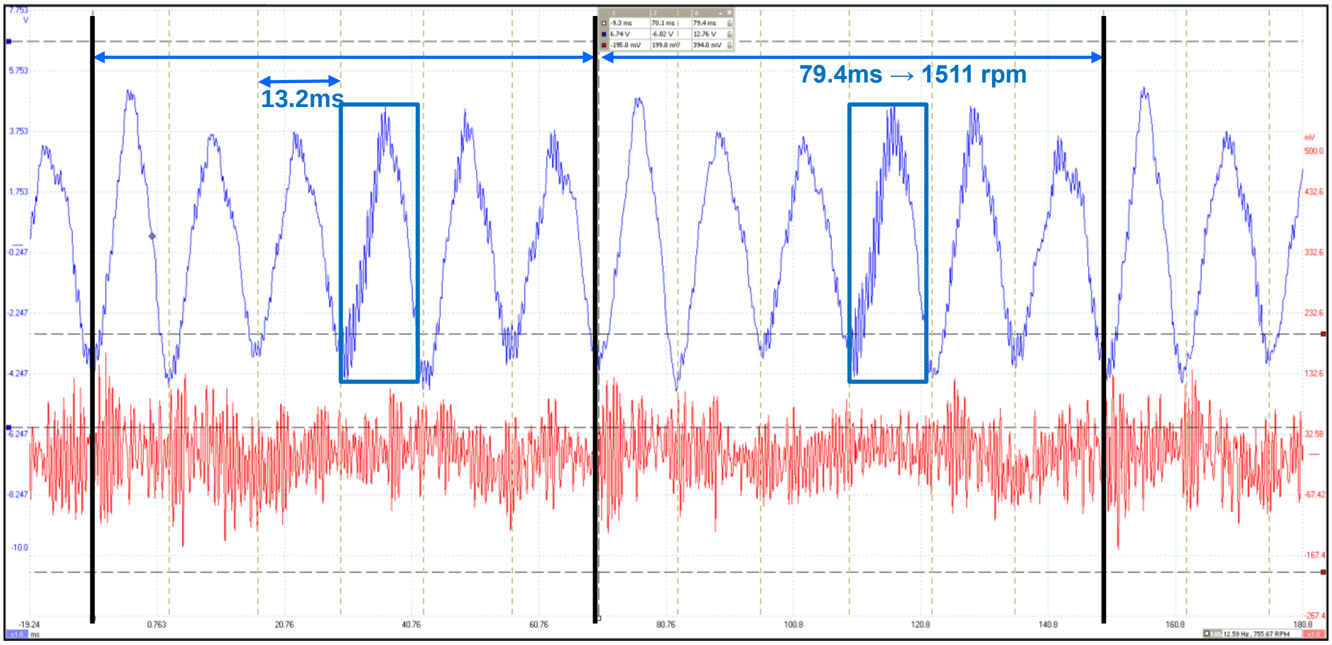
Here, we see that the engine shows more regularity across the cylinders . The voltage range of the exhaust pulses is now 5.7 volts compared with .36 volts in the cold-crank. The crankcase variation has also become more uniform; the voltage in the crankcase here is .16 volts compared to .05 volts in the cold-crank test. Two valves show that they are not seated well [the high frequency (jagged shape) shown in the first and fourth cylinders (exhaust – blue) shown in the previous signature].

The relatively uniform crankcase pulses with small range of voltage imply that there is not much blow-by.

3. Load Engine Signature Analysis

We now keep our equipment unchanged and have our partner rev the engine to a more typical operating speed. This just puts more pressure on components, providing some stress that might provide additional insight.

On this same engine, we see that all valves have become better seated with only one cylinder showing that it is not yet fully seated. Likewise, the rings are behaving more uniform. The exhaust voltage range is now 9.45 volts and the crankcase voltage has a .35 volt range.



The basic conclusion from this series of Diagnostic Tests is that this engine is not yet 'broken-in' but shows no problem of concern. It might be wise to run these tests again in a month or so.

II. Diesel Test Analysis for Engine Assessment

As mentioned earlier, if one is interested to find if an engine that runs (fairly) well, has mechanical integrity, running only the 'Hot' tests at Idle and Load enables a quick check to make buy/sell and mission deployment decisions. There are hand-held oscilloscopes that can be used with a visual check of the displays for uniform and appropriately shaped signatures. In many cases, for example if you are looking for a used vehicle with good mechanical integrity, you probably are not interested in diagnosing any problem – you have the information not to buy the equipment.

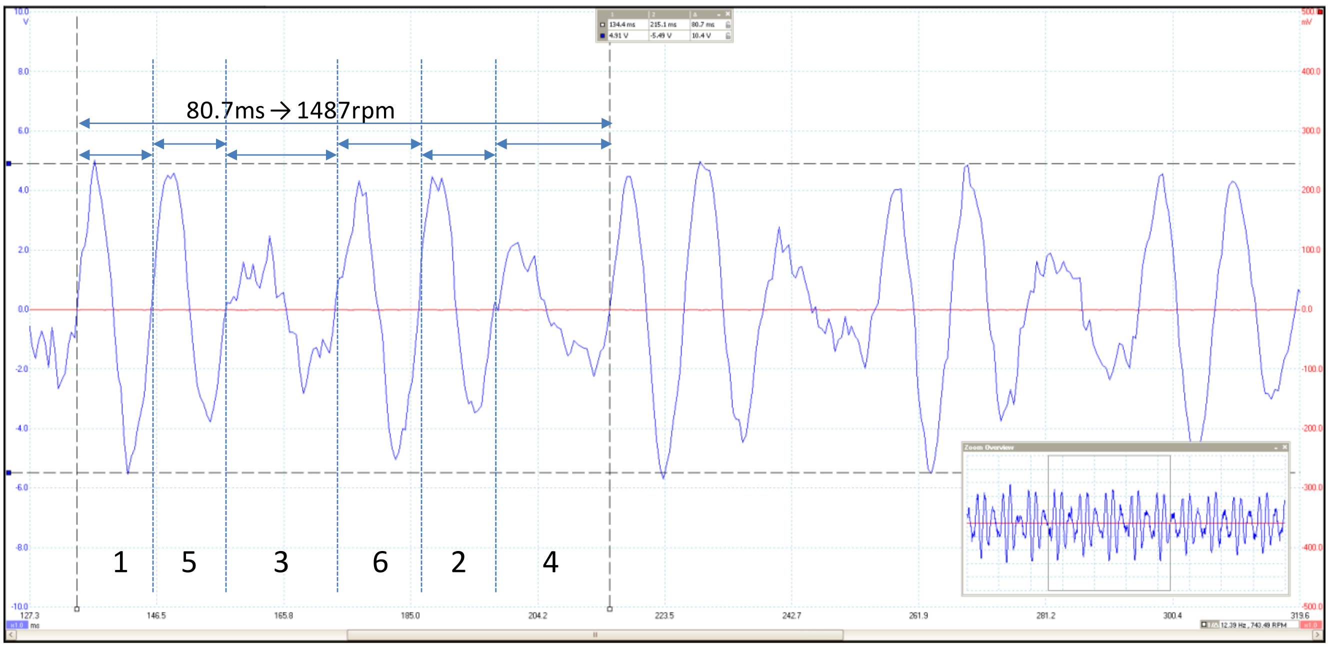
III. Diesel Test Collection for Predictive Analysis

It is expected that well-managed fleets will have their engines routinely tested as assessments and the results stored in a database for periodic analysis to predict failures using trends in the signatures to project when critical value might be realized. This information can be valuable in making improvement, repair and culling decisions. (If any symptoms are showing, the fleet manager needs to be informed before dispatch of the asset to a new mission/trip; a complete diagnosis is probably warranted.)

To perform this function, one goes through the previously described assessment protocol with a PC to enable the storage of the signatures to transmit it to a platform where all signatures can be collected under the engine serial number in chronological order with the odometer readings. Thus, it is important to collect the signature engine data in a spreadsheet of the format of the SenX Signature Log on page 19. Be sure to document each test for a complete picture.

Diesel Engine Test Analysis Example 2

In the following example, we show the hot exhaust test of a CAT 3208 I6, 4-stroke engine at about Load. Two cylinders appear quite different from the others. The firing sequence for the CAT 3208 engine is 1 5 3 6 2 4. If we lay this sequence down on the signature with cylinder 1 in the first exhaust pulse, we see that cylinders 3 and 4 are the ones with problems. (Since we do not have a trigger signal to show physical cylinder 1, we cannot be sure that we have marked the cylinders correctly. However, as we try the other combinations in that sequence, we see that this is the only way those two cylinders are adjacent. The suggestion is that the head gasket between cylinders 3 & 4 is compromised so that the ignition pressure from cylinder 3 is largely blowing into cyl 4 (which is in its intake stroke) and vice-versa. (See Cylinder Offset Diagram on page 45; but we typically have to replace the firing sequence on page 45 with this engine's firing sequence.)



Appendix

Troubleshooting Guide

If you cannot get a pulse signature during a test:

1. Verify your lab scope has power and is set up and functioning properly.
2. If the lab scope is OK, verify the sensor cable connections are tight.
3. If your scope and the cable connections are OK, check the continuity in the sensor cable. If there is a problem with the cable, contact SenX about cable replacement.
4. If both the lab scope and the cable are OK, there is a sensor problem. Please contact SenX about sensor repair or replacement.

If you create 'Check Engine' codes during a crankcase test:

1. Verify the computer-controlled optimization was disabled correctly.
2. Verify the fan was turned OFF or ON properly.
3. With a crankcase test, make sure the sensor in the oil level indicator tube is sealed enough to prevent airflow into the crankcase.

Contact Us

Please contact us with any questions or problems that are not addressed in this User's Guide.

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Visit our Web Site

http://senxtech.com

Our web site includes

- FAQs
- Additional reference pulse signatures
- Additional technical information about the FirstLook® sensor

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ES 100 Timing Chart for 4-Stroke Engines

Time to complete 1 cycle = 2 engine revolutions

	Time Between Valve Opening Events (milliseconds)							
Engine Speed (rpm)	Time to Complete 1 Cycle in 4 Stroke Engine (ms)	A 2 Cylinder	B 3 Cylinder	C 4 Cylinder	D 5 Cylinder	E 6 Cylinder	F 8 Cylinder	Starting Time Base Reference (ms)
150	800.0	400.0	266.7	200.0	160.0	133.3	100.0	
175	685.7	342.9	228.6	171.4	137.1	114.3	85.7	Cold Crank
200	600.0	300.0	200.0	150.0	120.0	100.0	75.0	600
225	533.3	266.7	177.8	133.3	106.7	88.9	66.7	
250	480.0	240.0	160.0	120.0	96.0	80.0	60.0	
300	400.0	200.0	133.3	100.0	80.0	66.7	50.0	
350	342.9	171.4	114.3	85.7	68.6	57.1	42.9	
400	300.0	150.0	100.0	75.0	60.0	50.0	37.5	
450	266.7	133.3	88.9	66.7	53.3	44.4	33.3	
500	240.0	120.0	80.0	60.0	48.0	40.0	30.0	
550	218.2	109.1	72.7	54.5	43.6	36.4	27.3	Idle Start
600	200.0	100.0	66.7	50.0	40.0	33.3	25.0	200
650	184.6	92.3	61.5	46.2	36.9	30.8	23.1	
700	171.4	85.7	57.1	42.9	34.3	28.6	21.4	
750	160.0	80.0	53.3	40.0	32.0	26.7	20.0	
800	150.0	75.0	50.0	37.5	30.0	25.0	18.8	
850	141.2	70.6	47.1	35.3	28.2	23.5	17.6	
900	133.3	66.7	44.4	33.3	26.7	22.2	16.7	
950	126.3	63.2	42.1	31.6	25.3	21.1	15.8	
1000	120.0	60.0	40.0	30.0	24.0	20.0	15.0	
1100	109.1	54.5	36.4	27.3	21.8	18.2	13.6	Low RPM
1200	100.0	50.0	33.3	25.0	20.0	16.7	12.5	100
1300	92.3	46.2	30.8	23.1	18.5	15.4	11.5	
1400	85.7	42.9	28.6	21.4	17.1	14.3	10.7	
1500	80.0	40.0	26.7	20.0	16.0	13.3	10.0	
1600	75.0	37.5	25.0	18.8	15.0	12.5	9.4	
1700	70.6	35.3	23.5	17.6	14.1	11.8	8.8	
1800	66.7	33.3	22.2	16.7	13.3	11.1	8.3	
1900	63.2	31.6	21.1	15.8	12.6	10.5	7.9	
2000	60.0	30.0	20.0	15.0	12.0	10.0	7.5	
2100	57.1	28.6	19.0	14.3	11.4	9.5	7.1	
2200	54.5	27.3	18.2	13.6	10.9	9.1	6.8	
2300	52.2	26.1	17.4	13.0	10.4	8.7	6.5	Mid Range RPM
2400	50.0	25.0	16.7	12.5	10.0	8.3	6.3	50

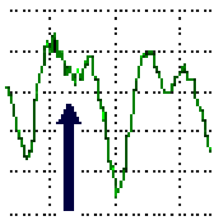
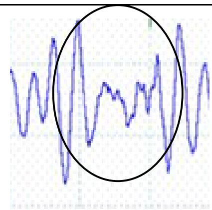
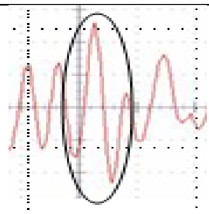
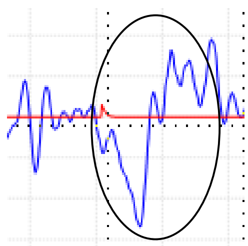
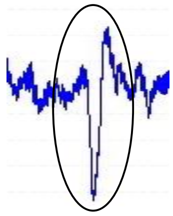
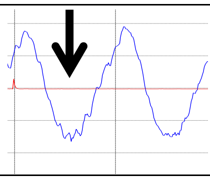
ES 100 Timing Chart for 2-Stroke Engines

Time to complete 1 cycle = 1 engine revolution

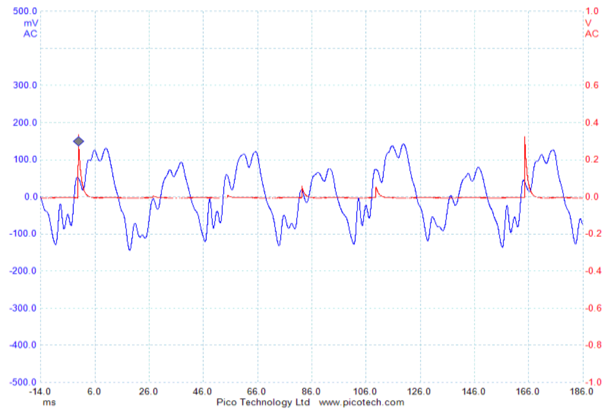
	Time Between Valve Opening Events (milliseconds)							
Engine Speed (rpm)	Time to Complete 1 Cycle in 2-Stroke Engine (ms)	A 2	B 3	C 4	D 5	E 6	F 8	Starting Time Base Reference (ms)
150	400.0	200.0	133.3	100.0	80.0	66.7	50.0	
175	342.9	171.4	114.3	85.7	68.6	57.1	42.9	Cold Crank
200	300.0	150.0	100.0	75.0	60.0	50.0	37.5	300
225	266.7	133.3	88.9	66.7	53.3	44.4	33.3	
250	240.0	120.0	80.0	60.0	48.0	40.0	30.0	
300	200.0	100.0	66.7	50.0	40.0	33.3	25.0	
350	171.5	85.7	57.2	42.9	34.3	28.6	21.4	
400	150.0	75.0	50.0	37.5	30.0	25.0	18.8	
450	133.4	66.7	44.5	33.3	26.7	22.2	16.7	
500	120.0	60.0	40.0	30.0	24.0	20.0	15.0	
550	109.1	54.6	36.4	27.3	21.8	18.2	13.6	Idle Start
600	100.0	50.0	33.3	25.0	20.0	16.7	12.5	100
650	92.3	46.2	30.8	23.1	18.5	15.4	11.5	
700	85.7	42.9	28.6	21.4	17.1	14.3	10.7	
750	80.0	40.0	26.7	20.0	16.0	13.3	10.0	
800	75.0	37.5	25.0	18.8	15.0	12.5	9.4	
850	70.6	35.3	23.5	17.7	14.1	11.8	8.8	
900	66.7	33.3	22.2	16.7	13.3	11.1	8.3	
950	63.2	31.6	21.1	15.8	12.6	10.5	7.9	Low rpm
1000	60.0	30.0	20.0	15.0	12.0	10.0	7.5	60
1100	54.6	27.3	18.2	13.6	10.9	9.1	6.8	
1200	50.0	25.0	16.7	12.5	10.0	8.3	6.3	
1300	46.2	23.1	15.4	11.5	9.2	7.7	5.8	
1400	42.9	21.4	14.3	10.7	8.6	7.1	5.4	Mid Range rpm
1500	40.0	20.0	13.3	10.0	8.0	6.7	5.0	40
1600	37.5	18.8	12.5	9.4	7.5	6.3	4.7	
1700	35.3	17.7	11.8	8.8	7.1	5.9	4.4	
1800	33.4	16.7	11.1	8.3	6.7	5.6	4.2	
1900	31.6	15.8	10.5	7.9	6.3	5.3	4.0	
2000	30.0	15.0	10.0	7.5	6.0	5.0	3.8	
2100	28.6	14.3	9.5	7.1	5.7	4.8	3.6	
2200	27.3	13.6	9.1	6.8	5.5	4.5	3.4	
2300	26.1	13.1	8.7	6.5	5.2	4.4	3.3	
2400	25.0	12.5	8.3	6.3	5.0	4.2	3.1	

Example Pulses

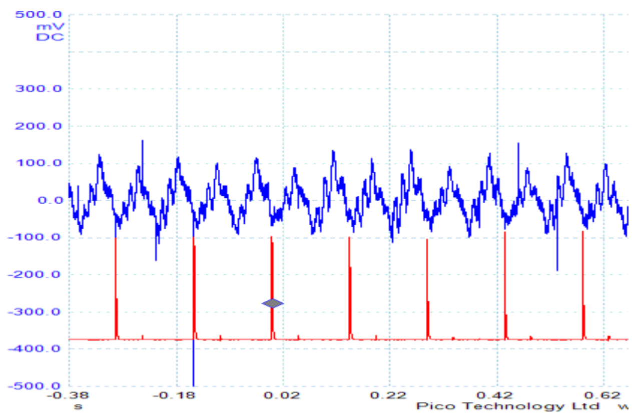
This is a starting point for reading the pulse signature. With experience, you will soon know more about reading pulse signatures than can ever be written in a table like this, but start here.

Pulse	Image	Possible Causes
saw-toothed shape across the top of an exhaust pulse		suspect dirty or sticky exhaust valves
undersize or missing exhaust pulse(s)		suspect a lean burn, less fuel was delivered: possible injector issue
oversize exhaust pulse(s)		suspect a fat burn, extra fuel was delivered: possible injector issue or possibly intentional to keep the catalytic converter hot
undersize or missing exhaust pulse followed by an oversize pulse example shows a missing pulse		suspect an ignition misfire: fuel was delivered, but did not burn until in the exhaust of the following pulse
oversize or non-uniform crankcase pulse		probable cause: severe piston blow-by
saw-toothed shape across the bottom of a vacuum pulse		suspect dirty or sticky intake valves

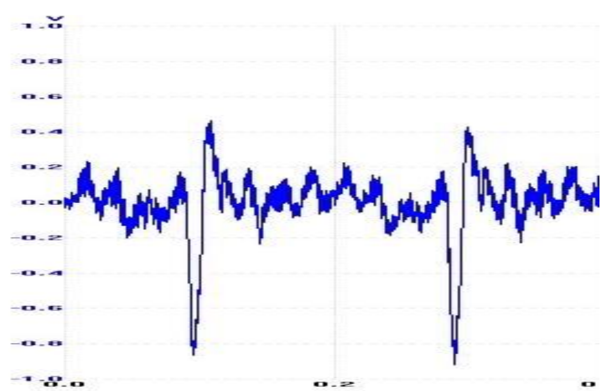
Reference Pulse Signatures



Idle Test – V6 exhaust signature



Crankcase Test – Good Cylinders Diesel



Crankcase Test – Bad Cylinder Diesel Idle

Offset Diagrams

4-Cylinder 4-Stroke Engine Offsets

The 4-Cylinder Offset Diagram is shown on the next page. An exhaust pulse signature is included for illustration. To help illustrate the processes, a trigger signal is attached to cylinder 1.

Exhaust pulses start when exhaust valves open just before bottom dead center (BDC) of the power stroke. They continue as the piston pushes exhaust gases out of the cylinder during its exhaust stroke. Notice how the exhaust pulses in the pulse signature start increasing before the end of the power stroke.

Find the exhaust stroke for cylinder 1 in the diagram and track it down to the exhaust pulse signature. This shows the exhaust pulse from cylinder 1 is offset one pulse to the right of the trigger pulse (+1).

You can identify the rest of the exhaust pulses the same way. Or you could just count them since you know both the firing order and the location of the exhaust pulse for cylinder #1.

A crankcase pulse signature is not shown. However, crankcase pulses are created when the piston strokes down during its power stroke.

Find the power stroke for cylinder 1 in the diagram and track it down. This shows the crankcase pulse is right at the trigger. There is no offset. Identify the other crankcase pulses the same way. Or again, you could just count them since you know both the firing order and the location of the exhaust pulse for cylinder #1.

Technically, in this 4-cylinder engine example, the trigger crankcase pulse is the sum of the pulses for pistons 1 and 3, which are both stroking down, minus the pulses for pistons 2 and 4, which are both stroking up. However, pulse deviations will be a result of the very high pressure in the cylinder that is firing. So for test purposes we identify the pulse as being only from the power stoke piston. Peak cylinder pressures in diesel engines are managed (by the fuel system) to occur somewhere between 10 to 20 degrees after top dead center (ATDC) to optimize the relationship between cylinder pressure and the mechanical advantage of the crank throw vector angle. Because the quantity and duration of the fuel being injected into the cylinder is controlled by engine electronics, the peak cylinder pressures closely complement the crank throw angle and leverage it produces. The result is a much smoother application of torque to the drivetrain components. This relationship between pressure and throw angle helps transmit the energy produced in the engine cylinder as smoothly as possible. As gas pressure acts on the piston and forces it through its stroke, the cylinder pressure will decrease, but as it does throw leverage increases.
However, because this is the objective at all engine speeds and loads it is much more difficult to uniformly achieve this with older hydromechanical engines. The peak cylinder pressure would decrease as the piston moves downward in its power stroke but the peak cylinder pressures could be at 30 degrees ATDC. This could possibly show as a more uniform crankcase pressure signal and hence a flatter blow-by shape in the diesel crankcase than one expects to find in a spark-plug engine.

Intake vacuum pulses are created when the piston strokes down during its intake stroke. Find the intake stroke for cylinder 1 and track it down. This shows the intake pulse for cylinder 1 would be offset two pulses to right of the trigger pulse.

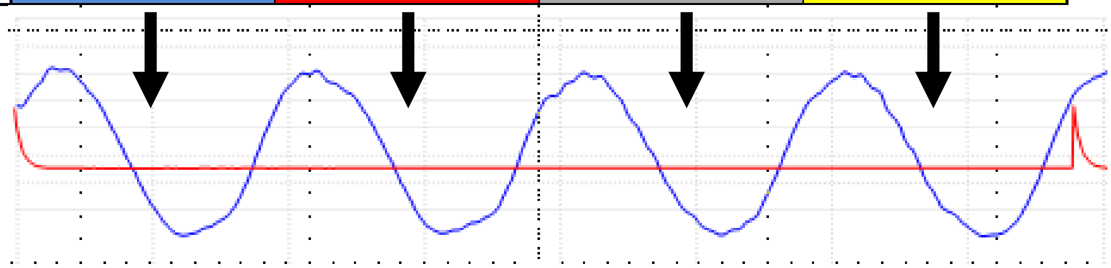
The offsets work no matter what cylinder you use for the trigger. Just remember you will identify the pulses for the trigger cylinder. When you attach the trigger to cylinder 2, for example, the offsets will identify the pulses for cylinder 2. And knowing the firing order, you can still identify the rest of the pulses.

Also, it does not matter which trigger you count from. The important thing is to remember the trigger pulse is the pulse just to the right of the trigger signal.

4-Cylinder 4-Stroke Offset Diagram

A 4-cylinder engine with firing order: 1 – 4 – 3 – 2

Crankshaft rotation:		0 to 180°	180 to 360°	360 to 540°	540 to 720˚
		180	360	540	585
Fire Seq 1	Cyl 1	Power Stroke	Exhaust Stroke	Intake Stroke	Compression Stroke
Fire Seq 2	Cyl 4	Compression Stroke	Power Stroke	Exhaust Stroke	Intake Stroke
Fire Seq 3	Cyl 3	Intake Stroke	Compression Stroke	Power Stroke	Exhaust Stroke
Fire Seq 4	Cyl 2	Exhaust Stroke	Intake Stroke	Compression Stroke	Power Stroke



The blue line is an exhaust pulse signature. The red line is the trigger signal.

	trigger pulse	+1	+2	+3
Exhaust pulses	#2	#1	#4	#3
Crankcase pulses	#1	#4	#3	#2
Intake vacuum pulses	#3	#2	#1	#4

6-Cylinder 4-Stroke Engine Offsets

Please review the 4-Cylinder Engine Offset Diagram and explanation if you have not already done so. It will be easier to see and understand the offsets here once you understand the 4-Cylinder Offset Diagram.

The 6-Cylinder Offset Diagram is shown on the next page. The first thing you will notice is that the 'extra' cylinders cause the pistons to overlap each other during their strokes. This makes the diagram look more complicated, but the analysis is the same.

An intake vacuum pulse signature, with a trigger on cylinder 1, is included for illustration. Remember, this is the vacuum side. You need to look at the 'negative peaks,' or 'valleys,' when reading these pulse signatures. This is NOT from a diesel engine.

The diagram identifies the trigger pulse as being the intake pulse from cylinder 6. There is overlap with cylinder 3 at the start, but the trigger pulse is *mostly* cylinder 6. The intake pulse just to the right of the trigger pulse is cylinder 2. Again, you can see the overlap with cylinder 6, but the pulse is going to be *mostly* cylinder 2.

If you need to, use the columns in table at the bottom under the pulse signature to divide the pulse signature into cylinders.

Now, find the intake stroke for cylinder 1 and track it down to the pulse signature. The intake pulse (valley) that is *mostly* cylinder 1 is three pulses to the right (+3) of the trigger pulse.

It is the same when you have exhaust and crankcase pulse signatures. For exhaust pulse signatures, find the exhaust stroke for the trigger cylinder (usually cylinder 1) and track it down. Exhaust pulses for a 6-cylinder engine will be offset two pulses to the right of the trigger pulse (+2). Follow the power stroke down to see that the crankcase pulse will be right at the trigger with no offset.

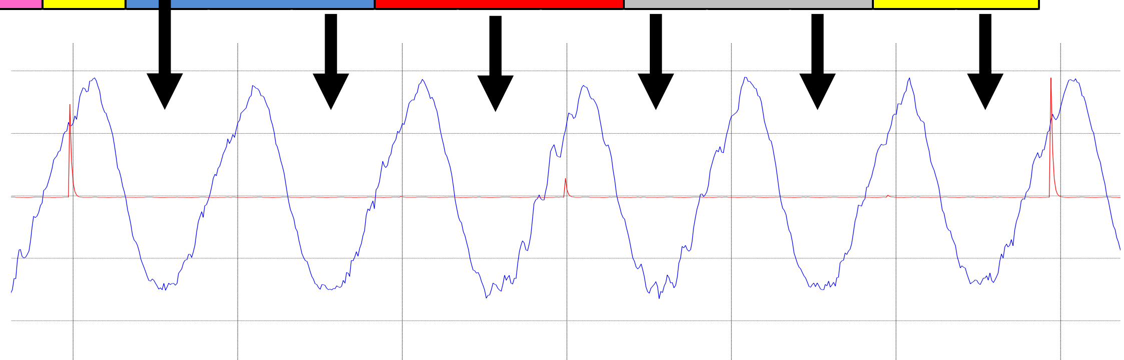
3-, 5- and 8-Cylinder 4-Stroke Engine Offsets

The 3-Cylinder, 5-Cylinder and the 8-Cylinder Offset Diagrams are included. The 8-Cylinder Engine Offset Diagram appears even more complicated than the 6-cylinder because there is more overlap. Still, the analysis is the same as with the 4-cylinder and the 6-cylinder diagrams.

6-Cylinder 4-Stroke Offset Diagram

A 6-cylinder engine with firing order: 1 – 5 – 3 – 6 – 2 – 4

crankshaft rotation		0 to 180°			180 to 360			360 to 540			540 to 720		
		60	120	180	240	300	360	420	480	540	600	660	720
Fire Seq. 1	Cyl #1	Power Stroke			Exhaust Stroke			Intake Stroke			Compression Stroke		
Fire Seq. 2	Cyl #5	Comp Stroke		Power Stroke			Exhaust Stroke			Intake Stroke			
Fire Seq. 3	Cyl #3		Compression Stroke			Power Stroke			Exhaust Stroke			Intake Stroke	
Fire Seq. 4	Cyl #6	Intake Stroke			Compression Stroke			Power Stroke			Exhaust Stroke		
Fire Seq. 5	Cyl #2	Exhaust Stroke		Intake Stroke			Compression Stroke			Power Stroke			
Fire Seq. 6	Cyl #4		Exhaust Stroke			Intake Stroke			Compression Stroke			Power Stroke	



The blue line is an intake vacuum pulse signature. The red line is the trigger signal.

	trigger pulse	+1	+2	+3		
Exhaust pulses	#2 exhaust	#4 exhaust	#1 exhaust	#5 exhaust	#3 exhaust	#6 exhaust
Crankcase pulses	#1 crankcase	#5 crankcase	#3 crankcase	#6 crankcase	#2 crankcase	#4 crankcase
intake vacuum pulses	#6 intake	#2 intake	#4 intake	#1 intake	#5 intake	#3 intake

3-Cylinder 4-Stroke Engine Offset Diagram

A 3-cylinder engine with firing order: 1 – 2 –3

Crankshaft rotation:		0 to 180˚			180 to 360˚			360 to 540˚			540 to 720˚		
		60	120	180	240	300	360	420	480	540	600	660	720
Fire Seq 1	Cyl 1	Power Stroke			Exhaust Stroke			Intake Stroke			Compression Stroke		
Fire Seq 2	Cyl 2		Compression Stroke			Power Stroke			Exhaust Stroke			Intake	
Fire Seq 3	Cyl 3	Exhaust		Intake Stroke			Compression Stroke			Power Stroke			

	Trigger pulse				+1				+2			
Exhaust pulses	#3			#1				#2				#3
Crankcase pulses	#1				#2				#3			
Intake vacuum pulses	#2		#3				#1				#2	

5-Cylinder 4-Stroke Engine Offset Diagram

A 5-cylinder engine with firing order: 1 – 2 – 4 – 5 – 3

crankshaft rotation		0 to 180°			180 to 360°		360 to 540°			540 to 720°	
		72	144	216	288	360	432	504	576	648	720
Fire Seq. 1	Cyl #1	Power Stroke		Exhaust Stroke			Intake Stroke		Compression stroke		
Fire Seq. 2	Cyl #2	Comp Stroke		Power Stroke		Exhaust Stroke			Intake Stroke		
Fire Seq. 3	Cyl #4	Intake stroke	Compression stroke			Power Stroke		Exhaust Stroke			Intake stroke
Fire Seq. 4	Cyl #5	Exhaust	Intake Stroke		Compression stroke			Power Stroke		Exhaust	
Fire Seq. 5	Cyl #3		Exhaust Stroke		Intake Stroke		Compression stroke			Power Stroke	

Notice that the intake strokes cover neighboring 'cylinder assignments', so consider this in doing your diagnosis.

	trigger pulse	+1	+2	+3	
Exhaust pulses	#3-5 exhaust	#1-3 exhaust	#2-1 exhaust	#4-2 exhaust	#5-4 exhaust
Crankcase pulses	#1 crankcase	#2 crankcase	#4 crankcase	#5 crankcase	#3 crankcase
intake vacuum pulses	#4-5 intake	#5-3 intake	#3-1 intake	#1-2 intake	#2-4 intake

8-Cylinder 4-Stroke Offset Diagram

An 8-cylinder engine with firing order: 1 – 8 – 4 – 3 – 6 – 5 – 7 – 2

Crankshaft rotation:		0 to 180˚				180 to 360˚				360 to 540˚				540 to 720˚			
		45	90	135	180	225	270	315	360	405	450	495	540	585	630	675	720
Fire Seq 1	Cyl 1	Power Stroke				Exhaust Stroke				Intake Stroke				Compression Stroke			
Fire Seq 2	Cyl 8			Power Stroke				Exhaust Stroke				Intake Stroke				Comp. Stroke	
Fire Seq 3	Cyl 4	Compression Stroke				Power Stroke				Exhaust Stroke				Intake Stroke			
Fire Seq 4	Cyl 3			Compression Stroke				Power Stroke				Exhaust Stroke				Intake	
Fire Seq 5	Cyl 6	Intake Stroke				Compression Stroke				Power Stroke				Exhaust Stroke			
Fire Seq 6	Cyl 5			Intake Stroke				Compression Stroke				Power Stroke				Exhaust	
Fire Seq 7	Cyl 7	Exhaust Stroke				Intake Stroke				Compression Stroke				Power Stroke			
Fire Seq 8	Cyl 2			Exhaust Stroke				Intake Stroke				Compression Stroke				Power	

	Trigger pulse	+1	+2	+3	+4			
Exhaust pulses	#7-5	#2-7	#1-2	#8-1	#4-8	#3-4	#6-4	#5-6
Crankcase pulses	#1-2	#8-1	#4-8	#3-4	#6-3	#5-6	#7-5	#2-7
Intake vacuum pulses	#6-3	#5-6	#7-5	#2-7	#1-2	#8-1	#4-8	#3-4

Each 1/8th of the 2 rotations of the crankshaft provides visibility of two cylinders: the first 45° is mostly from the first cylinder noted; the second 45° is largely from the second cylinder noted. We are assigning ring blow-by primarily to the first half of the power stroke.

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4-Cylinder 2-Stroke Engine Offsets

The 4-cylinder, 2-stroke engine offset diagram is shown on the next page.

In a 2-stroke engine, each cylinder goes through a full cycle of ignition, exhaust, intake and compression during each rotation of the crankshaft. This is illustrated in the diagram as the angle of rotation of the crankshaft goes from 0° through the four phases of the cycle, completing the cycle at 360° where it starts all over again.

Each row in the diagram shows the activity in one cylinder. The firing sequence of each cylinder is shown in the top row; the firing sequence might be different for different engine models.

Let us start by describing the activity in cylinder one as it goes through its cycle:

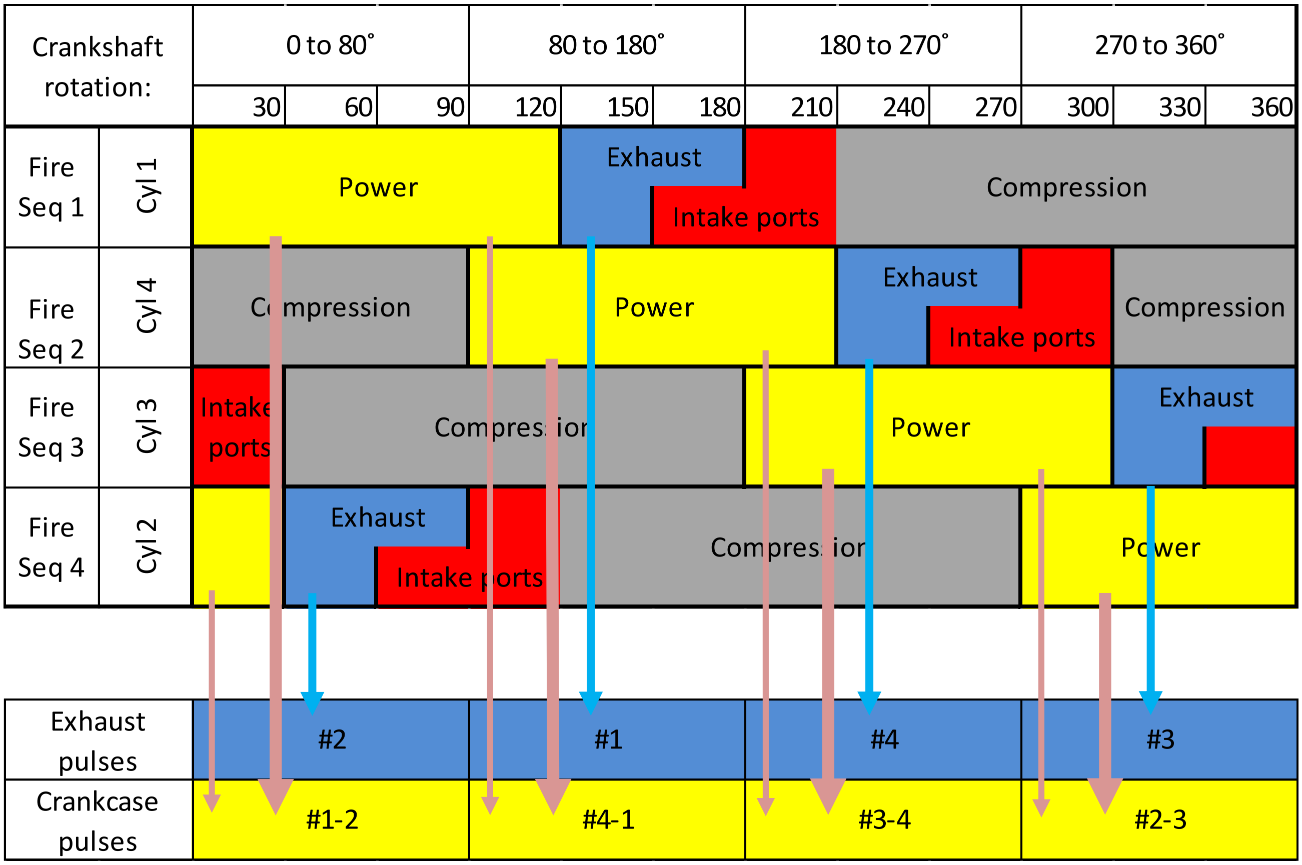
1. The process starts at 0° when ignition from the injection of fuel into hot, compressed air causes the burning fuel to heat the air and expand, pushing the piston down, increasing the angle of crankshaft rotation during this *power* phase (yellow). If the piston and rings are not tight, some of this burning gas will 'blow-by' the piston into the crankcase. Likewise, if the exhaust valves are 'dirty', some of the expanding gas can 'whistle past' the small openings around the valves to allow a small vibration into the exhaust. If the head gasket has lost integrity, gas will escape through the defect.
2. As the piston goes down near the bottom, the exhaust valves will open allowing the hot gas flow out the exhaust manifold (blue); also, any blow-by from this cylinder into the crankcase should stop.
3. As the piston nears the bottom, it will encounter the intake ports (holes) in the cylinder wall (no intake valves!) allowing compressed air from the turbo-charger into the cylinder (red/blue), pushing the exhaust out the top through the still open exhaust valves (scavenging).
4. At 180°, bottom of the piston movement, the exhaust valve closes but the turbo-charged intake manifold continues to push air through the cylinder ports (red).
5. Air continues to be pushed into the cylinder until the piston gets up past the intake ports, stopping the intake process.
6. From this time, the piston continues up to the 360° top (grey), compressing and thus heating the air in the cylinder so that the injected fuel will ignite at the cylinder top. Here again, the compression might blow-by to produce a 'small' pulse into the crankcase and/or out past dirty valves into the exhaust.

The exact angles of valve opening and fuel injection, as well as the location of the intake ports varies by engine manufacturer and model.

The exhaust pulse is represented on the bottom of the next page; it is the result of any gases flowing into the exhaust manifold ***from all the cylinders*** at any instant. The exhaust pulse row is shown in steps of 30°, listing the cylinders of primary impact to the signature. The cylinders that have primary impact on the crankcase signature are listed on the crankcase pulses line.

4-Cylinder 2-Stroke Engine Offset Diagram

A 4-cylinder engine with firing order: 1 – 4 – 3 – 2



The blue line lists the cylinders of primary impact to the exhaust pulse signature at that rotation/time during one rotation of the crankcase. The red line lists the cylinders of primary impact to the crankcase pulse signature.

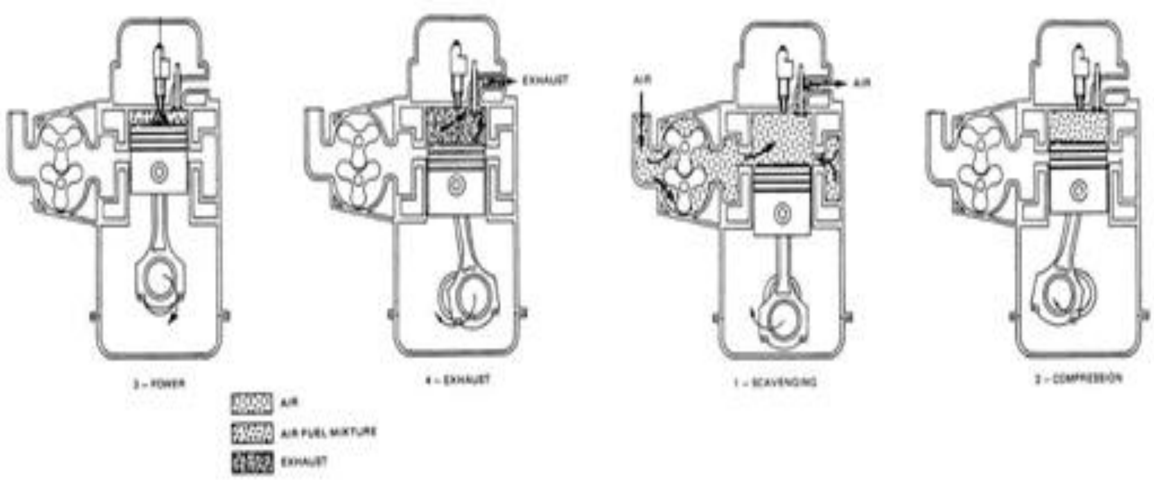
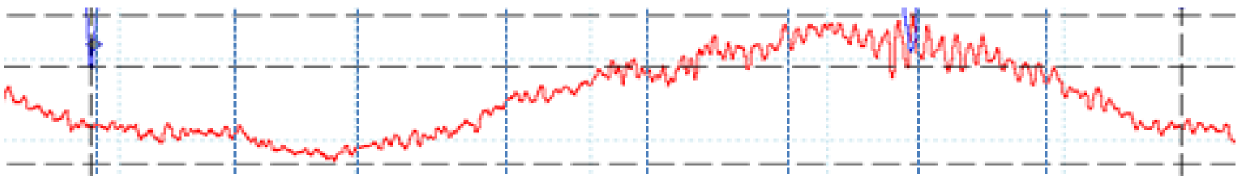


Illustration of the 4 phases of a 2-stroke engine
http://enginemechanics.tpub.com/14081/css/14081_23.htm

8-Cylinder 2-Stroke Engine Offset Diagram

Each cylinder of an 8-cylinder, 2-stroke engine goes through the same phases of the cycle during each rotation of the crankshaft. With 8 cylinders firing during each rotation, the signatures look more complicated. But they are read the same and the Offset diagram is on the next page. A signature trace of the exhaust (blue) and crankcase (yellow) is shown in scale to match the diagram.

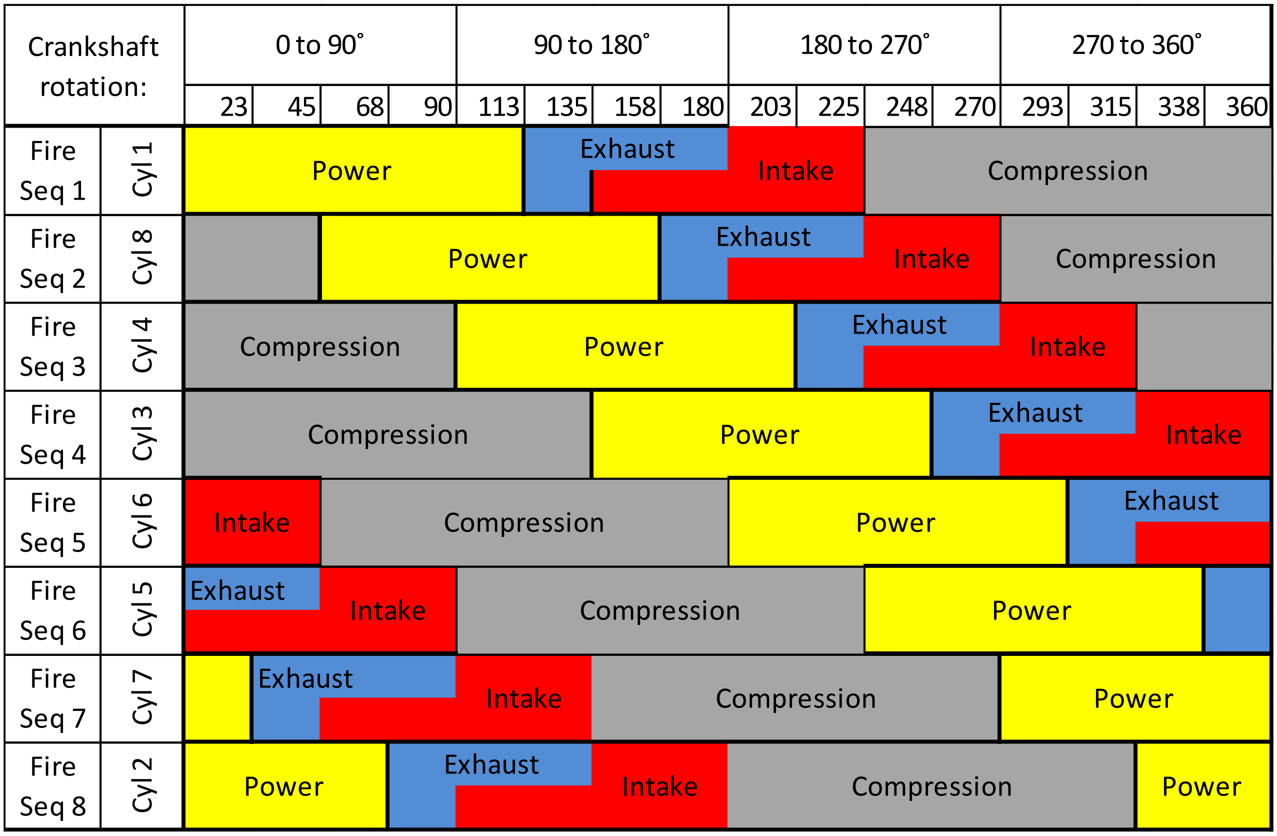
The red crankcase signature shows that the exhaust crankcase ventilation valve (ECV) opens and closes once each rotation providing the major wave of the curve. Pressure changes in the crankcase due to blow-by add and subtract from the overall cycle controlled by the ventilation valve. This is illustrated below:

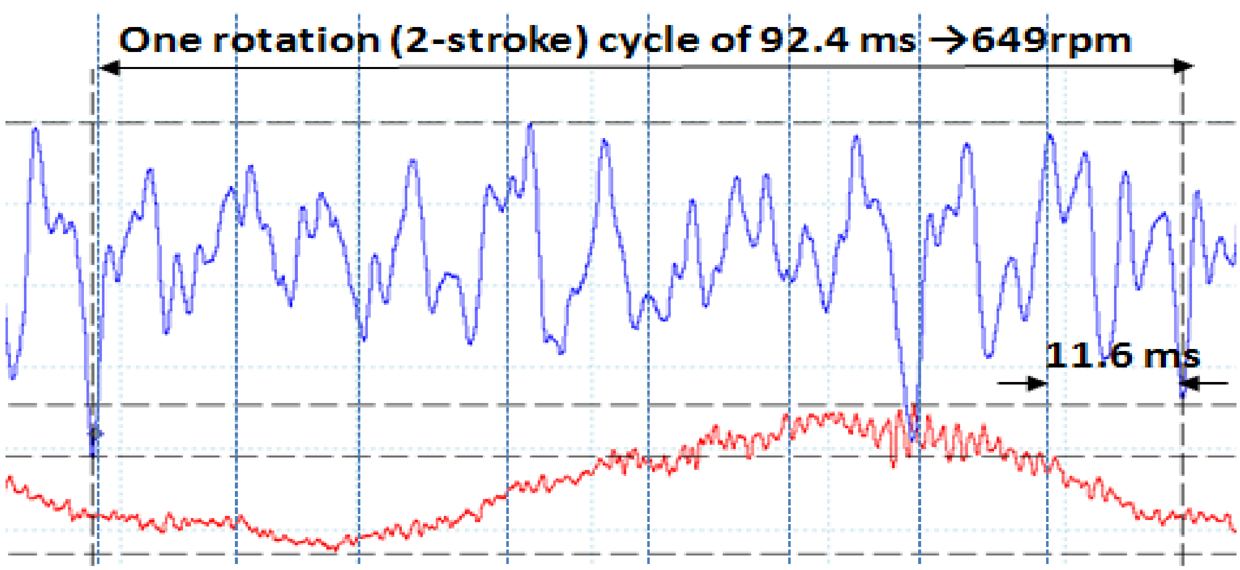


The variation in the red line between the top two dashed lines (above) show the maximum range of the blow-by in this engine's crankcase. The variation between the top and bottom dashed lines is due to the ECV valve.

8-Cylinder 2-Stroke Offset Diagram

An 8-cylinder, 2-stroke engine with firing order: 1 – 8 – 4 – 3 – 6 – 5 – 7 – 2





Exhaust pulses:	#5-7	#7-2	#2-1	#1-8	#8-4	#4-3	#3-6	#6-5
Crankcase pulses:	#1-2-7	#8-1-2	#4-8-1	#3-4-8	#6-3-4	#5-6-3	#7-5-6	#2-7-5