Px script

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1. Purpose

The Px script automatically analyzes the cylinder pressure waveform and generates a print out or report with a number of additional parameters and characteristics of the engine and the associated control unit. The calculated values are pneumatic and geometric characteristics of the cylinder; the list of found deviations is displayed in the form of text messages. To improve speed and accuracy of valve timing research, the cylinder pressure waveform is converted into diagram of the gas amount in the cylinder and is displayed in two different ways, using a script. A detailed diagram of the cyclic filling of the cylinder during the intake stroke, which characterizes the properties of the entire intake manifold of the engine is also provided. A diagram showing the energy consumption for scavenging exhaust gases from the cylinder is provided as well. Using the above diagrams and the the ignition timing signal, the ignition timing diagram is built and can be displayed.

2. Recording the waveforms and starting the script

To display the waveform, we use a transducer that converts pressure in to voltage. The voltage output can then be displayed as a trace on an oscilloscope screen.

Recording the waveforms for the Px script

- It is recommended to disconnect the fuel injector for the cylinder to be diagnosed if the engine to be diagnosed is equipped with a fuel injection system. The engine control computer may set a DTC (Diagnostic Trouble Code) for injector open circuit on the disconnected cylinder. In some cases a 100 Ohm resistor can be connected to the disconnected circuit to avoid setting trouble codes. Alternatively, a scan tool can be used to erase the trouble code after the testing is concluded.

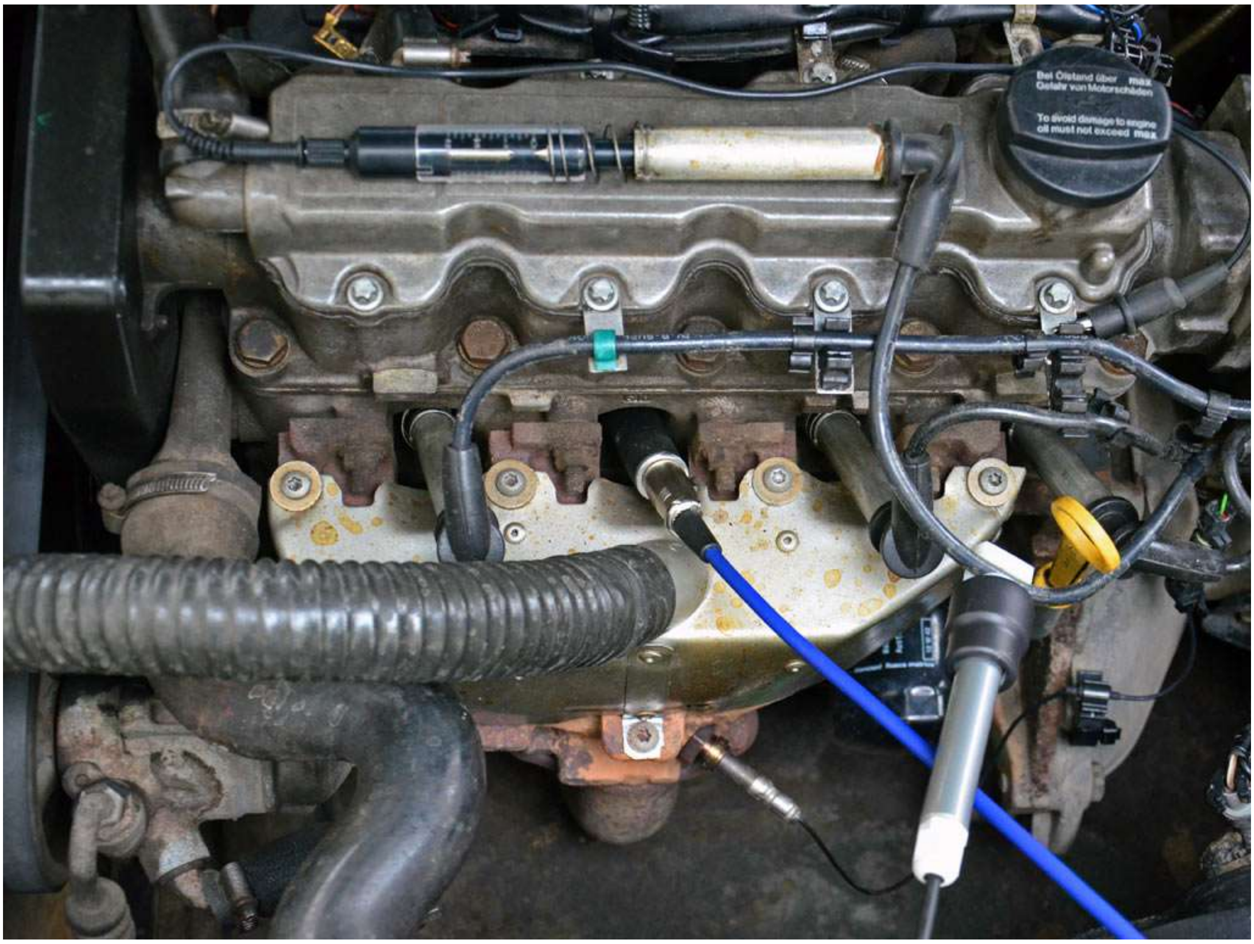
  If fuel supply to the cylinder being tested is not interrupted, hot surfaces in the cylinder can cause ignition of the air-fuel mix which could cause damage to the pressure transducer. Additionally, the unburnt fuel can wash down the cylinder walls and cause wear and / or loss of compression. The low tension piston rings used on late model engines are very susceptible to loss of ring seat and compression when washed with fuel. The unburnt fuel entering the exhaust system may also cause the catalytic converter to overheat.

  If it is not possible to interrupt the fuel supply to the diagnoses cylinder, such as with carburetors or throttle body injection, allow the combustion chamber to cool for approximately 5 minutes. A good procedure is to remove the spark plug, wait 5 minutes, then install the pressure transducer. To avoid damaging the catalytic converter due to the unburned fuel entering it, it is recommended to reduce the duration of the measurements to a minimum.

  In any case, the duration of the measurement should not exceed 3 minutes.

- Install pressure transducer Px or Px35 [1] in place of the spark plug for the diagnosed cylinder and connect it to the input №3 of the USB Autoscope IV. If using the USB Autoscope III, USB Autoscope II, USB Autoscope I, or USB Autoscope, connect the pressure transducer to input №1.

  The plug wire for the disconnected and removed spark plug must always be connected to a spark tester with the spark gap set to about 5 mm.



The pressure transducer replaces the spark plug.

1 High pressure (in cylinder) transducer Px35 is compatible with USB Autoscope IV and USB Autoscope III but, is not compatible with USB Autoscope II, USB Autoscope I and USB Autoscope.

If necessary, use the deep well adapter when installing the pressure transducer and a plug wire to connect the spark tester to the ignition coil. This would be the case with DIS and / or coil on plug type ignition systems.

If the spark plugs are recessed, necessitating using an extension, a deep well adapter should be used.

- Connect the sync transducer to the plug wire that is connected to the spark tester and connect to the input In Synchro.
- Start the engine and allow it to idle.
- In the USB Oscilloscope window select mode "Px => Px" or "Px => Px35" (depending on the pressure transducer type) or, if the deep well adapter is used, select "Px => Px+Longer" or "Px => Px35+Longer".
- Turn on "Record".
- After 3…5 seconds slowly raise the engine speed to 3000…5000 RPM with minimum opening of the throttle and then close the throttle.
- After the idle speed has stabilized, quickly snap the throttle wide open. Then immediately close the throttle. Alternatively, instead of closing the throttle, you can turn off the ignition while keeping the throttle open until the engine comes to a complete stop. If keeping the throttle open while shutting off the ignition, additional information will be recorded for the script tabs "Inlet" and "Exhaust".
- Turn off the waveform recording.

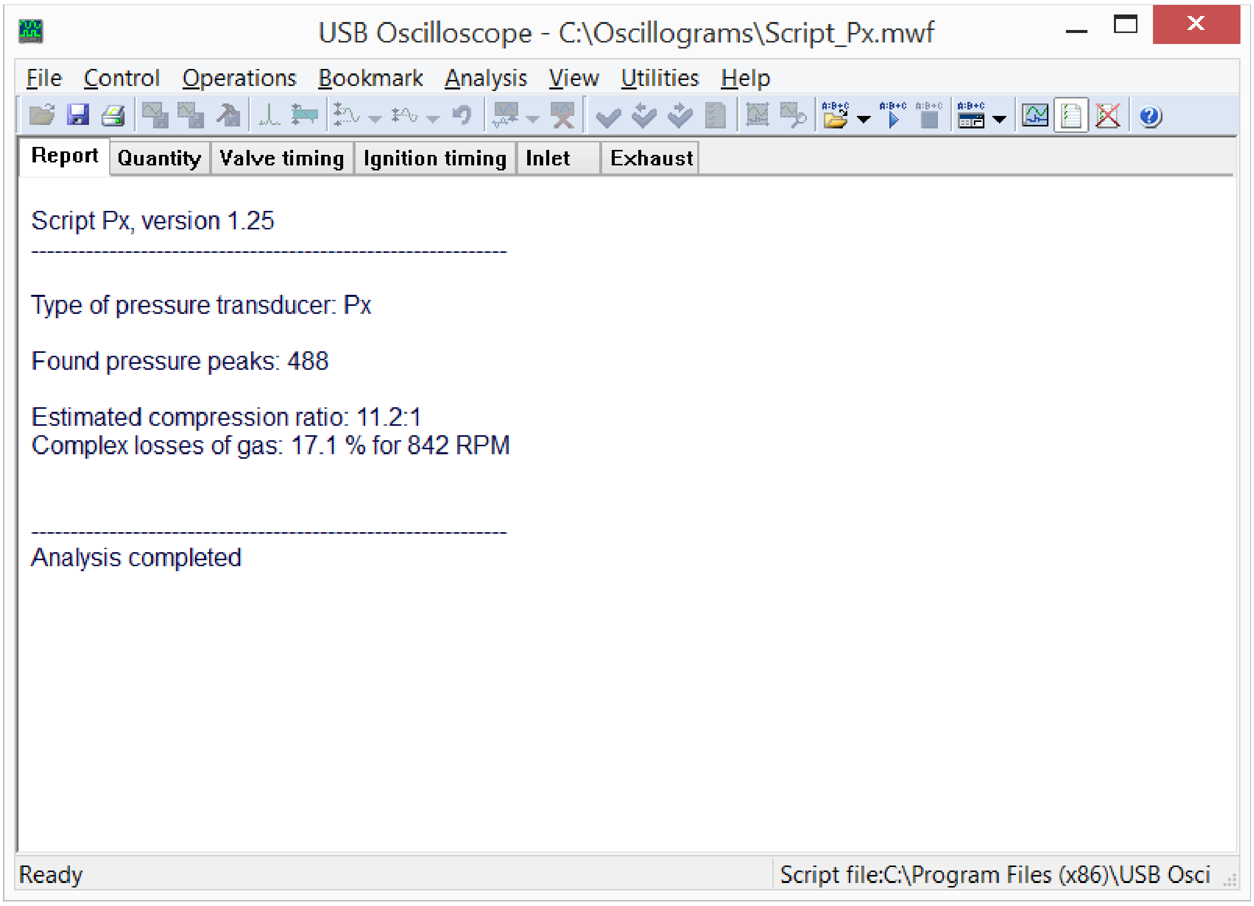
- Save the recorded waveforms using the menu "File => File save as…".
- Analysis of recorded signal by the Px script is performed by selecting "Analysis => Execute script".

Note that the script analyzes the entire file of recorded waveforms. It is also possible to select a part of the recording, the script will then analyze only the selected part.

3. Analysis results

3.1 The "Report" tab

The conventional or classic tool for assessing the state of an engine cylinder and piston is a compression gauge. It is designed to measure the compression or peak pressure in the cylinder obtained while cranking the engine. The measurement is a complex value and depends on losses through cylinder leakage, the compression ratio, the valve timing, the cranking speed, and the state of the intake and exhaust ports or manifold. A reduction of compression pressure in a cylinder is usually thought of as being caused by cylinder leakage or valve timing. However, the reason can also be reduced geometric compression ratio, from for example, a bent piston rod, due to hydro lock. Hydro lock occurs when a piston tries to compress something non-compressible, such as a liquid. The Px script, can distinguish cylinder leakage from low compression ratio, because it independently calculates gas losses and the compression value.



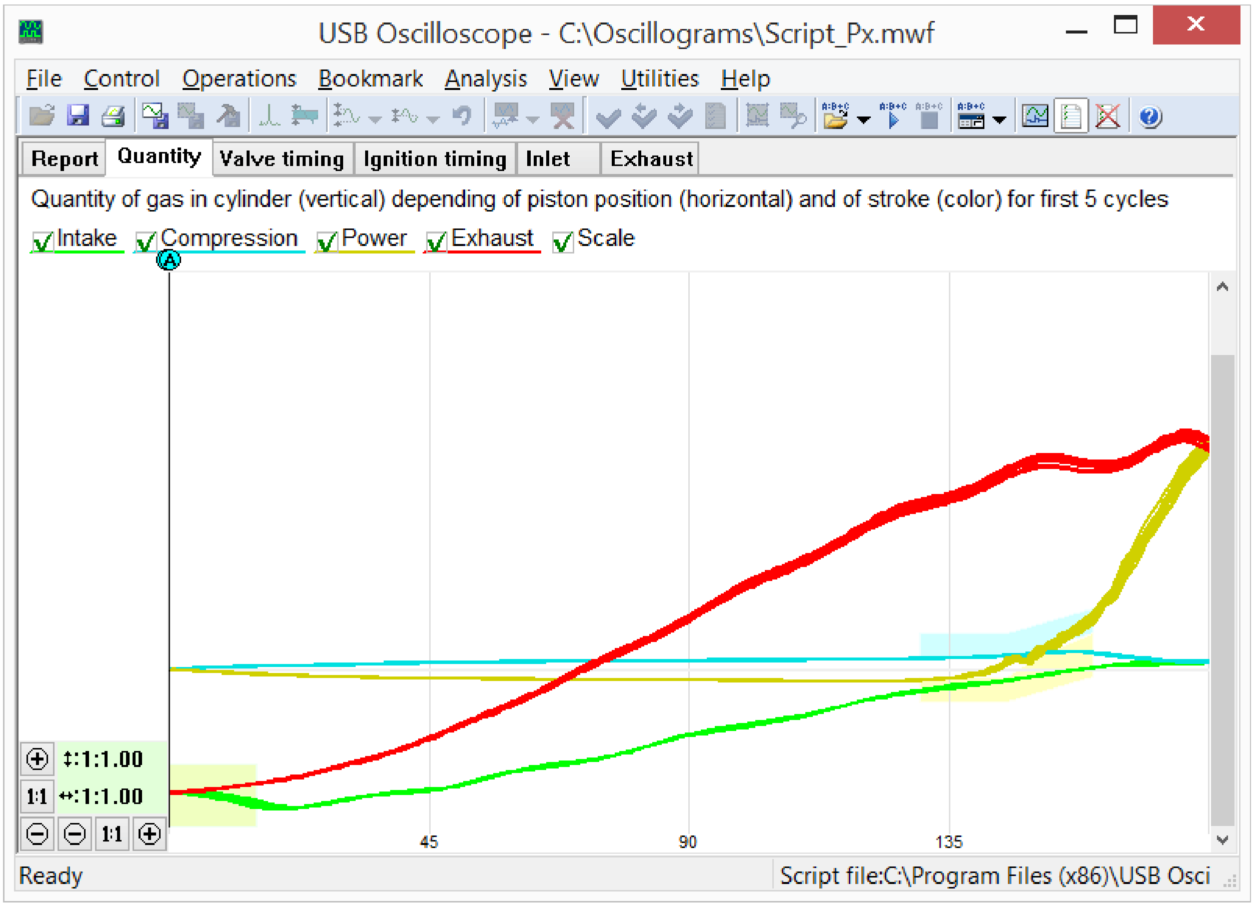
The "Report" tab from the Px script.

The compression ratio can usually be found in the service information, under general engine data, and depends on the engine's design.

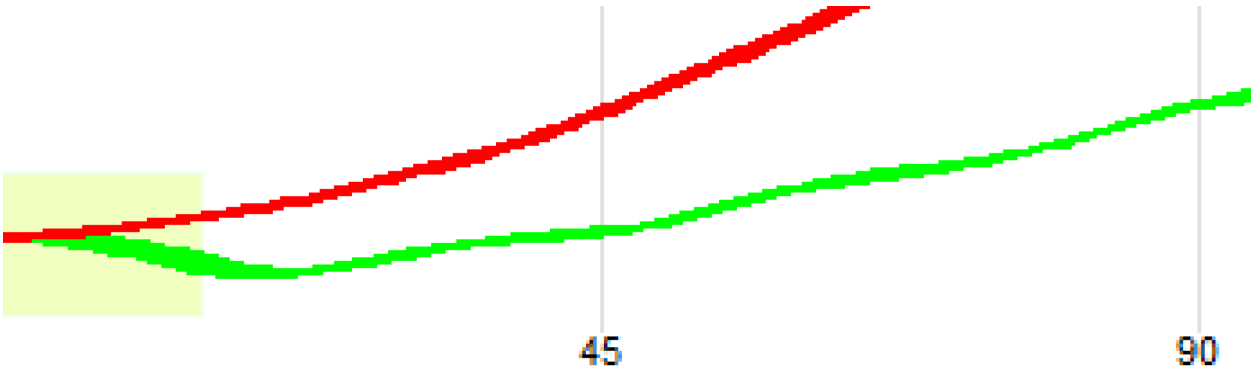
Normal pressure or gas loss for an engine in good condition is in the range 10…18 %. A loss of more than 20 % could indicate excessive leakage in a cylinder. The algorithm for calculating cylinder losses is complex, with some variables that are difficult to account for. A typical problem is the heat loss of the gas in the cylinder. The heat loss arises from the fact that the gas temperature in the cylinder during compression, even without ignition, is rising above the temperature of the cylinder walls. Consequently, part of the heat energy of the gas in the cylinder is transferred to the piston, cylinder and cylinder head. The loss of heat causes a loss of pressure. In practice, the calculated cylinder pressure loss of an engine in good condition is about 10 %.

3.2 The "Quantity" tab

Shows a diagram of gas in the cylinder depending on the piston position and the stroke.



The "Quantity" tab from the Px script report, this engine is in good condition. The graph indicates the amount of gas in the cylinder relative to the position of the piston in the cylinder and the stroke.



This is the characteristic shape of the left part of the red and green traces from an engine in good condition.

When plotting a diagram of the amount of gas in the cylinder 4 colors are used that reflects the working strokes. The piston is at TDC on the left side of the diagram and at BDC on the right side. The volume of gas in the cylinder is represented by how high the trace rises in the vertical direction.

As the piston move farther away from TDC on the intake stroke, given as the green trace on the diagram, read from left to right, the volume in the cylinder is increased, the pressure is lowered, and so ambient air flows from the intake manifold and in to the cylinder. This causes the green trace to rise.

At BDC the piston changes direction and the volume in the cylinder begins to decrease, but the amount of gas in the cylinder continues to increase as evidenced by the blue trace on the diagram. The increase in gas volume occurs because the gas has weight and thus have inertia, causing the flow to continue even after the piston has changed direction on BDC. After the gas flow has stopped, gas may start to flow back in to the intake manifold due to the piston action. This back flow depends on the timing of the intake valve. When the intake valve is closed, no flow will exist, and the blue trace becomes essentially flat. In this particular case, the filling of the cylinder is maximized at 155° before TDC, and the intake valve closed approximately 140° before TDC.

After the piston passes TDC, previously compressed gas in the cylinder begins to «decompress», but since the valves are closed, the amount in the cylinder is still almost unchanged, so the graph looks almost straight line (yellow trace of the diagram, the left side, read from left to right). However, the clearly visible gradual spread between the straight yellow diagram trace and the blue trace, indicates the quantitative and heat loss of the gas in the cylinder. The greatest amount of loss is observed near TDC when the gas pressure and temperature are at their maximum.

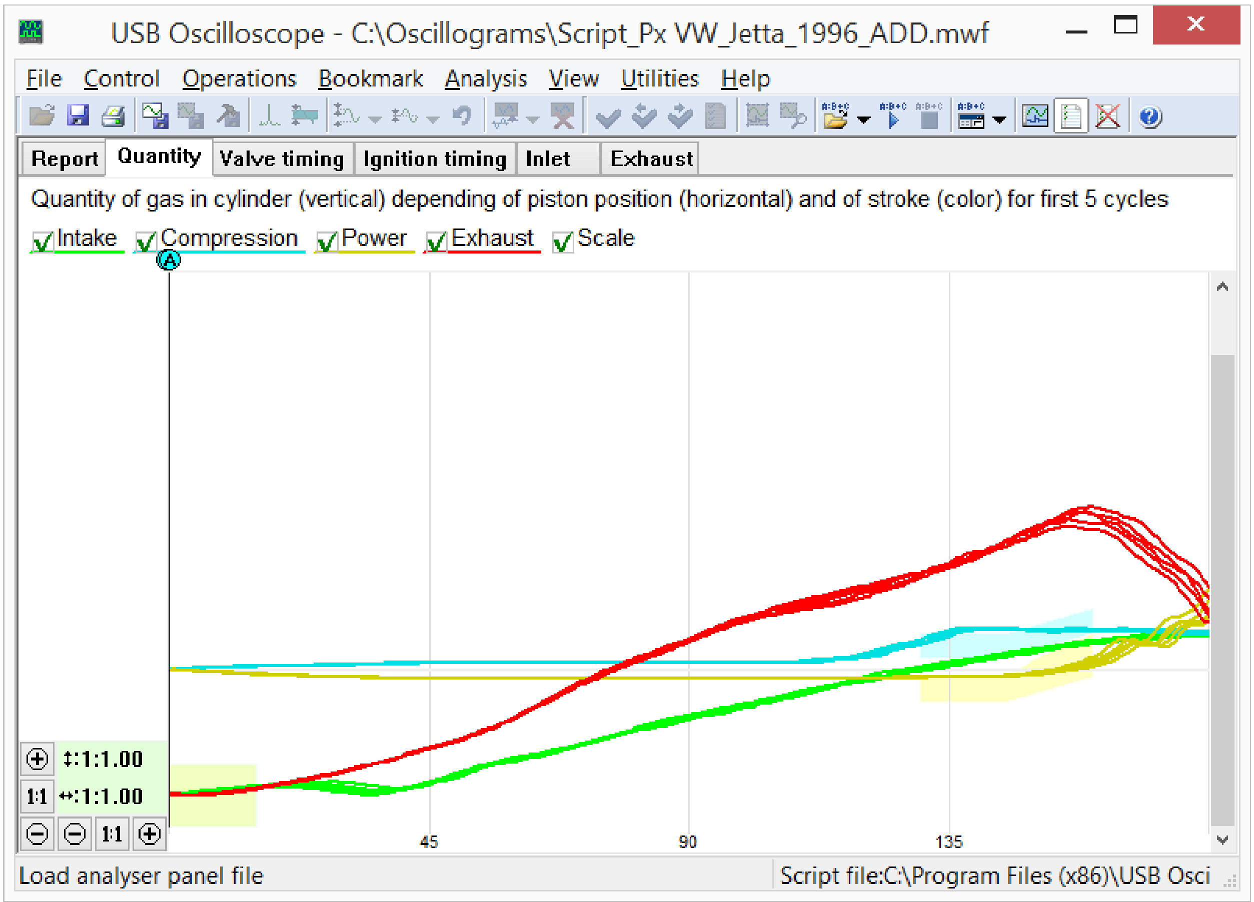
The exhaust valve begins to open before the piston reaches BDC, in this particular case the opening starts at 140° after TDC. Since the pressure measurements are made without a source of ignition so no combustion, the cylinder pressure at this point is almost identical to the pressure in the intake manifold. which is well below atmospheric pressure. The pressure in the exhaust manifold is close to the atmospheric pressure, and exceeds the pressure in the cylinder. Therefore, once the exhaust valve starts to open, the exhaust gases from the exhaust manifold begins to flow into the cylinder. This flow equalizes the pressure in the cylinder with the atmospheric pressure. This equalization is reflected in the diagram as a sharp rise of the yellow trace.

After passing the BDC point, the piston starts to push gas from the cylinder into the exhaust manifold (red trace on the diagram, read from right to left). When approaching TDC, the exhaust valve begins to close and the intake starts to open. At this point, the pressure in the cylinder is still close to atmospheric, as the cylinder is still open to the exhaust manifold. After passing through the TDC point, when the exhaust valve is fully closed and the intake is opening, part of the remaining gas in the cylinder flows into the intake manifold, since there is low pressure or vacuum in the intake manifold. Thus, the amount of gas in the cylinder is not minimum at TDC, but later. In this case, the minimum amount is reached approximately 20° after TDC, as shown on the diagram as a drop in the green trace. Further, because the volume in the cylinder is increasing, the gas flows from the intake manifold again.

Thus, using the graph of the gas quantity in the cylinder we can detect and measure where the intake valve closes and where the exhaust valve opens. If the nominal values for valve opening and closing are not given, deviations will have to be detected based on cylinder to cylinder variation (or comparing to a known good engine).

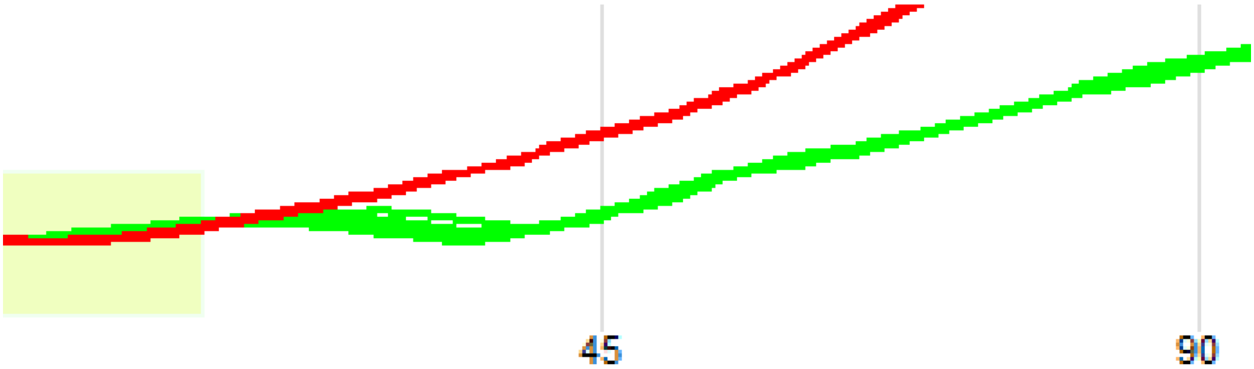
Different manifold designs will show different relative timing with respect to intake and exhaust phases. However, the width of the intake phase is always substantially the same as the exhaust phase. The phases are always substantially symmetrical relative to TDC as well. In practice this means that when the intake valve closes at 140° before TDC, the exhaust valve must be opened approximately the same 140° after TDC. In other words, in the same relative position of the piston. Because of this symmetry, on the diagram of the amount of gas in the cylinder the same characteristic points are located above one another. This is true for engines with narrow valve timing and with wide valve timing – phase asymmetry usually does not go beyond ±10°. This rule does not necessarily apply to engines equipped with Variable Valve Timing, however.

If the timing belt or chain is installed one tooth late on an engine with a single overhead camshaft, the error generally cause about a 15° delay. In figure of the amount of gas in the cylinder is reflected as an offset of the closing of the intake valve at about 15° to the left, and the opening of the intake is about 15° to the right. In this case it turns out that the characteristic points are away from each other by approximately 30°.



Valve timing is set incorrectly so the valves open and close late.

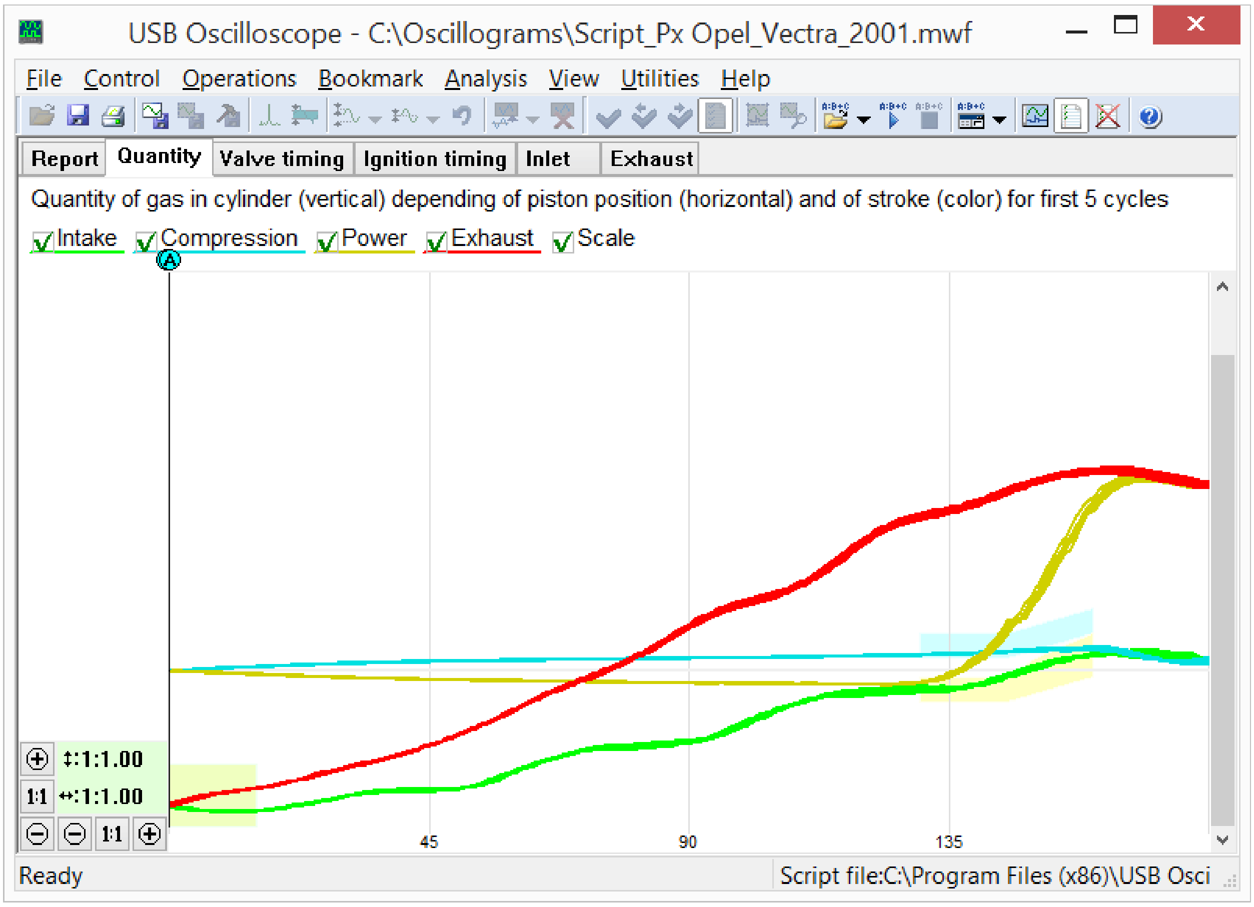
With late cam timing, the red and the green traces, showing exhaust and intake gas volume, respectively, overlap for the first approximately 20…30° of crankshaft rotation away from TDC.



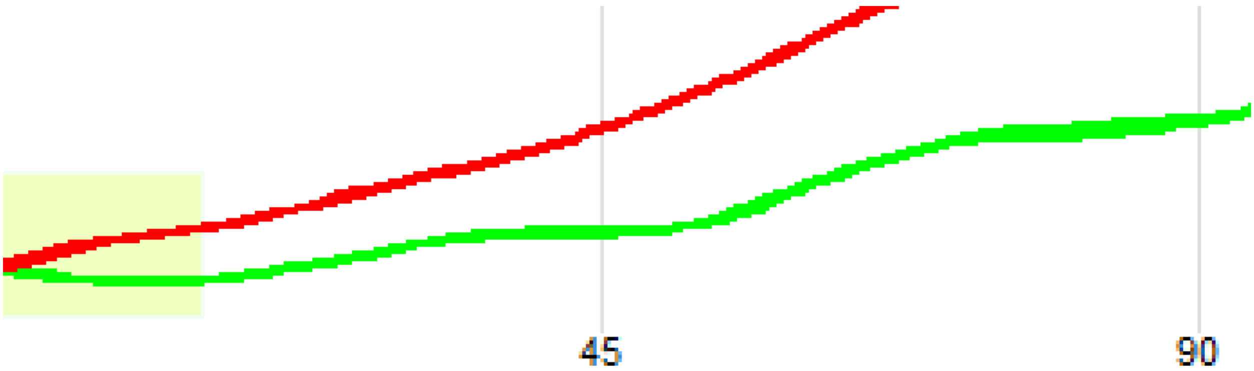
In this figure, can be seen that the red and green traces displaying the amount of gas in the cylinder are superimposed on each other for the first part of the crankshaft rotation.

In such case, the green trace rises up, superimposing on the red trace and after deviates down.

If the camshaft is installed 1 tooth early, the valve timing is advanced. This is the same as early opening and closing of the valves. In the diagram that is shown as an offset of the closing of the intake valve to the right, and opening of the intake valve to the left. Again, the characteristic points are again moving away from each other approximately 30°.



Valve timing set incorrectly – the valves open and close early.

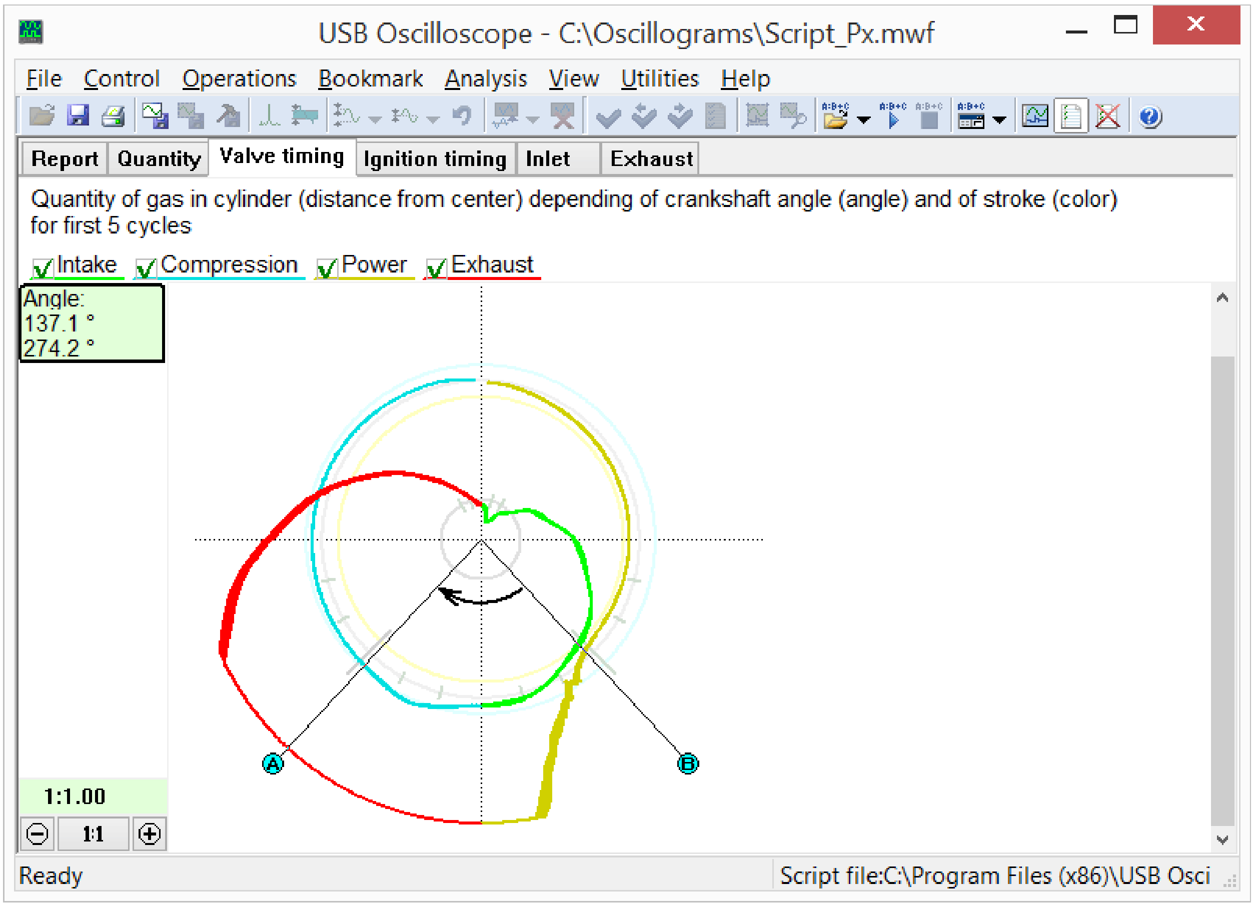


Typical waveform distortion seen when the valve timing is advanced.

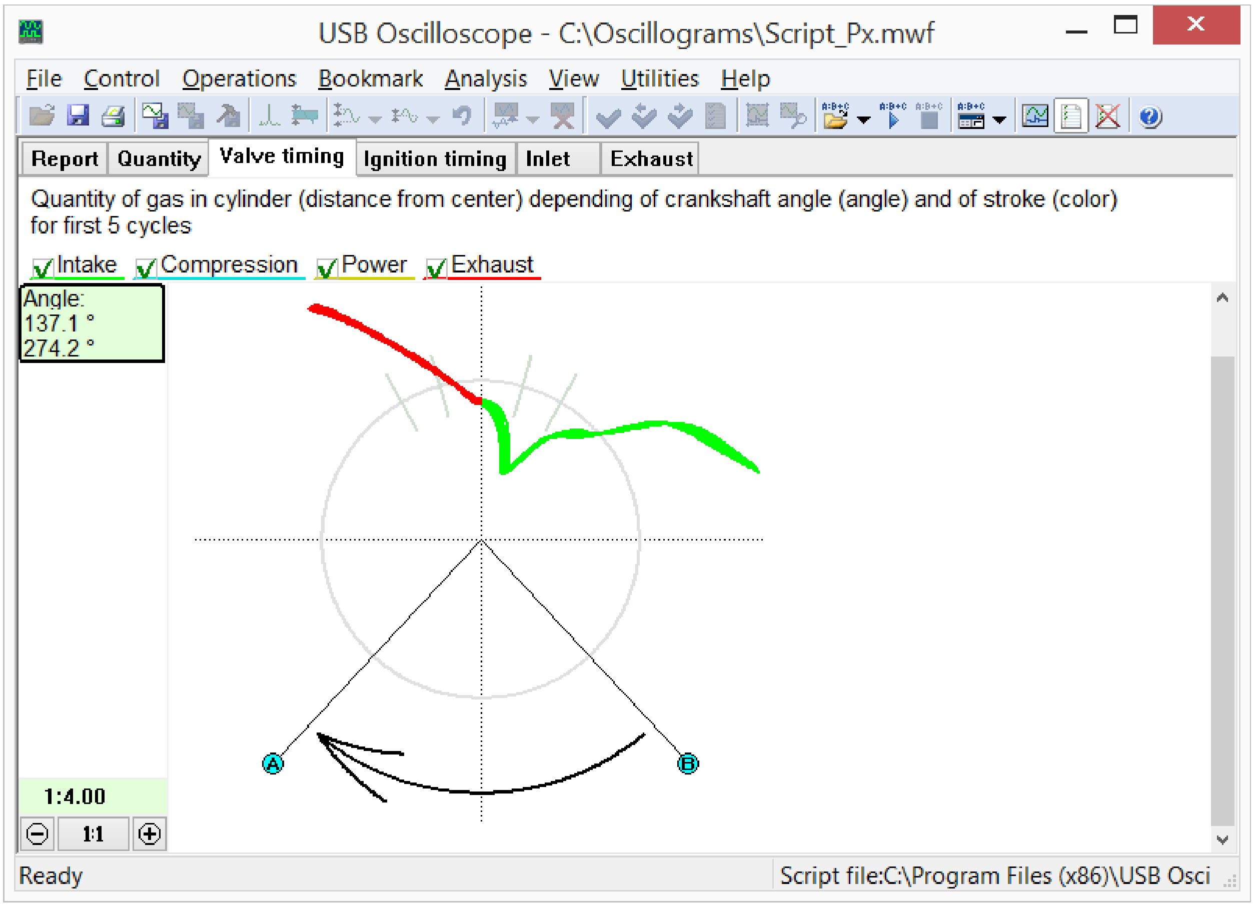
The waveform distortion shown in figure where the valves are overlapping is typical for advanced valve timing. The red and green traces do not overlap each other as they did with late valve timing and they have characteristic angles.

3.3 The "Valve timing" tab

This diagram gives the same information about the volume of gas in the cylinder as the "Quantity" tab does, but shown in relation to the angle of the crankshaft. The amount of gas in the cylinder is expressed as the distance from the center of the diagram. The trace's distance from the center is a visual representation of the amount of gas in the cylinder.

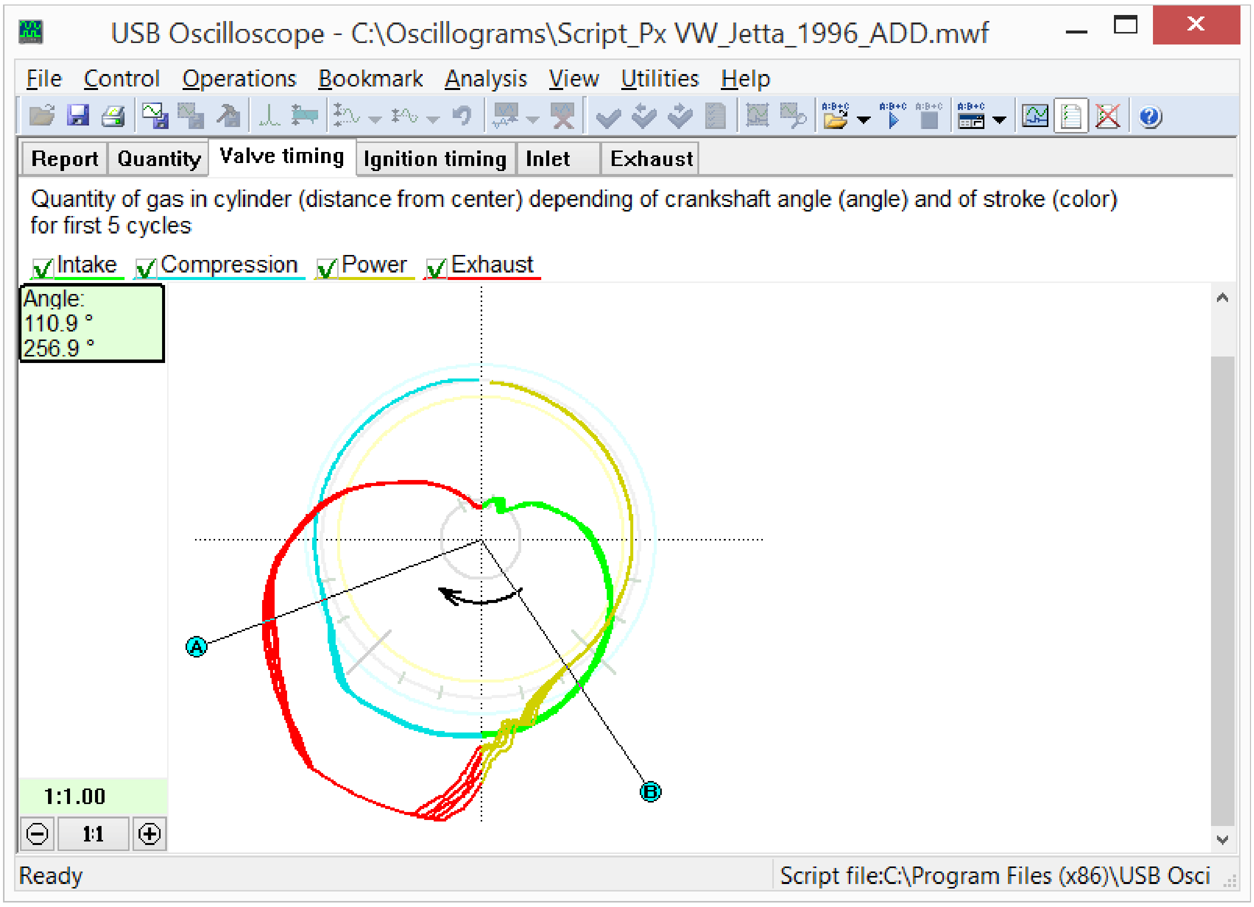


Typical diagram from the "Valve timing" tab. This is an engine in good working order. This diagram shows the amount of gas in the cylinder depending on the angle of the crankshaft and the stroke of the tested cylinder. The A marker shows where the intake valve is closed, and the B marker shows when the exhaust valve begins to open. Note that the marker locations are symmetrical relative to the vertical line.

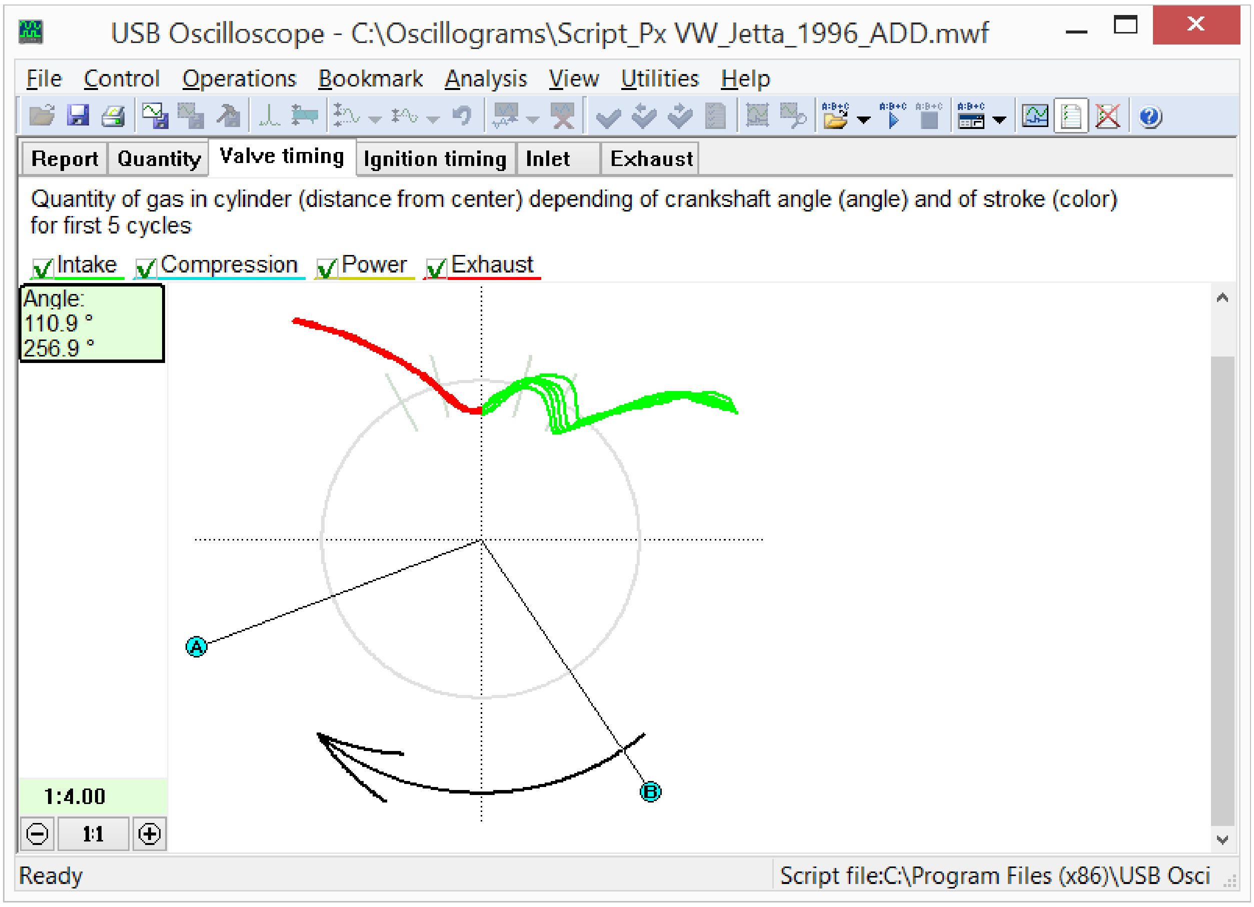


Zoomed figure in capture showing more detail on the center of the diagram from a typical engine in good working order.

If the timing belt or chain is installed one tooth late, on engines equipped with a single camshaft, the valve timing for both intake and exhaust will be late. On the polar diagram this shows as a rotation of the valve phase diagram clockwise about 15° (if a timing belt, more if a chain). The intake valve closing and the exhaust valve opening are no longer symmetrical relative to the center line or TDC.



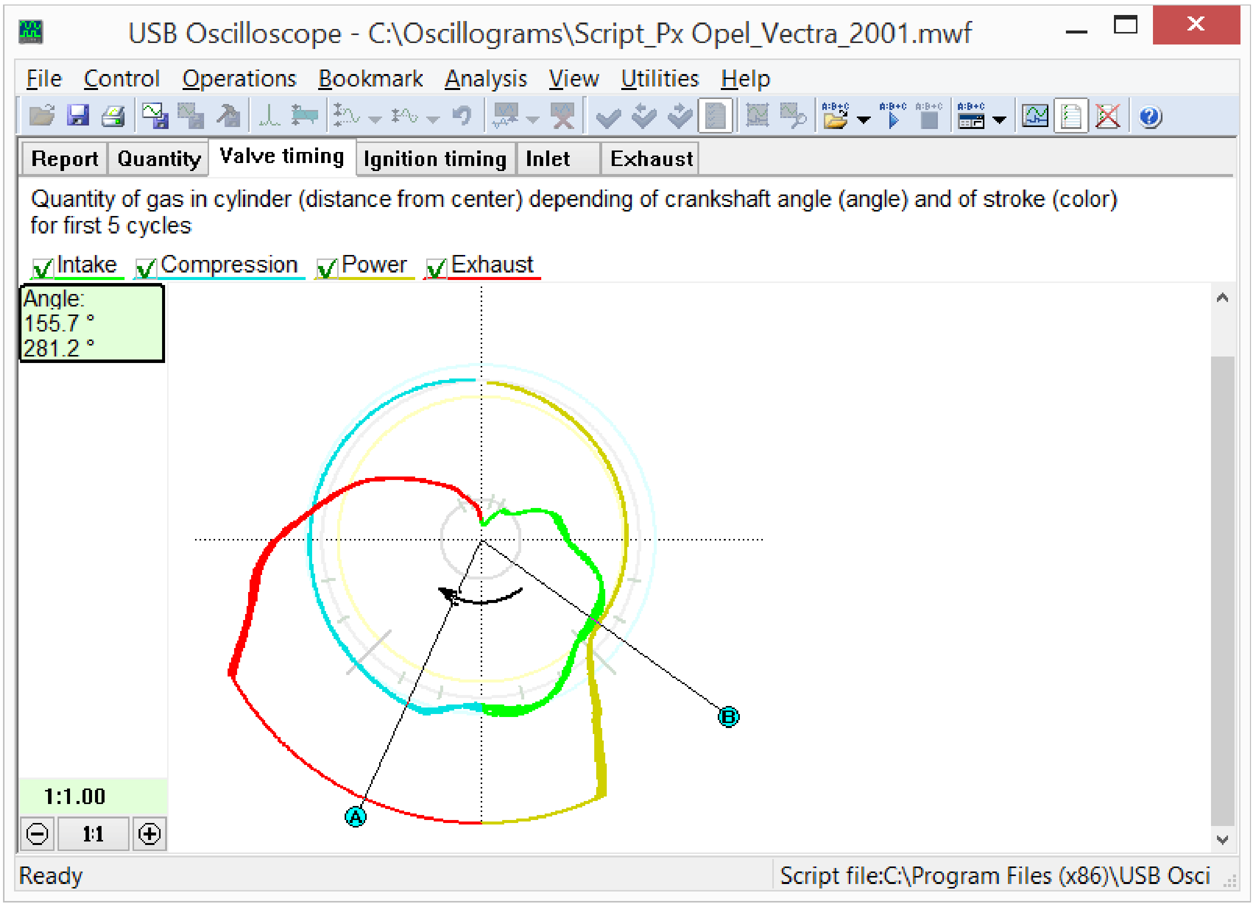
Polar diagram from an engine with late valve timing. The valves are opening and closing late. The A marker shows where the intake valve is closed, and the B marker shows where the exhaust valve starts to open.



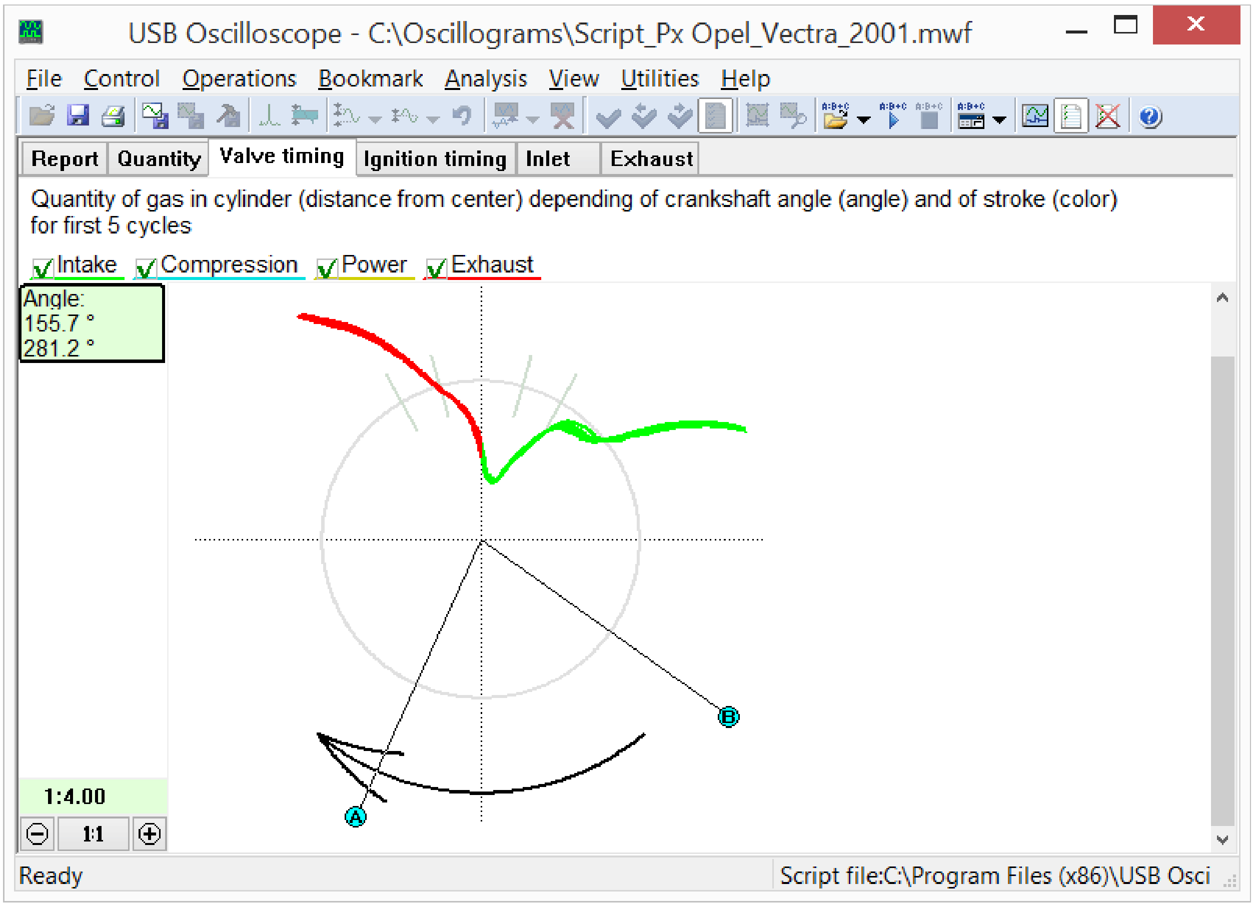
Typical distortion of the valve timing diagram in the zoomed center. The distortion is due to late valve timing.

The first phase of the distortion occurs because the piston, after passing TDC in the cylinder, starts to create low pressure in the cylinder and gases will flow from the exhaust manifold through the still open exhaust valve. The second part of the distortion occurs because the piston is already on its way down in the cylinder when the intake valve opens.

If the timing belt or chain is installed a tooth early, the valve timing will be advanced and the polar diagram will again be asymmetrical. Under this condition, the diagram will be rotated counter clock wise. The valve phases will again be asymmetrical relatively to the horizontal or TDC line.



The valve timing phases are asymmetrical showing an incorrect valve timing. In this example the cam timing is advanced one tooth. The A marker shows the angle when the intake valve is closed, and the B marker shows when the exhaust valve started to open.

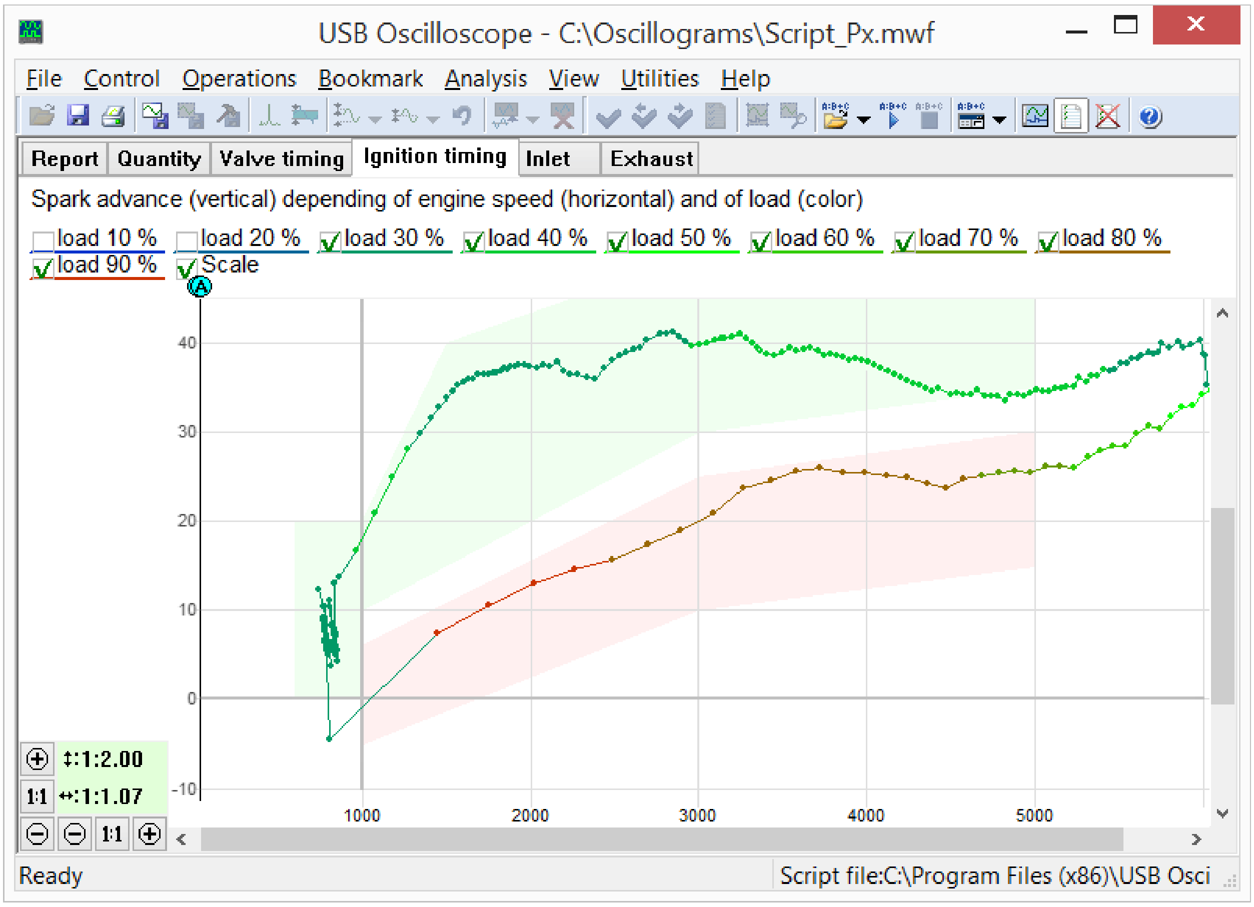


This zoomed figure shows the distortion of the timing diagram in the center, due to the early or advanced valve timing.

The distortion of the red trace on the diagram is due to gases from the cylinder flowing into the intake manifold because the intake valve opens too early.

3.4 The "Ignition timing" tab

If a sync signal from a plug wire or similar was recorded along with the data from the pressure transducer, the Px script will also construct an ignition timing diagram.

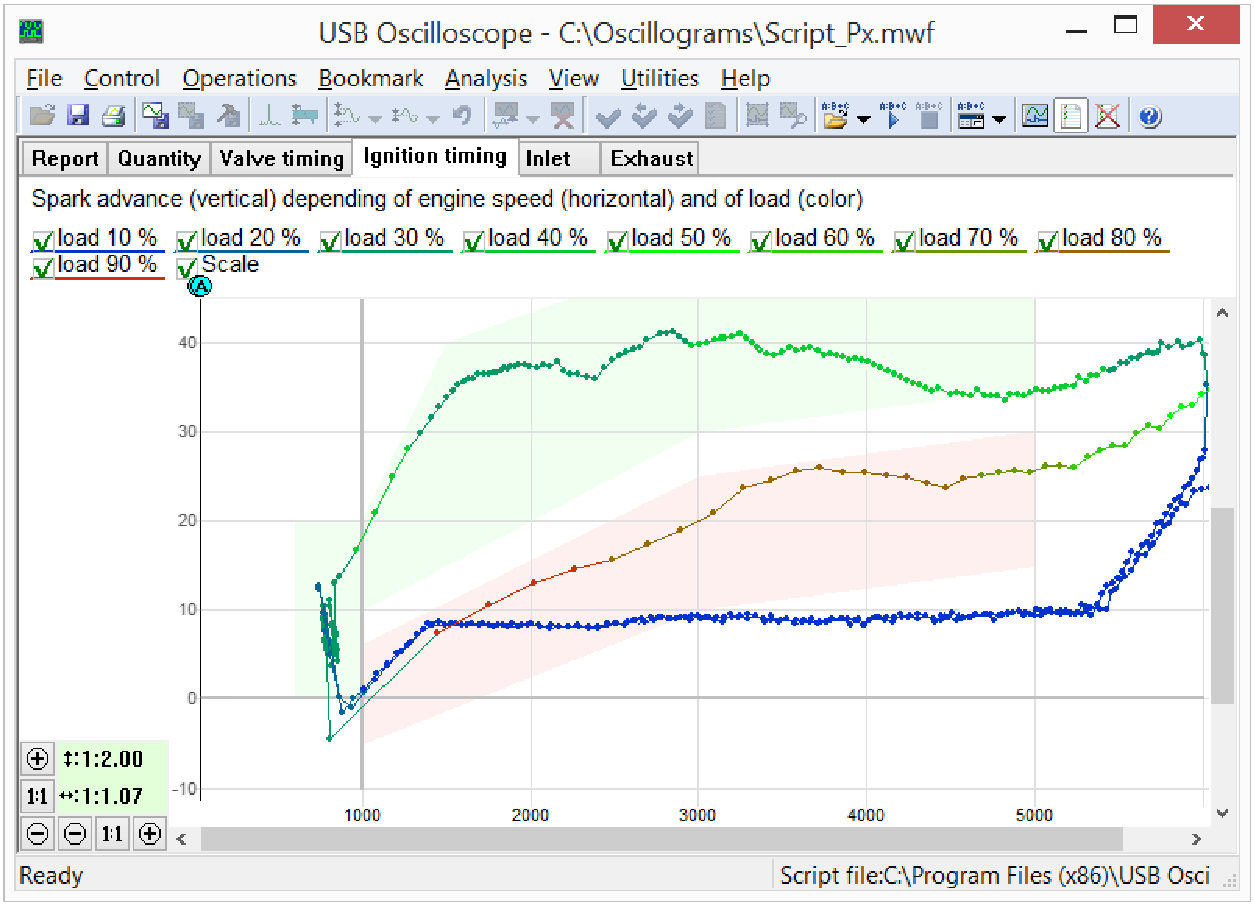


This is an ignition timing diagram from an engine in good working order. The data is taken from two throttle openings. One sharp and one smooth opening.

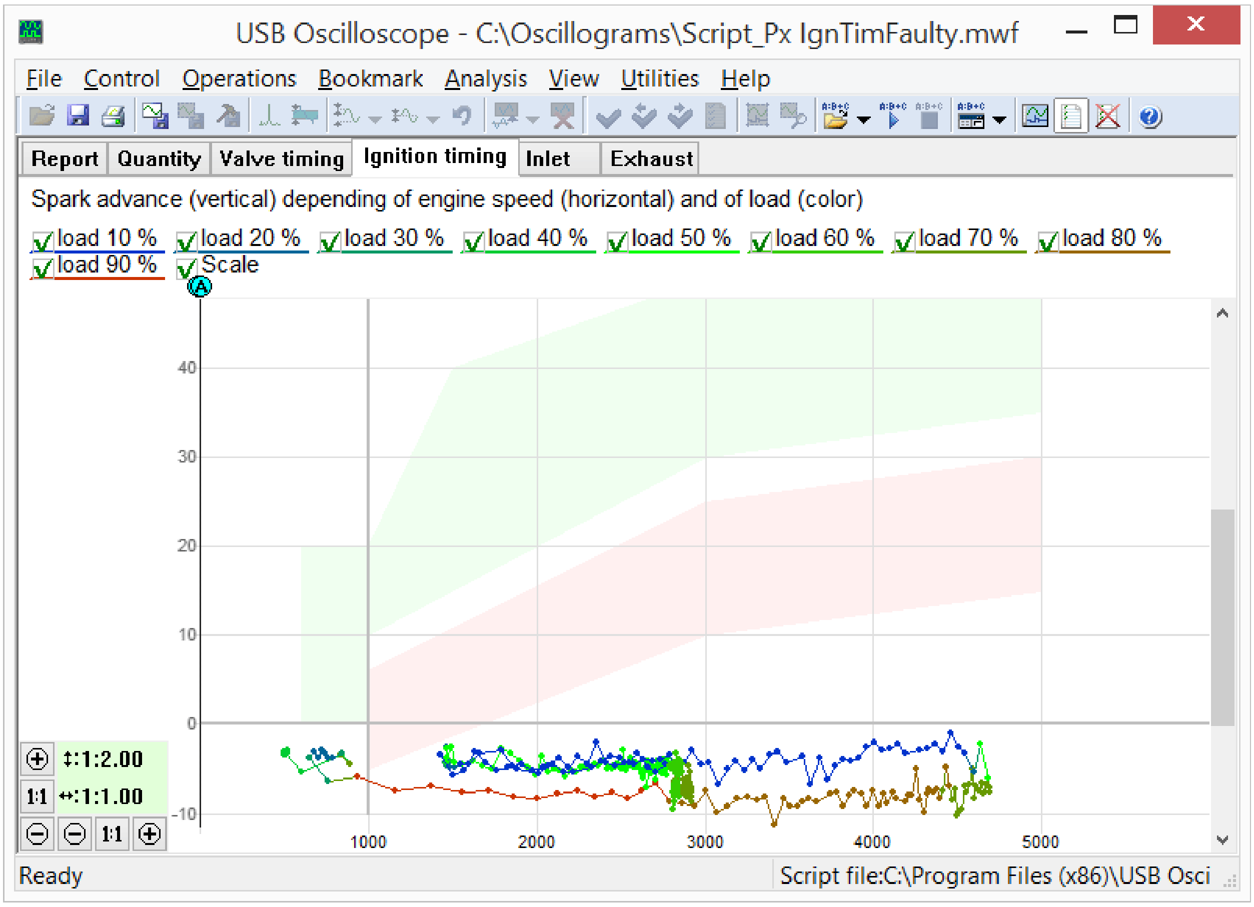
In the diagram colors are used to signify the load on the engine with blue being the lowest engine load and red the highest. The higher the load, the warmer the color.

Normal operation of the ignition timing is shown in the diagram. As the engine RPM increases, so does the ignition timing. This is what used to be called centrifugal advance. On the diagram this advance is shown as an increase in the graph height as we move towards higher RPM (to the right). Normal operation also implies that the ignition timing will vary with load on the engine. With increasing cylinder pressure, also known as decreasing manifold vacuum, the ignition timing should delay, so the spark occurs later. The opposite is also true; with decreasing cylinder pressure, also known as increased manifold vacuum, the ignition should occur earlier, or advanced. Because the ignition is delayed with increased load, the red trace, which signifies high load, is located lower in the diagram than the green. The shaded areas signify where the ignition timing will normally occur. Events outside the shaded areas indicate malfunction.

When the engine in a modern vehicle is overrunning, as happens when you abruptly release the the accelerator pedal, or when the vehicle is decelerating, for example going downhill, the fuel supply is interrupted. Because there is no fuel supply in this mode, the ignition timing does not affect to the engine performance, so the corresponding traces on the diagram in this tab are not displayed by default. They can be turned on manually and will display as blue traces. Blue signifies very little load.



Typical diagram from the "Ignition timing" tab. This engine is in good operating condition. Here the low load or overrun trace is activated.

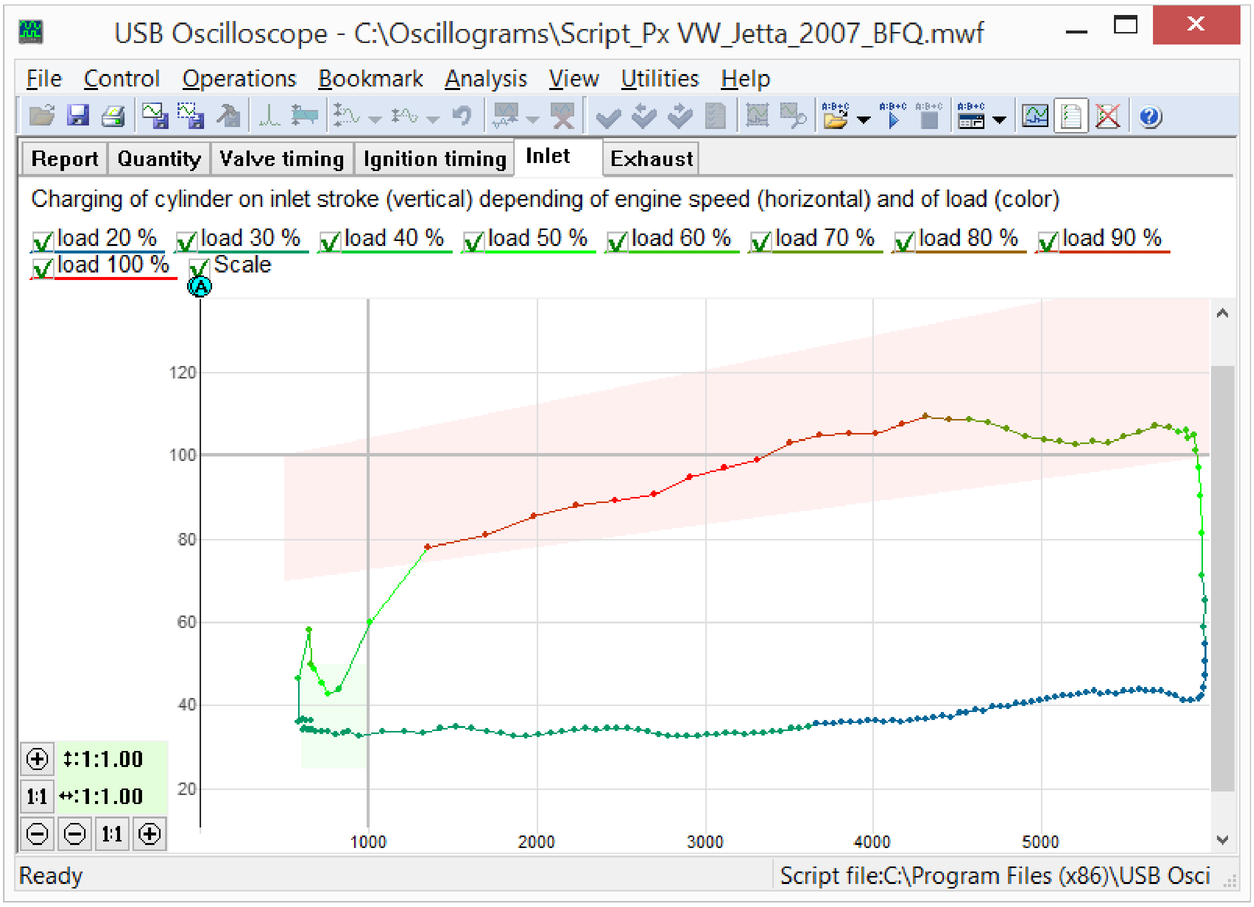


This is a timing diagram showing abnormal timing control.

If there is a control or adjustment problem, the timing traces will appear outside the shaded areas. In this example, the ignition timing is very late and does not adjust with either RPM or load. The engine will have very low power. This problem was caused by a faulty engine control unit.

3.5 The "Inlet" tab

This tab displays a diagram of cylinder fill, depending on the engine speed and load. The height of the graph represents the amount of gas remaining in the cylinder after the intake valve closed. The colors of the diagram traces reflect the engine load, the load value is being calculated by the vacuum in the cylinder during the intake stroke.



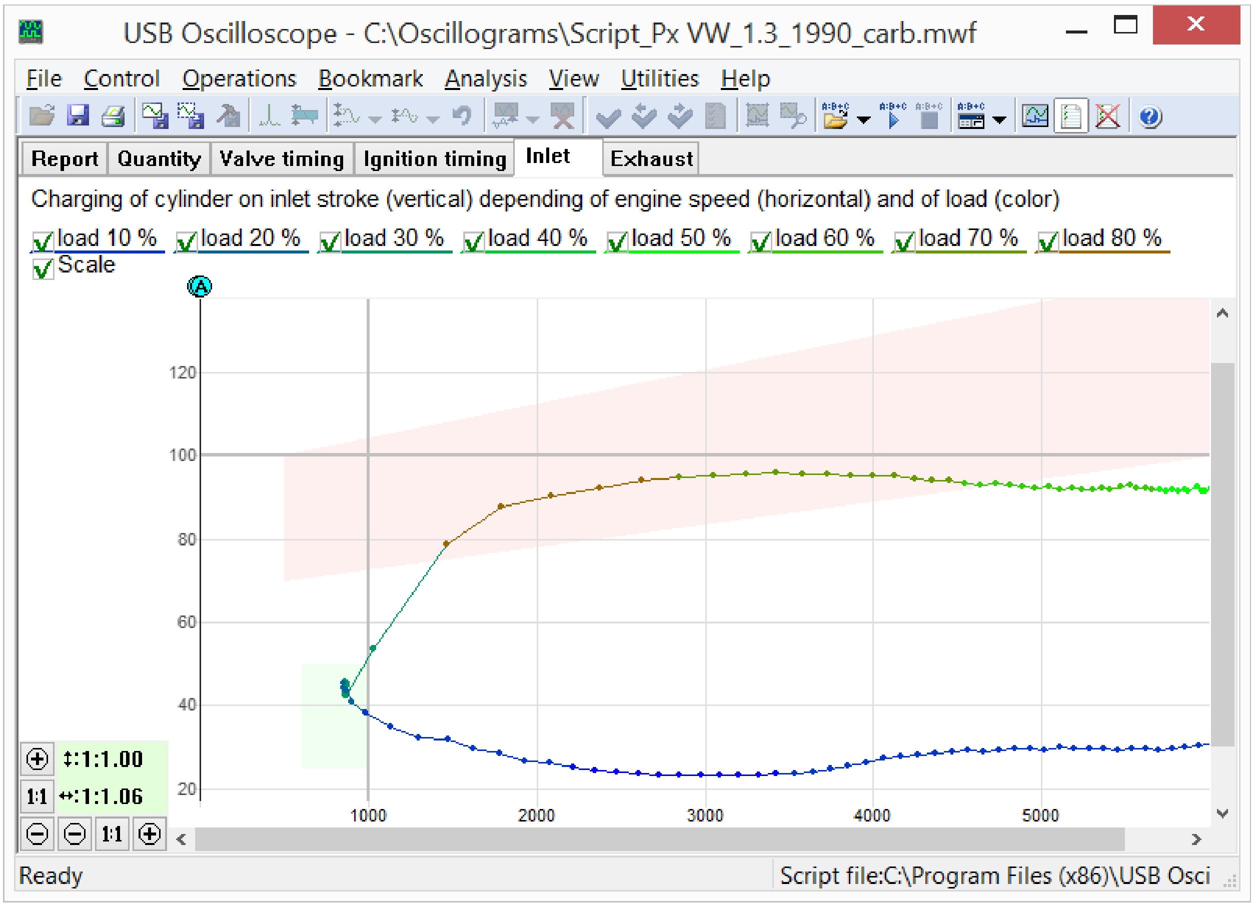
This graph from the Inlet tab was recorded using two throttle snaps, fast and slow.

The red trace of the diagram allows us to estimate the influence of all the components of the intake system in filling the cylinder. The red trace is a measure of VE (Volumetric Efficiency). The higher the trace, the larger is the maximum cylinder fill. In most circumstances, this directly relates to the cylinder's efficiency. Some of the factors that affect the cylinder fill are: Variable Valve Timing, lift, duration, and overlap, the intake manifold design and geometry, the maximum cross section of the throttle body, the throttle angle, and the flow restriction of the air filter and the induction system.

The traces show the cylinder fill with low RPM or idle to the left and higher RPM to the right. The lower the trace is, the more efficient and economical the engine is operating. The height of the trace depends on variables such as: Air-fuel mixture, ignition timing, EGR (Exhaust Gas Recirculation), any restriction from the exhaust system and power required from the engine. As the AFR (Air Fuel Ratio) changes away from optimum, the trace will move higher. The more EGR is used, the higher the trace will be. The more exhaust restriction there is, the higher the trace will move. As ignition timing changes, so will the trace. An finally, as demand on the engine changes, so will the height of the trace. Power demand can vary due to a number of reasons, even at idle; head lights on / off, air conditioning on / off and so on.

Next we will compare the inlet diagram from two engines. These two engines have significant differences in their induction system design. Neither of the engines use turbo or super charging.

The first one is an engine equipped with a carburetor and one intake and one exhaust valve. No Variable Valve Timing is utilized on this engine. The intake manifold design has to accommodate fuel as well as air.

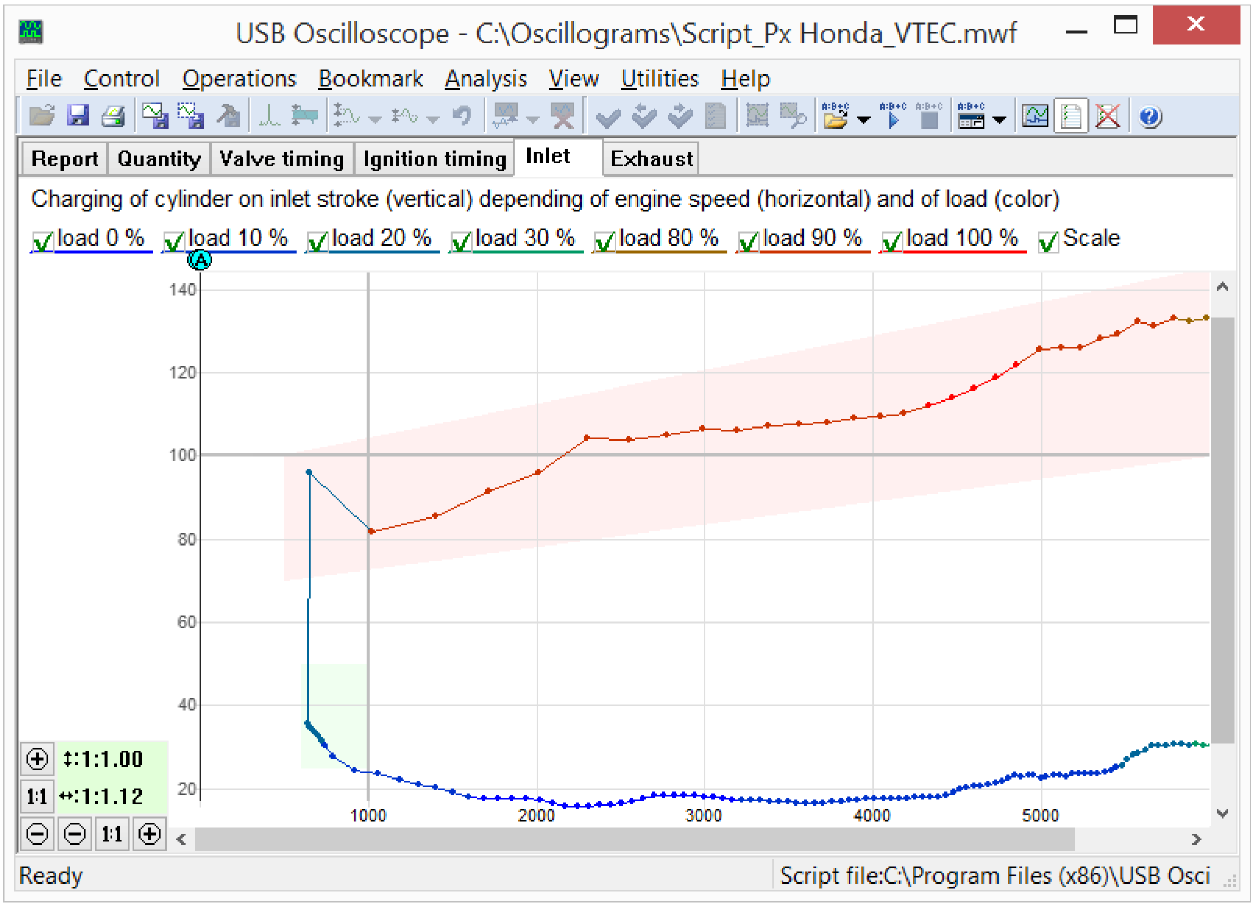


Cylinder filling diagram from an engine equipped with a carburetor and one intake and one exhaust valve per cylinder.

It is can clearly be seen that this engine does not have increased cylinder fill with increased RPM. Also, the red trace is only within what is considered the normal band in the 1200…4600 RPM range, outside that RPM band the cylinder fill is below. Based on this, it is clear that this is an engine designed to operate in a low RPM range.

It should be noted that with the increase in RPM, the color of the diagram gradually goes from warm to cold. This is especially pronounced after 4500 RPM. This is because the induction system represents a restriction in this RPM range and the cylinder fill is decreasing.

Let's see the diagram from an engine with a different design. This engine is equipped with Variable Valve Timing and is using 4 valves per cylinder, 2 intake and 2 exhaust valves. The induction system is designed very differently, the engine uses port fuel injection and the intake manifold is designed for air only.



Cylinder filling diagram from an engine with a 4 valves per cylinder and a different induction system design.

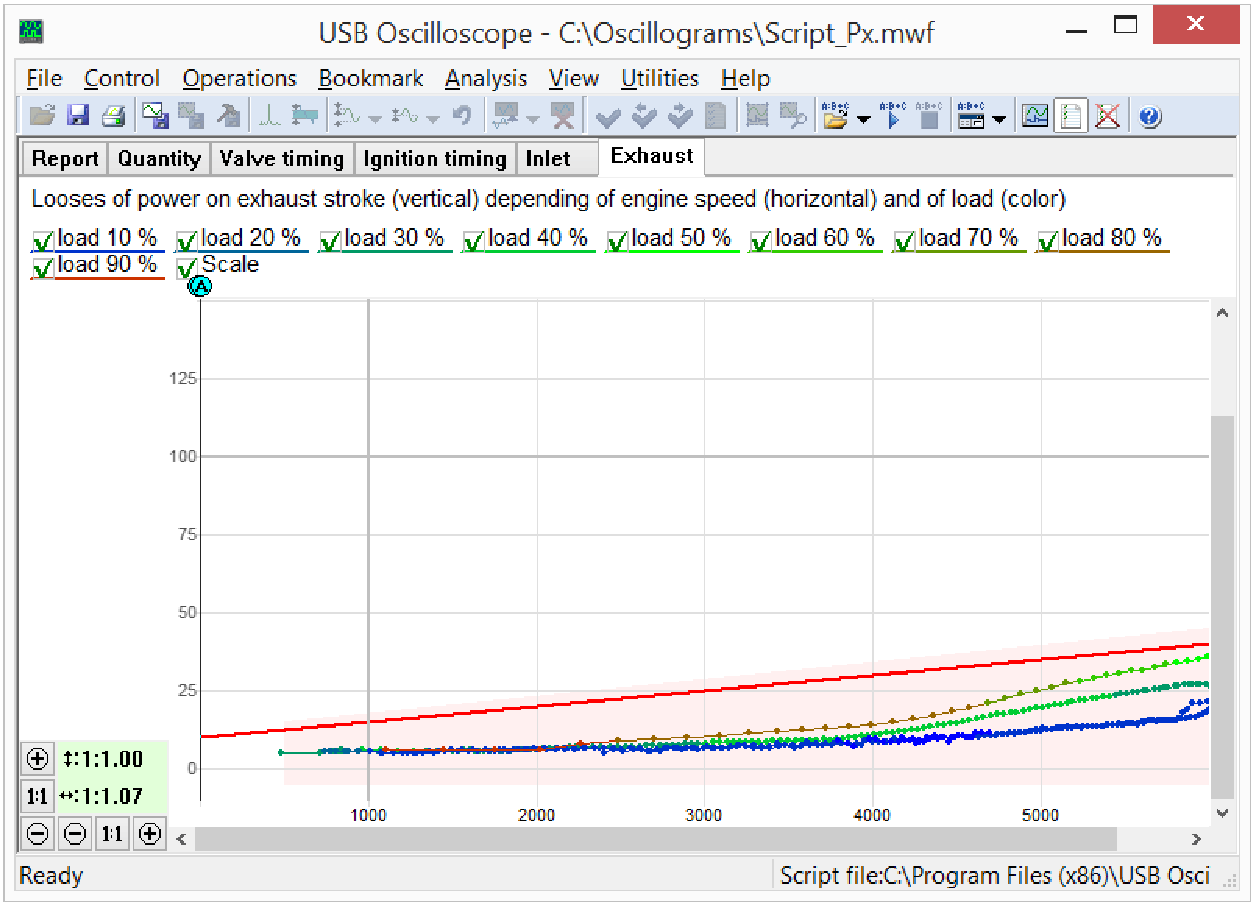
The red trace clearly shows that this engine has much better cylinder fill throughout the RPM range compared to the previous example. This engine is designed to operate well at higher RPM. Even though the engine is designed for higher RPM, the cylinder fill at low RPM is comparable to the diagram from the low RPM engine.

The color of the diagram is hotter than in the previous example, and starts to change towards warm only after 5500 RPM. This means that the induction system is causing little or no resistance to air flow into the cylinder.

Also noticeable is that the cylinder filling of this engine at RPM higher 4000 RPM significantly exceeds 100 %. This is achieved without forced air injection. The over unity cylinder fill is achieved through the use of Variable Valve Timing and a tuned induction system. The intake valve is left open for some degrees of crankshaft rotation after BDC on the intake stroke. The velocity of the incoming air is high and will continue to fill the cylinder even after the piston has passed BDC, thus creating a slight over pressure in the cylinder.

3.6 The "Exhaust" tab

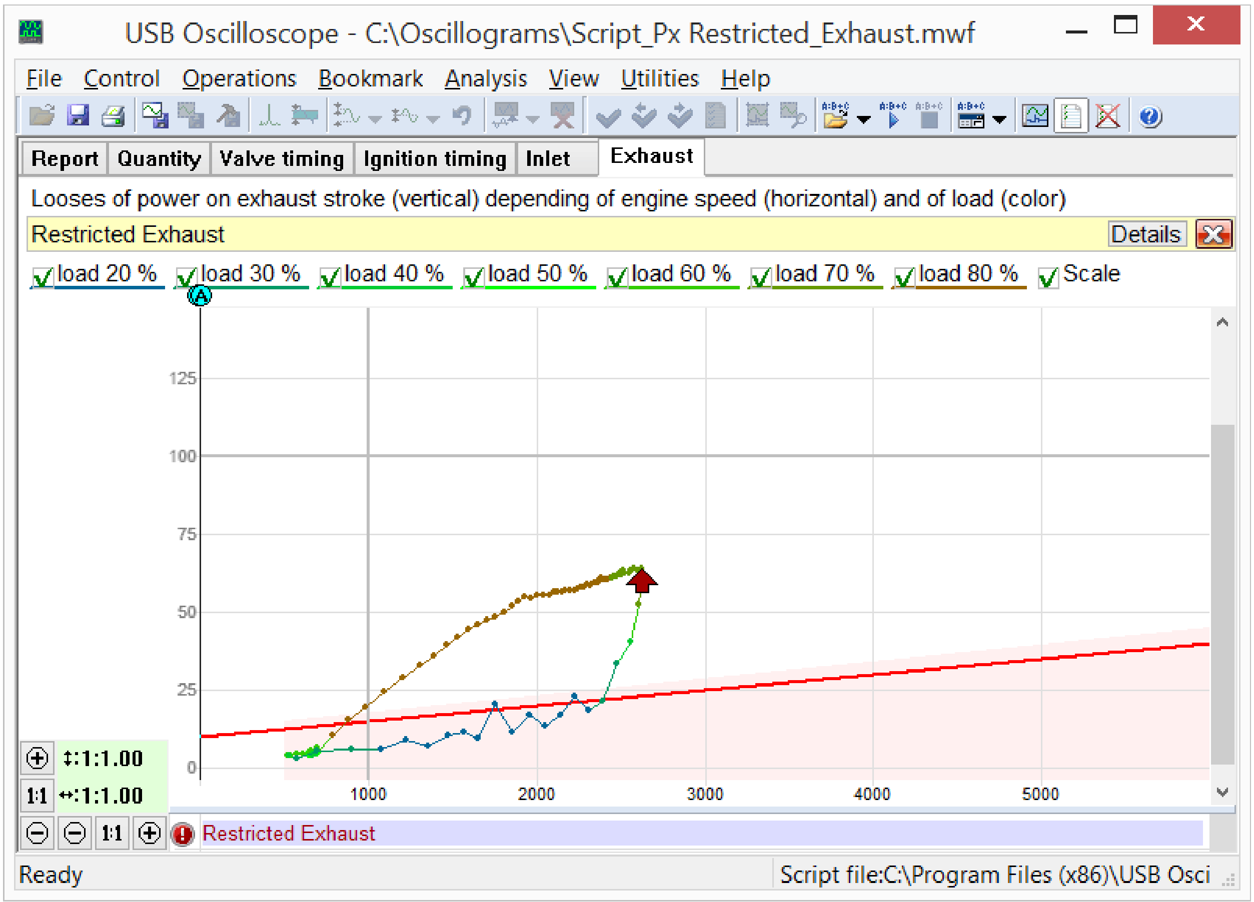
The "Exhaust" tab displays a diagram showing the amount of work spent on expelling the exhaust gases from the engine.



The "Exhaust" tab. This diagram taken from an engine with normal exhaust system restriction.

The lower the trace, the less exhaust restriction exists.

The sloping red line signifies the allowable exhaust restriction. This trace was determined empirically by collecting data from several engines, some in good working order, some not.



This diagram shows a fairly severe exhaust system restriction. In this case the problem was a plugged catalytic converter.

The diagrams in this tab are calculated based on the effect the exhaust system back pressure has on the piston movement. If the peak back pressure occurs when the piston is close to TDC, the effect of the back pressure is minimal. This is because the piston speed is minimal at that moment. On the other hand, if the peak back pressure occurs when the piston is approximately midway through the stroke, the effect is much more pronounced. For this reason, the actual exhaust system design does not have as much of an effect on the trace as does unintended restrictions. Because of the dynamic manner in which the restriction is measured and calculated, smaller restrictions can be detected before they significantly affects the engine performance.

Andrew Shulgin

v4.3.6.1