Analyzing the Cylinder Pressure Waveform from a Running Engine, Part 2

In Part 1 of this Maximizing Tools series, we discussed an alternative approach to diagnosing an engine using the pressure waveforms from an in-cylinder pressure transducer. Part 2 continues our discussion in more detail, analyzing the Valve Timing and Ignition Timing tabs on the waveforms. Part 3, which will be featured in our October/November issue, will discuss the Inlet (or Intake) and Exhaust tabs. To view Part 1, see the April/May 2014 edition or visit http://bit.ly/StA6pi.

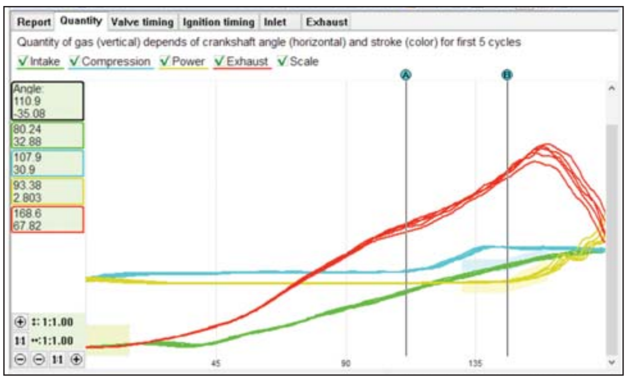

Figure 1: Valve timing is set incorrectly so the valves open and close late. Marker A is set in the position of the piston coinciding with the end of closing of the intake valve and marker B with the start of the exhaust valve opening.

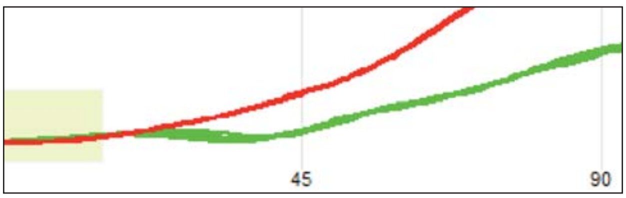

Figure 1a: In this figure, which a zoomed part of Figure 1, it can be seen that the red and green traces displaying the amount of gas in the cylinder are superimposed on each other for the first part of the crankshaft rotation.

As can be seen in **Figures 1 and 1a**, with late cam timing, the red and green traces — showing exhaust and intake gas volume, respectively — overlap for the first approximately 20-30° of crankshaft rotation away from TDC.

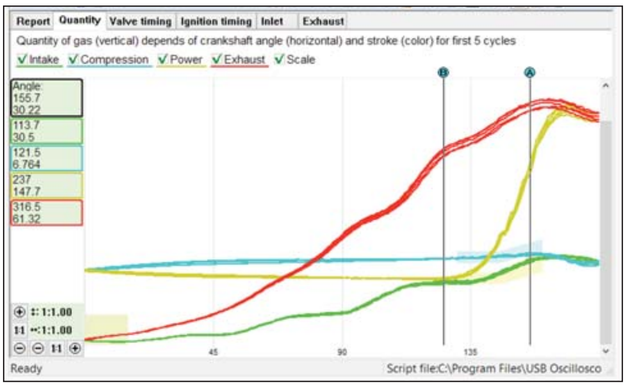

Figure 2: Valve timing is set incorrectly — the valves open and close early. The A marker is set to the position of the piston or crank angle that coincides with the end of closing of the intake valve and marker B is set to coincide with the start of the exhaust valve opening.

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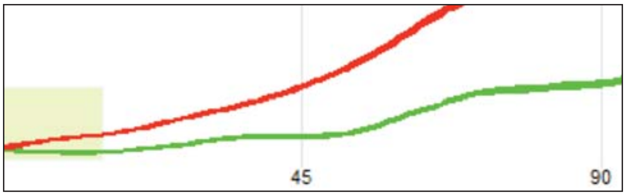

Figure 3: Typical waveform distortion seen when the valve timing is advanced.

If the camshaft is installed one tooth early, the valve timing is advanced. This is the same as early opening and closing of the valves. In **Figures 2 and 3**, 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 moving away from each other approximately 30°.

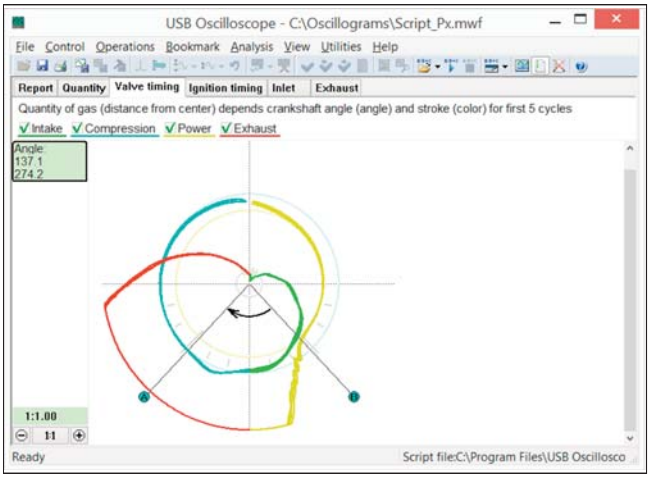

Figure 4: Typical diagram from the "Valve Timing" tab. This is an engine in good working order.

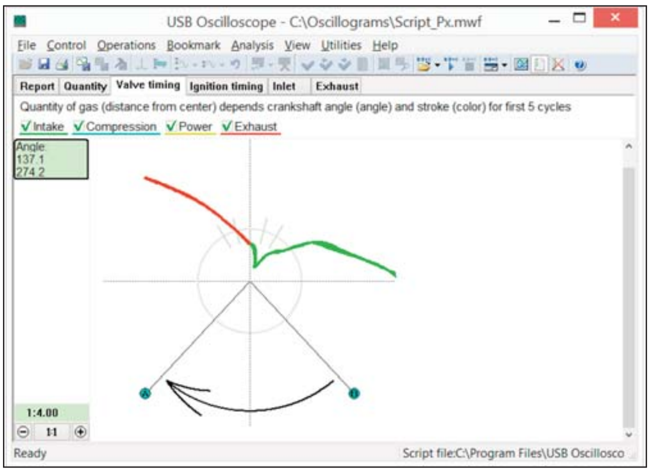

Figure 5: This is a zoomed in picture from the capture in Figure 4.

The waveform distortion shown in **Figure 3**, 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.

On engines equipped with a chain-driven camshaft, the shift of the opening and closing valves becomes larger than on engines equipped with a timing belt.

We have shown that valve timing can be quickly and accurately analyzed and verified using the method described.

The "Valve Timing" Tab

This tab provides a diagram that gives the same information about the volume of gas in the cylinder

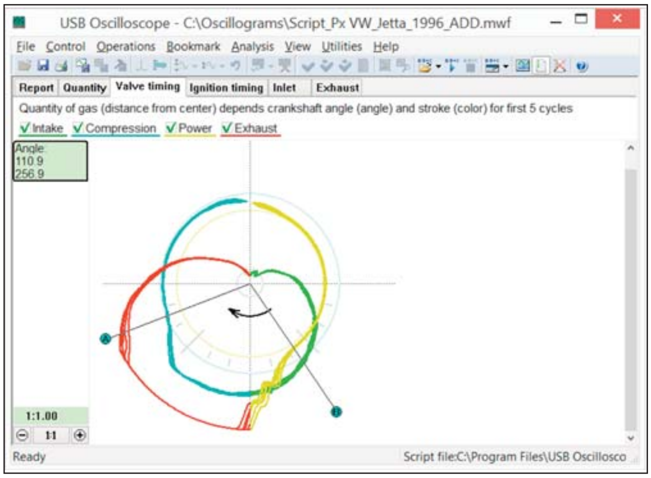

Figure 6: Polar diagram from an engine with late valve timing. The valves are opening and closing late. The A marker shows where the intake valve is closed, and the B marker shows where the exhaust valve starts to open.

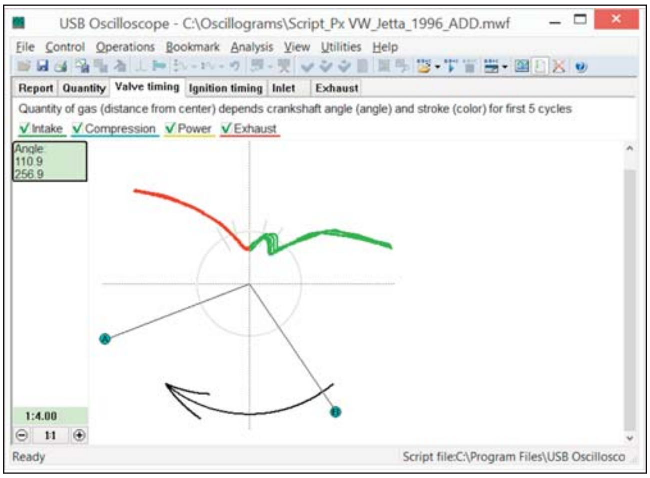

Figure 7: Typical distortion of the valve timing diagram in the zoomed center. The distortion is due to late valve timing.

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.

Figure 4, which is a polar 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.

Figure 5 on page 18 is a zoomed 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 there's a timing belt; more if there's a chain). The intake valve closing and the exhaust valve opening are no longer symmetrical relative to the center line or TDC. This asymmetry is shown in **Figure 6** on page 18. The late valve timing also manifests as a distortion in the center of the diagram, as shown in the zoomed-in diagram in **Figure 7** on page 18.

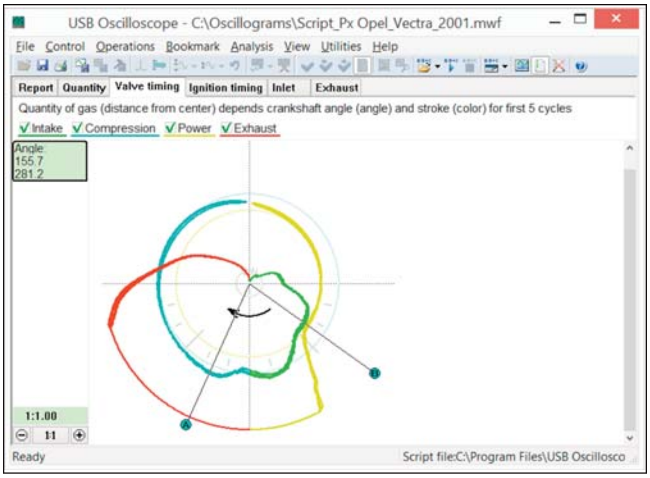

Figure 8: The valve timing phases are asymmetrical showing an incorrect valve timing. In this example, the cam timing is advanced one tooth. The A marker shows the angle when the intake valve is closed, and the B marker shows when the exhaust valve started to open.

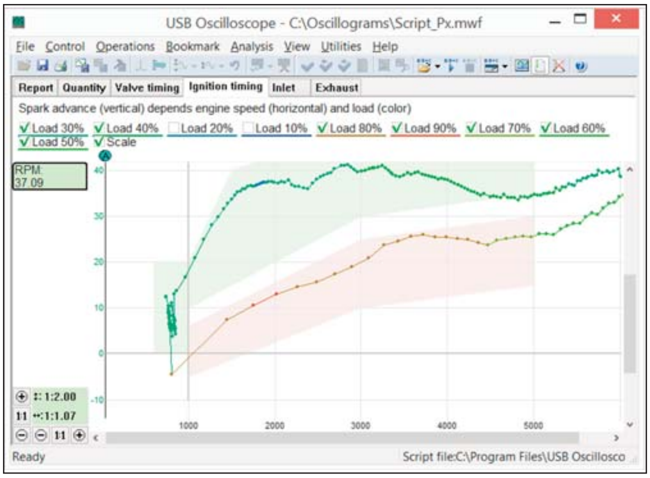

Figure 10: This is an ignition timing diagram from an engine in good working order. The data is taken from two throttle openings. One sharp and one smooth opening.

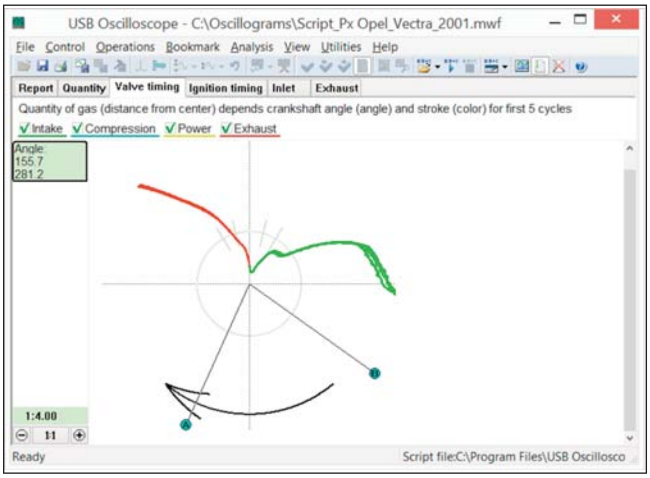

Figure 9: This is a zoomed-in part of Figure 8 and shows the distortion of the timing diagram in the center, due to the early or advanced valve timing.

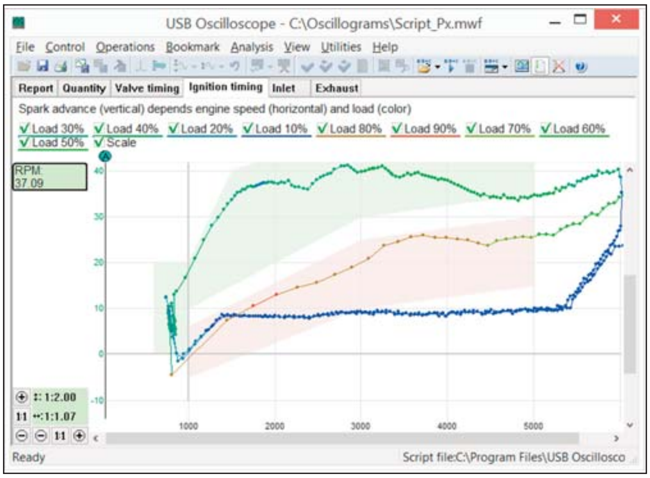

Figure 11: Here, the low load or overrun trace is activated. This engine is in good operating condition.

The first phase of the distortion in **Figure 7** 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 counterclockwise. The valve phases shown in **Figure 8** will again be asymmetrical relatively to the horizontal or TDC line. **Figure 9**, which is a zoomed in part of **Figure 8**, shows distortion in the center. Note that the distortion looks different from what it does with late valve timing.

The distortion of the red trace on the diagram in **Figure 9** is due to gases from the cylinder flowing into the intake manifold because the intake valve opens too early.

As is shown, the "Valve timing" and the "Quantity" tabs can both be used to determine and diagnose valve timing issues. Which one to use is simply a matter of personal preference.

With some practice, these diagrams can be used with variable valve timing as well. If the diagram from an engine in good working order is known, variations due to timing belt, chain or cam phasers are readily apparent in the waveforms.

The "Ignition Timing" Tab

If a synch signal from a plug wire or similar was recorded along with the data from the pressure transducer, the Px script will also

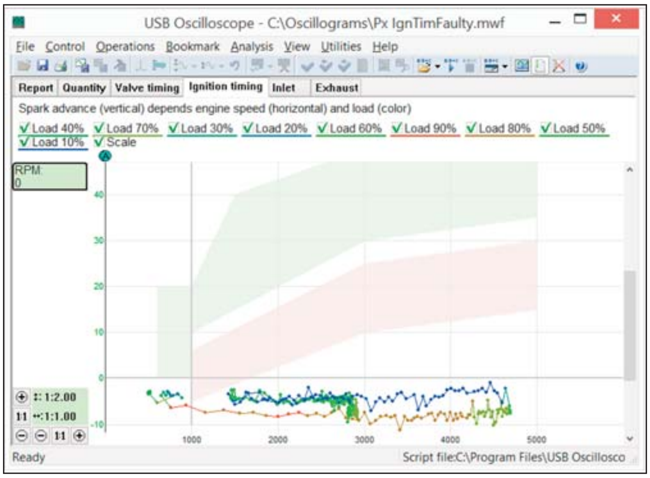

Figure 12: This is a timing diagram showing abnormal timing control.

construct an ignition timing diagram, as shown in **Figure 10** on page 20.

In **Figure 10**, colors are used to signify the load on the engine with green being the lowest engine load and red the highest. Green is 20% load and red is 90% load. 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 toward 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 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 as is shown in **Figure 11** on page 20, and will display as blue traces. Blue signifies very little load. Note that the ignition timing is very late unless the engine is at very high rpm. This can be verified and proven with a timing light, if needed. Because the operating conditions are outside normal range (overrunning), the blue trace is slightly below what is considered normal range.

If there is a control or adjustment problem, the timing traces will appear outside the shaded areas, as is shown in **Figure 12**. 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. TS