ENGINE DIAGNOSIS WITH PRESSURE TRANSDUCER

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Analysis of the cylinder pressure waveform on a gasoline engine makes it possible to determine the proper synchronization between the crankshaft and the camshafts. Measurement and comparison of cylinder pressure values at certain points provides real-time data that can be very helpful in determining engine health. The pressure at the Top Dead Center (TDC) on a running straight four-cylinder engine fluctuates between about 65 and 90 psi. Smaller readings than these typically indicate serious mechanical defects in the cylinder tested, and the larger readings typically mean extra air is entering the cylinder or that the engine is under heavy load.

During the intake stroke, cylinder pressure is reduced to a point lower than the pressure in the intake manifold. During the exhaust stroke, the pressure in the cylinder should not exceed atmospheric pressure. If it does, look for clogging of the exhaust ports, reduced exhaust valve lift, or restricted exhaust.

1. Distinctive features when observing the measured waveform

Cylinder pressure waveform also allows you to collect the following important pieces of data:

- Connecting an inductive probe to the cylinder in question on one channel and a pressure sensor on the second channel in that cylinder will provide a more accurate indication of the spark event timing in relation to TDC than is possible using the scan tool data stream. If there is a large discrepancy between the two values, it is good to check the crankshaft trigger wheel for proper indexing, since the ignition is triggered based on input from the crank sensor.
- The mechanical condition of the engine can be deduced by skillfully observing scope pattern of the the pressure difference before and after the compression stroke.

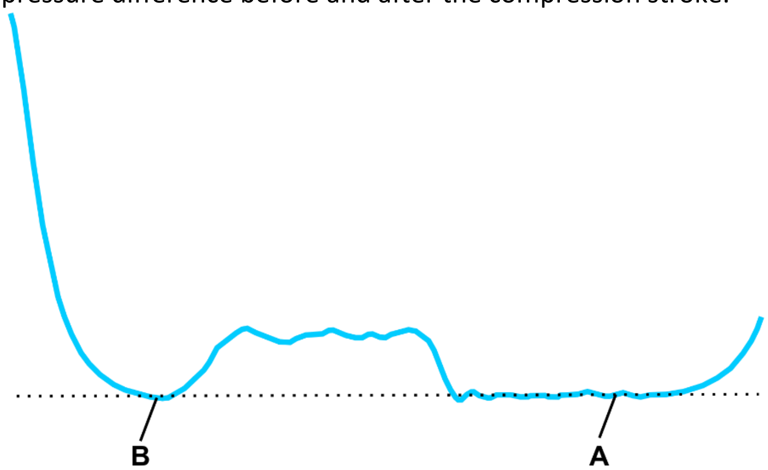


Fig.1. Normal engine operation

When a cylinder is operating properly, the pressure at point A should be approximately equal to the pressure at point B. If the cylinder has mechanical issues (burnt valve, broken segments, camshaft timing issues, etc.), the pressure at point A will be noticeably higher than the pressure at point B due to compression leaks. An example is shown below:

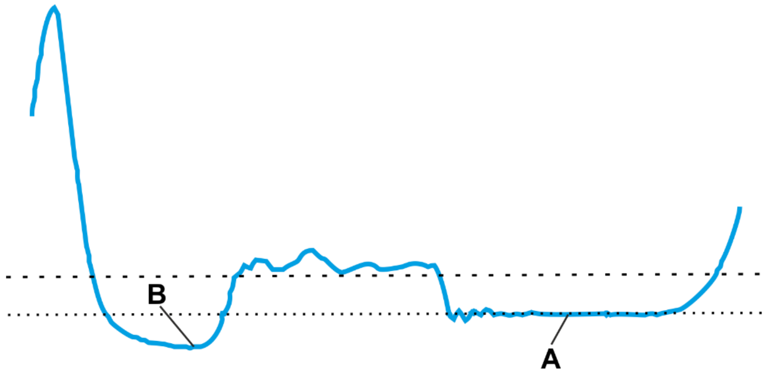


Fig.2. Cylinder mechanical defect

- The position of the exhaust camshaft can be deduced this way by observing the timing of the exhaust valve opening. Note that it is necessary to apply the 720 degree measuring lines on the scope used to perform this test. Measure the angle from the TDC spike until the exhaust valve is opened. It is important to note that on most engines the crank spins between 140 and 145 degrees from TDC compression to exhaust valve opening. On some Opel engines, however, this angle is 160 degrees.

- The correct position of the intake camshaft can be determined by observing the intake/exhaust valve overlap position and the opening of the intake valve. For example, the intake valve should close 580 degrees after the TDC pressure waveform on that cylinder. Intake camshaft timing can be determined both by the valve overlap position, and the indicated closing (580^{o}) of the intake valve.

- The condition of the exhaust valve guide in the cylinder tested can be determined by waveform analysis. On a cylinder with healthy valve guides, the waveform should be as smooth as possible during the exhaust valve opening during its entire lift. Pulsations as shown below indicate worn exhaust guides:

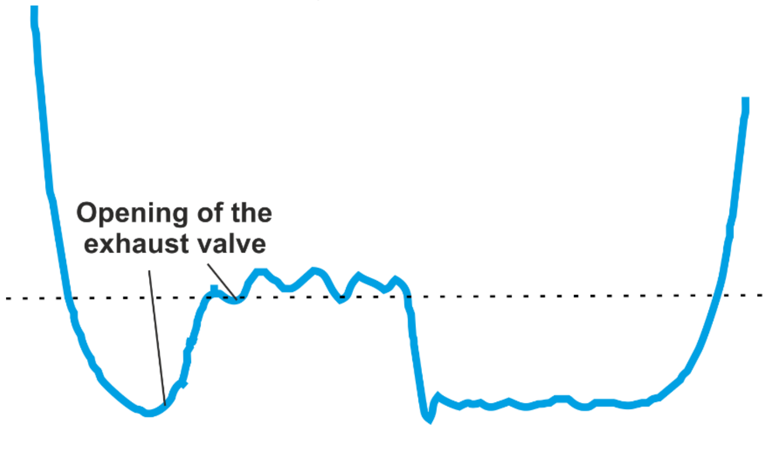


Fig.3. Worn Exhaust Valve Guides Indicated by Pulses Here.

- A clogged exhaust can be determined by unusually high pressure during the exhaust stroke, which occurs between 180^{o} and 360^{o} after the TDC compression wave. The pressure in the cylinder and the pressure in the exhaust are equal when the exhaust valve is open, and cylinder pressure should fluctuate slightly above the atmospheric pressure when the exhaust valve is open. This pressure is assumed to be perfectly normal if it is under 2 psi (relative). The higher this pressure goes above 2 psi, the more likely there is to be exhaust clogging. A pressure of 5 psi or higher will be notice by most customers as a loss of power.

- Intake vacuum can be detected using this waveform. The average value of the vacuum in the intake manifold for the upright engine, must be about 8-9 psi.

- Timing belt issues can be detected by comparing valve action from frame to frame. In the overlap window (at 360 degrees) of the intake and exhaust valves, watch for changes from frame to frame with the engine idling. If you see it, suspect a loose timing belt.

2. Specific points and sections in the cylinder pressure waveform

To better understand the big picture, the waveform screen can be numbered according to the firing order throughout the 720 degrees of engine cycle, even though only one cylinder is being checked for pressure.

To perform a diagnostics of the engine mechanical condition by the pressure graph in the cylinder, it is necessary to:

- put the pressure sensor in place of the spark plug on the cylinder which you want to diagnose.

  - attach a spark tester or other method to the disconnected high voltage lead so as not to damage the ignition system;

  - apply power to the pressure sensor by plugging the red and black cables to the corresponding battery terminals (or make sure your sensor has a good 9v battery);

  - connect the pressure sensor signal cable to the oscilloscope input;

  - the engine must be preheated to operating temperature and idling;

  - Measurement time should not exceed 2-3 minutes to keep the pressure sensor temperature below 70 degrees.

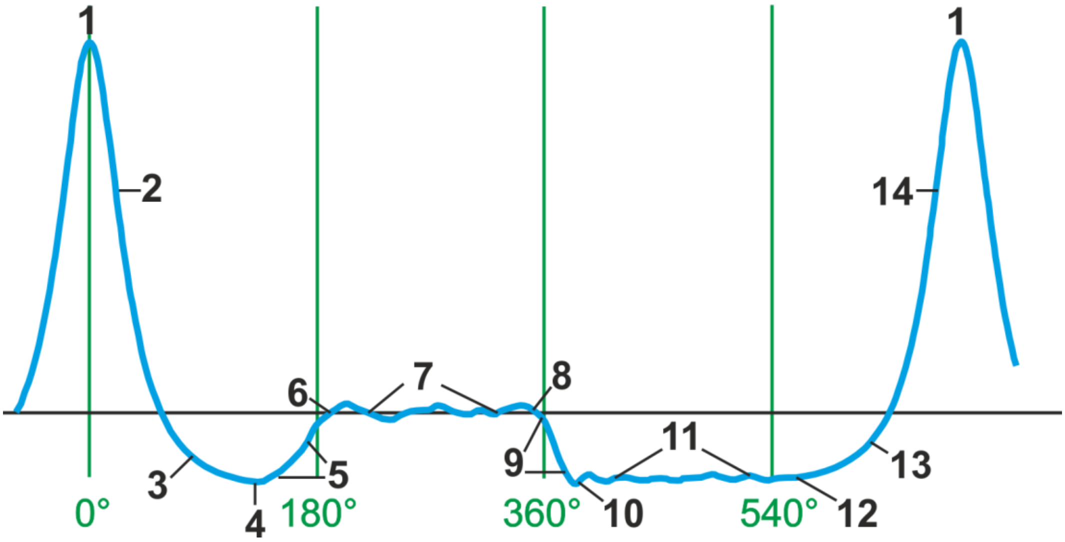


Fig.4. Cylinder pressure waveform

Point 1 (or TDC 0°)

At **point 1**, the cylinder pressure reaches its max. At this point, the piston is closest to the cylinder head. This is called Top Dead Center (TDC). At TDC compression, intake and exhaust valves are closed. Cylinder pressure in **point 1** can vary considerably depending on compression ratio, cylinder leakage, crankshaft speed, and the amount of air and fuel allowed to enter the cylinder. A richer mixture in the cylinder will produce a higher the value at **point 1.**

Point 2 (30°)
After TDC 0°, the piston changes direction and the distance between the piston and the cylinder head begins to increase, which naturally causes the cylinder volume to increase, and with it, a decrease in cylinder pressure, because both valves are still closed. When the crankshaft has rotated 30° after TDC 0°, the cylinder pressure will be halfway between what it was at **point 1** and the lowest pressure on the wave (**point 4**). This halfway point is indicated on the waveform as **point 2**.

Point 3 (90°)
When the piston passes **point 3**, it continues to accelerate downward until the crankshaft has passed 90° after TDC 0°. The piston is, at this point, halfway down its power stroke and has reached its maximum speed for that single cycle. At this point, the piston stroke speed begins to decrease. This point is indicated as **point 3**. At this point the pressure in the cylinder will be very close to atmospheric pressure (14.7 psi). As the piston movement continues, the volume between the piston and cylinder head continues to increase and a vacuum is created in the cylinder right after **point 3**.

Point 4
Just before the piston reaches Bottom Dead Center (BDC), the exhaust valve opens, which can be seen at **point 4**. The piston is still moving away from the cylinder head and the volume between the piston and the cylinder block continues to increase, but as **point 4** is passed, cylinder pressure begins to increase due to incoming exhaust pressure when that valve opens.

Section 5 (BDC 180°)
Exhaust gas enters the cylinder because the exhaust pressure is greater than the pressure in the cylinder at this point. On the cylinder pressure waveform, the influx of exhaust into the cylinder is marked as **section 5**. It is important to note that the center of **section 5** must be at the bottom dead center (BDC 180°).

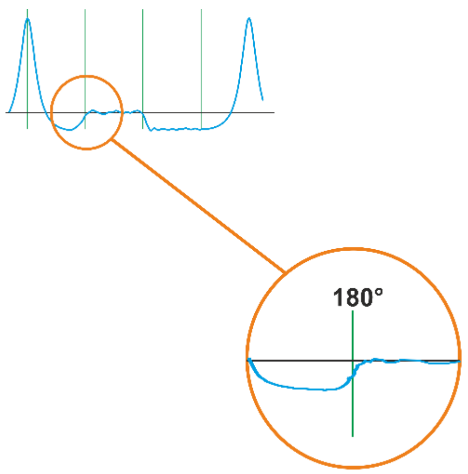


Fig.5. Section **5**

If the center of **section 5** lies anywhere from 170° - 195 ° after TDC 0°, then the exhaust valve timing can be assumed correct.

Point 6
At this point, the pressure in the cylinder increases until it equalizes with the pressure in the exhaust manifold. The point of the waveform, where the cylinder pressure equals the pressure in the exhaust manifold, is marked with as **point 6.**

Section 7
Once the piston has reached BDC (180°), it starts to move towards the cylinder head, once again reducing the volume of the cylinder, but since the exhaust valve is now open, the gas charge escapes into the exhaust. The piston continues to accelerate until the crankshaft has rotated to 270° (90° after BDC 180°). After passing 270 degrees, the piston speed decreases once again. **Section 7** represents the time during which the piston is pushing exhaust gas out and during this time the pressure in the cylinder should be nearly equal to the atmospheric pressure. If **section 7** indicates a pressure increase rather than remaining a plateau, look for adequate opening of the exhaust valve or clogged exhaust.

Point 8 (330° - 360°)
Approximately between 30° before TDC (360°), the plateau of **section 7** ends as the intake valve opens. The moment of the opening of the valve is indicated as **point 8**. When the intake valve is opened, but the exhaust valve hasn't yet closed (overlap), and this allows for purging of the last of the inert exhaust gas. At this point, the pressure in the cylinder continues to equalize with the pressure in the exhaust manifold as air enters through the still opened exhaust valve. Because of this valve opening overlap period, it is very difficult to precisely locate **point 8** of the cylinder pressure waveform.

Section 9
When the piston reaches TDC 360°, the exhaust valve is closed and the intake valve continues to open so that the pressure in the cylinder begins to equalize with the pressure in the intake manifold. This is a drop from what was atmospheric pressure to the much lower pressure in the manifold, which causes the gases from the cylinder to begin to rush into the intake manifold. This area of the plot is indicated as **section 9**, where the plateau of **section 7** ends. The center of **section 9** should be 380° after TDC 0° (20° after TDC 360°).

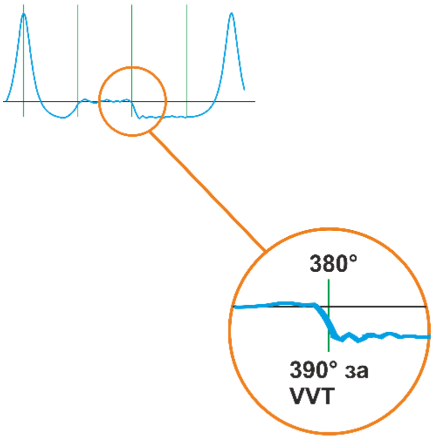


Fig.6. Section **9**

Correct intake valve timing can be verified If the center of **section 9** lies within the range of 370° to 390° after TDC 0°. For VVTi engines, the center of **section 9** should be within the 380° to 400° range after TDC 0°.

Point 10
At **point 10**, the pressure in the cylinder is equal with the pressure in the intake manifold as the intake valve continues to open.

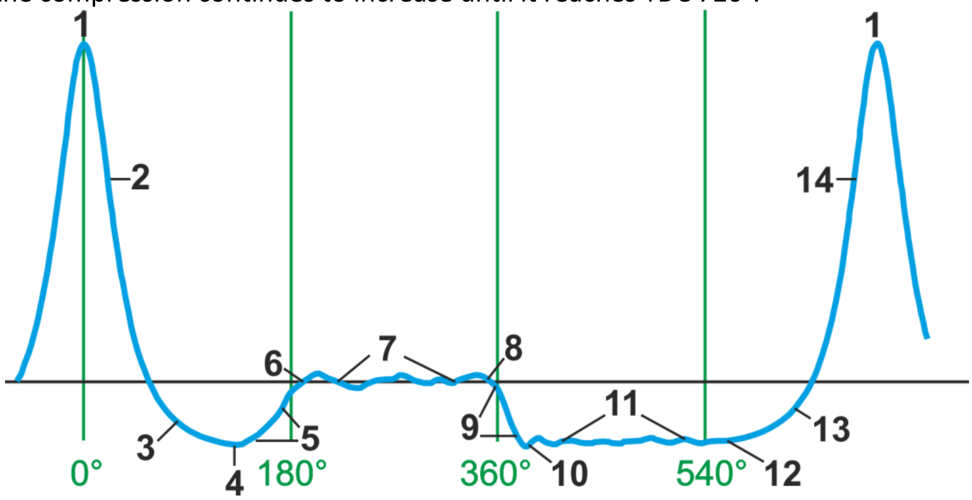
Section 11 to the second BDC (540°)
Even though the piston is moving down and the cylinder volume is increasing, the cylinder pressure drop is not reflected in the waveform due to incoming air past the open intake valve.

Section from the second BDC (540°) to Point 12
After BDC 540°, the piston is on the cusp of beginning its compression stroke while the intake valve is still closing, but air driven by inertia continues to rush into the cylinder, which naturally improves filling of the cylinder with a fuel air mixture on port fuel injected engines. Note the small ripples present in this section as long as the intake valve remains open.

Point 12 (580°)
At **point 12**, the intake valve has closed. From this moment on, the cylinder pressure begins a sudden increase. If the intake valve is completely closed from 560° to 600° after the previous TDC (0°), correct intake valve timing can be verified.

Point 13 (630°)
At this point, the pressure in the cylinder will be at or near atmospheric (14.7 psi), but due to the upward movement of the piston with the now-closed intake and exhaust valves, the compression continues to increase.

Point 14 (690°)
At this point - 30° before TDC 720°, the cylinder pressure is approximately half of the minimum pressure (**point 12**) and the maximum cylinder pressure (**point 1**). Once the piston has passed this position, the compression continues to increase until it reaches TDC 720°.



[Automotive Advanced Pressure Diagnostic Kit]
[Introduction **Video** of the Advanced In-Cylinder Pressure Transducer Kit PDS500x]