iEA™
Intelligent Engine Analyzer

Training

Introduction to In-Cylinder Pressure Testing Part 1
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This exciting diagnostic method opens new possibilities in driveability troubleshooting.

Every decade or so a new automotive technology is discovered that is truly game changing. The use of pressure transducers in automotive service bays is one of the most exciting discoveries of the 21st century. This innovative technology saves repair shops time and money on a grand scale.

This technology can be used to check engines, transmissions, power steering, brake systems, EVAP systems, and air conditioning systems. Basically any system that uses pressure can be analyzed by the use of a pressure transducer. These transducers measure physical pressure changes, negative or positive, and convert these changes to an electrical output signal. Pressure transducers need a power source, ground source, and they will produce a voltage signal that is proportional to the physical quantity applied. An oscilloscope is used to display and analyze the signal output produced from the pressure transducer by graphing the pressure changes over time thereby identifying changes that occur within the system.

Pressure transducers allow the technician to see the inner working of the internal combustion engine without disassembly. In order to check the spark ignition internal combustion engine, three pressure transducers are used; one in the cylinder, one in the intake, and one in the exhaust. To place the one in the cylinder; remove the spark plug from the cylinder head (be sure to ground the spark), then install a compression test hose with the one way check valve removed, and place a 300 psi transducer on the compression hose. The -30 Hg vacuum transducer on the intake manifold will be centrally located on the vacuum port close to the throttle body. Place the exhaust 25 inch/H20 transducer hose in the end of the tailpipe. With these transducers in place, the engine will be operated in three different modes; crank no start, idle, snap throttle and each of these engine operating conditions will produce different pressure waveforms on the oscilloscope and will use different techniques to diagnose them with.

The engine under these three operating conditions can be checked for: camshaft to crankshaft timing problems; variable camshaft timing problems; intake and exhaust valve sealing problems, both consistent or intermittent; valve spring problems; piston ring sealing problems; worn camshaft lobes; restricted exhaust problems; ignition timing problems; or cylinder misfire identification. As you can see, this list includes some of the toughest problem to diagnose. These difficult diagnoses will become routine in your service bay with just a little understanding of the pressure changes that occur within the engine.

Let us start by analyzing the idle compression waveform as seen in figures 1 and 2. Figure 1 is a camshaft chart with the compression waveform overlaid on the cam card. Figure 2 is a basic compression waveform produced at closed throttle at low RPM. The large pink lines divide the compression waveform into 180 degree divisions of crankshaft rotation or the strokes (intake, compression, power, exhaust) of the engine, and the small pink lines divide the crankshaft rotation into 30 degree divisions as seen in figure 2. The large pink line in the middle of figure 2 represents when the piston is at 360 degrees of crankshaft rotation at Top Dead Center (TDC). The intake valve opens just before this point. The crankshaft is in rotation so the piston is in motion, the piston moving away from the cylinder head increasing the volume within the cylinder. This in turn creates a low pressure area contained within the cylinder which pulls a negative pressure (vacuum) against the closed throttle plate. This reduction in pressure can be seen from "G" which is atmospheric pressure to "I" which is negative pressure. This drop in pressure should start at the TDC point and fall rapidly to "I" and this pressure change should occur before the two small pink markers after TDC or 60 degree after TDC. "I" indicates the lowest pressure obtained during the intake stroke, whereas "J" indicates the average pressure during the intake stroke. The intake duration is from "G" to "K", note that "K" occurs after the intake stroke ends at the Bottom Dead Center (BDC) mark. The intake pressure stays low after the BDC mark occurs even through the piston is in an upward movement. One would think that this upward piston movement would create an increase in pressure within the cylinder; however, since the intake manifold has volume under low pressure, the intake manifold acts as an accumulator storing negative pressure. As long as the intake valve is open, it is exposed to this low pressure area contained within the intake manifold. This accumulator effect stabilizes the low pressure area in the cylinder which in turn keeps the low pressure in the cylinder even with the upward rising piston. When the intake valve closes, the pressure will start to rise which occurs at "K". The intake valve should close at 40 to 60 degrees after the BDC mark.

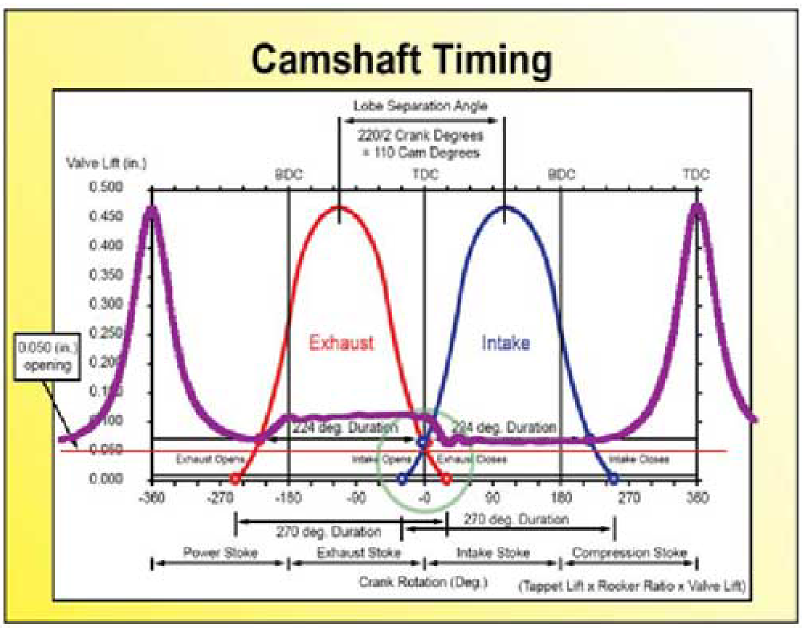

Fig. 1

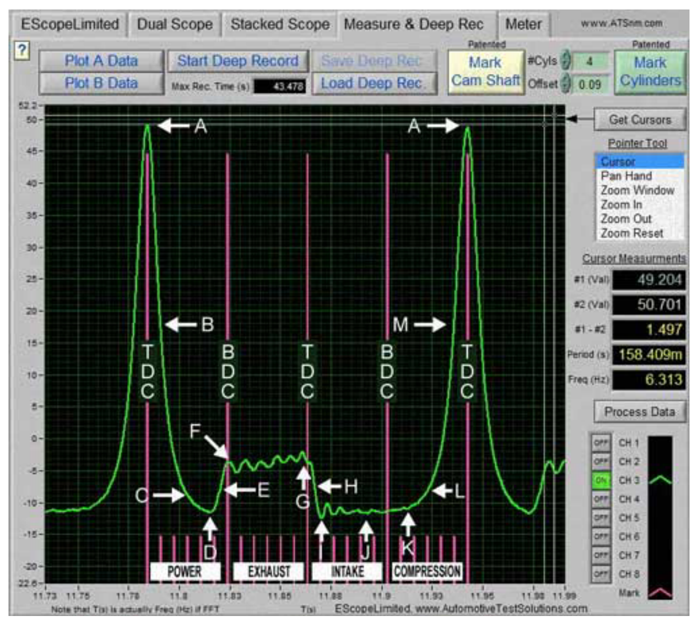

Fig. 2

The piston is now in an upward movement in the cylinder and both valves, intake and exhaust, are closed. The volume contained within the cylinder is now trapped. The crankshaft is rotating and thus is moving the piston toward the cylinder head. As the piston comes closer to the cylinder head, the area within the cylinder is diminished. This reduction in cylinder area creates less space for the volume contained within the cylinder; this in turn increases the pressure within the cylinder. Peak pressure occurs where the piston comes as close to the cylinder head as mechanically possible. This is the compression TDC point which is "A". This peak pressure at "A" can be used to identify the TDC position for such things as checking the ignition timing, injector timing, and checking the crankshaft or camshaft position sensor. It is interesting to note that 60% to 70% of the compression pressure within the cylinder is created within the last 30 degrees of crankshaft rotation before TDC (BTDC) during which time the piston is slowing down and will stop though momentarily, at the TDC point. Although the piston velocity is slow the pressure is rising due to a decrease in the area contained above the piston crown. Since the volume contained within the cylinder works against the area contained within the cylinder, any volume loss due to cylinder leakage during the compression stroke will affect the peak pressure within the cylinder. It is important to check the peak pressure points over multiple cylinder cycles as they should be the same. If one peak is high and the next peak is low by just a few pounds (PSI), and then the next peak is high again, the cylinder is leaking. The air flow into the cylinder cannot change fast enough to allow a high/low/high pressure change. This is due to a volume change or leakage problem within the cylinder.

Since the crankshaft is in rotational motion, the piston is then pulled downward by the connecting rod. The downward movement of the piston allows the area between the cylinder head and piston to increase, thus the cylinder pressure decreases. Since there is no spark present within the cylinder (the spark plug is removed), this stroke is not the power stroke but instead is a decompression stroke. The compression tower has an upward ramp and a downward ramp, if the tower is measured from "K" to "A" and the pressure is divided in half there is a point on both sides of the tower that represent the point of half mast. Half mast is identified by "B" and "M". These points will be measured in crankshaft degrees to the TDC mark, and must be within 20 degrees of each other. If the compression tower has more than a 20 degree differential between the rising and falling ramps, there is a mechanical failure. When this occurs the compression tower will look like it is leaning, one side will have a lot more space between the ramp and the TDC mark, compared to the other ramp and the TDC mark. The piston continues its downward movement and at 90 degree after TDC the waveform has returned to a negative pressure state. This point is denoted by "C". The piston continues downward increasing the area within the cylinder and the compression waveform also continues downward to a point "D"; this is the point where the exhaust valve opens. There should be a clear point of definition at point "D" that indicates the valve seal is intact. The point at "D" should look like clones cycle to cycle with very little change occurring to the exhaust pocket. If point "D" is changing cycle to cycle this is an indication that the valve has a seating problem. In figure 3 it is clear that none of the exhaust pockets look alike and therefore indicates that there is a valve seating problem. It is important to understand that either valve, intake or exhaust, can cause the exhaust pocket to change. It will be necessary to check the intake manifold pressure and exhaust pressure to determine which valve is not seating properly.

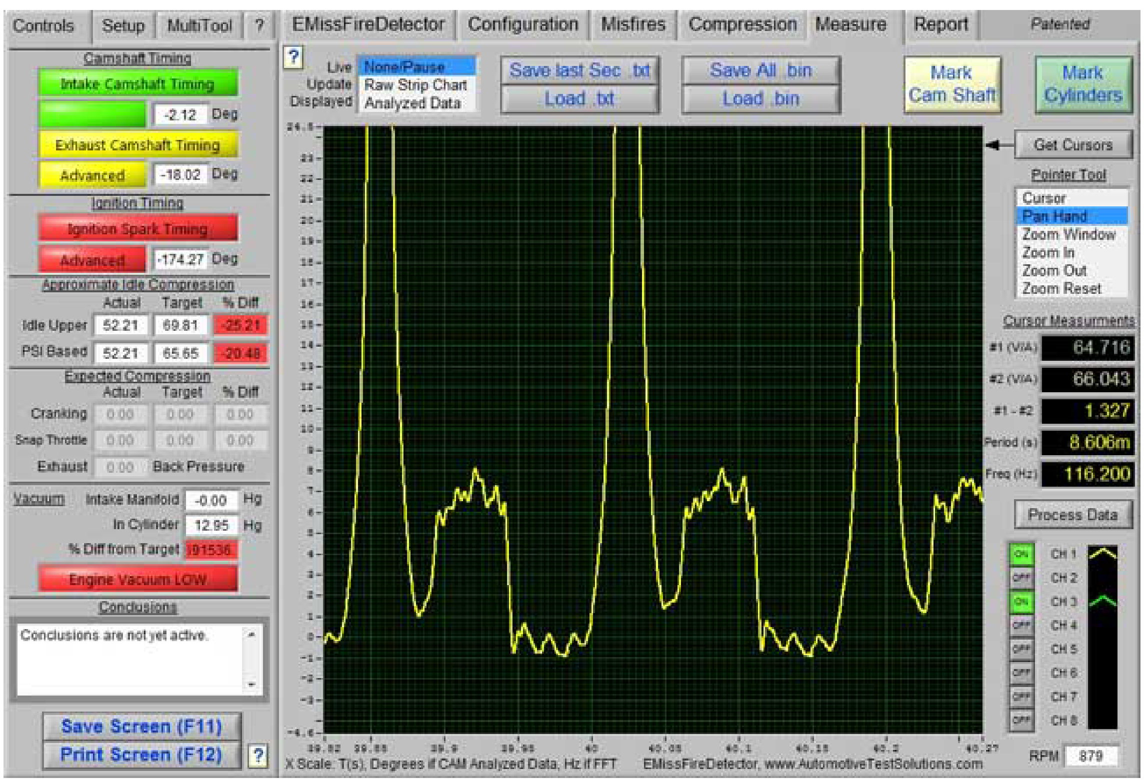

Fig. 3

The pressure within the cylinder starts to rise at point "D"; however, the piston is still moving downward. It would seem that because the piston is moving downward and increasing the area within the cylinder that there would be a corresponding decrease in pressure. The exhaust pressure is near atmospheric pressure and the pressure within the cylinder is in a negative state. Since a high pressure area always moves to a low pressure area, the exhaust pressure rushes into the cylinder as soon as the exhaust valves opens. This pressure rise within the cylinder from "D" to "F" is the pressure equalizing to the atmospheric pressure within the exhaust system. Point "D" is where the exhaust valve opens. This valve opening event should occur at 30 to 50 degrees before BDC (BBDC) and it is used to check camshaft timing. The exhaust ramp from "D" to "F" will also be used to check the exhaust camshaft timing. If the pressure is measured at "D" and then at "F", and this pressure ramp is divided in half (this is shown at point "E") this point should fall on the BDC mark. If the BDC mark falls between "E" and "F" the exhaust cam timing is correct. If the BDC mark falls below the "E" mark then the camshaft timing is retarded. If the BDC mark falls to the right of the "F" mark, the exhaust camshaft timing is advanced. The BDC mark on newer engines may fall several degrees to the right of the "F" mark and be timed correctly. It is important to measure the exhaust ramp and find point "E" and mark it with a vertical cursor. This cursor will now cross the pink grid that represents the crankshaft degrees. On older engines this cursor should fall between the 15 degree BBDC and the BDC marks. On newer engines this cursor should fall between the 23 degree BBDC and the 12 degree BBDC marks.

The piston will rise from the BDC mark to the TDC mark and during this time the exhaust valve will be open. As the piston moves upward the area within the cylinder is decreasing thus creating a higher pressure than the slightly elevated atmospheric pressure within the exhaust. This in turn forces the volume contained within the cylinder into the exhaust system. The ripples between "F" and "G" represent the exhaust pressure resonance within the exhaust system. Since the exhaust valve is open, the pressure within the exhaust system can be seen within the cylinder. The area between points "D" and "I" is referred to as the exhaust plateau. This plateau is created by the intake manifold vacuum. The intake stroke pulls the cylinder into a negative pressure area and the intake valve is then closed, trapping the negative pressure within the cylinder. The piston then moves up compressing the volume within the cylinder to its peak pressure, and then moves down decompressing the volume within the cylinder. At the point the piston returns to the same position within the cylinder as it was when the intake valve closed, the pressure within the cylinder will also return to the same pressure as it was when the intake valve closed, which is negative (vacuum). Since the intake stroke changed the cylinder pressure to a vacuum relative to the exhaust pressure and the exhaust valve opened when the cylinder returned to the same point and then rises back to the exhaust pressure, thus the exhaust plateau is created by vacuum. The points "D" and "I" should be the same. If point "D" is lower than point "I" the cylinder is leaking volume, if point "D" is slightly higher than point "I" at about 2 psi or less the cylinder leakage is ok. If this is greater than 2 psi the cylinder is leaking volume.

The intake ramp will be used to check the intake camshaft timing. Since the intake valve will need to open in order for the intake pressure to drop rapidly, the intake valve opening can be calculated using the intake ramp which is "G" to "I". If the pressure is measured at "G" and then at "I" and this pressure ramp is divided in half (this point shown at point "H"), this point should fall 20 degrees after the TDC mark. The intake camshaft timing is correct if the 20 degrees after the TDC mark falls within + or - 5 degrees of "H". If the 20 degrees after the TDC mark falls below the "H" mark the camshaft timing is advanced. If the 20 degrees after the TDC mark falls to the right of the "H" mark, the exhaust camshaft timing is retarded. On newer engines with variable camshaft timing (VVT) on the intake cam, the 20 degrees after the TDC mark will be adjusted to 30 degrees after the TDC mark. It will be important to measure the intake ramp and find point "H", then mark point "H" with a vertical cursor. This cursor will now cross the pink grid that represents the crankshaft degrees. On older engines this cursor should fall between 10 and 20 degrees after TDC. On newer engines this cursor should fall between 20 and 30 degrees ATDC. The point at which the intake valve closes can also be used to check intake camshaft timing. This point is marked as "K", and should occur between 40 and 60 degrees after BDC.

Now let's look at figures 4 and 5 which are camshaft to crankshaft timing problems. We will first analyze figure 4 in which it is quite easy to see that the compression waveform is not like figure 2. Let's start with the location of the exhaust pocket. In figure 2, the exhaust pocket is located at 35 degrees before BDC whereas in figure 4, the exhaust pocket is at 65 degrees before BDC. Next the exhaust ramp at "E" in figure 2 is at 12 degrees before BDC, and in figure 4 the exhaust ramp at what would be "E" is located at 45 degrees before BDC. On the intake ramp in figure 2, "H" is located at 18 degrees after TDC, and in figure 4 the intake ramp at what would be "H" is located at TDC. The intake valve closes in figure 2 at 45 degrees after BDC, in figure 4 the intake valve closes at 30 degrees after BDC. Whether you look at the exhaust cam or intake cam, it is quite apparent that this camshaft is advanced.

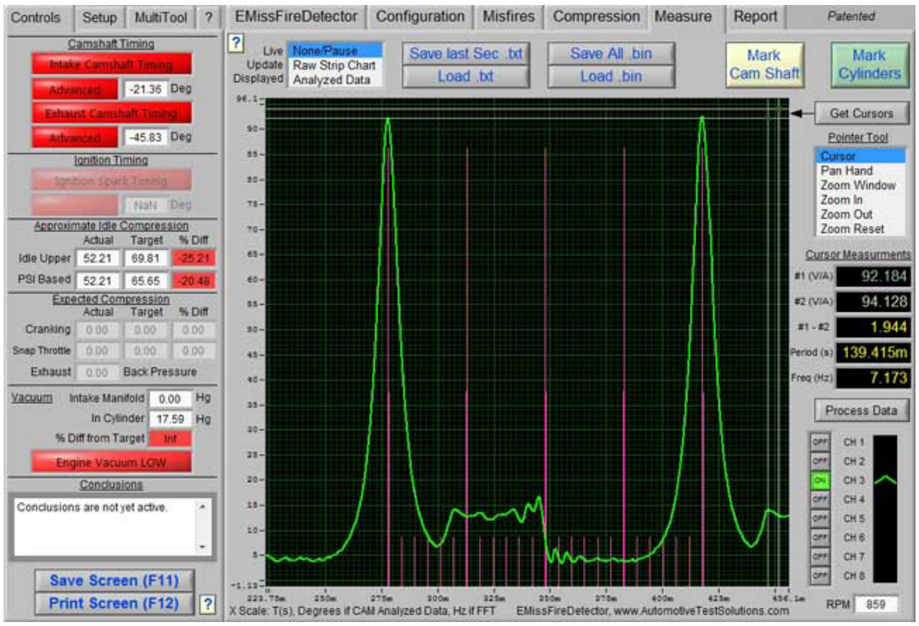

Fig. 4

Now we will analyze figure 5. In figure 5 again it is quite easy to see that the compression waveform is not like figure 2. Let's start with the location of the exhaust pocket. In figure 2, the exhaust pocket is at 35 degrees before BDC and in figure 5, the exhaust pocket is at 0 degrees TDC. Next, the exhaust ramp at "E" in figure 2 is at 12 degrees before BDC, in figure 5 the exhaust ramp at what would be "E" is located at 13 degrees after BDC. On the intake ramp in figure 2 the point at "H" is located at 18 degrees after TDC, in figure 5 the intake ramp at what would be "H" is located at 35 degrees after TDC. In figure 2, the point at "G" is located just before the TDC mark whereas in figure 5 this point is at 25 degrees after TDC. The intake valve closes in figure 2 at 45 degrees after BDC; however, in figure 5 the intake valve closes at 70 degrees after BDC. Whether you look at the exhaust cam or intake cam, it is quite apparent that this camshaft is retarded.

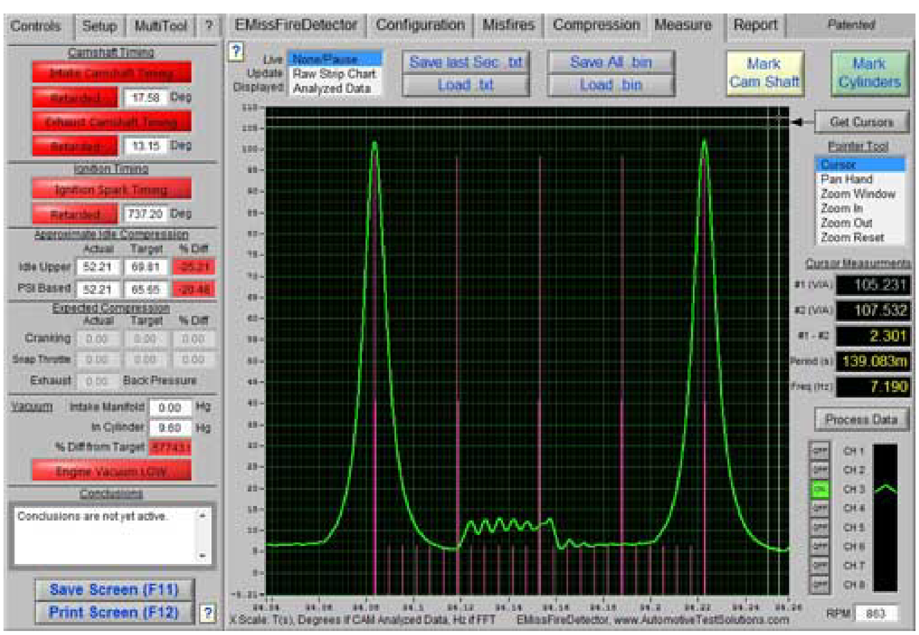

Fig. 5

Be aware that these compression waveforms that have been explained above are idle compression waveforms, and some of these techniques do not work on cranking or snap throttle waveforms. With a little practice, these compression waveforms will start to provide your shop with fast actuate diagnoses. These diagnostic techniques will bring your shop into the 21st century, and provide your shop with the winning edge over the competition.