Intelligent Engine Analyzer

Training

Introduction to In-Cylinder Pressure Testing Part 4

by Bernie Thompson - ATS

This simple technique has changed the way the internal combustion engine is diagnosed around the world. If you are not aware of the power of this simple truth please read the articles “Mastering In-Cylinder Pressure Testing” I, II, and III. These articles cover the basics of in-cylinder compression waveforms at crank, idle and snap throttle.

This technique is not only good when used to find failures, but is great in eliminating possible problems as well. I can recall a time when checking a drivability problem would include checking the ignition timing, not necessarily to find an ignition timing problem but to rule one out. The in-cylinder compression waveform can be used in the same way. Many times in my career I have found myself diagnosing a problem with an engine I thought was of a mechanical nature, but with no way to confirm my suspicions. Now, with this game-changing technique, you can test the mechanical condition of the engine quickly and accurately.

The spark plug is removed from cylinder No. 8 and a 300 PSI transducer installed. The engine is then started and allowed to idle. The in-cylinder running pressure waveform taken from cylinder No. 8 is shown in Figure 1.

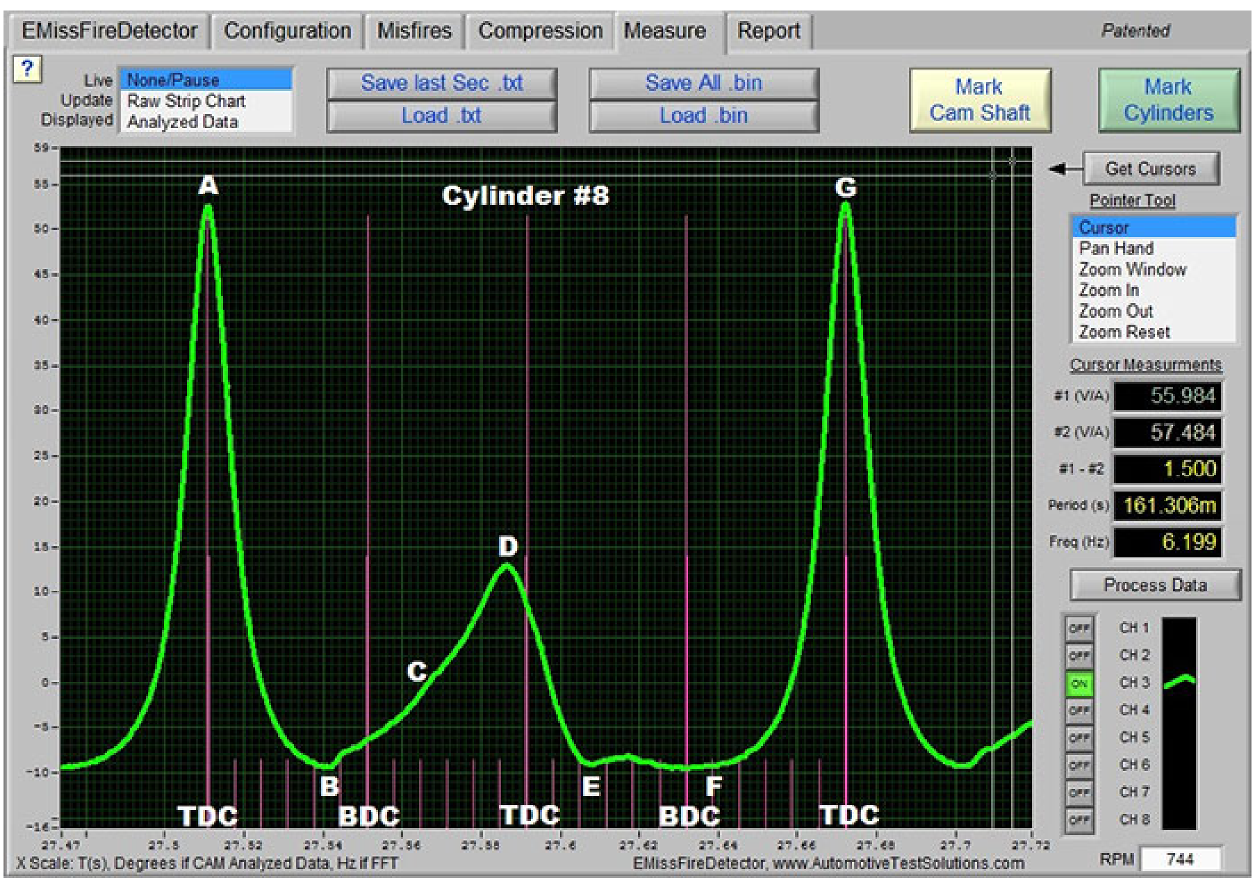

Fig. 1

This waveform clearly shows a problem, which can be seen by comparing it to an in-cylinder compression waveform taken from good cylinder No. 6, as seen in Figure 2. Let's look at problem cylinder No. 8 in Figure 1. Point A is where the piston came as close to the cylinder head as mechanically possible; this is a true Top Dead Center (TDC) position. Point B is where the exhaust valve opened far enough to establish flow. This can be seen by the pressure changing direction at the 40-degree marker located before Bottom Dead Center (BDC). The pressure then starts to rise and crosses the BDC marker with -6 PSI, this would indicate a problem is present with cylinder No. 8. This pressure at the BDC marker should have risen to 0 PSI. Let's look at Figure 2. It can clearly be seen at point B that the exhaust valve opening occurred and the pressure is changing direction at the 40-degree marker located before BDC. Once the exhaust valve has opened, the pressure changes direction, quickly rising to 0 PSI at point C located just before the BDC marker. The pressure rise to 0 PSI happens in less than 40 degrees of crankshaft rotation. Now, let's look at Figure 2. At point C where the pressure achieves 0 PSI, there is some 110 degrees of crankshaft rotation after the exhaust valve opened. As the piston continues to rise toward the cylinder head, the pressure continues to rise to its peak pressure of 13 PSI, located at point D just before the TDC marker. When compared to good cylinder No. 6 in Figure 2, the pressure located at D is very close to 0 PSI.

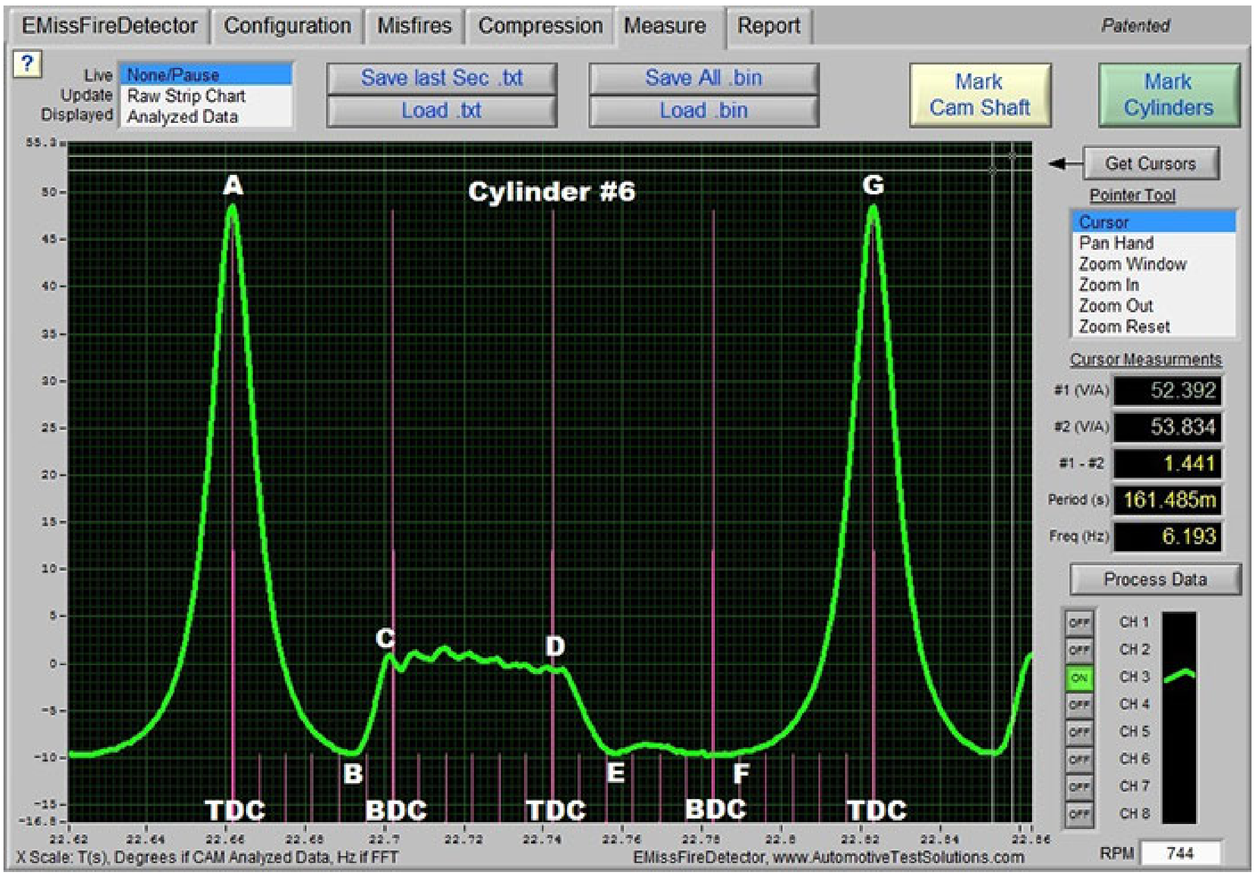

Fig. 2

Now let's look at Figure 3. This is a snap throttle waveform of cylinder No. 8. Point A is the peak pressure within the cylinder located at TDC. Point B is where the exhaust scavenge cycle is started. As the piston moves toward the cylinder head, the volume becomes less, forcing the exhaust out of the cylinder and into the exhaust system. At point C the pressure has increased to 64 PSI and then drops just before TDC. This drop occurs due to the intake valve opening, allowing the high pressure within the cylinder to move to the low pressure within the intake system. In Figure 4, good cylinder No. 6 is shown on a snap throttle event and it can be clearly seen that no pressure increase occurs as the piston comes up to the TDC marker located at point C.

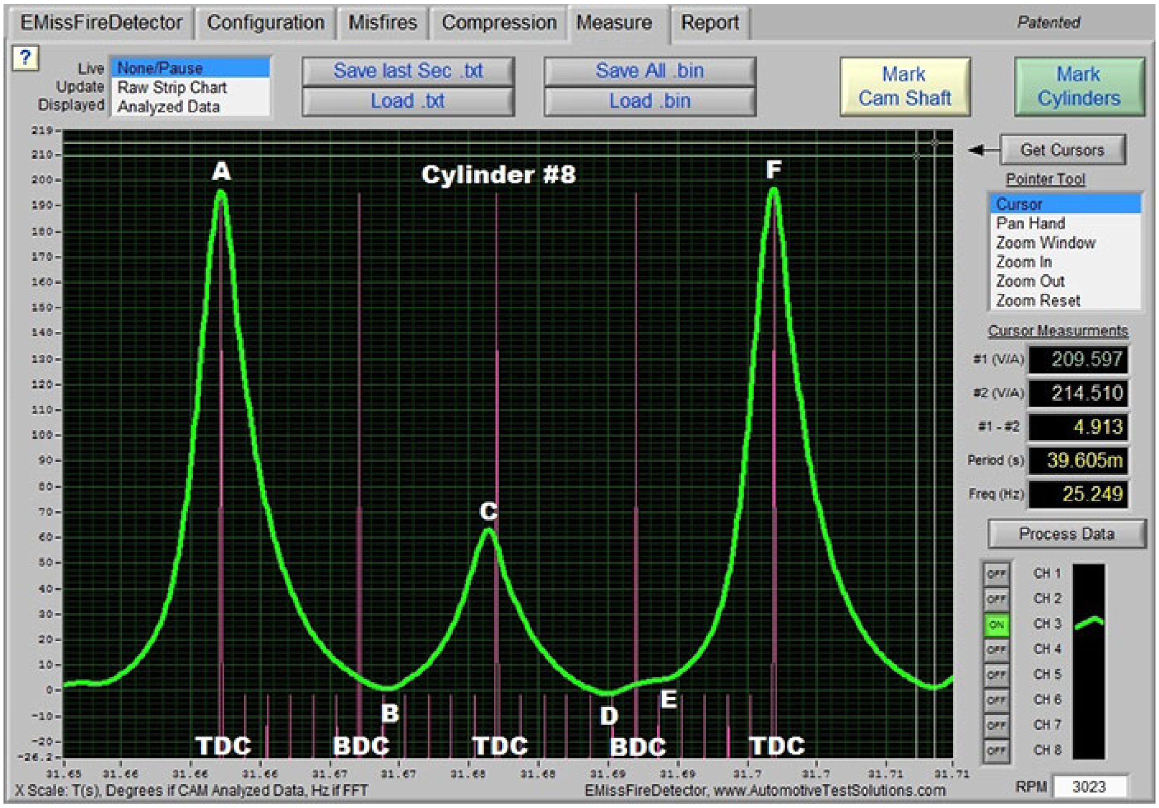

Fig. 3

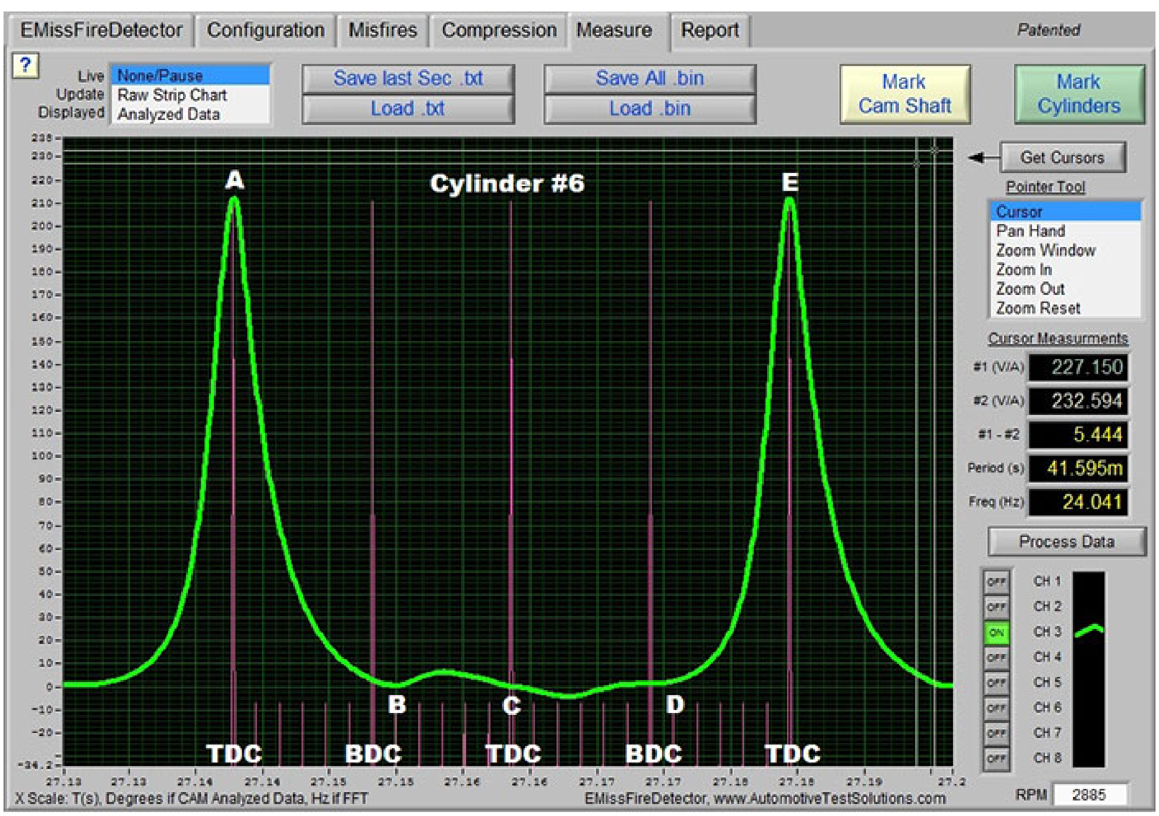

Fig. 4

Interpreting the results

The question is what is happening in bad cylinder No. 8? Let's look at Figure 1. When the exhaust valve opens at point D, the pressure should rise rapidly to atmospheric pressure which is 0 PSI. At point D the cylinder pressure is in a negative state of pressure shown at -10 PSI or -20.36 inHg. Since a high pressure (more energy) always moves to a low pressure (less energy), when the exhaust valve opens the exhaust pressure, being close to that of the atmospheric pressure, moves to the low-pressure area contained within the cylinder. This inflow of atmospheric pressure causes the in-cylinder pressure to rise rapidly until it matches the atmospheric pressure. However, this is not what is happening in bad cylinder No. 8. Since the cylinder is in a vacuum state when the valve opens and the pressure does not change quickly, the path for the flow volume must be impaired. Additionally, as the piston moves toward the cylinder head, the volume contained within the cylinder does not move out of the cylinder. If it did then the pressure within the cylinder would not increase.

This increase in pressure as the piston moves upward at the 360 marker clearly shows an exhaust gas scavenging problem. An exhaust gas scavenge problem at idle could be caused by (1) an exhaust camshaft timing issue; (2) an exhaust valve that is limited in its opening; or (3) an exhaust runner that is restricted. (1) If the exhaust camshaft has an advanced valve closing then the pressure at TDC will increase. Any exhaust gas volume still in the cylinder will be trapped with the early valve closing, and the piston moving toward the cylinder head will create additional pressure within the cylinder. However, if this was the cause of the pressure rise at the 360 marker on cylinder No. 8, the exhaust valve opening would be much earlier than the 40-degree opening that cylinder No. 8 has. Additionally, the pressure would change quickly from a vacuum to atmospheric pressure with the exhaust valve opening, which is not the case with cylinder No. 8.

If the exhaust valve opening is the cause of this pressure increase, depending on how far the exhaust valve is moving off of the valve seat, the pressure rise within the cylinder will move more quickly. This is due to the volume being trapped within the cylinder. When limited exhaust gas can escape from the cylinder, the pressure within the cylinder will build quickly.

If the exhaust runner is plugged, at least some of the cylinder volume will be able to move out of the cylinder, allowing a slower pressure build rate within the cylinder. This is what is happening in cylinder No. 8, as can be seen in Figure 5. Figure 5 shows an exhaust runner that is restricted by carbon. Even with a problem as unusual as this, it is quite easy to diagnose when using in-cylinder pressure testing.

Fig. 5

On to a Hyundai

Now let's look at another vehicle — a Hyundai XG 350 with a V6 3.5 Liter DOHC engine. This engine cranks and tries to start but fails to run. In Figure 6, cylinder No. 1 from bank 1 is shown. Points A and E are the TDC positions. By marking these two positions, which represents one fire cycle or 720 degrees of crankshaft rotation, you can now divide this waveform into segments. These segments can represent the four stokes of the internal combustion engine or be divided into the number of cylinders the engine you are working on has. If your scope does not automatically mark these segments, then this can be accomplished on your scope by simply marking the compression waveform with the scope cursors. Now look at the time given by the scope for the time between the cursors, then take the time and multiple it by .25 = 180; .50 = 360; .75 = 540. So in Figure 6, take the time shown on the right in the period (S) display, which is 474ms, and multiple this to set your TDC and BDC locations. So in this example: 474ms x .25 = 118.5ms BDC; 474ms x .50 = 237ms TDC; 474ms x .75 = 355.5ms BDC. This will provide the time to move your right-side cursor to so you can mark the stroke of the engine. In moving the right-side cursor, the TDC and BDC mark can be identified. Whether you mark the four strokes of the engine or mark the number of cylinders, this is a very important technique, as you clearly see on this Hyundai.

Now let's look at Figure 6 taken from cylinder No. 1. Point B is where the exhaust valve opening is located at 70 degrees before BDC. While cranking the engine, this exhaust valve opening position should fall between 30 degrees to 60 degrees before BDC. So at 70 degrees, this exhaust valve opening is clearly in an advanced position. Now look at point C. The pressure increases as the piston nears the TDC position. At 15 degrees before TDC, the pressure tops out and then quickly drops, due to the intake valve opening. If the exhaust valve opens too early, it will also close too early. When the exhaust valve closes early, the volume that is still contained in the cylinder will be trapped. As the piston continues to move upward, the trapped volume is compressed, thus increasing the in-cylinder pressure. At point D the intake valve is closing. This can be seen at the point the pressure starts to increase at some 50 degrees of crankshaft rotation. From point D to point E, the volume within the cylinder is compressed, thus increasing the in-cylinder pressure. It is interesting to note that the rising pressure is not smooth, but has slight changes in it. Additionally the compression tower has a sight lean to it. This can be seen by looking at the pink TDC marker and comparing the rising and falling pressure. The falling pressure is closer to the marker than the rising pressure. These two pressures should be within 20 degrees from one another, or should look even from the TDC marker on a cranking compression waveform.

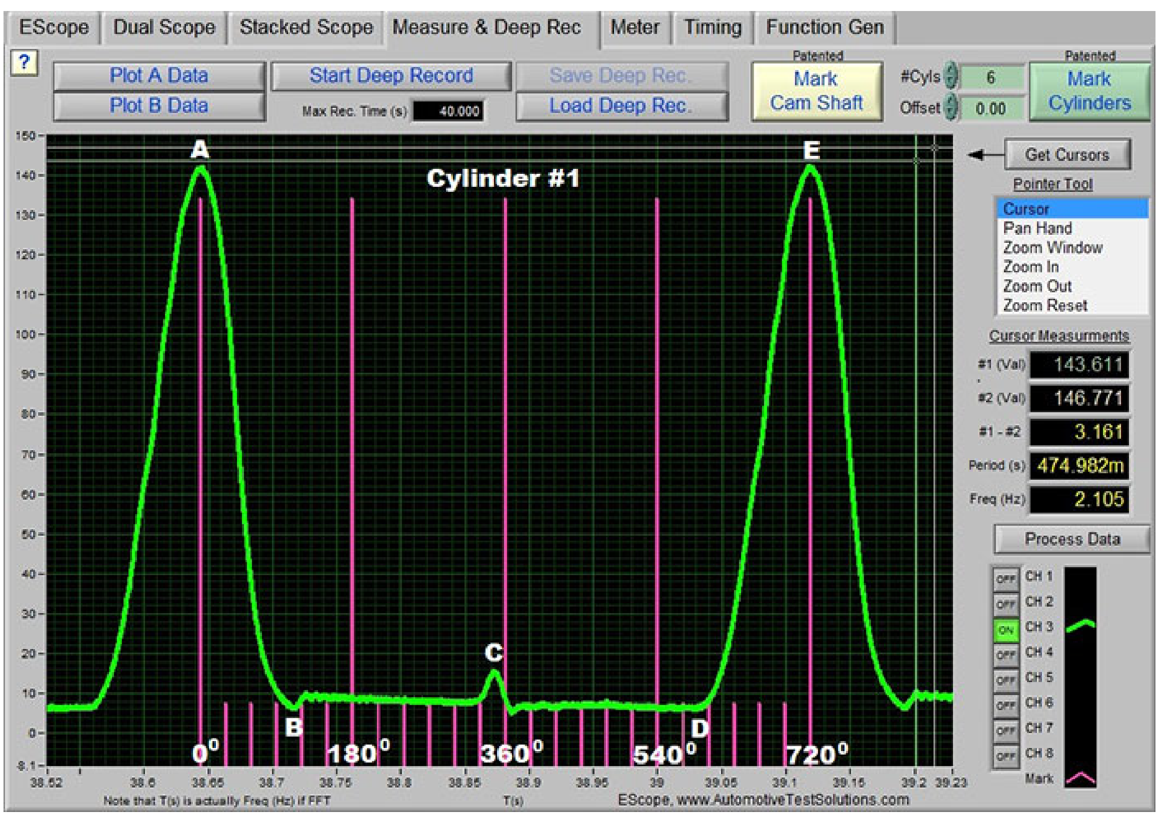

Fig. 6

Now let's look at Figure 7. Point B is where the exhaust valve opened on cylinder No. 6. It can be determined that the valve opening position is located at 50 degrees before BDC, which is some 20 degrees different from cylinder No. 1. Additionally, at point C there is no pressure increase occurring. Point D, where the intake valve is closing, occurs at the 30-degree mark after BDC, which shows some 20 degrees difference from cylinder No. 1 as well.

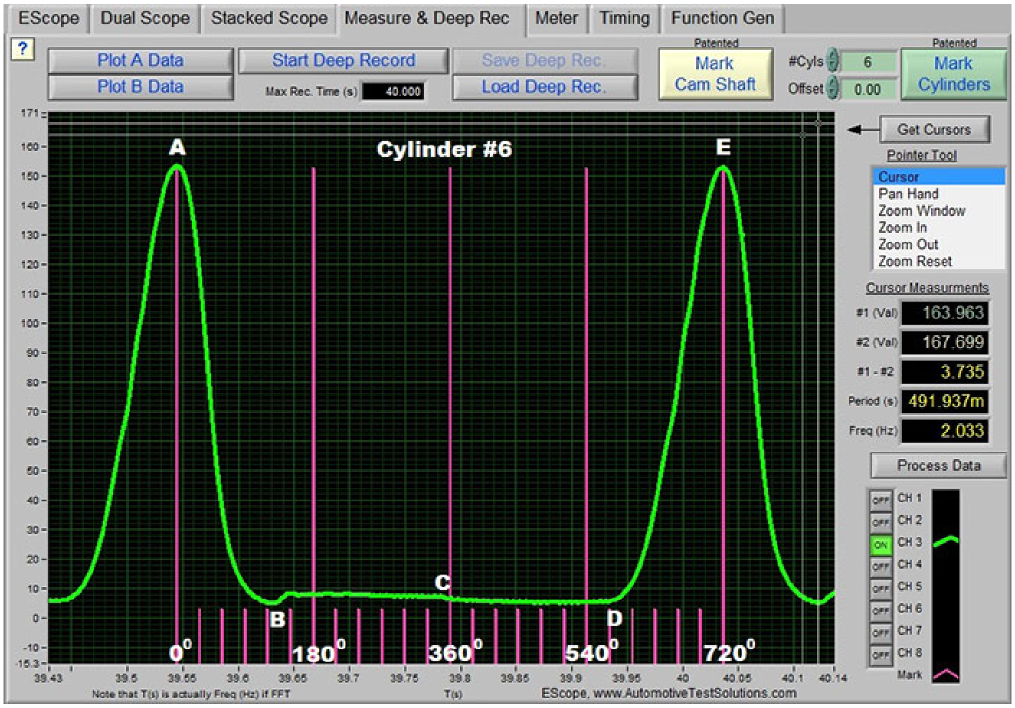

Fig. 7

It will always be very important to look at the intake pressure changes and exhaust pressure changes at the same time you are looking at the in-cylinder pressure changes; this is shown in Figure 8. The green trace shown is from the in-cylinder pressure, the blue trace is from the intake pressure and the yellow trace is from the exhaust pressure. The pink markers are dividing the pressure waveforms by the number of cylinders contained within the engine. This 3.5 Liter Hyundai engine has 6 cylinders, so there are six cylinder boxes. Each cylinder box is marked for the cylinder number of each intake box in blue or exhaust box in yellow. These boxes are marked by the firing order from the engine. To find the intake box and exhaust box from the cylinder under inspection, simply find the 360 marker; the intake box is located to the right of the 360 marker and the exhaust box is located to the left of the 360 marker.

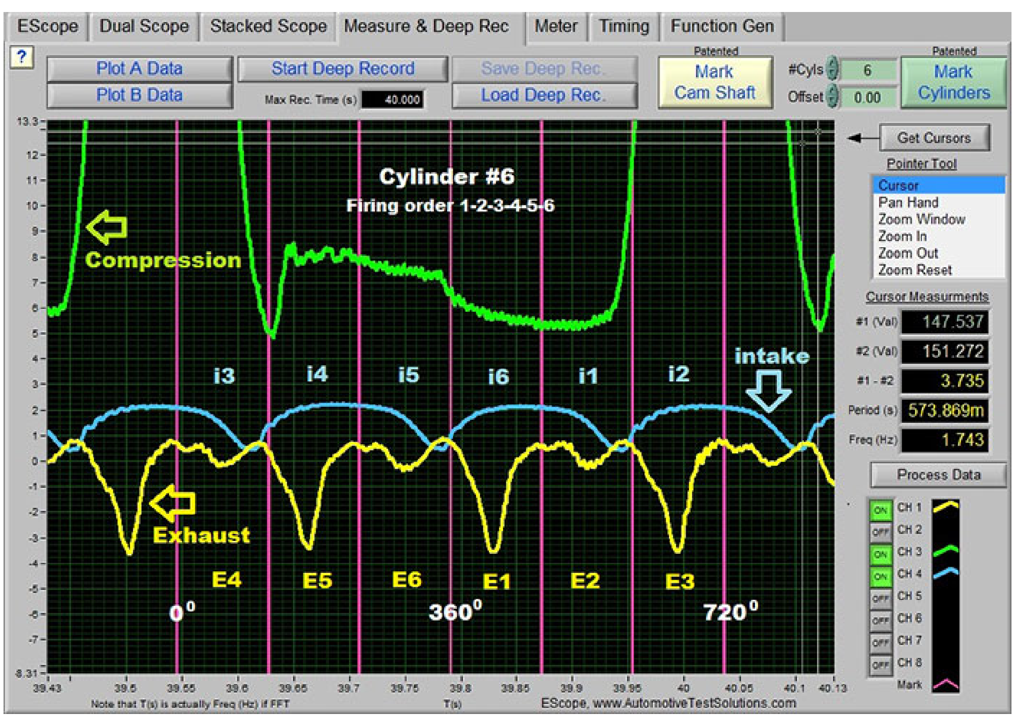

Fig. 8

Data collected

These waveforms are extremely interesting. The first observation you can make is that there are not enough pressure pulses from the intake or from the exhaust. This is a 6-cylinder engine, so there should be six intake pulls and six exhaust pushes; however, there are only three intake pulls and three exhaust pushes. When analyzing the intake pulls, there should be one pull for each cylinder box. These intake pulls are formed smoothly to produce one pull for two cylinder boxes, which is incorrect. If this waveform was produced correctly, there should be six evenly formed smooth humps, one associated with each cylinder box. As the intake hump moves upward, more vacuum is indicated and as it drops, less vacuum is indicated. As each piston is moving downward, more vacuum is created thus more vacuum is indicated in the pressure waveform. As the piston reaches BDC, the intake valve for that cylinder starts to close, causing the vacuum to drop. Then another intake valve opens and the piston starts its downward movement, thus increasing the vacuum again. Therefore, each individual cylinder will produce a vacuum hump.

When looking at the exhaust pushes, there should be one exhaust push for each cylinder. During the exhaust cycle, the exhaust valve opens before BDC and the piston starts its upward movement. This creates a higher pressure in the cylinder than in the surrounding atmospheric pressure, allowing the cylinder contents to be forced out of the cylinder. During a cranking compression test the engine is downed so it cannot start. This allows the cylinder to be in a vacuum state when the valve is opened so the atmospheric pressure rushes back in to the tailpipe. This inflow of air is shown in the exhaust pressure waveform by a drop in the waveform. These vacuum drops can be seen in cylinders E5, E1 and E3. Each individual cylinder should have this drop, but perhaps the drop would not be as great as these drops are in this 3.5 Liter Hyundai. A typical exhaust pressure drop during a no-start cranking event would be 1 to 2 inches of water, where this Hyundai has 5 inches of water in exhaust drop.

Now let's look over the data; Bank 1's camshaft timing is off by some 20 crankshaft degrees, whereas Bank 2's camshaft timing is correct. Bank 1 contains cylinders 1, 3 and 5. Bank 2 contains cylinders 2, 4 and 6. If the camshaft timing is off by 20 crankshaft degrees, there should still be an intake pull and an exhaust push for each cylinder. Additionally, the exhaust valve opening on Bank 1 is opening when the cylinder is in a greater vacuum than would be expected. These data points indicate that either the camshafts in Bank 1 are the wrong camshafts for this engine or the camshafts have been crossed. In other words, the exhaust camshaft is in the intake side and the intake camshaft is in the exhaust side. When the valve cover was removed and the camshafts were inspected, the intake camshaft was marked RI and the exhaust camshaft was marked RE. The shop that had towed the vehicle in was called and asked if the camshafts could have been replaced with the wrong camshaft for this 3.5 Liter Hyundai. They assured us this could not have happened. Therefore, there is only one possibility: the camshafts have to be crossed. The camshafts were then removed and positioned correctly and this 3.5 Liter Hyundai engine roared to life. What is important is to always follow the data; make your diagnostic decisions based only on the data. If you do this you will always fix the vehicle.