iEA

ntelligent Engine Analyzer

Training

Introduction to In-Cylinder Pressure Testing Part 2

The impossible is upon us, the ability to see into the internal combustion engine while it is running.   Could this really be true, can this really happen? Modern technology is ever expanding helping us with every facet of our daily lives from our homes to our phones to our vehicles; advancements in technology are just out right amazing! With such advancements in technology it is an exciting time to be an automotive technician. The modern vehicle has more computer power than the space shuttle while carrying the appearance of a sophisticated aerodynamic road machine. These advancements in the modern automotive industry are moving at such a rapid pace that it seems like we are being left behind. With all of the advancements in the modern vehicle where is the technology that can help us keep pace with the repair of these sophisticated machines? Just like the rapid advancement in the modern vehicle, rapid advancements have recently been made in automotive tools. Now the tools that we can use in our service bays have reached the next level and have finely caught up with the advancements of the automotive industry. These tools can make a huge difference in your shop's ability to quickly and accurately diagnose modern vehicle systems.

I would like to cover one of these modern tools that allows you to see into the internal combustion engine! Just several years ago this would have been impossible; but today for many shops, this is routine and is accomplished with the use of pressure transducers. A pressure transducer is a device that measures a physical quantity of pressure (negative or positive) and converts it to an electrical output that is proportional to the applied pressure. In order to check the in-cylinder pressure the spark plug is removed and a compression testing hose with a pressure transducer is attached to the hose and inserted into the cylinder head as seen in figure 1. Since the internal combustion engine pumps air volume into and out of a cylinder, pressure changes will occur that will be proportional to the air volume being pumped. By using pressure transducers to monitor this volume-to-pressure change, one can "see" into the internal combustion engine.

Figure 1

In order to monitor the voltage output from these pressure transducers an oscilloscope will be used. The oscilloscope will trace the pressure transducer's voltage output over time. This will allow one to see the inner workings of the engine such as the intake and exhaust valves opening and closing. When diagnosing using pressure transducers there are three different distinct in-cylinder waveforms that will need to be analyzed; (1) Cranking, (2) idle and (3) Snap Throttle. Additionally each of these in-cylinder pressure waveforms come with different intake vacuum waveforms and different exhaust pressure waveforms that will need to be analyzed as well.

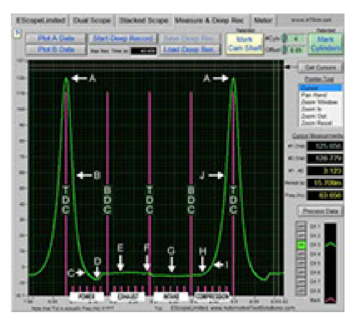

Figure 2

Now let us analyze a cranking in-cylinder pressure waveform as shown in figure 1. The cranking pressure waveform is designated by the green trace while the engine strokes are designated by the pink vertical lines. These pink vertical lines are broken down in 2 degree marks, the large vertical lines are 180 crankshaft degrees, while the small vertical lines are 30 crankshaft degrees. The pink mark on the left of the screen marked TDC or Top Dead Center shows the point where the piston came as close to the cylinder head as mechanically possible. This occurs on the compression stroke where both the intake and exhaust valve are closed. The peak pressure can be checked by the scale seen on the left side of the screen, which currently indicates that the peak pressure is 120 PSI. You will need 7 to 10 seconds of cranking data obtained with the throttle in the closed position. It will be important to check the peak pressure on all the cylinders during the crank. These pressure peaks should be less than 1 psi from each other. Make sure that the engine is not trying to start thus changing the cranking RPM. If the RPM is changing, the peak pressure will also be changing. You need a steady crank RPM so the peak pressure will not change. If a large leak is present in one of the cylinders the RPM cannot be stable, additionally this leak can usually be heard as the starter spins the engine faster during the low pressure cylinder event and then slows down on the next high pressure cylinder event. If a steady crank RPM is obtained and the peak pressure is changing cycle to cycle then the cylinder volume is changing, this is usually caused by a leak within the cylinder.

After the TDC compression event at “A” the piston, after being stopped momentarily, will start to be pulled away from the cylinder head by the connecting rod which is connected to the rotating crankshaft. This will increase the volume within the cylinder thereby decreasing the cylinder pressure. This would normally be the power stroke, but remember there is not a spark plug present in the cylinder to start the point of ignition (On cylinders with dual spark plugs the second spark plug must be disabled). Since this stroke does not have a point of ignition this will be referred to as the decompression stoke. As the piston moves further away from the cylinder head, the pressure within the cylinder follows the volume change and continues to decrease. Point “B” is the point at half mast, which is the point half way between point “A” and point “D”. This Point “B” on the decompression ramp as well as point “J” on the compression ramp should be within 20 crankshaft degrees of the TDC mark. If these half mast points fall greater than 20 crankshaft degrees of the TDC mark then the cylinder is most likely leaking. When this happens the compression tower looks like it is leaning. These leaning towers can be caused by cylinder leakage from valve sealing issues, piston sealing issues, head gasket sealing issues, or camshaft timing problems.

As the cylinder pressure decreases further point “C” is reached. Point “C” is at 90 crankshaft degrees after TDC compression. As the decompression of the cylinder continues point “D” is reached. Point “D” is the point of exhaust valve opening and this should occur between 30 and 60 crankshaft degrees Before Bottom Dead Center (BBDC) exhaust. The exhaust valve pocket at “D” should be formed with a definition point that is clear, concise, and repeats over and over. This shows the exhaust valve seal is intact. Right after point “D” the waveform starts to rise up until the exhaust plateau is reached. It is interesting to note that the piston is still moving down when the pressure waveform is rising right after point “D”. This is caused by the vacuum created during the intake stroke and seal within the cylinder when the intake valve closed. When the exhaust valve opens the higher atmospheric pressure in the exhaust system rushes into the cylinder to fill the low pressure area contained in the cylinder. This allows the pressure to rise even though the piston is still moving down, creating more volume which in turn should create a lower pressure. The point at “D” is how you can see if the exhaust camshaft timing is off during engine crank. This point can be up to 1 tooth off and you may not be able to identify the exhaust camshaft timing is off; however, you will be able to identify if it is 2 teeth off. This is very helpful because most engines will still start with the camshaft timing being 1 tooth off. If the engine will start it is better to check the idle compression waveform for camshaft timing which will identify a 1 tooth camshaft timing error. During the idle compression waveform the exhaust plateau ramps will be used to check camshaft timing. It is important to understand these exhaust plateau ramps will not be used to check camshaft timing for a cranking waveform.

Point “D” will rise into the exhaust plateau which is at atmospheric pressure and is shown as the average pressure at point “E”. At point “F” the intake valve opens allowing the air to flow into the cylinder. As the piston moves away from the cylinder head the cylinder volume is increased, creating a lower cylinder pressure. This pressure drop should occur at the TDC intake mark and should fall rapidly to the lower intake pressure, shown as an average at point ”G”, and is a lower pressure than the atmospheric pressure shown at point “F”. This pressure differential between “E” and “F” is at engine crank and is low compared to engine idle. At engine crank the pressure difference is 1-2 PSI, and at engine idle this pressure is 8-11 PSI. The faster the engine is turning the more energy is available to pull against the close throttle. This is why the exhaust plateau is larger at engine idle and smaller at engine crank. Additionally the pressure differential at point “D” and at point “G” should be within 2 psi of each other. If the pressure at point at “D” is lower than 2 psi from point “G”, there has been volume loss and you should suspect a leak within the cylinder. During the compression stoke the in-cylinder pressure is increased which allows a larger volume to escape past a leak point. As the cylinder decompresses the decrease in air volume within the cylinder will show greater vacuum at point “D” than the intake pull pressure at point “G”. This allows the exhaust pocket at point ”D” to have more vacuum than the intake vacuum pull had at point “G”.

At point “H” the intake valve closes as can be seen by the rapid rise in pressure after point “H”. This pressure rise should occur between 40 and 60 crankshaft degrees After Bottom Dead Center (ABDC) compression. This point is where the intake camshaft timing will be checked. It is interesting to note that as the piston is rising, reducing the volume in the cylinder, the pressure within the cylinder remains the same and does not increase as one might expect. This is due to the intake valve still being open during the piston’s upward movement, thus exposing the cylinder pressure to the pressure from the intake manifold. The intake manifold having volume area will store other cylinders intake pulls, which act like an accumulator storing a lower pressure. This lower pressure will stabilize the in-cylinder pressure from rising until the intake valve is closed, which makes this an ideal point to check the intake camshaft timing.

The piston continues its upward movement lowering the volume thus increasing the in-cylinder pressure. The pressure will increase and come to point “I” which is at 90 crankshaft degrees. As the pressure increases it will come to point “J” which is the point of half mast on the compression tower. The piston will continue its upward travel to the point where the smallest volume and highest pressure in the cylinder is reached, which is TDC. It will help to understand that the majority of the in-cylinder pressure is made in the last 30 degrees of crankshaft rotation and very little piston travel occurs at this point. If any of the cylinder volume leaks out of the cylinder it will have a great impact on the overall pressure at TDC within the cylinder.

In order to fully understand the in-cylinder pressure waveform we will need to look at the intake and exhaust waveform that is produced during engine crank as well, as seen in figure 2. The green waveform is the same compression waveform that we have analyzed thus far. It will be very helpful to overlay the intake waveform (blue trace) and the exhaust waveform (yellow trace) over the compression waveform (green trace). When analyzing the in-cylinder pressure waveform this overlay will help show where the cylinder leak is located.

We will start by analyzing the intake waveform (blue trace) which is read in inches of mercury. The cylinder that is producing the in-cylinder pressure waveform will have the intake pull located right after the TDC 360 crankshaft degree mark. The intake pull indicated by the blue trace hump marked number 1 is produced from the in-cylinder pressure waveform (green trace). As we have covered previously, the point at “F” is where the intake valve opened first which then affects the manifold pressure. The intake manifold pressure is falling across the TDC mark and then starts to rise; this is the point that the cylinder intake flow is great enough to change the accumulated intake pressure. It will be important to check this point on each of the cylinder pulls. This point where the intake pressure is falling and then rising is the point where the vacuum pull is transferring from one cylinder to the next. These transfer points should all be very even, as well as the overall pressure increase located next to the cylinder number. If they are not even a cylinder leak is the likely cause. To locate the cylinder vacuum pull, first locate the pull from the cylinder that is producing the in-cylinder pressure waveform as described above and then apply the firing order for the engine you are working on. As can be seen on the blue trace each of the cylinder vacuum pulls is marked by the firing order, indicating the cylinder that created it.

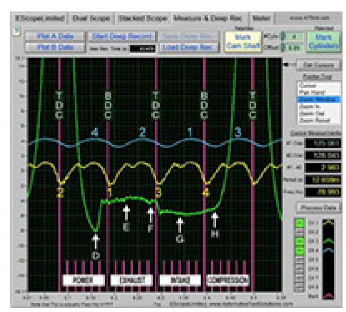

Figure 3

Now we will analyze the exhaust pressure waveform (yellow trace) which is read in inches of water column. The cylinder that is producing the in-cylinder pressure waveform will have the exhaust push located right before the TDC intake 360 crankshaft degree mark. As we have covered previously, the point at “D” is where the exhaust valve opened and this exhaust valve opening will affect the exhaust manifold pressure. The yellow trace where the number 1 is located is where the exhaust valve opening, allowed the vacuum contained within the cylinder to pull the exhaust manifold pressure into the cylinder, thus creating a low pressure area in the exhaust. This low pressure, indicated by the number 1 mark, is the transfer area or the point that one cylinder exhaust is transferring to the next cylinder’s exhaust. These exhaust transfer points should be even from one cylinder to the next cylinder. Just after the BBDC exhaust mark the piston starts to move upward creating a pressure push which in turn increases pressure in the exhaust manifold. As the piston moves upward this pressure will increase until it reaches a level just above atmospheric pressure. This pressure level will have slight ripples which is normal. At the point the exhaust valve is closing and the next cylinder exhaust valve is opening the pressure drops into the next exhaust pressure transfer point.

Now we will look at a problem cylinder as seen in figure 4; the green trace is the in-cylinder pressure waveform, while the blue trace is the intake waveform, and the yellow trace is the exhaust waveform. When analyzing the in-cylinder waveform several things stand out, such as the leaning compression towers, and the deep exhaust pocket. These items clearly show the cylinder is leaking. Now look at the intake waveform in blue. The cylinder intake pull marked 1 is from the cylinder we are currently testing. The intake pull marked 3 as we can see is narrow and the transfer point at the TDC mark has moved to a positive pressure. This is caused from an intake valve sealing problem. As the piston moves up ward on the compression stroke the air volume in the cylinder is push into the intake manifold past the leaking intake valve. This creates the narrow intake pull on 3 and then the positive pressure in the intake manifold.

Now we will look at a problem cylinder as seen in figure 5; the green trace is the in-cylinder pressure waveform, while the blue trace is the intake waveform, and the yellow trace is the exhaust waveform. When analyzing the in-cylinder waveform several things stand out, such as the leaning compression towers, and the deep exhaust pocket. These items clearly show the cylinder is leaking. Now look at the intake waveform in blue. The cylinder intake pull marked 1 is from the cylinder we are currently testing. Notice that the intake pulls from 1 and 3 are slightly lower, additionally the transfer point after 1 is lower. If the exhaust valve is leaking when the intake valve opens, some of the air is pulled from the intake manifold and some of the air is pulled from the exhaust manifold past the leaking valve. This lowers the intake manifold pressure until the intake valve closes. To be sure that this is not a piston sealing issue, the engine will be run and the exhaust pockets will be check. If the exhaust pockets are changing cycle to cycle the exhaust valve is likely the problem. If the exhaust pockets are good the piston seal is likely the problem. The crank case pressure can also be tested to see if pressure is building in the crank case when the compression stoke is made indicating the piston is not sealing.

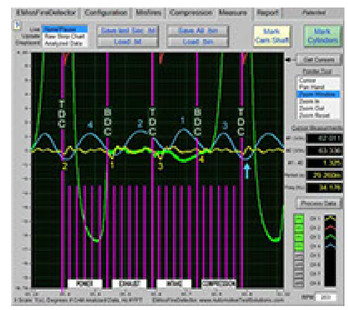

Figure 4

Technology is a great asset in our lives, but one must use these assets in order to gain from them. Could you imagine not using a cell phone? Not that long ago we didn’t have cell phones but now the cell phone serves a purpose and helps us in our daily lives so now most people carry one of these high tech units. Once you start to use pressure transducers in your service bays you will wonder how you ever got along without these high tech marvels!

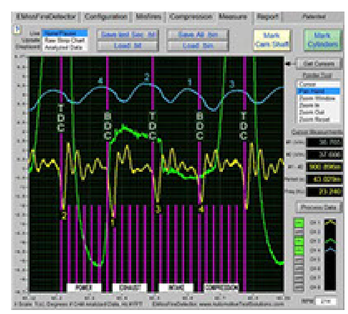

Figure 5