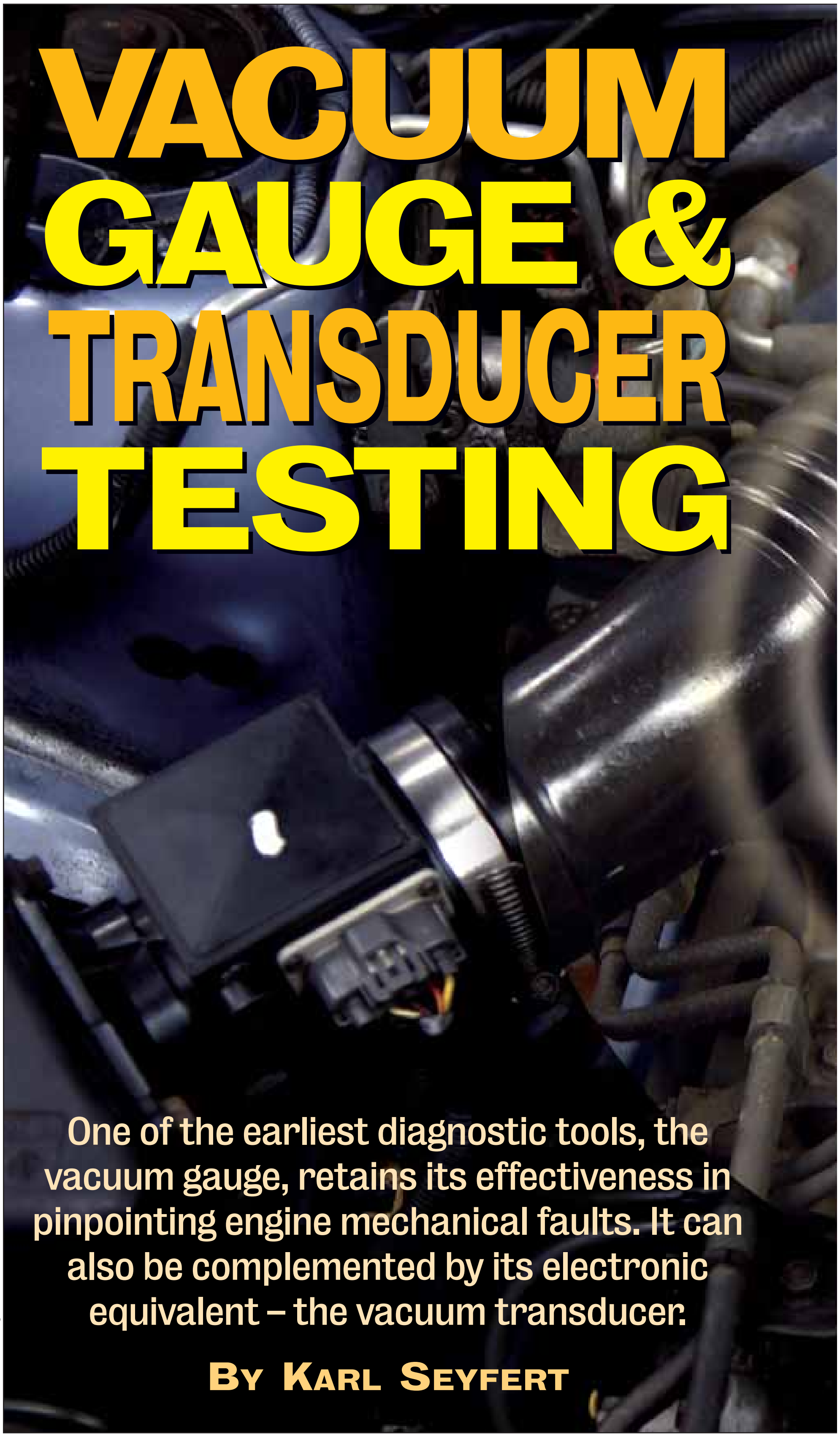


VACUUM GAUGE & TRANSDUCER TESTING

One of the earliest diagnostic tools, the vacuum gauge, retains its effectiveness in pinpointing engine mechanical faults. It can also be complemented by its electronic equivalent – the vacuum transducer.

BY KARL SEYFERT

Photos: Karl Seyfert

Is there still a place for the vacuum gauge? We're living in a world that's filled with engines that may never need a valve job and that adjust their own ignition timing, monitor their own misfire conditions and correct fuel delivery to compensate for small vacuum leaks. And yet the typical computer-controlled fuel system still depends heavily on a sound engine and strong, reliable vacuum signals.

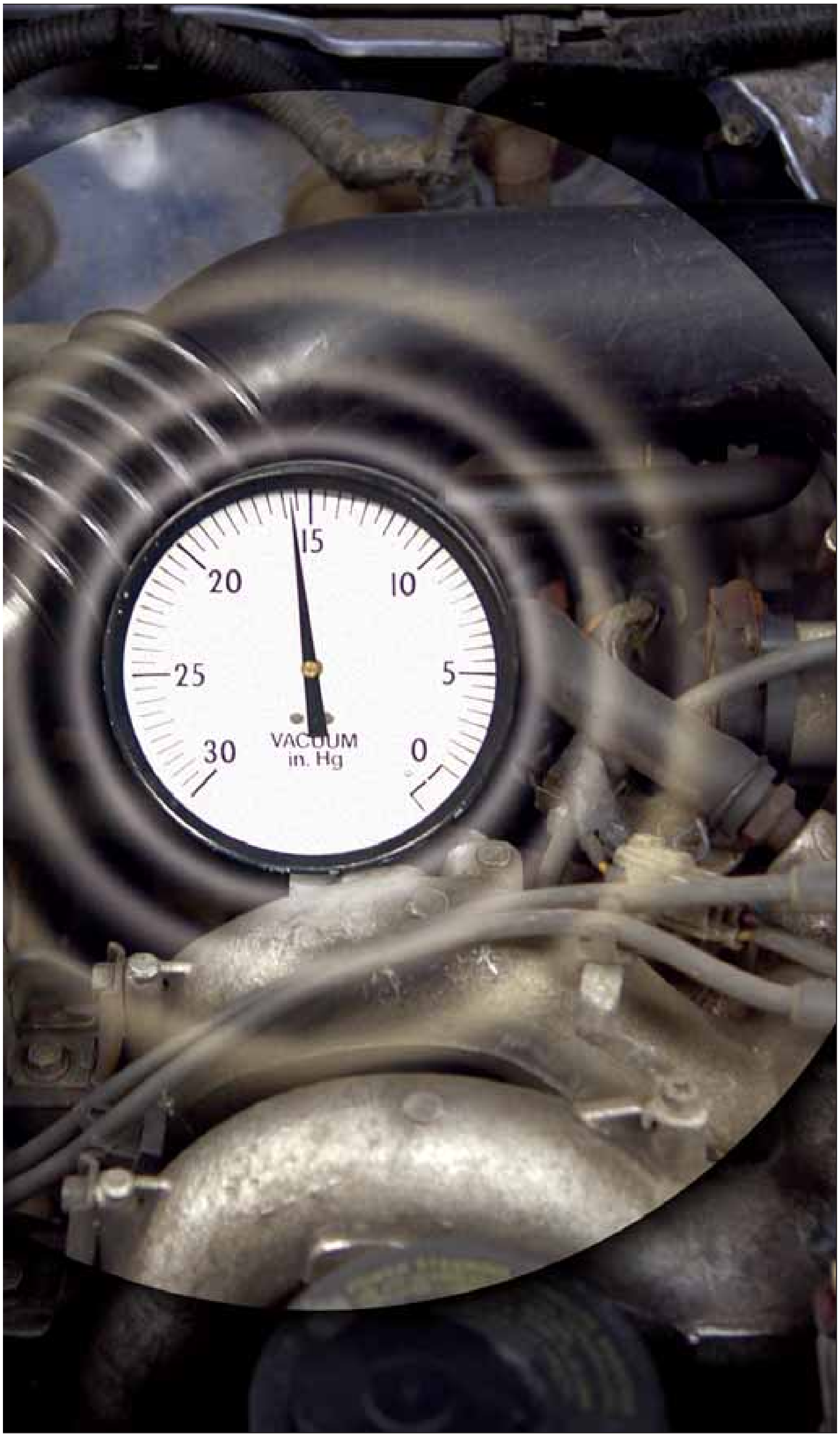
That's why vacuum readings are as valuable today as they've ever been. Vacuum testing also happens to be the fastest, easiest-to-perform test in the book. You don't need to hunt down special fuel gauge fittings as you do for many fuel pressure tests. You won't need to remove spark plugs as you do for a compression test. Just find a good place to tee in a vacuum gauge and hook it up.

Let's take a moment to discuss the concept of *vacuum*. "Vacuum" is really a misnomer. What we really mean when we talk about engine manifold vacuum is *less pressure*. Depending on weather conditions and the unit of measurement you use, the air at sea level has an atmospheric pressure of about 14.7 psi, 101 kpa or 29.9 in./Hg. At higher elevations, atmospheric pressure is lower.

When pressure is lowered in an area, it causes the air to rush in from the surrounding high-pressure area. We often refer to the low-pressure area as a vacuum, when it's simply an area of relatively lower pressure.

When we measure the pressure in an intake manifold, we're really comparing the pressure inside the manifold to the pressure of the atmosphere outside the manifold. It's this pressure differential that causes the air and fuel to be pushed into the combustion chamber. Because it's a term we all use, we'll continue to refer to the lower pressure in an intake manifold as "vacuum."

The amount of manifold vacuum created is directly related to the engine speed and position of the throttle plates. If we take away fuel and ignition, then spin the engine, we'll still produce vacuum in the intake manifold. The faster the engine spins, the higher the vacuum will be—as long as the throttle plates create a restriction by remaining closed.



However, if we move the throttle plates open, the vacuum will decrease—as long as engine speed remains constant. It's important to understand this basic concept before moving further.

You've probably heard of using a vacuum gauge to check cranking vacuum. This is a useful test because spark and fuel are taken away so that all we see is the engine's mechanical condition. Without fuel and ignition, vacuum is a simple concept to understand. It's based strictly on mechanical integrity, as long as we know rpm and throttle position.

Things get complicated when we add fuel and ignition because fuel and ignition have a direct effect on engine rpm. For example, if identical engines are running at the same throttle position, a lean condition will cause one engine to spin slower than the other engine running at the correct mixture. This will cause a lower vacuum reading at the same rpm because the throttle plates must be opened further (reducing the restriction) to bring the rpm up.

You can see why vacuum provides such an accurate indication of how well an engine is running. The higher the vacuum for a specific rpm and throttle opening, the better the engine is running. We know a problem exists when the vacuum is low, but where do we start looking? Realistically, a low vacuum reading can be the result of absolutely anything, including ignition, fuel delivery or mechanical problems.

This is where vacuum interpretation can simplify the process. Each item that affects engine vacuum leaves a unique fingerprint.

Vacuum Gauge Testing

Whenever possible, connect the gauge to a large, centrally located vacuum port. Be sure the port isn't obstructed by carbon deposits. Depending on engine and intake design, where you connect the gauge can have a big effect on the accuracy and sensitivity of the readings you get.

In order to start, an engine usually has to pump at least 1 in. of vacuum. When it's developing **normal cranking vacuum**, a healthy engine will pump a fairly steady 3 to 6 in. The more vacuum the engine pumps, the quicker it'll start. The more cylinders the engine has, the

Find a reliable vacuum source located after the throttle plate (manifold vacuum). This port is after the throttle plate, but it's located on a single intake manifold runner. Readings may be biased toward the cylinder that's closest to the transducer or gauge.

stronger and steadier cranking vacuum tends to be.

When the engine cranks erratically, the cranking vacuum will also fluctuate erratically. Valve timing problems (a belt or chain) are the most common cause of **abnormal or erratic cranking vacuum** and cranking speed. However, the engine could also be so hot it's actually dieseling during cranking.

Compression problems can also produce **abnormal cranking vacuum.** If cranking vacuum is healthy but drops regularly and rhythmically, look for a compression problem. Every time the weak cylinder tries to fire, two things happen momentarily: The cranking speed increases and the vacuum decreases. A burned valve can make the needle drop regularly to zero vacuum.

Do you have zero cranking vacuum? Before you look for large air leaks, see if the throttle blade(s) are sticking open. If they are, close them and retest. Unless the throttle blade(s) are closed or nearly closed, some vacuum gauges may not respond very well to a cranking vacuum test.

On a normal engine, **normal idle vacuum** should be a steady reading between 17 and 21 in./Hg. Larger displacement engines tend to produce stronger idle vacuum than smaller engines do. The better the rings and valves are sealing, the more vacuum the engine will pump.

Steady, lower-than-normal idle vacuum can be due to a vacuum leak, an EGR leak or an ignition/valve timing problem. If it's a vacuum leak, artifically richening the mixture will improve idle quality. If richening the mixture doesn't help, look elsewhere and continue following your diagnostic procedure.

Abnormal idle and high-speed vacuum causes the needle to drop regularly and predictably at idle, and is usually caused by one or more valves that are leaking. During the compression stroke, a burned intake valve allows positive pressure pulses to enter the intake manifold. When you rev the engine, the reading doesn't stabilize.

When the **vacuum reading drops erratically and unpredictably at idle,** a valve or valves are sticking. The needle may not drop as much as it does when the valve is burned. If the valves are sticking, cooling the engine down or using a valve-freeing oil additive may temporarily steady the vacuum reading.

A healthy engine should be able to produce 3 to 6 in. of vacuum while cranking. Multicylinder engines that are in good shape will show a stronger reading with less fluctuation.

When the **vacuum reading fluctuates sharply between a normal and a very low reading,** there may be a compression leak between adjacent cylinders. If so, these two cylinders will both show up weak on a cylinder balance test.

Weak valve springs will cause **abnormal idle and high-speed vacuum readings.** The gauge needle will flutter rapidly—more rapidly when you rev the engine. Depending on rpm and spring condition, the needle may flutter irregularly. When weak/broken springs can no longer close a valve, the reading will take on the pumping motion a burned valve creates.

Badly worn valve guides will cause **abnormal idle and normal high-speed vacuum.** At idle, the gauge needle will flutter rapidly over a wide area, but the reading steadies when you rev the engine. When the guides are this worn, the engine will have a serious oil consumption problem.

At 2500 rpm in Neutral, the **normal high-speed vacuum reading** should at least equal idle vacuum. Usually, vacuum at 2500 will be greater than idle vacuum. If vacuum at 2500 rpm is less than idle vacuum, disable the EGR system and retest. If the reading is still low, check for an exhaust restriction.

You can monitor a vacuum device and its vacuum source simultaneously. For example, connect one gauge to manifold vacuum and tee the other one into the tranny's vacuum modulator hose. If both readings don't react the same way during a road test, inspect the modulator hose and its connections.

Use your vacuum gauge on as many road tests as time allows. The more you use it, the quicker you'll learn what "normal" readings are. With an exhaust restriction, under-load readings will all be lower than normal, and it will take very little throttle movement to drop a reading to zero.

Too Much to Remember?

Unless you have a photographic memory, remembering all the possible combinations of vacuum gauge readings and their causes is darn near impossible. To make things easier, we've boiled vacuum gauge testing down to its bare essentials.

On a normal engine, idle vacuum should be steady between 17 and 21 in. of vacuum. Once again, larger engines that are in good shape will tend to produce higher vacuum readings at idle than smaller engines with fewer cylinders.

The MAP sensor can also be used to collect vacuum readings, as long as you've figured out the conversion factor. Remember, vacuum is really pressure that's less than atmospheric pressure. The MAP sensor measures manifold absolute pressure.

The following two simple tests will verify the presence of good vacuum before resorting to other test procedures:

1. Cranking vacuum.
2. Vacuum readings on a warm, running engine at idle, at part throttle, with no-load at 2000 and 3000 rpm and during closed-throttle decel from a WOT stab.

First, test cranking vacuum (usually conducted on an engine that won't start). Connect a vacuum gauge to a manifold vacuum source. Make sure the throttle is closed and that the engine cranks at the recommended speed. Cranking vacuum should be at least 3 to 6 in.

Second, test the warm engine vacuum at idle, part throttle and during closed-throttle decel.

Measure engine manifold vacuum at idle first. Vacuum should be "high" and steady at idle (17 to 21 in./Hg).

Now raise the engine speed to about 2000 rpm. Hold it steady and watch the vacuum gauge. After an initial drop in the vacuum reading as the throttle opens, it should return to the idle vacuum level recorded in the previous step, or close to it. Some EGR valves will kick in no-load. If you see a small drop in vacuum during a steady throttle test, disable the EGR and repeat the test.

Do the same test at 3000 rpm and look for the same results.

Allow the throttle to snap shut from a snap WOT. Vacuum readings should rise above idle vacuum (20 to 25 in.), then fall slowly as the engine speed falls. The vacuum needle should come back to rest at the idle reading seen at the beginning of this test, and hold steady there.

If the engine passes these tests, the odds are high that it's mechanically sound—at least sound enough to pump air at idle, part throttle and closed-throttle decel.

Steady vacuum readings in the range of 17 to 21 in. at idle are good. Vacuum readings should stabilize at the same levels or better at part-throttle cruise. The engine wouldn't be able to do this if it had a broken valve spring or two. And the valve/piston synchronization must be correct or the engine couldn't keep pumping at higher engine speeds. Finally, internal engine parts (valves and piston rings) must be sealing well enough to jack up the vacuum on closed-throttle decel.

This Fluke transducer can read vacuum or pressure and can be used with a scope or a DSO. DSO use requires an adapter to convert the transducer's banana plugs to the scope's BNC connector.

If the vacuum readings *are* good but the engine still doesn't run right, look for your problem elsewhere, with checks of specifics like fuel pressure, secondary spark and emissions. If the vacuum readings *aren't* good, here are your options:

- If the cranking vacuum is low, or zero, look for a major problem—like a camshaft that stopped dead in its tracks, or a large vacuum leak.
- If idle vacuum is low but steady, check valve timing first.
- For all the in-between gauge readings, refer to the information at the beginning of this article to help you match up the results.

The vacuum gauge's biggest strength is its ability to pinpoint low-vacuum problems. Other tests, such as power balance, four gas, secondary ignition and fuel pressure tests, will also help you isolate specific problem areas.

Vacuum Transducers

Reading the needle on a vacuum gauge is almost a lost art. If you'd prefer to not be a gauge practitioner, there's another way to check the engine's vacuum sig-

To stabilize and synchronize the scope trace, we need an external trigger. Usingan inductive trigger attached to the No. 1 cylinder and plugged into the DSO's trigger terminals allows us to identify the activity in specific when analyzing a vacuum waveform.

nal. An oscilloscope is a very useful tool for testing electronic signals. A transducer can take a certain condition and convert it into an electronic signal. For example, the vacuum pulse from an engine can be converted in this way. Using a transducer to convert a vacuum pulse into an electrical signal, then synchronizing it with the ignition produces a very useful scope pattern.

The first step is to acquire a transducer that will convert vacuum into an electronic signal. There are a few ways to do this. The first is to use a MAP sensor on the vehicle you're testing (if one exists). This works well because you can test the MAP sensor and engine integrity with one connection.

Another way is to use the transducer that came with your engine analyzer. Some of the older Allen and Sun analyzers had this feature. When connecting these transducers, be sure to find a central location on the intake manifold. Don't connect to one intake runner, as this will greatly affect your waveform.

The third way to get a waveform is to use a remote transducer that's connected to your DSO. You can make one yourself with a 9-volt battery and an old MAP sensor. If you want to get fancy, you can even construct one that's calibrated correctly.

After you've decided which transducer to use, connect it to a central vacuum source with a short vacuum line. Make sure the source is as large as possible with no restrictions. If you're checking a V6 or V8, your readings will be incorrect if the vacuum line is connected to a single plane of the manifold.

Once the transducer is installed, connect and adjust your scope. If you're using the factory MAP sensor on the car, connect the scope lead to the signal wire from the MAP. There should be three wires—ground, reference voltage and signal wire. The signal voltage will change with changes in vacuum.

The vacuum signal is of little use at this time because we can't determine which signal is caused by a particular cylinder. We must synchronize our transducer with the ignition. The easiest way is to connect on inductive lead to the No. 1 cylinder.

The inductive lead can be connected to the DSO with a couple of adapters. The rpm input can be connected to the external trigger or Channel 2, so we'll know when the No. 1 cylinder fires. Adjust the scope until you see the first inductive hump on the left of the screen and another at the right.

Think of a vacuum waveform as an inverted signal. An increase in pressure drives the signal lower. A conversion factor is necessary to translate the voltage levels shown in the vacuum waveform to actual vacuum readings. This conversion factor is specific to individual transducer types.

With the time base adjusted for one engine period, move the signal to the bottom of the screen. Set the trigger to this channel. Use the Normal mode, which causes the scope to draw only when the trigger is present. This assures that the pattern for cylinder No. 1 will always appear first on the screen.

Think of a vacuum waveform as an inverted signal. An increase in pressure drives the signal lower. Setting up the trace for the vacuum signal can vary depending on the transducer and what you want to see. If you want to see the signal amplified as much as possible, set your scope to AC coupling. Adjust the voltage level until the signal looks good. A voltage setting of 200 to 500mV/div works well.

If vacuum readings are necessary, turn off AC coupling and measure actual voltage levels. Then convert the voltage into vacuum measurements. These measurements will vary, depending on the transducer you're using. Use a vacuum pump and an accurate gauge to convert your transducer readings before attaching the transducer to the engine.

Most factory MAP sensors use the same inches-of-vacuum-per-volt conversion factor, so once you convert them you're set to read others. Check the calibration of the MAP sensor with a vacuum pump before assuming there is a problem.

Start by learning what good vacuum waveforms collected from sound engines look like. Then, if you notice any irregularities, you'll know you need to check further. As you become more proficient at using vacuum waveforms for engine diagnosis, you'll be able to determine whether cam timing is correct, whether the exhaust system is plugged and even whether the engine has EGR problems. M

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