Timing And Vacuum Advance 101

SPARK TIMING AND CENTRIFUGAL AND VACUUM ADVANCE IN TERMS THAT NON-ENGINEERS CAN RELATE TO

BY JOHN HINCKLEY

PHOTO BILL ERDMAN

In this day and age, when modern automotive powertrains are computer-controlled and engines don't even use distributors anymore, the knowledge of what distributors did and how they operated to control ignition timing has begun to fade; for those just entering the classic automotive hobby, the function of the distributor and the notion of "timing" is even more mysterious. To keep your classic Corvette running reliably and at maximum efficiency, some knowledge about the principles of spark timing and how it's controlled is essential. The objective of this article is to de-mystify the principles of spark timing and to explain why and how your distributor-equipped Corvette's spark timing is controlled and varied to suit changing driving conditions.

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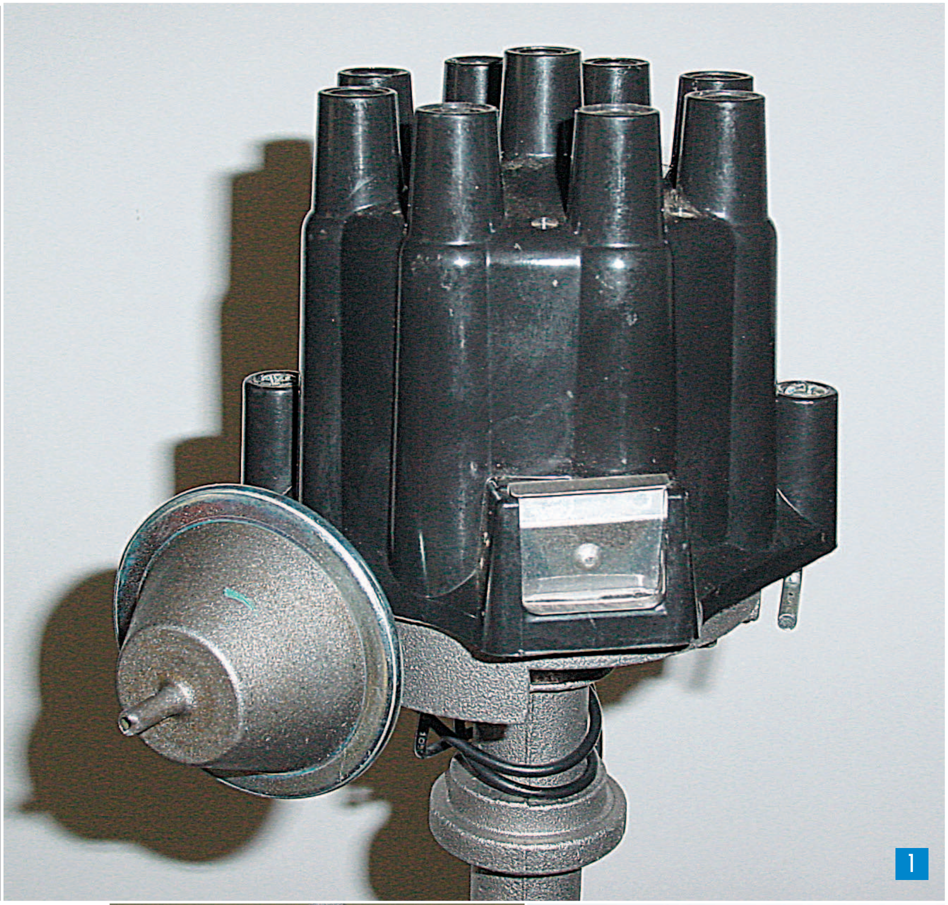
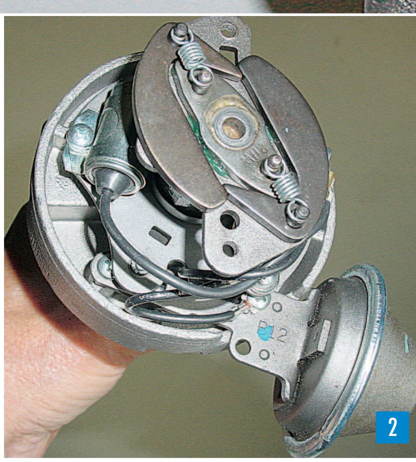
I won't get into the gory details of combustion theory, but let's understand a little about what happens as the piston is traveling upward on the compression stroke toward the point where the spark plug "lights the fire." Before we light the fire, let's talk a little about what we're lighting – the fuel/air mixture that's been metered by the carburetor and atomized in the intake manifold as it heads for each cylinder's intake valve.

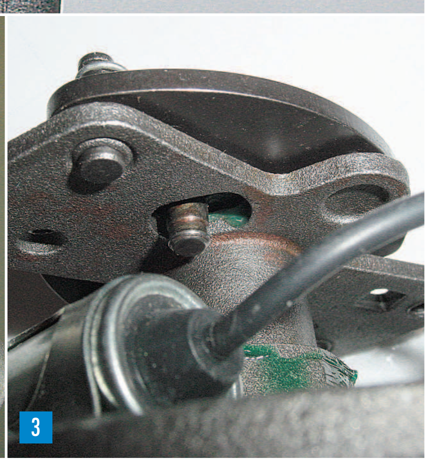
FUEL/AIR MIXTURE AND "BURN RATE": At idle and steady cruising speed, the load on the engine is low, and the air/fuel mixture is "lean" (more air/less fuel); when accelerating, the load on the engine is higher, and it's fed a "rich" air/fuel mixture (more fuel/less air). These are two very different conditions, as a lean mixture burns relatively slowly, and a rich mixture burns faster. Remember this distinction – it's a key factor in ignition timing.

Back in the cylinder, with the piston rising and compressing the air/fuel mixture, the idea is to fire the spark plug at just the right moment such that the mixture is ignited (starting the "burn," as the flame front proceeds across the cylinder) and the rapidly expanding gases reach peak cylinder pressure just after the piston reaches TDC (top dead center), exerting maximum force to push the piston down on the power stroke for maximum efficiency.

SPARK TIMING: Referring back to the burn rate comparison, slower-burning lean mixtures need to have the "fire lit" earlier in the compression stroke (because they take longer to reach peak cylinder pressure) than faster-burning rich mixtures (which take less time to reach peak cylinder pressure). With either mixture condition, the objective is to reach peak cylinder pressure at exactly the same point after TDC, which means they have to be "lit" at different points during the piston's upward travel







1 Here's the distributor, that wondrous device that hides back there in the dark under your ignition shielding and contains the two totally independent, but complementary, spark-advance systems that determine how your Corvette performs.

PHOTO JOHN HINCKLEY

2 This is the centrifugal advance mechanism that hides under the rotor – the "autocam pivoting weights," and tension springs. The faster it spins, the more the weights move outward, advancing the spark timing.

PHOTO JOHN HINCKLEY

3 The pin and slot in the "autocam" that limits maximum centrifugal advance weight travel is visible directly above the end of the condenser.

PHOTO JOHN HINCKLEY

4 Two different sets of centrifugal advance weights and three different strengths of tension springs are shown. How these are combined determines the "advance curve" for each specific engine combination.
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5 A typical vacuum-advance distributor, showing the vacuum diaphragm on the right and the centrifugal advance mechanism at the top. These two systems are independent, but work together.
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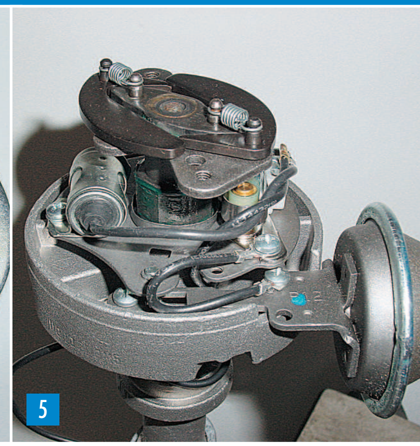

– this is what "spark timing" is all about – managing the point at which the spark plug fires under different operating conditions. This point is expressed as "spark advance" in degrees of crankshaft rotation before the piston reaches top dead center. When someone says their initial timing is set at 10 degrees, that means the distributor is set to fire the spark plugs when the crankshaft is 10 degrees of rotation before the piston reaches top dead center, which is 10 degrees of advance. This is the "initial" or "base" spark timing which is checked and set at idle during a traditional tune-up (with the vacuum advance disconnected); it's fixed at the point where it's set by clamping down the distributor hold-down bolt, and doesn't change – it's always there.

EARLY SPARK TIMING: In the days of the simple, low-compression, inefficient Model T, spark advance was set manually to a fixed level with a lever on the steering column. About all the driver did was to "retard" (delay) the spark timing while turning the crank to start the engine, then move the lever to "advance" the spark timing once the engine was running. If the driver forgot to retard the spark when cranking and left the lever in the advanced position, the engine could "kick back" while the operator turned the crank to start the engine, which could result in a broken arm (an unforgettable lesson in spark timing). Once the engine was running, the operator could vary the spark advance with the lever for best performance (such as it was), or just leave it alone (which most operators chose to do). With that big, low-compression, slow-running, low-powered engine, little damage could be done by improperly setting the spark advance.

Fast-forward to the 1960s and high-compression 350-horsepower Corvette engines howling at 6500 rpm. Suddenly the spark timing equation is much more complex, and spark timing errors can result in scattering expensive engine parts all over the street at one extreme, and poor performance and fuel economy at the other extreme. An automatic device has to recognize the entire spectrum of operating conditions and manage the complexities of spark timing in a manner completely independent of, and transparent to, the driver, who has other things to keep him occupied – like traffic, flashing blue lights in his mirrors, etc.

THE DISTRIBUTOR AND ADVANCE: This wondrous device that handles all that work is the distributor, which lives quietly in the dark, at the back of the engine, hidden forever under the Corvette's ignition shielding, demanding only an occasional set of points, a condenser, and a rotor to continue doing its job. Let's talk about the two different ways the distributor manages spark timing while you're watching traffic and grabbing gears – centrifugal advance and vacuum advance.

The centrifugal advance mechanism under the rotor in the distributor advances spark timing based solely on engine rpm (it's driven at half crankshaft speed); a pair of weights pivots on pins, retained by little coil springs. The faster the shaft turns, the more the weights tend to pivot outward (centrifugal force), and the rate at which they move outward is controlled by the tension of the little springs. Lighter springs let them move fully outward at relatively low shaft rpm, and stronger springs require higher shaft rpm for full outward movement. The pointed "tail" of the weights, at the pivot end, bear against a cam (called the "autocam") attached to the top of the distributor shaft and, as the weights move outward, the eight-sided cam that opens and closes the contact points (which trigger the coil to fire the spark plugs when the points open) is "advanced" so it opens the points earlier than when the weights are fully retracted (as they are at idle). In most distributors, this mechanism provides up to 20-25 (crankshaft) degrees of spark advance when the weights are fully extended. The maximum advance this system can provide is limited by a bushing installed over a pin, which moves in a slot in the lower plate of the autocam. The system is designed so that the weights don't begin to move until slightly above normal idle rpm, so the initial timing can be set accurately without any influence from the centrifugal advance mechanism.

CENTRIFUGAL ADVANCE CALIBRATIONS: There are many different calibrations of weight configurations and spring tensions specified for production Corvette distributors, depending on the performance level of the engine, manual or automatic transmission, etc. The points between the rpm at which the weights begin to move and the rpm at which they're fully extended, providing maximum advance, is referred to as the "centrifugal advance curve," which is tailored to each engine combination. The key point to remember here is that the centrifugal advance mechanism advances and retards spark timing in response only to engine rpm, and nothing else. Its function is to advance spark timing as engine rpm increases. As upward piston speed increases with rpm, effectively shortening the time for the compression stroke, the spark has to fire sooner, as the air/fuel mixture still takes the same amount of time to burn as it does at lower rpm. In effect, the centrifugal advance mechanism handles only the basic physics of lighting the fire sooner at higher rpm so peak cylinder

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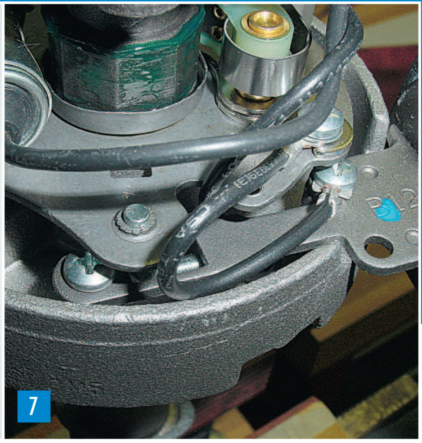

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6 A typical vacuum advance unit. The rod at the bottom is connected to the vacuum diaphragm, and connects to the movable points breaker plate at the other end. When vacuum is applied, it advances the breaker plate.

7 The vacuum advance unit, attached with two screws to the distributor body. The tip of its actuating rod is visible at the left, protruding through the movable breaker plate.

pressure is still reached at the same point just after TDC.

Now we have the basic physics handled, but we still need another system to manage spark advance based on all the variations of driving conditions and engine load variations experienced in normal operation. This is handled by the vacuum advance system.

VACUUM ADVANCE: The vacuum advance system consists of a vacuum diaphragm mounted on the distributor body. The diaphragm is spring-loaded in the zero-advance position, and has a rod that connects to a hole in the breaker plate, which is the movable plate the points are mounted on. When vacuum is applied to the diaphragm, it pulls on the rod, which in turn pulls on the breaker plate, rotating it with respect to the eight-sided cam on the distributor shaft which opens and closes the points. When viewed from the top, the distributor shaft (and the eight-sided cam for the points) turns clockwise. When the vacuum advance rod pulls on the breaker plate, it rotates the breaker plate (and the points) counter-clockwise, which "advances" the opening of the points (triggering the coil to fire the spark plugs). A typical vacuum advance unit, when fully deployed, will add about 15 (crankshaft) degrees of spark advance over and above what the distributor's centrifugal advance system is providing at the moment, which depends on engine rpm. They are two independent systems, but they work together to provide the correct amount of spark advance.

CONTROLLING VACUUM ADVANCE: Let's look at how the vacuum advance system is controlled. Referring back again to burn rates, remember that lean mixtures burn slower and rich mixtures burn faster. Engine load conditions (idle, steady cruise, acceleration) result in how lean or rich the air/fuel mixture is (the carburetor handles this), and the best indicator of engine load is intake manifold vacuum. At idle and steady cruise, engine load is low, and intake manifold vacuum is high due to the nearly closed carburetor throttle plates. Under acceleration, the throttle plates open wider, and intake manifold vacuum drops. It is essentially zero at wide-open throttle. As a result, intake manifold vacuum is a "free" indicator of engine load, which correlates nicely with fuel mixture being supplied – lean mixture at high vacuum, and rich mixture at low vacuum.

At idle, the engine needs additional spark advance in order to fire the lean (and exhaust-diluted) idle fuel/air mixture earlier in the cycle in order to develop maximum cylinder pressure at the proper point after TDC for efficiency, so the vacuum advance unit is activated by the high manifold vacuum, and adds another 15 degrees of spark advance on top of the fixed initial timing setting. For example, if your initial timing is set at 10 degrees, at idle it's actually 25 degrees with the vacuum advance connected (a properly calibrated centrifugal advance mechanism will not have started to move yet at idle rpm).

The same thing occurs under steady highway cruise conditions. The mixture is lean, takes longer to burn, the load on the engine is low (it takes only about 40 horsepower to cruise at 50mph) and the manifold vacuum is high, so the vacuum advance unit is again deployed and adds 15 degrees of spark advance over and above whatever the distributor centrifugal advance mechanism is providing at that engine rpm. If you had a timing light connected so you could see it as you cruise down the highway, you'd see about 45-50 degrees of spark advance – your fixed initial advance of 10 degrees, 20-25 degrees provided by the centrifugal advance mechanism, and the 15 degrees added by the vacuum advance unit.

When you accelerate, the fuel/air mixture is immediately enriched (by the accelerator pump, power valve, metering rod piston, etc.), and that rich mixture now burns faster and doesn't need the additional spark advance anymore. When the throttle plates open, the manifold vacuum drops, and the vacuum advance unit diaphragm retracts to its zero position, "retarding" the spark timing back to what is being provided at that moment by the fixed initial timing and the centrifugal advance mechanism. The vacuum advance doesn't come back into play until you back off the gas and manifold vacuum increases again as you return to steady-state cruise, when the mixture again becomes lean and needs more spark advance for fuel efficiency.

VACUUM ADVANCE CALIBRATION: There are also many different calibrations of vacuum advance units. Some begin to deploy at different vacuum levels than others, and some provide more degrees of advance when fully deployed than others. The original calibration was selected based on the intake manifold vacuum characteristics of that particular engine/transmission combination and how it was expected to perform in daily use. Vacuum advance units were connected to full manifold vacuum for decades. In the late '60s and early '70s, when emissions began to become an issue, many were instead connected to "ported" or "timed" vacuum sources. We'll discuss this aberration a little later.

THE ADVANCE COMBINATION: Now we have two different advance systems working independently, but complementing each other, to manage spark timing – centrifugal, based on engine rpm, and vacuum, based on engine load and operating conditions. The centrifugal advance system is purely mechanical and is only rpm-sensitive; nothing changes it except engine rpm. Vacuum advance, on the other hand, responds instantly to engine load and rapidly changing operating conditions, providing the correct amount of spark advance at any point in time, to deal with both lean and rich mixture conditions.

By today's engine management terms, this was a relatively crude mechanical system, but it did a good job of optimizing engine efficiency, throttle response, fuel economy, and idle cooling, with absolutely zero negative effect on wide-open throttle performance, as the vacuum advance is inoperative under that condition. In modern cars with computerized engine controllers, all those sensor inputs to the computer change both spark timing and fuel/air mixture 50 to 100 times per second, and we don't even have a distributor anymore – it's all electronic.

"PORTED" VACUUM: Now to the widely misunderstood manifold vs. "ported" vacuum aberration. After 30-plus years of controlling vacuum advance systems with full manifold vacuum, that "free" indicator of engine load and fuel mixture, along came early emission control requirements (seven years before catalytic converter technology was introduced), and all manner of crude band-aid systems were introduced to try to reduce hydrocarbons and oxides of nitrogen in the exhaust stream. One of these crude, but effective systems was GM's Air Injection Reactor (A.I.R.) system, which pumped fresh air into the exhaust ports to "afterburn" pollutants in the exhaust manifolds. The key to making this system work at maximum efficiency was retarded spark at idle; with retarded idle spark timing, the "burn" begins late, and is not complete when the exhaust valve opens, which does two things that were important for emissions. The incomplete burn reduced combustion chamber temperatures, which reduced the formation of oxides of nitrogen (NOX), and the significant increase in exhaust gas temperature ensured rapid "light-off" and combustion of the hydrocarbons in the exhaust gas stream when the fresh, oxygen-carrying air was introduced from the air pump.

As a result, these engines ran poorly, and an enormous amount of wasted heat energy was transferred through the exhaust port walls into the coolant, causing them to "run hot" at idle; cylinder pressure fell off, engine temperatures went up, combustion efficiency went down the drain, and fuel economy went down with it. "Ported Vacuum" was easy to implement – they just moved the distributor vacuum port orifice in the carburetor from below the throttle plate (where it was exposed to full manifold vacuum) to above the throttle plate, where it was exposed to manifold vacuum only after the throttle plate opened. This meant that the vacuum advance was inoperative at idle (retarding idle spark timing from its optimum value), and these applications also had very low initial timing settings; they were usually set at four degrees before TDC or less, and some even had initial timing settings as much as two degrees after TDC. The vacuum advance still worked at highway cruise, but not at idle, which caused all manner of problems. "Ported Vacuum" was strictly an early pre-converter crude emissions strategy and nothing more. Don't believe anyone who tells you that ported vacuum is a good thing for performance and drivability – it's not. Anyone with a street-driven car without manifold-connected vacuum advance is sacrificing idle cooling, throttle response, engine efficiency, and fuel economy, probably because they don't understand what vacuum advance is, how it works, and what it's for. There are lots of long-time experienced mechanics who don't understand the principles and operation of vacuum advance either, so they're not alone.

THE BOTTOM LINE: Now that we've covered the why's and how's of spark timing and its control systems, you can appreciate what's going on underneath your ignition shielding and how it affects performance and drivability. Checking the operation of the centrifugal and vacuum advance systems during periodic maintenance and tune-ups can pay real dividends that you can feel in the seat of your pants. Well, you say, "How do I do that?" Tune in next month, when we'll show you how to check out those systems, how to "map" your advance curves against their design specifications and verify proper operation, and pass along some simple tips and techniques for improving your Corvette's performance by "tweaking" its advance systems for peak efficiency. ■