Displacement on Demand

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With all the scientific technology computing power out there in the world today I have yet to hear an answer to the age old question: What came first, the chicken or the egg? Well the automotive industry has a similar dilemma that continues to plague its existence. Which is more desirable, large displacement and horsepower or smaller displacement and better fuel mileage?

What if you could have a large displacement, high-horsepower engine that you could call upon when you needed it and have a smaller displacement better fuel mileage engine available when you don't. For those of you old enough to remember, that would be a "Doublemint" commercial: double your pleasure and double your fun!
Well, that technology is here right now and growing in popularity and it has more names and acronyms than "Carter has pills" (another commercial, for those old enough).

The one that is probably best known is "Displacement on Demand" (DOD), but there is also "Active Fuel Management" (AFM) that GM has laid ownership to; "Multiple Displacement System" (MDS) from Chrysler; "Active Cylinder Control" (ACC) at Mercedes Benz; and "Variable Cylinder Control" (VCM) from Honda.

You may also hear it called cylinder deactivation. But no matter what you call it, the bottom line is that you have the ability to go down the road driving your gas guzzling road thumping V8 (or bigger) and have half or more of your cylinders go dead, start sipping fuel, run more efficiently and gain an increase of fuel economy up to as much as 20 percent. Imagine being on the highway with the cruise on and only 4 cylinders pushing you down the road (because you only need 30 percent of your available power). No one has to know, and you still retain your V8 dignity. It's here today, it really works and it will be an even bigger part of future engine development of all sizes.

HOW IT WORKS
Cylinder deactivation is used to reduce the fuel consumption and emissions of an internal combustion engine during light load operation (LLO). Since we already know that the vehicle only needs 30 percent of its maximum engine power to keep moving (a body in motion tends to stay in motion; see Newton's Laws), there are other issues that come into play during this reduced demand for power.

The throttle valve is nearly closed, and the engine is literally starving for air, which is a very inefficient point of operation known as pumping loss. Larger displacement engines are throttled back so far during light load that the cylinder pressure at top dead center (TDC) can diminish as much as 50 percent. Low cylinder pressure means low fuel efficiency.

The use of cylinder deactivation at light load means there are fewer cylinders drawing air from the intake manifold, which works to increase its fluid air pressure. This reduces pumping losses and increases pressure in each operating cylinder. Fuel consumption can be reduced by approximately 20 percent in highway conditions.

Cylinder deactivation is achieved by keeping the intake and exhaust valves closed for a particular cylinder, which creates an "air spring" in the combustion chamber. The trapped exhaust gases from the previous charge burn are compressed during the pistons up stroke and push down on the piston on the downward stroke. The compression and decompression of the trapped exhaust gases have an equalizing effect and overall there is virtually no extra load on the engine.

The engine management systems also cut fuel delivery to the disabled cylinders. The transition between normal engine operation and cylinder deactivation is kept smooth using changes in ignition timing, cam timing and throttle position thanks to electronic throttle control (ETC), commonly known as "drive by wire." Two issues to overcome with all variable displacement systems are the unbalanced cooling and vibration tendencies of cylinder deactivation engines. This is done in different manners by different manufacturers and designs.

HISTORY
The oldest engine technological predecessor for the variable displacement engine is the hit and miss engine, developed in the late 19th century. These single cylinder stationary engines had a centrifugal governor that cut the cylinder out of operation so long as the engine was operating above a set speed typically holding the exhaust valve open.

Cadillac L62 V8-6-4

The technology was first experimented on multiple cylinder engines during WWII, but was truly pioneered in 1981 on Cadillac's ill-fated L62 V8-6-4 engine. GM paved the way (and lost its way) with this innovative engine. Unfortunately, cylinder deactivation still carries a bit of a stigma among some older drivers with long memories that stemmed from this engine.

Through the late '70s Cadillac was under immense pressure to improve the fuel consumption of its V8 powered boulevard cruisers due to the introduction of the U.S. Corporate Average Fuel Economy (CAFÉ) regulations that forced the issue, so Cadillac developed a cylinder deactivation system in conjunction with the Eaton Corporation.

The existing 368 cid push rod V8 was used as the platform and an all-new valve control system allowed the sequential deactivation of two pairs of cylinders, creating an 8, 6 or 4 cylinder engine (see Figure 1). Interestingly, Cadillac chose to deactivate opposing pairs of cylinders rather than a bank of cylinders as is commonly done today.

Fig 1

Cadillac and Eaton developed a series of solenoids that were used to release the fulcrum on the intake and exhaust valves' rocker arms. The lifters and pushrods continued to operate as normal but the rocker arms sat motionless and the valves remained closed due to valve spring tension. When increased engine power was required, the solenoids returned the rocker fulcrums to their normal operating position and full valve operation resumed.

Coordinating the activation and deactivation of cylinders was an electronic control unit (ECU). The ECU controlled the engine's throttle body fuel injection system as well as the cylinder deactivation solenoids.

The engine was set to run on all 8 cylinders during starting, heavy acceleration and at all speeds up to 27 mph. At light to moderate engine load the system would deactivate pairs of cylinders as required. It was stated that interstate driving only required 4 cylinders for the majority of the journey. It even had a dashboard display that showed the number of active cylinders and the system relied on the driver applying more throttle to maintain speed, a trait that many drivers never became comfortable with or accepted.

Despite being a technological marvel, the L62 V8-6-4 had numerous problems and Cadillac found itself faced with many legal battles.

The throttle body fuel injection (TBI) system (a carb with an injector) was a major cause of the problems. The TBI would continuously deliver fuel to all cylinders irrespective of the cylinder deactivation. Fuel would build up in the intake ports of the deactivated cylinders until full engine operation was again required, at which point a fuel dump would occur in those cylinders and the engine would stumble momentarily.

There just was not enough technology or electronics available at the time to resolve the issue, so the V8-6-4 died in 1982 after just one year. Now before you want to condemn Cadillac's efforts, Google "Cadillac 16" and see what is happening in their latest and greatest efforts and you will be pleasantly surprised.

Mitsubishi MD
In 1982 Mitsubishi Motors Corporation (MMC) developed its own cylinder deactivation system in the form of Modular Displacement (MD) first used in the MMC 1.4L 4G12 inline 4 cylinder. It functioned successfully, and it was hailed as the world's first since the Cadillac system proved to be a bust. The technology was later used in MMC V6 engines but the effort was short lived due to lack of response from car buyers.

In 1993 MMC developed its own variable valve timing (VVT) called Mitsubishi Innovative Valve Timing Electronic Control (MIVEC) with the MD variant. The revived MD technology was now in its second generation with improved electronic engine controls enabling the switch from 4 to 2 cylinders, which reduces the energy wasted due to pumping losses. In addition, power loss due to engine friction is also reduced. However, the final conclusions were that the major gain in fuel economy was the VVT system not from the MD feature and it was dropped in 1996.

Mercedes Benz
In 1999 Mercedes was considered to be the first to apply cylinder deactivation to mass production vehicles since the Cadillac. The first models to appear with it were the European spec 1999 CL600, S600 and CL500. These vehicles were powered by either a DOHC 6.0L V12 or DOHC 5.0L V8.

The Mercedes cylinder deactivation system, known as Active Cylinder Control (ACC), is unlike the system used in many other applications. The approach involves deactivating half of the engine cylinders using the common principle of keeping the intake and exhaust valves closed. In doing so Mercedes uses a pair of arms that replace the conventional roller-type rocker arm. One of the arms follows the cam profile while the second arm connects to the valves.

During normal engine operation a locking pin joins the two arms. When cylinder deactivation is required, solenoid-controlled oil pressure is used to move the locking pin, which disengages the two arms and the valves remain closed by spring tension. It acts like a floating fulcrum at this point (see Figure 2).


Fig 2

Mercedes uses sequential fuel delivery that cuts fuel to cylinders that are deactivated, preventing the drivability issues that the Cadillac encountered. In addition, the use of electric throttle control, valve timing, ignition timing and a variable intake manifold help give a seamless transition.

Mercedes even took it to another level by teaming with Eberspaecher to install an ECU-controlled valve in the exhaust system downstream of the cats to preserve the sound of all cylinders in operation. Now if that is not "uber" I don't know what is. Fuel economy benefits indicated are 7 percent city, 20 percent highway.

Chrysler
Originally released as DaimlerChrysler in the 2004 Chrysler 2004 300C, Dodge Magnum, Charger, Durango, Ram and Jeep Grand Cherokee and Commander, the 5.7L Hemi featured cylinder deactivation as well. The HEMI cylinder deactivation system is known as MDS (Multiple Displacement System) disabling 4 of the 8 cylinders at road speeds above 27 mph and with the engine speed at less than 3,000 rpm.

The HEMI uses a special set of lifters that are referred to as "lost motion devices." To enable the 4-cylinder operation, the lifters are fed oil at high pressure controlled by ECU operated solenoids that pushes on an internal locking pin that causes the lifter to collapse. Once the lifter collapses, the camshaft is disengaged from the push rods and valves and the cylinder is deactivated (see Figure 3).


Fig 3

MDS can switch between 8- and 4-cylinder operation in just 40 milliseconds or approximately one camshaft revolution. Fuel is cut to deactivated cylinders and an electronic–controlled throttle is used to maintain engine power during the transition.

GM V8 and V6

Displacement on Demand (DOD) as it was originally called is now Active Fuel Management (AFM), and it's GM's latest cylinder deactivation system. After its association with the notorious 1981 Cadillac, GM waited until 2004 to re-release cylinder deactivation. AFM was initially released in the GMC Envoy and Trailblazer SUV's.

Like the HEMI, the GM system uses specially developed hydraulic lifters by Eaton corporation for the intake and exhaust valves (see Figure 4). The lifters can be collapsed by disengaging an internal locking pin.


Fig 4

The locking pin is disengaged by using solenoids (Figure 5) to alter oil pressure fed into the lifter. When the locking pin is disengaged and the lifter collapses, the camshaft is isolated and the valves remain closed.

Fig 5

A new 32-bit ECU orchestrates the valve deactivation solenoids, throttle control, ignition timing and sequential fuel delivery which also cuts fuel to the deactivated cylinders as the other systems. A pressure operated valve in the muffler also serves to maintain a subtle exhaust note in the V8 and 4-cylinder operating modes. It's hard to believe that during beta testing periods of cylinder deactivation the single most common complaint was that the vehicle did not sound like a V8 anymore. Apparently bigger is better even if it is only in sound.

A typical oiling diagram (Figure 6) is included to show the ins and outs of how all of this comes together

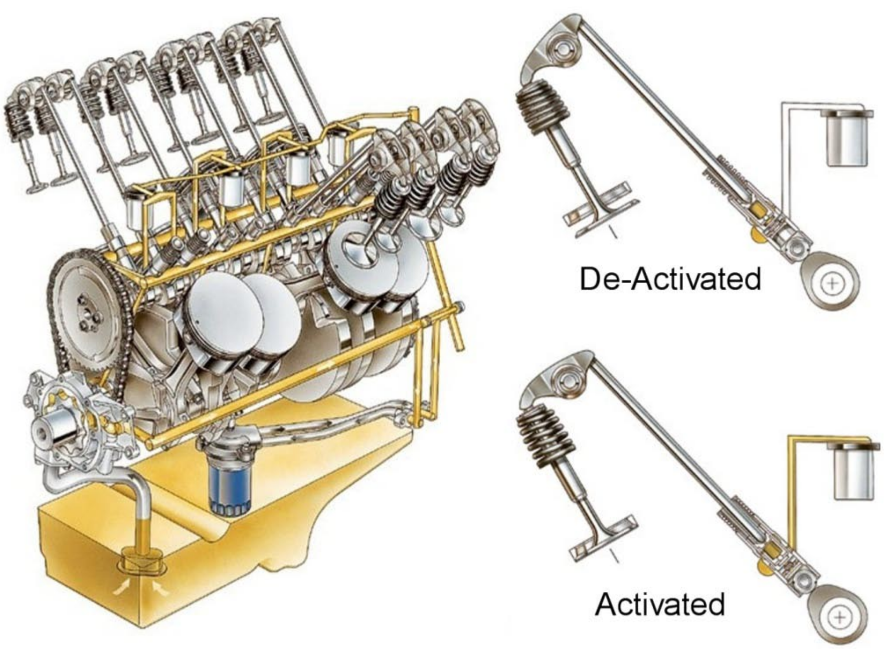

Fig 6

Honda

Honda introduced its Variable Cylinder Management (VCM) system in 2005 in the J-series V6 3.5L and the 3.0L.
Honda's VCM system initially deactivated an entire bank of cylinders at light load, with the engine switching from 6- to 3-cylinder operation. Currently the system goes from 6- to 4- to 3-cylinder operation, and a really great animated illustration of how the system operates is at www.hondavcm643.com. Click on the "How VCM 643 works" tab. Road speed, rpm, and throttle position are the major factors used in determining when the engine switches to 3-cylinder mode.

Deactivation of cylinders is achieved by releasing a synchronizer pin that normally interlocks the cam follower and rocker arms (see Figure 7). The synchronizer pin is released using hydraulic pressure which is controlled by a dedicated solenoid. Once the synchronizer pin is released, the cam follower continues to move against the camshaft but the rocker arms and valves remain in a closed position.

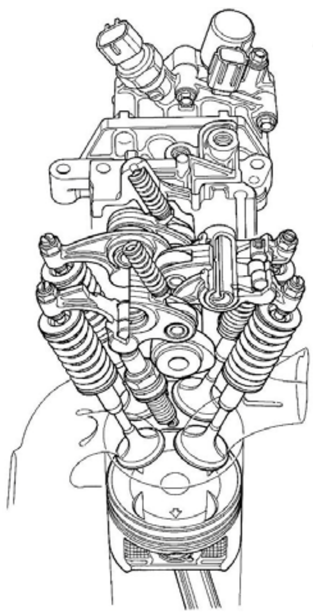

Fig 7

Honda also does something unique that will be up and coming on a number of vehicles. An Active Noise Control (ANC) system uses the audio system speakers to cancel undesirable engine boom during 3 cylinder operation. The ANC controller uses two microphones inside the cabin and generates an out-of-phase signal to cancel out the sound waves. ANC is not used during six-cylinder operation.

THE FUTURE

Eaton continues to develop variable-lift and timing devices with several global customers. The company is also working on variable ratio rocker systems that that allow the rocker arm geometry to be changed literally on the fly. Instantaneously changing the geometry enables the engine to achieve variable lift and timing simultaneously. Eaton also is in the concept development stage of a camless actuation system device that will be packaged with the cylinder head module that includes valve train components.

The ultimate situation for internal combustion engines would be a configuration that can change both displacement and compression based upon the vehicle need and demand. Imagine being able to have 1,000 horsepower when you need or want it and only 100 during times when you are on the economy run. Cylinder deactivation is an attempt in providing just that. Obviously the range of expectations is limited with current production technology. Remember the Cadillac in 1981 – it was 20 years ahead of its time but did not have the electronic controls, ECU power, electronic throttle and many of the other technologies available today to complete a successful cylinder deactivation production engine.

If you want a glimpse of what may be coming in the future I suggest that you look at Hefley Engine company (www.hefleyengine.com) and watch the video of how this variable displacement-compression engine operates and its ability to use gasoline, E85 or even diesel fuel for that matter. The future of the internal combustion engine in that configuration is limitless.

In closing there are some things that are going to have to be adhered to that will affect cylinder deactivation longevity. One is that oil change intervals are more critical than ever. Dirty oil will take these systems to their knees. The complexity of having activation pins engage and disengage controlled by oiling solenoids requires clean oil to operate, so dirty oil can contaminate these systems and render them ineffective. The other thing to remember is OE-recommended viscosity is imperative. The use of heavier or lighter weight oils will also have an ill effect on the operation of cylinder deactivation and its longevity.

These engines will also present new challenges in the remanufacturing process as well. Cylinder deactivation lifters are upwards of eighty dollars each and can dramatically change your reman cost. GM recommends replacing the entire solenoid manifold assembly when engine replacement is required. I was too afraid to even look up the pricing for that. And if the previous engine had a bearing failure and a customer reuses the activation solenoids they will reintroduce the residual debris of the failed engine to the new reman.

This technology is here to stay and will be more and more popular as time goes on so we need to be up to the challenge of making certain that the reman process is successful.