The ABC's of DOD, AFM, and MDS

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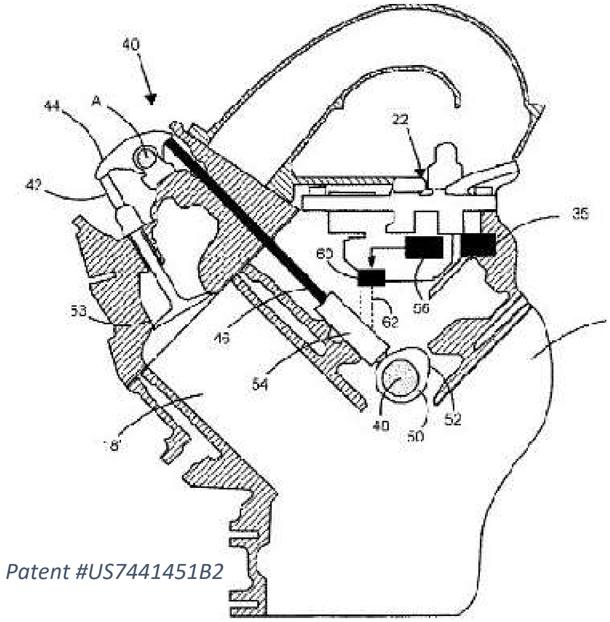
Manufacturers of modern V8 engines have realized that we don't always need all eight cylinders all the time. If the vehicle is cruising along with a low torque output from the engine required to maintain the current speed, there are plenty of cases where half the engine would be enough to get the job done. After all, plenty of four and six cylinder cars are also capable of cruising along a the same speeds on the same roads, right? The whole reason we have the "extra" cylinders if to satisfy our need for on-demand power whenever we mash our right foot. Admittedly, this is only a fraction of the time the engine is running, so being able to dial back to something that mimics a smaller engine when loads are light can have very real advantages in both fuel economy and emissions.

Different OEMs call this same basic strategy by different names. You'll see variants like DOD (Displacement on Demand), AFM (Active Fuel Management), or MDS (Multiple Displacement System), or the latest DSF (Dynamic Skip Fire). It has actually been applied to more than just V-8 engines, with multiple six-cylinder applications out there as well. Fundamentally, they're all doing almost exactly the same thing. These systems have a way of being able to interrupt the camshaft lobe movement before it opens the valve on one or more cylinders. This is usually done by blocking the supply of oil to a hydraulic lifter, allowing it to collapse under spring pressure as the cam lobe presses on it. The result is a valve that stays closed and blocks charge flow either in or out of the cylinder.

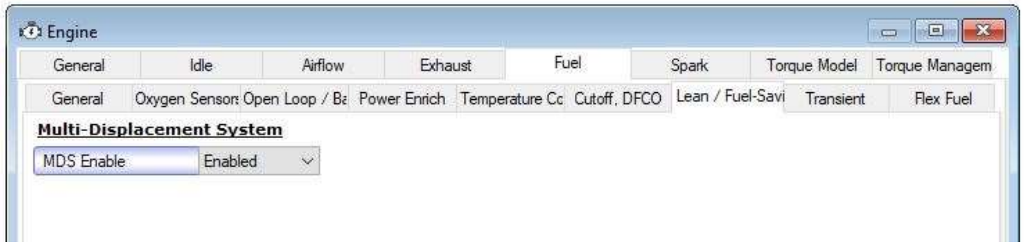


Patent #US7441451B2

With no fresh air charge entering the cylinder in question, the fuel injector can also be shut off. The remaining cylinders must pick up the slack in order to deliver the total amount of torque needed by the engine, but they actually get more efficient during this process. When feeding all cylinders, we control the airflow with the throttle body, and must restrict this airflow to avoid making too much torque at any moment during light loads. This restriction comes with a loss in overall pumping efficiency for the engine. By shutting off some of the cylinders, we find that we need to increase the relative flow to the remaining cylinders, which is accomplished by opening the throttle slightly and bringing the intake Manifold Absolute Pressure (MAP) up as well. Not needing to draw as much vacuum across the throttle blade is the mechanism that frees up some of the pumping losses and, thus, improves our fuel economy.

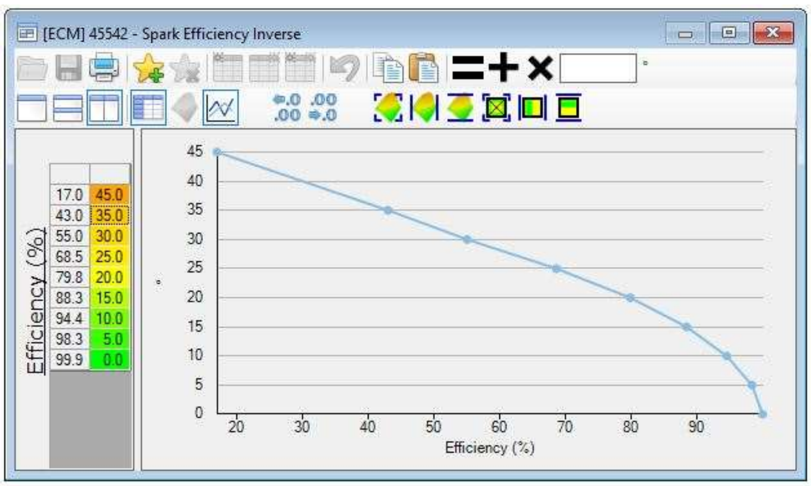
With only a fraction of the original total of cylinders working during this deactivation period, total available torque can be limited. If the driver requests a torque greater than can be delivered with the current number of active cylinders, the system is deactivated and the engine transitions back to a normal mode of operation with all cylinders in play. The system is also sometimes deactivated for other reasons such as hitting the minimum manifold vacuum required for power braking assist, oil temperature/pressure, or oil aeration.

“But my truck gets better fuel economy with DOD disabled”



This may indeed be true, but first we need to ask “why is this driver seeing such a difference?” As mentioned before, there is a clear steady-state advantage at light load to shutting off half the engine and just running the remaining cylinders a little harder. But some drivers still swear they get better mileage without the system active. They’re not wrong.

The answer lies in their driving style. Their problem is not so much the engine running in cylinder deactivation mode as it is the transitions to and from that mode. In order to have a smooth transition from normal operation to fewer cylinders, the ECU plays a game with the torque control system. While it’s waiting for the throttle to open and change the MAP, it temporarily retards the spark advance on all cylinders until the transition to fewer cylinders is complete. The ECU does this again on the way as the new cylinders come online before the throttle can close slightly and reduce MAP. This avoids the step change in torque that a driver might feel during each transition.



While all of this is nice and smooth to the drivability butt-meter, operating with retarded spark during the transition pulls the engine off of the mechanical efficiency associated with operating at MBT spark. When timing is retarded from MBT, we have a case where cylinder pressure from combustion is phased too late and loses the opportunity to push as hard on the piston (and crankshaft) during the most useful part of the cycle.

This loss in efficiency can show up as reduced fuel economy. Having these transitions too often lets those individual losses in efficiency add up and outweigh the fuel consumption benefit of operating with fewer cylinders in the first place. If we have a nervous driver who constantly exceeds the thresholds to get in and out of cylinder deactivation, the numerous transitions make the overall result worse than a driver who just gets into cylinder deactivation and stays there for a while. Some of this can be helped in the ECU calibration by making sure the limits that trigger a change are wide enough to avoid switching states with small input changes from the driver.

Performance Camshafts

Changing camshafts in a performance application almost always means going bigger in both lift and duration for the valve opening events. The idea here is to allow more opportunity for air to make it into the cylinder from the intake manifold and for exhaust to escape out on the other side, leaving more room for fresh air on the following cycle. Whenever we make a cam change in an engine, it’s always a good idea to evaluate the rest of the valvetrain at the same time. Usually, we opt to install more capable valve springs. This lets us avoid bind at higher lift and maintain proper contact between the follower and cam lobe at high RPM, reducing valve float.

If the engine is equipped with a cylinder deactivation system, we face a new potential failure mode. Increasing the valve spring pressure or just increasing the amount of lifter movement at speed may be enough to overwhelm the oil pressure keeping the lifter in full operation versus cylinder deactivation mode. If the oil can't keep the lifter pumped up, it collapses just the same as when the ECU intentionally shuts off the solenoid controlling that lifter/cylinder. Obviously, this is not great for WOT performance.

The solution has traditionally been to forego use of the cylinder deactivation system with out new cam and valvetrain. Performance enthusiasts are seldom deterred by this tradeoff in part throttle fuel economy, citing the previous mileage loss above from their heavy feet and many transitions. If one is willing to walk away from the potential light load fuel economy improvement with DOD, the new cam (and lifters) gets installed much the same way as any other engine. Since many performance camshafts add valve event duration and some degree of low lift overlap that increases natural EGR, there can even be a net benefit in fuel economy here if the system is properly calibrated later.

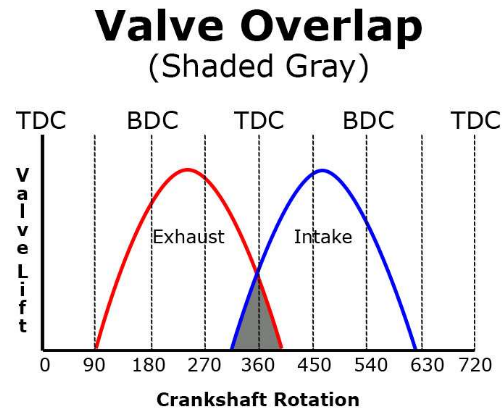
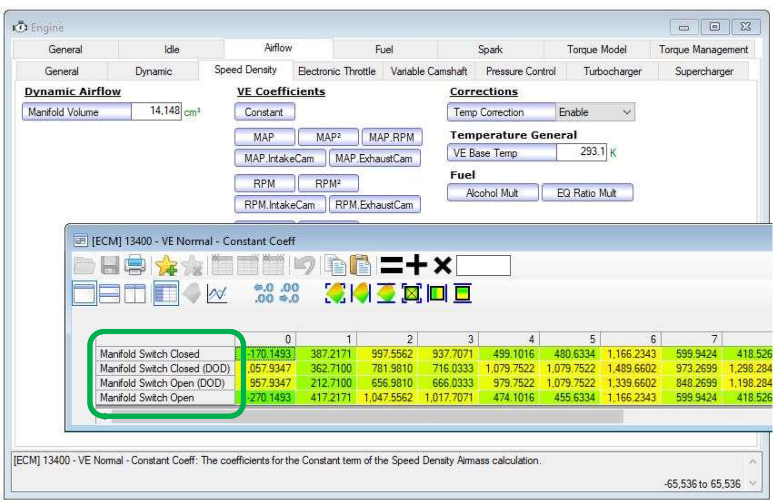


Image courtesy of Summit Racing

Impact on ECU Calibration



We must recognize that when we shut off some of the cylinders, it has an effect upon pumping efficiency for whichever cylinders are still operating. The OEMs know this too. That's why their airflow models inside the ECU often have separate values for when all cylinders are operating vs shutoff mode.

Running with half the cylinders shut off almost doubles the effective plenum volume for the remaining operational runners. It also changes the dynamics of the many pressure waves bouncing back and forth inside the intake manifold. These forces can combine to result in a volumetric efficiency table (which may be "virtual" in some models) that is significantly different than the baseline table. The differences are also usually not just an across the board offset, but rather a series of more here and less there tradeoffs that must be independently calibrated and combined into a new model specific to the cylinder shutoff mode. In short, if AFM/DOD is to be used, it requires its own separate speed density model.

Running with some cylinders shut off and others presenting stronger intake pulses at a lower frequency can also impact the MAF sensor readings. For this reason, you'll see OEM air ducts incorporating Helmholtz resonators that look like appendages dangling off the main inlet tube. These carefully tuned volumes and lengths are designed to dampen out some of these stronger pulsations in cylinder shutoff mode to give the MAF sensor itself a smoother signal and improve fuel delivery accuracy.

Unexpected Impact

Hot Rodders have long had a love for "cold air intakes" that replace the OEM carefully tuned inlets with smooth, higher flowing units in the name of increased WOT horsepower. Unfortunately, this sometimes comes with a tradeoff of increased signal noise at the MAF while cruising. In fact, it can be another contributing factor to their earlier claim that the vehicle gets better fuel economy with DOD shut off. If we have done something that negatively impacts the airflow measurement and fuel delivery (like get rid of that nice ¼ wave cancelation from the Helmholtz resonator), it's no surprise that we might lose some fuel economy in the process. A self-inflicted wound, as they say.

"What can we actually do with it?"

Ah, the BIG question, in my humble opinion. As a calibration engineer, I would love nothing better than to retain the cylinder shutoff capability on my projects whenever possible. After all, the OEM guys went to great lengths to put the feature there, and there is some great potential if we can just use it as intended.

Unfortunately, optimizing the system requires that we adjust the triggers that make us step from all cylinders to shutoff mode and back again. Looking at popular aftermarket tuning software options, they give use several ways to ***disable*** the system based on RPM, VSS, gear, voltage, run time and more. What I don't really see is what I would consider "the important tables" for shutoff mapped for us at all. I would expect to see table that represent thresholds of torque, throttle position, or cylinder airmass that once crossed would change the engine over to shutoff mode. As of this writing, I'm just not seeing it in the list of things we can adjust. (Remember that we only see a couple hundred of the tens of thousands of parameters actually inside the ECU)

So, if we are to keep the cylinder shutoff functionality, we are locked into using the existing trigger thresholds for both activation and deactivation. Our only other option is to disable the feature. Sometimes it works with the OEM triggers, sometimes it's better to just work around it. This is the difference between tuning with publicly available aftermarket tools and being a calibration engineer on the inside of a program. This is just another chunk of the very large iceberg that we don't see from the outside.

I wish I had better news. Maybe the aftermarket software companies will read this and sharpen their pencils working on unlocking some of these tables. Even if they do, it doesn't alleviate the physical concerns discussed earlier with bigger cams and stiffer valve springs making life difficult for variable lifters.

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