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Assignment 2

"VARIABLE DISPLACEMENT"

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Submitted by

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“VARIABLE DISPLACEMENT” OR “ACTIVE CYLINDER TECHNOLOGY”

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1.INTRODUCTION

The global market for new vehicles is set to grow from today’s level of 71 million vehicles to 103 million by 2020. And according to market researchers and experts, around 100 million of these vehicles will be fitted with a combustion engine. As a result, automotive technology that reduces fuel consumption and CO_2 emissions in gasoline and diesel engines is gaining importance. The key contributors towards reducing CO_2 emissions include technology packages for increased energy efficiency in the drivetrain, hybrid concepts that combine combustion engines and electric motors, start/stop functions for economical gasoline and diesel engines, energy-saving accessories in the drivetrain and innovative engine concepts such as cylinder deactivation.

Cylinder deactivation is an automobile engine technology that allows the engine displacement to change, usually by deactivating cylinders, for improved fuel economy. The technology is primarily used in large, multi-cylinder engines.

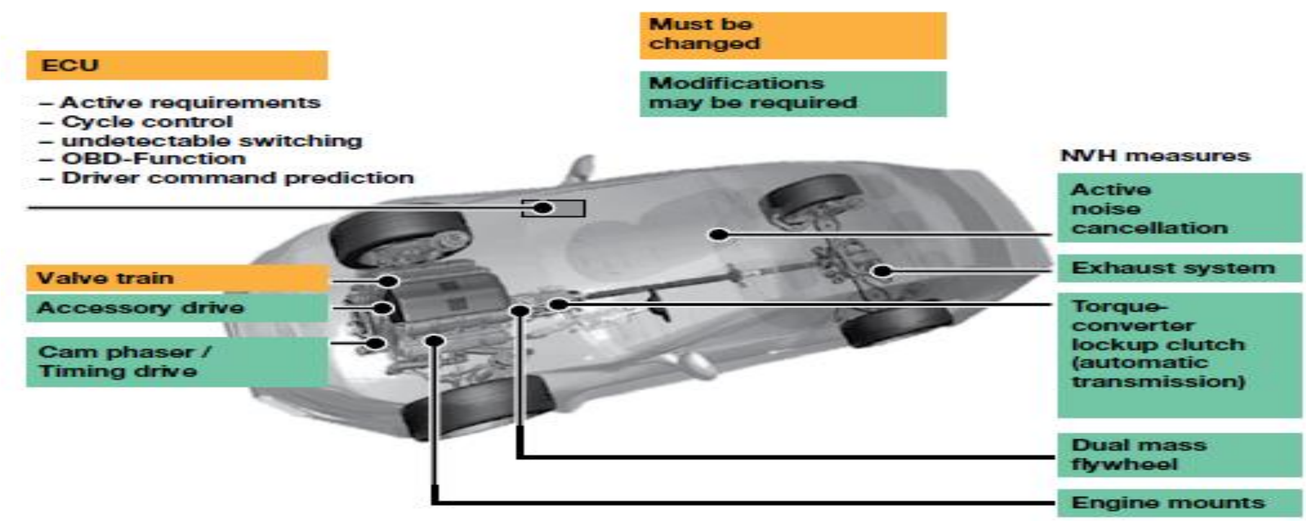
One of the ways manufacturers can minimize fuel consumption is to downsize the engines they offer. In practice, downsizing therefore frequently leads to a reduction in the number of cylinders. “Temporary downsizing” in the form of cylinder deactivation offers an attractive compromise, since this allows an engine to shift its operating mode to achieve the specific consumption figures it is rated for, especially when low loads and operating speeds are encountered. At the same time, the driver still has a sufficiently powerful engine at his disposal that ensures the same level of driving pleasure and comfort with regard to acoustics and vibration characteristics.

Deactivating cylinders reduces fuel consumption and CO_2 emissions in combustion engines without compromising on performance and comfort. A key component in this concept, in addition to structural modifications to the engine, is the engine control unit, which connects and controls all of the relevant subsystems of the engine.

2.DESIGN

The most consistent form of cylinder deactivation is to not only to cut injection and ignition for the respective cylinders, but also to stop all moving parts (including the pistons). This, in turn, utilizes the entire thermodynamic potential available and considerably reduces the friction that occurs inside the engine. It goes without saying that compromises must be made when it comes to the ignition sequence and dynamic balancing.

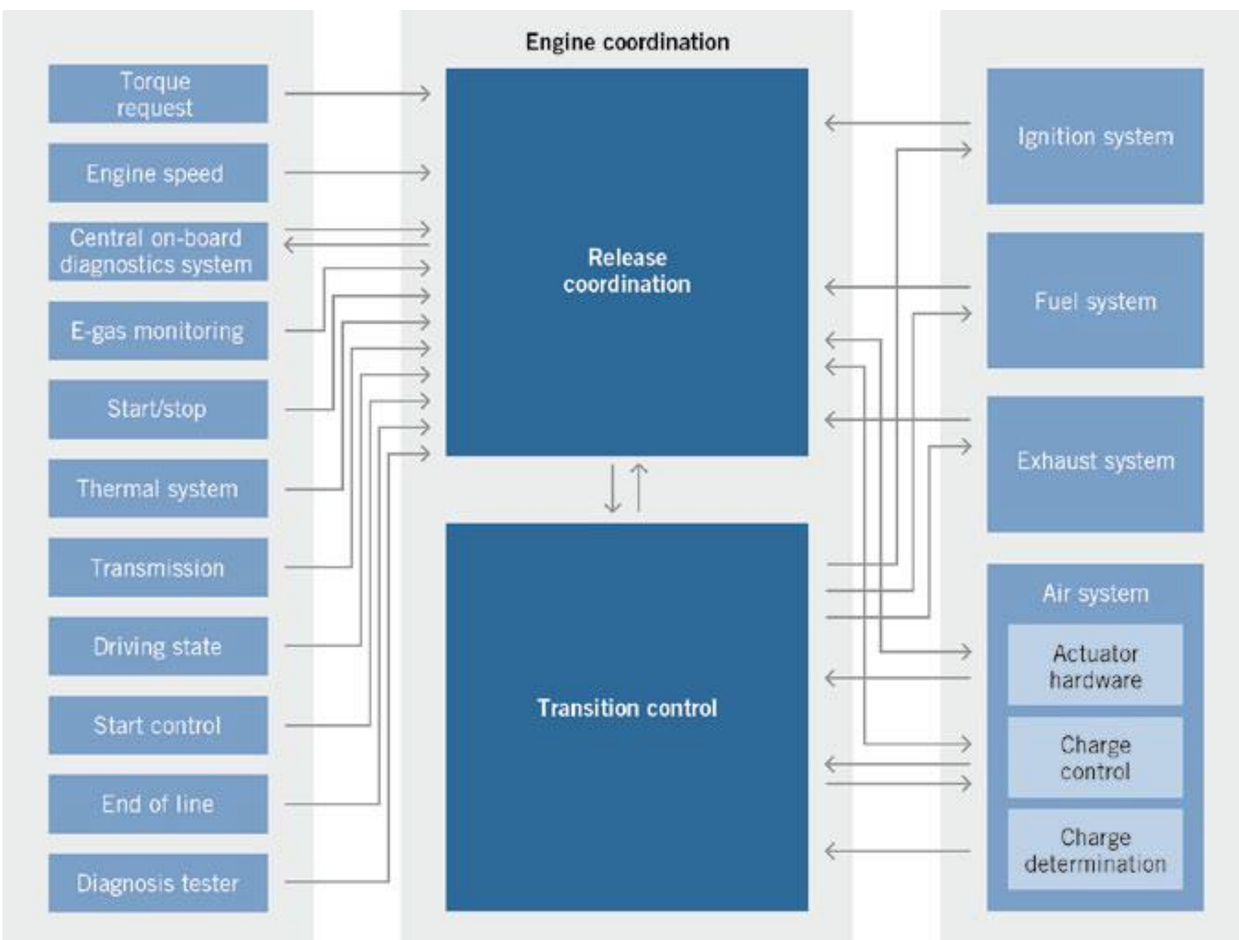
When developing engines with cylinder deactivation, the torque and emissions neutrality, as well as the response behavior, are both challenges and quality criteria. This means that transitions between full engine operation and cylinder deactivation must be carried out in such a way that is imperceptible to the driver, and without any loss of comfort due to torque jerks. If full engine mode is required while in cylinder deactivation mode – such as when overtaking – this transition must be made within a few milliseconds. Furthermore, transitions must be made without any additional emissions being generated. In order to deal with these challenges, the engine control unit (ECU), takes center stage in development activities. It analyses all of the data that is relevant for selecting the operating mode (full engine mode or cylinder deactivation) and approves transition. It also connects all of the relevant actuators for the engine mode transition control, including the air system with throttle valve, the fuel and ignition system and the gas exchange valve hardware. In doing so, ECU uses software functions to coordinate and control all of the relevant engine subsystems, influencing the torque progression, as well as the response and emission behavior.



Overview of the measures accompanying cylinder deactivation

3.ENGINE CONTROL UNIT REQUIREMENTS

Cylinder deactivation can be implemented in two-cylinder engines or in engines with a large number of cylinders. Various configurations are possible based on the position of the cylinders to be deactivated, the particular design features of an engine with cylinder deactivation lead to special requirements in the ECU function software, including the ignition sequence or the respective design of the intake and exhaust-gas tracts. In addition, the type of injection (intake-manifold or direct fuel injection) defines the function software for cylinder deactivation systems. Depending on the CO_2 reduction target, deactivation of the gas exchange valves may also to be omitted. This reduces the effort associated with the engine design, as well as the costs, but does not fully exploit the CO_2 savings potential of cylinder deactivation.

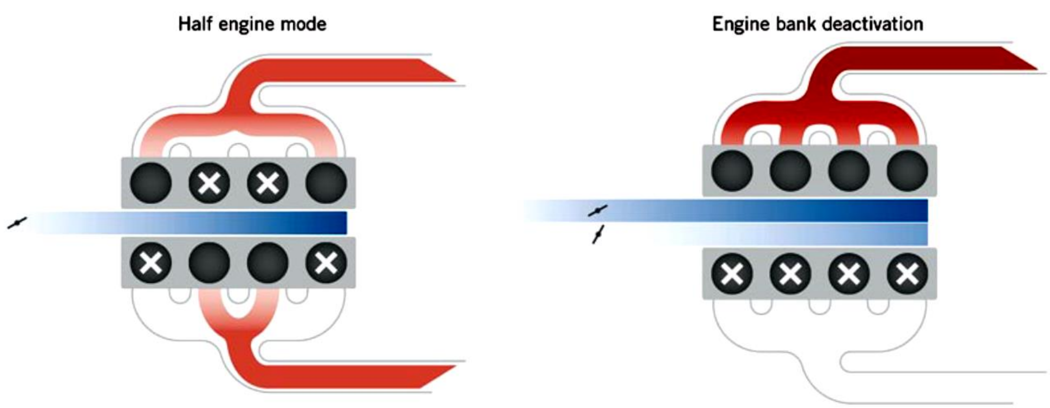


Cylinder deactivation system overview

4.TRANSITION TO CYLINDER DEACTIVATION

In order to operate an engine with cylinder deactivation, certain precautions must be taken for the deactivation of cylinders during full engine mode. The difference in loss torque must be pre-controlled from the point of view of the target torque calculation. This torque is determined by the difference in loss between full engine mode and cylinder deactivation. The target torque therefore increases by the difference in loss torque in full engine mode, which is not applicable in cylinder deactivation. As a result, the calculation of the target air charge is valid for both operating modes, and a contribution is made towards the torque neutrality of the transition.

In full engine mode, the ECU operating mode control constantly checks a large number of conditions for switching the operating mode. The target torque to be set by the engine is one of the most important input parameters, as there is a limited maximum torque that can be set in cylinder deactivation. The physical impact of this limit is determined by the driving properties and the acoustics. Another important input parameter is the engine speed, as it is not possible to switch the gas exchange valves safely above a certain speed limit. Other input parameters include the engine temperature and vehicle speed. The ECU release coordination assigns a condition to each input parameter. In order for cylinders to be deactivated, each condition must be met. The ECU diagnostic system can delay a cylinder deactivation request, for example if a diagnostic analysis, which requires full engine mode, has not yet provided a final result. Finally, the request function checks for approval from the hardware for deactivating the gas exchange valves. Only after this condition has also been met can a transition to cylinder deactivation be requested.



Cylinder deactivation configurations

In this context the ECU coordinates all of the engine actuators, the sequence and the exact time are decisive factors in meeting all of the aforementioned quality criteria. The transition process begins by increasing the air charge so that the cylinders that are still activated can generate all of the required torque. In an engine with a single intake manifold, the increase is made across all cylinders. In an engine with separate intake manifolds, the air charge can be changed for the active engine bank independently of the engine bank to be deactivated. In principle, the air charge in the active cylinders does not have to be twice as high as in full engine operation, as the air charging proportion to overcome the difference in gas-exchange losses is not required.

Increasing the target-air charge results in a higher operating point. In order to supply the exact target torque required, the ignition timing must be adjusted accordingly. As soon as an adequate torque reserve has been created through the increased air charge, ECU sends the trigger to deactivate the gas exchange valves. Up to this point in time, the transition can be aborted at any time with a new request for full engine operation. The deactivation process starts by determining which cylinder can be deactivated first. This cylinder is determined by the angular position of each relevant intake and exhaust cam of the camshaft as well as the delay times of the deactivation actuators. The corresponding output stage is actuated at precisely the right time. It takes into account the fact that the gas exchange valves must be in their rest position at the actual time of deactivation. Deactivation of the other cylinders continues in the ignition sequence. When the gas exchange of the first cylinder is deactivated, the injection into the cylinders to be switched off is also deactivated in good time. The index of the first cylinder is also used to synchronize all systems affected by cylinder deactivation. It is particularly important for torque neutrality that the ignition is switched to the early, optimum ignition timing as soon as the first cylinder to be deactivated no longer generates any torque.

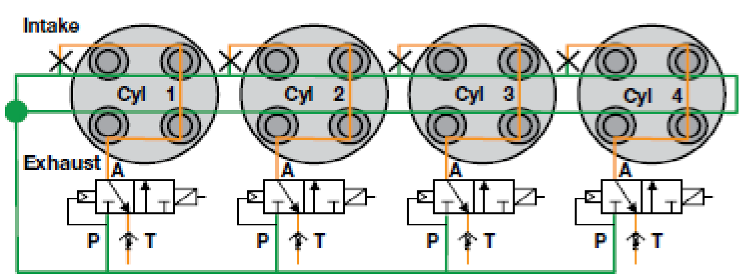
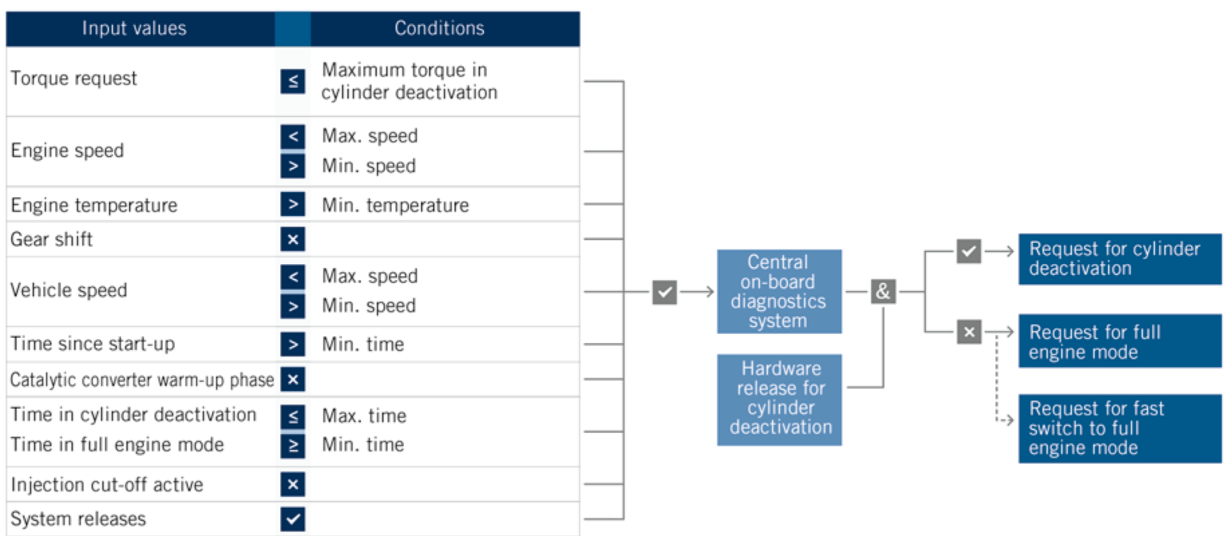


illustration of a valve stroke deactivation system featuring one switching valve per cylinder

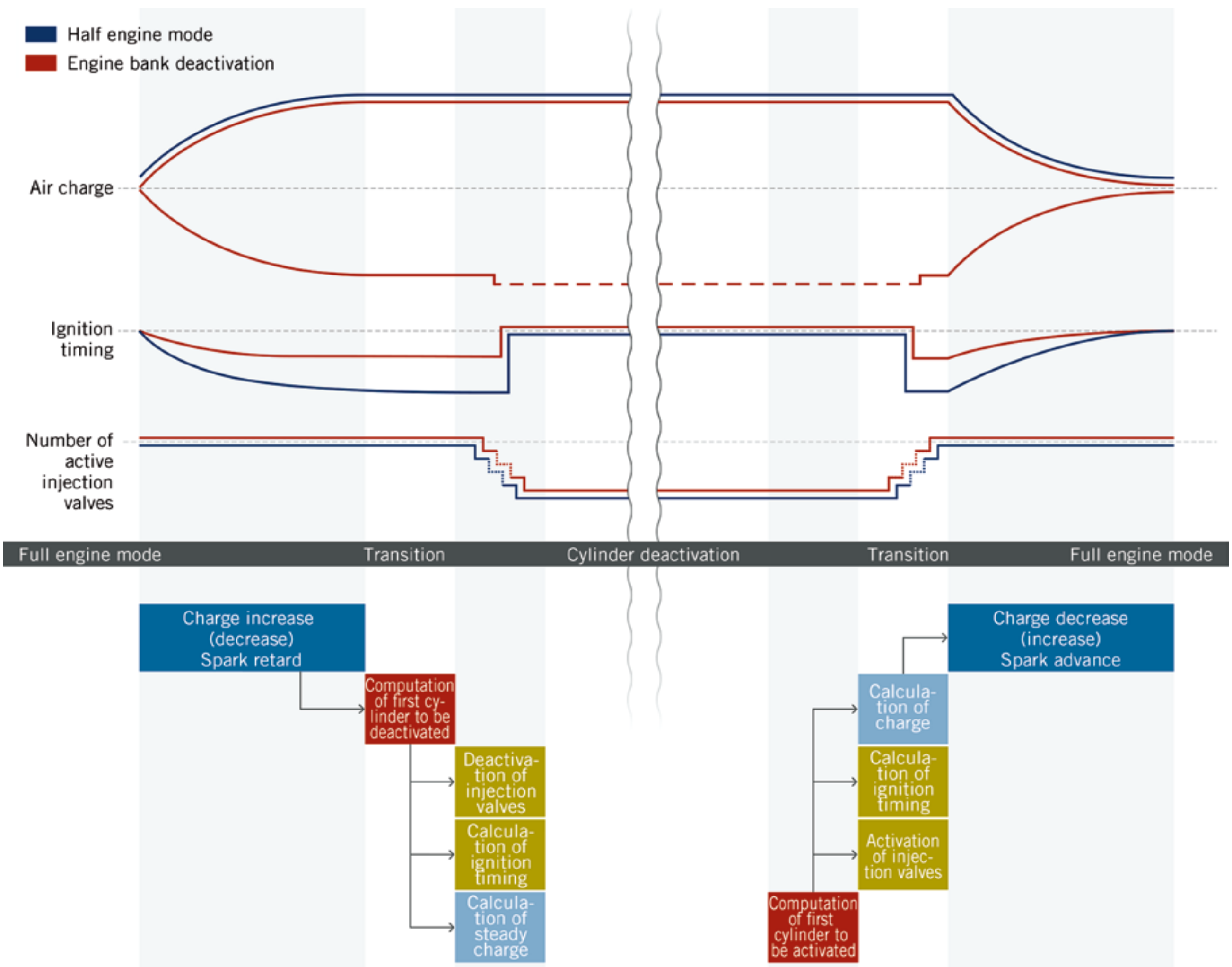
In an engine with a single intake manifold, the air system calculations must be adapted to the effective engine displacement when deactivating the gas exchange valves. The throttle valve opening is now reduced again: The target air charge that is not quite twice as high and that is distributed across half of the cylinders causes the throttle valve to have an opening that is smaller than that in full engine mode. In an engine with separate intake manifolds, the air charge is increased on the active engine bank via the throttle valve. On the deactivated engine bank, the air charge is reduced accordingly. As the gas exchange has been fully deactivated, the intake-manifold pressure reaches ambient pressure. The transition into cylinder deactivation is completed by the response from the gas exchange valve hardware. The engine is now operated with the reduced number of cylinders. ECU therefore ensures a torque-neutral transition to cylinder deactivation at the greatest possible efficiency, with the transition made in just a few operating cycles. The lower pumping and gas exchange losses, which are not applicable at all for the deacti-vated cylinders, reduce consumption.



Release coordination of cylinder deactivation

5.TRANSITION TO FULL ENGINE MODE

The release coordination continues to evaluate all of the required parameters for cylinder deactivation. As soon as a parameter is no longer met, it requests full engine mode again. The steps required to activate the cylinders are taken in reverse order to those required for deactivation. If the ECU operating mode coordination requests a transition back to full engine mode, the first cylinder that can be activated is determined. Reactivation of the outlet valves then begins, whereby the cylinder contents are pushed out. The inlet valves are then activated and the combustion chamber is filled with a defined quantity of fresh air. ECU subsequently activates the injection valves and transitions from calculation of cylinder deactivation to calculation of full engine mode.



Transition control for cylinder deactivation (schematic view)

In engines with a single intake manifold, no explicit air charge reduction phase is required as air is extracted from the intake manifold naturally thanks to the cylinders being activated at a constant mass flow. The air system calculates with the full engine displacement and the target air charge is reduced accordingly, as all cylinders are now generating torque again. As soon as the previously deactivated cylinders contribute towards the torque, ECU must consider the increase in intake manifold pressure, which is a result of the cylinder deactivation phase, when providing the requested torque. The torque is lowered to the requested value by adjusting the ignition timing until the intake manifold pressure has reduced to the steady-state value required for full engine mode.

In engines with separate intake manifolds, the air charge is gradually increased in the previously deactivated cylinders and decreased in the active cylinders. This enables reduced interference by the ignition timing. As soon as the first cylinder, that will be activated, is reached, the activation process is completed within one operating cycle, ensuring fast response behavior. The transition to full engine mode is complete as soon as there is a response from the gas exchange valve hardware.

6.EFFECT AND POTENTIAL

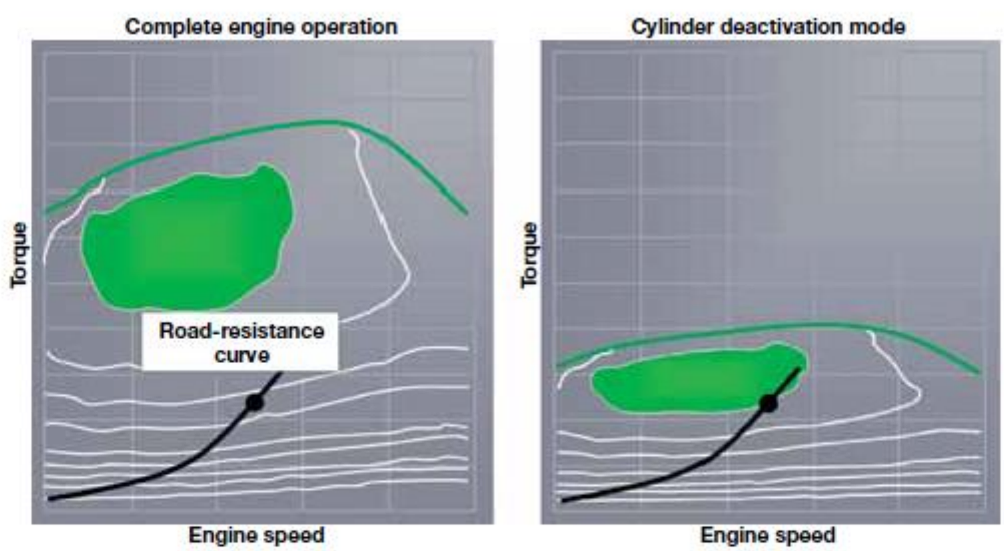


Figure I: Operating data map and driving resistance curve: The operating ranges associated with the lowest specific fuel consumption are approached in cylinder deactivation mode (graphic on the right) and not when all cylinders are operating

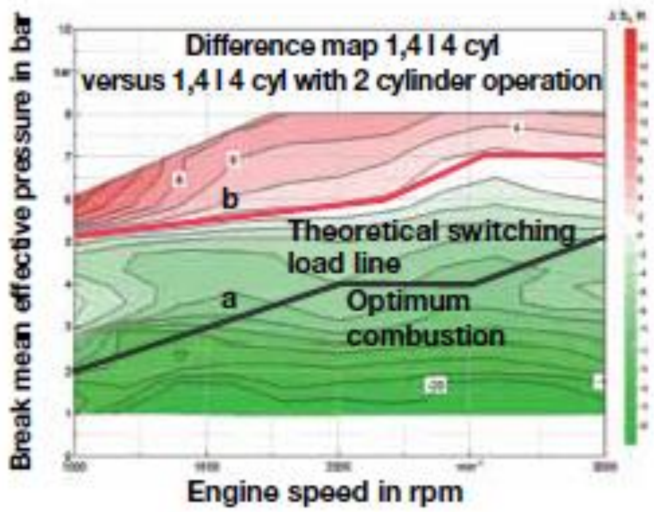


Figure II: Reduction in fuel consumption as a result of cylinder deactivation

When there is a specific performance requirement, the cylinders that are still being operated following cylinder deactivation must generate a higher mean pressure. This load-point shifting leads to a reduction in the throttle losses of the engine and ultimately helps to conserve fuel (Figure I). Deactivating the valves also reduces friction loss in the cylinder head, which further minimizes consumption. The potential for reducing consumption when an engine is operated on two as opposed to four cylinders can be illustrated in a simulation exercise carried out on a 1.4-liter four-cylinder engine. Line “a” plots the mean pressures at which the engine operating in two-cylinder mode can achieve its optimum combustion point (8 crankshaft degrees after TDC) (Figure II). When higher mean pressures are infrequence must be retarded to avoid knocking. The resulting effect is that combustion no longer achieves its peak efficiency, and additional fuel is consumed. Opening the throttle valve further counteracts this and has a positive impact on consumption in cylinders running higher mean pressures. Line “b” represents the theoretical switchover or transition line, as operating the engine above these plotted points in two-cylinder mode leads to additional fuel consumption. This line can also drop considerably below line “b”, depending on the application and customer requirements.

7.SUMMARY AND PROSPECTS

Thanks to cylinder deactivation in partial-load mode, it is possible to reduce fuel consumption and CO_2 emissions in combustion engines without compromising on performance and comfort. The precise and intelligent control over the engine actuators offered by the ECU significantly influences the quality of the entire system and the satisfaction of the end customer when evaluating driving quality.

Temporarily deactivating cylinders offers an attractive compromise between downsizing an engine to reduce fuel consumption and retaining high levels of comfort and driving pleasure. Even three-cylinder engines can profit from the economic benefits of cylinder deactivation. Simulations point to the potential that an alternating cylinder deactivation system has for maintaining a balanced temperature level in the engine and reducing vibrations, particularly in three-cylinder engine applications. Several options are available for temporarily deactivating valves, especially in the context of finger follower regulation systems. When cylinder deactivation is the only variable aspect required, switchable pivot elements offer a very cost-effective solution without noticeably compromising the basic functions of the valve train assembly. In the case of multi-stage systems or entire engine families, cam shifting systems are more favourable because they can be easily adapted. Fully-variable valve train systems go hand in hand with cylinder deactivation in the presence of discretely switchable elements as a minimum expenditure item. Depending on the size of the engine and the expectations customers have regarding comfort levels, additional design measures may be required for the engine and overall vehicle that conflict with the potential for reducing fuel consumption, which can be especially prominent in lightweight vehicles equipped with powerful engines. In the future, it is highly probable that cylinder deactivation will play an ever increasing role in optimizing powertrains that use engines with three or more cylinders.