STRATEGY TO CONTROL THE CYLINDER DEACTIVATION

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. Drawing on a wealth of experience from many series projects, Bosch Engineering GmbH uses innovative software functions and engine application to realise the cylinder deactivation concept.

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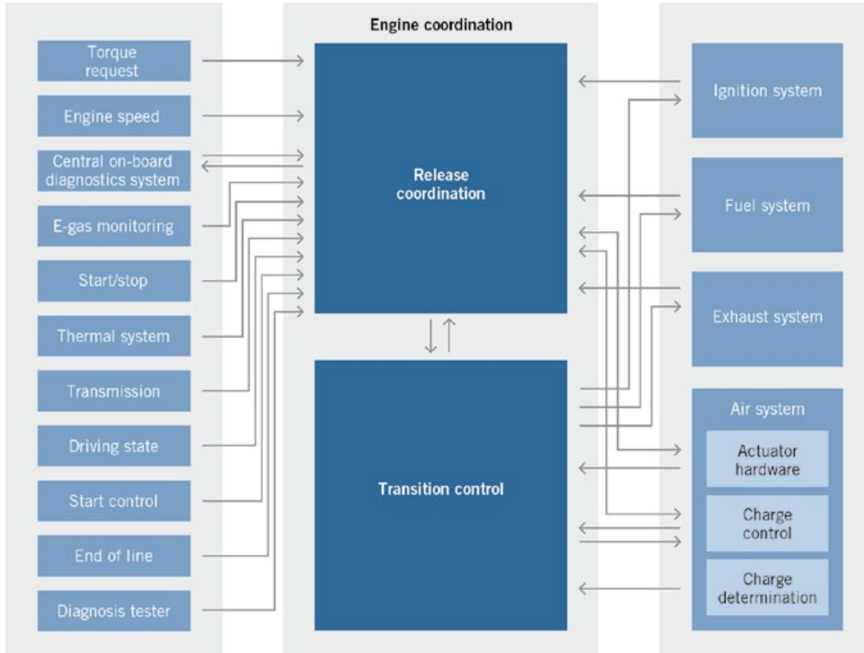
CYLINDERS MUST BE SWITCHED OFF IMPERCEPTIBLY

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 Bosch market researchers and external 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, for which Bosch already offers products and services: 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. This concept enables cylinders to be deactivated when not required in part-load operation, e.g. when engine torque requirements are moderate on a motorway or country road. This deactivation means that the cylinders that are still activated must produce the torque of the deactivated cylinders. To achieve this, the load point is shifted and charge cycles are omitted partially. Fuel consumption and CO_2 emissions are reduced as a result.

When developing engines with cylinder deactivation, the torque and emissions neutrality, as well as the response behaviour, 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 from Bosch, called Motronic, ❶, takes centre 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, Motronic uses software

❶ Bosch engine control unit ME(D) 17 for gasoline engines functions to coordinate and control all of the relevant engine subsystems, ❷, influencing the torque progression, as well as the response and emission behaviour.



❷ Cylinder deactivation system overview

ENGINE CONTROL UNIT REQUIREMENTS

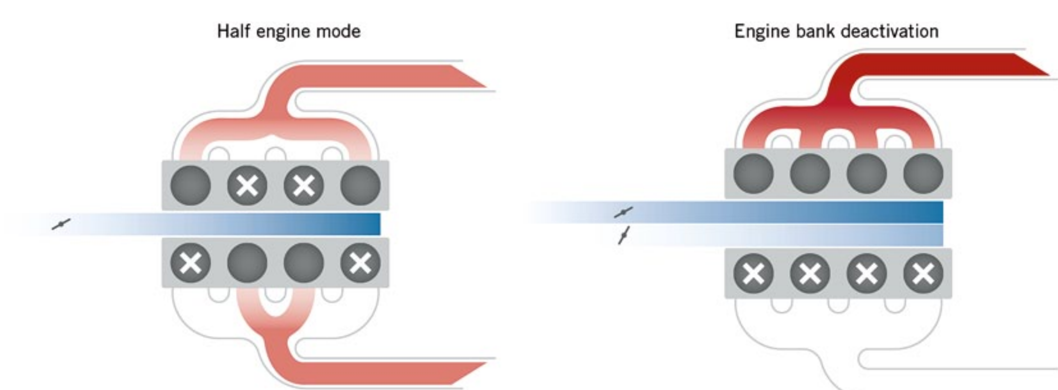
Cylinder deactivation can be implemented in two-cylinder engines or in engines with a large number of cylinders. Various configurations are possible based on the position of the cylinders to be deactivated, ❸. The particular design features of an engine with cylinder deactivation lead to special requirements in the Motronic 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.

TRANSITION TO CYLINDER DEACTIVATION

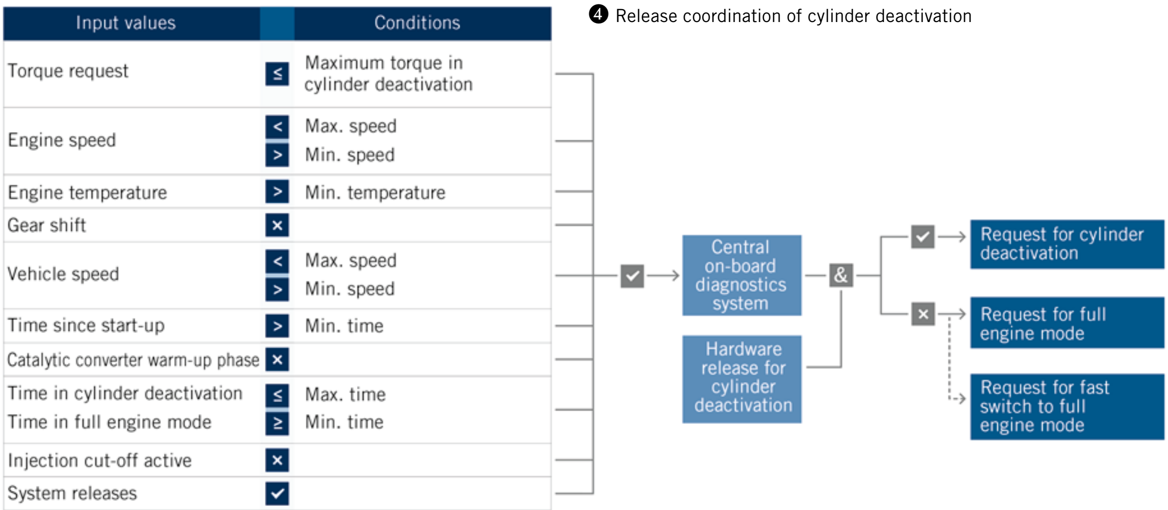
In order to operate an engine with cylinder deactivation, certain precautions must be taken for the deactivation of cylinders during full engine mode. The difference in loss torque must be pre-controlled from the point of view of the target torque calculation. This torque is determined by the difference 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 Motronic operating mode control constantly checks a large number of conditions for switching the operating mode, ❹. 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 Motronic release coordination assigns a condition to each input parameter. In order for cylinders to be deactivated, each condition must be met. The Motronic 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.

In this context the Motronic coordinates all of the engine actuators, ❺. The sequence and the exact time are decisive factors in meeting all of the aforemen-



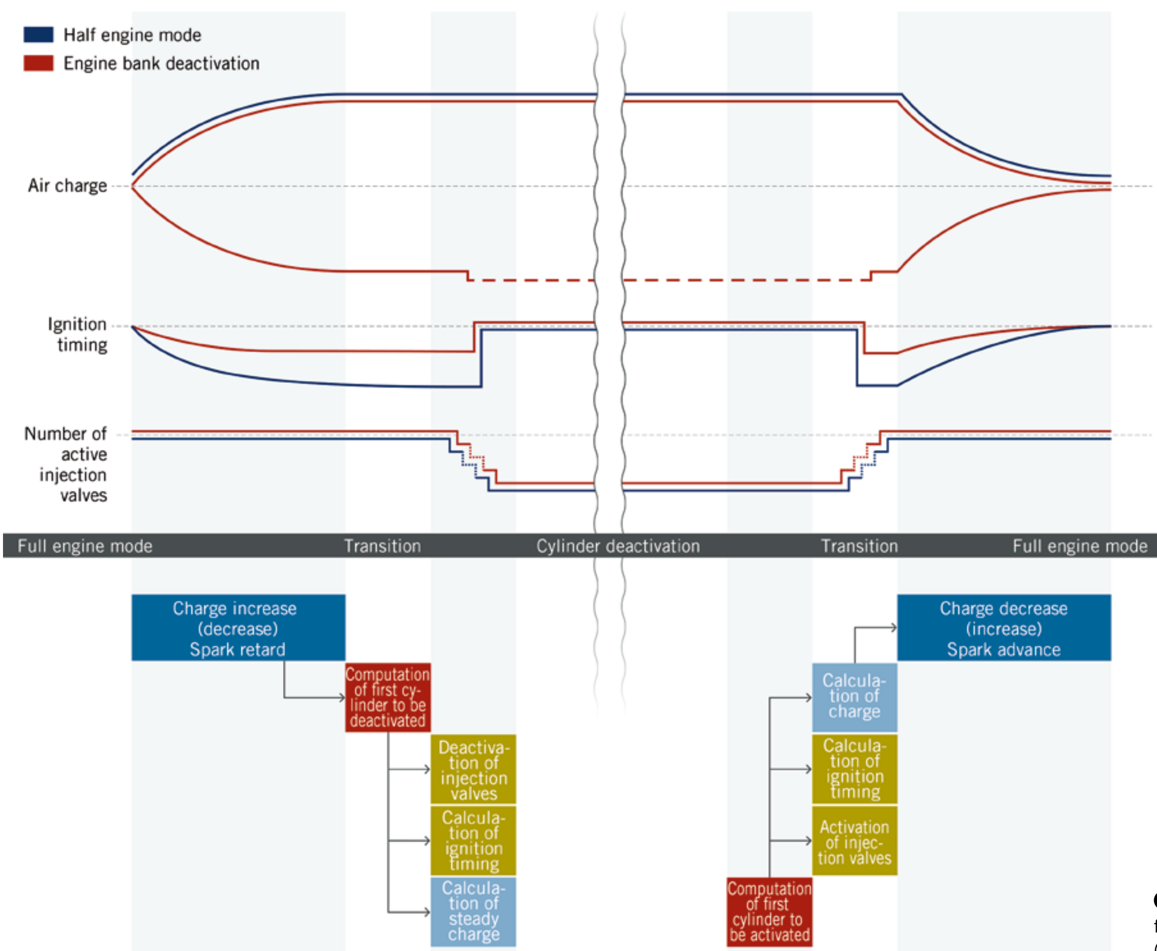
❸ Cylinder deactivation configurations



❹ Release coordination of cylinder deactivation

tioned 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



❺ Transition control for cylinder deactivation (schematic view) 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, Motronic 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 synchronise 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.

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. Motronic 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 deactivated cylinders, reduce consumption.

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, ⑤. If the Motronic 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. Motronic subsequently activates the injection valves and transitions from calculation of cylinder deactivation to calculation of full engine mode.

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, Motronic 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 behaviour. The transition to full engine mode is complete as soon as there is a response from the gas exchange valve hardware.

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 Motronic significantly influences the quality of the entire system and the satisfaction of the end customer when evaluating driving quality. Based on the status of the technology described above, there is further potential for optimisation available. The torque range can be increased further by deactivating a variable number of cylinders. Cylinder deactivation can also make a significant contribution towards increased efficiency in hybrid vehicles. The benefits of cylinder deactivation in steady-state partial load operation can then be combined with the benefits of the hybrid system in non-steady-state driving mode.