Individual-Cylinder Pressure-Based Engine Control Strategy

By

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Currently, spark-ignited engines are calibrated by manufacturers in order to determine the so-called minimum ignition advance for best torque (MBT) map covering the entire operating range of the engine. At the MBT ignition timing the engine delivers its maximum output torque (or brake torque). Figure 1 shows the mean cylinder pressure at three different ignition timings with MBT at 29 degrees before Top Dead Center (TDC). During the calibration process, engine load and speed are changed to determine the MBT ignition timing. Therefore, the MBT timing is a function of both the engine speed and load. Knowing the MBT values, the actual ignition timing map is decided. This actual timing is slightly retarded from the MBT values to allow for variabilities in manufacturing and fuel octane number. The engine control unit (ECU) requires information on load (taken from the throttle valve position sensor) and speed (from crankshaft encoder pulses) to select the calibrated actual ignition timing from a stored table. Therefore, when adjustment to the spark timing is needed, for example when knock is detected or air/fuel (A/F) mixture is changed, all cylinders feel such a change irrespective of their individual A/F mixture and thermodynamic conditions. A more refiner control system should be able to adjust ignition timing for each cylinder independently. However, such a control system requires individual-cylinder information.

Demands for a higher fuel economy, stringent emission standards, and compliance with the on-board-diagnostics (OBDII) requirements necessitate a more advanced engine control strategy. Individual cylinder feedback control system is the target for such an advanced approach. However, sophisticated, reliable, and cost-effective sensors are needed for such a strategy. The objective of majority of the sensors used in the past has been to directly or indirectly measure individual cylinder pressures. Cylinder pressure is the ultimate and fundamental indicator of the combustion quality in engine. Direct measurement involves incorporation of a reliable pressure transducer in each cylinder. Indirect methods included stress measurements in an engine head component such as head gasket, spark-plug washer, or spark-plug-boss and ionization current detection using the ion current sensed by the spark plug electrodes.

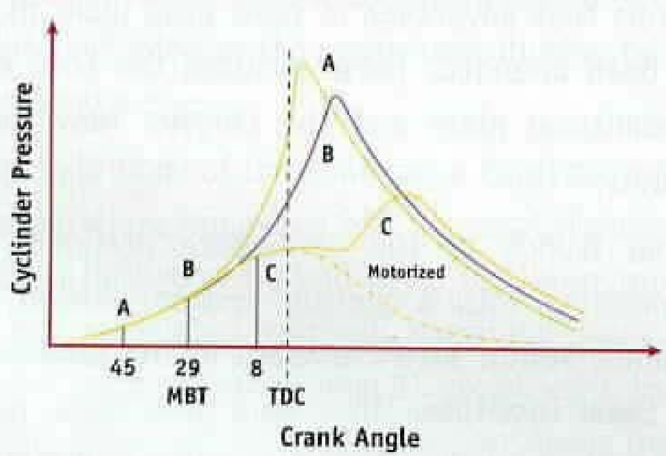

Figure 1: Mean cylinder pressure as a function of crank angle at the same engine speed. Spark timing for A, B, C are at 45, 29, 8 degrees before TDC respectively. A, B, C curves are for fired and dashed curve is for motored (nonfired) cases.

There are many benefits in individual-cylinder pressure-based engine control strategy as described in Table 1.

Benefit	Why?
Fuel Economy	Increased exhaust gas recirculation (EGR) reduces the pumping work. Individual cylinder spark timing optimizes each cylinder. Ability to actually time the ignition at MBT avoids fuel economy loss.
NOx Emission	EGR levels can be beyound normally practical levels with MBT timing
HC Emission	Enhanced catalyst conversion efficiency by lean exhaust biasing
Cold Start HC Emission	A/F control allows leaner A/F than usually used. Also, accurate control of retarded ignition improves catalytic heating.
Misfire Detection	Outstanding misfire detection using cylinder pressure
Knock Detection	Improved detection allows closer to MBT operation and hence higher torque and efficiency. Also, replaces knock sensor.
Calibration	Simplifies and reduces calibration requirements.
A/F adjusting	Improves limits of dilution and thereby improves A/F-control, reducing emission dispersion
Others	Eliminates need for a number of sensors: Mass air flow, knock and cam sensors (cost benefit)

Another important component of any cylinder-pressure based control strategy is the logic or the algorithm employed for initiating the changes in the control parameters. The following algorithms have been considered in the past.

1. Location of the peak cylinder pressure for spark timing adjustment. An optimum value is about 15 degrees after TDC.

2. Calculation of the indicated mean effective pressure (IMEP). IMEP is defined as the ratio of the individual cycle work to the engine displacement volume. Work is calculated through integration of the pressure-versus-crankangle curve. This is used for monitoring engine torque fluctuations, combustion lean limit, and misfire cycles.

3. Calculation of the first, second, and third moments of pressure-versus-crankangle curve and their use as inputs to an “estimator algorithm.” (only used for A/F calculation)

4. “Difference pressure” approach. The difference of the combustion pressure and the calculated motored pressure for the same cycle is determined. The integral of the “difference-pressure” from the TDC to 180 degrees after the TDC is calculated as the final control parameter. It is used for the misfire detection, spark timing control, and lean limit detection.

5. Pressure-ratio management system. Ratio of combustion pressure to the motored pressure at identical crankangles and for the same cycle is needed for at least four crankangles. The following crankangles are proposed: two prior to (one could be just after) the spark ignition (50 and 35 degrees before TDC) and three after TDC (10, 25, and 55 degrees after TDC). This approach used for spark timing adjustment, lean limit detection, misfire detection, EGR and A/F adjustment, cold start control, and knock detection.

Determination of the changes in bias and calibration gain of these pressure sensors are important and should be thoroughly addressed by the users. Some control logics are insensitive or less sensitive to the transducer bias and calibration gain and therefore are favored over others. In particular, they are control algorithms 1, 3, 4 (gain is required), 5 (bias is needed and determined through two compression samples with the assumption of polytropic behavior). For further information, the readers are referred to SAE2000-01-0932 and SAE2000-01-0928.