Cylinder Deactivation: The Idea and Its Practice

Bruce Chehroudi, PhD

Considering that the transportation's share of the US petroleum use is about 66% and that the average household transportation expenditure is about 20% of the average income (before tax), plus the prediction by the so-called "Peak-oil" theories that the production of oil will peak sometime around 2005-10, one should not be surprised by a recent special attention to all engineering innovations that attempt to reduce the automotive fuel specific consumption. In addition to the energy consumption and production, we have an environmental corner to help us play the balanced global triangle game.

At the consumption corner, automotive engineers have been working on many ideas to increase the fuel conversion efficiency of spark-ignited (SI) engines. Ideas such as reduction of heat losses, reduced pumping energy, improvement of combustion efficiency, and reduced frictional losses are at the top of the list of endeavors. In practice, many of these ideas can be turned to reality through engine design changes such as a transition to gasoline direct injection (GDI), fully variable valve train, high-pressure charging with variable compression ratio, and cylinder deactivation. In this tutorial the essence and some recent applications of the cylinder cutout or deactivation are concisely discussed. There are different designs used to implement the idea which will be covered in future tutorials.

Engine can be viewed as a breathing organism quite similar in many respects to human respiratory system. Like a human lung, a modern gasoline port fuel injection (PFI) SI engine spends a significant of its produced energy simply to inhale air into the combustion chamber and exhale exhaust gases out to the environment. This energy (or work) is called as "pumping work". Normally the amount of this work is minimal at wide open throttle (WOT) operation when the throttle valve is fully opened, and gradually increases to its highest value at engine idle operation. The main objective of cylinder deactivation is reduction of this pumping work through deactivation of usually half of the cylinders during a limited range of operating condition.

Historically, limited production of this idea was first made by General Motors for a single model year (1981 Cadillac Eldorado V8-6-4), Chrysler (V8 Hemi engine in 300C and Dodge Magnum RT), Mistsubishi in Japanese market, and most recently by Mercedes (1999, S 500 V8) and Honda's popular Odyssey minivan (2005, i-VTEC V6). The main difficulties at the early days were transient control of the torque and air/fuel mixture ratio during the cylinder deactivation and reactivation when throttle valve was controlled mechanically. With the advancement in all areas of technology, in particular the electronically-controlled fuel injection and "drive-by-wire" throttle valve adjustment, like many good old ideas, cylinder deactivation can be successfully implemented on production engines with satisfactory gains. However, noise, vibration, and harshness (NVH) remain as fundamental limitations of this technology.

Deactivation of usually half of the cylinders leaves the remaining ones to provide the same amount of work necessary at that operating condition. Consequently, each of these firing cylinders must produce more work per cycle than they were producing when all the cylinders were firing, see Fig. 1. Hence, they require more fuel and air per cycle which can be accommodated through opening of the throttle valve. It is this additional opening of the throttle valve that reduces the pumping work when cylinders are deactivated. Furthermore, the frictional losses may also be reduced due to lowered total load on the valvetrain. The cylinder cutout is normally achieved through, first, deactivation of the exhaust valves, entrapping the burned gases in the cylinder (keeping it warm and at high pressure, preventing any oil leakage), and second, deactivating the intake valves. Reactivation is done by first allowing the exhaust valves to operate normally.

The Mercedes S 500's fuel consumption in the New European Driving Cycle (NEDC) is claimed to have reduced by about 7%. Even greater improvements are possible in other driving situations. For example, at a constant speed of 120 km/h, consumption is cut by around 13%, and at a steady speed of 90 km/h, by as much as 15%. Mercedes engineers state that in conditions such as city traffic, out-of-town driving, or when traveling at constant speed on the motorway in the mid-speed range, an 8-cylinder engine suffers due to impaired "volumetric efficiency" and high pumping losses. In some cases, the large-displacement engine has to be throttled to the point that cylinder pressure at top dead center (TDC) is approximately half that of a 4-cylinder engine. Lowered cylinder pressure implies lower fuel efficiency, in turn leading to high fuel consumption. Shutting off four of the cylinders momentarily eliminates this fundamental drawback of a V8 engine. In four-cylinder-mode, volumetric efficiency is greater and the quantity of exhaust gas recirculated (EGR) into the engine can be increased for additional improvement in efficiency.

As stated earlier, the NVH is an issue that must be addressed by the design engineers. For example, a 6-cylinder engine can be quite easy to balance for dynamical forces, but the power pulses on a 3-cylinder engine are so far apart in time that some vibration inevitably exists. For example, Honda reduced the impact of this effect by, first, using the "drive by wire" technology. Here, the electronic control unit (ECU) instantly controls the throttle valve so that engine power increases or decreases during the switching events. In addition, a unique Active Noise Control (ANC) design uses sound waves generated from the audio speakers to cancel out any noise generated by the powertrain as a result of this switching action. The ANC controller employs a microphone to detect the noise and then produces a signal 180 degrees out-of-phase to cancel out the original activation/deactivation noise. The canceling sound waves are originated from the front and rear speakers during the 3-cylinder operation phase, idling and at-start running only. Active control engine mounts (one front and another behind) controlled by engine computer were also used to damp the cylinder switching through use of solenoid valves to damp fluid movement in the mounts.

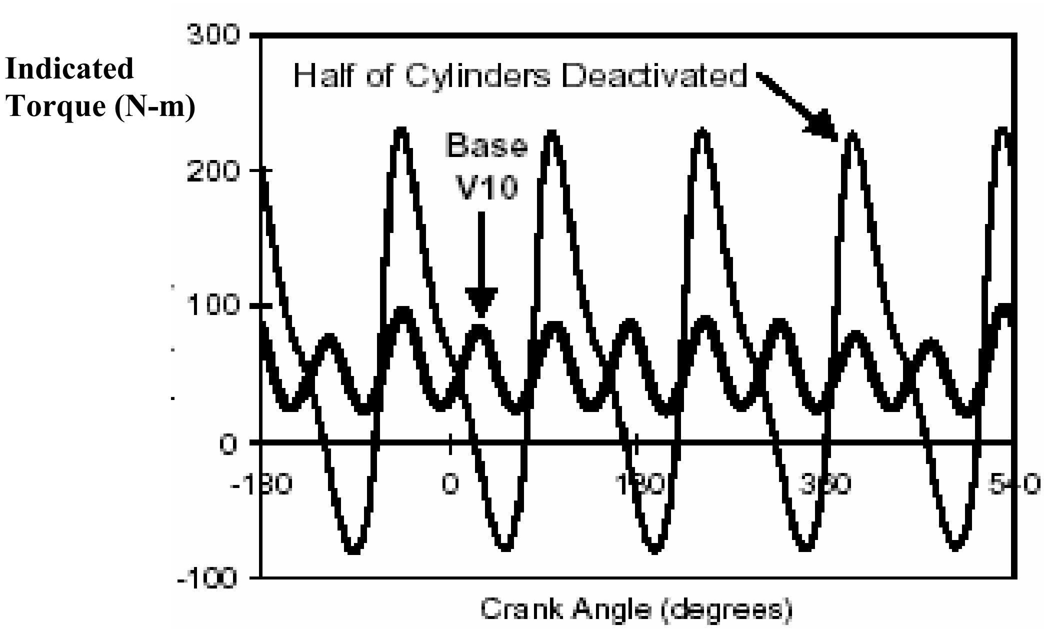

Figure 1. Torque pulsation as a function of crank angle showing the base engine (10-cylinder) and when half of the cylinders were deactivated. 500 rpm at 0.8 bar BMEP.