

CHALLENGES AND OPTIMIZATION IN TRANSPORTATION TECHNOLOGIES RECENT DEVELOPMENTS IN IC ENGINES

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Abstract: This paper aims to increase the efficiency of an internal combustion engine by the technology of cylinder deactivation by increasing the efficiency of an internal combustion engine in low rpm period. Analysis in the paper are carried out with and without cylinder deactivation technology in order to investigate its effect upon the estimated fuel consumption saving and lower NO_x emissions, resulting in an economical and environmentally friendly transportation.

Keywords: Cylinder-deactivation (CDA), Dynamic Skip Fire (DSF), Active Cylinder Control (ACC), Variable Displacement Cylinder, Dynamic Cylinder Management

1. Introduction

The maritime industry is driven by the need to manufacture more efficient ships, with ever-stringent global emission directives and regulations to reduce the effects of greenhouse gases and sulphur content. Better fuel economy and reduced emissions are key motivations for increased efficiency in internal combustion engines.

Different technologies have been used to reduce emissions and improve fuel economy. These include Variable Valve Actuation (VVA), turbocharging and Cylinder De-activation (CDA). Although these technologies show potential for reducing emissions and fuel economy. They also promote certain undesired side-effects such as decreased durability or/and increased frictional losses in some of the older variant of these technologies.

2. Working of IC Engine during Normal Working Load

Combustion, also known as burning, is the basic chemical process of releasing energy from a fuel and air mixture. In an internal combustion engine (ICE), the ignition and combustion of the fuel occurs within the engine itself. The engine then partially converts the energy from the combustion to work. The engine consists of a fixed cylinder and a moving piston. The expanding combustion gases push the piston, which in turn rotates the crankshaft. The crankshaft is connected via a flywheel, either to the alternator or to a propeller arrangement.

The marine main engine is started by cranking it with starting air of pressure 25-30 bar. This entry of air is controlled by a pneumatic valve actuated by control air of 7 bar in the firing order of the IC engine. The fuel is injected after the engine's crankshaft reaches a nominal rated rpm.

During the condition of normal working load, the fuel is burnt just before the end of the compression stroke (TDC). Leading to the work being done on the crankshaft by the expansion of gases, which we know as power stroke. During the exhaust stroke, the exhaust gases are expelled from the combustion chamber leading to a pressure wave which is the driving mechanism for the turbine of the turbocharger.

The turbine in the turbocharger is coupled to a centrifugal compressor. The compressor feeds the compressed air to the scavenge manifold via an air cooler. This pressurised air waits outside the suction valve and enters the combustion chamber only when the valve opens, i.e. when the suction valve follower is on the rise of its travel.

2.1 Working Of An IC Engine During Low RPM

An IC engine running at low load condition and/or low rpm are notorious for their high emission rate and a drop in efficiency. This is due to the simple fact that, the IC engine though operational at those conditions isn't designed for it.

2.3 Reason For High Emissions

During the low rpm period, the exhaust gases do not have enough energy or pressure pulse to rotate the turbocharger at the required rpm. Thus, the air supply from the turbocharger also reduces, starving the combustion space of air. This disturbs the air-fuel ratio and it dips, i.e. for the given amount of fuel the required amount of air isn't being supplied to the combustion chamber. This results in parts of fuel being unburnt or incomplete combustion, leading to higher emissions of carbon monoxide and greenhouse gases. Furthermore, due to some amount of fuel being unburnt and thus wasted, the power output is reduced. Hence the governor sends in more fuel. This leads to a higher rate of fuel consumption and thus isn't economical.

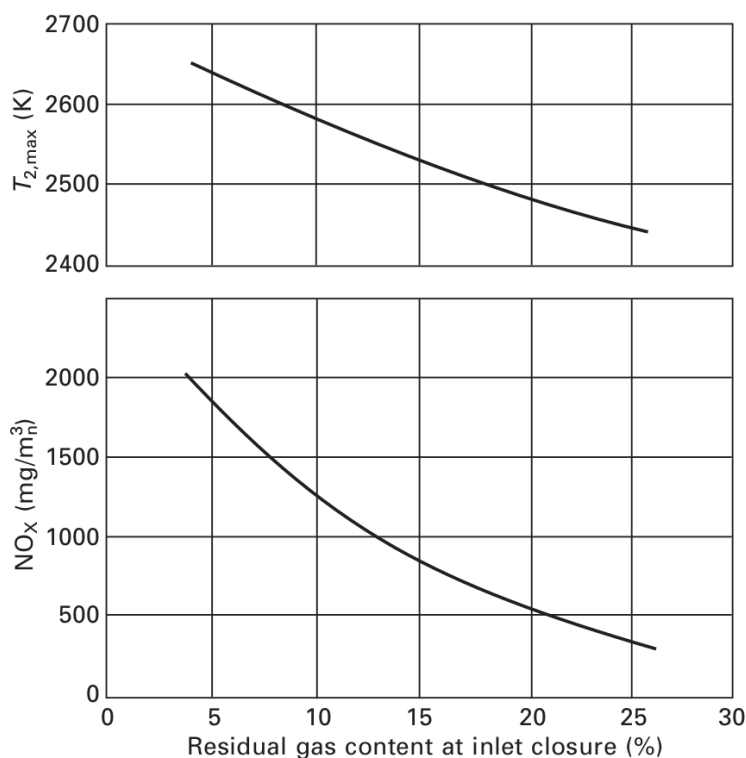


Fig. 1

2.4 Reason For Low Efficiency At Low Load

In typical light-load driving the driver uses only around 30 percent of an engine's maximum power. In these conditions, the throttle valve is nearly closed, and the engine needs to work to draw air. This causes an inefficiency known as pumping loss. Some large capacity engines need to be throttled so much at light load that the cylinder pressure at top dead centre is approximately half that of a small 4-cylinder engine. Low cylinder pressure results in lower fuel efficiency. (Figure 2) The use of cylinder deactivation at light load means there are fewer cylinders drawing air from the intake manifold, which works to increase its fluid (air) pressure.

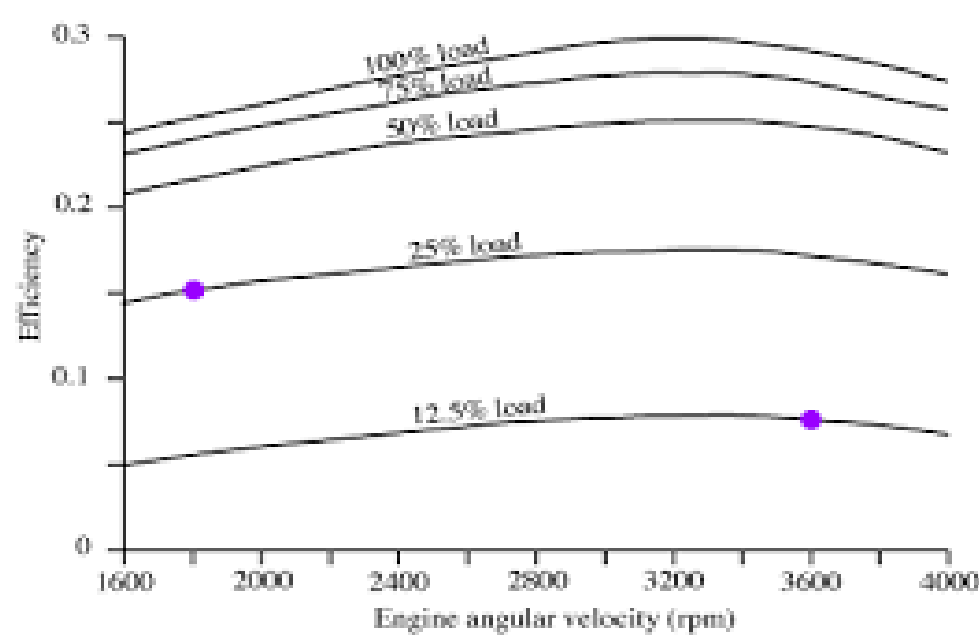


Fig. 2

2.5 Overcoming These Disadvantages By Cylinder De-Activation Technology

Cylinder de-activation is used to reduce the fuel consumption and emissions of an internal combustion engine during light-load operation. Operation without variable displacement is wasteful because fuel is continuously pumped into each cylinder and combusted even though maximum performance is not required. The governor controls the amount of fuel entering the combustion chambers but if we throttle it too much, a very small amount of fuel enters the chamber leading to a drop in peak pressure. Thus, leading to a drop in efficiency.

By shutting down half of an engine's cylinders, the amount of fuel being consumed is much less. Between reducing the pumping losses, which increases pressure in each operating cylinder, and decreasing the amount of fuel being pumped into the cylinders, fuel consumption can be reduced by 8 to 25%.

Cylinder deactivation is achieved by keeping the intake and exhaust valves closed for a particular cylinder. By keeping the intake and exhaust valves closed, it creates an "air spring" in the combustion chamber – the trapped exhaust gases (kept from the previous charge burn) are compressed during the piston's upstroke and push down on the piston during its downstroke.

The compression and decompression of the trapped exhaust gases have an equalising effect – overall, there is virtually no extra load on the engine.

In the latest breed of cylinder deactivation systems, the engine management system is also used to cut fuel delivery to the disabled cylinders. The transition between normal engine operation and cylinder deactivation is also smoothed, using changes in ignition timing, cam timing and throttle position (thanks to electronic throttle control). In most instances, cylinder deactivation is applied to relatively large displacement engines that are particularly inefficient at light load. In the case of a V12, up to 6 cylinders can be disabled.

2.6 Variation Of Cylinder Pressure In Cylinder Deactivation (CDA)

In order to increase the efficiency at low load condition the compression pressure of the active cylinders is increased to deliver the same power. Figure shows the corresponding measured variation in the liner temperature. The results correspond to:

1. All active cylinders.
 2. An active cylinder in an engine with Cylinder Deactivation.
 3. A deactivated cylinder in an engine with Cylinder Deactivation.
- i. The crank angle $\Theta = 0$ degrees marks the position of the TDC at the onset of the power stroke.
 - ii. combustion occurring at 20 degrees crank angle.
 - iii. For active cylinders during Cylinder Deactivation, combustion occurs later.

The maximum cylinder pressure for the deactivated cylinder occurs at the TDC. Pressure in deactivated cylinder results from entrapped air and any residual charge.

2.7 Methods Of Cylinder De-Activation (CDA)

There are currently two main types of cylinder deactivation mechanizations used today, depending on the type of the engine's valvetrain. The first is for pushrod designs which uses solenoids to alter oil pressure delivered to lock pins in the lifters. With lock pin out of place, the lifters are collapsed and unable to elevate their companion pushrods under the valve rocker arms, resulting in valves that remain closed when the cam pushes on the part in lost motion.

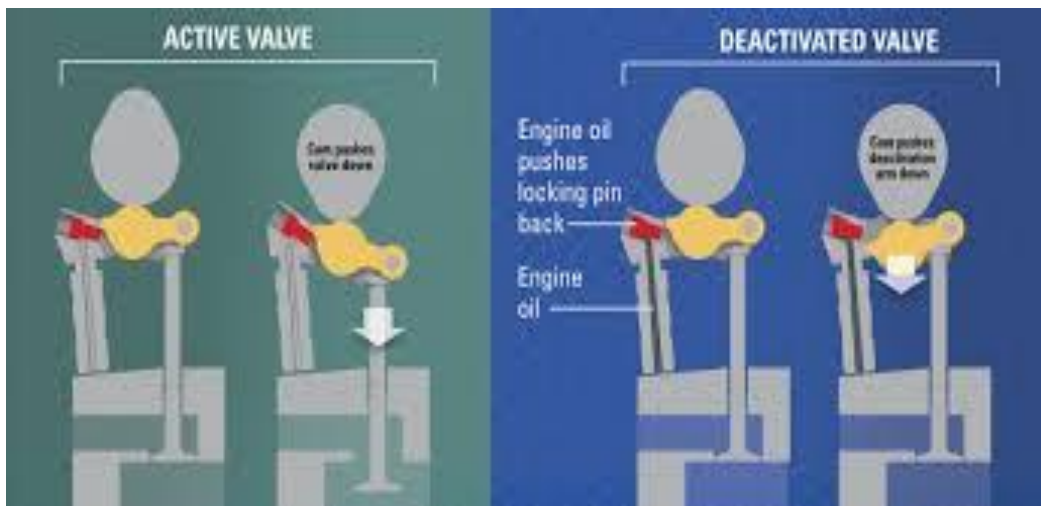


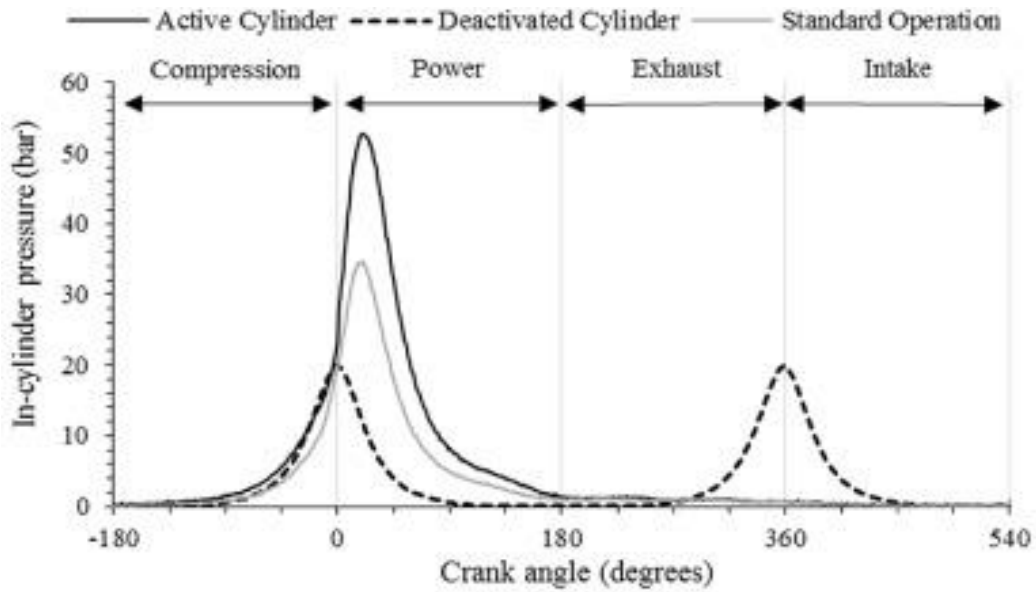
Fig. 3

Fig. 3 shows the second type of cylinder deactivation. It is for overhead cam engines, and uses a pair of locked-together rocker arms that are employed for each valve. One rocker follows the cam profile, while the other actuates the valve. When a cylinder is deactivated, solenoid-controlled oil pressure releases a locking pin between the two rocker arms. While one arm still follows the camshaft, the unlocked arm remains motionless and doesn't move the valve. With computer control, fast cylinder deactivation and reactivation occur almost instantly.

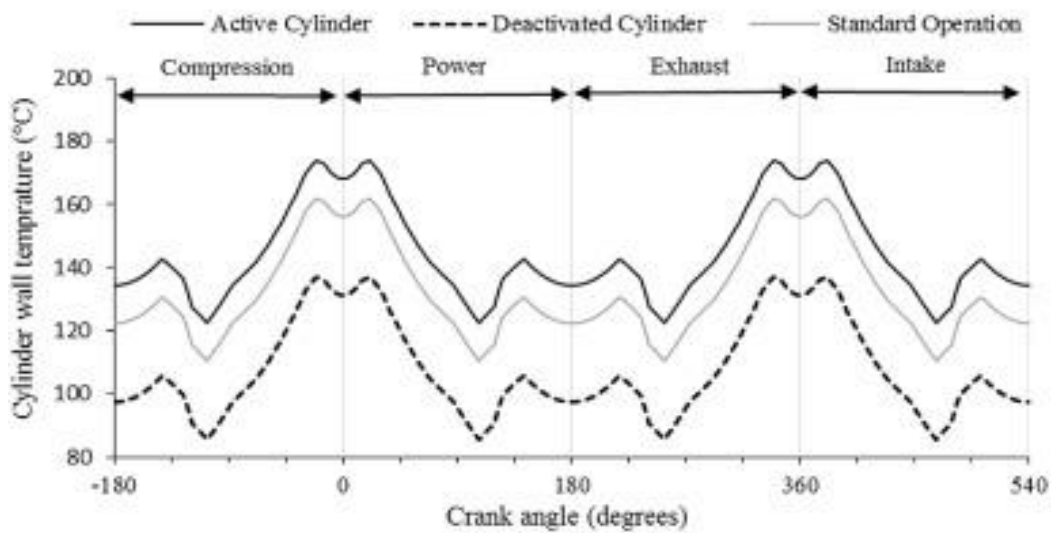
2.8 Disadvantages of Cylinder De-activation (CDA)

2.8.1 Liner Temperature

In figure we can see the relation between the liner temperature and crank angle. The figure illustrates the difference in liner temperatures amongst all cylinders active in normal mode, active cylinders during cylinder de-activation and the de-activated cylinders of the CDA. (Figure 4)



(a)



(b)

Fig. 4

- The middle curve shows the liner temperature of all cylinders active when CDA isn't used.
- The top curve shows the liner temperature of active cylinders in CDA mode. An increased liner temperature is observed as the combustion pressure in active cylinders in CDA is more than that of the normal cylinders.
- The bottom most curve depicts the liner temperature of the de-activated cylinder in CDA. A comparatively low liner temperature is observed. This is due to the fact that no combustion takes place in the de-activated cylinders.

2.8.2 Dynamic Imbalance

For a rotating body dynamic balance is must. Dynamic balance is achieved when the centre of mass of the rotation object coincides with the axis of rotation. However, in the case of CDA, the cutting off or de-activation of cylinders leads to a power imbalance of the IC engine. This leads

to a dynamic imbalance. This leads to vibration. In worst case scenario, it may be possible that he the crankshaft start wobbling.

2.8.3 Cooling

Internal Combustion engines of cylinder de-activation variant are known for their high combustion pressures. This leads to a higher liner temperature. Moreover, there is a temperature gradient which exists across the different cylinders, i.e. amongst the active cylinders and the de-activated cylinders. This creates an issue with the cooling of the IC engine.

2.9 Case Study:

2.9.1 Active Cylinder Control Concept Of Mercedes-Benz

German automaker Mercedes-Benz introduced their proprietary Active Cylinder Control concept to help boost the fuel efficacy of their flagship 12-cylinder engines.

All 12-cylinder cars burn an excessive amount of gasoline because they are strictly designed for performance. Wasting gasoline is an expected trade-off should a person want a car to drive with as much power as possible. Though most drivers, including owners of very high-end sports cars, rarely maximize the potential of their vehicle or ever put its engine to full use.

Active Cylinder Control (ACC) is a simple but effective system that will turn off some of an engine's cylinders if they aren't needed at a given time. ACC allows the car's computer to determine the number of cylinders required for the best possible performance, and can temporarily cut fuel to only these cylinders. ACC then greatly helps a 12-cylinder engine to operate through common traffic and driving conditions while consuming the least amount of fuel.

2.9.2 Multi Displacement System (MDS)

MDS - Multi Displacement System is coming on the 2005 Chrysler 300C and Dodge Magnum R/T with the 5.7 Litre Hemi V8 engine. The V8 saves fuel by running on 4 cylinders. The system deactivates the valve lifters. This keeps the valves in four cylinders closed, and there is no combustion. In addition to stopping combustion, energy is not lost by pumping air through these cylinders. estimated fuel economy gains of up to 20 percent under various driving conditions, and a projected 10 percent aggregate improvement.

2.9.3 Honda's Variable Cylinder Management (VCM)

Variable Cylinder Management (VCM) is Honda's term for its variable displacement technology, which saves fuel by using the i-VTEC system to disable one bank of cylinders during specific driving conditions—for example, highway driving. The 2008–12 Accords took this a step further, allowing the engine to go from 6 cylinders, down to 4, and further down to 3 as the computer sees fit.

Honda's VCM uses overhead cams. A solenoid unlocks the cam followers on one bank from their respective rockers, so the cam follower floats freely while the valve springs keep the valves closed. The engine's drive by wire throttle allows the engine management computer to smooth out the engine's power delivery, making the system nearly imperceptible on some vehicles.

2.9.4 Ford's Eco-boost Technology

The three-cylinder Ford Eco-boost engine is to be offered with fuel-saving cylinder deactivation technology that will enable it to operate as a two-cylinder unit

Similar technology is seen on many four-cylinder engines, but Ford claims this is the first time it has been engineered into a three-pot. Some manufacturers have dismissed the idea, citing refinement as one of the main issues, but Ford hasn't been deterred.

Cylinder deactivation will automatically stop fuel delivery and valve operation for one of the engine's cylinders under conditions where full capacity is not needed, such as when coasting or cruising with light demand on the engine. The technology can disengage or re-engage one cylinder in 14 milliseconds.

Capable of operating at speeds of up to 4500rpm, the system uses engine oil pressure to activate a special valve rocker and interrupt the connection between the camshaft and the valves of cylinder number one. Software uses factors including speed, throttle position and engine load to determine when to deactivate the cylinder.

Ford engineers predict that the system will be active for a few seconds at a time in most driving scenarios and has the potential to improve fuel efficiency by up to 6%.

2.10 Overcoming the Disadvantages of CDA using Dynamic Skip Fire Technology

The all-new 2019 Chevrolet Silverado 1500 will offer updated versions of the proven 5.3L and 6.2L V-8s with Dynamic Fuel Management (DFM), based on Tula's Dynamic Skip Fire (DSF) technology.

Tula's DSF technology modulates power output by dynamically deciding to fire or skip each cylinder immediately prior to firing. DSF software and engine control algorithms create optimal engine and fuel efficiency by firing only the number of cylinders needed to match the driver's request for torque. Because each firing is made at its peak power and combustion efficiency, DSF minimizes fuel use and reduces CO₂.

The fully-variable digital cylinder deactivation technology has been developed to the point that it can enable the vehicle to creep ahead in traffic while operating on a single cylinder in the V8.

Compared to Active Fuel Management on V8s, which alternates between eight- and four-cylinder modes, DFM features 17cylinder patterns. That greater authority mixes cylinder patterns constantly to optimize efficiency and power delivery at all speeds.

DFM is powered by a sophisticated controller that continuously monitors every movement of the accelerator pedal and runs a complex sequence of calculations to determine how many cylinders are required to meet the driver's requested torque. It can make this determination 80 times per second.

An electromechanical system deactivates and reactivates all 16 of the engine's hydraulic valve lifters, controlling valve actuation. The system uses solenoids to deliver oil pressure to control ports in the lifters, which activate and deactivate the lifters' latching mechanisms. When a cylinder is deactivated, the two-piece lifters effectively collapse on themselves to prevent them from opening the valves. When the cylinder is reactivated, solenoids send an oil pressure signal to the control ports on the lifters and the latching mechanism restores normal function, allowing the valves to open and close.

3. Conclusion

In order to draw the highest efficiency from marine Internal Combustion engines, they must run at the highest rated rpm. However, with several norms, traffic rules etc, marine Internal Combustion engines cannot always be operated at high speed. During low rpm, there is a drop in the efficiency and rise in the emission of an IC engine.

The cylinder de-activation technology has been used in the automobile industry. Though the earlier variants of CDA have their own disadvantages of dynamic unbalance and cooling, the later variants have learnt from its predecessors and have overcome it. From, a simple deactivation of half the cylinders to the Dynamic Skip Fire (DSF) technology, monitored by the electronically computerized algorithm, the CDA has advanced in its own way.

Overcoming its disadvantages, the latest variant which is being used in Tula Technology was featured in Wards Top 10 Best Engines of 2019.

As with any technological revolution, in order to avoid being made obsolete, maritime industry need to ensure they take advantage of this new opportunity to optimize transportation.

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