CYLINDER DEACTIVATION ON FOUR STROKE ENGINES

[1]Gobikrishnan Udhayakumar [2] Karthick.R [3] Saravanan .K.G

[1]Assistant Professor, Sona College of Technology, Salem, Tamil Nadu, India-636 005.

[2]PG student, Engineering Design, Sona College of Technology, Salem, Tamil Nadu, India-636 005.

[3]Assistant Professor, Sona College of Technology, Salem, Tamil Nadu, India-636 005.

kgsmechanical@gmail.com

ABSTRACT

The project aimed at designing a sustainable passenger car for the future with less exhaust emissions and increased efficiency and consumption of fuel. Sustainability is a very broad topic, which reaches further than fuel economy and exhaust emissions. Reducing the fuel consumption and the related CO2 emissions is increasingly important these days. Increasing the power train efficiency is therefore one of the major goals within the project .Better matching of the real engine load with the optimal engine load can be obtained by applying cylinder deactivation. By deactivation of cylinders the load of the still activated cylinder is increased with improved efficiency as a consequence. Cylinder deactivation increases the torsion vibrations of the engine. Currently cylinder deactivation is used on multi-cylinder engines, V12, V8 or V6, where the torsion vibrations do not cause much of a problem due to the still acceptable combustion intervals and combustion peaks during deactivation. In order to analyze the effect of cylinder deactivation on power train dynamics, the important criteria regarding power train vibrations are analyzed. Vibrations can be suppressed or damped by using for instance a torsion damper (TD) or an integrated starter alternator damper (ISAD), which can apply a positive or negative torque to the crankshaft. The power train with all its components are modelled, in order to analyze the effect of cylinder deactivation on the power train dynamics. These models describe the engine dynamics, manual trans-mission, driveshaft, wheels and vehicle. Deactivation of cylinders leads to increased power train vibrations. These vibrations are the cyclic speed fluctuation, primary transmission shaft acceleration, longitudinal vehicle acceleration and power train unit acceleration. The influence of the engine speed, engine load and gear ration on these vibrations are studied. The ISAD system can be used as a passive damper to reduce the vibrations caused by cylinder deactivation. Simulation results show how effective this damping system will be.

INTRODUCTION

Powertrain Concept

The choice for a powertrain concept (Internal combustion engine, fuel cell, or other primary mover) is mainly driven by the availability of fuels or energy carriers in the future. Which fuel or energy carrier will be used in the future is not clear and hard to predict, however there is a great desire to shift away from fossil fuels because of the political and economical instability the oil and gas market causes. The availability of fuels and energy carriers now and the uncertainty in the future requires a flexible solution regarding the powertrain of the concept vehicle. Flexibility is maximized by the modularity concept, which makes it possible to replace a complete powertrain concept in case of changed demands regarding fuel availability or state of technology.At a lower level this flexibility can also be guaranteed within one powertrain concept, the internal combustion engine. The internal combustion engine is capable of running on various fuels with more or less adjustments to its construction. Its flexibility is also of great value to support transitions to new fuels or energy carriers. This flexible characteristic makes the internal combustion engine the primary mover of choice within this thesis. Other powertrain options like the Fuel Cell (FC) or Battery Electric Vehicle (BEV) are discussed in other theses .The design is not only focussed on optimizing the engines energy efficiency, but also on integrating the powertrain inside the vehicle in order to optimize the efficiency of the entire vehicle. New engine technology is capable of reducing engine losses, increasing efficiency and letting the engine operate in its most optimal point. Cylinder deactivation is one of those technologies.

POWERTRAIN PACKAGE AND LAYOUT

By choosing a smart powertrain layout it is possible to increase the total efficiency of the vehicle. The vehicle layout is however constrained by the desired space for occupants and luggage. From an interior point of view it was desired to have an entirely flat cabin space, leaving room for powertrain and suspension between the four wheels, see figure 3.1a. Furthermore, due to the modularity requirements the position of the powertrain is also constrained by possible other powertrain configurations. Layout L1 represents the layout as used in the majority of passenger vehicles today. It has a front mounted engine transmission unit driving the front wheels. The fuel tanks and battery are placed in the rear, under the rear seats. Layout L2 consists of a front mounted engine with a rear mounted transmission. Battery and fuel tanks are positioned around the transmission. Layout L3 is the opposite of layout L1. The engine and transmission is mounted at the back, below the rear passenger seats. Fuel tanks and batteries are mounted in the front of the vehicle.

MODELING

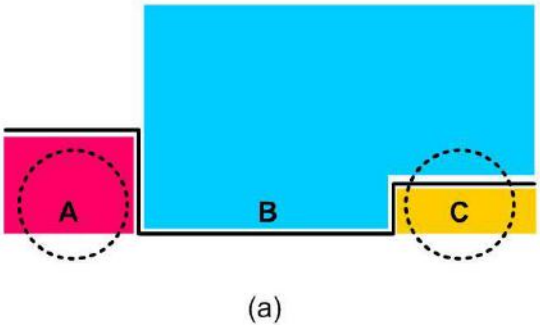


Figure 1 The volumes A and C are available for suspension and powertrain components, while B is reserved for passengers and luggage

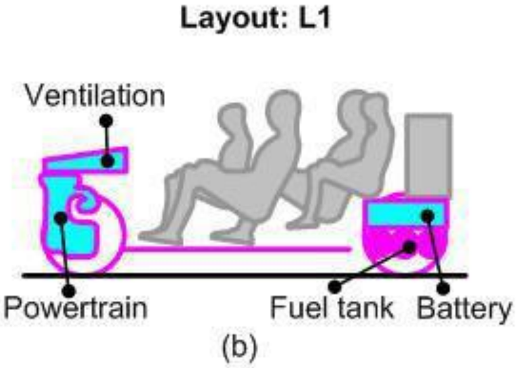


Figure 2 Engine and transmission in the front driving the front wheels.

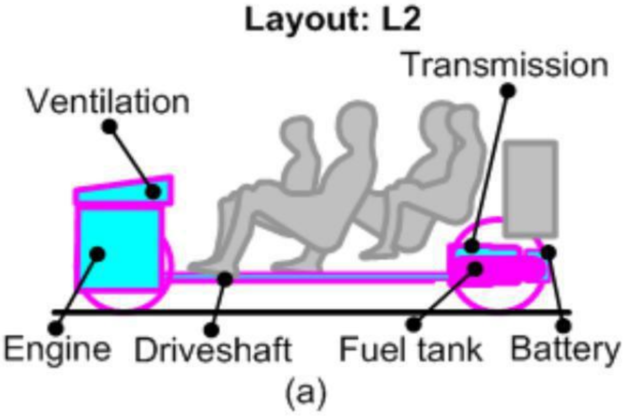


Figure 3 Engine in the front and transmission in the back

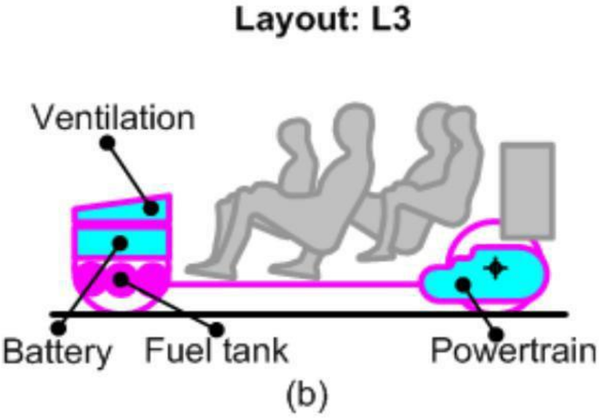


Figure 4 Engine and transmission at the back driving the rear wheels

Different Layout and Properties

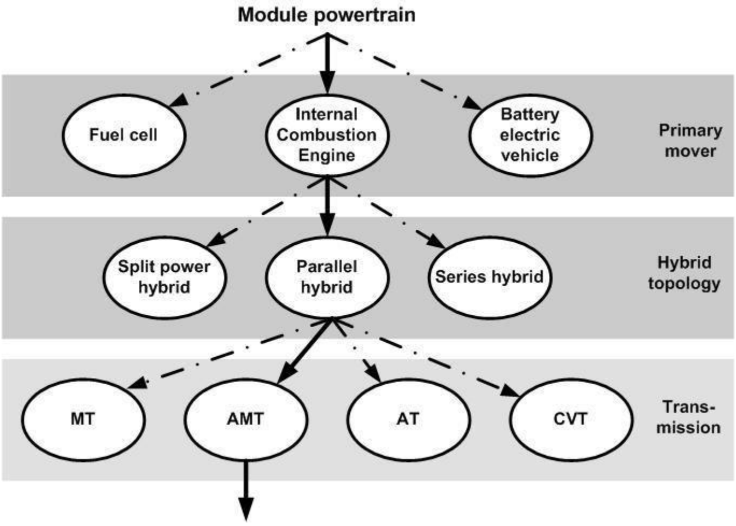
Placing the engine in the rear of the vehicle improves the aerodynamic properties of the vehicle. The underside of the vehicle is not interrupted by an exhaust system. Furthermore the air flow for cooling and intake can be drawn around the rear wheels, which is already a turbulent area. The less dense heated air coming from the engine and radiator can be used to fill the void behind the vehicle in order to reduce the drag at the rear of the vehicle.

Powertrain vibrations are isolated from the steering wheel, improving comfort for the driver.

Because of the non-steering rear wheels, there is more space available between the rear wheels. This makes it possible to use a horizontally opposed engine (also known as Boxer), which has a lighter construction compared to an inline engine with the same displacement and number of cylinders.

The entire vehicle concept requires the acceptance of other powertrains, for instance a fuel cell or battery electric powertrain. The frontal crash behavior of the vehicle can be more constant when more or less the same components like batteries and/or fuel tanks are placed in the front of the vehicle, no matter what powertrain is used. Also, fuel cells are very expensive and vulnerable components which will have to be protected in case of small accidents.

MODULAR POWERTRAIN



CYLINDER DEACTIVATION

Cylinder deactivation is realized by deactivating (closing) the valves and blocking injector or ignition (Otto-engine) signals. Current cylinder deactivation systems use a mechanical valvetrain, where a hydraulic control element is used to prevent the cam followers from actuating the valve. By closing the valves the cylinder is being used as an ”air spring”. This air spring performs a periodical compression and expansion cycle, which eliminates the pumping losses .There are three moments to start the deactivation, before the exhaust stroke, after the intake stroke and after the exhaust stroke. Deactivation before the exhaust stroke results in hot exhaust gases being trapped inside the cylinder. This keeps the cylinder warm and according to this hightemperature has advantages regarding thermal efficiency. The consequence of this timing is a higher compression end pressure. Deactivation after the intake stroke results in near ambient temperature and pressure conditions. Compression end pressure will consequently be lower. Deactivation after the intake stroke leads to even lower compression end pressures. Blow-by effects and cylinder wall heat transfer will eventually level the cylinder pressure and cylinder temperature

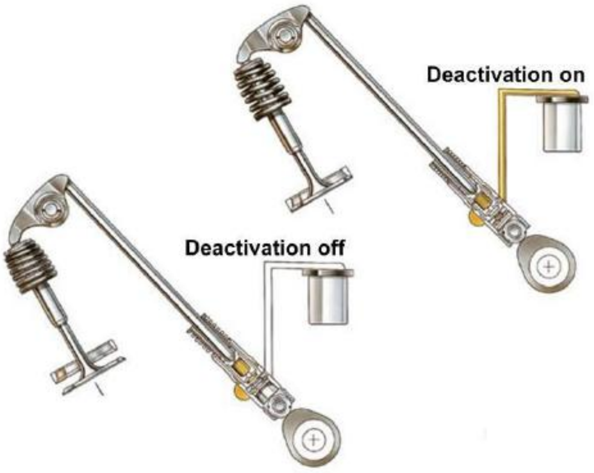
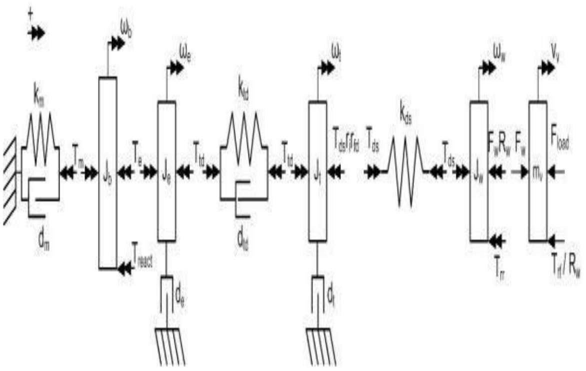


Figure 5 Cylinder deactivation by deactivating the pushrod

POWERTRAIN MODEL



Analyzing the effects of cylinder deactivation on the vibrational behavior of the powertrain requires a dynamic model of this powertrain. This chapter gives the equations of motion of two powertrains, necessary to create these models. The first powertrain is the torsion damper (TD) powertrain. The TD powertrain will serve as benchmark, since it is used most frequently on passenger cars. The model, represented describes the engine, powertrain mounts, torsion damper, transmission, driveshafts, wheels, vehicle body and roadload.The second powertrain or ISAD powertrain, differs slightly from the TD powertrain in a sense that an ISAD system is used instead of the torsion damper. Analysis will show later on if it is indeed the preferred setup when cylinder deactivation is taken into account

SIMULATION RESULTS

Simulations are executed in order to gain information about comfort levels, relevance of air spring torque and relevance of the deactivation order. This chapter describes how the simulations are exe-cuted and discusses the results of these simulations. With these simulations the timing of valve closing is studied as well as the possible order of deactivation.

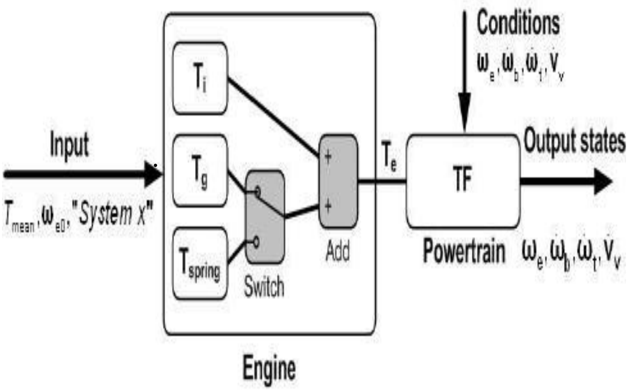


Figure 6 Schematic representation of an engine and powertrain model, used in Matlab.Engine represents 1 cylinder

Simulation Model

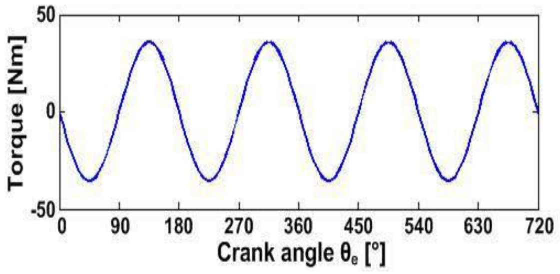


Figure 7 Inertia torque for 4 cylinders at 2000 [RPM]

Cylinder Deactivation order

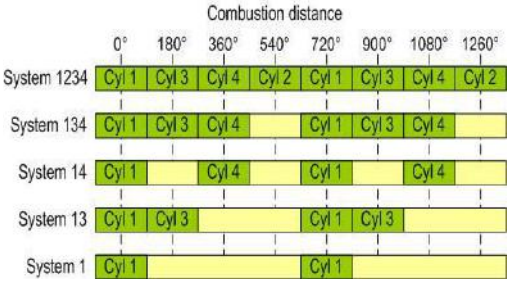


Figure 8Deactivation diagram showing the combustion intervals during deactivation for all deactivation Systems

CONCLUSION

Simulations made clear that the timing of cylinder deactivation, regarding valve closing, has an influ-ence on the peak-to-peak engine torque. The valve timing determines the compression start pressure of the air spring torque cycle. Preferable is to keep this pressure around the ambient pressure, achieved when the valves are closed after the intake stroke.

Deactivation of two cylinders can be achieved with two different configurations. The difference between these two configurations is the interval between consecutive combustion events. When using an inconsistent combustion interval, *System 13*, the peak-to-peak engine torque is increased leading to increased engine speed fluctuations. *System 14* has an evenly spaced combustion interval and due to the lower peak-to-peak engine torque this system is preferred in case of two cylinder deactivation.

Four different comfort criteria have been analyzed, cyclic speed fluctuation, gear rattle, vehicle shuffle and engine shake. Resonances are visible in all responses, but only the gear rattle response shows resonances within the engine speed range of 1700 - 2500 [RPM]. The resonance in the speed fluctuation and vehicle acceleration are caused by the driveshaft resonance, whereas the torsion damper resonance causes resonance peaks in the transmission acceleration response. From literature a maximum allowable cyclic speed fluctuation limit was found. When cylinder deactivation is eval-uated with this limit, it is possible to deactivate up to three cylinders above 1600 [RPM]. The cyclic speed fluctuation and vehicle acceleration also show that the response of two cylinders deactivation is better than the response of one cylinder deactivation. One cylinder deactivation has therefor not much use, when taking the fuel efficiency benefit of two cylinder deactivation into account (only based upon cyclic speed fluctuation criteria).

The level of damping by the ISAD system is not good enough to obtain the same comfort level un-der deactivation as under normal operation (*System 1234*). The best damping performance is obtained around the first powertrain resonance frequency. The relative effect of damping is the highest when less cylinders are deactivated. Modifications to the powertrain setup are needed in order to bring the comfort level during deactivation back to the non-deactivation level.

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