

Start/Stop Strategies for Two-Wheelers in the Emerging Markets

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ABSTRACT

Fuel economy of two-wheelers is an important factor influencing the purchasing psychology of the consumer within the emerging markets. Additionally, air pollution being a major environmental topic, there is a rising concern about vehicle emissions, especially in the big cities and their metropolitan areas. Potentially, the relatively expensive engine management systems are providing more features and value in comparison to the carburettor counterpart. The combustion system analysis is carried out on a 125 cm³ motorcycle engine and the subsequent numerical simulation comparing the carburettor and the Electronic (Port) Fuel Injection which provides a basis to establish the fuel consumption benefit for the electronic injection systems [1].

In order to add more flexibility to the engine management systems and provide additional fuel economy benefit the following strategies were numerically simulated and later validated on a chassis dynamometer:

1. Start/Stop: Engine is switched off at a stop while neutral gear is selected.
2. Stop-in-gear: Engine is switched off at a stop in any gear.
3. Idle Coasting: Engine is idling but disengaged from the transmission during coasting.
4. Start/Stop Coasting: Engine is switched off and decoupled from the transmission during coasting.

Simulation and dynamometer measurements are obtained based the same implementation of test cycles, which are, the Indian Drive Cycle (IDC) and the World Motorcycle Test Cycle (WMTC), urban part 1. Both cycles represent urban driving patterns, which are very common for two-wheeled transportation within the dynamically growing cities of the emerging markets. The resulting fuel efficiencies were compared to a stock bike configuration - a motorcycle without any of the above mentioned Start/Stop strategies, but with Electronic (Port) Fuel Injection.

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INTRODUCTION

Currently, air pollution in megacities is a very concerning topic. Especially in developing countries, like India, the air quality is regarded to be one of the worst in the world. According to the yearly environmental performance index by Yale University, India is one of the weakest performers in terms of environmental care [2]. The pollution, specifically in the megacities has led to higher awareness towards vehicle emissions, whilst the fuel economy influencing the

purchasing psychology of the consumers. Within the emerging markets, two wheeled vehicles have a great market share as they provide an affordable access to individual transportation. In India for example, 60 per cent of all motor vehicles were two-wheelers in 2004 [3].

Start/Stop and Start/Stop Coasting systems have already proven their potential for fuel savings in cars [4], but they haven't found their way into the two-wheeler mass market as yet, although they provide an opportunity for fuel savings,

which leads to a decrease in vehicle emissions. Although these strategies can be implemented at minimal cost in terms of hardware, an Electronic (Port) Fuel Injection (EFI or PFI) is necessary as its engine management systems provide the platform to implement advanced Start/Stop strategies. As the initial cost of a two-wheeler equipped with PFI is higher than a comparable carburettor variant, it is especially important to demonstrate the resulting benefits in fuel economy to the end-customers in order to influence their buying decision.

In the current study, the authors attempt to quantify the fuel economy benefits of advanced Start/Stop strategies for two-wheelers. Therefore, a 95 cm³ motorcycle was chosen as a test vehicle. It represents a motorcycle, which is typical used within the emerging markets. [Table 1](#) shows the general specification of the motorcycle. Not all the necessary data for coasting and fuel consumption calculation are readily available. Additionally, also considering the need to maintain equal conditions for simulation and test bench validation, it was necessary to first generate data via dynamometer measurements. Subsequently, in addition to the collection of the data, a simulation was performed to derive fuel economy benefits of the mentioned Start/Stop strategies. Lastly, the simulation results were validated on the chassis dynamometer.

Table 1. Specifications of the test vehicle

Engine	1 cylinder, 4 stroke, Air cooled
Engine capacity	94.38 cm ³
Fuel System	Electronic Port Fuel Injection
Number of gears	5
Kerb weight	115 kg

START/STOP AND COASTING FUNCTIONALITIES

Start/Stop and coasting strategies have proven their capabilities as an enabler for relevant benefits in fuel economy with Start/Stop currently being state-of-the-art for automotive applications [4]. The coasting functionality is built on Start/Stop systems. Both strategies are easily applicable with motor management software, such as provided by PFI engine management. With the introduction of PFI for two-wheelers, one of the subsequent steps needed is the introduction of advanced Start/Stop strategies.

Start/Stop

When the vehicle is at standstill, the combustion engine normally is running and therefore fuel needs to be injected to overcome the engine's inner drag torque. The introduction of

Start/Stop for two-wheeler vehicles makes it possible to omit the injection of fuel during standstill phases as the engine is completely shut off. The engine is restarted again when acceleration is requested. When coming to a stop the driver has to pull the clutch lever in order not to stall the engine. The gear selection given by the test cycle often proposes neutral gear during standstill phases. Neutral gear guarantees that the drive train is not closed, meaning there is no torque path between the combustion engine and the wheel. Because the engine can safely be restarted in the neutral gear, this state allows the Start/Stop-controller to turn off the engine and safely restart it. For the limited time period, from the initial pulling of the clutch lever before the engagement of neutral gear until the lever is pulled again, the engine is turned off and fuel is saved compared to an idling engine. The trigger for the engine restart is the clutch lever. Nevertheless, it is important to mention that the engine restart consumes a certain amount of fuel, which has to be taken into account. Besides Bosch, other manufactures like SKF or Honda have also done previous research on Start/Stop systems for two-wheelers [5, 6].

Stop-In-Gear

The engagement of neutral gear at a stop might not always be comfortable in terms of usability. Sometimes it is sufficient enough to pull the clutch lever in order not to stall the engine, but as soon as a drive off is predicted the engagement of neutral gear is obsolete. Also, in terms of homologation issues Start/Stop does not always succeed to achieve the maximum standstill benefit, which means that the omission of all emissions is not completely possible. This issue is due to the proposal made for the test cycle gear shift, which sometimes demands the engagement of first gear long before the vehicle is determined to drive off. Stop-in-gear allows maximum standstill benefit, whereas the engine is shut off from the time the clutch lever is pulled while decelerating to a stop until the throttle lever is pulled to drive off. Therefore, the Stop-in-gear operation strategy also maximizes the Start/Stop benefit in daily use. The clutch lever has to be pulled while starting the engine again. To reduce the driver effort, the clutch shall remain disengaged throughout the whole standstill period. This can be achieved by a hydraulic system, which holds the lever in the pulled position and automatically releases it at any given time. The engine start trigger is pulling the throttle lever.

Idle Coasting

The PFI engine supports immediate fuel cut-off, where no fuel is consumed if there is no acceleration request. This has led to a better fuel economy as compared to its carburettor counterpart, which is not able to completely stop consuming fuel. But during fuel cut-off the velocity of the motorcycle decreases because of external resistance forces as well as the inner resistance forces of the engine, which is dragged by the wheel movement. [Figure 1](#) shows the coast down curves of the vehicle while different gears are engaged. The curves

displaying velocity over time, were measured on the test bike and performed with a driver. Another option during coasting down is to disengage the clutch and thus eliminate resistance forces through inner drag of the engine. The vehicle coasts with less deceleration and only external resistance forces (e.g. aerodynamic drag) are applicable. Consequently, the coast down curve is flatter when the motorcycle decelerates less and covers more distance compared to a coast down with an engaged engine (Figure 2).

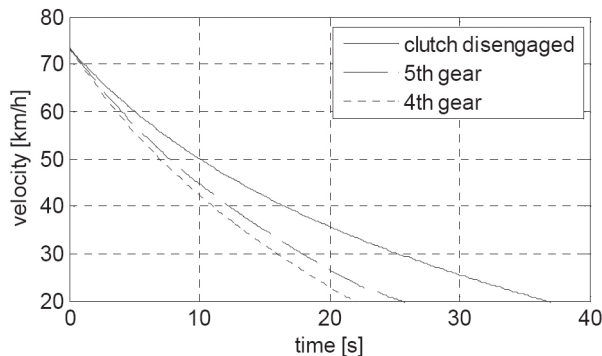


Figure 1. Coast down curves with different gears and disengaged clutch over time

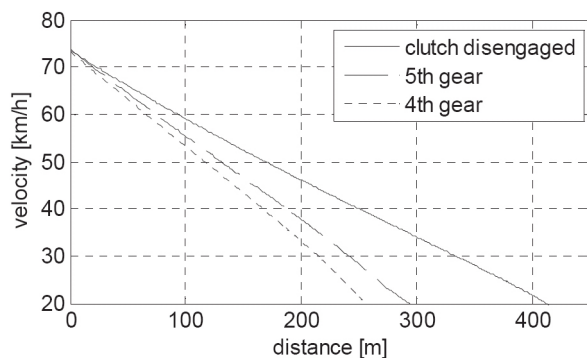


Figure 2. Coast down curves with different gears and disengaged clutch over distance

The disengagement of the clutch can be achieved through the driver manually by pulling the clutch lever after an indicator lightens up. Furthermore, the hydraulic system which was previously mentioned could reduce lever forces or even hold the lever in a particular position. Another option can be a full automatic clutch actuation by an electrical actuator. The engine operates at idling speed during the time it is disengaged from the wheels. Hence this operating mode is called Idle Coasting. It is beneficial when the motorcycle is determined to hold the speed or slightly decrease the speed because the vehicle can cover more distance even though more fuel is consumed as compared to fuel cut-off.

Start/Stop Coasting

The maximum benefit of coasting with disengaged clutch is achieved through Start/Stop Coasting. During this mode of

operation, the coasting is initiated like Idle Coasting, which means the clutch lever needs to be pulled to disconnect the engine from the wheels. The coast down curve is the same as illustrated in Figure 1. During Idle Coasting, fuel had to be injected so the engine can overcome its inner drag. Whilst, Start/Stop Coasting shuts off the engine completely. The flat coast down curve and zero emissions are combined for the coasting. It concludes that the engine is only running if there is an acceleration request.

For the Start/Stop strategies, the increased fuel injection during the engine restart and the electric energy for the starter motor are to be considered.

Additionally, it is possible to combine Start/Stop Coasting phases with Start/Stop phases. When the vehicle is coasting and the driver is about to apply brakes to slow down to come to standstill, the engine can stay switched off then.

SIMULATION ENVIRONMENT

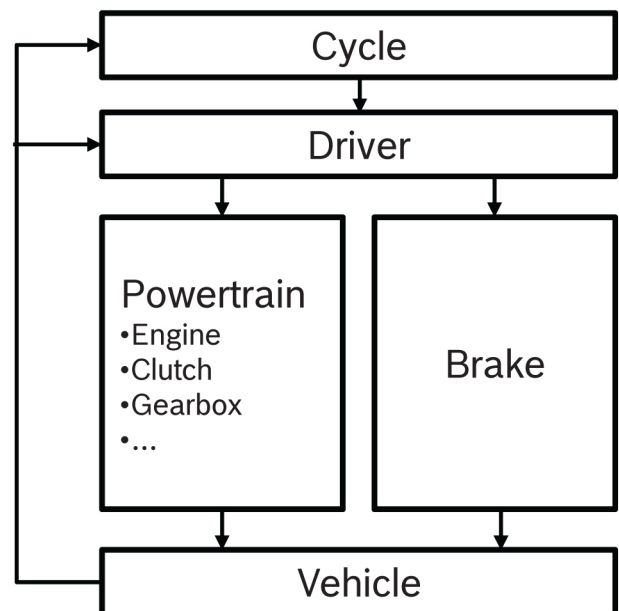


Figure 3. Basic structure of a forward simulation

The performed CO₂-simulation is based on longitudinal dynamics and does not take any transverse dynamics into account, which is accurate enough for the estimation of emissions. The simulation approach can be described as a forward simulation. The simulation tool, which is implemented within the MATLAB/SIMULINK environment, calculates the torque through the powertrain in the same direction as the actual mechanical torque translation occurs. A nominal value for the velocity is defined within the test cycle, where an additional driver-model uses actuators such as the (virtual) acceleration or brake pedal and a gear shift strategy to request a torque from the combustion engine, which later gets translated to the torque at the wheel via the models for the powertrain and brake. The current velocity of the vehicle can be calculated through the summation of the