

Online Engine Speed Based Adaptation of Air Charge for Two-Wheelers

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ABSTRACT

Regarding the strongly growing two-wheeler market fuel economy, price and emission legislations are in focus of current development work. Fuel economy as well as emissions can be improved by introduction of engine management systems (EMS). In order to provide the benefits of an EMS for low cost motorcycles, efforts are being made at BOSCH to reduce the costs of a port fuel injection (PFI) system.

The present paper describes a method of how to reduce the number of sensors of a PFI system by the use of sophisticated software functions based on high-resolution engine speed evaluation. In order to improve the performance of a system working without a MAP-sensor (manifold air pressure sensor) an air charge feature (ACFn) based on engine speed is introduced. It is shown by an experiment that ACFn allows to detect and adapt changes in manifold air pressure. Cross-influences on ACFn are analyzed by simulations and engine test bench measurements. Whereas the air-fuel ratio can be neglected, the temperature influence has to be considered. Finally, additional applications of engine speed based features for small engine control are discussed. Algorithms for ignition angle optimization and air-fuel ratio adaptation are part of the current development work at Bosch.

CITATION: Steinbrecher, C., Reineke, B., Berkemer, J., Heikes, H. et al., "Online Engine Speed Based Adaptation of Air Charge for Two- Wheelers," *SAE Int. J. Engines* 6(4):2013, doi:10.4271/2013-32-9037.

INTRODUCTION

The need of improving fuel consumption as well as pollutant emissions while preserving excellent drivability, robustness and competitive costs necessitates the detailed understanding and optimization of the 2-wheeler system. In order to address the aforementioned potentials the increase of the market share of motorcycles equipped with engine management systems and electronic fuel injection is ongoing [1]. Especially in fast growing markets such as India, China and the ASEAN countries the number of units of 2-wheeler systems with displacement volumes smaller than 250ccm is rising rapidly. One of the benefits compared to conventional carburetor systems is the more precise control of the air-fuel ratio which enhances starting reliability [2] and allows an effective exhaust after treatment via 3-way-catalyst. As shown in [Figure 1](#) intelligent engine control functions are able to increase the system robustness as well as to reduce maintenance effort and system costs by a replacement of sensors.

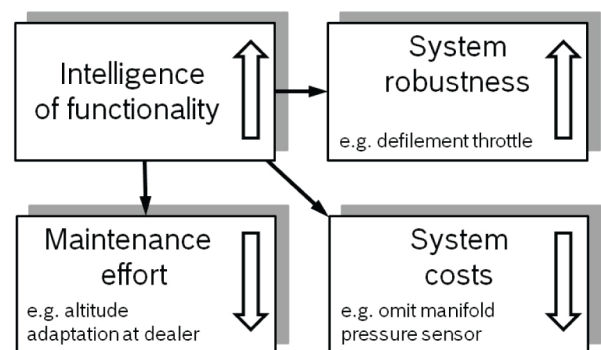


Figure 1. Benefits of intelligent engine control functions

The evaluation of the engine speed signal is already used in automotive series applications e.g. for misfire detection. Especially for single cylinder engines with low overall inertias the high fluctuations of engine speed allow more detailed analysis of the operating conditions. The investigations described by Seuling et al. [3] show the

possibility of a calculation of air mass and indicated mean effective pressure (imep) from the engine speed measured with an optical high resolution reference trigger wheel on the engine test bench. The work presented in this paper focuses on the technical realization of the air charge estimation with a series production engine speed sensor on an actual vehicle with a data processing within the ECU. Therefore the software functions for processing of the engine speed sensor signal and calculation of the corresponding features are developed and implemented on a Motronic M17.8.42 from BOSCH. The examinations are done on a series motorcycle equipped with a 125cc water-cooled engine with port fuel injection (PFI).

In order to determine the robustness of the calculated air charge feature different sensitivity analyses are performed. Several methods are used for this purpose, starting with elementary considerations from the ideal gas law, over complex engine simulations with the tool GT-POWER by Gamma Technologies Inc. to measurements on the engine test bench. First results for the adaptation of leakage air in idling without usage of a manifold pressure or oxygen sensor are shown on the vehicle.

DESCRIPTION OF ENGINE SPEED EVALUATION

A high-resolution engine speed signal of a combustion engine contains useful information about the combustion process in the cylinders. The mean rotational speed is superimposed by periodical fluctuations, which are dominantly affected by the in-cylinder pressure and mass-forces occurring due to the crank angle dependent inertia of the engine. By taking into account the kinematics of the engine, the effects of in-cylinder pressure and mass-forces can be separated as described by Hamedovic [5]. The basic relationship between in-cylinder pressure, torque and the resulting rotational speed of the crankshaft is illustrated in [Figure 2](#). Here the impact of different engine load at constant average engine speed on the high-resolution engine speed signal is shown.

The different phases of the working cycle deliver different kinds of information about the four-stroke cycle process. In order to get information about the combustion itself the combustion phase from top dead centre (TDC) to TDC plus 180°CA has to be evaluated. The in-cylinder pressure and correspondingly the behavior of the engine speed in this phase contains information about air charge, air-fuel ratio and the ignition angle. The pressure during compression phase (−180°CA...0°CA regarding ignition TDC) on the other hand provides information on the amount of air charge. The more air has to be compressed in the crank angle region between inlet valve closing and the combustion onset the higher is the in-cylinder pressure and the following torque resulting in a decrease of engine speed. This behavior can also be seen in [Figure 2](#), since the air charge increases with higher loads in terms of imep. The necessary mechanical work W needed for

the compression of the air charge corresponds to the integral over the torque in the considered angular region:

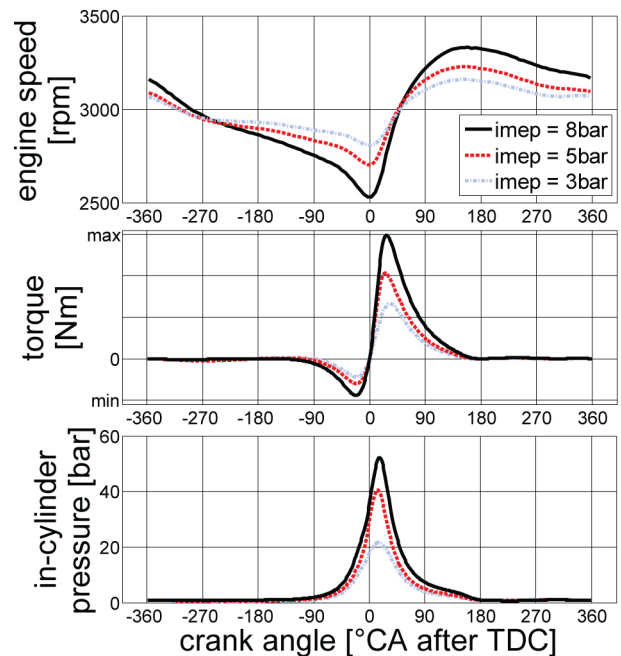


Figure 2. Relationship between in-cylinder pressure, torque and resulting engine speed at different imeps

$$W = \int_{\varphi_1}^{\varphi_2} p(\varphi) dV = \int_{\varphi_1}^{\varphi_2} M(\varphi) d\varphi \quad (1)$$

This work can be estimated from the engine speed signal.

Based on the described relationship between in-cylinder pressure, torque and rotational speed Seuling introduced in [3] two different features: ACF_n for charge estimation and imep_n for the estimation of the indicated mean effective pressure. Due to model based considerations of the crankshaft physics very good correlations are reachable with only little calibration effort.

The estimation approach for the air mass and the imep is described in [Figure 3](#).

A high resolution engine speed signal is calculated from the so-called tooth times, which are the measured times from one tooth flank of a trigger wheel which is mounted on the crankshaft to the next. Therefore the resolution of the engine speed signal depends on the number of teeth of the trigger wheel, whereas twelve teeth are already enough for calculation of the introduced features. One possibility to detect the tooth flank events is the use of an inductive sensor. [Figure 4](#) gives an overview of the high resolution engine speed signal acquisition. The incremental errors due to the allowed construction tolerance and inaccurate mounting can corrupt the measurements significantly. Thus, an appropriate compensation is the first step in the procedure. After filtering, the features for the air mass estimation ACF_n and for the

estimation of the indicated mean effective pressure imep_n are calculated by the use of physics based models.

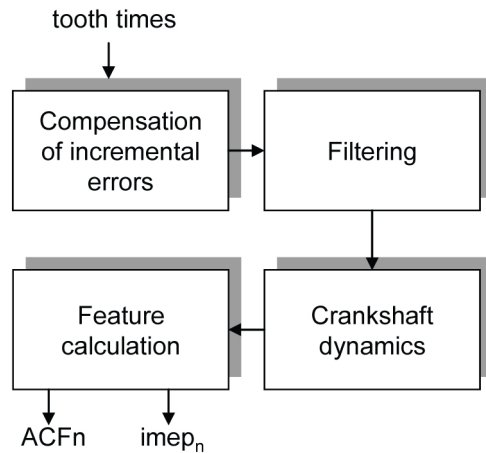


Figure 3. Calculation of engine speed based features

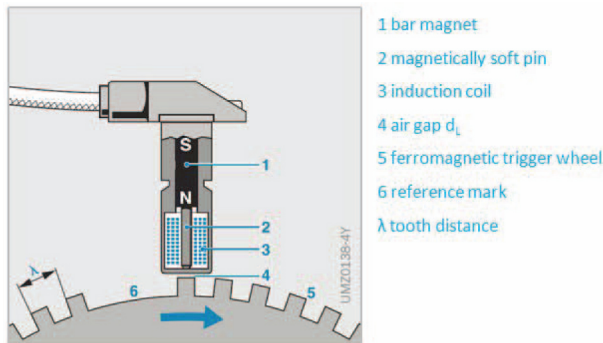


Figure 4. High-resolution engine speed acquisition

AIR CHARGE ADAPTATION BASED ON ENGINE SPEED

Motivation

In order to improve the accuracy of the pre-control of the basic charge determination via throttle angle position and average engine speed, a secondary charge signal for adaptation purposes is necessary. Currently the usage of an intake pressure and temperature sensor for these adaptations is state of technology. To reduce the number of sensors and accordingly costs different alternatives are feasible. One approach is based on the signal of the oxygen feedback control. In cases where the air-fuel ratio control is inactive - e.g. because the oxygen sensor is too cold while engine warm up or the fuel injection is cut - further measures have to be considered as described in [4].

The aim of these investigations is to increase the accuracy of the air charge determination by adaptations via the engine speed based charge feature ACFn. In absence of a manifold pressure sensor this feature should be able to adapt additive errors on the air path like varying leakage air and multiplicative errors like altitude changes independent from the oxygen feedback control.

Sensitivity Analysis

While the engine speed based feature delivers information about the in-cylinder pressure p , the rearrangement of the ideal gas law (formula 2) shows that the mass of the air charge inside the cylinder also depends on volume V , absolute temperature T of the charge, fuel mass m^{fuel} and residual gas m_{exhaust} .

$$p \cdot V = m_{\text{charge}} \cdot R \cdot T$$

$$\Leftrightarrow m_{\text{charge}} = \frac{p \cdot V}{R \cdot T} \quad \text{with } m_{\text{charge}} = m_{\text{air}} + m_{\text{fuel}} + m_{\text{exhaust}}$$

$$\Rightarrow m_{\text{air}} = \frac{p \cdot V}{R \cdot T} - m_{\text{fuel}} - m_{\text{exhaust}} \quad (2)$$

In order to judge the impact of these theoretic disturbances and to find other potentially influencing values GT-POWER simulations of the gas exchange process including combustion have been performed. As a result none of the analyzed variables apart from the temperature seems to be crucial for the air charge estimation by ACFn. For validation of the simulation results, measurements are necessary, which have been done for temperature and air-fuel ratio until now.

The validation measurements have been done at an engine test bench which enables to vary influencing parameters separately. For the analysis of the temperature influence the engine temperature t_{mot} and the intake temperature t_{intake} were varied independently for different measurements. ACFn is calibrated for $t_{\text{mot}}=60^\circ\text{C}$ and $t_{\text{intake}}=50^\circ\text{C}$ (reference condition). The relative deviations in ACFn due to the temperature variations compared to the reference air mass r_l (relative air mass) are depicted as results in Table 1.

Table 1. Temperature influence on ACFn

$ \text{ACFn} - r_l / r_l$	$t_{\text{mot}} = 25^\circ\text{C}$	$t_{\text{mot}} = 60^\circ\text{C}$
$t_{\text{intake}} = 25^\circ\text{C}$	16 %	10 %
$t_{\text{intake}} = 50^\circ\text{C}$	5 %	reference