

Online Engine Speed based Adaptation of Combustion Phasing and Air-Fuel Ratio

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ABSTRACT

Equipping low cost two-wheelers with engine management systems (EMS) enables not only a reduction of emissions but also an improvement in fuel consumption and system robustness. These benefits are accompanied by initially higher system costs compared to carburetor systems. Therefore, intelligent software solutions are developed by Bosch, which enable a reduction of the necessary sensors for a port fuel injection system (PFI) and furthermore provide new possibilities for combustion control.

One example for these intelligent software solutions is a model based evaluation of the engine speed. By use of the information contained in the engine speed signal, characteristic features like air charge, indicated mean effective pressure (imep) and combustion phasing are derivable. The present paper illustrates how these features could be used to reduce the system costs and to improve fuel consumption and system robustness. Especially in the low cost segment there are significant bike-to-bike variations e.g. compression ratio or valve timing deviations. These deviations which are increased by ageing effects have a significant influence on the combustion process. For instance a variation in the valve timing, causing a different amount of residual gas to be left in the combustion chamber, might lead to deviations in the pre-defined combustion phasing. As a result either fuel consumption or emissions could deteriorate. After analyzing the potential benefits of the introduced features, two applications for model based engine speed evaluation are presented. One uses a rotational speed based estimation of the combustion phasing for a closed loop ignition angle adaptation, the second is able to adapt the air-fuel-ratio by estimating imep.

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INTRODUCTION

The current development in the low cost two-wheeler segment is driven by fuel economy, price and emission regulations. Compared to a conventional carburetor system the introduction of engine management systems (EMS) with electronic port fuel injection (PFI) allows a reduction of fuel consumption and tail pipe emissions. As a result, the market share of motorcycles equipped with EMS is increasing [1]. For the low cost segment competitive costs compared to a carburetor system are the special challenge. One potential way to reduce the system costs is reducing the number of sensors used. Reducing the number of sensors, though, makes it even harder to handle the comparatively high bike-to-bike variations in this segment. Therefore, a detailed system understanding and optimization is the key for a robust and cost effective two-wheeler system.

In order to analyze and increase the performance of a combustion process, in-cylinder pressure indication is an established tool for the development of combustion control.

Achievable features are the indicated mean effective pressure (imep) and the combustion phasing. Whereas Seuling et al. [2] showed that the imep can be estimated by the use of sophisticated software functions based on high-resolution engine speed evaluation, the contribution of this paper is the likewise estimation of the combustion phasing. The online calculation of these two engine speed based features on a off-the-shelf Bosch Motronic M17.8.42 provides possibilities for new applications. Two potential applications are presented in this paper. Based on a developed feature for estimation of the combustion phasing, the ignition angle is adapted online in order to adjust the combustion phasing to a pre-set value. In the second application, the engine speed based imep feature and an active excitation of the system is used for the estimation and adaptation of the air-fuel ratio. These approaches can help to increase the robustness of the system and at the same time the air-fuel ratio adaptation approach might be an enabler for an open loop system without oxygen

sensor. These examples show how sophisticated software solutions can help to make the EMS even more attractive for the low cost two-wheeler market.

After illustrating the principles of engine speed evaluation the estimation approaches for the combustion phasing and the air-fuel ratio are introduced. Afterwards the adaptation functions and their potential benefits are discussed. By experiments on a 125cc one cylinder water cooled motorcycle possible use cases are evaluated. The paper will end up with a discussion of the open issues.

PRINCIPLES 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 [3]. The basic relationship between in-cylinder pressure, torque and the resulting rotational speed of the crankshaft is illustrated in Figure 1. Here the impact of different engine load at constant average engine speed on the high-resolution engine speed signal is shown.

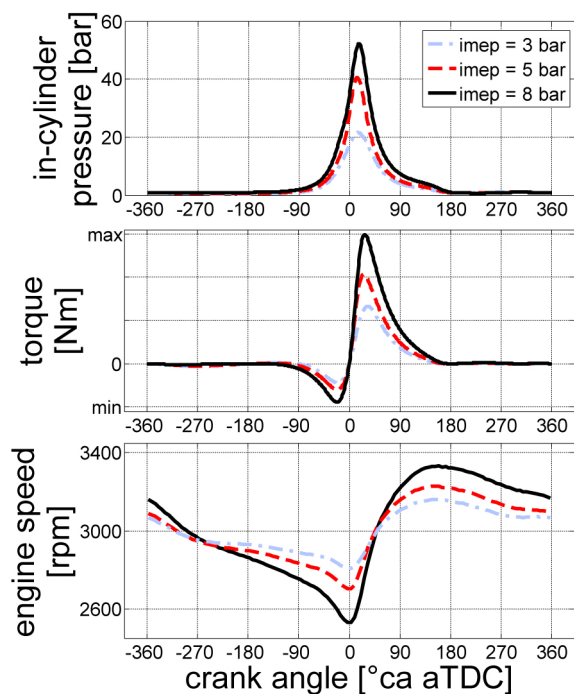


Figure 1. Relationship between in-cylinder pressure, torque and resulting engine speed for different charges

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 the imep (mean effective pressure) and thereby information about air charge, air-fuel ratio and the ignition angle. More information on the amount of air charge can be gained by taking into account the pressure during the compression phase (-180°CA...0°CA referring to ignition TDC). The more air enclosed in the combustion chamber during compression, the higher the in-cylinder pressure during compression and thus the torque needed, resulting in a decrease of engine speed.

Besides charge and imep, the combustion phasing is another characteristic property of a combustion process. While Figure 1 showed that changes in the amount of air charge are visible in the rotational speed, Figure 2 illustrates that also variations in the combustion phasing are visible. Both, variations in charge and variations in combustion phasing, result in different imeps and by that in different levels of fluctuations in the rotational speed. In addition to the different levels of fluctuations the change of combustion phasing also leads to a significant phase shifting in the torque release and thus in the fluctuations of the engine speed.

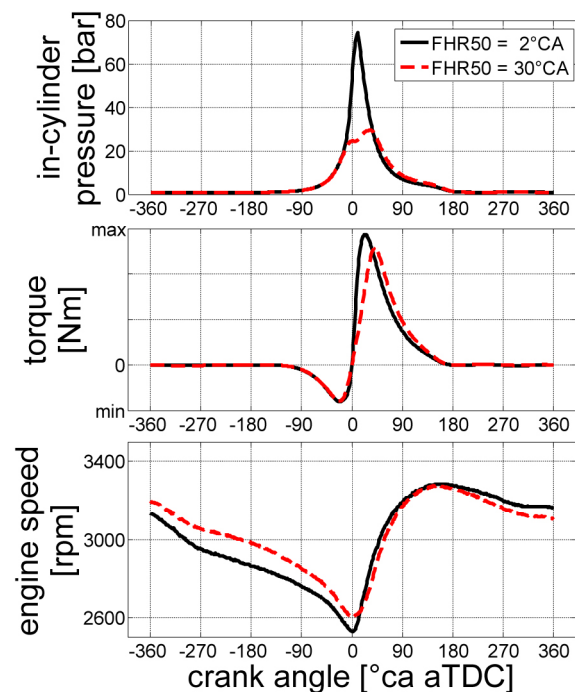


Figure 2. Relationship between in-cylinder pressure, torque and resulting engine speed for varied combustion phasing

By the use of model based evaluation the information about the combustion process is extracted from the rotational speed. Three features for the characterization of the combustion process are calculated: ACF_n for charge estimation, imep_n for the estimation of the indicated mean effective pressure and FHR50_n for estimation of the combustion phasing. The estimation approaches are described in Figure 3.

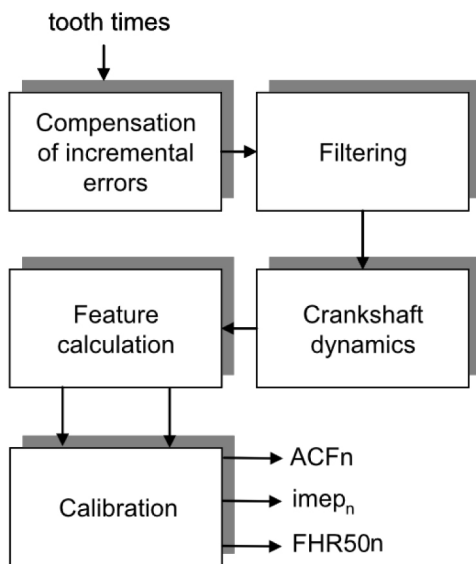


Figure 3. Calculation of engine speed based features

A high resolution engine speed signal is calculated from the so-called tooth times, which are the measured times from one tooth flank on a trigger wheel mounted on the crankshaft to the next. Therefore the resolution of the engine speed signal depends on the number of teeth on the trigger wheel. 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 ACFn, for the estimation of the indicated mean effective pressure imep_n and the combustion phasing FHR50n are calculated by the use of physics based models.

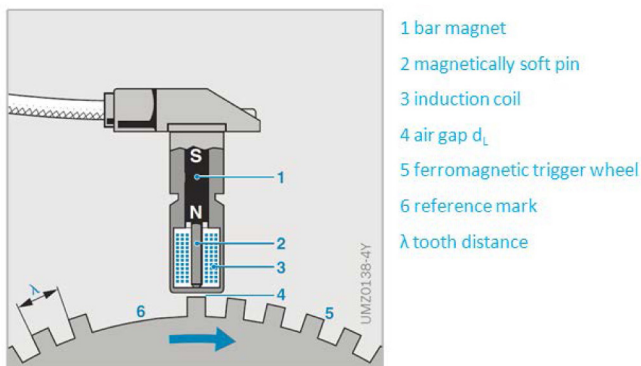


Figure 4. High-resolution engine speed acquisition

The features for air charge and for imep were already introduced by Seuling et al. [2]. Seuling showed that by the use of model based considerations of the crankshaft physics very good correlations can be reached with only little calibration effort. Whereas possible applications for the air charge feature ACFn are discussed in [4] and [5], this paper concentrates on the introduction of the FHR50n feature and on the new possibilities for combustion control by use of the imep_n and the FHR50n feature.

EVALUATION OF THE ROTATIONAL SPEED BASED COMBUSTION PHASING FEATURE

The introduced combustion phasing feature FHR50n is based on an energy evaluation similar to the fast heat release characterization. By use of a crankshaft model with the engine speed as input, the crankshaft angle where 50% of the combustion energy is converted into mechanical work is estimated. This estimated crankshaft angle (CPnmot - combustion phasing based on engine speed) shows a good correlation to an in-cylinder pressure based reference calculation of the combustion phasing (FHR50- combustion phasing from fast heat release). Mapping of the CPnmot feature on the in-cylinder pressure based reference value leads to the introduced combustion phasing feature FHR50n. The derivation of FHR50n is illustrated in Figure 5.

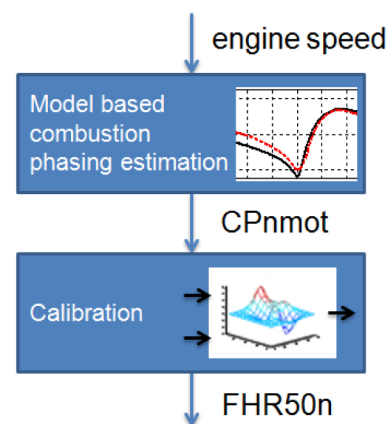


Figure 5. Calculation of engine speed based combustion phasing feature FHR50n

In order to evaluate the performance of the presented combustion phasing estimation concept, all features have been applied to a 125cc motor cycle with a water-cooled engine and a PFI-system. On a vehicle dynamometer various series of measurements are being conducted using static operation points and grid measurements. That way potentially influencing factors on the combustion phasing, such as air-fuel ratio, air charge, temperatures or bike-to-bike variations are being identified and evaluated. Figure 6 shows the results of the engine speed based combustion phasing feature (CPnmot) after ignition angle sweeps for different amounts of air charge at 3000 rpm and λ=1. The upper graph shows the relationship between the ignition angle and the reference FHR50. The different charges lead to different burn durations and by that to different relationships between the ignition angle and the combustion phasing. The graph in the middle shows the resulting imep with its known dependency on the charge and the combustion phasing. The lower graph shows the results of the engine speed based combustion phasing estimation (CPnmot). A clear reproducible relationship between CPnmot and the reference FHR50 is visible. The slope and by that the information content is decreasing for early combustions. But for the region of interest (FHR50>5°ca) the slope is big enough for estimation of the combustion phasing.