

Investigation on the Transient Behavior of a High Compression Two-Wheeler Single Cylinder Engine Close to Idling

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Abstract

The introduction of stricter emission legislation and the demand of increased power for small two-wheelers lead to an increase of technical requirements. Especially the introduction of liquid-cooling over air-cooling allows the introduction of higher compression ratios, which improves power output as well as thermodynamic efficiencies and thereby fuel consumption.

But an increase in compression ratio also introduces further challenges during transient behavior especially close to idling. In order to keep the two-wheeler specific responsiveness of the vehicle, the overall rotational inertia of the engine must be kept low. But the combination of low inertia and high compression ratio can lead to a stalling of the engine if the throttle is opened and closed very quickly in idle operation. The fast opening and closing of the throttle is called a throttle blip.

This paper describes the development of a procedure to apply reproducible blipping events to a vehicle in order to derive a deeper physical understanding of the stalling events. Goal is to identify influencing factors that determine whether a blip will lead to a stalling of the engine or not. These factors contain e.g. the timing of the blip within the working cycle or calibration parameters like average idle speed and ignition timing.

The investigations are carried out on a motorcycle with a water-cooled 400cc single cylinder engine from the performance segment with high compression ratio and an engine management system with port fuel injection. Several thousand blipping events are automatically applied and evaluated with the focus on the stalling probability.

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INTRODUCTION

The robustness of internal combustion against stalling at sudden throttle opening is an important measure for dimensioning of the engine (e.g. overall inertia), development of the engine management system (e.g. accurate fuel metering and ignition timing) and calibration. In order to perform an objective optimization a reliable methodology for applying throttle blips (also known as tip-ins) and evaluating the system response is mandatory. This paper will focus on the following aspects:

1. development of a representative throttle blip which can be applied automated and reproducible
2. classification of the mechanisms which lead to a stall and introduction of stall modes
3. introduction of the stall probability (ratio of all stalling throttle blips compared to all applied throttle blips in a certain operating point) as an objective measure for comparison

4. identification and investigation of influencing factors on the stall probability
5. definition of a procedure for an optimized calibration of idle operation

Motorcycle engines are usually equipped with one throttle valve per cylinder to create small intake manifold volumes and therefore ensure good transient behavior. This transient responsiveness of the induced intake air is much higher than in typical automotive applications. According to the sensitivity towards stalling during fast transients single cylinder engines can be considered the worst case as combustion only occurs once per 720 °ca to accelerate the crank train. The kinetic energy stored within the crank train (e.g. crank, con rod, piston and fly wheel) is the only source to overcome the necessary work of compression in the next working cycle. Stalling can take place if the crank speed and therefore the kinetic energy stored are too small to ensure a complete compression process in the next working cycle. In this case the piston will revert its moving direction before top dead center and the crank is turning backwards until the engine comes to a complete stop.

Several design parameters are influencing the necessary work of compression and therefore the blip stall behavior. Aside of the overall inertia, the compression ratio is one of these factors. Therefore engines with high power density and high performance are in focus. Another parameter is the displacement of the engine and the present cylinder charge.

EXPERIMENTAL SETUP

Derived from the physical understanding of the blip stall phenomenon a representative vehicle from the single cylinder segment is chosen. Table 1 contains the relevant technical data. All investigations have been conducted in idling operation as this can be considered the worst case situation for fast throttle transients because of the low engine speed and therefore the low kinetic energy of the crank train. Furthermore the gradient of positive or negative throttle blips can be considered as independent from engine speed. But the influence of a fast changing throttle on the cylinder charge is more critical at low engine speeds, as full load air charge is already reached at throttle angles significantly below the maximum throttle opening.

Table 1. Technical data for demonstrator vehicle

Displaced volume	400 cc
Number of cylinders	1
Compression ratio	13:1
Number of valves	4
Trigger wheel	36-2 teeth
Cooling System	liquid

Figure 1 depicts the experimental setup of the demonstrator vehicle. It consists of two main building blocks. The upper part is the data acquisition system, where the analog signals for ignition current, injection voltage, crank voltage from the inductive sensor and the voltage of the throttle position sensor are measured with a time based resolution of 0.01ms. These signals are a basis for the automated evaluation of the blipping events. Especially the crank signal has a high relevance, as it is used to transform the measured time basis into a crank angle basis for all the other measured signals. The lower part gives more details on the blip automation system. This system is based on an embedded micro controller which also reads in the crank and the ignition signal. The controller creates a trigger signal for the throttle position actuator which contains an electrical motor. This motor is connected via a lever to a bowden cable which replaces the original bowden cable on the mechanical throttle body of the motorcycle. The crank signal is utilized to create the blipping event at a defined crank position in the working cycle. The ignition signal is used as a reference to indicate the phase of the crank signal and therefore distinguish between firing and gas exchange top dead center.

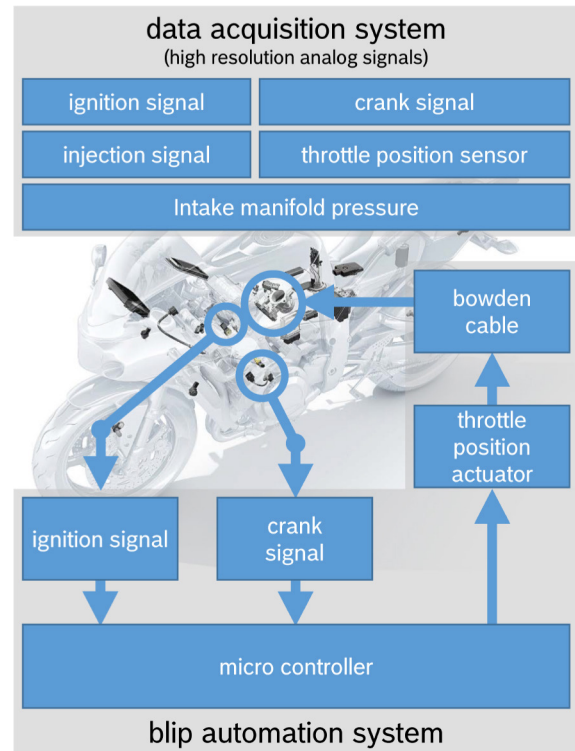


Figure 1. Experimental setup for data acquisition and blip automation

EXPERIMENTAL RESULTS

Definition of Blip Event

As a first step around two hundred blipping events have been applied manually with the goal to create very short blip durations. Within this two hundred events the engine stalled four times. Out of this four stalling events the throttle position profile with the shortest duration is defined as the reference target blip as shown in Figure 2. The throttle is opened to around 80 % of the maximum throttle opening within 45 ms and closed again immediately within 50 ms. The derived target blip has an overall duration of 100 ms. Converted towards the crank angle basis this transfers to around 1000 °ca at idling speed. In the second step this target throttle blip has been reproduced via the automation system. As visible the manual and the automated throttle blips are matching well with a slightly longer duration of the automated blip. The reproducibility of the automated blips is adequate. To create an even worse blipping event, coming from the 100 ms target blip another shorter reference blip is defined. The target for the blip duration is 50 ms and it is not utilizing the full throttle opening but is limited to around 45 %. By this measure the overall blip duration of the automated blips can be reduced to around 70 ms which is slightly higher than the target of 50 ms but still sufficient. Dependent on the instantaneous engine speed during the blip this translates to about 720 °ca which is the length of one working cycle. As 45 % throttle opening already leads to the maximum cylinder charge at idle speed, this allows for a transient jump between idle air charge, full load air charge and back to idle air charge within three consecutive working cycles. This shorter and therefore more critical 70 ms blip will be used throughout all the following investigations.

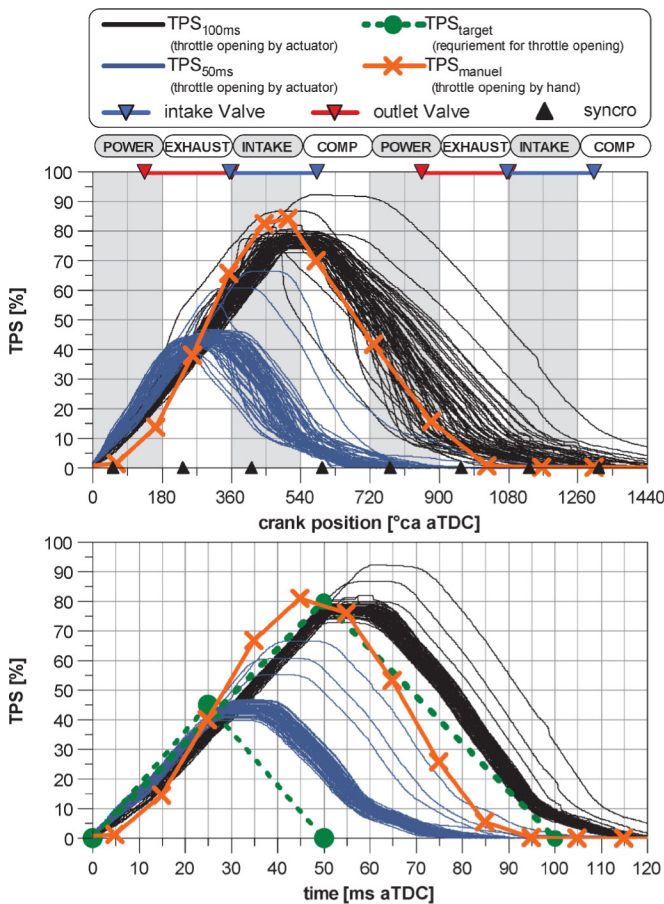


Figure 2. Definition of target blip for automation

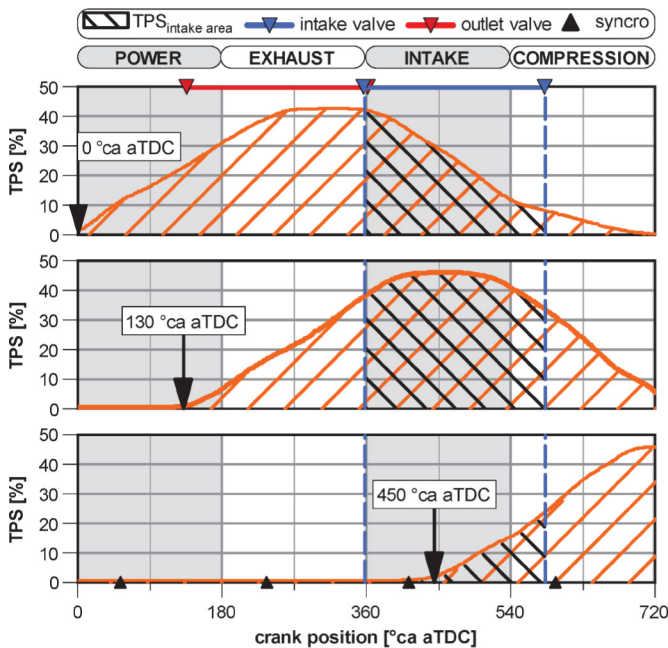


Figure 3. Definition of blip start position

Apart of the blip duration, the positioning of the blip within the working cycle is a main influencing factor. Therefore the blip start position is defined as shown in Figure 3. This value describes the distance between blip start and the firing top dead center of the working cycle in which the blip occurs. The throttle position profile is depicted over the crank position for three different blip start positions. Dependent on this position the influence of the throttle blip during the intake event is different.

Figure 4 illustrates the high engine speed dynamic which is induced by a sudden throttle blip. The blip start position in this case is exactly at firing top dead center. The lower part contains the throttle position as well as the high-resolution signal of the inductive crank sensor over time. This signal is used to calculate the instantaneous engine speed from every tooth on the trigger wheel which is given in the upper plot as well as a crank angle basis for all measured signals. The Average engine speed in idling is around 1700 rpm. During the compression stroke of the working cycle in which the blip takes place the high cylinder charge leads to a very strong decrease of the crank speed to values around 350 rpm afterwards the combustion accelerates the engine again to about 2800 rpm. In this case there is no stalling and the engine returns to idle speed because the throttle is already closed when the next intake stroke begins.

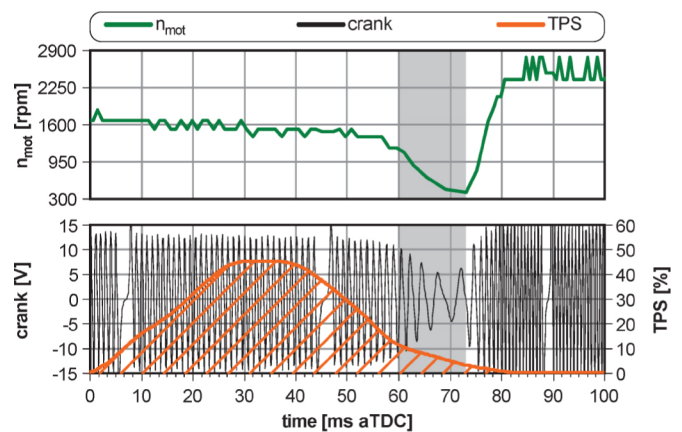


Figure 4. Example for regular engine speed behavior during throttle blip

Observed Stall Mechanisms

In order to detail out the mechanisms leading to a stalling of the engine first the definition of the numbering of the working cycles is discussed in Figure 5. The numbering always starts with the working cycle 1 (WC1) which is the one before the working cycle with the actual blip event. The working cycle with the blip is numbered as WC2. It is followed by the working cycle WC3 right after the blip start and in certain cases by an additional work cycle WC4. The figure displays a non-stalling throttle blip with a blip start position of 400°ca aTDC.