

# Alternative Engine Speed Sensing Using the Electric Signals of the Alternator

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## ABSTRACT

In the low-cost segment for 2-Wheelers legislative, economic and ecologic considerations necessitate a reduction of the emissions and further improvement in fuel consumption. To reach these targets, the commonly used carburetors are being replaced by engine management systems (EMS).

One option to provide these systems for acceptable and attractive system costs is to save a sensor device and to substitute its measure by an estimation value.

In many motorcycles the rotor of the vehicle's alternator is rigidly attached to the crankshaft. Therefore, the voltage and current signals of the alternator contain information about the engine's speed, which can be retrieved by evaluating these electric signals. After further processing of this information inside the electronic control unit (ECU), the absolute crankshaft position can be obtained.

A high-resolution speed signal without mechanical distortions like tooth errors is gained, whose signal quality equals the one of a common speed sensor. Hence, it can be used for the timing of injection and ignition and for calculations of more elaborate speed based control functions.

Because the existing alternator signals are used to determine the speed and no extra installations inside the crankcase are necessary, this method may ease the transition from carburetors to EMS.

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## INTRODUCTION

In order to reduce emissions and fuel consumption in the low-cost 2-Wheeler market the use of carburetors is replaced by engine management systems (EMS) with port fuel injection (PFI). At the same time diagnosis requirements from legislation will be challenging in the future e.g. for misfire detection. In order to fulfill these requirements, there is a need for cost-efficient control systems. One approach is to replace sensors by intelligent software solutions (virtual sensors) using the high-resolution information of a conventional engine speed sensor as described in [1], [2] and [3].

At many 2-Wheelers the alternator is rigidly attached to the crankshaft, so the phase voltage of the alternator contains the information of the high-resolution engine speed. This provides the opportunity to save the engine speed sensor and the trigger wheel by evaluation of the electric signals of the alternator. It also eases the transition from carburetor to EMS as no modifications of the crank case are necessary. To precisely extract the absolute crank angle position, new software algorithms are needed, which use the computational power provided by a new generation of engine control units (ECU).

In order to extract the engine speed signal out of the electric signals of the alternator, several challenges have to be solved. Firstly, the rectifier/regulator has to be modified in a way that the raw engine speed information can be provided to the ECU. Secondly, there is a need for algorithms in the ECU to detect the absolute crank position inside an engine revolution. This is necessary because there is no reference position mark comparable to the gap in the trigger wheel. Furthermore, a compensation for the dependency of the electrical phase angle regarding the generator load is needed.

Finally, the quality of the high-resolution engine speed signal out of the electric signals of the alternator is presented in this paper.

All considerations and measurements in the following chapters are exemplified at a 2-Wheeler with a 1-cylinder combustion engine and a permanent magnet synchronous alternator with three phases and six pole pairs, which is rigidly attached to the crankshaft. The series engine speed signal is gained by an inductive sensor and a trigger wheel with 36-2 increments. The increments have a distance of 10°CA and a gap of 2 increments to mark the engine's absolute position (e.g. a fixed angle to top dead center (TDC)).

## CONVENTIONAL ENGINE SPEED SENSING

The engine speed is one of the most important information in a modern, EMS-controlled vehicle. Using this information, basic operations like injection and ignition are timed and quantified. Evaluating a high-resolution engine speed information enables advanced EMS-functions, which perform an estimation of cylinders' air-charge or the air-fuel-ratio ( $\lambda$ ) and may substitute respective sensors (e.g. [1], [2]).

This high-resolution speed signal is usually obtained using a trigger wheel and an inductive sensor as illustrated in Figure 1. The trigger wheel is attached to the crankshaft and carries mechanic increments, which are equidistantly placed along the circumference. The sensor captures the passing of increments as they influence the magnetic flux through the sensor device.

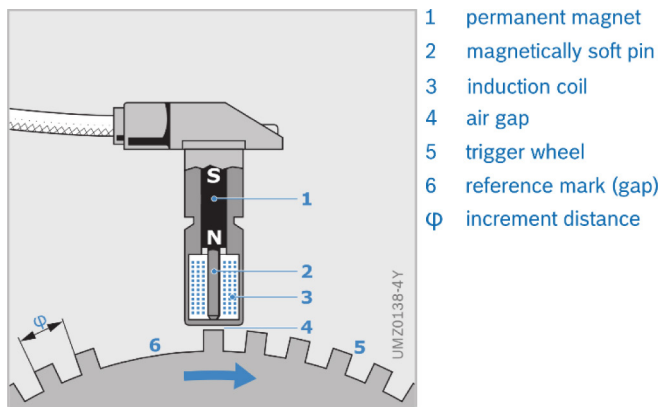


Figure 1. Setup for conventional engine speed sensing [4]

As an example, the increments of a trigger wheel are shown in Figure 2, as the trigger wheel and the alternator's rotor are commonly combined into one component for the relevant bikes.

## ALTERNATOR BASED ENGINE SPEED SENSING

### Generating the Engine Speed Signal

Every modern vehicle powered by a combustion engine uses an alternator to supply the battery and the board electronics with electric energy. This electric energy is necessary for the engine operation as it drives the fuel pump and injector, the ignition system and the controlling ECU.

An alternator is built up of a rotor, which generates a turning magnetic field, and a stator consisting of coils, which are flowed through by the magnetic flux and in which a voltage is induced. The rotor is driven by the rotation of the crankshaft, so its mechanic energy is transformed into electric one.

Many motorcycles use an alternator whose rotor is rigidly attached to the crankshaft, so the rotor of the bike's alternator performs precisely the same movement as the crankshaft does. In contrast to a common passenger car's alternator, there is no belt between crank and rotor, so there are no influences of belt-dynamics to be considered.

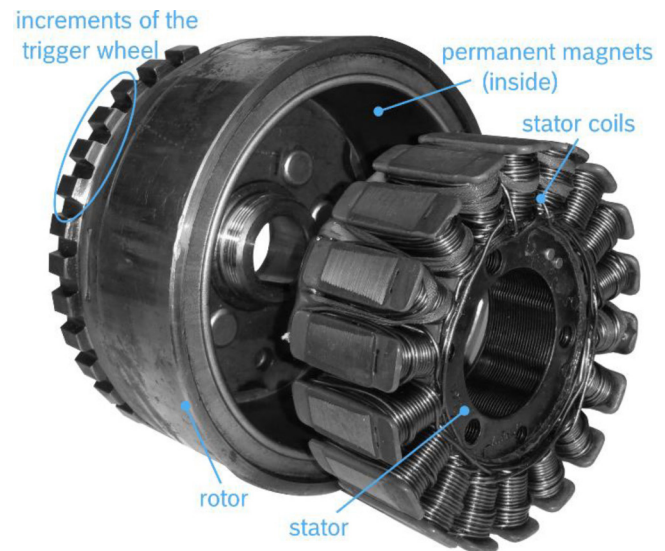


Figure 2. Setup of a 2-Wheeler's alternator

Figure 2 exemplifies the overall setup of a typical bike's alternator: the rotor surrounds the arrangement of the stator coils. These stator coils retain in their fixed positions, whereas the rotor rotates around them due to its fixation to the crankshaft.

There are permanent magnets situated inside the rotor, which create a magnetic field inside the stator's space. When the rotor is rotating, the magnetic field profile is rotating synchronously, and as it flows through the stator coils, a voltage is induced inside them according to Faraday's law of induction.

This law states that the induced voltage inside the coils is caused by the alternation of the magnetic flux flowing through them. As the flux alters synchronously with the rotor's movement around the stator, also the characteristics of the induced voltage change synchronously to the rotor's position, respectively the crankshaft's position, too.

Therefore, the electric signals of the alternator contain information about the engine's speed and the crank's position.

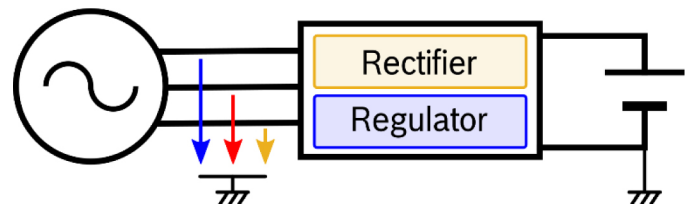


Figure 3. Measuring setup for alternator signals

This connection of crank position and alternator signals is illustrated by the measurement plots in Figure 4:

the upper plot shows the processed voltage signal of the standard inductive speed sensor. As mentioned before the increments are equidistantly placed in  $10^\circ\text{CA}$ , so the signal's periodicity marks a raster of  $10^\circ\text{CA}$ . This signal is used as a reference for the crankshaft angle.

In the lower plot, there are depicted the voltage signals of the three alternator phases recorded by the measuring setup in Figure 3. The alternator is connected to the vehicle's battery via the rectifier. Hence, the voltage is limited to the voltage range of the battery (0 ... 13V). Obviously, the voltage signals are synchronous to the reference signal of the crankshaft movement. This is illustrated by the rising edges of phase 1, which rise in a parallel way to the edges in the reference signal. As there are 6 magnets inside the rotor, the induction process in one coil repeats 6 times per crank revolution, and each phase performs a cycle with a periodicity of 60°CA.

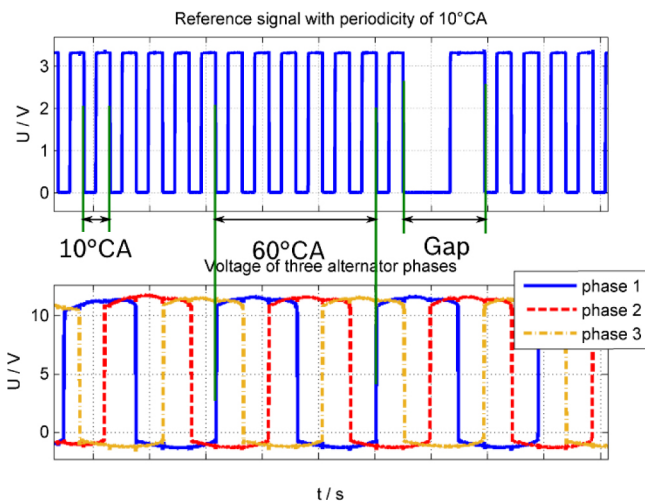


Figure 4. Measurement of trigger wheel sensor and alternator voltage

Therefore, the voltage signals and their attributes are periodic in the crank angle. In order to determine the engine speed, the time difference between 2 characteristics has to be measured. Appropriate characteristics are the phases' edges as they are steeply rising and falling and very suitable to define a discrete time event. Using a trigger circuit, this information can be transformed easily into a binary signal and be used for further evaluation in the ECU, schematically illustrated in Figure 5.

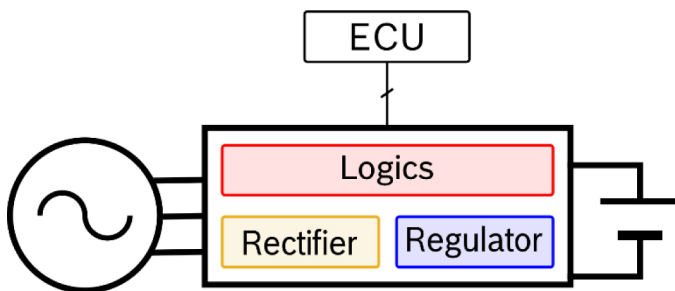


Figure 5. Wiring diagram for the evaluation of alternator based engine speed

Inside the ECU, the time lags between the edges are converted into the engine speed information. Because different characteristics and several phases are examined, the resulting speed signal is high-resolution regarding the crank angle.

### Synchronization to the Absolute Crank Position

For a correct timing of the ignition and the fuel injection the EMS necessitates information about the absolute crank position, e.g. regarding the TDC. In order to operate the combustion engine, the crank angle has to be known before the very first ignition.

In the conventional trigger wheel system, this information is provided by a singularity along the circumference of the trigger wheel. An extraordinarily wide gap between two increments is marking a reference crankshaft position (pictured in Figure 1).

In contrast to that the speed information obtained by the alternator signals does not contain any explicit characteristic to determine the absolute engine's position. It is rather perfectly periodic along the crank angle as Figure 4 illustrates.

In order to gain information about the absolute engine position, though, it has to be ensured that a characteristic of the alternator's signal occurs at a known crankshaft angle. This condition is achieved by an appropriate mounting of the rotor, so the magnets are in a known location regarding the engine's position.

As an example, Figure 6 shows the shape of the engine speed calculated by the alternator signals during engine start. The highlighted points belong to the speed information obtained by the rising edges of one single alternator phase. As the rotor has been mounted in a suitable way, one of these points refers to a reference crank position, in this example TDC.

Because each of the rotor's magnets induces a rising edge per engine revolution, in the reference phase there are numerous markers per crank turn, depending on the number of magnets. In this example the rotor contains 6 magnets, so there are 6 rising edges of the indicator phase per rotation and 12 edges per working cycle. Though one of these indicator points refers precisely to the reference crank position TDC, it is not clearly defined by itself, which of them is the reference marker.

To identify the correct reference crank position, the symptomatic shape of the engine speed over a complete working cycle has to be examined. For a 1-cylinder engine the 4 strokes of a working cycle are clearly divisible as they occur strictly consecutively. These strokes are visible in the shape of the engine speed, as the crankshaft decelerates during compression stroke and clearly re-accelerates in the expansion stroke. Because the position indicating edge is placed in the TDC, and the expansion is distinctively detectable by the sharp increase of the engine speed, the one reference point can be identified and the complete speed sensing can be synchronized to crank angle.

The surrounding markers are distanced by an angle of 360°CA/ number of pole pairs, in this example 60°CA, so there is a sufficiently long guard interval to avoid misdetection.

Having once found the reference edge, the present crank angle is obtained by counting the consecutive edges as they appear in known angular distances.