

Development of Electronic Control System for a Single Cylinder Motorcycle Engine

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ABSTRACT

In this paper, an Electronic Control System (ECS) is designed to manage a 125cc single cylinder air-cooled motorcycle engine. The aim of this study was to accomplish low cost, high reliability and mainly meet the motorcycle engine emission standard of China Stage III.

The intake port fuel injection mode was chosen with a redesigned part of intake pipe. Gathering information of speed, throttle position (TP), inlet temperature and pressure, cylinder temperature, switch-type exhaust gas oxygen sensor and the battery voltage, an Engine Control Unit (ECU) was devised to calculate fuel injecting pulse width, advance ignition angle and control the working conditions of the fuel pump and the exhaust gas oxygen sensor. Additionally, a three-way catalytic converter (TWC) was used to reduce exhaust gas emissions.

The basic fuel injection Table and ignition advance angles Table according to the speed-TP were calibrated accurately through bench test with consideration to engine performance, emission and AFR. Taking account of the cylinder temperature correction term, air pressure correction term, the inlet air temperature and pressure correction terms and the battery voltage term, the AFR in stationery on a feedback control constantly fluctuated around the stoichiometric ratio. In terms of transient AFR control, a nonlinear compensator based on the fueling dynamics parameters x and τ was designed and the x Table and τ Table were acquired through the method of pulse-changing the fuel injection rate and recording the AFR response. As for the fact that either x or τ varies among speed, TP and cylinder temperature, the final value of each other was calculated by timing the MAP-searching value and the cylinder temperature coefficient. For startup conditions, cold or hot, an approach by reducing the enriching fuel gradually rather than the nonlinear compensator was applied to ensure the success of start.

The following bench tests demonstrated that the fuel economy, exhaust gas emission and output torque under low-medial load conditions all showed great improvement while less than 5% decrease in maximum power compared to the original motorcycle engine equipped with a carburetor.

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INTRODUCTION

With increasing concerns on air pollution and smog, emissions regulations for motorcycles have become more and more stringent in China. Many high-cost motorcycles, often with a water-cooling system, have already been equipped with Electronic Control Systems including electronic fuel injection systems, three-way catalysts, and feedback control. These systems are often based on compatible improvement

from automobile control systems, which would not be applicable to most air-cooled motorcycles, especially small air-cooled motorcycles, due to the lower costs and simplicity. In order to meet increasingly strict emission standards, it is essential to develop a suitable electronic control system of lower cost, high reliability and enough accuracy for their great population around the world. More accurate control over the air/fuel ratio has become necessary. In addition to a

reduction of engine output emissions, precisely controlling the air/fuel ratio can also provide a significant improvement in fuel economy and performance.

OBJECTIVE

In order to meet the motorcycle engine emission standard of China Stage III, while maintaining performance characteristics, an electronic control system for a 125cc single cylinder air-cooled motorcycle engine, as described in Table 1, has been developed. The emissions targets were the China Stage III (Reference to EURO-3) emissions standards, as indicated in Table 2, based on the UDC (including 6 cycles on urban road conditions) test.

Table 1. Basic Parameters of the study engine

Displaced volume	125cc
Stroke	57 mm
Bore	49.5 mm
Compression ratio	10.2:1
Number of Valves	2
Exhaust Valve Open	30°
Exhaust Valve Close	0°
Inlet Valve Open	2.5°
Inlet Valve Close	20°
Normal rated Power	7.3kW / 8500r/min
Maximum Power	7.5kW / 8500r/min
Maximum Output Torque	9.0 N·m / 7000r/min

Table 2. China Stage III emission regulations for 125cc engine

Emissions	HC	CO	NO _x
units	g/km	g/km	g/km
limits	0.8	2.0	0.15
UDC: ECE R40 test cycle, sample from T=0 second			

INSTRUMENTATION AND ECS SETUP

This section describes the bench test instrumentation, the electronic control system setup and the installation of sensors.

Instrumentation

The motorcycles were installed on electric dynamo-meter. This low-inertia dynamo-meter offers the capability to simulate any load and speed condition during any steady-state and transient phase. The dynamo-meter is used for performance, steady-speed/ variable-load tests. Additionally, the dynamo-meter is equipped with a data acquisition system specifically designed for motorcycle development. In order to monitor the vehicle and engine characteristics continuously, the motorcycle was instrumented to record the following data:

- Engine Speed

- Output Torque and corrected output Torque
- Output Power and corrected output power
- Lubricating Oil Temperature
- upstream exhaust gas temperature
- SFC(specific fuel consumption)
- Cylinder Head Temperature
- Fuel Pressure
- Fuel Temperature
- Atmospheric Temperature
- Atmospheric Humidity
- Atmospheric Pressure
- A/F ratio using UEGO wide range O2 sensor
- The volume fractions of CO, HC, NO_x, CO₂, O₂ of the exhaust gas

It is vital to monitor and record the exhaust emission continuously all over the testing and calibration process. A small bypassing pipe was designed to lead the exhaust gas to the five-gas emissions bench. Through the data acquisition system, the emissions were recorded real-time at a rate of 1 Hz.

ECS Setup

The ECU should gather the data of speed, throttle position (TP), inlet temperature and pressure, cylinder temperature, switch-type exhaust gas oxygen sensor and the battery voltage to judge the engine work conditions and then compute and carry out the appropriate fuel injection and ignition. In order to calibrating the ECU effectively, additional data, such as close-loop correction efficiency, Transient fuel model parameters (Epsilon and Tau) and other correction factors, were needed. The whole data collected by the calibration system m could be described as:

- Crank Shaft Rotational Speed
- Manifold Pressure
- TPS position and change ratio of TP
- A/F ratio feedback from switch-type O2 sensor
- inlet temperature and pressure
- cylinder Temperature
- battery voltage
- close-loop correction factor
- Transient mode parameters(x and τ)
- fuel film thickness

- fuel injection pulse width
- Advanced ignition angle

Sensors and Actuator Installation

The motorcycle was originally equipped with a carburetor, therefore a new intake bend pipe was designed to install the fuel injector, inlet air pressure and temperature. The TWC was welded to the upper part, just behind of the installation of O2 Sensor, of the outlet pipe.

Speed and crank shaft phase sensor

Since a crank shaft phase sensor was not available in the original carburetor equipped motorcycle, the camshaft drive wheel was modified to generate crank shaft position signal. The combination of a 36-2 uniform convex banding on the outer circle of drive wheel and the original magnetic pickup sensor offers the best result. Two of the 36 convex teeth were milled to form 30 degrees interval spacing, following which the first tooth indicated TDC.

TPS and map sensor

TPS was installed on the throttle body assembly while the MAP sensor was placed on the redesigned part of intake pipe. The inlet pressure was used to correct the fuel injection process, since the fuel was supplied by a standard 300kPa fuel pump without return, and the inlet pressure fluctuation would affect the fuel injection mass flow rate. Measuring the inlet pressure accurately as a engine load signal in a single cylinder engine is challenging on account of the various pressure changes resulted, primarily, from intake valve events. In order to simplify the system structure as well as cost, the crankshaft speed-tp method was chosen to estimate the air intake amount, which also shows enough precision.

Cylinder temperature sensor

Not like a water-cooled engine, the air-cooled engine could acquire Cylinder Head Temperature rather than the cooling water temperature as a signal of the whole engine work temperature level. Cylinder Temperature was a vital factor on consideration of engine startup and transient mode parameters. Since the small air-cooled motorcycle engine is very tight, the ntc sensor was placed on the engine setting arm close to the intake port finally.

System integration

As above, the whole ECS could be described as [Figure 1](#).

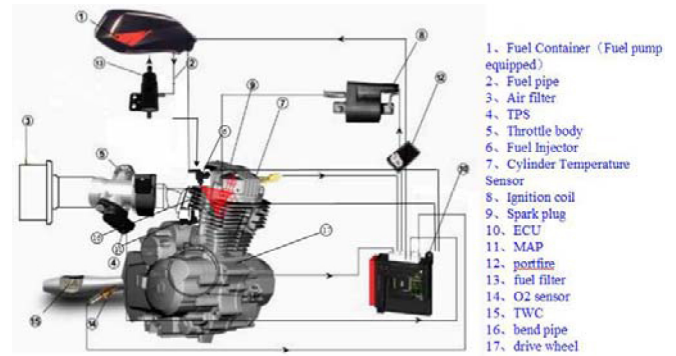


Figure 1. ECS Integration

CONTROL STRATEGIES AND CALIBRATION

This section demonstrates the calibration systems setup and the calibration process of the ECS.

Initial calibration focused on cold-starting procedures and base tables adjustment. In order to improve the cold-start characteristics, while avoiding any additional air assistance, the base fuel injection pulse width table, ignition timing, and cylinder temperature correction tables were adjusted to provide more fuel and optimum spark during cranking. Once the engine had satisfactory cold start behavior, the focus shifted to overall ECU calibration to meet the original targets. Initial values for the base calibration tables were entered in order to achieve a satisfactory engine performance over the entire operating range.

Startup Calibration

The aim of startup calibration was to improve startup characteristics, especially cold-startup, as well as exhaust gas emission. Much thick air-fuel mixture was need to ensure the success of startup and after startup, it was important to make the TWC work effectively as soon as possible, since the HC emission during startup accounts for the main part, perhaps 2/3, of the whole HC emission during a test of procedure.

A compensator based on the transient mode parameters x and τ was applicable theoretically, but it was challenging to calibrate the parameters x and τ for cold startup conditions, which limited its actual usage. Therefore, an approach by decreasing the enriching fuel part gradually according to the number of engine working cycles was applied, while the original enrichment of fuel was calculated in accordance with Cylinder Temperature from a single-dimension Startup enrichment Table. And the mainly work of startup calibration was to adjust these values. [Figure 2](#) illustrates the adjusted results.