Engine Idle Speed and Coolant Temperature Simulation and Diagnosis System Design

Chih-Hai Fan* and Jen-Chain Shu
Department of Mechanical Engineering, Chung Hua University
No. 707, Sec 2, Wufu Road, Hsin Chu, Taiwan 30012
*Email: fan@chu.edu.tw

Abstract. Engine idle speed is important for engine diagnosis. For different engine temperatures, the corresponding idle speeds are dissimilar. The relationships of idle speed and engine (or coolant) temperature for Mitsubishi 4G9 engine is studied, so that it can be used for engine diagnosis system development. The established hardware system can interface with the signals from engine under test, so it is useful for engine performance evaluation. A software program based on LabVIEW is developed, such that the engine testing becomes easy. The temperature obtained from either real engine coolant and the simulation system are applied for comparison, so the system model is confirmed to replace the real engine. The whole system can be used as a platform for engine analysis and diagnosis.

Keyword: engine idle speed control, coolant temperature, engine diagnosis

1. Introduction

The idle speed is the minimum operating speed (generally measured in revolutions per minute, or rpm, of the crankshaft) of a combustion engine. At idle speed, the engine can generate sufficient power to run smoothly and operate its ancillaries (water pump, alternator, and, if equipped, other accessories such as power steering), but it usually cannot deliver useful work to move the automobile. For a passenger-car engine, the idle speed is usually between 600 rpm and 1,000 rpm.[1-2]

If the engine is incorporated with a large number of accessories, particularly with air conditioners, the idle speed must be raised to make the engine generate enough power to run smoothly and operate the accessories. Most air conditioning-equipped engines have automatic adjustment feature [3-6] in the carburetor or fuel injection system to raise the idle speed.

The Idle Speed Control (ISC) system regulates engine idle speed by adjusting the volume of air through throttle valve. The Electric Control Unit (ECU) controls the idle speed control valve based on the signals of various sensors.

Every engine has its proper range of idle speed for fuel economy and emissions concerns. The correct idle speed changes when the temperature of engine (or coolant) changes. Therefore, the relationship between idle speed and coolant temperature is significant. If the engine is in bad conditions, the technician can diagnose the engine by using the specific equipment from automobile manufacturers. However, each instrument has limited functions and can be applied to only one particular type of engine. Therefore, a unified diagnostic system for various types of engine is needed.

2. System Configurations

The engine injection system in Figure 1 includes the following equipments: a personal computer, a data acquisition card, three multi-functional cards, a signal
interface card, as well as a 4G9 engine.

2.1 4G9 Engine

This is a gasoline engine with a four-cylinders and four-strokes. It is connected with an air inlet system, a fuel injection system and an electric control unit (ECU). The air inlet system has the following parts: filter, flow meter, regulating valve, inlet channel, inlet valve and combustion chamber. The fuel injection system contains oil tank, pump, gasoline filter, pressure regulator, nozzle, and combustion chamber. The engine operations, such as fuel injection, ignition as well as idle speed, are controlled by ECU.

2.1.1 Electric Control Unit (ECU)

More and more electronic devices are applied in the automobiles. The ECU can control the fuel injection system, air inlet system, air condition system, safety system, and etc.

2.1.2 Idle Speed Controller

In order to reduce the gasoline consumption, the engine operates at the idle speed when the car stops for a little while. The idle speed control is to keep the engine rotating under various engine conditions. The idle speed control need accomplish the following tasks:
1. The engine power at idle speed can overcome the friction force of mechanical parts.
2. When the power steering, the air conditioner, and electric devices are used, more air is sent into engine to elevate the idle speed, thus more electricity should be delivered from the generator.
3. The data of ideal idle speed are reserved in ECU.
4. ECU compares the information from sensors, stores data and sends commands to the idle speed controller.

The functional block diagram of idle speed controller is shown in Figure 2. The idle speed controller for LANCER 4G9 engine uses a stepping motor to control the valve (Figure 3.) for air flow control.

![Figure 1. The structure of engine injection system.](image1)

![Figure 2. The functional block diagram of idle speed controller.](image2)
2.1.3 Engine Air Flow Meter

Karman Vortex Flow Meter employs the following principle for measurement of flows. When a columnar object (object that generates vortices) is placed in the flow path of fluid, regular channels of vortices, called Karman vortex channels, are generated at the rear part of the object. Since the frequency of a vortex generated is linearly proportional to the flow velocity within a given range, the amount of flow can be obtained by counting the number of vortices. When the frequency of each vortex generated is detected by the incorporated vortex detector, the signal processing circuit would output a signal which is linearly proportional to air volume flow.

The relationship of vortex frequency $f$ and the air velocity $V$ is

$$ f = S_f \frac{V}{d}$$  \hspace{1cm} (1)

where

d: vortex dimension,
$S_f$: Strouhal constant.

The Reynold number is defined as:

$$ R_e = \frac{V \cdot d}{\nu}$$  \hspace{1cm} (2)

and air flow ($Q$) is described as:

$$ Q = C_1 \cdot A \cdot f$$  \hspace{1cm} (3)

where $C_1$ is a constant, and $A$ is the area of air flow channel in Karman vortex sensor.

The time for fuel injection (T$p$) is

$$ T_p = \frac{Q/N}{K_i \cdot (A/F)}$$  \hspace{1cm} (4)

$Q$: the air flow quantity per unit time,
$N$: the number of engine revolutions per second (revolution/sec),
$Q/N$: gas quantity for one revolution of engine,
$A/F$: the specified mole ratio of air to fuel present during combustion,
$K_i$: constant depending on nozzle injection style method and the number of cylinders.

By substituting Equation (3) into Equation (4) the injection time is

$$ T_p = \frac{C}{K_i \cdot (A/F)} \cdot \frac{f}{N}$$  \hspace{1cm} (5)

with $C = C_1 \cdot A$.

The air density is affected by temperature and pressure, so the injection time need to be corrected.

The normal air mass flow rate is defined as the absolute pressure of 101 kPa (1 bar), and the temperature of 293.15 K (20 °C) is represented as $G_s$. The air mass flow rate related to the pressure and temperature is given as $G$. Their relation is

$$ \frac{G}{G_s} = \frac{\rho \cdot Q}{\rho_s \cdot Q}$$  \hspace{1cm} (6)

where

$Q$: air flow rate $\text{m}^3$/s,
$\rho$: air density,
$\rho_s$: air density at normal condition.

Substitute Eq. (3) into Eq. (6), then Eq. (7) is obtained as:

$$ \frac{G}{G_s} = \frac{\rho}{\rho_s}$$  \hspace{1cm} (7)

The ideal gas equation is

$$ \rho = g \cdot P/R \cdot T$$

then
\[
\frac{G}{G_s} = \frac{T}{T_s} \cdot \frac{P}{P_s}
\]

where \( T_s \) and \( P_s \) are at normal condition and \( T \) and \( P \) are at arbitrary condition. The corrected terms are

\[
\frac{T}{T_s} = \frac{273 + 20}{T}
\]

\[
\frac{P}{P_s} = \frac{P}{101}
\]

The injection time is then modified as

\[
T_p = K \cdot \frac{f}{N} \cdot \frac{273 + 20}{T} \cdot \frac{P}{101}
\]

where

\[
K = \frac{C}{K_1 \cdot (A/F)}
\]

2.2.1 Data Acquisition (DAQ) Card

The PCI-6024E multi-function I/O card (Figure. 4) of NI company is used as the DAQ card.

2.2.2 Multi-function Card

In order to demonstrate various functions of the system, three multi-function cards are used. The first one is related to the following signals: oil pump relay, engine control relay, ignition signal, temperature sensor and pressure sensor. The second card is the interface of the following signals: idle speed valve, regular sensor, water temperature sensor, car speed sensor, generator voltage, ignition coil, crank axis position, cam position sensor, engine control relay, air pressure sensor and idle speed valve. The third card is connected with stepping motor and ignition.

3. Experiment System Design

3.1 Hardware design

In order to obtain the engine state signals and transmit the signals to engine, ECU and LabVIEW program, the system testing installation includes: a data acquisition (DAQ) card, three multi-function cards and a signal transition card, and is shown in Figure 5.

The signal flow graph of the engine testing system is shown in Figure 6. In order to translate the signals easily, three multi-function cards are connected to ECU, and then transmit the information to the personal computer, depending on which test is executed.

3.2 Software design

To speed up the test, a simulation system for test is established in Figure. 7 by using LabVIEW.
For example, if the temperature of engine coolant is assigned to the computer interface (Figure 8), and then sent to ECU. Subsequently, ECU can send out commands to control the air flow and gasoline injection time, and then the simulation system can find the idle speed by using the voltage of temperature sensor of engine coolant.

4. Experiment Results

Firstly, the temperature simulator sends a value of coolant temperature to ECU. The idle speed is then calculated by the operating system. The temperature value begins at 0°C and then increases 20°C degrees for each step. The results of idle speed are shown from Figure. 9. - Figure.13.
By using Mathematica software package one can analyze the test data, the relationship for engine temperature and engine idle speed is shown in Figure 14.

The curve fitting result is obtained as following:

\[ f(T) = 1198 - 40705T + 0.606458T^2 - 0.0170937T^3 + 0.000130729T^4 - 20.3125 \times 10^7T^5 \]  

(12)

where \( T \) is engine temperature and \( f(T) \) is engine idle speed (RPM).

For the second part, the true engine is applied in the experiment. The temperature of engine coolant is set at 24°C when the engine starts to operate, and it is continuously increased to 80°C. The results are shown in Figure 15.

Finally, for each assigned coolant temperature, the real idle speed and the simulated results are listed in Table 1 for comparison.

Owing to the actual coolant temperature range limitation, only three different temperature results are compared in Table 1. The allowable deviation value is 50 RPM from automobile manufacture handbook. The results show the errors are below two percents. Thus, the developed methodology and system can replace the real engine for testing.
Table 1. The comparison of real idle speed and the simulated results for each assigned temperature.

<table>
<thead>
<tr>
<th>Coolant Temperature</th>
<th>40°C</th>
<th>60°C</th>
<th>80°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average idle speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average idle speed of real coolant temperature (RPM)</td>
<td>1176</td>
<td>935</td>
<td>753</td>
</tr>
<tr>
<td>Average idle speed of simulated coolant temperature (RPM)</td>
<td>1200</td>
<td>943</td>
<td>738</td>
</tr>
<tr>
<td>Error (RPM)</td>
<td>24</td>
<td>8</td>
<td>15</td>
</tr>
</tbody>
</table>

5. Conclusions

1. The relationship of engine idle speed and coolant temperature is obtained by the proposed methodology and system. The idle speed by using a simulated temperature can get acceptable results, so the simulated system can replace the real engine.

2. When the engine temperature is higher, the engine can generate more power so the engine idle speed is lower.

3. The established system can be used to identify the engine characteristics under various parameters operation conditions.

4. The software based on LabVIEW can easily and quickly find the relationship of engine idle speed and coolant temperature without using the real one, as long as some parameters of the engine is known. Therefore, the system can be used as a tool for engine diagnosis.

5. The entire system can be used as a platform to develop the diagnostic software for various purposes.

6. Reference


