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Satoru Watanabe, Masamichi Imamura, and Naoki Tomisawa
Japan Electronic Control Systems Co., Ltd.

Hai-jio Guo, Mitsuo Satoh, and Hiroshi Takeda
Tohoku Univ.

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1. Abstract

Control of internal combustion engines depends on reduced idle speed and stabilized idling to improve fuel consumption.. Using a valve (ISC/V) to adjust air intake at idling, various idle speed control techniques have been proposed to improve response to variations in the target idle speed due to disturbance and to enhance speed control stability.

Many conventional idle speed control systems utilize P and I control. They cannot compensate for the phase difference caused by the intake air volume between the throttle and intake valves. This leads to poor response to variations in the target idle speed and unsatisfactory control accuracy, that is, problems in preventing engine stalling and maintaining idle speed stability.

To solve these problems, an idle speed control system based on fuzzy control[(1)*] theory is proposed. However, it is impossible to determine the control constant (membership function) theoretically. This must be determined on an experimental basis and it is very labor-intensive.

This paper describes a control system with the following features:

(1) As idle speed control using engine torque signals offers an effective response to disturbance, a model was prepared that provides the desired control characteristics of both engine speed and torque.

(2) A feedback control system with rapid following to model output was built.

(3) Phase difference caused by intake air volume is compensated.
The model following idle speed control system with these features was installed on an engine control unit and its evaluated performance was far superior to conventional control systems.

2. Objectives of Idle Speed Control

Idle speed control recovers and stabilizes the actual engine speed reduced by load variations due to known and unknown disturbances to the target speed.

One method provides extra intake air and fuel to generate the torque required for the given load and to control ignition timing. This method is unfavorable because fuel cost regulations are expected to be stricter in the future, and fuel consumption deteriorates when idling with this method. For this reason, we selected a method that reduces intake air as much as possible and controls air intake to generate the required torque.

3. Objectives of Auxiliary Air Control

Figure 1 shows a typical intake system which is controlled electronically.

The opening of the air passage that bypasses the throttle valve is controlled for variations in engine speed. However, the size of the intake system extending from the throttle valve to the intake valve is far greater than the volume of bypass air. This makes response to load changes slow and increases variations in engine speed. The method we now use is designed to control air intake by the difference between the target idle speed and actual engine speed. The situation is further aggravated by the engine speed changing energy or the delay in the transmission system, that is, the torque-speed converter.

To solve these problems, we studied how to compensate for the delay in the intake system and to estimate actual torque.

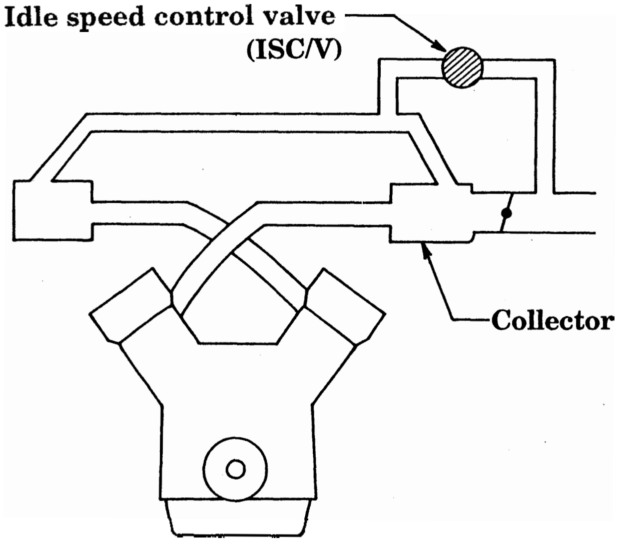

Fig. 1 Typical Intake System

4. Compensation for Intake System Delay

Figure 2 shows a model of a simple intake system.

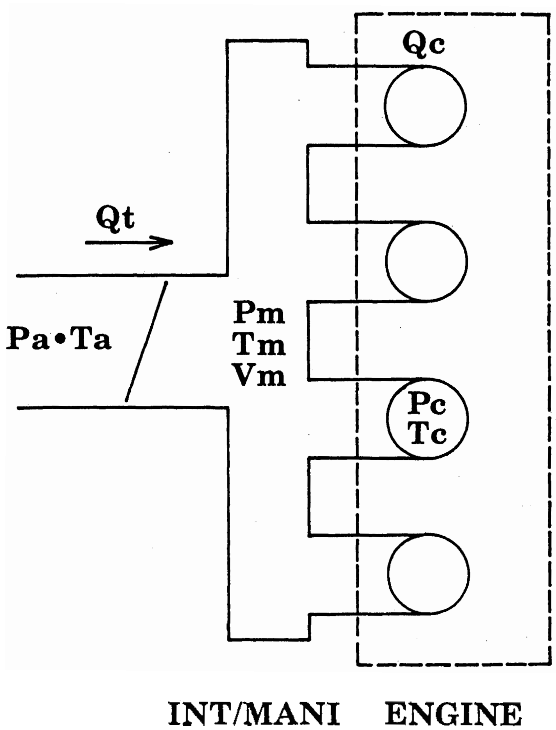

Fig. 2 A Simple Intake System

To compensate for the delay in the intake system, we need only compensate[2] for the delay in the collector filling which has the largest size in the intake system. The volume of air passing through an intake value Q is shown by equation 1.

$$Qt = Qc + p \bullet Vm \bullet \Delta(Pm/Tm)/\Delta t \quad \text{.......... (1)}$$

where p: air density.

Assuming that the change in pressure and temperature in the collector is the same as that immediately before the intake valve, we obtain the following equation:

$$\Delta(Pm/Tm) = \Delta(Pc/Tc) = \Delta('Qc/(Vc \bullet p \bullet \varepsilon)) \quad \text{.......... (2)}$$

where ε: ratio of fresh air.

From equations 1 and 2, we obtain:

$$Qt = Qc + Vm \bullet \Delta(Qc/(Vc \bullet \varepsilon))/\Delta t$$
$$= Qc + Vm \bullet (Qc - Qc_{-1})/(Vc \bullet \varepsilon \bullet \Delta t) \quad \text{.......... (3)}$$

where *Ne*: engine speed,
η: filling efficiency

Total volume of intake air in the cylinder is given by equation 4.

$$Qc = Vc \bullet Ne \bullet p \bullet \eta \quad \text{.......... (4)}$$

where Ne: engine speed,
η: filling efficiency

Equations 3 and 4 lead us to:

$$Qt = Ne \bullet p \bullet (Ve \bullet \eta + Vm \bullet (\eta - \eta_{-1}/(\varepsilon \bullet \Delta t)) \quad \text{.......... (5)}$$

Compensation for delay in the collector filling is determined by equation 5, so we need only to introduce the result in the control system.

5. Torque Estimating Method

Torque generated in a normal operating engine is determined by total inertia moment I, coefficient of viscosity of engine C, and pumping loss Tpump, and is given by equation 6.

$$Torque = I\dot{\omega} + C\omega + Tpump \quad \text{.......... (6)}$$

Pumping loss is determined uniquely by the piston displacement of an engine, and hence may be omitted when considering a feedback control system.

$$Torque = I\dot{\omega} + C\omega \quad \text{.......... (7)}$$

Target torque Tset at no-load is given by equation 8.

$$Tset = C\omega set - k \quad \text{.......... (8)}$$

where ωset: target speed,
k: load torque.

Torque = Tset must be satisfied if actual torque is to coincide with the target torque. From equations 7 and 8, we obtain

$$K = -I\dot{\omega} + C(\omega set - \omega) \quad \text{.......... (9)}$$

This means that torque can be estimated using an engine's angular velocity and angular acceleration.

6. Seletion of Control System

Conventional idle speed controls use classical control formats such as PID control shown in Figure 3. However, since engine characteristics are non-linear and include secondary delay, it is necessary to assign PID control constants to each condition for various types of disturbance. This requires a huge amount of time and skill for proper vehicle fitting.

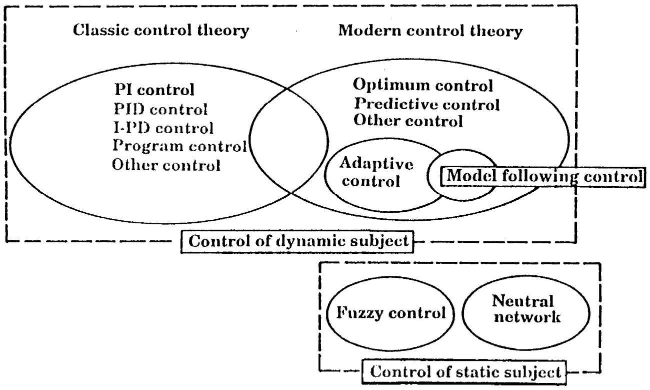

Fig. 3 Position of Model Following Control in Control Theory

Since the characteristics of the control subject can be clearly expressed by modeling the delay of the collector filling and estimating the torque required for an engine, we studied application of modern control theory using these characteristics.

MRACS, which has a reference model and an application system for the model, is considered the most suitable control because of its adaptability and ability to withstand environmental changes. But, MRACS requires complex algorithms and is difficult to mount on an actual engine control unit. For these reasons, we decided to adopt model following control that compensates for errors in the model by integral element.

7. Application of Model Following Control

The outline of model following control is shown in Figure 4.

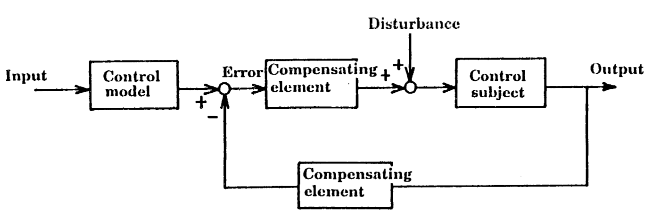

Fig. 4 Concept of Model Following Control

Inputs are made to a control model with the same characteristics as the control subject. Outputs from both controller and control subject are detected and the difference compared to perform necessary compensation. Outputs of the control subject always follow those of the control model. Figures 5 and 6 show block diagrams of idle speed control that uses model following control.

Target speed is input as a control input to the engine model. The torque and speed of the model and those of the actual engine are compared. Torque error calculated from the comparison is compensated by load and no-load torque estimating circuits and an integrator followed by compensation of delay in the collector filling using a collector model.

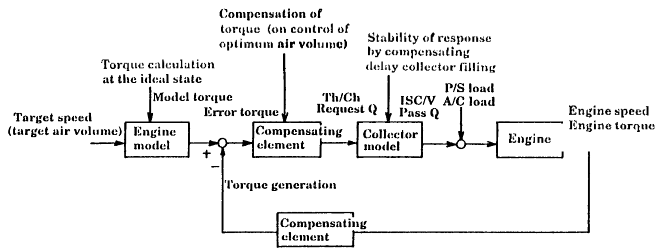

Fig. 5 Application to Idle Speed Control

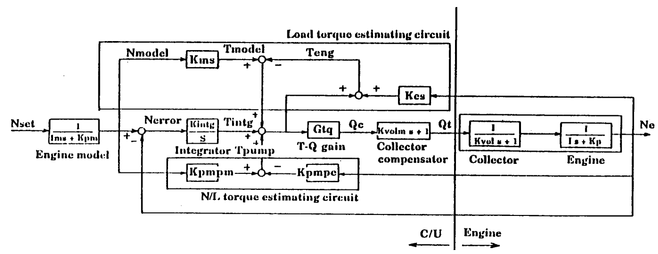

Fig. 6 Idle Speed Control Block Diagram

The load torque estimating circuit cancels the angular velocity of rotation caused by load torque and maintains constant speed as shown in Figure 7. The no-load torque estimating circuit and the integrator cancel the rotational deviation from the target and converge the speed to the target speed as shown in Figure 8.

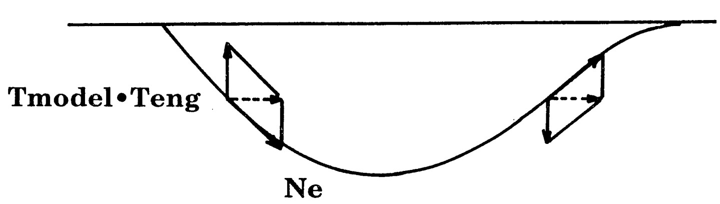

Fig. 7 Load torque estimating circuit

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