Modeling and Control of Methanol Engine Speed with GT-Power and Simulink

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Abstract. With a 4-cylinder methanol engine as the research object, GT-Power was used to build a one-dimensional simulation model for the methanol engine and verify its accuracy. The PID and fuzzy PID control models were built based on MATLAB/Simulink, and the methanol engine model was coupled with the control models. The speed control effects of the methanol engine under different control strategies were compared and analyzed. The results showed that traditional PID control method could meet the control requirements under a singular load, but the overshoot of the engine speed step response curve under fuzzy PID control was decreased by about 12\% compared with traditional PID controls methods, also showing significantly lower speed fluctuations. When the working conditions of the engine changed, the fuzzy PID control method had better engine speed control performance than the traditional PID control method.

1. Introduction

A generator is a device that converts other forms of energy into electrical energy, and an engine is the most common source of power for the generator. At present, the diesel engines and gasoline engines are used as the prime movers for the most of the engine-generator sets, but all of them seem to have problems in terms of resource reserve and emission [1]. Methanol is a type of fuel with a wide range of sources that can be produced from a variety of carbon-containing resources, including various fossil resources and biomass [2]. Methanol, which can be easily prepared and is cheap, is economically feasible as an alternative fuel [3]. Burning methanol can also improve engine thermal efficiency and reduce the equivalent fuel consumption [4]. Methanol fuel has many advantages, so alcohol-based oxygenated fuel, as represented by methanol, is an alternative fuel with great development potential [5].

Frequency is a key factor influencing power supply quality of the generator. Frequency control is achieved when the power frequency of the generator is controlled within a certain range, which is actually the engine speed control in essence. In 2006, Qi Weiquan studied the control of engine rotate speed of hybrid electric vehicle based on the PID control [6]. Methanol engine is a new type of engine, and the research on rotational speed control of methanol engine is of great value for the application of the methanol generator [7]. However, there are few studies on the control of engine rotate speed of methanol engine. In view of this, methanol engine speed control would be studied in this paper.
2. Methanol Engine Modeling and Model Validation
A 4-cylinder 1.3T methanol engine control model was built based on GT-Power. The main parameters are as shown in Table 1.

| Engine displacement / mL | Piston stroke / mm | Normal idle speed / (r/min) | Compression ratio | Cylinder bore / mm |
|-------------------------|--------------------|-----------------------------|-------------------|-------------------|
| 1299                    | 73.5               | 750                         | 9.5               | 75                |

The methanol engine model was built based on GT-Power, as shown in Figure 1.

![Methanol engine model](image1)

**Figure 1.** Methanol engine model

The engine fuel system was designed to be the port fuel injection type that accepts methanol as the fuel. In GT-Power, the throttle flow coefficient acted as an important parameter for evaluating the airway and valve fluid flow [8]. The data measured by an experiment bench were entered into the throttle model. The variations of the throttle airway flow coefficient with the opening angle of the throttle were entered, and the curve was fitted according to the corresponding data, as shown in Figure 2.

![Throttle airway flow coefficient-opening curve](image2)

**Figure 2.** Throttle airway flow coefficient-opening curve
The formula for calculating the Gas flow coefficient are:

\[ m = A_{eff} \rho_{is} U_{is} = C_p A_r \rho_{is} U_{is} \]  

\[ \rho_{is} = \rho_0 \left( \frac{P_r}{P_t} \right)^{\frac{1}{\gamma}} \]  

\[ U_{is} = \sqrt{RT_0 \left( \frac{2\gamma}{\gamma - 1} \left[ 1 - \left( \frac{P_r}{P_t} \right)^{\frac{\gamma - 1}{\gamma}} \right] \right)^{\frac{1}{2}}} \]  

Where: \( m \) is the mass flow rate, in kg/s; \( A_{eff} \) is the effective flow rate, in \( \text{mm}^2 \); \( \rho_{is} \) is the density at throat, in \( \text{kg/m}^3 \); \( U_{is} \) is the isentropic speed at throat, in m/s; \( C_p \) is the flow coefficient, a dimensionless quantity; \( A_r \) is the reference area, in \( \text{mm}^2 \); \( P_r \) is the absolute pressure ratio (outlet static pressure/total inlet pressure), a dimensionless quantity; \( R \) is the gas constant, in 8.314J/(mol*K); \( T_0 \) is the upstream stagnation temperature, in K; \( \gamma \) is the specific heat ratio (1.4 at 300K).

The engine speed was controlled based on the throttle opening. Therefore, the consistency between the simulation results with the experimental data could be verified under the same speed but different throttle opening. The engine speed was 4000r/min during verification. The comparison results between engine torque calculated under different throttle opening, and the original experimental data are shown in Figure 3.

![Graph showing experimental and simulative torques](image)

***Figure 3.*** Methanol engine model validation

It could be seen from Figure 3 that, the simulation results were consistent with experimental data under various working conditions, and the errors were less than 5% (namely allowable error for engineering calculation). The maximum error value was 2.91% when the throttle opening was 27°, so an accurate engine simulation model had been built and could be used for speed control simulation.

### 3. Control modeling

In this paper, the engine speed was controlled based on the throttle opening, and the control strategy model was built based on MATLAB/Simulink. The corresponding control strategy was established, as shown in Figure 4. The speed sensor transmitted an engine speed signal to the Simulink control model,
and the Simulink control model output the required throttle flow coefficient after the calculation. The throttle opening signal was transmitted to the engine for speed control.

![Figure 4. Methanol engine control strategy](image)

Traditional PID control law [9]:

\[
u(t) = K_p[error(t)] + \frac{1}{T_i} \int error(t) dt + \frac{T_d}{T_i} \frac{derror(t)}{dt}
\]  

(4)

Where: \( K_p \) is the proportion coefficient; \( \frac{1}{T_i} \) is the integral time constant; \( \frac{T_d}{T_i} \) is the differential regulation coefficient.

The PID control model was built in Simulink, as shown in Figure 5. The initial engine speed was set at 4000r/min and the target speed was set at 3500r/min. The simulation time was set at 6s and the step size was set at 0.1s. The actuator was an imported GT-power methanol engine model.

![Figure 5. A traditional PID control model](image)

In this paper, a one-dimensional self-regulating fuzzy PID [10] was designed to compare the control effects with those of traditional PID. A fuzzy domain for speed deviations was set at [-1000, 1000], and the fuzzification was divided into 3 levels. The fuzzy domain of the output parameter P was set at [0.00045, 0.0005], and the fuzzification was divided into 2 levels. The fuzzy domain of the output parameter I was set at [0.0002, 0.0005]. The corresponding fuzzy rules were established according to the control ideas where a large deviation corresponded to a large output P, while a small deviation corresponded to a small output P. A fuzzy PID control model was built in Simulink, as shown in Figure 6.
4. Result Analysis and Discussion
In terms of the PID control effects, the control effects of P regulation, PI regulation, and PID regulation were compared and simulated, as shown in Figure 6. The results showed that the response curve for independent P regulation had very small deviations, and the steady-state error of about 60 r/min existed, so the control objectives were not achieved. According to the response curve for PI regulation, the overshoot was increased to 200 r/min and speed oscillation existed. However, the errors were eliminated, and the control objectives were achieved. According to the response curve for PID regulation, the overshoot was decreased by 28% compared to PI regulation, and the oscillation for PI regulation was eliminated. The test found that, under the working condition of sharp decrease from 4000 r/min to 3000 r/min, better regulation effects were achieved when the parameter was set at $K_p=0.0005$, $K_i=0.0003$, $K_d=0.0001$.

Under the working condition of sharp decrease from 4000 r/min to 3500 r/min, better regulatory effects were achieved when the parameter was set at $K_p=0.0005$, $K_i=0.0005$, $K_d=0.0001$. In order to simulate the adaptation of the traditional PID to different working conditions, $K_p=0.0005$, $K_i=0.0005$ were applied under the working condition of sharp decrease from 4000 r/min to 3000 r/min. The control effects are shown in Figure 8. The results showed that, when the PID parameters for the control effects under the working condition of sharp decrease from 4000 r/min to 3500 r/min were applied into the working condition of sharp decrease from 4000 r/min to 3000 r/min, a large overshoot and oscillation occurred, and the control effects were relatively poor.
The target speed: 3000 r/min

The target speed: 3500 r/min

Figure 8. The engine speed response curve for traditional PID under different working conditions

The fuzzy control model was applied into the working conditions of sharp decrease from 4000 r/min to 3500 r/min and from 4000 r/min to 3000 r/min, and its control effects were compared with those based on the traditional PID parameter, and the parameter was set to $k_p=0.0005$, $k_i=0.0005$. The comparison of the control effects of the two control methods under the working condition of sharp decrease to 3000 r/min and 3500 r/min are shown in Figure 9 and Figure 10 respectively.

Figure 9. Effect comparison of two control methods under working conditions of sharp decrease from 4000 r/min to 3000 r/min

Figure 10. Effect comparison of two control methods under working conditions of sharp decrease from 4000 r/min to 3500 r/min
It could be seen from Figure 9 that, under the working condition of sharp decrease from 4000r/min to 3000r/min, the overshoot of fuzzy PID control was decreased by 11% compared with traditional PID control, and the oscillation was eliminated. Besides, the stability was maintained 1.5s ahead of time. It could be seen from Figure 10 that, under the working condition of sharp decrease from 4000r/min to 3500r/min, the overshoot of the fuzzy PID control was decreased by 12% compared with the traditional PID control, and the oscillation was eliminated. The results showed that, fuzzy control could be better applied into speed control under various working conditions of the engine compared to the traditional PID control.

5. Conclusion
In this paper, a joint simulation environment involving GT-power and MATLAB/Simulink was created, and methanol engine speed control was studied by controlling the throttle.

1. An accurate engine simulation model had been built and could be used for speed control simulation.
2. The steady-state error of about 60 r/min existed in the response under P regulation by comparing different PID control effects. The response overshoot for PI adjustment was increased to 200r/min, and speed oscillation occurred, but the steady-state error was eliminated. According to the response curve for PID regulation, the overshoot was decreased by 28% compared to the response curve for PI regulation, and other deficiencies of PI regulation were made up for.
3. By comparing the fuzzy PID control and the traditional PID control, the overshoot of fuzzy PID control was decreased by about 12% compared to that of traditional PID control, and the stability was maintained 1.5s ahead of time. When the working conditions of the engine changed, fuzzy PID control had better engine speed control effects than traditional PID control.

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