Experimental Study on Static Characteristics of Turbocharged Internal Combustion Engine with Low CBM Components

Guoqi Lu’ and Suxia Ma
School of Electrical and Power Engineering, Taiyuan University of Technology, Taiyuan 030024, China
*Corresponding author e-mail: 240386740qq.com

Abstract. In order to improve the operation efficiency of internal combustion engine, the static relationship between the concentration and flow rate of coalbed methane and the operation parameters of internal combustion engine was studied. Based on the experiments, the effects of CBM component concentration and gas flow rate on air-fuel ratio, exhaust gas temperature, exhaust gas flow rate and compressor outlet pressure are summarized. It provides a certain technical support for the optimization control of internal combustion engine to change gas flow rate to adapt to the change of coal-bed methane composition.

Keywords: Turbocharged engine, Air-fuel ratio, Smoke exhaust-flow, Compressor outlet pressure

1. Preface
Turbocharged internal combustion engine is a kind of energy-saving and emission reduction equipment that can generate electricity with low coal-bed methane (CBM) and prevent gas explosion and enhance coal mine safety [1]. A 6000kW gas generator can generate 6.24 million KWh of electricity every year, and the emission reduction of CO₂ can reach 5000t [2-5], which has obvious social and economic benefits. In this paper, the turbocharged internal combustion engine (ICE) with a rated power of 500kW is taken as the research object. The static characteristics of the ICE system are studied when the concentration of CBM component is 20%, and the regulating effect of gas flow on the ICE is given in this case to provide reliable technical support for the stable operation and efficient utilization of the ICE.

2. Experiment
2.1 Experimental system
Turbocharged ICE, shown in Figure 1, is mainly composed of turbocharged subsystem, intermediate cooling subsystem, intake and exhaust subsystem and cylinder subsystem.
2.2 Measuring device

The experimental system of the ICE and the layout of the measuring points are shown in Figure 1. The measuring point of exhaust gas temperature is detected by Pt1000 platinum thermistor with the accuracy of class A; the compressor outlet pressure measuring point is detected by a spring type pressure gauge with an accuracy of 1.6; the measuring point of CBM flow rate and the exhaust gas flow are measured by the vortex flowmeter, and the accuracy is ±1.0%; the concentration of CBM in the gas cylinder inlet is detected by the concentration measuring instrument, and the accuracy is ±0.1%; the power of the load is detected by the power measuring instrument, and the accuracy is ±0.1kw; and the air-fuel ratio of the cylinder of the ICE is determined by the concentration measuring instrument with an accuracy of ±0.1kw.

2.3 Experimental plan

This experiment mainly studies the influence of the flow rate and component concentration of CBM on the outlet pressure, air-fuel ratio and exhaust flow rate of the compressor. After starting the unit and running stably for 20 minutes, the concentration of a certain CBM component is determined, and experiments can be conduct by changing the flow rate of CBM. And the parameter change ≤ ±0.1 kW is identified as the stable operation state, and the power of the stable operation of the ICE is recorded.

The design parameters of the ICE are shown in Table 1. In the experiment, we set three groups of concentration and flow gradients of different CBM components respectively, and carry out data collection every second. The results can refer to the third section.

Table 1 The design parameters of the ICE

| Power of ICE | the flow rate and component concentration of CBM on the outlet pressure | air-fuel ratio | Exhaust gas temperature | flow rate of exhaust gas |
|--------------|------------------------------------------------------------------------|---------------|-------------------------|-------------------------|
| kW           | kPa                                                                    | %            | ºC                      | Nm³/s                   |
| 500          | 26.6                                                                   | 0.6          | 550                     | 0.6                     |
3. Experimental Calculation

The change of exhaust gas temperature and effective power of the unit directly reflects the load state of the unit, and the calculation formula is as follows:

$$D_fH_u + D_aC_{pa}T_3 = Q_w + P_e + (D_f + D_a)C_{pg}T_4$$  (1)

$D_f$ is the fuel consumption, kg / s; $H_u$ is the low calorific value of CBM, kJ / kg; $Q_w$ is the heat taken away by cooling water in unit time, kW; $C_{pa}$ is the specific heat of constant pressure of intake fluid, kJ / (kg•K); $C_{pg}$ is the specific heat of constant pressure of exhaust fluid, kJ / (kg•K); $P_e$ is the effective power of engine, kW.

$$P_e = \eta_eD_fH_u$$  (2)

$$Q_w = \zeta_wD_fH_u$$  (3)

$\eta_e$ stands for the effective efficiency of the engine, %; and $\zeta_w$ is the coefficient of cooling loss.

$$T_4 = T_3 + \frac{Z}{D_a / D_f + 1}$$  (4)

$Z$ is the exhaust temperature factor of the engine and is a function of the air-fuel ratio $D_a/D$, which can be calculated according to the line diagram given in reference [6-10].

$$Z = H_u(1 - \eta_e - \zeta_w)/C_{pg}$$  (5)

4. Experimental Results and Analysis

4.1 Influence of concentration and flow of CBM components on air-fuel ratio

With the increase of component concentration and flow rate of CBM, the air-fuel ratio increases.

As shown in Figure 2, when the methane concentration is 20% and the gas flow is 0.36 kg/s, 0.38 kg/s and 0.40 kg/s, the corresponding air-fuel ratio is 0.60, 0.62 and 0.64; when the gas flow is 0.38 kg/s and the methane concentration is 18%, 19%, 20%, 21% and 22%, the corresponding air-fuel ratio is 0.62, 0.623, 0.63, 0.632 and 0.64.

![Figure 2. Effect of methane concentration on parameters](image)

4.2 Influence of concentration and flow of CBM components on outlet pressure of compressor

Compared with the gas flow rate, the outlet pressure of the compressor is less sensitive to changes in the concentration of the components. Only when the concentration is increased to a certain extent, the outlet pressure of the compressor is increased.

When the methane concentration is 20%, the gas flow is 0.36 kg/s, 0.38 kg/s, and 0.40 kg/s respectively, the corresponding outlet pressures of compressor is 26.71 kPa, 26.57 kPa and 26.42 kPa respectively; when the gas flow rate is 0.38 kg/s, the methane concentration is 18%, 19%, 20%, 21% and 22%, the corresponding outlet pressures of the compressors to of is 26.57 kPa, 26.57 kPa, and 26.57 kPa, respectively. 26.60 kPa and 26.62 kPa.
4.3 Influence of concentration and flow of CBM components on exhaust gas temperature
As the concentration and the flow of CBM components increase, the exhaust gas temperature increases.

When the methane concentration is 20%, the gas flow rate increases to 0.36 kg/s, 0.38 kg/s, and 0.40 kg/s, the corresponding exhaust gas temperature is 548.5 °C, 550.3 °C, and 552.0 °C. The gas flow rate is 0.38 kg/s, the methane concentration is increased to 18%, 19%, 20%, 21%, and 22%, and the corresponding exhaust gas temperature is 549.2 °C, 549.7 °C, 550.3 °C, 550.9 °C, and 551.4 °C.

4.4 Influence of concentration and flow of CBM components on flow rate of exhaust gas
As the concentration and the flow of CBM components increase, the flow rate of exhaust gas increases.

When the methane concentration is 20%, as the gas flow rate increases to 0.36 kg/s, 0.38 kg/s, and 0.40 kg/s, the corresponding exhaust flow rate is 0.566 Nm³/s, 0.604 Nm³/s, 0.644 Nm³/s; when the gas flow rate is 0.40 kg/s, the methane concentration is increased to 18%, 19%, 20%, 21%, 22%, and the corresponding exhaust flow rate is 0.544 Nm³/s and 0.574 Nm³/s, 0.604 Nm³/s, 0.634 Nm³/s, 0.664 Nm³/s.

In summary, under the condition of single variable change, the air-fuel ratio, outlet pressure of compressor, exhaust gas temperature and flow rate of exhaust gas curve with the flow and concentration of CBM components curve and static equation, as shown in Figure 3.

5. Conclusion
The experimental research on the static characteristics of turbocharged internal combustion engine is of great significance for the stable operation setting and optimal regulation control of internal combustion engine. Through theoretical calculation and experimental analysis, the following conclusions can be drawn:

(1) With the increase of gas flow, the air-fuel ratio, exhaust gas temperature and flow rate of exhaust gas are all on the rise, and the outlet pressure of compressor is on the decline. With the increase of CBM component concentration, the air-fuel ratio, exhaust gas temperature, flow rate of exhaust gas and the outlet pressure of compressor are all on the rise.

Figure 3. Fitting of static characteristic curve
(2) The change of gas flow rate has a great influence on the parameters of ICE, while the change of flow rate of CBM component has a little influence on the parameters of ICE.

(3) According to the change law of parameters of ICE with the concentration and flow of CBM, the change curve and static equation are fitted, so that reliable technical support can be provided under the dynamic conditions in combination with the actual working conditions.

Acknowledgements
Shanxi Key Coal Science and Technology Key Project (MD2014-07); Shanxi Provincial Science and Technology Innovation Key Team Construction Project (2013131014)

References
[1] Shi Rutao. Simulation Research on CCHP System Based on the Gas Engine and Lithium Bromide Chiller [D]. Jinan: Shandong University, 2015.
[2] Zhang Wansheng, Wu Zhengxin. Tri-generation for Energy Conservation and Emission Reduction in Coal Mines [J]. China Coalbed Methane, 2009, 6 (2): 41-43.
[3] Fan Qinghu, Li Hongyan, Yin quansen, et al. Low concentration coal bed methane liquefaction technology and its application [J]. Natural gas industry, 2008, 28 (3): 117-120.
[4] Guo Jianghua, Liang Shuhai, Wang Yinghui, et al. Summary of modeling methods for marine diesel engines [J]. Ship engineering, 2005, 27 (2): 58-61.
[5] Shuai Yingmei. Model and Simulation of electronic control speed regulation system of turbocharged diesel engine [D]. Wuhan: Huazhong University of science and technology, 2004.
[6] Li Ruixue. Research on the average model modeling and model checking method of turbocharged diesel engine [D]. Beijing: Beijing University of technology, 2014.
[7] Dong Tao. Current situation and development trend of thin coal seam mining technology in China [J]. Coal mine safety, 2012, 43 (5): 147-149.
[8] Tao Xian, Xue Xiangming, Li Jun, Lin Fuyan. Design of networked remote control scheme for hydraulic support [J]. Coal mine safety, 2013, 44 (3): 109-110114.
[9] Tong Jun, Liu Lijun, Zhang Qian. Design of mining combined switch protection system [J]. Coal mine safety, 2019, 50 (1): 103-105109.
[10] Zhang Yifu, Liang Bing, Zhang zunguo. LBM study on the influence of interphase force on two-phase displacement seepage in microporous channel [J]. Coal mine safety, 2019, 50 (6): 1-5,10.