Gasoline engine optimal performance with oxygen-enriched air intake condition and analysis of system remanufacturing

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Abstract
The gasoline engine performance verification test was performed by two air intake ways: normal air intake and MAP controllable oxygen-enriched air intake. After comparison between the test data of oxygen-enriched and normal air intake ways, the average torque growth rate of oxygen-enriched air intake way is obtained. The average fuel consumption reduction rates of oxygen, HC, CO, and NO_x with rotate speed respectively are also analyzed and approved under the experiment. The comprehensive performance of gasoline engine under oxygen-enriched condition is improved and the goal of energy conservation and emission reduction is achieved. The remanufacturing technical condition parameters allowable limits and the reliability evaluation of electronic control system for electronic controlled engine were analyzed systematically.
Keywords: OXYGEN-ENRICHED AIR INTAKE, GASOLINE ENGINE, ELECTRONIC CONTROL SYSTEM, REMANUFACTURING.

1. Introduction

With the gradually strict vehicle emission limit and continuous update of various engine control methods, the combustion control process is required to be improved. Lower emission, superior economy, and higher dynamic property should be gradually realized. Optimal control of engine working process by the air intake methods of oxygen-enriched, nitrogen-enriched, and EGR reforming is the one of the dominate research directions at present [1]. The oxygen-enriched air intake method can effectively increase the combustion temperature, shorten the fire delay time, facilitate the complete combustion of fuel [2], enhance the effective output power of engine, reduce its fuel consumption rate, improve its dynamic property and economic property [3], and reduce the amount of CO and HC originated from incomplete combustion, which is a new approach to realize energy conservation and emission reduction [4].

Engine is a dynamic, multivariable, highly nonlinear time-varying system with response delay from the view of control technology. The researches of engine working parameter control methods are mainly focused on the oil injection control, ignition control, and EGR control. But seldom research is carried out on the respect of air intake control [5,6]. The basic MAP corresponding to different operation conditions are parameter set of advance angle of ignition and injection pulse-width when the engine reaches its optimum performance. It's crucial to obtain the initial MAP. Kinds of MAP control data are usually obtained by filtrating and statistical analysis of plenty of experimental data, which are obtained by engine bed test and road driving test [7].

Aiming to reuse the engine renewable resources, the engine remanufacturing is systematic engineering activities which will enable engine renewable resources to be accomplished high-quality reproduction processes and full advantage by the production organization mode and advanced remanufacturing technology, strict quality control and systematic management for reusable assembly or parts [8]. Engine Remanufacturing should not only pay attention to take full advantage of the value of used electronic engine parts, extract additional value and prolong the automobile life as well as other aspects of the automotive industry chain extension, but also to upgrade electronic control system performance of remanufactured engine and make remanufactured electronic controlled engine performance in line with the latest national technical standards. Finally, engine remanufacturing reaches a new fuel economy and emissions regulations, achieve technological progress under remanufacturing conditions [9, 10].

The research object in this work is air cooling single cylinder gasoline engine with four strokes. The gasoline engine performance is optimal controlled based on air intake MAP under oxygen-enriched air take condition. The oxygen volume fraction in the intake air is accurately controlled by real time recording the MAP image of intake oxygen volume fraction and releasing the control instruction based on the actual working conditions of gasoline engine, making sure that the engine can realize controllable combustion under the objective oxygen-enriched intake air condition. Thus the dynamic and economic performances are optimized on the basis of ensuring non-obvious deterioration of the emission performance. The effect of energy conservation and emission reduction is verified by universal characteristic test. Based on electronic control system performance upgrades of remanufactured engine, the remanufacturing mode, the technical condition parameters allowable limits and the reliability evaluation of electronic control system for electronic controlled engine were analyzed systematically.

2. Set up of test bed

Industrial oxygen of purity higher than 99.2% and pressure of 13±0.5MPa is provided by oxygen bottle. After the pressure is reduced to standard atmospheric pressure by oxygen bottle pressure reducer, the oxygen is introduced to premix chamber. The other entrance of premix chamber is connected with atmosphere. The industrial oxygen and air are premixed in the premix chamber using several mixing fans. The mixed gas is introduced to the gas chamber and further fully mixed. The air flow and intake oxygen volume fraction are accurately controlled by oxygen flow meter and oxygen flow control valve, forming a mixed intake air with objective oxygen-enriched proportion. Then the mixed gas is provided to engine in the naturally aspirated way. Fig.1 shows the test bed structure of oxygen-enriched optimal control system of gasoline engine. Table 1 displays the key technical parameters of test engine.

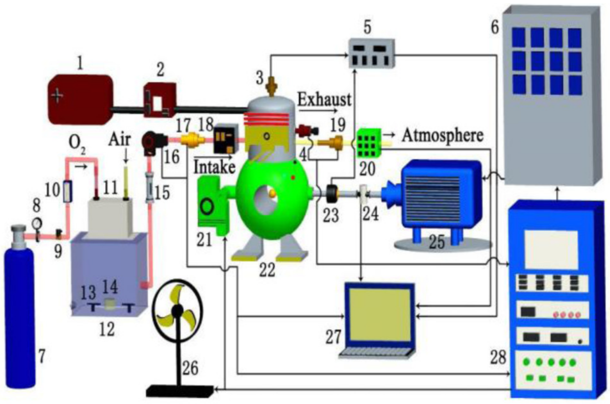

Figure 1. Test bed structure of oxygen-enriched optimal control system of gasoline engine.
(1-the fuel tank, 2-smart fuel consumption, 3-cylinder pressure sensor, 4-cylinder temperature sensor, 5-Combustion Analyzer, 6-control cabinet, 7-oxygen bottles, 8-oxygen bottle pressure reducer, 9-oxygen flow control valve, 10-oxygen flow meter, 11-pre-mixing chamber, 12-with the gas chamber, 13- gas mixing fan, 14-temperature hygrometer, 15-gas flow meter, 16-throttle position sensor, 17-intake temperature sensor, 18-oxygen analyzer, 19-exhaust gas temperature sensor, 20-exhaust gas analyzer, 21-throttle actuator, 22-engine, 23-incremental encoder, 24-speed torque sensor, 25-DC Electric Dynamometer, 26-cooling fan, 27-monitor and collection system, 28-engine automatic monitoring and control system.)

Table 1. Key technical parameters of test engine

Parameters	index	parameters	index
cylinder diameter route/mm	56.5×49.5	max power/kW	7.5/(7500 r/min)
displacement/mL	124	rated power/kW	6.5/(6500 r/min)
compression ratio	9:1	max torque/(N·m)	8.5(5500 r/min)
Fuel	93#Gasoline	Max Speed/ r/min	8500

3. Performance optimal control of gasoline engine

3.1. Control objective

Oxygen-enriched air intake control is aimed at controlling the optimum intake oxygen volume fraction under different working conditions and are also not totally the same. It must not only split the difference between economic, dynamic, and emission optimizing the dynamic, economic, and emission performances of gasoline engine. When the intake oxygen volume fraction is changed, the dynamic, economic, and emission performances of gasoline engine are also changed with it. Sensitive degrees of influence of intake oxygen volume fraction on these performances are different with each other. Change situations of emission targets of HC, CO, and NO_x performances, but also balance the emission targets of HC, CO, and NO_x. Therefore, comprehensive consideration of torque, oil consumption, and emission performances should be chosen as the optimal control objective of gasoline engine performance under oxygen-enriched air intake condition.

3.2. Control process

MAP control parameters such as MAP image of oxygen-enriched air intake interpolation, corresponding time period, and single period conducting time are saved beforehand into the read-only memory of MC9S12DP256 type microprocessor by the PC upper computer of measurement and control system. When the engine actual runs, its working condition can be judged according to various working condition parameter signals such as sensor collect rotate speed, throttle percentage, etc. The basic control value of oxygen-enriched volume fraction is acquired by searching MAP image of corresponding oxygen-enriched air intake interpolation based on the optimal control objective. Control instruction is carried out by MC9S12DP256 type microprocessor, as well as adjusting the PWM control parameters such as period and single period conducting time. Thereby the industrial pure oxygen flow in mixed chamber can be accurately controlled, the objective control flow can be stably outputted, and the oxygen-enriched air intake with objective oxygen volume fraction can be stably provided for the test gasoline engine. So the optimal control of gasoline engine under oxygen-enriched air intake condition can be realized. Fig.2 displays the MAP image of oxygen-enriched air intake interpolation.

3.3. Control realization

The industrial oxygen flow and engine intake oxygen volume fraction in mixed gas proportion rage can be accurately controlled by matching the duty ratio

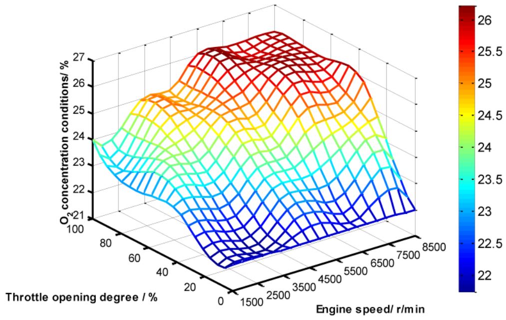

Figure 2. MAP image of oxygen-enriched air intake interpolation

and controlling the on-off of oxygen flow control valve in the form of output PWM square wave under different working conditions using MC9S12DP256 type microprocessor based on pulse width modulation (PWM) principle. The intake air component is accurately configured for engines with different oxygen-enriched proportion demands. Fig.3 shows the drive circuit of oxygen flow controlled valve. Take the non-load work condition as an example, PWM matching result and control parameters are displayed in Table 2.

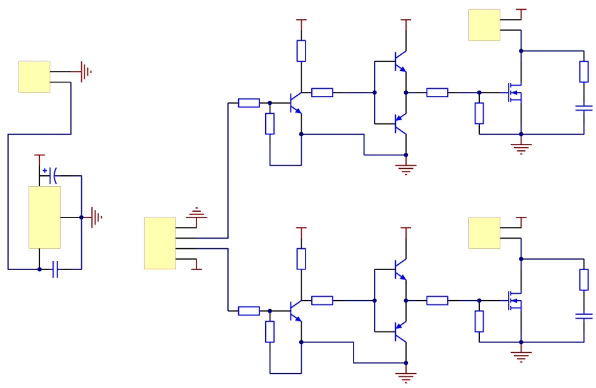

Figure 3. Drive circuit of oxygen flow controlled valve

4. Optimal effect test and analysis

The verification test of gasoline engine performance optimal control effect was performed under oxygen-enriched condition according to the test methods of engine speed characteristic, load characteristic test method, and universal characteristic test method in National Standard “The car engine performance test methods (GB/T 18297-2001)”.

4.1. Dynamic performance analysis

The throttle percentage is chosen as 50%, 75%, and 100%, which represent three working conditions of part load, large load, and full load. When the throttle percentage is maintained constant as 50%, 75%, and 100%, respectively, six rotate speed points are chosen as 2000 r/min, 3000 r/min, 4000 r/min, 5000 r/min, 6000 r/min and 7000 r/min. Two air intake ways are

Table 2. PWM matching result and control parameters

Rotate speed n (L/min)	Objective value λ_O (%)	Conducting time t (ms)	Period T (ms)	Duty ratio β (%)	Calculated pure oxygen flow $Q_{pureoxygen}$ (L/min)	Control pure oxygen flow $Q_{pureoxygen}$ (L/min)	Control value λ_O (%)	Response time Δt (s)	Control error δ (%)
1500	22	20	1100	1.82	1.20	0.94	21.79	5	-0.95
	23	29	1150	2.52	2.44	2.58	23.12	3	0.52
	24	42	900	4.67	3.70	3.96	24.20	7	0.83
	25	53	950	5.58	5.00	4.87	24.90	6	-0.40
	26	61	1000	6.10	6.33	6.59	26.19	8	0.73
2500	22	35	1800	1.94	2.00	2.41	22.19	5	0.86
	23	49	1500	3.25	4.06	3.85	22.89	7	-0.48
	24	62	1200	5.20	6.17	6.43	24.11	4	0.46
	25	70	1100	6.36	8.33	8.02	24.85	3	-0.60
	26	75	950	7.89	10.56	10.20	25.83	6	-0.65
3500	22	35	1600	2.19	2.80	2.96	22.04	6	0.18
	23	49	1400	3.50	5.68	5.05	22.77	8	-1.00
	24	60	1100	5.40	8.63	8.12	23.81	5	-0.79
	25	65	1000	6.50	11.67	11.98	25.09	3	0.36
	26	73	850	8.60	14.78	15.41	26.18	6	0.69
4500	22	32	1400	2.29	3.61	3.27	21.91	4	-0.41
	23	45	1200	3.75	7.31	7.04	22.93	7	-0.30
	24	54	950	5.65	11.10	11.43	24.08	4	0.33
	25	63	900	7.00	15.00	15.46	25.11	5	0.44
	26	70	750	9.33	19.00	19.61	26.14	7	0.54
5500	22	30	1300	2.31	4.41	5.02	22.14	4	0.64
	23	45	1100	4.09	8.93	8.16	22.83	6	-0.74
	24	53	900	5.90	13.57	12.89	23.86	8	-0.58
	25	62	850	7.30	18.33	19.81	25.30	7	1.20
	26	66	650	10.10	23.23	24.64	26.28	5	1.08
6500	22	30	1250	2.40	5.21	4.43	21.85	8	-0.68
	23	45	1000	4.50	10.55	9.31	22.77	6	-1.17
	24	51	850	6.00	16.04	16.67	24.11	5	0.46
	25	61	800	7.60	21.67	23.04	25.24	3	0.96
	26	65	600	10.80	27.45	29.15	26.29	4	1.11
7500	22	30	1200	2.50	6.01	5.32	21.89	8	-0.50
	23	45	950	4.74	12.18	11.06	22.82	5	-0.78
	24	50	800	6.25	18.50	19.83	24.21	4	0.88
	25	60	750	8.00	25.00	26.51	25.23	7	0.92
	26	63	550	11.50	31.67	33.89	26.33	4	1.27
8500	22	52	1500	3.47	6.81	8.47	22.24	5	1.09
	23	56	1050	5.33	13.80	15.24	23.20	8	0.87
	24	67	950	7.05	20.97	19.28	23.77	6	-0.96
	25	74	800	9.25	28.33	26.05	24.69	3	-1.24
	26	85	650	13.08	35.90	37.58	26.22	7	0.85

adopted such as normal state intake and MAP control oxygen-enriched intake. Oxygen volume fraction of normal state intake is 21%, while that of MAP control oxygen-enriched intake is calculated by MAP image of oxygen-enriched air intake. The speed characteristic test is carried out and its torque indicator data are tested, compared, and analyzed after the gasoline engine works stably. The optimal result is shown in Fig.4. Three red curves marked with symbols of ●, ■, and ▲ represent the gasoline engine speed characteristic curves when the throttle percentage is 50%, 75%, and 100% using normal air intake way. While three blue curves marked with symbols of ○, □, and △ represent the gasoline engine speed characteristic curves when the throttle percentage is 50%, 75%, and 100% using MAP control oxygen-enriched air intake way.

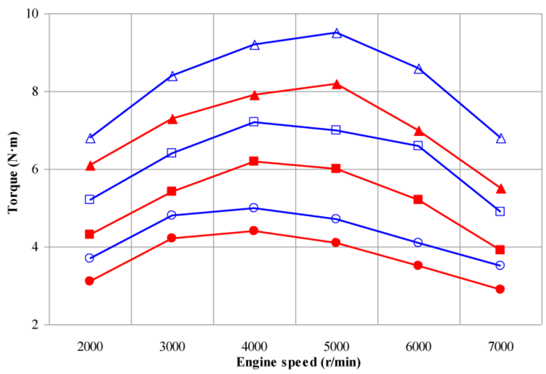

Figure 4. Dynamic characteristic optimal result using MAP

The blue curves of MAP control oxygen-enriched air intake way are always located above the red curves of normal air intake way, indicating the dynamic characteristic of MAP control oxygen-enriched air intake is generally improved in the whole rotate speed range than that of normal air intake way. When the throttle percentage is maintained constant at 100% under full load condition, the curves marked with ▲ and △ represent the gasoline outer characteristic of normal and MAP control oxygen-enriched air intake ways, respectively. The torque increases first and then decrease with the gradually increase of rotate speed, showing an obvious increase trend in all. The torque reaches its largest value 8.2 N•m when torque is 5000r/min under normal air intake condition, while the largest value 9.6 N•m is achieved when torque is 5000r/min under oxygen-enriched air intake condition. Compared with normal air intake with oxygen volume fraction of 21%, under the MAP oxygen-enriched air intake control condition, the torque increase rates of rotate speed of 2000r/min, 3000r/min, 4000r/min, 5000r/min, 6000r/min, and 7000r/min are 11.48%, 15.07%, 16.46%, 17.07%, 22.86%, and 23.64%, respectively, whose average torque increase rate is 17.76%.

4.2. Economic characteristic analysis

The rotate speed is constant at 2000r/min and 3000r/min, respectively. The load value is chosen as 0%, 25%, 50%, 75%, and 100%. Two air intake ways such as normal and MAP control oxygen-enriched air intake ways are adopted. The oxygen volume fraction of normal air intake way is 21%. Oxygen volumes fraction of MAP control oxygen-enriched air intake is calculated from the economic type intake air MAP image. The load characteristic is carried out. When the gasoline engine works stably, its oil consumption indicator data are measured, compared and analyzed. The optimal result is shown in Fig.5. Two red curves marked with ● and ■ represent load characteristics curves of gasoline engines using normal air intake way with rotate speed of 2000r/min and 3000 r/min, respectively. While the two blue curves marked with ○ and □ represent load characteristics curves of gasoline engines using MAP control oxygen-enriched air intake way with rotate speed of 2000r/min and 3000 r/min, respectively.

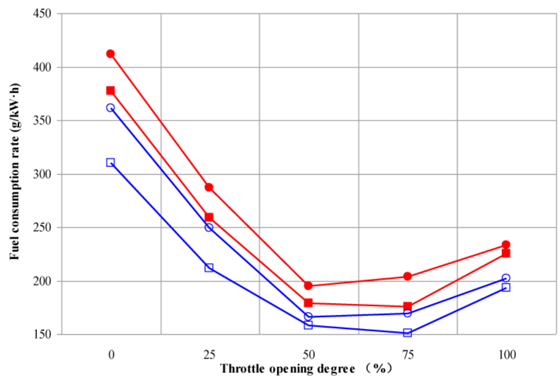

Figure 5. Economic optimal result of MAP control oxygen-enriched air intake

The blue curves of MAP control oxygen-enriched air intake way are always located below the red lines of normal air intake way, revealing the oil consumption of test gasoline engine using MAP control oxygen-enriched air intake way is generally reduced in the whole load range. When the rotate speed is maintained at 3000r/min, the oil consumption rate firstly reduced rapidly and then slightly increased with the gradually increase of throttle percentage, displaying an obviously reduced trend in all. The oil consumption rate reduced to its lowest point of 176 g/(kW•h) at 75% under normal air intake condition, while oil consumption rate reduced to its lowest value of 151 g/(kW•h) at 75% under oxygen-enriched air intake condition. Compared with the normal air intake with oxygen volume fraction of 21%, the oil consumption reducing rate under MAP control oxygen-enriched air intake condition is 17.77%, 18.15%, 11.73%, 14.20%, and 14.22% when throttle percentage is 0%, 25%, 50%, 75%, and 100% respectively, whose average oil consumption reducing rate is 12.68%.

4.3. Emission characteristic analysis

Rotate speed is maintained unchanged at 2000r/min and 3000r/min, and five load points of 0%, 25%, 50%, 75%, and 100% are chosen. Two air intake ways of normal and MAP control oxygen-enriched air intake are adopted, in which the oxygen volume fraction of normal air intake way is 21%. The oxygen volume fraction of MAP control oxygen-enriched air intake is calculated from oxygen-enriched air intake MAP image. Load characteristic tests of emissions of HC, CO, NO_x are carried out. When the gasoline work stably, emissions of HC, CO, NO_x are measured, compared, and analyzed. The optimal result is shown in Table 3.

Emission of HC is obviously reduced using oxygen-enriched air intake way. The reducing rate of lowest value at 2000r/min condition is 18.26%, and the average reducing rate is 14.88%. Emission of CO is also reduced by a large extent. The reducing rate of lowest value at 2000r/min condition is 16.87%, and the average reducing rate is 17.85%. At the same time, the emission of NO_x is degraded and increased, whose increasing rate of lowest value at 2000r/min condition is 10.61%, and the average increasing rate reaches 7.42%. Emission increase of NO_x is obviously less than the emissions reduction of HC and CO. Therefore, comprehensive compared the variations between HC, CO, and NO_x, MAP control oxygen-enriched air intake way can split the difference between these emission indicators, reduce the comprehensive emission of test gasoline engine effectively, and improve the emission performance of gasoline engine.

5. Optimal effect test and analysis

With the growing natural resources dwindling and environmental pollution, the use of renewable resources has caused considerable attention. As the main way of renewable resource use, remanufacturing can promote the circular economy with its significant resources, environmental and economic. Additional, with the development of engine remanufacturing industry and the extension of automobile scrapped cycle in China, and the engine overhaul will be replaced by remanufacturing. Oxygen-enriched intake can significantly improve the performance of electronic controlled gasoline engine, and the key technical issues of electronic controlled system performance upgrading of remanufactured engine are mainly reflected in remanufacturing mode, technical condition parameters allowable limits and reliability evaluation of electronic control systems.

5.1. Remanufacturing mode

On the basis of a comprehensive collection of control system type, structural features and technical performance of electronic controlled engine for the automobiles in use, remanufacturing technical programs was researched of electronic control system and remanufacturing mode was determined. The optimization principles and selection methods are proposed according to the study of life cycle assessment and life cycle cost for remanufacturing mode of electronic controlled engine control system.

5.2. Technical condition parameters allowable limits of electronic control system

Evaluating working capacity of electronic control system of remanufactured engine with a single performance indicator cannot comprehensively reflect the changes of technical station. Technical station allowable limits determining method with factor parameter as an indicator of electronic control system or components should be researched based on extracting the variation characteristic factor of technical station of electronic control systems. Determining comprehensively the allowable limits of remanufactured engine electronic control system based on the statistical indicators for group technical conditions change characteristic with the same brand, the same model or same type control system. In addition, the deterioration degree of technical station parameters, the dam-

Table 3. Compare result of emissions of MAP control oxygen-enriched air intake way

Emissions \ Performance indicator	Rotate speed (r/min)	Normal air intake	MAP control oxygen-enriched air intake		
		Lowest value	Lowest value	Reduce/increase rate of lowest value (%)	Average reduce/increase rate (%)
HC ($\times10^{-6}$)	2000	115	94	-18.26	-14.88
	3000	107	92	-14.02	-12.21
CO (%)	2000	0.83	0.69	-16.87	-17.85
	3000	0.90	0.74	-17.78	-14.92
NO_x ($\times10^{-6}$)	2000	66	73	10.61	7.42
	3000	69	75	8.70	7.87

nification degree of component and mutation status should be considered properly.

5.3. Reliability evaluation of electronic control systems

The reliability of remanufactured engine electronic control system should be evaluated by failure physics-based accelerated life test. The remanufactured engine life characteristics can be extrapolated under normal stress level according to the life characterized under high stress level. Failure distribution characteristic parameters can be obtained by nonlinear programming method or likelihood equations estimating directly through the establishment of the objective function for failure analysis with maximum likelihood estimation method, eventually, the reliability evaluation of remanufactured engine control system can be realized.

6. Conclusion

(1) Verifying test of gasoline engine performance is carried out using normal air intake and MAP control oxygen-enriched air intake ways, respectively. The test result shows that compared with those under the normal air intake way with oxygen volume fraction of 21%, the torque under oxygen-enriched air intake condition increases, the oil consumption reduces, emissions of HC and CO reduces obviously, and emissions of NO_x degrades non-obviously.

(2) After comparison between the test data of oxygen-enriched and normal air intake ways, the average torque increase rate of oxygen-enriched air intake under full load condition is 17.76%, the average oil consumption reducing rate of oxygen-enriched air intake way under 3000r/min condition is 12.68%, the average reducing rate of HC emission of oxygen-enriched air intake way is 14.88%, average reducing rate of CO is 17.85, and average increasing rate of NOx is 7.42%.

(3) The dynamic and economic performances of gasoline engine are obviously optimized under oxygen-enriched condition. The emission performance is enhanced relatively. The comprehensive characteristic of gasoline engine is improved and the goal of energy conservation and emission reduction is achieved.

(4) Based on electronic control system performance upgrades of remanufactured engine, the remanufacturing mode, the technical condition parameters allowable limits and the reliability evaluation of electronic control system for electronic controlled engine were analyzed systematically.

7. Ackonwledgement

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Research of Utility Boiler's NOx Combustion Optimization Based on Relevance Vector Machine

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Abstract
In order to reduce NOx emissions from utility boilers, we draw a new machine learning method Relevance Vector Machine into the modeling of a 300MW pulverized coal boiler's NOx output and twenty-six inputs as drum secondary air, oxygen and so on, then we use Gravitational Search Algorithm to optimize the parameters of the model to obtain the optimal pattern, also we make comparisons of the outcome of Particle Swarm Optimization's and Genetic Algorithm's optimizing Relevance Vector Machine and Gravitational Search Algorithm's optimizing Support Vector Machine . Last we make the boiler adjustable variable input parameters as the optimization variables for the target of cutting down NOx emissions to achieve the appropriate input parameters of lower NOx emissions. The result shows: Gravitational Search Algorithm's optimizing Relevance Vector Machine gets better accuracy than the others, the model is well performed in the optimization of NOx emissions.
Keywords: NOX, OPTIMIZATION CONTROL, BOILER

1. Introduction

The nitrogen oxides are both a danger to human health and a destruction of toxic pollutants to the atmosphere. They are generated in the combustion process when the nitrogen compounds in the coal and oxygen in the air burn at high temperatures. Therefore, high NOx emissions of boilers is a problem worthy of attention in power plant, but it is difficult to establish accurate models of boiler because the boiler system is complex, coal and boiler operating conditions is