# Study on Twin Modes Pilot Control of Turbocharger

**Sicong Lin, Jian Wu, Anwei Zhang, Jujiang Liu and Jin Hu**

**Abstract** As the operating status of the turbocharger is complex, nonlinear and requires high transient response, this paper studies a new control strategy which add self-adaption pilot control to the traditional PID control method, and adopts the static PI control or the dynamic PID control according to the control error, finally, carries out nonlinear transform on the output signal. The control strategy can both increase the respond speed of the turbocharger and avoid the over boost phenomenon. The experimental study is carried out under a 1.8 L turbocharged engine on the engine test bench and the automobile hub test bench, validates the feasibility and practicability of the control strategy.

**Keywords** Twin modes · Pilot · Nonlinear · Self-adaption · Control strategy

## 1 Foreword

Current focus on the reduction of tailpipe $CO_2$ emissions and fuel consumption of road vehicles, people is increasing the interest on downsizing and turbocharging. As the operating status of the turbocharger is complex, nonlinear and hysteresis, thus increases the control difficulty of the control system.

The traditional PID control method is provided with the excellence of structure simpleness, high stability, high reliability and easy to realize and therefore it is widely applied in industry control, and acquires good control effect, but the traditional PID control method just can be used on the control system whose control

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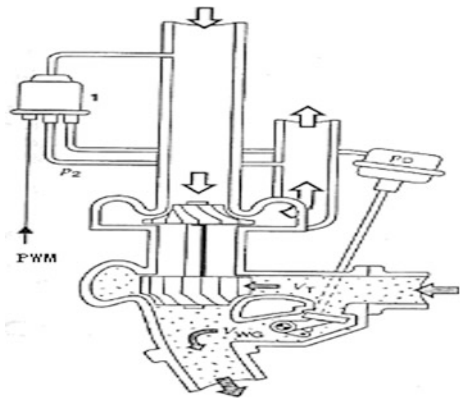


**Fig. 1** Trubocharger control system. 1-three way electromagnetic valve, $p_2$—boost pressure, $p_D$—pressure chamber's pressure, PWM-control signal, $V_T$—volume flow through turbocharger, $V_{WG}$—volume flow through waste gate

object can be described with precise mathematical model better, it is not suit for the turbocharger control system.

Contraposes the complex operation status of the turbocharger and requires high transient response, the control strategy discussed in this paper designs static and dynamic control modes with self-adaption and pilot control. In order to avoid the influence of the nonlinear between the control signal and the control result, carries out nonlinear transform specially before the signal outputs, and reaches satisfying control effect at last.

## 2 The Characteristics of Gasoline Engine Turbocharging System and its Control Requirements

The turbocharger depends on a three ways electromagnetic valve to control the opening angle of the waste gate valve, the turbocharger control system is illustrated in Fig. 1, the three ways electromagnetic valve connects to upstream of the compressor, downstream of the compressor and the pressure chamber of the valve, the control system controls the pressure of the pressure chamber to change the opening angle of the waste gate with the control signal PWM, then realizes the control of the boost pressure [1].

In order to reach both good driveability and excellent power from a car which equipped with turbocharged engine, the control system need to control the turbocharger accurately and rapidly, and reduce the hysteresis of the power as more as possible.

## 3 Twin Modes Pilot PID Control Strategy

The PID control method is applied in the industry control widely, both practical application and theoretical analysis indicate that the PID control for most industry control object can reach satisfying control effect, but for gasline engine turbocharging system which with characteristic complex working condition, nonlinear and hysteresis, it can't reach good control effect with a group preset PID parameters.

This paper designs twin modes PID control strategy which will execute static PI control or dynamic PID control according to the control error, when the control error is smaller than a certain value, carries out the static PI control to realize good and stably control effect, when the control error is bigger enough, carries out the dynamic PID control for the purpose of increasing the respond speed and resisting environment influence. The proportional coefficient Kp, integral coefficient Ki and differential coefficient Kd of the dynamic PID control are not a group of fix data, they will change along with the control error. To increase respond speed and reduce the control error quickly the greater proportional coefficient Kp and integral coefficient Ki will be used when large control error occurs, they are an increasing function of the control error [2, 3]. To ensure the stability of the control the D part of the PID control will not work unless the engine speed is higher than 3,000 r/min. The dynamic PID parameter need to be set through dynamic test on the engine test bench, and should be checked carefully on car [4, 5].

In order to avoid overshooting and increase control precision, set the preset value and the upper limit, lower limit of the I part to define the range of the I part. When the control error is less than a certain value for some time, the range of the I part will move down, when the control error is bigger than a certain value, the range of the I part will move up, therefore it will adjust the range of the I part automatically, then the I part parameter will keep in reasonable scope all the time, this is self-adaption pilot control of the PID control [6, 7].

## 4 Nonlinear Transform of the Control Output Signal

As the turbocharging system is nonlinear, the controller outputs the PID control signal after nonlinear transform to make the control signal and the control result present a linear relationship, and the control precision will increases.

The nonlinear transform make the traditional PID control method which is suit to linear system can apply to nonlinear system. The controller computes the PID control duty cycle base on the control error first, and then computes the preset boost pressure base on the PID control duty cycle via the I part precontrol line, finally, computes the output duty cycle base on the preset boost pressure via the curve of the boost pressure and the duty cycle, the process is illustrated in Fig. 2.

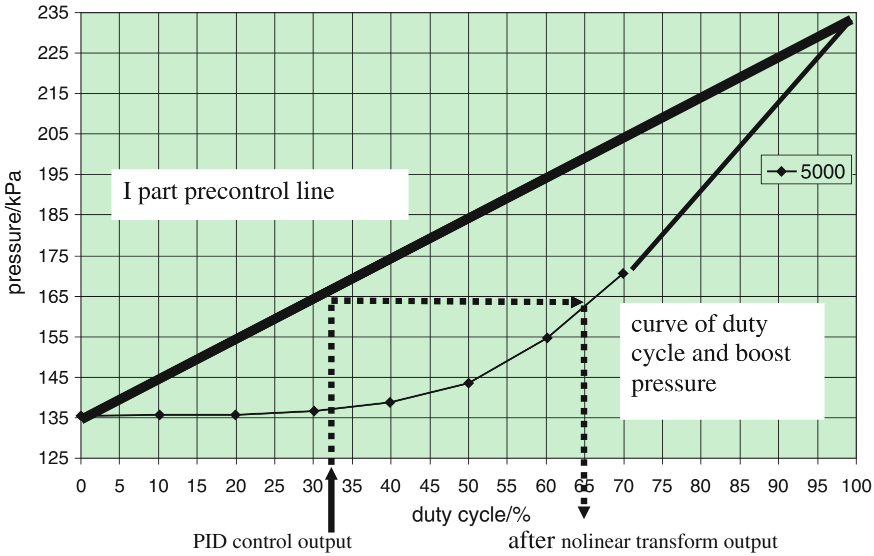


**Fig. 2** Nonlinear transform of the output signal

**Table 1** Parameters of test engine

| | |
|---|---|
| Engine type | T483, DOHC, Multi-injection |
| Displacement | 1.75 L |
| Bore × stroke | 83 × 91 mm |
| Compress ratio | 9.5 |
| Intake system | Turbocharge |
| Number of intake valve | 16 |
| Max torque | 230 N·m/1,700 ~ 5,000 r/min |
| Max power | 130 kW/5,500 r/min |

## 5 Test and Analysis

Carries out the tests of an 1.8 L turbocharged engine on the engine test bench and on the automobile hub test bench that simulates the real road condition, validates the feasibility and practicability of the control strategy.

### *5.1 Parameters of Test Engine*

See Table 1.

**Table 2** Test result of steady working condition on engine test bench

| Engine speed/r/min | BMEP/bar | Target boost pressure/mbar | Actual boost pressure/mbar | Duty cycle/ % | Control error/mbar | Error rate/ % |
|---|---|---|---|---|---|---|
| 2,000 | 14.06 | 1,557 | 1,561 | 31.18 | −4 | −0.256904 |
| | 15.26 | 1,623 | 1,621 | 35.52 | 2 | 0.1232286 |
| | 16.19 | 1,706 | 1,706 | 42.88 | 0 | 0 |
| | 16.56 | 1,752 | 1,751 | 46.1 | 1 | 0.0570776 |
| 3,000 | 13.94 | 1,483 | 1,480 | 18.37 | 3 | 0.2022927 |
| | 14.97 | 1,550 | 1,549 | 26.14 | 1 | 0.0645161 |
| | 16.02 | 1,593 | 1,593 | 30.66 | 0 | 0 |
| | 16.72 | 1,653 | 1,652 | 35.88 | 1 | 0.0604961 |
| 4,000 | 14.01 | 1,457 | 1,457 | 20.25 | 0 | 0 |
| | 14.93 | 1,496 | 1,492 | 25.81 | 4 | 0.2673797 |
| | 15.9 | 1,541 | 1,542 | 32.75 | −1 | −0.064893 |
| | 16.83 | 1,651 | 1,651 | 41.5 | 0 | 0 |
| 5,000 | 13.97 | 1,532 | 1,531 | 38.86 | 1 | 0.0652742 |
| | 14.99 | 1,619 | 1,617 | 47.74 | 2 | 0.123533 |
| | 16.08 | 1,734 | 1,733 | 56.56 | 1 | 0.0576701 |
| | 16.58 | 1,820 | 1,820 | 62.21 | 0 | 0 |

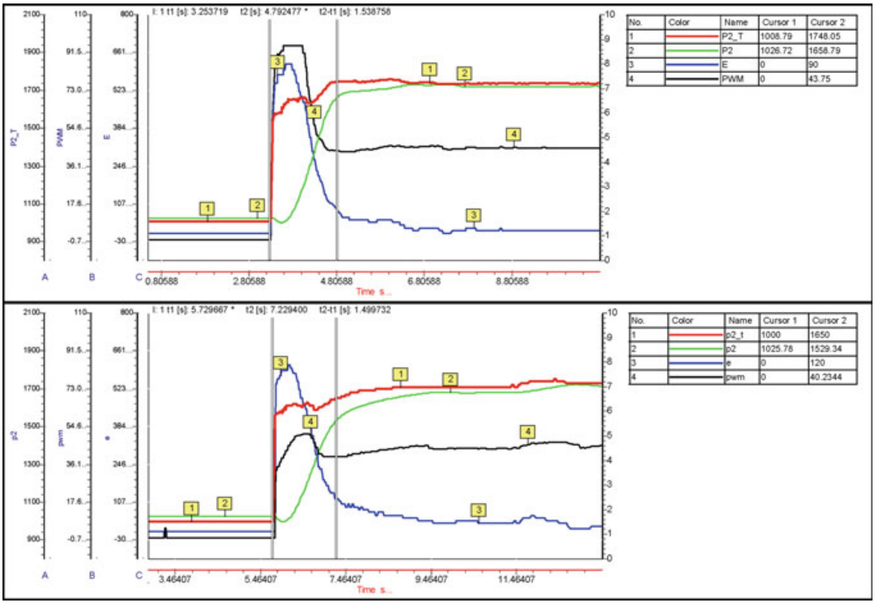


**Fig. 3** Test result of with and without twin modes PID control of dynamic condition on 2,500 r/min *P2_T*(*p2_t*)—target boost pressure, *P2*(*p2*)—actual boost pressure, *E*(*e*)—control error, *PWM*(*pwm*)—control signal

## *5.2 Tests of Steady Working Condition on Engine Test Bench and Results*

### 5.2.1 Test Conditions

Carries out the tests on the conditions below:

Engine speed (r/min): 2000, 3000, 4000, 5000
BMEP(bar): 14, 15, 16, 17, BMEPmax

### 5.2.2 Test Results

The twin modes pilot PID control strategy discussed in this paper carries out nonlinear transform of the control signal, make the traditional PID control method can apply to the nonlinear turbocharging system. It shows very high control precision on all the steady working conditions of turbocharger PID close loop control, and the control error is less than 5 mbar, see Table 2.

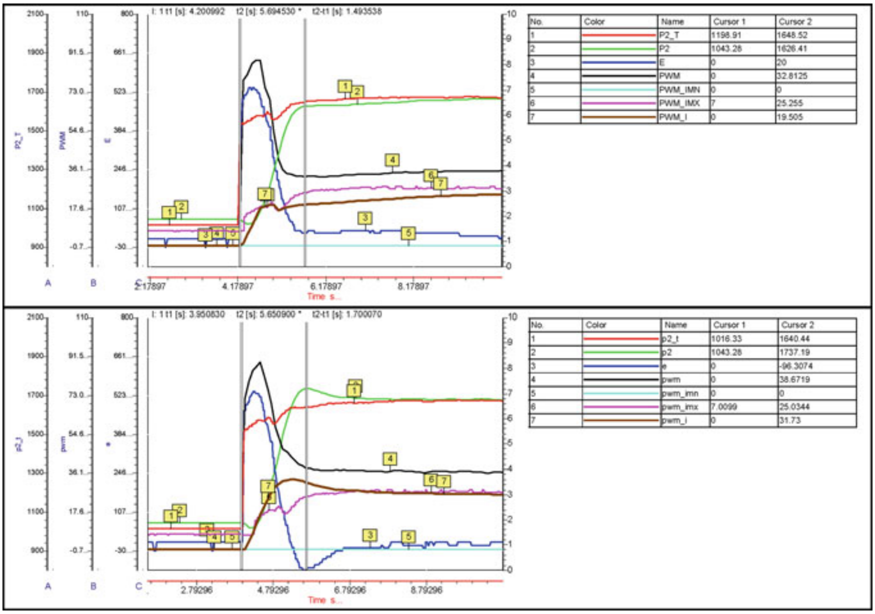


**Fig. 4** Test result of with and without pilot control of dynamic condition on 2,500 r/min *PWM_IMN*(*pwm_imn*)—I part lower limit, *PWM_IMX*(*pwm_imx*)—I part upper limit, *PWM_I*(*pwm_i*)—I part value

## 5.3 *Tests of Dynamic Working Condition on Engine Test Bench and Result*

### 5.3.1 Test Condition

Keep the engine speed on 2,500 r/min, increase the load of the engine from low load to full load in 0.1 s, carries out the tests of PID control with and without twin modes, and then carries out the tests of PID control with and without pilot control.

### 5.3.2 The Test Tesults of PID Control With and Without Twin Modes

On 2,500 r/min, the increase of the boost pressure is 632 mbar for the test with twin modes PID control in 1.5 s, and 503 mbar for the test without twin modes PID control. The former increase 25.6 % more than the latter, illustrated in Fig. 3.

When use twin modes PID control strategy, it will adopt static or dynamic control mode according to the control error automatically. The dynamic mode can output larger duty cycle quickly and increase the dynamic respond of the turbocharger especially when rapid accelerate acceleration condition take place.

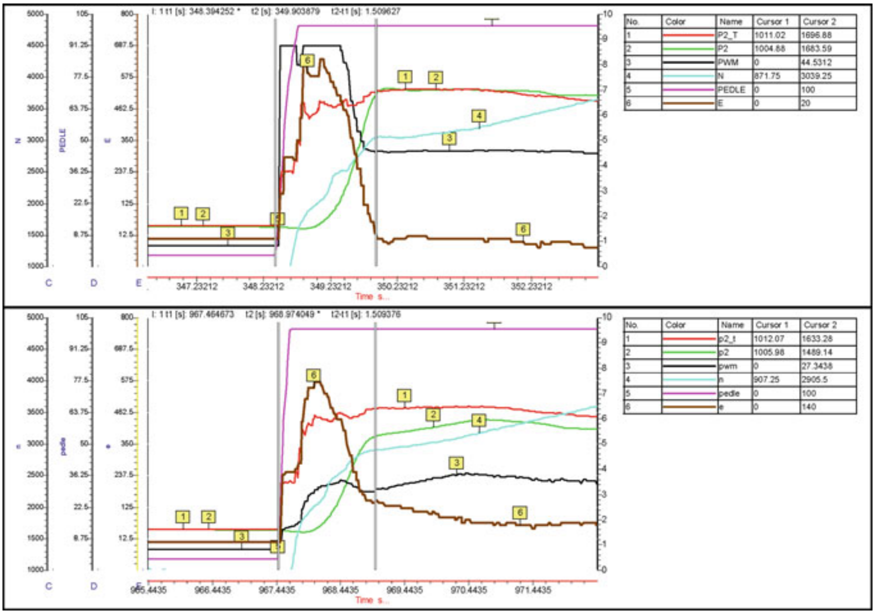


**Fig. 5** Test result of with and without pilot PID control on automobile hub test bench *N*(*n*)—engine speed, *PEDLE*(*pedle*)—opening angle of fuel pedle

### 5.3.3 The Test Results of With and Without Pilot Control

It can be found that it can avoid the boost pressure overshoot with pilot control from Fig. 4, the overshoot take place in different level when without pilot control. Adds pilot control to the PID control method to regulate the upper limit and lower limit of the control signal, and reach the purpose of avoiding overshooting.

## *5.4 Tests of Dynamic Working Condition on Automobile Hub Test Bench*

Carries out the tests with and without twin modes pilot PID control on the automobile hub test bench.

The test results is illustrated in Fig. 5, when with twin modes pilot PID control, the boost pressure reaches the target value quickly without any overshoot, and then follows the target value very well; when without, the boost pressure increases slowly, and can't follows the target value well. In 1.5 s, the former make the boost pressure increase 679 mbar, and the later just 483 mbar, the former increase 40.6 % more than the latter.

## 6 Summary

The turbocharging system has the characteristics of nonlinear, hysteresis and model uncertain, the traditional PID control method is not competent for the control of the gasoline engine turbocharger.

The twin modes PID control strategy executes static PI control or dynamic PID control according to the control error, to increase respond speed of the turbocharger and reduce the control error quickly the control parameters of the dynamic PID control are the increasing function of the control error. Make the self-adaption pilot control of the I part can increase the control precision and avoid overshooting. The controller outputs the PID control signal after nonlinear transform to cover the disadvantage that the traditional PID control method is not fit to the nonlinear system. Finally, realizes the stably and effectively control of the turbocharger. The test results indicates that the twin modes pilot PID control discussed in this paper can reach good control effect.

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