The Application of PLC Technology in Automobile Engine Intake Manifold Leak Detection System

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Abstract

A leak detection device of the automobile engine intake manifold is designed. Based on the shape features of the intake manifold and PLC, we carried out the mechanical structure design of the detecting platform and PID control system design. The integral separation method is used for achieving the closure process. Measurement processes adopts automate operations to improve the production efficiency. Leakage measurement results show that the system is in very good working state.

Keywords: Intake manifold, Tightness, PLC, PID, Detection system

1. Introduction

With the progress of modern industrial production technology, the requirements of detections are increasing in the engine production process. The leak detection of sealed containers plays an increasingly important role in ensuring the quality of products [1]. The intake manifold is an important element of the automobile engine. It's an intake pipe between the throttle and the cylinder head inlet. Its main function is to evenly distribute air to each cylinder's intake [2]. If the intake manifold leak may cause the engine to run weakly, or unstably idle so to disrupt the normal operation of the engine electronic control management system, resulting in engine control disorders; it also affects the automotive brake actuation [3-4].

In recent years, PLC is widely used in the pneumatic system. Conventional pneumatic control and relay control are gradually being replaced for achieving better control and automation. Programmable Logic Controller (PLC) is composed by the CPU, power, memory, and interface circuits of input and output. It is a controller with better anti-interference functions, shock resistance and simple to operate, and it is also inexpensive [5]. With the development of the leak detection technology and the increasing applications of PLC, we use PLC to carry out the intake manifold leak detection in the study. We add leak testing before installing the intake manifold that it can effectively avoid the failure of the intake manifold fitted to the engine. Therefore, the quality of the engine has a reliable guarantee [6].

2. The Structure of the Engine Intake Manifold Tightness Detection System

In the control system of leak detection by air pressure system and PLC system, PLC system accepts the signals from travel switches, buttons etc. We control the operation of the system by applying the electrical signal to the electromagnetic valve. Figure 1 shows the overall structure of the composition [7].

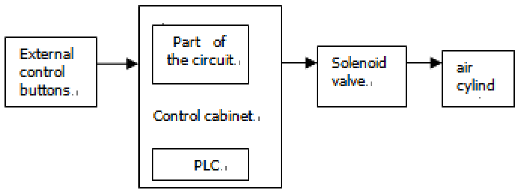

Figure 1: Overall structure of block diagram

The leak detection system consists of an external control section, circuit control part and pneumatic machinery parts. The shape of the intake manifold was decided by the type and the arrangement form of the engine, and also a number of other factors. The types of engine are different, and the requirements of intake manifold are different. Therefore, the mechanical structure platforms of air tightness testing are not the same. According to the requirements of the shape of the intake manifold, the mechanical structure is shown in Figure 2.

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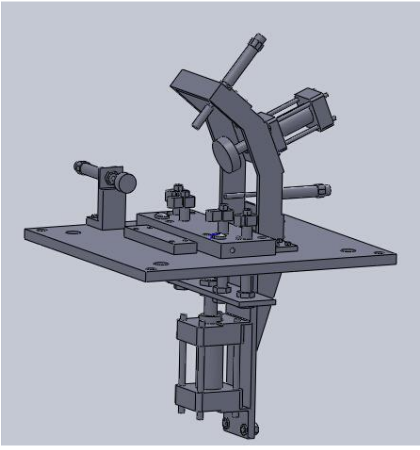


Figure 2: Mechanical Structure of the system

There are five cylinders which need to be controlled in this design. The position of the work piece on the operation is determined by the positioning pins. The larger cylinder is fixed vertically and sealed. The cylinder-two, cylinder-three and cylinder-four are on the above, and the cylinder-five is in the left block with each hole of the intake manifold. According to the requirements of the position of the hole in the intake manifold, the three cylinders in the above are designed into suitable angles. It installs easily, operates simply and increases the working space.

3. The Control System Analysis of Leak Detection System

The leak detection process includes sealing and testing, and the seal process is achieved by PLC. The PLC controls solenoid valves are changed with the gas to achieve seal process[8], whose principle is shown in Figure 3.

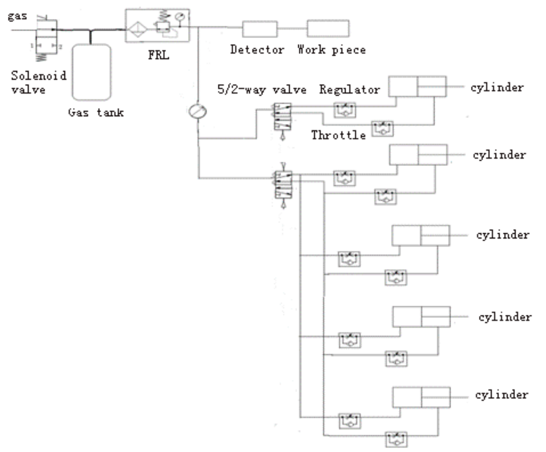


Figure 3: Schematic of system gas path

The solenoid valves of each cylinder and the name in the work operation are shown in Table 1.

Table 1: Each cylinder and valve action names and definitions

Cylinder action definition	Direction of the Cylinder movement	5/2-way valve through a power outage
Cylinder1（down）	A-	a1+
Cylinder1（up）	A+	a2+
Cylinder2 (down)	B-	b2+
Cylinder2 (up)	B+	b1+
Cylinder3 (down)	C-	b2+
Cylinder3 (up)	C+	b1+
Cylinder4 (down)	D-	b2+
Cylinder4 (up)	D+	b1+
Cylinder5 (left)	E-	b2+
Cylinder5 (right)	E+	b1+

Note: A- represents the cylinder-one's cylinder in the down limit position relative to the piston. A+ represents the cylinder-one's cylinder in the up limit position relative to the piston. a1+ represents the 5/2-way left valve energized. a2+ represents the 5/2-way right valve energized.

The cylinder's initial state of the leak detection system is that cylinder-one is upwards, cylinder-two, cylinder-three, and cylinder-four are backward, and cylinder-five is left; so are the state is A+、B-、C-、D-、E-. At the same time the status of 5/2-way valve is a2 +, b2 +. To achieve the actions that closure the intake manifold, the status of cylinders change to A-、B+、C+、D+、E+. This pneumatic system is equipped with two 5/2-way valve. A 5/2-way valve makes gas filled into the cylinder which makes the work piece fixed in the vertical position. Turning on the b 5/2-way valve fills the clear air to the remaining four cylinders. The velocities of the four cylinders are adjusted by regulators to ensure the cylinder moving with the same speed. Each rail is equipped with pneumatic limit switches of electromagnetic induction to detect the state of the cylinder action in place [9].

The requirements of the control system of intake manifold leak detection are that, firstly, each cylinder is in the initial state, and PLC via a button on the control panel accepts the instruction of the operator and chooses the testing procedures and methods of the leak detection. After blocking the completion of the determination by the leak detector tightness of the work piece is qualified, and the test results will display through the lights on the control panel [10-11]. On the control panel, the lights' blinking operation indicates the current test status and test results.

4. The Analysis of Control System

Leak detection systems include two systems: manual and automatic. Manual process is operated by the operator in accordance with the operator panel buttons and lights. The manual mode's function is that it uses the buttons of the operation to control each action of solenoid valve individually. In order to detect whether the control system is normal, an automatic process is controlled by the program. After the debugging of the entire control system, we press the start button that the system goes into operation by automatic cycle work processes. When you press the stop button, the cylinder will return to starting state and be shutdown automatically[12].

The b 5/2-way valve controls the motion of four cylinders simultaneously. We should ensure synchronization blocks to make the sealing process of intake manifold more secure and stable. They have the same blocking route. So it is necessary to ensure that the other four cylinders have the same speed. Only in this way can we make the intake manifold sealing process more stable and secure. This project uses PID control system to control the speed of the cylinder rod.

4.1 The Application of PID Control Theory for Leak Detection System

PID control system is a linear control system. According to a given value and the actual output value constituting the control deviation, the deviation becomes the control volume by the proportional, integral and differential linear combination, and then controls the object [13]. The function of proportion in the control system is quick to react to deviations. Once the bias is produced, the controller reacts immediately, so that the deviation of the controlled object becomes smaller.

Integral part's function is to eliminate the steady state error, but it also slows down the response speed of the system, increasing the overshoot of the system.

Differential aspects reflect the trend of deviation signal. It can introduce a correction signal effectively early in the system before the error signal becomes big. Thus it can speed up the movement speed of the system, and reduce the regulation time [14].

In this project using PID controls the speed of the cylinder rod, so it can complete the sealing process simultaneously.

Mathematical models of the PID controller can be expressed by the following Formula (1)

$$u(t)=K_p\,[e(t)+1/T_i*\int e(t)dt+T_d*de(t)/dt] \qquad (1)$$

where u (t) is the controller output, and e (t) is the input of the controller. It is an error of the given value and the output value of the deviation of the actual controlled object, called the error signal. K p is a proportional controller coefficient, Ti is the integral time constant of the controller, and Td is the derivative time constant of the controller.

Since PLC can't directly control continuous formula for computing, therefore, the control system must be discrete control law algorithm design. We separate mathematical model (1):

$$u(n)=K_p\{e(n)+T/T_I\sum e(i)+Td/T[e(n)-e(n-1)]\}+U_0 \qquad (2)$$

where U_0 is the initial value when the bias is zero [15].

PID control is one of the earliest developed control strategies. It is widely used in industrial process control, because its algorithm is simple, robust, and highly reliabe. The strength of integral action depends on the integrator time constant Ti. The larger of the integral constant, the weaker of the cumulative effects. Therefore, the system is relatively stable during transition. It does not oscillate. But if the time integral coefficient is larger, the time to eliminate steady-state error will become longer. It will affect the system's response time. The response time will become long, so response action will become slow.

Therefore an integral separation PID control algorithm is proposed. The idea is to set a separate threshold integral M. According to the requirements, we decide whether to use integral part. This algorithm is based on the original PID control algorithm. When the error of the control system is large, the integral control doesn't effect. When the bias error is reduced, the integral control acts. Through the study of integral action it can be learned that integral separation can reduce the overshoot of the control system and improve the dynamic characteristics of the system [16]. Its concrete realization is as follows: according to the actual situation, we set a deviation threshold M; when the deviation $|e(n)| > M$, it gives up the integral part of the system. It uses PD control algorithm; when $|e(n)| \leqslant M$, we use the integral aspect of the system. It uses PID control algorithm. This design idea can save time and increase productivity.

Since there will be hysteresis in the movement of the cylinder rod. This will not only reduce the control accuracy of the system, but also produce a phase shift and harmonic distortion associated with the input signal amplitude. Thus it will weak the feedback of the closed-loop system, and it can cause the system instable. The output of the hysteresis system is not only related to the instantaneous value of the input signal, but also to the historical characteristics of the input signal and the changing signal. These two characteristics of the hysteresis system make common classical control theory and modern control theory difficult to implement an effective control.

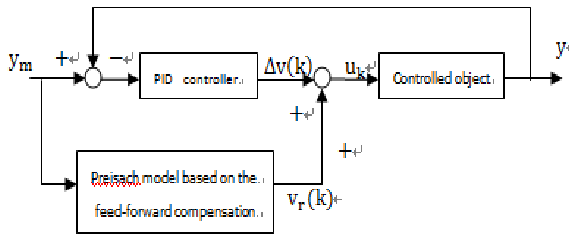
Currently, Preisach model is the most widely used model of hysteresis, and it is more used in the design of the static hysteresis compensation. The static hysteresis compensation scheme distinguishes the hysteresis characteristics offline at the first, then it transfers the data to the memory. When the system is operating, we use the stored data to compensate the system directly. The advantages of the static program are: it can carry out high-precision static hysteresis compensation, and the algorithm is simple.

Preisach hysteresis model considered hysteresis characteristics is the result of a simple superposition of the hysteresis unit [17], namely

$$\boldsymbol{H}[\boldsymbol{v}](\boldsymbol{t}) = \iint_{s} u(\alpha,\beta)\gamma_{\alpha,\beta}[v](t)\,\boldsymbol{d\alpha d\beta} \qquad (3)$$

$$\gamma_{\alpha,\beta}[v](t) = \begin{cases} 1 & v(t) > \beta \\ -1 & v(t) < \alpha \\ \varepsilon & \alpha < v(t) < \beta \end{cases} \qquad (4)$$

wherein: $\gamma_{\alpha,\beta}$ is the weight function; $\gamma_{\alpha,\beta}$ [V](t) is the hysteresis unit of the Preisach model; $\alpha, \boldsymbol{\beta}$ respective the Upper and lower switching value of the hysteresis unit, $\varepsilon = \gamma_{\alpha,\beta}[v](\boldsymbol{\tau}$



$(\tau i) = \boldsymbol{\alpha} \quad (\tau i) = \boldsymbol{\beta}$

Figure 4: Compensation scheme of Ping Ge

Ping Ge proposes a static compensation scheme based on Preisach model, it is shown in Figure 4.

The basic idea of this control is: after giving the desired output signal $\boldsymbol{y_m}$(k), we use the inverse model of Preisach to obtain the corresponding control signals $\boldsymbol{v_r}$(k). We deposited the date ($\boldsymbol{y_m}$(k) , $\boldsymbol{v_r}$(k)) to the memory in the range of input signals. In the real-time operation, we use the input signal to obtain the appropriate control signals. In this design, the key is to access the static hysteresis inverse model, and it also needs to complete the work offline. The inverse diagram of Ping Ge is shown in the Figure 5.

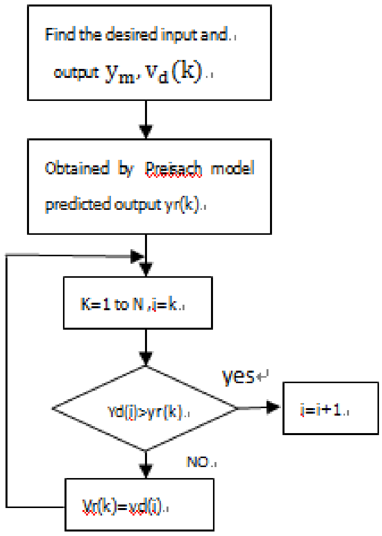


Figure 5: Feed-forward algorithm of Ping Ge

To compensate the dynamic changes of the hysteresis characteristics, Ge combines the static hysteresis feed forward compensation and the conventional control to reduce the error of model mismatch. Compared with a single PID control scheme, the accuracy of the controller can improve greatly [18].

4.2 PLC Control System and the Circuit

The hardware circuit of PLC system is composed of three parts by the input and output circuits and the PLC basic unit. According to the control requirements, this design contains a total of 22 points input and 9 points output. Considering that it may increase the I/O devices in the design process, the change after the production process and the reliability requirements, the I/O points need to set aside a certain amount of wealth. So we use the Omron's CPIE-N60 series, since it is economical and reliable, and it can meet the requirements of the design [19].

In the circuit, we prepare the power 220V AC converted to DC 24V to supply the stable power for the solenoid valve and the PLC. We select the voltage of the same level and type, and use the exchange -point connection in the I/O cable connection diagram. All peripherals share a power supply. It can avoid configuring power separately to reduce the cost. The related electrical components include a 24V power supply, PLC, solenoid valves and all cables installed in the cabinet. It is compact with specification layouts and firm installation [20].

4.3 Program Control of the System

The flow chart of an automatic program in the system is shown in Figure 6. According to the flowchart, we write the ladder program and put it into the PLC. PLC can be connected directly to a computer via RS232 cable that brings with itself. We can directly upload operation after setting communication parameters, it is convenient and simple.

An automatic procedure is completed as follows. After turning on the power switch and gas source, the system will get into the ready state, and the design is carried out according to various signals associated with the implementation of the various actions, until procedures finish. If you press the stop button during the test, the action will stop at the current position; when pressing the start button again, the action will go on.

After the design task is completed, it can transmit the program into the PLC for debugging energized. In the debugging, we don't install components such as solenoid valves and cylinders. First, we view whether the input and output points of the PLC are displayed properly throw the action of button. In order to determine compliance with the requirements of the design, the design system has to undergo a rigorous acceptance testing. The finished overall unit is shown in Figure 7.

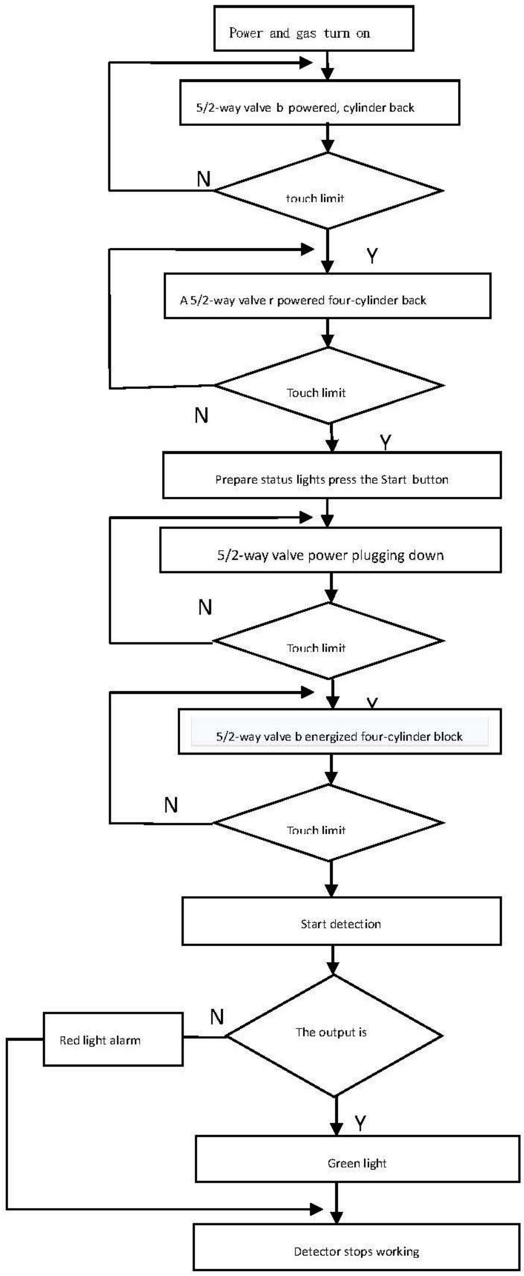


Figure 6: Program flow chart

Figure 7: The finished overall unit (without COSMO's LS-1822A)

4.4 Experimental analysis

This project uses the COSMO's LS-1822A air leak tester for testing. It tests by injecting pressurized air to the test product. It uses the differential detection method to measure the internal pressure variation to detect leaks.

Detection method is based on the substance of the differential pressure placed on standard parts and sensors on both sides of the work piece as the basis for determining the difference between the sealing performances of the work, while the pressure difference is caused by the leakage of the work piece [21-22].

In the predetermined detection time, the standard work piece has no leaks; if the test work piece has no leaks, then the pressure sensor maintains balance [23]. If the test work piece has leaks, the pressure differential pressure sensor of the work piece measurement chamber will change the balance. So first we prepare the standard work piece, then inject regulator air to test products and standards simultaneously [24]. After stopping inflation, we measure the internal pressure variation by the high sensitivity differential pressure sensors, where the differential pressure was between the test article and the standard.

We use a traffic unit to illustrate the leakage amount per unit of time. Leakage Q (m L / min) is expressed as

$$Q=Ve\times\Delta P/(1.013\times100000)\times T/60 \qquad (5)$$

where ΔP is the differential pressure (Pa), Ve is the equivalent volume (mL), and T is the detection time (s).

$$Ve = Vw + Vt + 0.005 \times (1+ Vw/109) \times (101.3 + P) \qquad (6)$$

where Vw is the volume of the test article and the pipe (mL), and P is the test pressure (kPa). Experimental gas pressure is 120Mpa. We make five measurements for each of the four work pieces, and the measurement results are shown in Table 1:

Table 2: Tightness test results of work piece

T / P	1	2	3	4	5
1#	9.57	5.18	4.90	5.14	7.09
2#	9.00	6.66	7.65	6.03	6.43
3#	10.07	7.79	6.45	6.84	6.40
4#	12.20	9.14	8.45	8.27	8.52

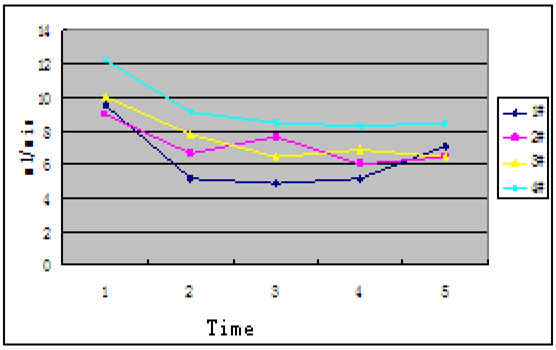


Figure 8: Leakage measurement results distribution

Figure 8 shows leakage measurement results distribution. In this trial, the staff only once put each piece into the test platform, and they carried out five times of block detection.

As can be seen from the figure, the first deviation result has low accuracy, and there is a big error. After a blocking test, the work piece moves smoothly, its measurement accuracy is increased and the error is reduced.

5. Conclusion

In the engine intake manifold installation, air tightness testing plays a vital role in the quality assurance of products, and is also an important indicator of product quality control. In order to improve the accuracy and efficiency of air tightness testing, some domestic and foreign equipment suppliers and research institutions propose several theories and methods, and the practical applications of these measures have been verified and developed.

The system is already in use, and the platform of the mechanical is safe and reliable. Each of the cylinders can be fixed in the accurate position. During the operation it uses integral separation PID control, and it can reduce the running time greatly and improve the productivity. Because we have considered the hysteresis phenomenon in the design, it improves the accuracy greatly. Regarding the two systems, automatic and manual, we can choose one of them. Experiments have proved that the system is well to meet the design requirements, so it can achieve automatic control for the engine intake manifold leak detection; and therefore, the working efficiency is improved greatly.

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