# Air Tightness Test System for Electric Pneumatic Valve Based on Differential Pressure Method

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Air tightness test is a necessary step in the performance test of electric pneumatic valves. Traditional air tightness test method cannot provide quantitative description of leakage rate, which results in the lack of theoretical data for the reproduction of electric pneumatic valves. In order to solve the problem, differential pressure method to realize the quantitative requirements of air tightness test of electric pneumatic valves is proposed. (Peng et al., 2008) The paper attempts to figure out the relationship between the leakage rate and the differential pressure in ways of modelling analysis. Furthermore, it designs an air tightness test system of electric pneumatic valves based on differential pressure method using MSP430 as controlling core. On the basis of this system, the hardware platform of pneumatic circuit and drive control is constructed. System integration and test is conducted with the use of software. The test proves that this system can realize quantitative description based on qualitative description for testing leakage rate. The automated air tightness test has advantages of low power consumption, quick testing process and stable system. The practicability of this method is obvious.

## 1. Introduction

Electric pneumatic valves are of great importance as small parts in electric traction of locomotive. Its performance has direct impacts on the effectiveness of electric traction. Air tightness is an important parameter of electric pneumatic valve performance. Therefore, it is necessary to conduct air tightness test during electric pneumatic valve performance test. (Chen et al., 2009)

Traditional air tightness test method can only realize qualitative test. It cannot provide quantitative description of leakage rate, which results in the lack of theoretical data for the reproduction of electric pneumatic valves. Differential pressure detection method does not need any special equipment and is easy to be conducted. Plus, it will not cause any pollution. When considering about measurement accuracy, this study mainly focus on how to overcome the interferences caused by external environment (like temperature) and how to quickly stabilize the airflow within the measured piece. In terms of control method, the number of it is bigger and bigger, for example, single chip control, PLC control, computer control, etc. The analysis proves that air tightness method is capable to satisfy the quantitative measurement requirements of leakage test, having lots of advantages and is of high cost performance. (Liu et al., 2010)

## 2. System Testing Principles and Model Establishment

### 2.1 Testing Principles of Differential Pressure Method

Differential pressure testing is a method to use precise symmetric gas circuit to switch a comparative module considered not to have any leakage into the testing gas circuit (Liu et al., 2008). During the testing phase, compressed gas is filled into tested piece and standard piece at the same time. Then high-precision differential pressure transducer is used to measure the pressure difference between tested piece and standard piece. Data collected will be further processed. Principles are demonstrated as Figure 1:
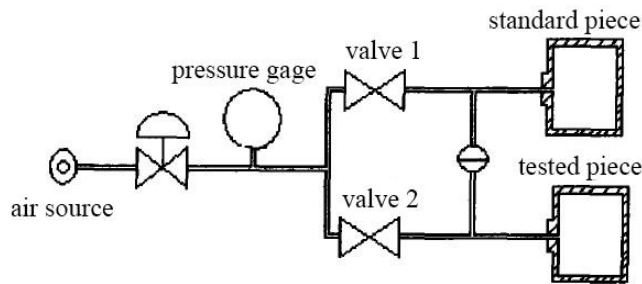
*Figure 1: Schematic of Differential Pressure Testing Method*

The differential pressure testing method has the following advantages: 1. Because the differential pressure only need to be measured, the range of transducer is greatly shortened, and the detection sensitivity are greatly increased; 2. Systematic measuring pressure is taken as testing zero point to test the offset value between recorded pressure and systematic pressure. Therefore, influences like zero-point drifting and temperature drifting have no relations with the measuring pressure but only to the measuring range of differential pressure transducer; 3. The comparative module and the tested module are considered to be synchronized in terms of temperature change and module deformation, so they have good adaptability.

## 2.2 Leakage Model Analysis and Calculation

General leakage issues can be abstracted into a resistance-capacitance coupling model (sensitive effects are too small to be considered) (Liu et al., 2009). Its simplified physical model is depicted on Figure 2 (r—equivalent air-resistance of representational leakage; C—equivalent air capacity):
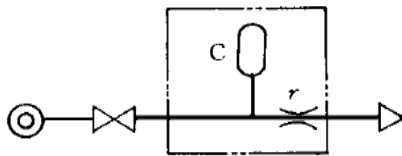


*Figure 2: Simplified Physical Model Schematic of Leakage*

An equation is obtained from the figure:

$$C = V / nRT \tag{1}$$

In the equation: $V$—volume of air capacity; $n$—specific heat ratio; $R$—gas constant; $T$—absolute temperature.
Circuit time constant of resistance-capacitance:

$$T_0 = r \times C = r \times V / (nRT) \tag{2}$$

A mathematic model of this leakage in line with pneumatological regulation is obtained:

$$P = P_0 \times e^{-t/T_0} \tag{3}$$

In the equation: $P_0$—initial pressure of air capacity; $P$—pressure of air capacity at the moment t.
As to general leakage process, it is regarded as constant temperature process. From the gas state equation pv=nRt it is obtained:

$$p_0 V = pV + p_a Qt \tag{4}$$

In the equation: $p_a$—atmospheric pressure; $Q$—leakage amount at Free State; $t$—leakage time.
From this the relationship between the pressure difference and the leakage amount is determined:

$$\Delta p = p_0 - p = Q \cdot t \cdot p_a / V \tag{5}$$

Based on differential pressure principle and utilizing high-precision differential pressure transducer, is acquired if leakage occurs, calculation formula is:

$$Q = \Delta p \cdot V / p_a \cdot t \tag{6}$$

In the equation: $p_a$—atmospheric pressure; $Q$—leakage flow; $t$—leakage time.

## 3. Design of the Hardware in the Detecting System

In the air inflation phase, two air inflation valves and confluence valves are at the states of being opened, two air deflation valves are closed. At this time vessel is filled by the air. Two air inflation valves are closed while air inflation is finished. Pressures and temperatures will still fluctuate due to the air flow at the moment, thus air status in two vessels must be waited to be stable. That is why confluence valves still need to be opened for a while. After this balancing phase, all valves need to be closed in order to conduct the test. Once the test is finished, two air deflation valves are opened to eject the residual air. A complete testing process is finished and the system turns into waiting period and is prepared for the next test. (Shao Wei, et al., 2010) The pneumatic system principle is demonstrated in Figure 3:
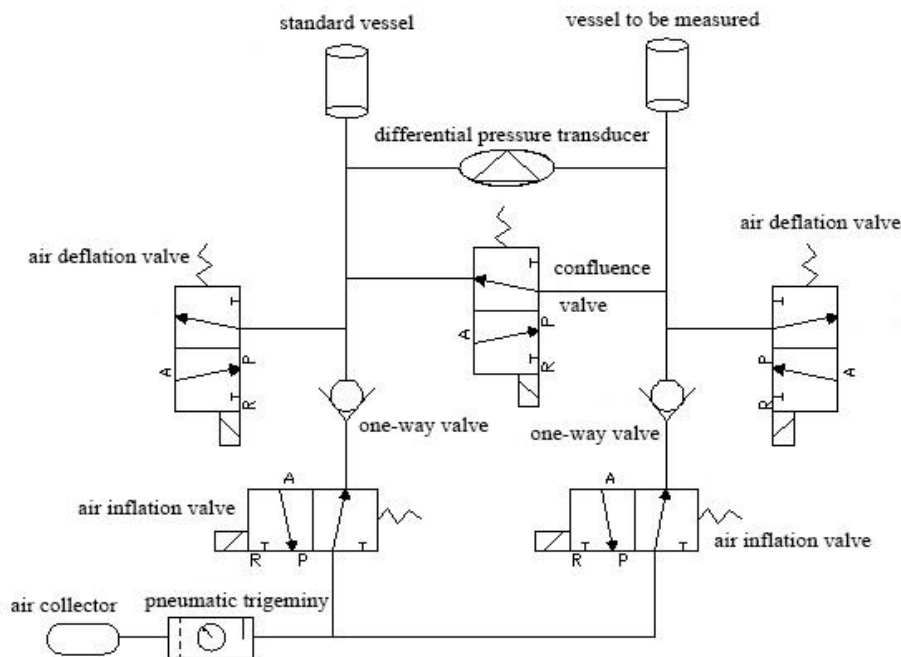


Figure 3: Principle Diagram of Pneumatic System

## 4. Drive Control

System drive control part is composed of MSP430, power source, liquid crystal display and differential pressure detection conditioning, relay drive and status indicator, etc. Its hardware structure is demonstrated in Figure 4.
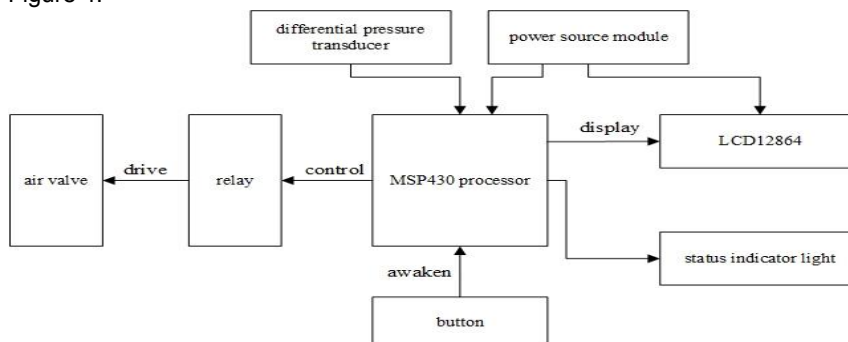


Figure 4: Block Diagram of General Drive Control Hardware

Single chip has only 16 signal ports (under situation of no external expansion). Hence external ports need to be allocated. IO allocation is done as shown in Table 2:

*Table 2: Allocation Table of MSP430 Single Chip IO*

| I/O | Function |
|---|---|
| P1.0 P1.3 | 10-digit AD channel for collection |
| P1.1 P1.2 | Serial communications |
| P1.4 - P1.7 | Control relay |
| P2.0 | Activation button |
| P2.1 P2.2 | Indicator light of running status |
| P2.3 - P2.5 | Control LCD display |
| P2.6 P2.7 | external watch crystal oscillator |

## 5. Software Design of Detection System

### 5.1 AD Collection

ADC10 is the analog-digit converter on chips of MSP430 single chip. Within the module is a SAR-type AD kernel which generates reference voltage in the chips and the core has a data transmission controller which can complete AD data transmission without CPU to any positions of internal storage.

The system adopts multichannel and repeated sample mode of ADC10, choosing DTC (Data Transfer Controller) conversion mode. Since real-time control is not required, average filtering method is selected as data processing method. Interruption servicing function is carried out after every time of sequence conversion. This function accumulates all results together until the frequency of setup conversion is reached. Then the accumulated value is averaged with AD collection being shut and AD conversion being positioned. Zone bit is fulfilled. The process flows are demonstrated as below in Figure 5:
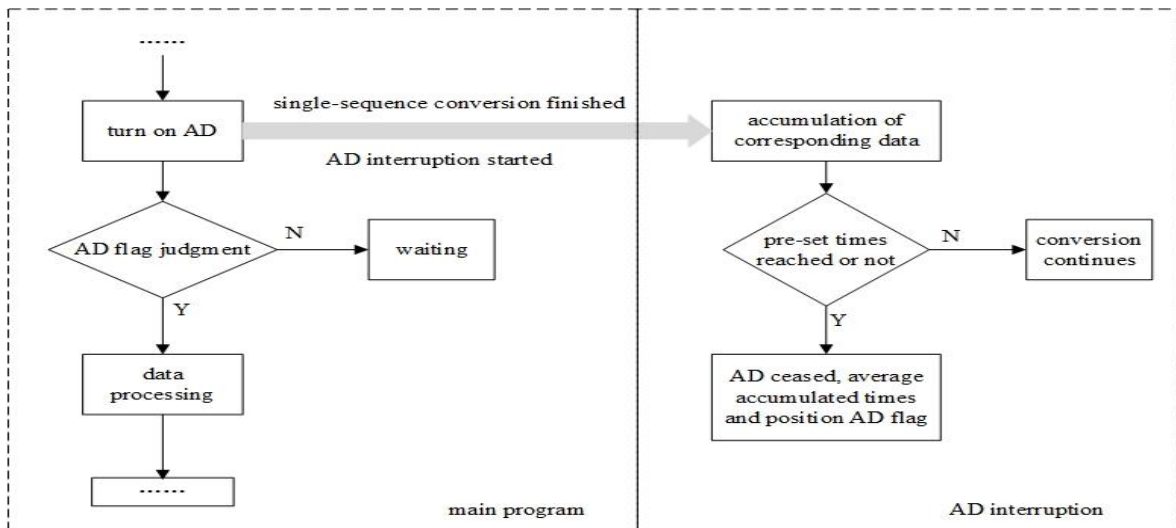


*Figure 5: Process Flow Chart of AD Conversion*

### 5.2 Main Program Design

Algorithm is demonstrated in Figure 6. The left side demonstrates the main program which corresponds to the main function. The right side is the interruption program including IO interruption function, WDT interruption function and AD interruption function. The program first initializes the clock, IO port, WDT and AD, and then lightens the green light, which means that low-power-consumption mode 3 is on right after the current waiting phase. When the mechanical button linked to P2.0 port is pushed, the red light is on, representing that the main program starts to run again. (Li et al., 2012)
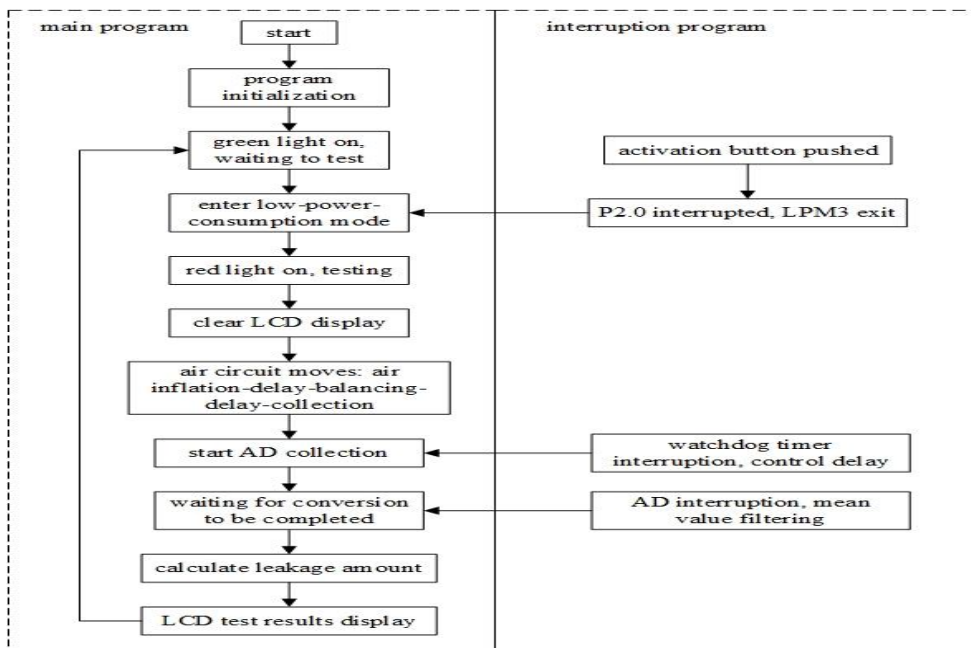
*Figure 6: Flow Mapping of Main Program*

## 6. Analysis of Experimental Results

By joint debugging software and hardware, the system can realize functions of air tightness test of electric pneumatic valves. Red light is on when the activation button is pushed to activate the MCU, which means the test is started. And green light being on gives signals that the test is finished. Results are displayed on the liquid crystal screen. The scene of the system joint debugging is demonstrated in Figure 7:



*Figure 7: Schematic of the Scene of System Joint Debugging*

### 6.1 Test under the Situation of No Leakage in Measured Vessel
When the air inflation time is 7s, balancing time is 1.5s, testing time is 1.5s, testing pressure is 25psi and vessel volume is 550ml, the test data are listed in Table 3:

*Table 3: Measured Data under the Situation of No Leakage in Measured Vessel*

| Times of Measurements | 1 | 2 | 3 | 4 | 5 | Average Value |
|---|---|---|---|---|---|---|
| Pressure Difference(0.001pa) | 3 | 4 | 3 | 6 | 4 | 4 |
| Leakage Amount(ml/s) | 11 | 14 | 11 | 17 | 14 | 14 |

Under the situation of no leakage in measured vessel, the measured leakage amount is not 0 ml/s. Cause of mistake is due to that the air filled into the two vessels at the same time is different. Because forward opening pressures of the two one-way valves are different in despite of their same types and sizes. This kind of mistake belongs to systematic error.

**6.2 Test with Leakage Occurred in Measured Vessel**
When the air inflation time is 7s, balancing time is 1.5s, testing time is 1.5s, testing pressure is 25psi and vessel volume is 550ml, the test data are listed in Table 4:

*Table 4: Measured Data when there is Leakage in Measured Vessel*

| Times of Measurements | 1 | 2 | 3 | 4 | 5 | Average Value |
|---|---|---|---|---|---|---|
| Pressure Difference(0.001pa) | 142 | 143 | 143 | 140 | 142 | 142 |
| Leakage Amount(ml/s) | 516 | 522 | 522 | 510 | 516 | 516 |

With leakage occurred in measured vessel, the measured leakage average amount is 516 ml/s, But the data is fluctuant. This error is caused by systematic error and random additional differential pressure together.
To draw a conclusion by comparing two tests in the same conditions, the measured leakage average amount is 14 ml/s; it means that there is no leakage in the measured electric pneumatic valve. However, the measured leakage average amount is 516 ml/s; it means that there is leakage occurred in the measured electric pneumatic valve. In short, there is leakage occurred in the measured electric pneumatic valve, the test data will be obviously different from the data under the situation of no leakage.

## 7. Conclusions

This system can realize the function of quantitative description of air tightness test of electric pneumatic valves and complete automated air tightness test. The benefits of quantitative description are high measuring accuracy and stable theory data to the re-production. The benefits of automated air tightness test are high work efficiency and alternative to manual detection. Practicability is well, however, mistakes also exist. Causes of mistakes include: 1. Standardized vessel is not used in the experiment, hence system leakage may occur; 2. Pressure difference will fluctuate due to the bad leakproofness of conduit joints of air circuit and reversing valve; 3. Differential pressure transducer is not precise enough, which results in inaccurate return values; 4. Change of environmental temperature causes the change of decay rate of electric pneumatic valve. Solutions such as using software to conduct error compensation or enhancing precision of hardware can be carried out to further diminish systematic error and improve the testing precision. Meanwhile, temperature testing module can also be applied to widen the application scenarios.

**Reference**

Chen Y., Lin M., Guo B., 2009, Design and Realization of Detectors for Pressure System Sealing based on Differential Pressure, Journal of China University of Metrology, 312-319, China

Liu W., Wang M., 2010, Gas Leak Detection by Differential Pressure Method, Mechanical Engineering & Automation, 133-135, China

Liu C., et al., 2008, The Principle of Checking Air-tightness of a Classical Detector, Chinese Hydraulics & Pneumatics, 20-25, China

Liu C., Wang X., Li Y., 2009, Principle of One Type of Detector for High Pressure Vessels, Chinese Hydraulics & Pneumatics, 33-38, China

Lin X., Chen J., Wang N., 2012, Design of A Novel Portable Differential Pressure Air Tightness Detector, Application of Electronic Technique, 92-95, China

Liu W., Li Y., Wu X., 2011, Application of Differential pressure method in Simulation of Engine Air-tightness, Machinery & Electronics, 127-128, China

Peng G., Ji C., Ge N., 2008, Current Status and Future Development of Air Tightness Detection Technique, Machine Tool & Hydraulics, 172-174, China.

Shao W., Jin X., Airigong B., 2010, Design of Testing System for Leak Detection and Leakage Rate, Computer Measurement & Control, 269-271, China

Zhang J., et al., 2007, Differential Pressure Method Applying on Air Tightness for Brake Master Cylinder of Automobile, Machinery Design & Manufacture, 116-118, China

Zhi G., Wu W., Liu J., 2012, Design and Realization of Air-tightness Test Device based on PLC, Digital Technology and Application, 21-22, China