CHEMICAL ENGINEERING TRANSACTIONS

VOL. 66, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216

DOI: 10.3303/CET1866210

Differential Pressure Airtight Intelligent Gauge for Locomotive Electropneumatic Valve

Wei Wei[a], Ning Chen[b], Jiufeng Zhang[c], Xinyu Zhang[d,*]

[a] Shaanxi Key Laboratory of Surface Engineering and Remanufacturing, Xi'an University, No.1 Science and Technology Six Road, Xi'an 710065, China
[b] School of Mechanical and Precision Instrument Engineering, Xi'an University of Technology, No.5 South Jinhua Road, Xi'an 710065, China
[c] School of Mechanical and Materials Engineering, Xi'an University, No.1 Science and Technology Six Road, Xi'an 710065, China
[d] School of Information Engineering, Xi'an University, No.1 Science and Technology Six Road, Xi'an 710065, China
zhangxinyu1112@sina.com

The hermeticity of the electropneumatic valve directly decides the availability of locomotive control. By far, some test methods at home and abroad effectively can detect its hermeticity but at the cost of lowering automaticity, detection efficiency and accuracy, as well as undermining environmentally friendly and adding overhead. In view of the above defects, we propose the differential pressure detection to achieve the hermeticity detection on the electropneumatic valve. Aerodynamic optimization and model analysis helps design a differential pressure hermeticity gauge with MSP430 as the control core. Composed of pneumatic circuit, valve body fixture and control circuit, this gauge can automatically complete the whole hermeticity detection on electropneumatic valve. A system test proves that the gauge can quantitatively and accurately reflect the spillage and the leakage rate and realize the automation of the valve hermeticity detection. As it features low power consumption, fast detection, system stability, etc., it can effectively fill the gaps of the existing technologies. In this sense, it indeed has a good practicality and promising prospect. (Wei et al., 2016)

1. Introduction

In railway industry, electropneumatic valves on locomotives are often used for brake system, pneumatic device, ductwork and sandboxes or air whistle. As a widget of electric traction equipment, it plays a decisive role in the control of locomotives. (Liu et al., 2010) How well the electropneumatic valve is in quality affects the availability of locomotive control. Hermeticity as a key parameter to measure the performance of electropneumatic valves directly determine the reliability, economy, and loco performance. Worse, it can also trigger off machine malfunction, abnormal operation, reduced efficiency, and shortened service life, oil waste and environmental pollution and other failures in practice. In this regard, it is of great importance for us to detect hermeticity of electropneumatic valve in its quality inspection process. (Zhang et al., 2016)
Up to now, there are new detection methods in foreign countries, such as helium mass spectrometry, ultrasonic wave, halogen, laser, etc., which can achieve qualitative and quantitative descriptions on hermeticity with high accuracy but accompanied by high costs and environmental pollution and other defects. If used for a bulk of electropneumatic valves, these give a relatively low efficacy. (Yan et al., 2015) In China, the traditional hermeticity detection often adopts water, flow and direct pressure detection approaches, among which, the direct pressure detection is the most conventional one for testing the hermeticity of the electropneumatic valve in the industry. These three methods all have the defects such as low automation and less efficiency. Rapid development of the railway industry has set a high requirement on the stability and safety for locomotive control, and traditional methods have fallen well short of accuracy, automation, and efficiency for electropneumatic valve hermeticity detection. For this purpose, this paper proposes differential pressure method for the detecting the hermeticity of locomotive electropneumatic valve. (Xiong et al., 2012)

Please cite this article as: Wei W., Chen N., Zhang J., Zhang X., 2018, Differential pressure airtight intelligent gauge for locomotive electropneumatic valve, Chemical Engineering Transactions, 66, 1255-1260 DOI:10.3303/CET1866210

2. Analysis of Gauge Model

2.1 Pneumatic circuit for differential pressure detection

As compared to the parallel mode, the system designs the pneumatic circuit in accordance with the standard vessel and the series electropneumatic valves to be tested. In this way, electromagnetic valves can be minimized. As the solenoid valve airway joints may not be airtight, air reflux will occur, the system leaks seriously. Check valves V5 and V6 are added, and pressure regulator valve may adjust the pressure entering the whole system to make system pressure adjustable.

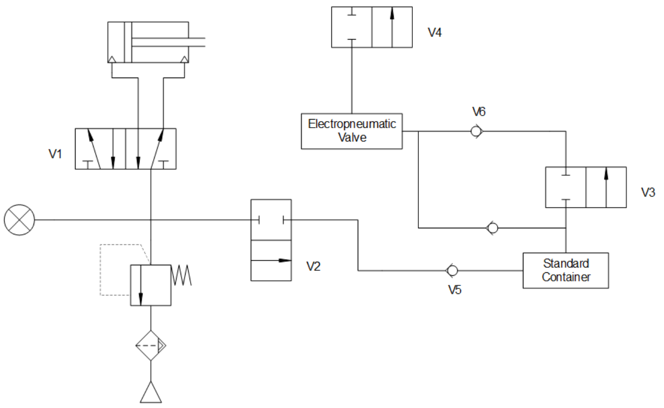

Figure 1: Schematic diagram of pneumatic circuit

The principle of the pneumatic circuit is shown in Figure 1. The whole detection process includes several periods such as standby, clamping, air inflation, testing, and exhaust. During the standby time, the pinch valve V1 and the inflation valve V2 are in the closed state, and the balance valve V3 and the exhaust valve V4 are in a conducting state, waiting for the electropneumatic valve to be clamped; during the clamping period, the pinch valve V1 is energized and the cylinder intakes to clamp it; during the air inflation period, the inflation valve V2, balance valve V3 are activated to inflate the standard container and electropneumatic valve; during the test period, the inflation valve V2, balance valve V3, exhaust valve V4 are switched OFF. After holding up the pressure for 10 minutes, the differential pressure pickup works to detect the differential pressure between the electropneumatic valve and the standard container.

2.2 Gas leakage model

The general leakage process may be treated as an isothermal process, we can obtain from the gas state equation pV = nRT:

$$p_0 V = pV + p_a Qt \tag{1}$$

p_a - Atmospheric pressure; Q - Leakage flow in free state; t - Leakage time; p_0 - Initial pressure of gas volume; p - Atmospheric pressure at time t.
Then we can obtain the relationship between differential pressure and leakage rate:

$$\Delta p = p_0 - p = Q \cdot t \cdot p_a / V \tag{2}$$

Since the differential pressure between the standard vessel and the electropneumatic valve to be tested is basically linear in the detection phase, we can derive the formula for calculating the gas leakage of the electropneumatic valve to be tested:

$$Q_L = \frac{\Delta p}{p_a}[V_T + \frac{\Delta V}{\Delta p}(1 + \frac{V_T}{V_R}) p_t] / t \tag{3}$$

Where: Q_L- gas leakage rate mL/s; △p - variation of differential pressure, Pa; p_a - atmospheric pressure, Pa;
t - the time that corresponds to the test on the differential pressure △p as produced, s;
△V/△p - differential pressure sensor coefficient, taking 1.36×10^{-7}mL/Pa;
V_R - volume of standard container, mL; V_T - volume of electropneumatic valve, mL; p_t - Test pressure, Pa

3. Design of Fixture for Electropneumatic Valve

Aiming at the two commonly used electropneumatic valve FSF and TFK5-110, the analysis shows that in order to ensure the hermeticity of the electropneumatic valve, the lower valve seat of the electropneumatic valve should be clamped correctly and tightly, as shown in Figure 2a. The lower valve seat face is a plane, and has air inlet and outlet in the middle, two Φ9 location holes at two sides, select the one side with two pins location mode to locate the lower valve seat with U hole semi-circular axis lead and the bottom surface of valve body as a reference using elements as shown in Figure 2b. In order to ensure the location accuracy and hermeticity, the air inlet and outlet that match those on the lower valve seat are designed on the dedicated valve seat, and the O ring is added; to achieve the university of the electropneumatic valve fixtures, self-localization pin that can rotate around the axis of the location hole; given that the electropneumatic valve is heavy, the gravity center skews to the rear part, so that the V block is used as the support at the end of the valve body. Position its fixture as shown in Figure 2c.

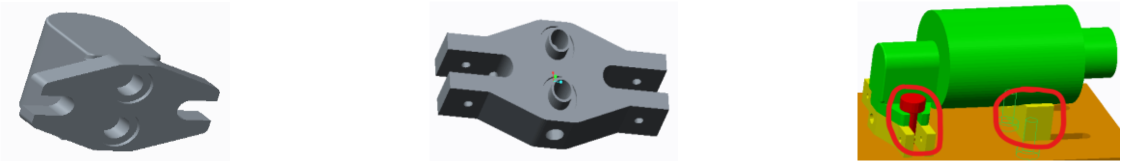

Figure 2: 3D map of electropneumatic valve location, (a) Lower valve seat, electropneumatic valve (b) Special valve seat for fixture (c) Location pin

In order to allow the fixture to clamp the electropneumatic valve to be tested, an air cylinder clamping mechanism is designed here, as shown in Figure 3a. It consists of the force source device, intermediate force transmission mechanism and clamping element. The cylinder and cylinder joints together constitute a force source device which provides clamping force for the fixture; the beam shown in Figure 3b is an intermediate force transmission mechanism where the sizes of the beam and clamping element location groove correspond to U groove in the valve seat. Two limits are the maximum and minimum location dimensions of the electropneumatic valve commonly used; pressure sensor connects beam and the location pin, also called clamping elements. When the cylinder moves upwards, the clamping force generated by the cylinder is transferred to the clamping element via the lever principle and push the self-location pin to clamp down, thereby clamp the electropneumatic valve. The fixture assembly is shown in Figure 3c.

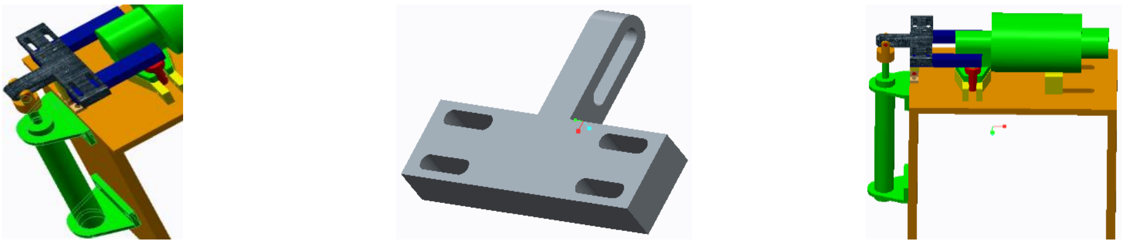

Figure 3: 3D map of electropneumatic valve clamps, (a) Clamp mechanism (b) Spacing adjustable beam (c) Fixture assembly

4. Design of Gauge Control System

4.1 Min. system MSP430G2553

The system uses the MSP430G2553 SCM as the control core. The minimum system, as shown in Figure 4, contains the power supply, reset circuit, internal clock, wake-up module, indicator module, and LCD driver module. Voltage regulator module stabilizes power supply to 3.3V; reset circuit uses a low-level mode, when pressing down the knob, RST is reset; the system performs a low-power key wake-up operation with P2.0, when the button is not pressed, the system is in a low-power state. If the system is awakened, it starts the detection; the indicator module uses P2.1, P2.2 control two color LEDs to remind whether the system supplies power and operates normally; LCD module uses P2.3, P2.4, P2.5 drive LCD display to timely display the test results.

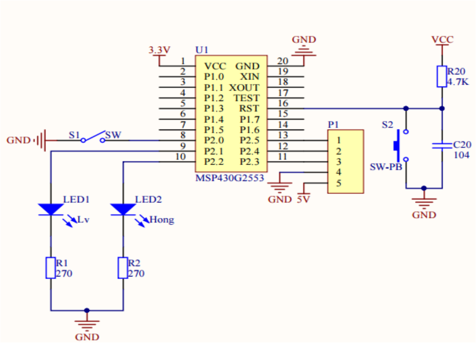

Figure 4: Schematic diagram of min system MSP430G2553

4.2 Differential pressure detection module

The differential pressure sensor uses the medical dual-channel pressure sensor SM5822-015-D, see Figure 5 for its principle. The sensor has advanced on-chip signal treatment and pressure sensor processing technologies, with in-chip auto amplification, calibration, correction, temperature compensation and other functions. In the pressure detection module, the external pressure acquisition interfaces A and B that access to the chip SM5822-015-D collect the amplified and high-level calibrated pressure signals at the analog output terminal, respectively. The signal is internally processed via the SM5822-015-D chip and transmitted by the P1.3 port to the processor.

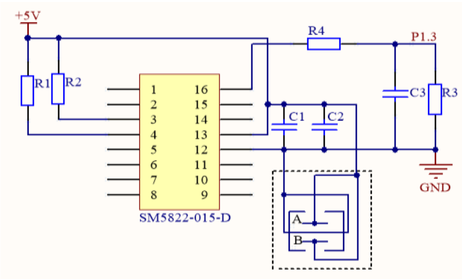

Figure 5: Schematic diagram of SM5822-015-D peripheries

4.3 Pressure detection module

It is deduced from calculation that the clamping force as required is at least 117.8 N, and the two arms are each subjected to 58.9 N. In order to timely supervise the system clamping force, a pressure sensor with a range of 0 Kg ~10 Kg and equipped with HX711 is selected as a 24-bit A/D converter chip designed for high-precision weighing sensor, see Figure 6 for external working principle. The input selector switch can arbitrarily select channels A or B to connect with its internal programmable amplifier. This sensor passes the signal via P1.1 and P1.2 to the SCM, and then uses its on-chip analog-to-digital converter ADC10 to convert the acquired analog signal into a digital signal, which is output to the display after SCM's operation. (Li et al., 2014)

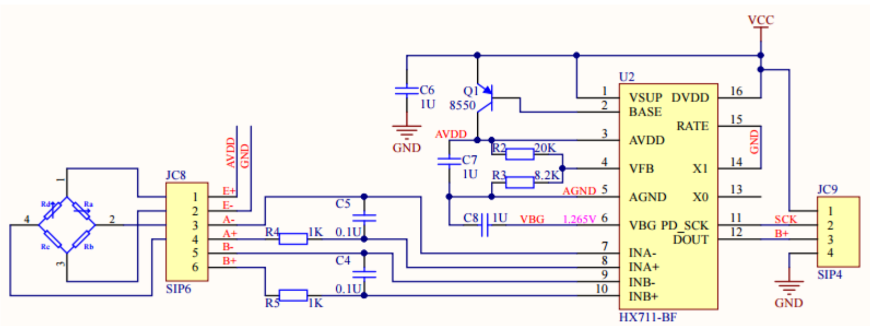

Figure 6: Working principle of sensor HX711 peripheries

5. Gauge Test

In accordance with the design standards, the modules such as pneumatic circuit, detection fixture and control system are assembled and debugged to constitute an experimental prototype for gauge, as shown in Figure 7. In order to improve the detection accuracy and reduce the system error, it is required to carry out zero setting for the initial state system, directly remove the electropneumatic valve, connect the inlet of the valve seat to the outlet, and then perform a normal detection. The software error compensation should be performed for the system based on the display result of the leakage rate so as to reduce system errors.

Figure 7: Schematic diagram of gauge debugging

Before formal measurement, manually adjust the pressure regulator valve to 100kPa. In the actual measurement phase, the system starts to operate. Finish the measurement after 10 minutes of pressure maintaining. Electropneumatic valve FSF is measured for 10 times at 100 KPa, refer to data in Table 1. The clamping force is kept within 119N-123N, the differential pressure within 8KPa-19KPa, the leakage rate within 62mL-129mL, the average clamping force is 120.7N, and the average pressure difference between the standard container and electropneumatic valve is 13KPa. The electropneumatic valve has an average leakage of 89.7 mL and an average leakage rate of 8.6%.

Table 1: Leakage measurements of electropneumatic valve FSF

Number of tests	Clamp strength (N)	Differential pressure (KPa)	Leakage amount(mL)	Leakage rate
1	120	13	86	8%
2	123	15	106	10%
3	121	15	102	10%
4	123	10	70	7%
5	121	8	62	6%
6	120	16	107	10%
7	121	19	129	12%
8	119	9	64	6%
9	120	12	82	8%
10	119	13	89	9%

Similarly, 10 measurements are performed on the electropneumatic valve TFK5-110, refer to data in Table 2. The clamping force is maintained within 119N-123N, pressure difference falls within 8KPa-17KPa, and leakage amount is controlled within 61mL-118mL. When the average clamping force is 120.5 N, the pressure difference between the standard vessel and the electropneumatic valve is 12.3 KPa. The electropneumatic valve leaks 86.9 mL at a leakage rate of 8.4%.

Table 2: Leakage measurements of electropneumatic valve TFK5-110

Number of tests	Clamp strength (N)	Differential pressure (KPa)	Leakage amount(mL)	Leakage rate
1	122	8	61	6%
2	120	13	89	9%
3	119	15	103	10%
4	123	10	78	8%
5	121	14	97	9%
6	120	16	107	10%
7	121	8	63	6%
8	119	9	64	6%
9	121	17	118	11%
10	119	13	89	9%

6. Conclusions

This gauge is used to measure the electropneumatic valve FSF and TFK5-110 samples sealed eligibly. Experimental data shows that the hermeticity of the electropneumatic valve is good, and their leakage rates do not exceed 10%, in accordance with the national standards. It turns out that the differential pressure method of gas hermeticity only needs to measure the value of the system pressure relative to the measurement pressure, the range of the sensor can be greatly reduced, so that the detection accuracy and sensitivity can be greatly improved; the system measurement pressure can reset to zero. Record the offset of pressure from system pressure only, so that the effects such as zero drift and temperature drift are only correlated to the measurement range of the differential pressure sensor, irrelevant to measurement pressure at the time of measurement; the temperature change and workpiece deformation are regarded sync when comparing the workpiece and the workpiece under test. With good adaptability to temperature changes and workpiece deformation, the electropneumatic valve hermeticity gauge can realize the qualitative and quantitative description for appropriate hermeticity detection, automatically complete the detection operation, improve the detection accuracy and efficiency, satisfy the objective requirements of locomotive control stability and safety while reducing the instrument cost. No environmental pollution will also occur. As above, it can effectively eliminate the existing defects in the hermeticity detection of electropneumatic valve, and also provide a reliable solution to the hermeticity detection of other equipment.

Acknowledgments

This article is supported by Xi’an science and technology planning project: CXY1443WL26.

References

Bai Z.S., Liu Z.Q., 2010, Level Measurement Based on Double Differential Pressure Method, Instrument Technique and Sensor, 1, 73-75, DOI: 10.3969/j.issn.1002-1841.2010.01.026.

Chen Y., Lin M., Guo B., 2010, Research on BP neural network in applied to air-leakage detection, Transducer and Microsystem Technologies, 4, 29-31, DOI: 10.13873/j.1000-97872010.04.024.

Kong X.F., Lian J., 2013, Air Tightness Detector Based on Embedded System, Instrument Technique and Sensor, 2, 28-30, 67, DOI: 10.3969/j.issn.1002-1841.2013.02.010.

Li D.Y., Hu Y.Y., Dang X.J., 2014, Determination of Process Parameters for Air Tightness Detection with Differential Pressure Method, 7, 64-66, 69, DOI: 10.3969/j.issn.1008-0813.2014.07.024.

Liu W.P., Wang M.Q., 2010, Gas Leak Detection by Differential Pressure Method, Mechanical Engineering & Automation, 1, 133-135, DOI: 10.3969/j.issn.1672-6413.2010.01.052.

Lu B., Shi Y., Zheng Z.J., Guo L.L., Tong X.M., Cai M. L., 2014, System Design and Experimental Verification of Air Tightness Detection System for Cylinder, Hydraulics Pneumatics & Seals, 7, 52-55, DOI: 10.3969/j.issn.1008-0813.2014.07.019.

Wei W., Zhang X.Y., Chen N., 2016, Air tightness test system for electric pneumatic valve based on differential pressure method, Chemical Engineering Transactions, 51, 1231-1236, DOI: 10.3303/CET1651206.

Xiong S.C., Liu X.Q., Qian B., 2012, Research on Temperature Compensation for Differential Pressure Type Leak Detector Based on Volume Compensation, Machine Tool & Hydraulics, 11, 44-46, DOI: 10.3969/j.issn.1001-3881.2012.11.013.

Yan R.J., Chen Z.Q., Wang J., Chai J., 2015, Design of Cylinder Valve Tightness Leak Quantitative Detection Device, Machine Tool & Hydraulics, 2, 168-170, 175, DOI: 10.3969/j.issn.1001-3881.2015.02.055.

Yang C.X., Yang H.J., Niu Y.L., 2015, Application of RT-Thread and Cortex-M4 for Intelligent and Airtight Detecting Device, Instrument Technique and Sensor, 3, 19-21, DOI: 10.3969/j.issn.1002-1841.2015.03.007.

Zhang J.L., Shang J., Pramanik N., Rao P.N., Li B., 2016, Development of Low-Cost Air-Based Hydraulic Leakage Detection System Through Real-Time Pressure Decay Data Acquisition Technology, The International Journal of Advanced Manufacturing Technology, 87, 3473-3483, DOI: 10.1007/s00170-016-8639-8.