Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

P2-26

DETERMINATION OF FLOW-RATE CHARACTERISTICS OF PNEUMATIC REGULATORS USING ISOTHERMAL TANK BY PRESSRE RESPONSE

Naotake ONEYAMA*, Huping ZHANG*, Mitsuru SENOO*, Guangzheng PENG**
and Jinglong YANG***

* Technology & Research Division, SMC Corporation Tsukuba Technical Center, 4-2-2, Kinunodai,
Tsukubamirai-shi, Ibaraki-ken, 300-2493 Japan
(E-mail: oneyama@smcjpn.co.jp)
** Automatic Control Department, Beijing Institute of Technology, PC 100081 Beijing, China
(E-mail: smcpeng@bit.edu.cn)
***Mechanics Department Tsinghua University, PC 100084 Beijing, China
(E-mail: yangjl@tsinghua.edu.cn)

ABSTRACT

ISO 6953:2000 prescribes that forward flow-rate and outlet pressure until maximum flow-rate shall be measured with a constant inlet pressure and two or more outlet set pressures, and their relations shall be indicated by curves on a graph [1][2]. Since this test requires not only a huge air compressor, but also keeping continuous large flow-rate for a long time, enormous energy is consumed. Thus, this paper proposes a method to obtain flow-rate characteristics from pressure response on charging/ discharging compressed air into/from an air tank as an alternative test. This test method requires none of a huge air source, a long testing time, and enormous energy consumption.

In this paper, the above-mentioned alternative test was performed to some pressure regulators which had different constructions and sizes from one another, and it was verified that the results of the alternative test successfully corresponded to the one by ISO 6953 using a flow meter. Examination to optimize the test method was also discussed. The running cost to operate the test, which consists of labor costs based on the test time and energy consumption, was reduced to approximately one-fifth.

KEY WORDS

Pneumatic pressure regulators, Flow-rate characteristics, ISO 6953, Isothermal tank

NOMENCLATURE

G: Mass flow-rate [kg/s]
m: Air mass within the isothermal tank [kg]
p_1: Gauge inlet pressure [MPa]
p_2: Gauge outlet pressure [MPa]
p_3: Gauge pressure within the isothermal tank [MPa]
p_{1abs}: Absolute inlet pressure [MPa]
p_{2abs}: Absolute outlet pressure [MPa]
p_{3abs}: Absolute pressure within the isothermal tank [Pa]
Q_{max}: Maximum outlet flow-rate [dm^3/min (ANR)]
Q_r: Choked relief flow-rate at p_{2abs} [dm^3/min (ANR)]
R: Gas constant 287 [J/(kg•K)]
t: Time [s]
T: Absolute temperature of air within the isothermal tank [K]

T_0: Absolute temperature at the standard conditions, 293 [K]
V: Volume of the isothermal tank [m^3]

INTRODUCTION

As shown in Figure 1, ISO 6953:2000 "Pneumatic fluid power – Compressed air pressure regulators and filter-regulators" prescribes that forward flow-rate and outlet pressure shall be measured with a constant inlet pressure and two or more outlet set pressures until the maximum flow-rate and their relations shall be indicated by curves on a graph. Since this test requires not only a huge air compressor, but also maintaining a continuous large flow-rate for a long time, enormous energy is consumed. Thus, this paper proposes a method to obtain flow-rate characteristics from pressure responses by charging/discharging compressed air into/from an air tank as an alternative test. This test method does not require a huge air source, long testing time, or enormous energy consumption.

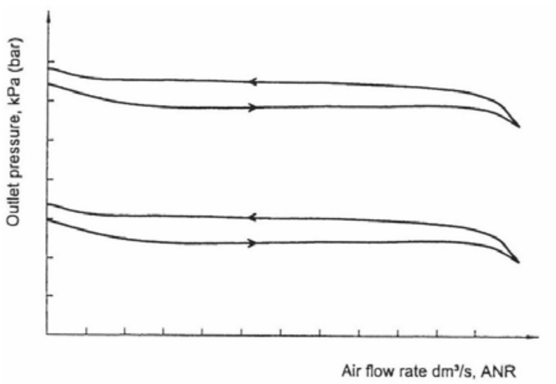

Figure 1 Forward flow characteristics

ISOTHERMAL TANK

The structure of the isothermal tank is shown in Figure 2. The tank consisting of container and the lid, is stuffed with material and has a flow port which connects test component. It also has a source port, with which air is charged or discharged in advance, a pressure measuring port and a drain port. The stuffed material should have a large heating surface area, large capacity, resistant to failure and corrosion-resisting. Thin wire with a diameter of 30μm or 50μm made of a material such as copper or stainless steel is suitable for stuffed material.
Figure 3 shows the temperature drop of each tank with different capacities and ratios of stuffed copper wire having a diameter of 50μm at air discharge. This data was taken when compressed air of 700 kPa was being discharged from the stuffed tank for approximately 15 seconds, that is, with a maximum pressure-drop rate of 100 kPa/s. If the density of the stuffed material is 0.3 kg/dm^3, the temperature drop can be suppressed to 3 K or less. In this case, the volume ratio of the stuffed material is 3.3 %.

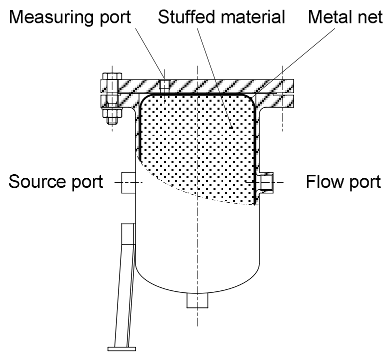

Figure 2 Structure of the isothermal tank

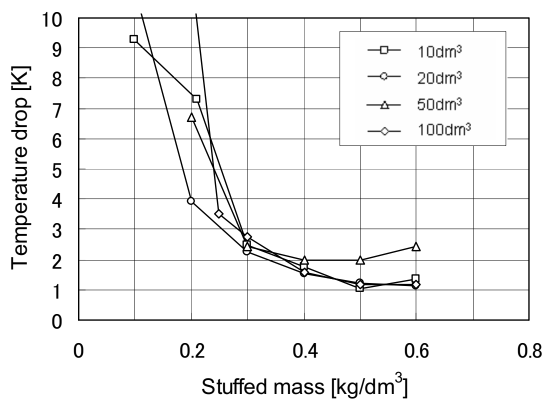

Figure 3 Isothermal performance

TEST INSTALLATION

Figure 4 shows the test equipment. The order of the connection of the test equipment is supply tank (A), regulator for setting inlet pressure (B), regulator under test (C), switching valve (D), and isothermal tank (E). Rectifier (F) and pressure measuring connector (M) are connected before and after the regulator under test. The sizes of the rectifier, regulator for setting inlet pressure, and connecting pipe are twice as large as or more than the size of the regulator under test. A high-pressure supply line (G) for relief test is also provided. If the relief capacity of the regulator under test is very small, discharge line (H) with a small isothermal tank and switching valve should be used to shorten the testing time.

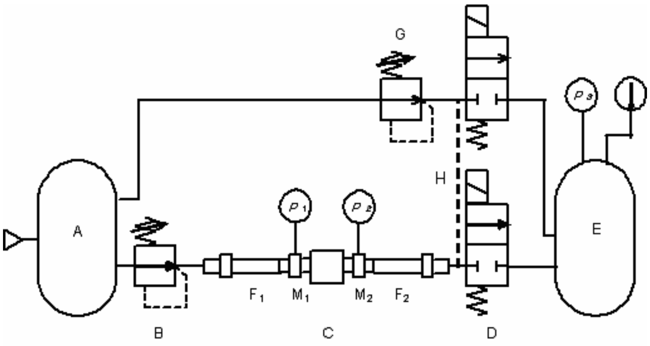

Figure 4 Test installation

TEST PROCEDURES

After inlet pressure is set at, say, 0.63 MPa and the regulator under test is set at, say, 0.4 MPa, charge air to the isothermal tank by opening the switching valve. The flow-rate can be calculated by time-differentiation of the pressure in the isothermal tank. The forward flow-rate characteristics can be obtained by illustrating the relation of the outlet pressure and this flow-rate.

Then, close the switching valve, and supply air to the isothermal tank from the high-pressure supply line up to, say, 0.9 MPa. Open the switching valve, and discharge air to the atmosphere from the relief port of the regulator under test. Calculate the flow-rate by the time differentiation of pressure within the isothermal tank. The relief flow-rate characteristics can be obtained by illustrating the relation of the outlet pressure and this flow-rate.

From the equation of the state of air within the tank,

$$p_{3abs} = \frac{mRT}{V} \tag{1}$$

Since the capacity of the isothermal tank and the temperature in the tank are constant, the mass flow-rate can be expressed by the following equation:

$$G = \frac{V}{RT}\frac{dp_{3abs}}{dt} \tag{2}$$

TEST RESULT OF REGULATOR (A)

Figure 5 shows the structure of direct operated regulator (A) of a body size of G1/2 with the relieving mechanism. The test results are as follows.

Figure 6 shows the pressure response when charging air to an isothermal tank of 100 dm^3 by opening the switching valve after inlet pressure at 0.63 MPa and regulated pressure at 0.4 MPa.

Since the regulator (A) had an extremely small relief flow capacity, the circuit was switched to the bypass discharge having an isothermal tank of 10dm^3 at the end of the line to shorten the testing time. The high-pressure supply line for relief was set at 0.9 MPa, and air was supplied to the small tank. The pressure response when discharging air to the atmosphere from the regulator (A) is shown in Figure 7.

Figure 8 shows the flow-rate characteristics obtained both from the pressure response when setting regulator (A) at 0.2, 0.3, 0.4, and 0.5 MPa, and from the test results of the flow-rate measurement based on ISO 6953. The characteristics curve obtained by calculating the measured pressure within the isothermal tank from equation (2) and by smoothing by the method of moving averages are in good agreement with the results of the flow-rate measurement.

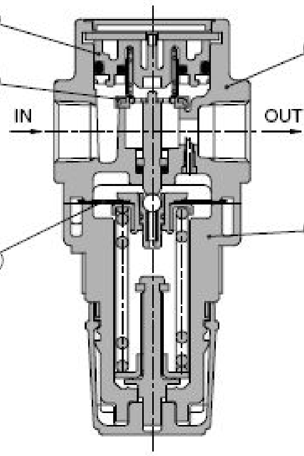

Figure 5 Regulator (A)

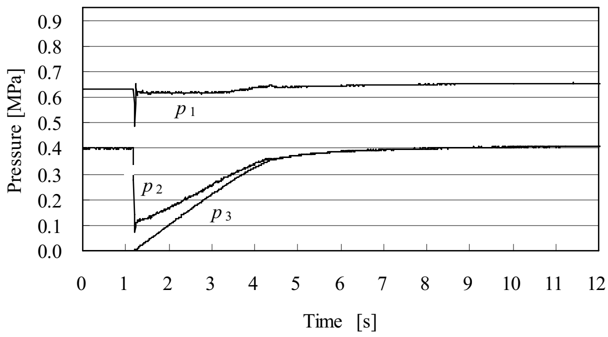

Figure 6 Pressure responses in the tank during charge – regulator (A)

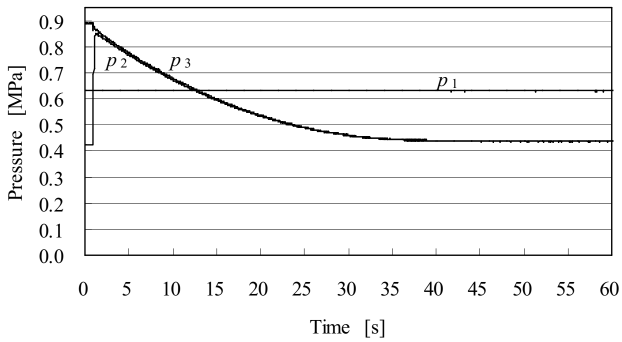

Figure 7 Pressure responses in the tank during discharge – regulator (A)

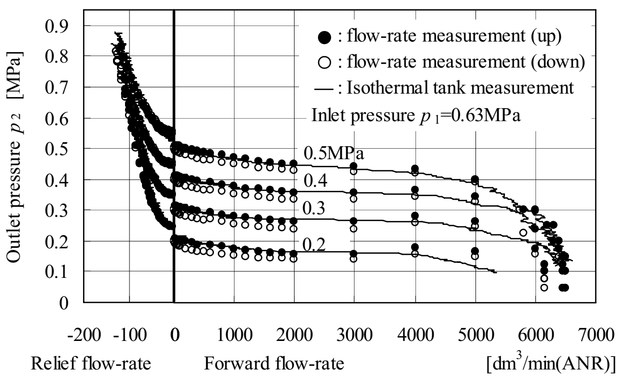

Figure 8 Flow-rate characteristics of regulator (A)

TEST RESULT OF REGULATOR (B)

Figure 9 shows the test structure of the internal pilot type regulator (B) of a body size of G1/4 with a nozzle-flapper type relieving mechanism. The test results are as follows:

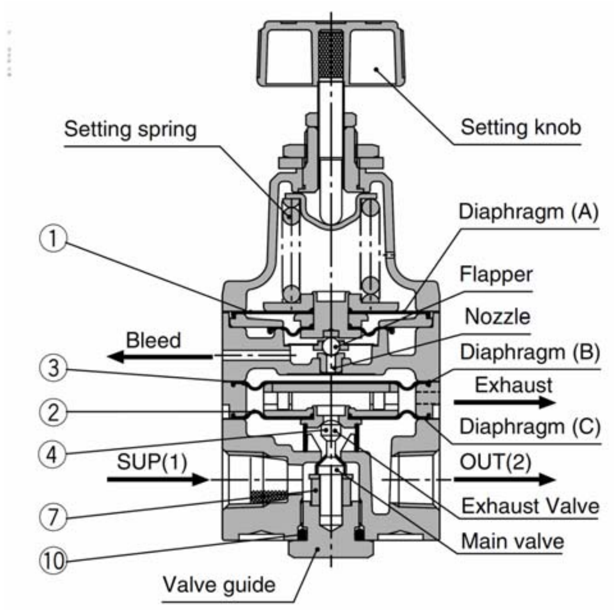

Figure 9 Regulator (B)

Figure 10 shows the pressure response when charging air to an isothermal tank of 10 dm^3 after setting inlet pressure at 0.63 MPa and regulated pressure at 0.4 MPa.

Figure 11 shows the pressure response when air is discharged to the atmosphere from test regulator (B) after the high-pressure supply line for relief is set at 0.9 MPa and air is supplied to an isothermal tank of 10 dm^3.

Figure 12 shows the flow-rate characteristics obtained both from the pressure response with the setting regulator (B) at 0.16, 0.25, 0.4, and 0.5 MPa, and from the results of the flow-rate measurement based on ISO 6953. The characteristics curves for the regulator (B) are also in good agreement with the results of the flow-rate measurement.

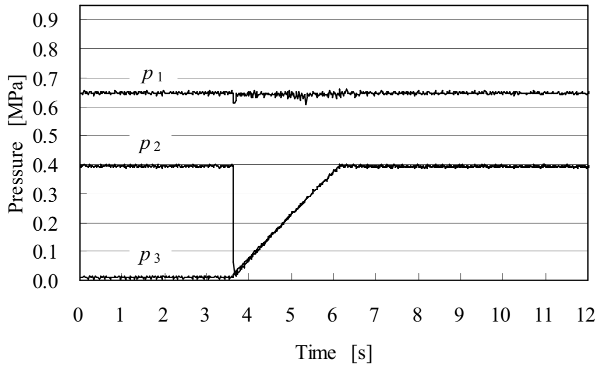

Figure 10 Pressure responses in the tank during charge – regulator (B)

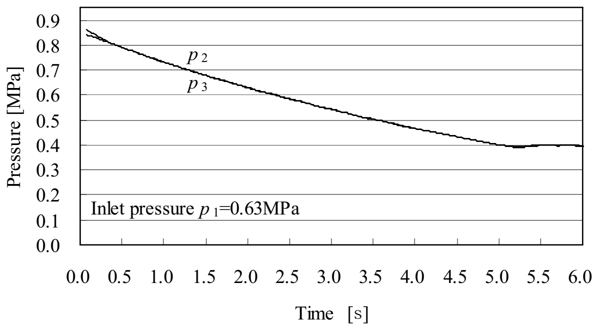

Figure 11 Pressure responses in the tank during discharge – regulator (B)

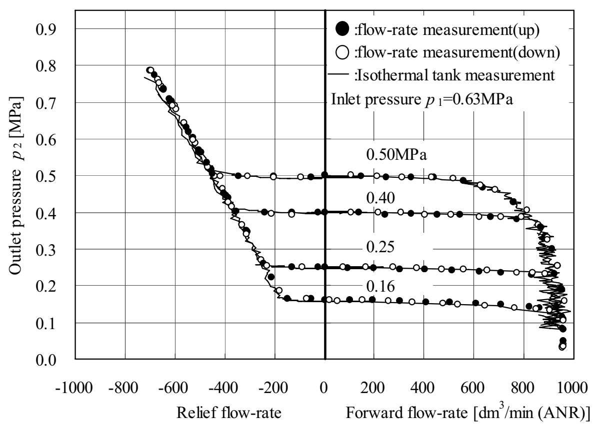

Figure 12 Flow-rate characteristics of regulator (B)

CHARACTERISTIC PARAMETERS

As shown in Figure 13, when the forward flow-rate characteristics of the regulator are approximated to the regression lines L_1 and L_2, and the relief flow-rate characteristics to the regression lines L_3 and L_4, calculated characteristic parameters of the regulator are obtained as shown in Table 1. The forward conductance and relief conductance represent the flow capacity of the regulator. The forward slope and relief slope represent the pressure regulating performance. The dead zone shows the initial pressure difference between the forward flow and relief flow. The regulator (A) is a regulator for general purpose which has extremely small relief flow capacity compared to the forward flow and has a large dead zone. The regulator (B) is a regulator for a precision use which has large relief capacity and extremely small dead zone.

ENERGY SAVING

The total testing time and the energy consumption which covers the mounting of the regulator under test to test installation, three repeated measurements, calculation, plotting, and removal of the regulator from the test installation were measured. Compared to the ISO 6953 flow-rate measurement test, this proposed test takes only 1/10 the amount of time and consumes only 1/30 the amount of air. It proves that this proposal offers a time- and energy-saving test method.

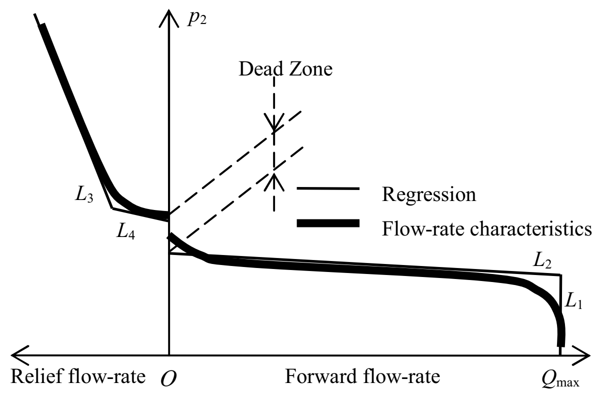

Figure 13 Definitions of the characteristic parameters

Table 1. Characteristic parameters of the regulators

Parameters	Calculation methods	Regulator (A)	Regulator (B)
Forward conductance	$C_0 = \dfrac{Q_{\max}}{600 p_{1abs}} \sqrt{\dfrac{T}{T_0}}$	16.1	2.49
Forward slope K_0	Gradient of regression L_2	-0.00884	-0.0123
Relief conductance	$C_{\mathrm{r}} = \dfrac{Q_{\mathrm{r}}}{600 p_{2abs}} \sqrt{\dfrac{T}{T_0}}$	0.306	1.46
Relief slope K_{r}	Gradient of regression L_3	-0.643	-0.0318
Dead zone P_{b}	Initial pressure difference between L_2 and L_4	30.3	0.00301

CONCLUSIONS

1. This paper describes designed test installation using an isothermal tank, and the results of the charging and discharging tests on two types shows good agreement with the test results based on ISO 6953 on two types of regulators which have different structures and sizes from each other.
2. This test method does not require a huge air pressure source. The testing time and energy consumption are extremely less than that of ISO 6953. This test method can save both time and energy.
3. This test method should be established as an alternative test method by further optimizing the equipment specifications and data processing.

REFERENCES

1. ISO 6953-1:2000, Pneumatic fluid power - Compressed air pressure regulators and filter-regulators - Part 1: Main characteristics to be included in literature from suppliers and product-marking requirements.
2. ISO 6953-2:2000, Pneumatic fluid power - Compressed air pressure regulators and filter-regulators - Part 2: Test methods to determine the main characteristics to be included in literature from suppliers.