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A NEW MEASUREMENT METHOD OF THE FLOW-RATE CHARACTERISTICS OF THE REGULATOR

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ABSTRACT

A new measurement method of the flow-rate characteristics of a regulator was proposed in this paper. Through charging a chamber connecting with the outlet of the regulator and measuring the pressure response in the chamber with a pressure sensor, the flow-rate characteristics curve was obtained from these sampled data. The process needs only one charge, so it brings high efficiency, good precision and less air consumption. The new method was studied through numerous simulations and experiments at different pressures. Results obtained from experiments and simulations were compared to find in good accordance, which verified the feasibility of the new measurement method.

KEY WORDS

Regulator, Flow-rate characteristics, Simulation, Measurement

NOMENCLATURE

B: viscous frictional coefficient, Ns/m
C_d: coefficient of the flow rate, Cd =0.7
G: mass flow rate, kg/s
K: spring coefficient of adjusting spring, N/m
K_1: spring coefficient of restoring spring, N/m
m: mass of the valve core, kg
p_0: absolute pressure of environment, MPa
p_2: outlet pressure of the regulator, MPa
p_s : absolute pressure of air source, MPa
R: gas constant, R=287N.m/(kg.K)
r: ratio of specific heats, r=1.4
S: effective area of elastic-membrane, m2
T: temperature of environment, K
V: cubage of the chamber, m3
W: air mass in chamber, kg
x: displacement of the adjusting spring, m
x_1: displacement of the valve core, m

INTRODUCTION

As well known, regulator is used in almost every pneumatic system. The function of the regulator is to maintain the working pressure of the system at a value which is set in advance and keep the outlet pressure constant while the flow rate changes. So it is very important to know the flow-rate characteristics of the regulator in order to optimize the design of a pneumatic system. The flow-rate characteristics is defined as the relationship of air flow capacity passing through the regulator and the differential pressure of the input pressure and outlet pressure[1]. The traditional measurement method[2] of the flow-rate characteristics of the regulator was showed in Figure 1. The working pressure of the system was set in advance. When the solenoid valve received an electrical signal, compressed air from the air source flew through the regulator. The pressure gauges *P1*, *P2* were used to record the input pressure and outlet pressure of the regulator, respectively, and the flow meter was used to measure the gas flow rate. One point in the flow rate characteristics curve was obtained at a set throttle uncork. By changing the uncork of the throttle, a curve was obtained from a group of points. It was apparent that this method was of low efficiency and needed large air consumption. In order to resolve these problems, a new measurement method of the flow-rate characteristics of a regulator was proposed in this paper.

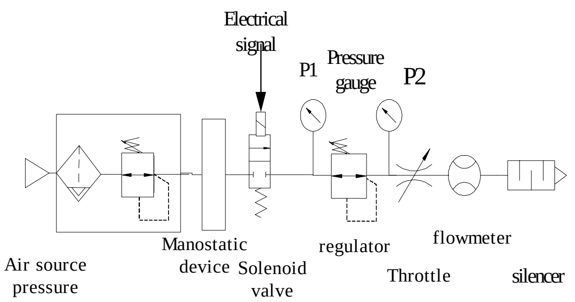

Fig.1Experimental Device Of The Conventional Method

The principle of the new measurement method was introduced and dynamic model of the regulator was established and simulated with Simulink[3]. Meanwhile, experimental research on the conventional measurement was carried out and LabVIEW was used to acquire data in the experiment. The simulation results and experimental results were compared in order to verify the feasibility of the new measurement method.

1. Principle of the new measurement method

The principle of the new method was shown in Figure 2. The system of the measurement was composed of a solenoid valve, a regulator to be measured, a chamber, a pressure sensor, a data acquisition card and a PC. When the solenoid valve received a signal from the PC, compressed air from the air source flew through the regulator to charge the chamber. The pressure response in the chamber was measured by the pressure sensor and the data acquisition card. And then a flow-rate characteristics curve was gained by analyzing the acquired pressure signals. It should be pointed out that only the quasi-equilibrium section of the regulator response in the course of charging was used to analyze its static characteristics in the new measurement method.

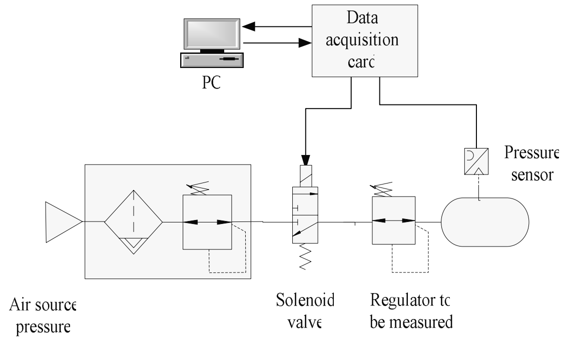

Fig.2 Principle Of The New Measurement Method

Assuming the pressure of air source and the cubage of the chamber were constant. The measurement principle of the new method could be explained using the equation of the energy and ideal-gas state equation. The state equation for compressed air in a chamber was written as Eq. (1).

$$PV = WRT \tag{1}$$

The following equation was derived by totally differentiating Eq. (1):

$$V\frac{dP}{dt} = GRT + WR\frac{dT}{dt} \tag{2}$$

If the state of compressed air in the chamber during charge or discharge remained isothermal, the following equation could be obtained from Eq. (2).

$$G = \frac{V}{RT}\frac{dP}{dt} \tag{3}$$

It was clear from Eq. (3) that if the cubage of the chamber V and the temperature of environment T were known, the mass flow rate G was proportional to the differentiated value of the pressure P in the chamber. Because the flow rate was continuous, the mass flow rate through the regulator was equal to which flew into the chamber. Assuming the outlet pressure was the same as the pressure in the chamber. So the curve of the flow rate characteristics of the regulator could be acquired from these data.

2. Simulation of the new measurement method

SIMULINK was used to verify the theoretical validity of the new measurement method by simulating the regulator and comparing the simulated curve with the traditional experimental curve. The simplified model of the direct-type regulator which was used to establish the mathematical model was shown in Figure 3.

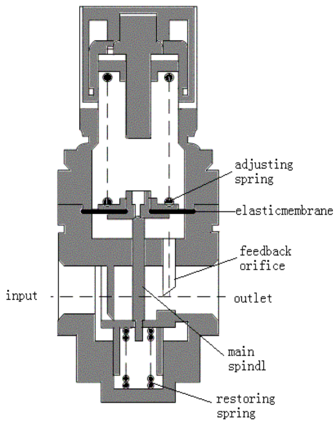

Fig.3 Simplified Model Of The Direct-type Regulator

2.1 Theoretical formulae used in simulation

When establishing the mathematical model[4][5] of the system, the following assumptions were made:

- Compressed air accorded with the ideal-gas state equation, and the air leakage because of ill sealing was neglected.
- The pressure and the temperature in the same chamber were even.
- The outlet pressure of the regulator was equal to the pressure in the chamber. Air source, atmospheric pressure and environmental temperature kept stable.
- The temperature of compressed air was isothermal in the chamber.

In the simulations, the mass flow rate *G* in the chamber was calculated with Eq. (3) and that through the regulator could be calculated with the following equation:

$$G = c_d S P_s \sqrt{\frac{2}{RT}}\varphi\left(\frac{P_2}{P_s}\right)$$

$$\varphi\left(\frac{P_2}{P_S}\right) = \begin{cases} \sqrt{\frac{r}{r-1}\left(\left(\frac{P_2}{P_S}\right)^{\frac{2}{r}} - \left(\frac{P_2}{P_S}\right)^{\frac{r+1}{r}}\right)} & 0.528 \le \left(\frac{P_2}{P_S}\right) < 1 \\ \left(\frac{2}{r+1}\right)^{\frac{1}{r-1}}\sqrt{\frac{r}{r+1}} & 0 < \left(\frac{P_2}{P_S}\right) < 0.528 \end{cases} \quad (4)$$

The force equilibrium equations were as follows:

For charging:

$$K(x_v - x) - P_2 S - K_1 x - B\dot{x} = m\ddot{x} \quad (5)$$

For discharging:

$$P_2 S - K x_v - K x_1 - B\dot{x}_1 = m\ddot{x}_1 \quad (6)$$

According to the Eq. (3), Eq. (4), Eq. (5), Eq. (6), the emulator of the regulator was shown in Fig 4.

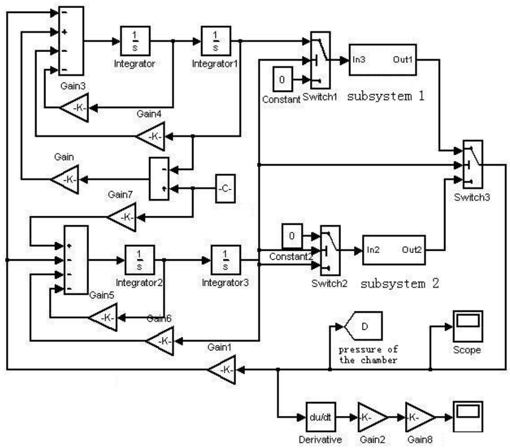

Fig.4 Emulator Of The Regulator

2.2 Results of simulation

2.2.1 The impact of the chamber cubage V

In the simulations, the pressure of air source and the outlet pressure were set 0.7MPa and 0.3MPa, and the chamber cubage V was 0.01 liter, 0.1 liter, 1 liter, 10 liter and 100 liter, respectively. Figure 5 showed the simulation results of the new measurement method of the flow-rate characteristics of the regulator. The five lines in the figure represented different chamber cubage. A conclusion was drawn from the figure: if the chamber cubage V was too small, there was no quasi-equilibrium process; if the chamber cubage V was too big, the pressure response became too slow. So it was very important to choose an appropriate cubage.

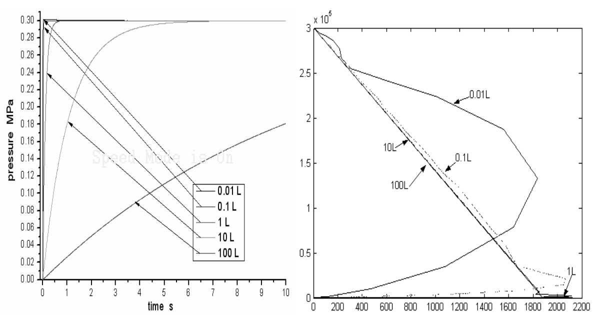

Fig.5 Simulated Curve Of The New Method

2.2.2 Comparison of the simulated curve and the traditional experimental curve

As shown in Figure1, the air source pressure and the outlet pressure of the regulator were set to 0.5MPa and 0.2MPa, respectively. Only the quasi-equilibrium phase in the simulated curve was analyzed in the research. As shown in Figure 6, the simulated curve agreed well with the experimental curve, which proved the feasibility of the new method.

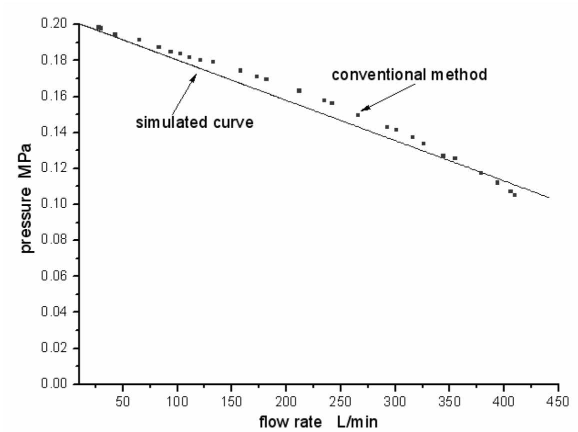

Fig.6 Comparison Of The Simulated Curve And The Experimental Curve

3. Experiment of the new measurement method

As shown in Figure 2, the air source pressure and the outlet pressure of the regulator were set 0.5MPa and 0.2MPa respectively to keep consistent with the conventional measurement method. The pressure signals in the chamber, which were sampled by the pressure sensor and the data acquisition card, were dealt with by ORIGIN, so the pressure-time curve and flow rate-time curve were shown in Figure 7 and the flow-rate characteristics curve of the new method was shown in Figure 8.

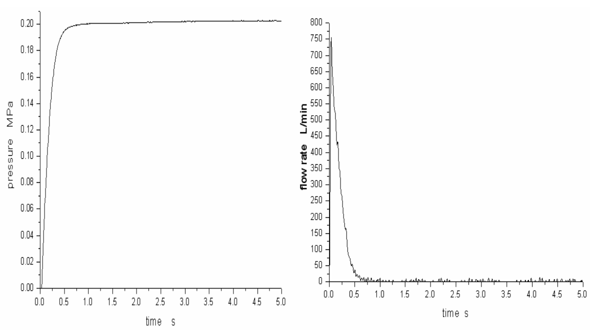

Fig.7 The Pressure-time And Flow Rate-time Figure

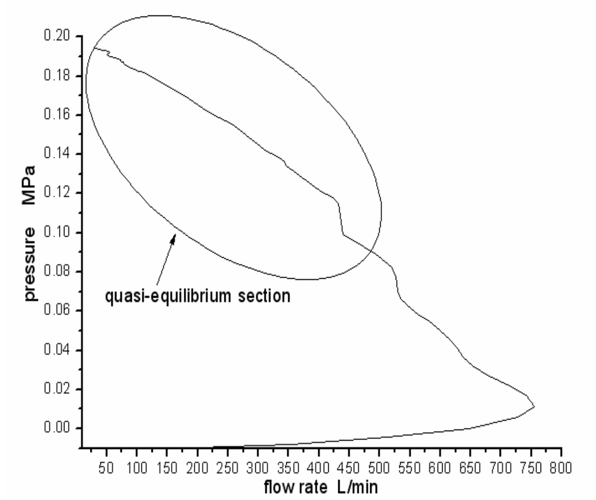

Fig.8 Flow-rate Characteristics Curve Of The New Method

Figure 9 showed the comparison result of the new measurement method and the conventional method. From this figure, it was clear that the curve gained by new method was similar to the curve obtained from the conventional method. Because the temperature was changing while charged the chamber, which was unchangeable during the simulation, there were some differences between two curves.

The result verified the feasibility of the new measurement method of the flow-rate characteristics of the regulator.

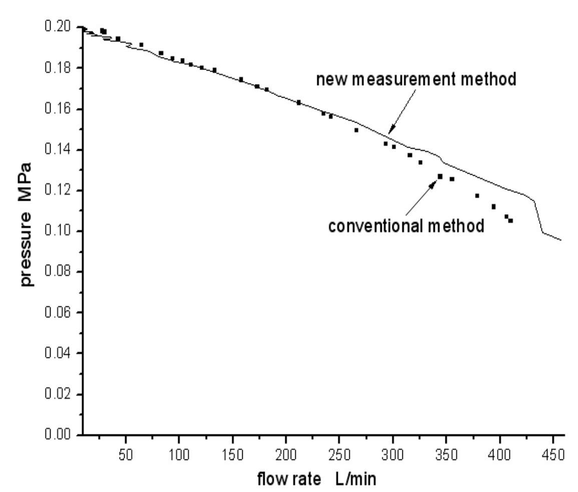

Fig.9 Comparison Result Of The New Method And The Conventional Method

4. Conclusion

This paper proposed a new measurement method of the flow-rate characteristics of a regulator. The basic principle of the new method was detailed. Then, simulations and the conventional method experiments were performed. The curves obtained from the conventional method and the new method were in good accordance, which verified the feasibility of the new method.

The new measurement method has some advantages such as high efficiency, good precision and less air consumption. So it will be possible to become a standard measurement method of the flow-rate characteristics of the regulator in future.

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