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PARALLEL CONNECTION MEASURING METHOD FOR GAS LEAKAGE BASED ON STANDARD FLOW

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ABSTRACT

The objective of work described in this paper is to propose a new method of measuring gas leakage for pneumatic industry. The measurement is enabled by employing standard flow. Standard flow is used to determine the internal volume of the measured equipment. An algorithm is formulated to describe, to the extent possible, the relationship between gas leakage and standard flow. This measurement method deviates from the theoretical leakage values by less than 5%, and shows a good precision and scope compared with the traditional flow measurements. In addition, the proposed parallel connection based on standard flow makes easy operation and fast measuring possible, thus promising new area of application for pneumatic equipments.

KEY WORDS

Gas Leakage, Parallel Connection, Standard Flow

NOMENCLATURE

G	: Massive flow rate	[kg/s]
k	: Kapper	
m	: Air mass	[kg]
P	: Internal pressure in pipeline of equipment	[Pa]
P_a	: Atmospheric pressure	[Pa]
P_f	: Reference pressure for standard flow	[Pa]
Q	: Volumetric flow rate	[l/min(ANR)]
R	: Ideal gas constant	[J/(kg • s)]
S_e	: Effective area	[m^2]
t	: Time	[s]
V	: Internal volume	[m^3]
θ	: Air temperature	[K]
θ_α	: Atmospheric temperature	[K]
ρ	: Air density	[kg/m^3]

Suffix:

l	: Leakage without Standard flow
s	: Standard flow
sl	: Leakage with Standard flow

1. INTRODUCTION

Today, compressed air has been widely used in industrialization since 1980s, because of cleanness, low-cost and easy maintenance of compressed air systems[1]. Compressed air systems are consuming approximate 5 percent of the total supplied electricity in china which reaches to two hundred billion kWh/year. But the consumption of gas leakage takes up to 10-50%[2]. Compared with traditional flow meters, the meter using the proposed new method can be connected parallel to the equipment to detect leakage in the equipment automatically. The relative measurement error can reach to less than 5%. So this method can be largely used for pneumatic equipment.

2. MEASURING PRINCIPLE

The Fig.1 shows the measuring circuit which includes a standard flow circuit.

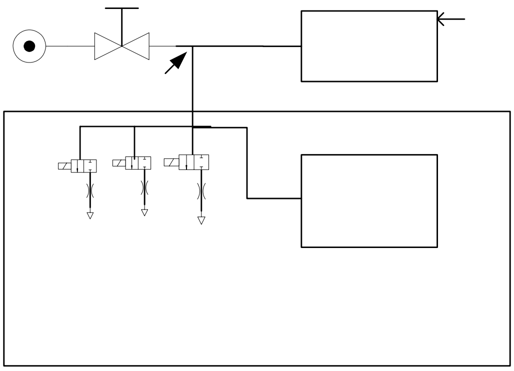

Figure 1 Measuring circuit

Based on thermodynamics, the state equation of compressible air in a chamber can be written as

$$PV = mR\theta \tag{1}$$

When leakage happens, the following equation is derived by differentiating Eq.(1):

$$V\frac{dP_l}{dt} = G_l R\theta + mR\frac{d\theta}{dt} \tag{2}$$

Where G is negative during discharging, and vice versa. To eliminate the temperature effect on the dynamic air pressure, it is necessary to wait until the temperature in equipment become constant after charging[3][4]. So the temperature in equipment can be considered as atmospheric temperature during the measurement. So the equation obtained from Eq. (2) is

$$V\frac{dP_l}{dt} = G_l R\theta_a \tag{3}$$

The volume V varies from different equipments and pipelines. To void the uncertainty of V, we design a standard flow circuit which includes three solenoid valves. For the volume of solenoid valve is far smaller than that of pipeline in equipment, when the standard flow circuit works, Eq. (3) can be written as

$$V\frac{dP_{sl}}{dt} = (G_l + G_s)R\theta_a \tag{4}$$

When leakage happens in the pipeline, compressed air flow through orifice with high speed, the heat can not transfer completely at all.So it can be considered as one-dimensional isentropic flow. For the downstream pressure of leakage passage equals to the atmospheric pressure, the mass flow rate can be expressed as Eq.(5):

$$G = S_e PB \tag{5}$$

Where B are:

$$B = \begin{cases} \sqrt{\dfrac{\kappa}{R\cdot\theta_a}\left(\dfrac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} & \dfrac{P_a}{P} \le 0.5283 \\ \sqrt{\dfrac{2\kappa}{(\kappa-1)}\dfrac{1}{R\cdot\theta_a}\left[\left(\dfrac{P_a}{P}\right)^{\frac{2}{\kappa}} - \left(\dfrac{P_a}{P}\right)^{\frac{\kappa+1}{\kappa-1}}\right]} & \dfrac{P_a}{P} > 0.5283 \end{cases}$$

For $P_a/P < 0.528$, leakage flow rate is proportional to internal pressure, and we can get the Eq.(6):

$$\begin{aligned} G_l &= S_{el}P_l\sqrt{\frac{\kappa}{R\cdot\theta_a}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} \\ G_s &= S_{es}P_f\sqrt{\frac{\kappa}{R\cdot\theta_a}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} \end{aligned} \tag{6}$$

In Fig.2, the simulation shows how the internal pressure in equipment pipeline changes during leakage, Where R =287, θ=293k, V=20L, P_f =0.5MPa, G_l= -0.987×10^{-3}kg/s, G_{s1}=-0.3957×10^{-3}kg/s, G_{s2}=-0.987×10^{-3}kg/s, G_{s3}= -2.0×10^{-3}kg/s.

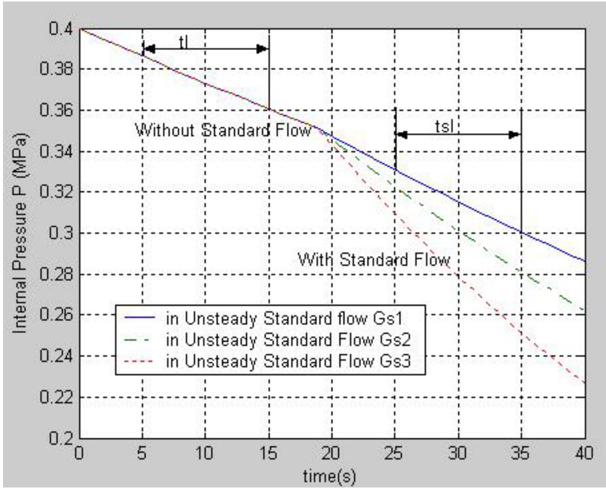

Figure 2 Pressure Change in the Leakage

In the state of leakage, the average internal pressure can be expressed by Eq.(7):

$$V\frac{dP_l}{dt} = S_{el}P_lR\theta_a\sqrt{\frac{\kappa}{R\cdot\theta_a}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}}$$

$$V\frac{dP_{sl}}{dt} = (S_{el}+S_{es})P_{sl}R\theta_a\sqrt{\frac{\kappa}{R\cdot\theta_a}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} \qquad (7)$$

Eq.(7) can be further expressed as Eq.(8) :

$$\ln(P_{ld}/P_{lb}) = S_{el}R\theta_a t_l\sqrt{\frac{\kappa}{R\cdot\theta_a}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}}$$

$$\ln(P_{sld}/P_{slb}) = (S_{el}+S_{es})R\theta_a t_{sl}\sqrt{\frac{\kappa}{R\cdot\theta_a}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} \qquad (8)$$

Based on Eq.(6) and Eq.(8) ,leakage flow rate at P_l can be written as Eq.(9):

$$G_l = \frac{G_s}{P_f}\cdot\frac{P_l}{\left(\frac{t_l}{t_{sl}}\cdot\frac{\ln(P_{sld}/P_{slb})}{\ln(P_{ld}/P_{lb})}-1\right)} \qquad (9)$$

Where P_{sld}: Internal pressure during leakage with standard flow at the end time, P_{slb}: Internal pressure during leakage with standard flow at the beginning time, P_{ld}: Internal pressure during leakage without standard flow at the end time, P_{lb}: Internal pressure during leakage without standard flow at the beginning time.

3. EXPERIMENT APPARATUS

The measuring circuit is shown in Fig.3. The pilot valve A and standard vale 1, 2 and 3 are all controlled by PC. The orifice of standard valve is 3 mm, and its maximum pressure can reach to 1.0MPa. The volume of chamber is 30L. The maximum measurement pressure of pressure sensor is 1.0 MPa , and the measurement error can reaches to 0.5%. Leakage flow is controlled by a control valve which provides maximum rate 1000l/min(ANR) at 0.6MPa. Real-time pressure signal in the pipeline is gathered by PC. When leakage happens, pressure in equipment will decrease. After standard flow happens, a different differential pressure will occur accordingly. Leakage flow rate can be calculated with two differential pressure changes.

The measuring program is ruled by the following steps:

i) Charge air into the pipeline, and then wait until the temperature recover to the room temperature.
ii) Close the standard flow circuit, then measure the internal pressure in equipment pipeline P_{lb} 、P_{ld} and leakage period t_l.
iii) The standard flow circuit will work automatically and measure the internal pressure in equipment pipeline P_{slb} 、P_{sld} and leakage period t_{sl}.

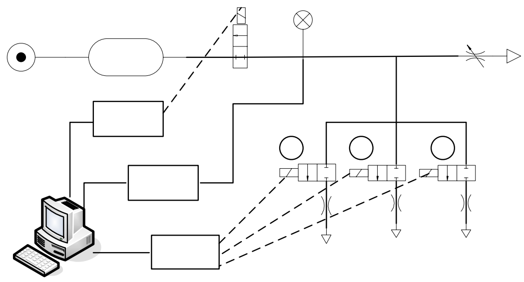

Figure 3 Leakage Flow Measuring Circuit Based on Standard Flow

4. RESULT AND DISCUSSION

Based on the measuring principle and experiment apparatus, experiments have been carried out for the different leakage flow. The measurement result is shown in Table.1. For a pressure wave effect to the pressure sensor when standard flow happens, there will be a sudden drop in the pressure curve in figures below. The internal meter pressure data in experiment with sampling frequency 40 HZ are shown in Fig.4 and Fig.5. The Standard leakage flow rate in Fig.4 equals to -365[l/min(ANR)] at 0.6MPa, and in Fig.5 equals to -114[l/min(ANR)] at 0.6MPa.

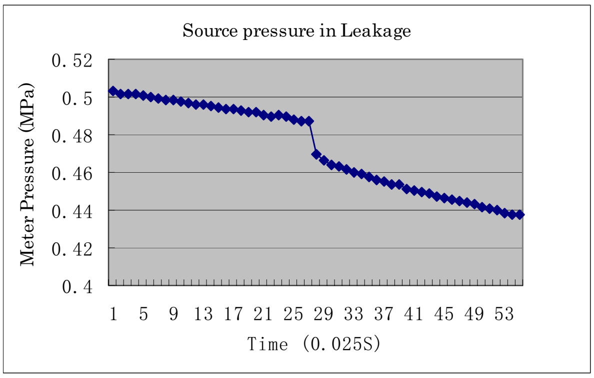

Figure 4 Source pressure in Standard Leakage

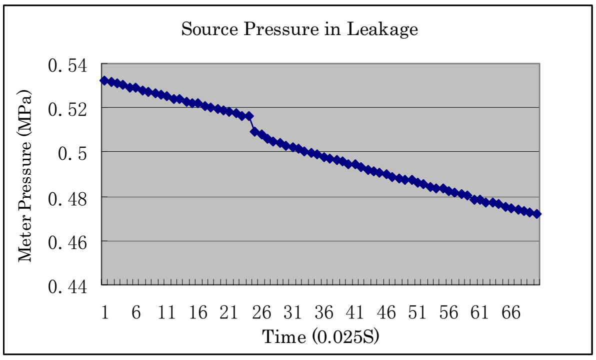

Figure 5 Source pressure in Standard Leakage

5. CONCLUSION

In this paper, a measurement method with parallel connection for gas leakage flow based on standard flow is developed. The relative error has been proved to be less than 5%. Compared with traditional method, it can be connected to equipment pipeline easily which promises the extensive use in pneumatic industry.

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Table 1 Measurement result Table

Leakage No.	Leakage Flow [l/min(ANR)]	Standard Flow [kg/s]	Measure Flow [l/min(ANR)]	ERROR [%]	P_f [MPa]
N0.1	-460	-365	-440.532	4.23	0.6
N0.2	-210	-365	-217.692	3.66	0.6
No.3	-80	-114	-77.2415	3.44	0.6
No.4	-60	-114	-61.007	1.66	0.6
No.5	-36	-114	-35.347	1.81	0.6
No.6	-20	-114	-19.380	3.10	0.6