

A NOVEL CONCENTRIC ANNULAR CLEARANCE MEASURING METHOD BASED ON PNEUMATIC FLOWRATE BALANCE

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Abstract: A novel method of measuring the annular concentric clearance is proposed to estimate the clearance height between the piston and the cylinder. The principle of the method is that pneumatic flow rate through the clearance is an assured function of the height and the upper stream pressure of clearance. Firstly, the measuring principle was proposed. Then the simulation model was built in AMESim, and the clearance-pressure data tables were obtained. Finally, the experiment was carried out, and the results showed that the clearance measuring method was effective and can be used to estimate similar clearances.

Keywords: high pressure pneumatic, concentric annular clearance, flow rate, indirect measurement

1. THE CLEARANCE MEASURING ASSEMBLY AND ITS WORKING PRINCIPLE

The designed pneumatic pressure assembly is shown in Fig.1, it's mainly consisted of gas supply, pressure valve, controller, pressure sensors and the controlled cavity with fixed concentric annular clearance^[1,2]. Gas in the controlled cavity flows through the concentric annular clearance into atmosphere under the pressure difference between the cavity and atmosphere, while the controller detects pressure in the cavity and controls opening of the pressure valve at the same time.

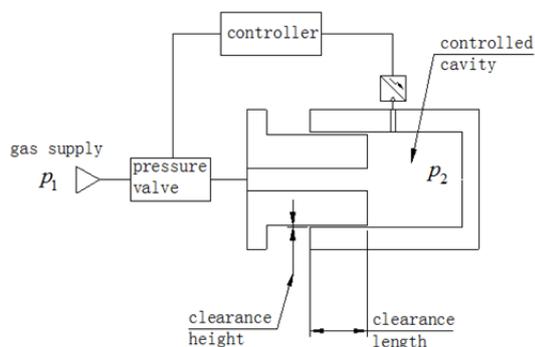


Fig.1, Schematic diagram of the clearance indirectly measuring assembly

Pressure valve is the core component of the pressure assembly. According to the requirement of continuity, rapidity, stability and low flow rate for its

pressure control, a single stage slide valve is proposed. Structure of the proposed valve is shown in Fig.2(a), and detailed structure of the spool is shown in Fig.2(b).

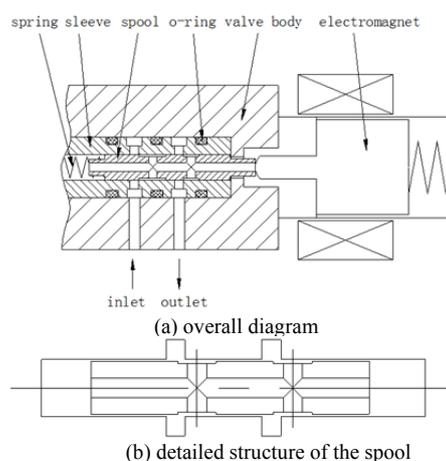


Fig.2 Schematic diagram of the pressure valve

The valve mainly consists of valve body, spool, sleeve and necessary sealing components, the throttle orifice of the sleeve is symmetrically rectangular structured and a proportional electromagnet is used to control displacement of the spool and hence to control pressure of the controlled cavity. According to its structure, the valve has such characteristics: (1) easy to be controlled and responses fast; (2) has a good linearity; (3) controllable flow rate is low; (4) has certain leakage.

Here the height of the annular clearance of the pressure valve is assigned as C_{h_v} , and the height of the annular clearance of the pressure chamber is assigned as C_{h_c} . Other parameters except for C_{h_v} and C_{h_c} could be measured. If the gas supply pressure p_1 is stable and the input signal of the pressure valve is set as zero, the leakage gas will flow through the pressure valve and the pressure chamber. Since the opening of the valve is zero, the pressure in the chamber is the minimum controllable pressure, which is assigned as p_{2_min} . When the valve is fully opened, the flow rate through the valve and the chamber is maximized. The pressure in the chamber is the maximum controllable pressure, which is assigned as p_{2_max} . Since other structure parameters and pressure could be measured directly, the value of C_{h_v} and C_{h_c}

could be derived with flow rate balance functions with p_{2_min} and p_{2_max} .

2. CONTROLLABLE PRESSURE SIMULATION OF THE ASSEMBLY

The simulation model of the clearance indirectly measuring assembly is built up in AMESim(Fig.2), and it is mainly consist of three parts: the gas supply, the pressure valve and the pressure chamber^[3-5]. The pressure of the gas supply and the atmosphere is set as 12 MPa and 0.1 MPa respectively. The designed height of annular clearance in the pressure valve C_{h_v} is 6 μm , while the designed height of annular clearance of the controlled cavity C_{h_c} is 30 μm . Due to uncertainty of machining and assembly process, the height of clearances may varies a lot from deigned size, it's assume that C_{h_v} varies in range of 1~30 μm and C_{h_c} varies in range of 1~50 μm in the simulation. The volume of the pressure chamber is $9.42 \times 10^3 \text{ mm}^3$, and the maximum passage area of the pressure valve is 0.96 mm^2 .

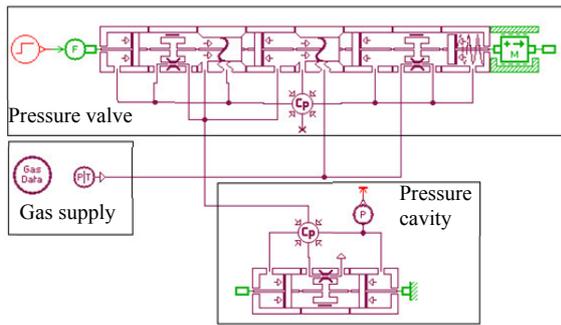


Fig.3, The AMESim simulation model of the clearance indirectly measuring assembly

Firstly, the p_{2_min} is simulated. We set C_{h_v} as a certain value, simulate different p_{2_min} under different C_{h_c} , and then change the value of C_{h_v} , and so on. Finally we get the p_{2_min} under different combinations of C_{h_v} and C_c as shown in Table.2, and get the p_{2_min} -clearances relationship (Fig.4) based on these data.

Table 1, Simulation results of p_{2_min}

| C_{h_v} (μm) | C_{h_c} (μm) | | | | | | | | | | |
|---------------------------------|------------------------------|-------|-------|-------|-------|------|------|------|------|------|------|
| | 1 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 1 | 12 | 3.58 | 1.27 | 0.69 | 0.45 | 0.32 | 0.25 | 0.19 | 0.16 | 0.13 | 0.11 |
| 5 | 12 | 9.48 | 4.49 | 2.53 | 1.65 | 1.19 | 0.9 | 0.72 | 0.59 | 0.49 | 0.42 |
| 10 | 12 | 11.44 | 8.43 | 5.57 | 3.84 | 2.81 | 2.16 | 1.72 | 1.41 | 1.19 | 1.01 |
| 15 | 12 | 11.81 | 10.43 | 8.18 | 6.18 | 4.72 | 3.71 | 2.99 | 2.47 | 2.08 | 1.79 |
| 20 | 12 | 11.91 | 11.24 | 9.81 | 8.09 | 6.55 | 5.31 | 4.37 | 3.66 | 3.11 | 2.68 |
| 25 | 12 | 11.95 | 11.58 | 10.7 | 9.43 | 8.05 | 6.79 | 5.73 | 4.88 | 4.19 | 3.64 |
| 30 | 12 | 11.97 | 11.75 | 11.19 | 10.28 | 9.17 | 8.03 | 6.97 | 6.04 | 5.26 | 4.62 |

It can be seen from Table 1 and Fig.4 that both C_{h_v} and C_{h_c} influence a lot on p_{2_min} : larger the C_{h_v} , higher the p_{2_min} ; larger the C_{h_c} , lower the p_{2_min} . When C_{h_v} is pretty small (1 μm) and C_{h_c} is pretty large (50 μm), p_{2_min} is low to 0.11 MPa which is close to atmospheric pressure; when C_{h_v} is big (>10 μm) and

C_{h_c} is small (<5 μm), p_{2_min} is higher than 11 MPa which is close to p_i , here the range of controllable pressure is quite small and pneumatic pressure assembly almost lose the ability to regulate pressure.

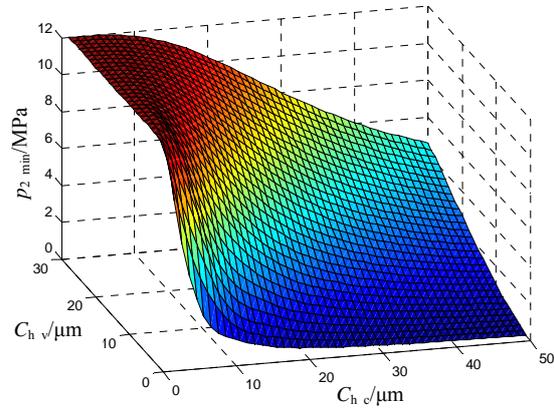


Fig.4, Relationship of p_{2_min} -clearances

Similarly as the simulation process of p_{2_min} , we change the value of C_v and C_c in turn and get simulation results of p_{2_max} as shown in Table 2, and then get the p_{2_max} -clearances relationship (Fig.5) by interpolation.

Table 2, Simulation results of p_{2_max}

| C_{h_v} (μm) | C_{h_c} (μm) | | | | | | | | | | |
|---------------------------------|------------------------------|----|-------|-------|-------|-------|------|------|------|------|------|
| | 1 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 1 | 12 | 12 | 11.98 | 11.84 | 11.24 | 10 | 8.5 | 7.1 | 5.94 | 5 | 4.23 |
| 5 | 12 | 12 | 11.99 | 11.84 | 11.24 | 10.01 | 8.51 | 7.11 | 5.95 | 5.01 | 4.28 |
| 10 | 12 | 12 | 11.99 | 11.84 | 11.26 | 10.06 | 8.59 | 7.21 | 6.05 | 5.11 | 4.38 |
| 15 | 12 | 12 | 12 | 11.85 | 11.29 | 10.17 | 8.77 | 7.42 | 6.28 | 5.35 | 4.59 |
| 20 | 12 | 12 | 12 | 11.85 | 11.35 | 10.35 | 9.05 | 7.77 | 6.65 | 5.71 | 4.94 |
| 25 | 12 | 12 | 12 | 11.86 | 11.43 | 10.56 | 9.41 | 8.22 | 7.12 | 6.18 | 5.39 |
| 30 | 12 | 12 | 12 | 11.88 | 11.51 | 10.78 | 9.79 | 8.71 | 7.67 | 6.74 | 5.93 |

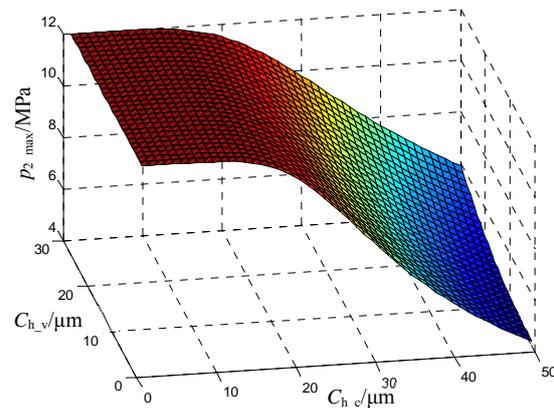


Fig.5, Relationship of p_{2_max} -clearances

It can be seen from Table 2 and Fig.5 that p_{2_max} is mainly affected by C_{h_c} . When C_{h_c} decreases from 50 μm to 10 μm , p_{2_max} increases from about 4 MPa to 12 MPa which is the pressure of gas supply.

For a certain p_{2_min} , the contour line could be obtained from the p_{2_min} -clearances figure and the contour line's abscissa axis and longitudinal axis represent for the combination of different C_{h_v} and C_{h_c} . We assume that the p_{2_min} is 5 MPa, and the contour line could be obtained as shown in Fig.6, and

the (C_{h_v}, C_{h_c}) could be (9, 15), (15, 24) or (28, 45) and so on.

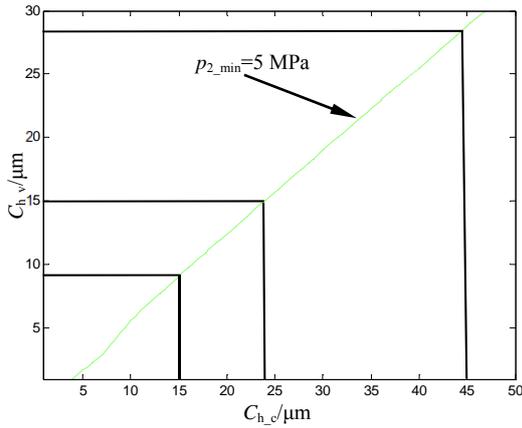


Fig.6, The contour line of $p_{2_min}=5$ MPa

Similarly, the contour line of p_{2_max} could also be obtained, hence the unique combination of (C_{h_v}, C_{h_c}) could be obtained.

4. EXPERIMENTAL RESEARCH

Based on the foundation of simulation, we carried out detailed experimental research, and schematic diagram of the test bench is shown in Fig.7. It mainly consists of gas supply, pressure valve, controlled cavity and necessary measurement and control facilities, p_i is 12 MPa.

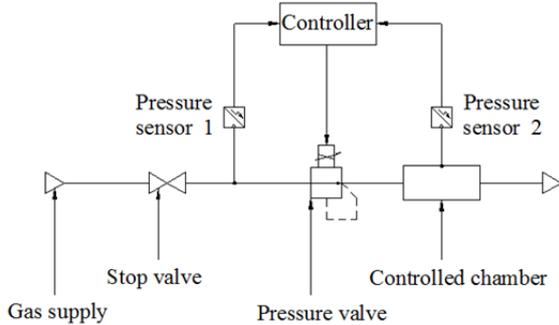


Fig.7, Schematic diagram of the test bench

When measuring p_{2_min} open the stop valve, cut off the control current of the pressure valve and let the gas flow freely, then measure steady pressure of the controlled cavity and the pressure measured is 1 MPa which is p_{2_min} of the pressure assembly; when measuring p_{2_max} , open the stop valve and manually apply control current on the pressure valve to make sure that the valve port is totally opened, then measure the steady pressure of the controlled cavity and get p_{2_max} as 8 MPa.

According to p_{2_min} and p_{2_max} charts in Fig.4 and Fig.5, we draw contour lines of $p_{2_min}=1$ MPa and $p_{2_max}=8.4$ MPa in the same coordinate system and get the curve as shown in Fig.8. Since each contour line represents a combination of the C_{h_v} and C_{h_c} , then ordinate and abscissa of the intersection point of these

two contour lines is the actual value of C_{h_v} and C_{h_c} respectively, that is $C_{h_v}=6$ μm and $C_{h_c}=31$ μm . These values are quite close to the designed value of $C_{h_v}=6$ μm and $C_{h_c}=30$ μm .

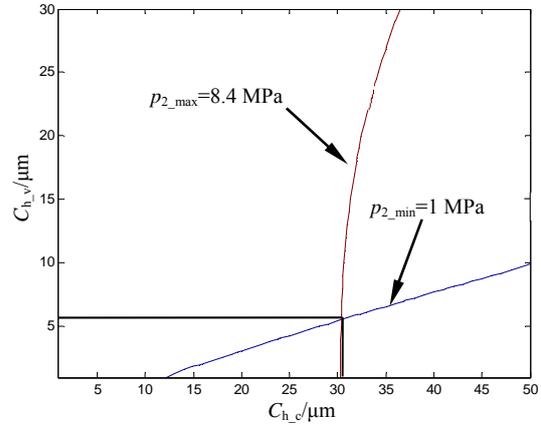


Fig.8, The contour line of p_{2_min} and p_{2_max}

5. CONCLUSIONS

1.Experimental results show that controllable pressure of the pneumatic pressure assembly ranges in 1~8.4 MPa with the p_i of 12 MPa, the designed pressure valve can achieve the function of fast and stable pressure controlling. C_{h_v} and C_{h_c} are derived as 6 and 31 μm according to simulation and experimental results.

2.Machining clearances like the annular concentric clearances are difficult to be measured. The indirect method combining with simulation and experimental results in this paper has a certain reference meaning for solving similar problems in mechanical field.

6. REFERENCES

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