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RESEARCH ON A NEW TYPE OF ENERGY SAVING PNEUMATIC PISTON VACUUM GENERATOR

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ABSTRACT

Currently used jet vacuum ejector has a defect of high air consumption due to its requirement of continuous air supply. Focusing on this problem, a new type of piston vacuum generator (PVG for short) has been researched. The PVG has two pairs of pistons. One is for driving and another is for vacuum generating. Besides the maximum vacuum value, the vacuum response time and air consumption are the most concerning performances. Special structural design is made so as to meet all the requirements, in which the unequal diameters of pistons, using directional control valves instead of the check valves and stepped flow rate control scheme are proposed and realized. Experimental results have shown that for the prototype of piston vacuum generator its maximum vacuum is about 93kPa, the response time is about 3.7s and the air consumption is reduced by about 71.3% in time interval of 60s compared to the same level of vacuum ejector.

KEY WORDS

Piston Vacuum Generator(PVG), energy saving, stepped flow rate control

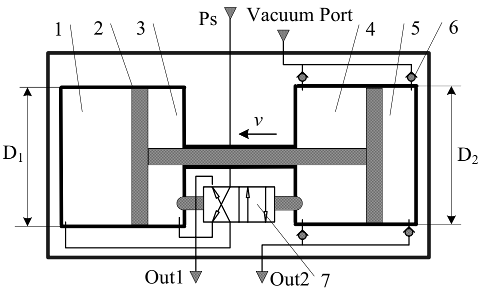
INTRODUCTION

Vacuum pads have been used extensively in vacuum picking operation in pneumatic control systems. Vacuum picking has advantages for moving tiny, easily-deforming or easily-breaking parts[1]. At present, main pneumatic vacuum generating component in industry is still vacuum ejector. According to the working principle of vacuum ejector, compressed air needs to be ejected directly from inlet to outlet and must be maintained for keeping a certain vacuum. Therefore, it has to consume large compressed air and be inefficient in application[2,3]. To solve the problem of high air consumption, a new type of energy-saving vacuum generator called Piston Vacuum Generator(PVG for shot), which works on the principle of generating vacuum by volume expansion, is proposed and researched. It provides a new technical approach for saving energy in pneumatic vacuum system. The structure, key technologies and testing results are introduced in following sections.

STRUCTURE OF PVG

Vacuum could be generated not only by air ejecting, but also by volume expansion[4,5], i.e., by means of piston moving, the piston chamber is enlarged so as to make air expand to decrease the pressure and form vacuum state in the chamber. For applying this principle to generate vacuum and draw air from vacuum pads, a double piston structure of a piston vacuum generator is designed as shown in Figure 1. One of the pistons is in the driving chamber and another is in the vacuum chamber in the PVG. Because of the restriction of structure sizes, the device can not provide the enough vacuum ability at one stroke of pumping operation. Therefore, the vacuum chamber piston must be reciprocated to generate vacuum continuously and two directional valves, which control piston reciprocating and four check valves, which control vacuum chamber pumping and exhausting, are needed in the structure of PVG.

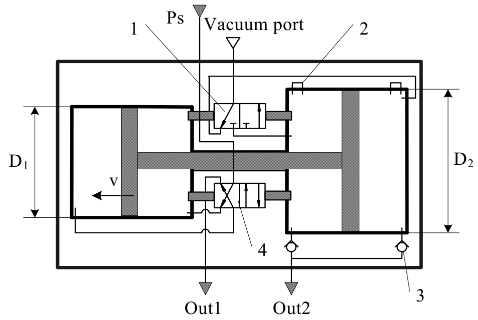
Due to limited space, the theoretical model is not described in this paper but it can be seen in reference [6]. The working process of PVG can be described as follows. Compressed air is fed into the driving chamber Ⅱ through directional valve and the piston is pushed onto left and the air in driving chamber Ⅰ is exhausted outside the chamber through the directional valve. At the same time, the volume of vacuum chamber Ⅱ is expanded thus to generate a certain vacuum in the vacuum chamber II and at vacuum port. Moreover the air in vacuum chamber Ⅰ is also exhausted through a check valve. When the piston moves to the end of stroke, the directional valves are switched and pistons move towards opposite direction. A new vacuum generating process starts and vacuum can be generated continuously.



1.driving chamber Ⅰ 2.piston 3. driving chamber Ⅱ
4.vacuum chamber Ⅰ 5. vacuum chamber Ⅱ
6.check valve 7.directional valve
Figure 1 Sketch of PVG structure

The preliminary testing is conducted with the PVG prototype shown in Figure1[6]. It is found that to open pumping check valve some local pressure loss would be taken place in the exhausting process and the effective area of pumping channel would be reduced gradually with increasing vacuum. Therefore, in structure the pumping check valve is not useful for reducing response time. Furthermore, the structure with equal diameters of driving chamber and vacuum chamber is not beneficial to decreasing response time. For overcoming these defects, the generator is improved base on PVG. The improved structure is shown in Figure 2 and is named as PVG-R (Piston Vacuum Generator-Rapid Response).

The main differences between PVG and PVG-R are: 1) The two original check valves are replaced by a pumping directional valve to increase effective area of pumping channel and reduce local pressure lost; 2) A structure with unequal diameters of driving chamber and vacuum chamber is designed so as to increase piston motion speed; 3) A structural form of pressure balance way is adopted in vacuum chamber to reduce initial expansion pressure in clearance volume. The aim to make these improvements is to reduce the response time of the generator.



1.pumping directional valve 2.pressure balance way
3.check valve 4.feeding directional valve
Figure 2 Sketch of PVG-R

FUNDEMENTAL CHARACTERISTS EXPERIMENT

The PVG-R prototype is made and tested. The constitution of testing and measuring devices is shown in Figure 3.

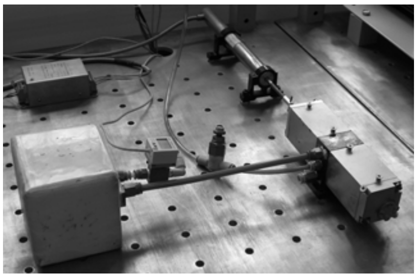


Figure 3 Photo of PVG-R prototype experiment

In the experiment, the main structural parameters of PVG-R prototype are: driving chamber diameter 30mm, vacuum chamber diameter 40mm, piston stroke 60mm, supply pressure 0.21MPa and vacuum vessel 1L. A prototype of PVG-R with above parameters is tested and the supply flow rate and vacuum response time are measured, which are shown in Figure 4 and Figure 5.

The average supply flow rate is near 55L/min and the maximum vacuum is about 93kPa. From the enlarging diagram in the lower right corner of Figure 5, it can be seen that the curve shape of vacuum response of PVG-R is sawtooth and increased gradually up to maximum vacuum. Then the vacuum is kept almost constant. In addition, from Figure 4 it can be seen that at the initial response stage the supply flow rate is increased rapidly and then decreased a little. But at the vacuum keeping state, the supply flow rate maintains a constant value.

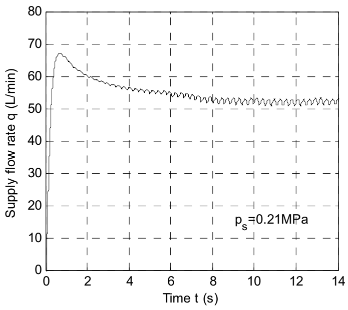


Figure 4 Supply flow rate of PVG-R prototype

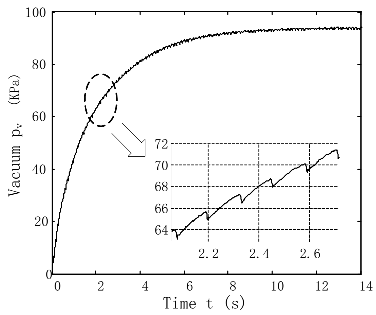


Figure 5 Vacuum response of PVG-R prototype

The average supply flow rate is near 55L/min and the maximum vacuum is about 93kPa. From the enlarging diagram in the lower right corner of Figure 5, it can be seen that the curve shape of vacuum response of PVG-R is sawtooth and increased gradually up to maximum vacuum. Then the vacuum is kept almost constant. In addition, from Figure 4 it can be seen that at the initial response stage the supply flow rate is increased rapidly and then decreased a little. But at the vacuum keeping state, the supply flow rate maintains a constant value.

For comparison of main performances of PVG prototype, PVG-R prototype and other type of vacuum ejector at the same pumping level, in this paper the vacuum response time is defined as the time when the pressure in 1L vessel is decreased from atmosphere to vacuum of 80kPa with supply flow rate 50L/min.

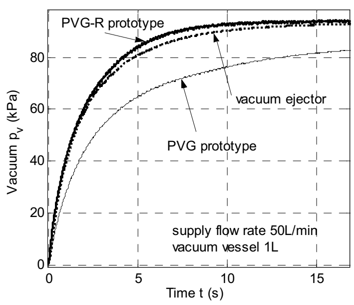


Figure 6 Comparison of vacuum response of two types of vacuum generators with the same pumping level

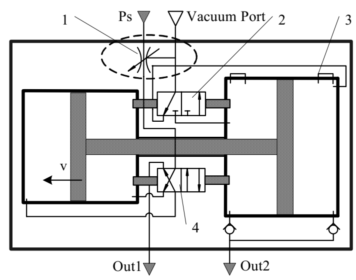
Comparison of the vacuum response of two types of vacuum generators with the same pumping level is shown in Figure 6. Comparison of the main performances is listed in Table 1. From Table 1, it can be seen that the maximum vacuum of PVG-R prototype is about 93kPa, which is higher than 91kPa of a vacuum ejector at a same level. The response time of PVG-R prototype is about 3.70s, which is less than that of a vacuum ejector at the same level.

Table 1 Comparison of main performances of two types of vacuum generators

Main performances	PVG prototype	PVG-R prototype	Vacuum ejector
Supply flow rate q [L/min]	50		
Supply pressure p_s [MPa]	0.13	0.21	0.40
Response time t [s]	12.60	3.70	4.80
Maximum vacuum p_{vmax} [kPa]	85	93	91

STEPPED FLOW RATE CONTROL

From Figure 4, it can be further analyzed that although the supply flow rate is slightly decreased after vacuum response stage the air supply in vacuum keeping state is still kept at a higher level than the desired. As we know, if the surface between the vacuum pad and picked part is well sealed, at the vacuum keeping stage only a little air supply is needed to replenish the slight leakage from the contacting surface. Based on this analysis, a technical approach for further decreasing air supply is presented. The idea of the approach is that the large air flow rate is supplied at the initial vacuum response state and then the air flow rate is reduced to a necessary low level enough to replenish the slight leakage and maintain the rated vacuum. This technical approach is called the stepped flow rate control method. In order to implement this stepped flow rate control method, a vacuum detecting and flow rate controlling component is designed and added into the structure of PVG-R, which is named as PVG-RL and is shown in Figure 7.



1.stepped flow rate control valve 2.pumping directional valve 3.pressure balance way 4.feeding directional valve
Figure 7 Sketch of PVG-RL

In the structure of PVG-RL, a stepped flow rate control valve which can adjust supply flow rate according to detecting result of the system vacuum is added near the air supply port. The valve can adjust effective area of supply channel to reduce supply flow rate according the preset vacuum.

Through experiments[7], the structural parameters of stepped flow rate control valve are modified and the photo of the modified PVG-RL prototype is shown in Figure 8.

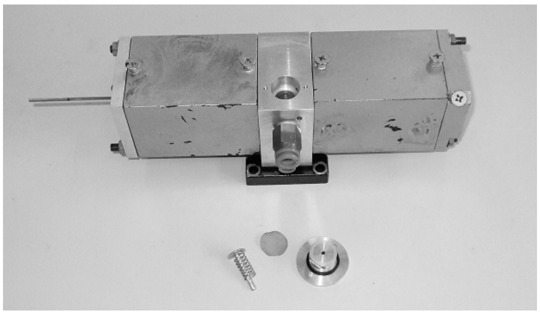


Figure 8 Photo of PVG-RL prototype

Experiments are conducted to measure the response characteristics of PVG-RL prototype. With the condition of supply pressure 0.21MPa, vacuum vessel 1L and preset vacuum 80kPa, the measured response characteristics of PVG-RL prototype is shown in Figure 9.

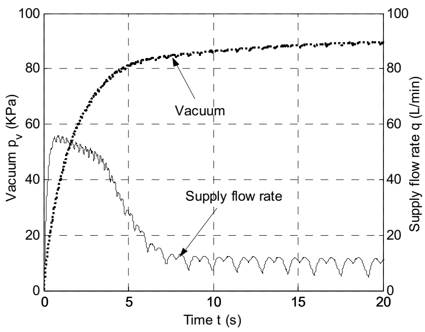


Figure 9 Response characteristics of PVG-RL prototype

From Figure 9, it can be seen that when the vacuum is above preset 80kPa the air flow rate is quickly decreased. This means that the control valve starts after the system vacuum is above the preset vacuum and the supply flow rate falls in a stepped shape. Thus the overall flow rate is obviously decreased.

Experimental results indicate that the minimum supply flow rate of PVG-RL prototype is about 12L/min and the air supply flow rate in vacuum keeping stage is obviously reduced compared with that in vacuum response stage. However, for maintaining a certain vacuum, the normal vacuum ejector has to be supplied with a constant air flow rate at a higher level. For example, a normal vacuum ejector must be supplied with a flow rate of 50L/min to generate and maintain vacuum. But in contrast the PVG-RL prototype only needs an air supply flow rate of 12L/min at vacuum keeping stage, thus reducing a lot of air consumption. Experimental data have figured out that with a quick vacuum response performance the new PVG-RL prototype could reduce the air consumption by 71.5% compared to a normal vacuum ejector at the same level.

CONCLUSIONS

Currently used jet vacuum ejector has a defect of high air consumption due to its requirement of continuous air supply. Focusing on this problem, a new type of piston vacuum generator (PVG for short) has been researched. How to maintain the original performances such as the maximum vacuum value and the vacuum response time that the normal jet vacuum ejector have realized and obviously decrease the air consumption is the key technical problem. For this, special structural design and technical approach are applied such as unequal piston diameters, using directional valves instead of two check valves, adopting pressure balance way and applying stepped flow rate control scheme. Experimental results have shown that for the prototype of piston vacuum generator its maximum vacuum is about 93kPa which a little higher than that of normal jet vacuum ejector, the response time is about 3.7s which is quicker than 4.8s of a normal ejector and the air consumption is reduced by 71.3% in time interval of 60s compared to the same level of vacuum ejector.

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