RESEARCH ON THE STATIC CHARACTERISTICS OF AIR DRIVEN GAS BOOSTER

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ABSTRACT

The process that the low pressure gas in two gas tanks were reclaimed through air driven gas booster to one empty high pressure tank has been studied in this paper. Calculation formulae of performance parameters of the gas booster such as the inlet pressure, outlet pressure, volume of discharge and intake, air consumption in per cycle were obtained, and the change tendency of these performance parameters during its isothermal quasi-static processes was analyzed and several static characteristics and structural parameters that influences the booster's working performance were found out. The importance of dead volume and the way to raise the booster's efficiency was stated. The results are helpful for model selection, design and application of gas boosters.

KEY WORDS

Air driven gas booster, Static characteristics, Compression ratio, Dead volume

NOMENCLATURE

A : Area of air driving piston
 a : Area of gas piston
 a_0 : Cross sectional area of piston rod
 P_a : Standard atmosphere pressure
 P_D : Driving air pressure
 P_{Ok} : Outlet air pressure of the k -th cycle
 P_{Sk} : Inlet air pressure of the k -th cycle
 S : Stroke of piston
 V_0 : Dead volume
 V_C : Total volume of high pressure chamber
 V_E : Air consumption volume per cycle
 V_{Ok} : Gas discharge volume of the k -th cycle
 V_{Sk} : Gas suction volume of the k -th cycle
 V_{in} : Total volume before inlet check valve
 V_{ou} : Total volume behind outlet check valve
 i : Pressure ratio
 i_{Ck} : Compressed ratio of the k -th cycle

INTRODUCTION

High pressure compressed air is usually needed in many industrial fields [4]. Air driven gas booster with the advantages of using low pressure air as power, supercharging efficiently, structured compactly, being portable and explosion-proof, reducing the cost and installing spaces to a great extent, has been widely used in many fields such as low pressure gas reclaiming, high-pressure gas injection, gas pressure testing and leak testing [1]. However, the tendency of pneumatic technology to high pressure has raised many new requirements to booster's structure and performance, such as higher pressure ratio and charging efficiency and more compact structure. Based on the working principle and structure of single acting gas booster, this paper has studied parameter factors that influences the booster's working performance and analyzed the booster's static characteristics.

WORKING PRINCIPLE OF AIR DRIVEN GAS BOOSTER

Air driven gas booster works according to PASCAL'S LAW as Figure 1 shows [3]. The large-area air driving piston 5 in the air driving chamber 4 is connected with the piston rod to the small-area gas piston 7 located in the high pressure chamber 6. Thus by using the area difference between the tow pistons, the purpose to compress the gas in the high pressure chamber with the low pressure air as power acting on the large-area piston is realized.

Figure 1 Working principle of air driven gas booster

Based on the static force balance principle,

$$P_O = \frac{A}{a} \cdot P_D = i \cdot P_D \quad (1)$$

$i = A/a$ is defined as pressure ratio. When $A > a$, $P_O > P_D$ [3]. The larger the area difference is, the more obvious the supercharging effect becomes.

The continuous operation is achieved by the cycling control valve 1 whose spool leads the drive air alternately on the upper and bottom surface of the air piston and is piloted through the upper pilot valve 2 and down pilot valve 3 which are mechanically actuated through the air drive piston in its end positions [1]. The exhaust air from the driving chamber is lead to the peripheral barrel to cool the high pressure gas chamber [2].

PARAMETERS CALCULATION AND ANALYSIS OF STATIC CHARACTERISTICS

The low pressure gas recovery process is studied as shown in Figure 2. At the beginning of recovery, low pressure gas is directly charged to high pressure tank

through inlet and outlet check valves as the existence of the pressure difference between the tow tanks, until the pressure of low and high tanks becomes balanced. Then gas booster works. The gas booster works as the sequence of suction, compression and exhaust. Now study on the k -th cycle.

Figure 2 Low pressure gas reclaiming

Inlet and Outlet Pressure P_{Sk} and P_{Ok}

According to law of mass conservation, when the k time cycle ends, there are the equations below:

$$P_{Sk} + V_{out} P_{Ok-1} = (V_0 + V_{out}) P_{Ok} \quad (2)$$

$$V_0 P_{Ok-1} + V_{in} P_{Sk-1} = (V_{in} + V_C) P_{Sk} \quad (3)$$

The inlet and outlet pressure of the k -th cycle is obtained

$$P_{Ok} = \frac{V_C}{V_0 + V_{out}} P_{Sk} + \frac{V_{out}}{V_0 + V_{out}} P_{Ok-1} \quad (4)$$

$$P_{Sk} = \frac{V_{in}}{V_{in} + V_C} P_{Sk-1} + \frac{V_0}{V_{in} + V_C} P_{Ok-1} \quad (5)$$

The change of P_{Ok} and P_{Sk} with the increase of working cycle is obtained recursively as shown in Figure 3. Figure 3 shows that with the increasing of working cycles both curves changes greatly on earlier stage, and change slowly on middle-later stage, and on the later stage when the cycle times reaches up to a certain value, both curves nearly keep stable.

Compressed ratio i_C is defined as follows [1]:

$$i_C = P_O / P_S \quad (6)$$

Figure 3 P_O and P_S with the change of cycle

i_C indicates the compressed degree of low gas. It is a variable, while pressure ratio i is a fixed value which shows the maximum ability of compression of the booster. The curve of i_C is shown in Figure 4 below, from which we know that i_C increases gradually, and keeps stable on the later stage.

Figure 4 i_C with the change of cycle

Gas Discharge and Intake Volume V_{Ok} and V_{Sk}

Gas discharge volume of the k -th cycle is equal to the standard difference volume of gas in high pressure chamber before and after the compression, so gas discharge volume of the k -th cycle is

$$V_{Ck} = \frac{P_{Sk}}{P_a} V_C - \frac{P_{Ok}}{P_a} V_0 \quad (7)$$

Formula 7 can also be expressed as follows.

$$V_{Ck} = \frac{P_{Sk}}{P_a} (V_C - i_{Ck} V_0) \quad (8)$$

The change of V_{Ck} with i_{Ck} is shown in Figure 6. With the increase of i_{Ck} , V_{Ck} reduces gradually, until to zero. And when i_{Ck} gets to a certain value, the discharged gas

becomes very little, and the working efficiency of gas booster is very low.

Figure 6 V_{Ck} with the change of i_{Ck}

The i_C when V_C is zero is defined as the maximum compressed ratio i_{Cmax} .

$$i_{Cmax} = \frac{V_C}{V_0} \quad (9)$$

The dimensions of V_0 and V_C have been decided when the booster was designed, after which the booster's maximum compressed ratio was determined. So when designing, if higher compressed ratio is wanted, reducing V_0 is feasible. For example, if the expected i_{Cmax} is 25:1, V_0 must be less than 4% of V_C .

Intake gas charge volume of the k -th cycle is equal to the standard difference volume of gas in high pressure chamber before and after suction, so intake gas charge volume of the k -th cycle is

$$V_{Sk} = \frac{P_{Sk}}{P_a} V_C - \frac{P_{Ok-1}}{P_a} V_0 \quad (10)$$

V_{Sk} has similar change law with V_{Ok} .

Air Consumption Volume Per Cycle V_E

The total air consume volume of the k -th cycle is equal to the sum of the air consume volume of the suction and compression stroke. So the air consumption volume of one cycle is

$$V_E = (2A - a_0) \frac{P_D}{P_a} \quad (11)$$

Formula 11 shows the air consume volume per cycle is a fixed value. On the later stage, the outlet pressure increases very slowly while the piston is still moving under the push of driving air, so lots of driving air is wasted. In addition, when model selecting, the maximum compressed ratio of the booster to be selected

should be bigger than the one needed in practical application, in order to save driving air and to limit the charging time to acceptable range.

CONCLUSIONS

Through the calculation and analysis above, the main structural parameters that influence the static characteristics of gas booster, the formulae of boater's performance parameters and its static characteristics combined with lots of graphs were obtained.

The main structural parameters include area of air driving piston A , area of gas piston a , cross sectional area of link rod a_0 , stroke of piston S and dead volume V_0 . The dead volume V_0 is proved having great influence on the booster's static characteristics, and its dimension should be determined with discretion when

designing. In addition, on the process of charging, the outlet pressure increases, inlet pressure reduces, both gas intake and discharge volume decreases, air consumption keeps constant cycle by cycle, and as on the later stage the growth rate of outlet pressure is very low and , it is not recommended to keep the booster working in this case for long time.

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