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A Study on the Design of Back Pressure for Automotive Scroll Compressor

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Abstract

The optimum design of back pressure chamber is one of the most important factors in designing scroll compressors because it has a great influence on the efficiency and other design parameters. The design process can be divided into 2 parts. One is obtaining the optimum pressure of the chamber and keeping it in constant value. The other is finding out the minimum inflow rate of medium with which back pressure chamber is filled. In this study we are focused on the first step.

At first we added a simple structure that can change back pressure without reassembling compressor. It makes possible to obtaining optimum back pressure. Then we designed an equipment that the back pressure control valve assembly could be independently tested with. Spring was redesigned to decrease stiffness variation. Also sealing mechanism of back pressure control valve was improved to more effective way.

As a result, it was verified that in a real mode test back pressure variation could be retained in 2.3 % with discharge pressure and operating frequency varied. In addition the integrated structure of back pressure control valve is expected to contribute to effective manufacturing process.

Key words: Scroll compressor, Back pressure, Control valve, Axial compliance, Automotive

Nomenclature

D : diameter of a hole [mm]
F : gas force [N]
k : stiffness of a spring [N/mm]
L : piston length [mm]
P : pressure [kgf/cm^{2}G]
x : deformation of a spring [mm]

Subscript

a : axial
b : back pressure
c : conventional
d : discharge
r : redesigned
s : suction
1 : state 1
2 : state 2

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1. Introduction

Recently as environmental problems becomes main issue, many car air-conditioner makers are interested in developing systems with alternative refrigerant in order to replace R134a which effects on global warming. Also as an effort to reduce CO_2 emission, biomass fuel is gradually replaced by fuel cell and hybrid cars. Fuel cell is eco-friendly because of no CO_2 emission which is responsible for global warming.

Hybrid and fuel cell vehicles are driven by motors not by engines, so conventional belt driven compressors should be replaced by the one in which motor is integrated. Because the frequency of driving motor is independent of the frequency of engine, the capacity variation can be attained by compressor itself. This makes it more efficient and effective.

Another effort to reduce CO_2 emission is to raise efficiency in order to reduce fuel consumption. In many cases, scroll compressor shows relatively good efficiency and low noise with the characteristics of no valve, smooth compression, and small variation of torque and so on.

Scroll compressor shows better volumetric efficiency compared to reciprocating compressor, because it doesn't have clearance volume and suction valve. But relatively long leakage path can lead to an internal leakage between compression chambers. The passage of internal leakage consists of radial and axial clearance. In many scroll compressors, the radial and axial compliant mechanisms are applied in order to reduce respective leakage.

Back pressure value was one of the most significant parameters in designing axial compliant mechanism and back pressure chamber. It also has an effect on internal leakage, power consumption, operating region and so on.

So far there are many researches about axial compliant mechanism. Koo et al. optimized back pressure chamber in order to minimize tilting moment of co-rotating scroll compressor.[(1)] Lifson was suggested new design technique using vent hole on scroll wrap in order to extend operating range of axial compliant mechanism.[(2)] Fushiki et al. were developed scroll compressor with compliant-frame type axial compliant mechanism.[(3)]

The object of this study is designing back pressure control valve that has better controllability and obtaining the optimum pressure of the chamber.

In this study we mainly focused on the back pressure control valve that plays an important role on designing axial compliant mechanism and back pressure chamber, and we improved back pressure control valve.

2. Design of back pressure control valve

2.1 Type of back pressure

Fig. 1 shows a back pressure structure that a chamber in a back side of orbiting scroll makes axial sealing between two scrolls. The back pressure chamber is filled with mid-pressure that is controlled by back pressure control valve.

If back pressure force F_b is smaller than axial gas force F_a, orbiting and fixed scroll are separated. Consequently, enlarged axial clearance results in leakage loss. If F_b is excessively large, friction between orbiting and fixed scroll becomes large and it results in mechanical loss and wear. So proper design of back pressure is one of the most important factors in designing scroll compressor.

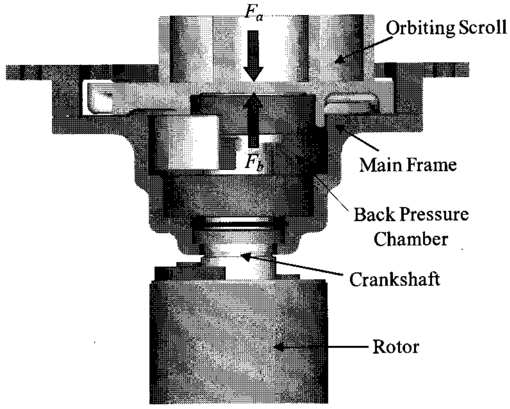


Fig. 1. Structure of back pressure mechanism.

2.2 Measurement of back pressure

In order to estimate input power of a compressor with respect to back pressure, the test device was designed as shown in Fig. 2. Discharge, suction, and mid-pressure chambers are linked with tube. In order to control back pressure using discharge gas, bypass valves are installed in discharge and suction tube. The openness of valve at discharge tube was set to be 6.5 kgf/cm^2 of the pressure difference of suction and back pressure chamber with the valve of suction tube closed. With the openness of discharge side valve fixed at that degree, adjusting the openness of suction

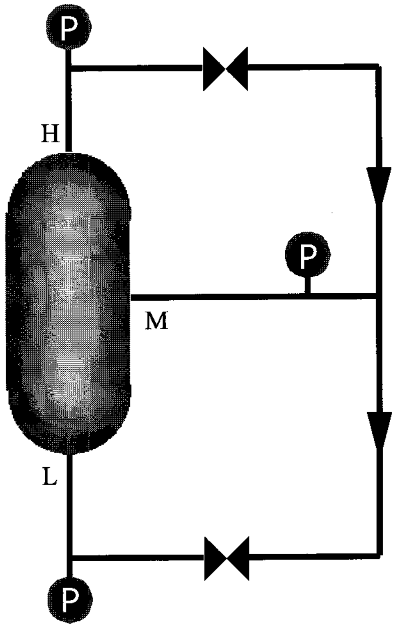


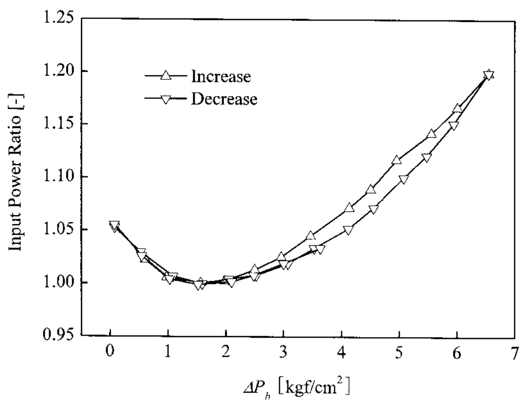
Fig. 2. Device for back pressure test.

side valve makes it possible to control the pressure difference with the value of 0 ~ 6.5 kgf/cm^2.

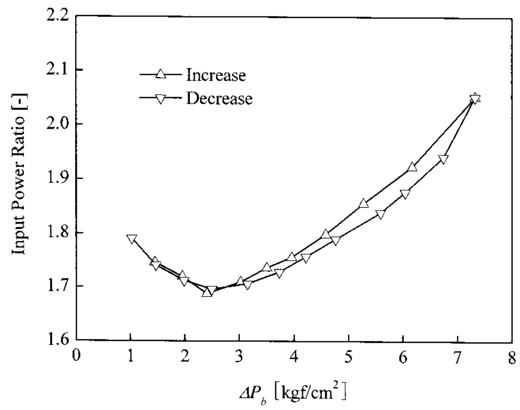
2.3 Optimum back pressure

Fig. 3 shows the input power of a compressor with respect to pressure difference(ΔP_b) between back pressure and suction chamber. The internal leakage results in the increase of input power as well as the decrease in mass flow rate. It is the reason why input power decreases in lower ΔP_b.

In order to evaluate the effect of hysteresis, two cases of increase and decrease ΔP_b were considered. As a result, two cases showed almost similar outputs. When ΔP_b is 1.6 kgf/cm^2, the compressor shows the minimum consumption of input power at rated condition. If ΔP_b is increase to 6.5 kgf/cm^2, the power input is also increased up to 20 % than that of the optimum case. But for overload condition, the optimum ΔP_b is elevated to 2.6 kgf/cm^2.



(a) Rated condition(P_s/P_d = 2/15 kgf/cm^{2}G)



(b) Overload condition(P_s/P_d = 2/20 kgf/cm^{2}G)

Fig. 3. Input power due to ΔP_b.

2.4 Design of back pressure control valve

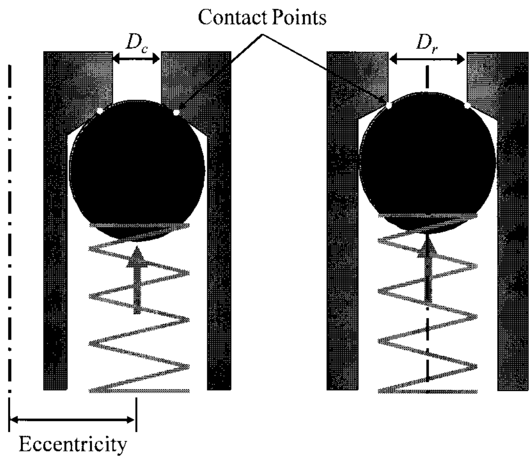
Fig. 4 shows both conventional and modified design of back pressure control valve.

The valve consists of ball, spring and cylinder and is located in the crankshaft with the integrated design.

In conventional design, back pressure control valve was located at the pin side of crankshaft. It makes the ball eccentric from the rotating axis of crankshaft. The exerted centrifugal force to ball makes it hard to control mid-pressure at an accurate value. So the back pressure control valve was modified to integrated design and placed at the opposite side of crankshaft in order to make a room for placing a ball concentric to rotating axis of crankshaft. Also the contact lines between the ball and the cylinder was designed to have the same diameter with the hole. This leads to an easy maintenance of sealing edge as line contact and accurate evaluation of contact area.

Fig. 5 shows the stiffness variation of the conventional and redesigned spring. As shown in this figure, using more flexible one, the variation of spring force can be reduced, and it results in more accurate control of back pressure.

Fig. 6 shows the modified integrated design of back pressure control valve.



(a) Conventional Design (b) Modified Design

Fig. 4. Back pressure control valve.

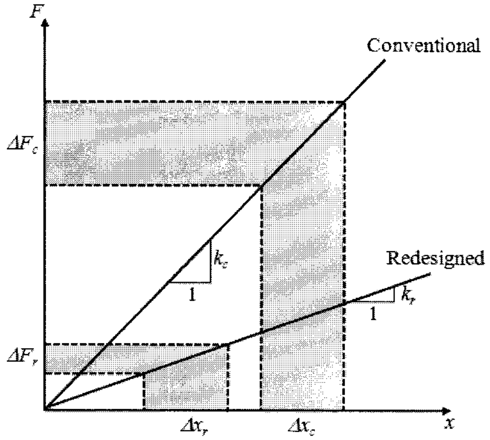


Fig. 5. Reduction of stiffness variation.

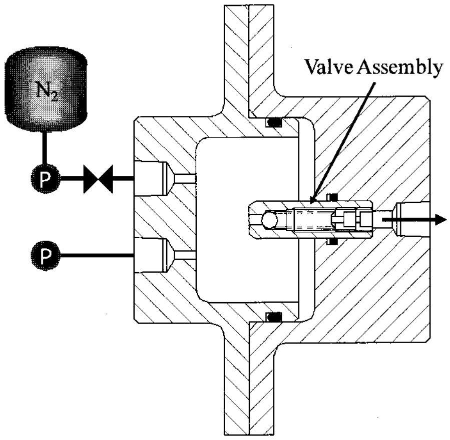


Fig. 7. Element test equipment of back pressure control valve.

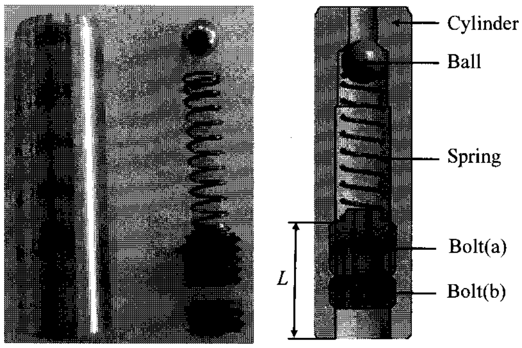


Fig. 6. Structure of redesigned back pressure control valve assembly.

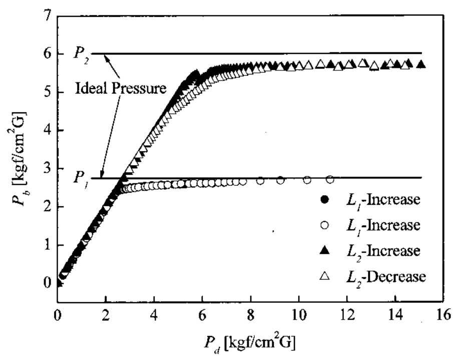


Fig. 8. Element test result of back pressure control valve.

3. Applying back pressure control valve

3.1 Element test

The element test equipment to evaluate control characteristics was designed as shown in Fig. 7.

In real compression state, separated oil at discharge plenum is supplied to back pressure chamber through orifice and is drained by back pressure control valve. In Fig. 7, N_2 chamber plays a role of discharge plenum, and the isolated internal space corresponds to back pressure chamber. The valve means orifice located between discharge and back pressure chamber, and the flow rate was determined by the valve openness. So the pressure change of N_2 chamber with fixed openness of the valve makes it possible to control the back pressure. In all over this study the pressure sensors of VALCOM VPRT(F) series are used.

Fig. 8 shows the change of back pressure with varying pressure of N_2 chamber at proper piston length L_1 and L_2. P_1 and P_2 are the calculated value of back pressure for piston length L_1 and L_2 respectively. For piston length L_1, the same test was executed twice with increasing pressure only. However, for the case of piston length L_2, the test was performed with increasing and subsequently decreasing pressure in order to investigate the presence of hysteresis effect. As a result, hysteresis was not found, and the measured back pressure value matched well with the calculated one. At a condition of steady back pressure, as discharge pressure grows up, back pressure is also raised.

3.2 Real mode test

A compressor in this study is inverter-integrated motor-driven horizontal scroll compressor as shown in Fig. 9, and Table 1 indicates the detailed specifications.

Required operating region in automobile compressor is wide as shown in Fig. 10. So appropriate back

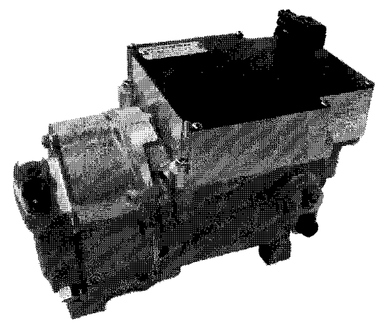


Fig. 9. Scroll compressor used in real mode test.

Table 1. Specifications of scroll compressor.

Items	Specifications
Displacement Volume	27.0 cc
Frequency Range	800 ~ 8600 rpm
Refrigerant	R134a
Motor	Sensorless BLDC
Inverter	180° Vector Control

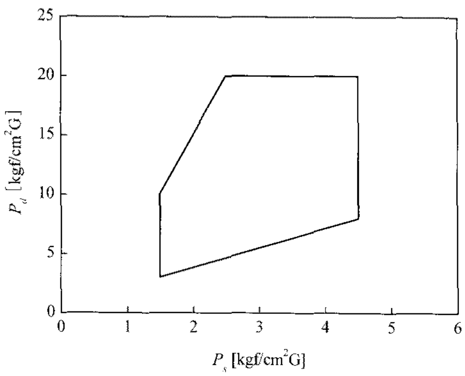


Fig. 10. Operating envelope.

pressure should be determined in order to prevent wrap-separation and tilting for all the region. In the previous test, the optimum back pressure to minimize input power was obtained; ΔP_b is 1.6 kgf/cm^2 at P_s = 2.0 kgf/cm^{2}G and P_d = 15.0 kgf/cm^{2}G and ΔP_b is 2.6 kgf/cm^2 at P_s = 2.0 kgf/cm^{2}G and P_d = 20.0 kgf/cm^{2}G. But for the larger pressure difference between suction and discharge pressure, the bigger back pressure force is required in order to prevent wrap-separation and tilting, so the back pressure should also be larger. To be considered this operating range, the value of back pressure ΔP_b was determined to be 3.4 kgf/cm^2, where the piston length L was 10.2 mm. This real mode test was done at various operating conditions.

Fig. 11 shows the behavior of back pressure with varying frequency. ΔP_b is retained constant about 3.5 kgf/cm^2, regardless of operating frequency, where the variation range of ΔP_b is under ±0.08 kgf/cm^2. It means that it is possible to control ΔP_b in a range of 2.3 %. ΔP_b increased until 6500 rpm, and it decreased after that.

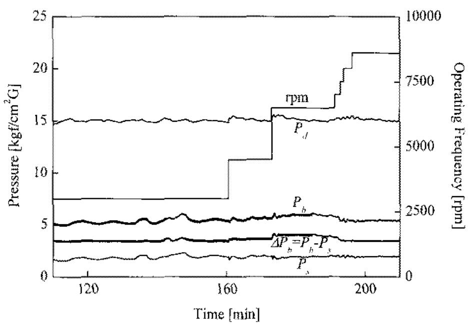


Fig. 11. Back pressure with frequency varied.

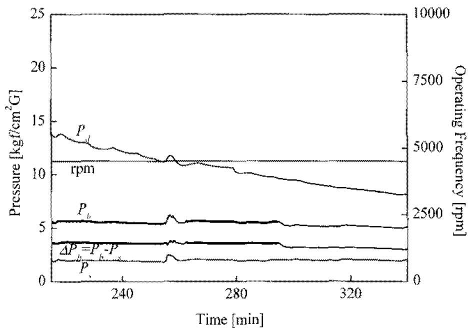


Fig. 12. Back pressure with discharge pressure varied.

Fig. 12 shows back pressure with varying discharge pressure. ΔP_b is kept steadily at 3.5 kgf/cm^2, regardless of discharge pressure.

4. Conclusions

As results of this study about design of back pressure control valve for automotive scroll compressor, conclusions were obtained as follows.

- The optimum value of back pressure could be obtained by minimizing input power as varying back pressure using simple test device, and the value is 1.6 kgf/cm^2.
- The back pressure value of 3.4 kgf/cm^2 was applied in consideration of various operating conditions.
- Integrated design of properly modified back pressure control valve was applied.
- An element test of modified back pressure control valve showed that calculated and tested value of ΔP_b were matched well as varying piston length.

- As a result of real mode test, back pressure ΔP_b was retained constant and was matched well to calculated value.
- Control characteristics of back pressure was as good as the variation of it was kept below the range of 2.3 %.

A design process of back pressure mechanism is divided into two steps. One is the optimization of back pressure value and the other is the minimization of oil-inflow to back pressure chamber. In this study the first step was discussed. The following step remains for future work.

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