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ABSTRACT

It is well known that the compressor with variable capacities has a higher efficiency than the typical single capacity compressors for the air-conditioner system. Therefore, many compressor makers are trying to develop variable types of capacity-controlling compressors, one of which is the by-pass type rotary compressor. This paper investigates the variable capacity rotary compressor using by-pass method to achieve the optimal condition for the high-energy efficiency at full and part load conditions. The by-pass method has a re-expansion loss caused by the suction gas mixed with the by-pass gas that is hot and partially compressed. To minimize this loss, several tests are conducted varying a by-pass hole diameter and its position. The PV-diagram at the part load condition is also observed to verify operating conditions according to the capacity variations. In addition, by-pass valve acted by a gas pressure difference is designed to have a proper operation at both loading conditions and its life reliability is checked.

1. INTRODUCTION

Developing the capacity control compressor is one of the interesting issues in the compressor makers, and the inverter system, which uses frequency modulation of input power to the motor, is the most advanced technology so far. However, its cost is too high to be applied to every air-conditioning system. Therefore, a mechanically capacity controlling compressor is one of the intermediate steps that many compressor designers are developing these days. There are many mechanisms applied to vary the capacity mechanically, and the by-pass type is one of them (Kwon et al. 2000). This type has many attractive advantages to be applied to the conventional single capacity compressor. However, this mechanism cannot help following the loss due to the by-pass refrigerant returning to the inlet path of the compressor, which causes re-expansion loss. Therefore, this paper discusses how to analyze the losses and how to reduce it.

2. DESIGN CHARACTERISTICS

2.1 Description of Capacity Control Mechanism

The variable capacity rolling piston compressor in Fig.1 is composed of three main parts, which are a by-pass hole, a by-pass valve and one or two control valves. According to the working condition, the control valve is activated or deactivated to operate the by-pass valve to vary the working volume of the pump. The compressing work is delayed until the rolling piston reaches where the by-pass hole is located (Kwon et al. 2000). After passing this position, the compressor compresses the gas with relatively smaller compressing volume, which leads decrement of the load to the motor. To achieve the optimum efficiency of the air-conditioner system, the compressor with a by-pass mechanism should have a proper loading ratio, which is about 40% cooling capacity of the full load condition (Kim et al. 2001). To have a part load driving condition desired, the position of the by-pass hole should be determined in advance and the following are the calculated result.

The control valve to operate the by-pass valve can be either one 3-way or two one-way valves, which are controlled by electric signal. The by-pass valve equipped certain angular position of the cylinder is activated by the pressure difference between suction and discharge refrigerant.

For a full cooling capacity driving, the control valve 1 is opened to supply the fully compressed refrigerant to the by-pass valve to be closed, which the cylinder is completely sealed. On the other hand, the partial capacity control is obtained, when the suction pressure is supplied to the by-pass valve, which can let the inlet refrigerant is escaped from the pump without being compressed until the rolling piston passes the by-pass hole. Therefore, the load that is applied to the motor is decreased as much as desired.

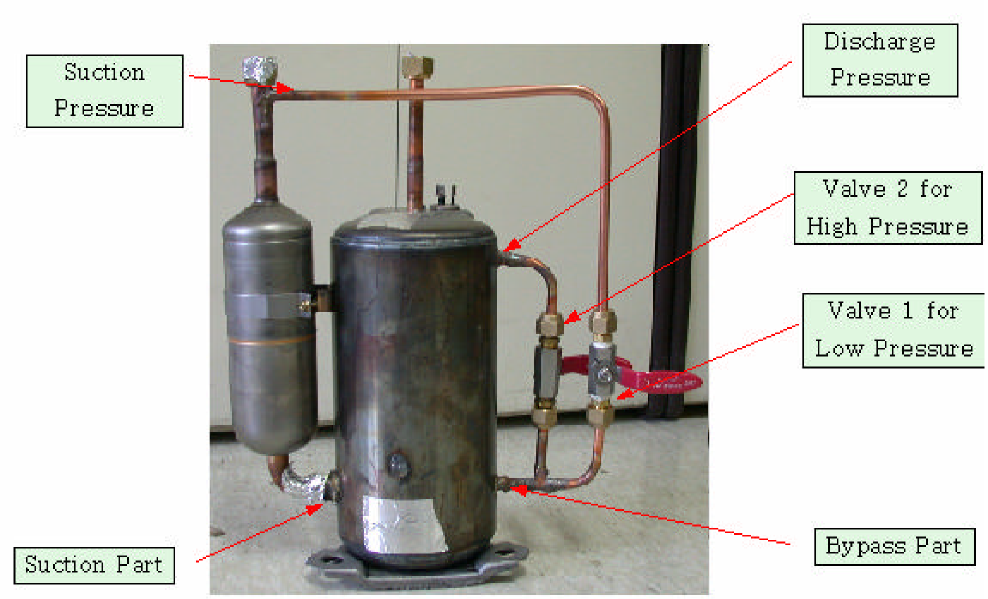


Fig.1. A by-pass type variable capacity rolling Piston Compressor

2.2 A selection of by-pass hole position

For the part cooling capacity, the compressing volume should be evaluated to fix the location of the by-pass valve. From the geometric feature of a rolling piston compressor as shown in Fig.2, the theoretical variable compressing volume can be calculated and the Table.1 shows the result. However, an actual capacity ratio form a test is some what far away form the theoretical value, due to the several factors such as the size of the by-pass hole.

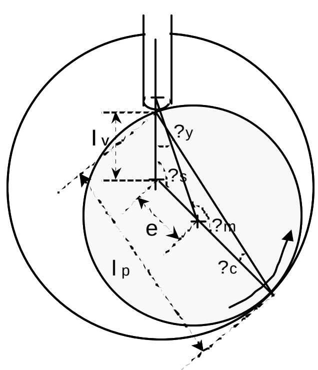


Fig.2. Geometric view of a rolling piston compressor

Table 1. A delay hole position selection table by a compressing volume

	Delay Hole Position			
	0°	140°	180°	220°
Theoretical varied capacity ratio	100%	66.7%	50%	28.7%
Actual varied capacity ratio	100%	84.3%	-	52.0%

2.4 By-Pass Valve Design and Control Method

The delay valve originally designed equips one or four springs to have smooth motion according to the driving condition. However, these designs have several potential problems due to failure of springs and weak shape factors. To improve its life reliability, the valve operation condition is investigated whether its spring can be removed without an operational problem. Above the pressure ratio, 2.1 under the ASHRAE-T condition, the valve operates without any problem and this result shows that the valve without spring can be applied at any air-conditioner working cycle. However, a valve makes an impacting noise under the pressure ratio, 2.1 due to the unstable pressure condition.

After having a test result referred above, the shape of the valve is modified to improve the life and functional reliability. The design of valve is focused on the operational reliability and securing the area for the bypassing refrigerant. The valve moves forward and backward to be opened and closed. The main problem is tilting, which causes failure in movement. Therefore, the valve has enough thickness to have a guiding surface. The Fig.3 shows how the valve operates under the driving condition.

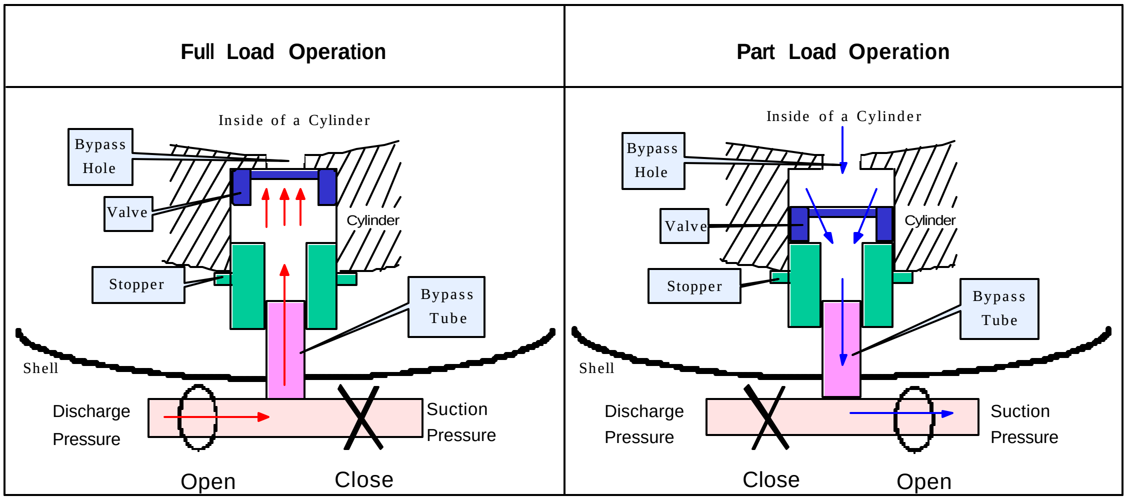


Fig.3. Schematic of by-pass valve operation under the load condition

2.5. A by-pass hole size determination

To get the cooling capacity desired, the by-pass hole diameter is one of the most important parameters should be considered. According to the size of it, the quantity of the escaped refrigerant passing through this hole can be influenced. To figure out the optimal size of a hole, 3 varied diameters of them, which are 4, 6, 9mm are applied to the cylinder. The cooling capacity of compressors with each diameter is measured, and is derived relationship according to the diameter.

2.6. The cooling for the bypassing refrigerant

The bypassing refrigerant is returned to the inlet of the compressor. However, the refrigerant escaped from the pump is partially compressed and contains heat, which causes re-expansion of inlet refrigerant form the evaporator. Therefore, the heated bypass refrigerant needs to be cooled to improve the over all efficiency of the compressor. The intercooler that uses water as cooling medium is installed between the by-pass hole and an accumulator as shown in Fig.4 to investigate the cooling effect for the system.

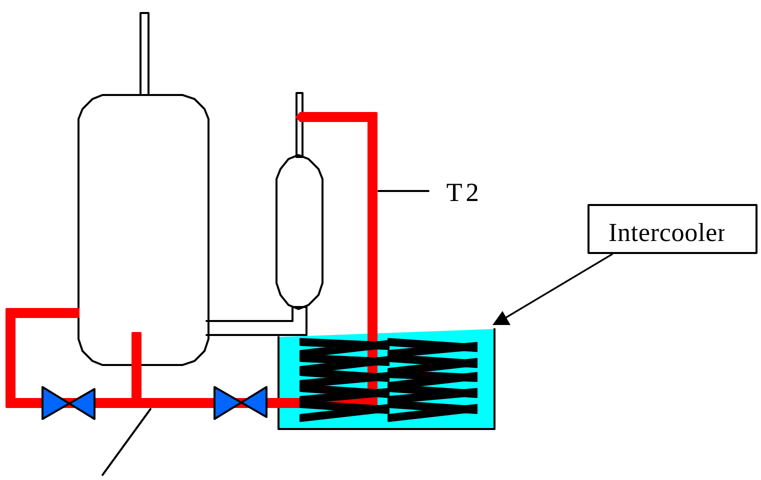
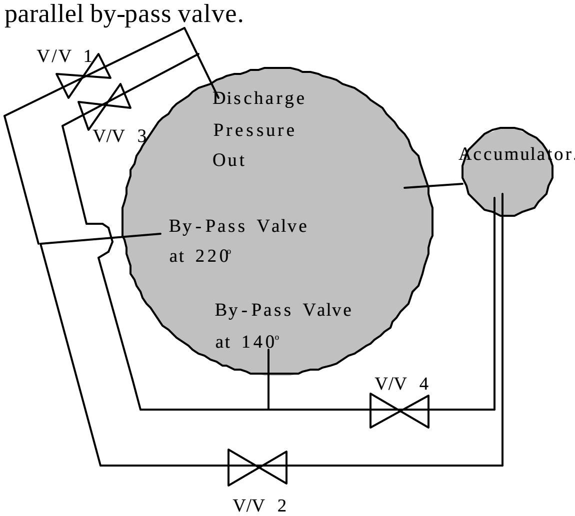


Fig.4. Schematic of the compressor with intercooler installed

2.7. Evaluation of the parallel by-pass valve

The By-Pass hole diameter is limited to 9mm due to the height of the cylinder used for this test. To remove or reduce the suction loss, additional by-pass hole is installed at near 140degree from the vane. Therefore, over all area that the refrigerant can escape from the pump is increased and the compressing work until the second by-pass hole is reduced to have lower suction loss, because the second at 140^{o} by-pass hole helps the refrigerant to escape without being compressed. The Fig. 5 shows the compressor with two by-pass valves working independently. The test performed has two cases, one of which is for measuring the efficiency of one single by pass mechanism and another of which is for the parallel by-pass mechanism. Those two test results are compared to figure out the effect of the parallel by-pass valve.



	V/V1	V/V2	V/V3	V/V4
Case1	Close	Open	Close	Close
Case2	Close	Open	Close	Open

Fig.5. Schematic of a compressor with two by-pass valve controlled independently. The table shows the case of experiment to measure the effect of this mechanism.

3. COMPRESSOR PERFORMANCE TESTING AND RESULT

3.1 P-V Diagram

To measure the pressures at each driving conditions to compare, two dynamic pressure sensors and one static pressure sensor are installed. To measure the compressing volume, a hole at one position of oil cap at the bottom of the shaft. To detect the rotational position of this hole, a gap sensor is installed at the 30 micrometer away from it, and the signal from this sensor is synchronized with the signal from pressure sensors. The positions for the pressure sensors and a gap sensor are shown in Fig.6. From the P-V diagram obtained from this test, the total compression work, effective compression work, suction loss, and discharge loss can be figured out. The test result is shown in Fig.7. The area with dashed line indicates the loss to be reduced or removed to improve the over all efficiency of the compressor under part loading operation.

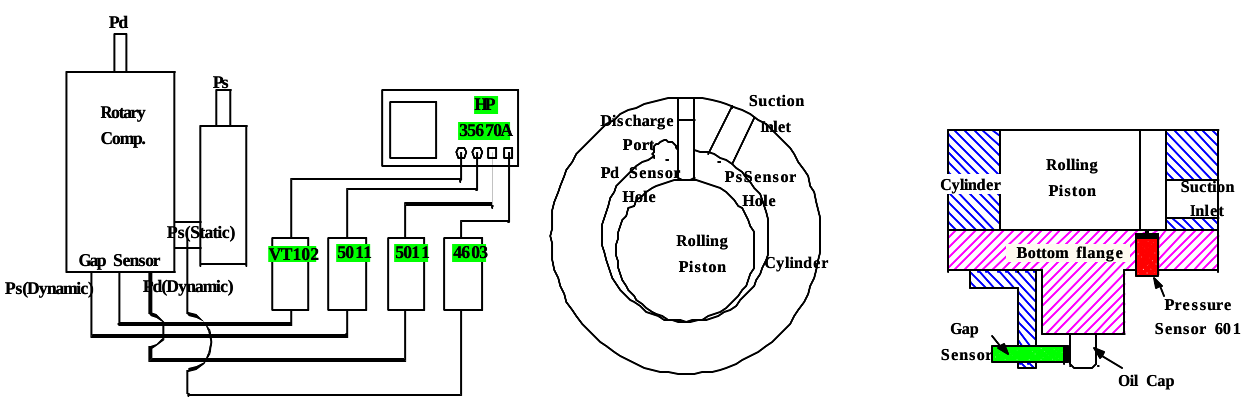


Fig.6. Schematics of experimental apparatus to measure the P-V diagram

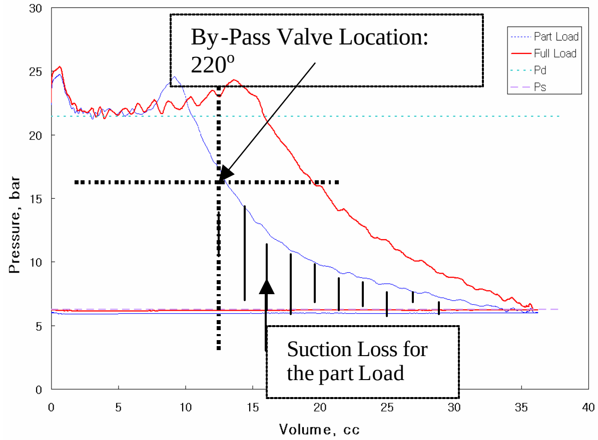


Fig.7. P-V diagram comparing each operation

Table2. Loss analysis result

Items \ Capacity		Full Load	Part Load
Input Power		100%	100%
Compression Work		87.4%	87.4%
Effective Compresson Work		82.3%	80.6%
Suction/Discharge Loss		5.1%	6.8%
Suction Loss		0.6%	3.2%
Discharge Loss		4.5%	3.6%
Motor/Mechanical Loss		12.6%	12.6%
Mechanical Loss		6.1%	6.0%
Motor Loss		6.5%	6.6%
Mechanical Efficiency	%	76.2	68.7
Compression Efficiency	%	82.5	69.8

The cross point of two broken line indicates that the rolling piston is passing the by-pass hole. Therefore, the compressed refrigerant escaping from the pump reaches almost 16bar, which is heated and returns to the inlet path of the compressor. The table shows that the suction loss at part load condition increases to 3.2% due to the by-pass refrigerant.

3.2 Changing the condition of By-Pass Refrigerant

To cool down the heated by-pass refrigerant to the same temperature of the inlet temperature of the compressor, 35°C, which is measured T2 as shown in Fig.4. The performance of compressor with this system is evaluated and the result comparing to the compressor without cooling system is shown in Table3. The efficiency of the compressor increases as the by-pass refrigerant is cooled as expected. However, the higher efficiency resulted from the increasing of the cooling capacity, not from the lower input power supplied to the compressor.

Table3. Test result of compressor with intercooler system. Temperature, T1 and T2 are indicated in Fig.4.

	T1 (°C)	T2 (°C)	EER	Input	Cooling
Without cooling	82.4	78.3	6.3% Increase	No Change	6.7% Increase
With Cooling	68.3	34.4			

3.3 By-Pass hole size variation Test

From the test result with different size of by-pass hole diameter, the optimum size can be evaluated from the experimental equation, which is linearly fitted. As the diameter of a hole increases, the efficiency decreases due to the refrigerant that is partially compressed and heated up when it escapes from the pump. To maximize the seasonal energy efficiency ratio (SEER), the hole size is chosen to 6.5mm. The compressor efficiency with the diameter chosen is verified with ASHRAE-T condition.

5. CONCLUSION

The variable capacity control rolling piston compressor with a by-pass mechanism can offer several benefits, one of which is low cost to apply this to conventional rolling piston compressor. Further more, that compressor does not need an expensive control circuit such as an inverter. However, the energy efficiency at a part load driving is somewhat lower than the compressor with inverter control. To improve this disadvantage, several ideas are proposed and shown the possibility to reduce the suction loss that is examined from the P-V diagram of part load operation.

An intercooler system to reduce the heat from the by-pass refrigerant that is partially compressed before escaping from the pump shows higher EER than the compressor without it. An additional by-pass hole helps to reduce the pressure of the bypassing refrigerant and it also improves the efficiency at a part load driving. If those two methods are applied together with an optimal by-pass hole size, the efficiency at part load can be increased to an acceptable level and the by-pass type capacity control compressor can be one of the good products to customers.

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