

DEVELOPMENT OF THE VARIABLE DISCHARGED VOLUME TYPE COMPRESSOR FOR GHP

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ABSTRACT

The variable discharged volume type compressor is being promoted to increase the efficiency of the GHP in order to reduce CO₂ emission and improve its competitiveness when compared to electric type heat pump. The COP in the low-load area, as well as COP in the rating, need to be improved.

Therefore, the variable discharged volume type compressor has been developed to achieve improvement of the COP in the low-load area of the GHP that is difficult to control by only the conventional engine RPM control. In this variable discharged volume type compressor, the compression volume can be controlled. This makes it possible to properly control the refrigerant volume even at a low-load level. Use of this variable discharged volume type compressor may eliminate useless refrigerant compression and improve the COP.

INTRODUCTION

We have promoted an increase in the efficiency of the gas heating pump (GHP) in order to reduce the CO₂ emission volume for the prevention of global warming and improve its competitiveness when compared to that of the electric type heat pump. The increase of efficiency is promoted as the coefficient of performance (COP) in the rating as the first target. However, it is also necessary to improve the COP in the low-load area.

This paper describes the development of the variable discharged volume type compressor that is able to control the refrigerant compression volume, aiming at the improvement of the COP in the low-load area.

1. BACKGROUND OF DEVELOPMENT

The air conditioning capability of the GHP is controlled as the engine RPM (2,400 - 1,200 min⁻¹ for 14 kW type) is changed corresponding to the load that adjusts the circulating refrigerant volume. In this engine RPM control, however, the RPM can only be reduced to a level of about half of the rated RPM. Therefore, it is difficult to use this control system for the low-load (approximately 50% or less of the rated load). Therefore, a part of the refrigerant, which is compressed by the compressor and discharged from the discharge port, is not used for cooling or heating and is returned to the suction side of the compressor through the bypass circuit as shown in Fig. 1. That is, a part of the refrigerant, which has been compressed by the compressor, is not utilized for cooling or heating and decompressed to its previous pressure. As a result, the bypass volume is increased as the load becomes lower. This causes the efficiency to lower.

To solve this problem, three gas companies, Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd., Toho Gas Co., Ltd. and Aisin Seiki Co., Ltd. started joint development of a variable discharged volume type compressor using a proportional control system that can variably stepless-control the compression volume for precise load control.

Additionally, development of the ON/OFF control system (2-step control of the compression volume) that achieves low cost, even when the efficiency is lower than that of the proportional control system, has also been promoted parallel to the development of the proportional control system.

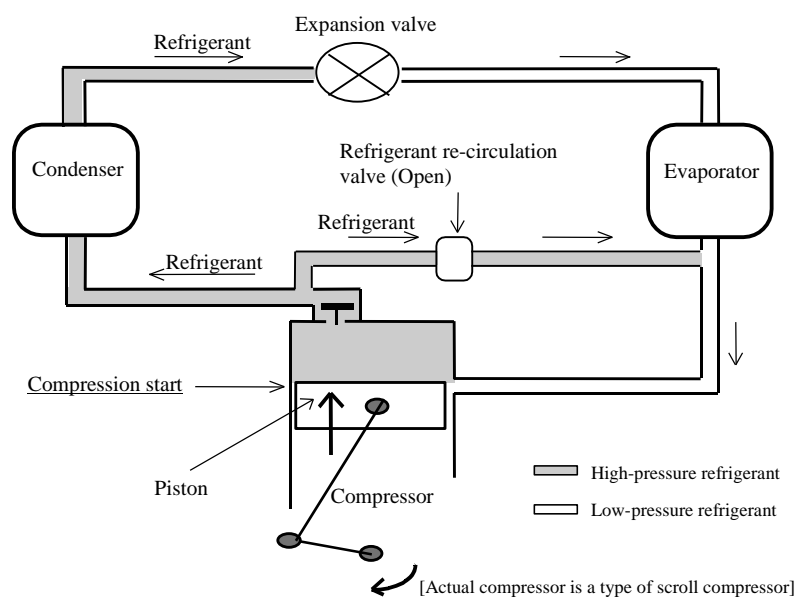


Fig. 1 Low-load control of conventional compressor

2. PURPOSE OF DEVELOPMENT

The development has been performed to improve the COP in the low-load area by about 50% (to improve the efficiency to a level equivalent to or better than that of the electrical heating pump {inverter control}).

3. OVERVIEW OF THE NEWLY DEVELOPED COMPRESSOR

3-1. STRUCTURE

The basic structure of the proportional control system is the same as that of the ON/OFF control system. This basic structure is shown in Fig. 2. In this Fig., a reciprocating-type compressor is used for easy understanding. Even though a "scroll type" compressor is actually installed, its operating principle is the same as that of the reciprocating type compressor. A bypass port called the "reduce port" is provided in the compression process of the compressor that bypasses the refrigerant to the suction side until the piston closes the reduce port. This controls the refrigerant volume to be compressed in order to eliminate useless compression even in the low-load area.

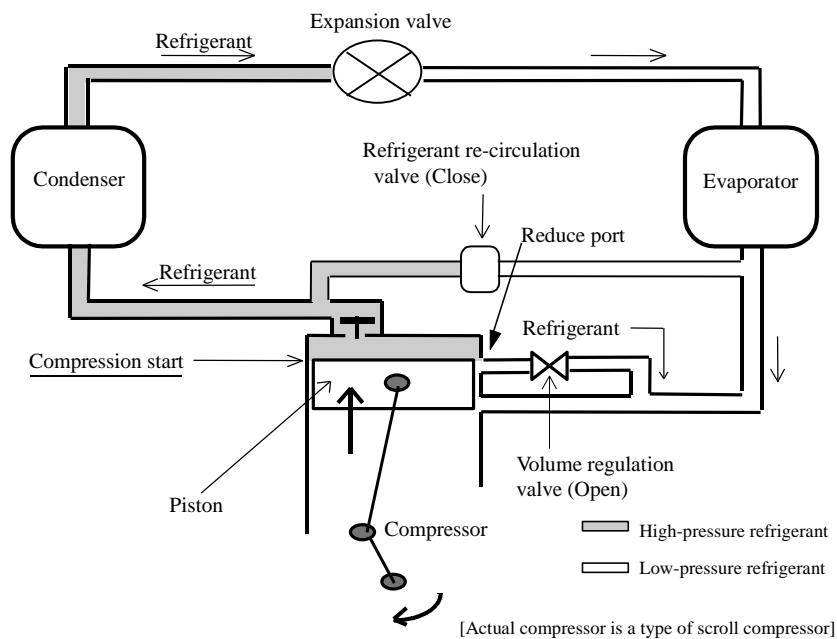


Fig. 2 Low-load control of newly developed compressor

Fig. 3 shows the structure and compression principle of the actual scroll type compressor. Since the scroll type compressor has a structure in which two areas are compressed toward the center at the same time, a reduce port is provided in each compression area (two ports in total). When investigating optimal positions by taking the improvement of the COP and minimal

volume required for the system into consideration, the reduce ports are located at positions so that the compression volume is 35%.

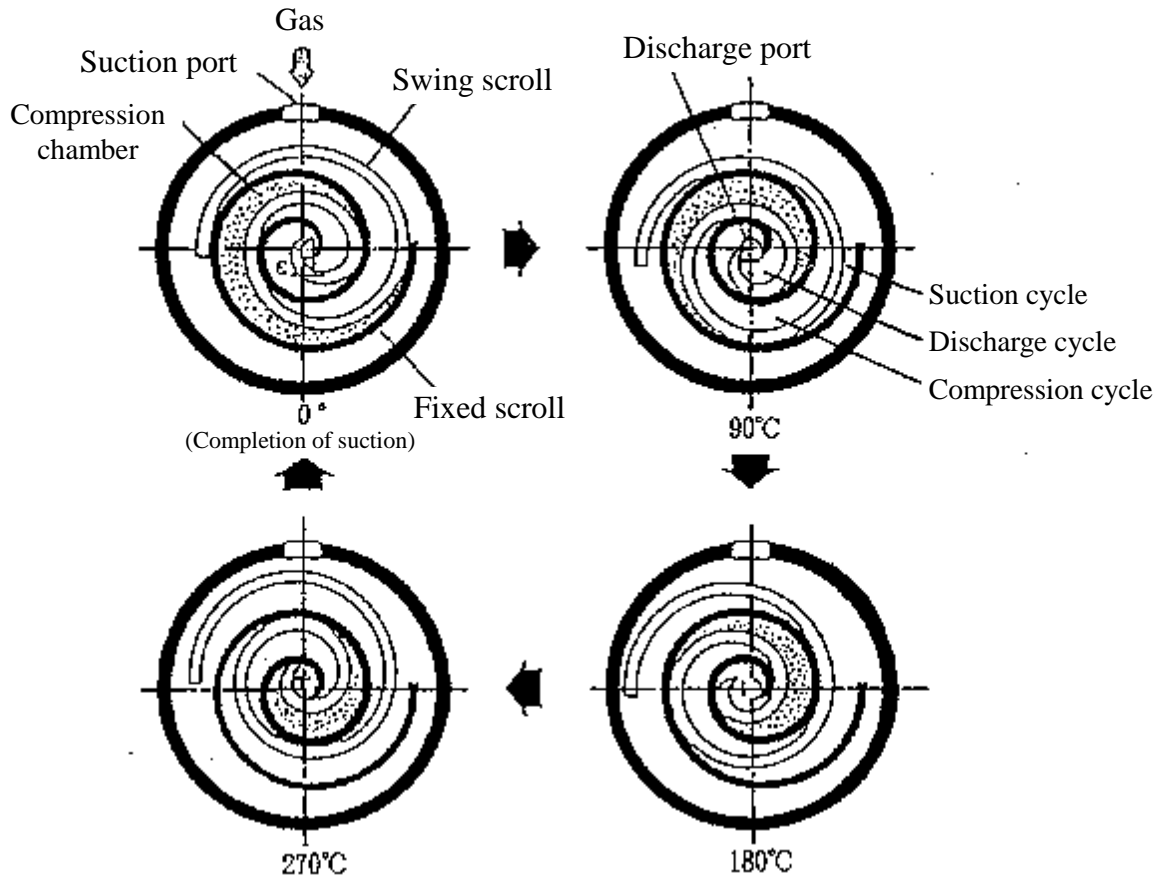


Fig. 3 Structure and compression principle of scroll type compressor

3-2. CONTROL

Proportional control system

In this proportional control system, a proportional valve is used for the volume regulation valve. As the opening of the valve is adjusted to correspond to the load, the refrigerant leak volume passing through the bypass circuit is changed to control the volume compressed by the compressor. Fig. 4 shows the operation during proportional control of the valve. For example, if the volume regulation valve is fully opened, compression is not performed until the piston closes the reduce port. This minimizes the compression volume. When the volume control valve is fully closed, compression is started as the piston starts rising.

The compression volume then reaches its maximum level. Next, when the volume control valve is opened slightly from its fully closed position, compression is started as the piston starts rising, but a small volume of the refrigerant leaks to the bypass circuit since the volume regulation valve is opened slightly. Thus, the refrigerant volume to be compressed may decrease slightly when compared to that compressed when the volume regulation valve is fully closed. As described above, if the opening of the valve becomes larger, the refrigerant volume leaking to the bypass circuit increases and the refrigerant volume to be compressed decreases.

Since the refrigerant volume to be compressed can be stepless-controlled in this system, useless compression is eliminated in all low-load areas, ensuring highly efficient operation. However, since the proportional valve is used for the volume regulation valve, the cost becomes high and this becomes a disadvantage.

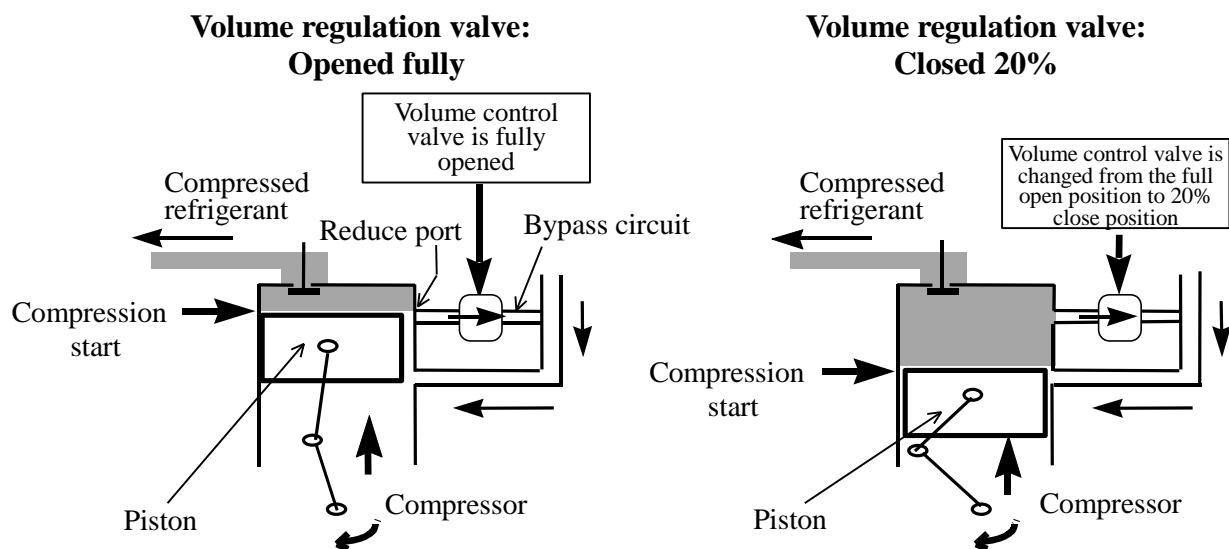


Fig. 4 Operation of the volume regulation valve in the proportional control system

ON/OFF system When compared to the proportional control system, a less expensive solenoid valve (ON/OFF valve) is used for the volume regulation valve in the ON/OFF system. Therefore, the efficiency of the ON/OFF system is lower than that of the proportional control system but the control is easy and the price of the system can also be made less expensive.

Fig. 5 shows the ON/OFF operation of the valve. Additionally, Fig. 6 shows the operation with the valve ON/OFF time ratio of 1:1. When the refrigerant circulation volume is averaged, it becomes similar to the refrigerant circulation volume obtained with the valve opening set at 50% in the proportional control system.

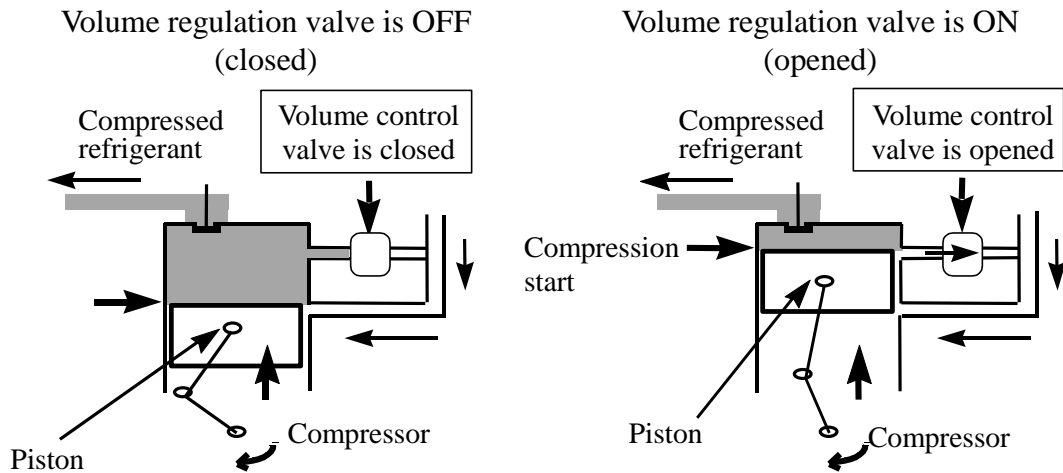


Fig. 5 Operation of the volume regulation valve in the ON/OFF system

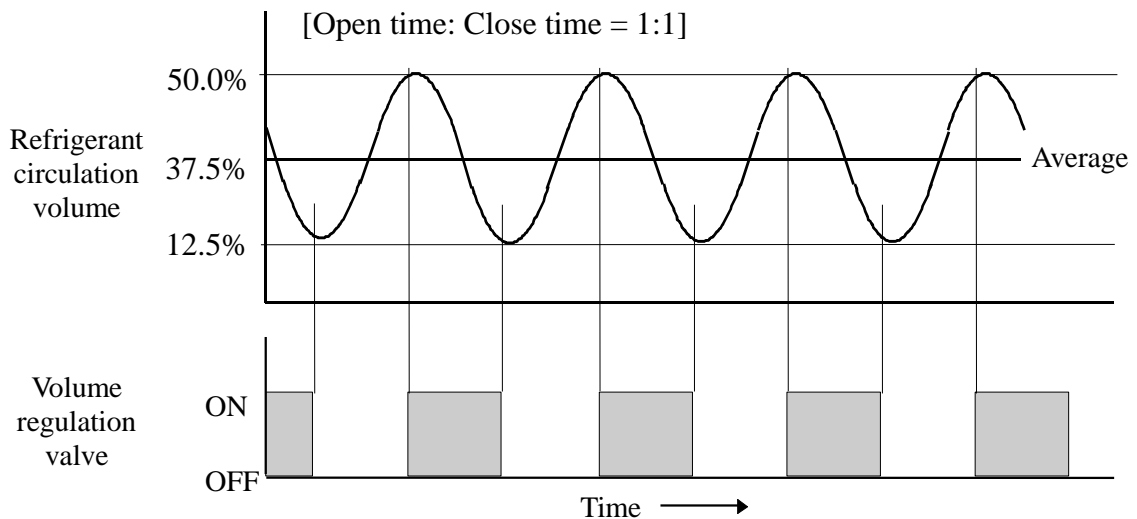


Fig. 6 Control of the volume regulation valve in the ON/OFF system

3-3. SPECIFICATIONS

Table 1 shows the specifications of the variable discharged volume type compressor

Table 1 Specifications of the variable discharged volume type compressor.

Type	Scroll type	
Compression volume	Maximum	60.5 cc/rev
	Minimum	21.2 cc/rev

4. RESULTS

4-1. PERFORMANCE

Proportional control system The newly developed variable discharged volume type compressor was assembled into the 28 kW (10 HP) type GHP (two compressors built-in type) manufactured by Aisin Seiki Co., Ltd. and a comparison test with a conventional machine was conducted.

Table 2 shows the test results. The development targets of both the JIS cooling and JIS heating ratings were achieved at a load ratio of approximately 8% (rated load is determined to 100%).

Additionally, the test result of the JIS cooling rating at a load ratio of approximately 16% was slightly lower than the target. However, a value close to 50% was obtained when averaging the cooling and heating test results.

Table 2 COP improvement effects by the proportional control system

Load condition	COP improvement ratio of system (at load ratio of approximately 8%)		
	JIS cooling rating	JIS heating rating	Average
Improvement effect	51.0 (%)	50.2 (%)	50.6 (%)

Load condition	COP improvement ratio of system (at load ratio of approximately 16%)		
	JIS cooling rating	JIS heating rating	Average
Improvement effect	44.1 (%)	52.3 (%)	48.2 (%)

* JIS cooling rating: Outdoor side 35°C (D.B)/24°C (W.B), Indoor side 27°C (D.B)/19.0°C (W.B)

* JIS heating rating: Outdoor side 7°C (D.B)/6°C (W.B), Indoor side 20°C (D.B)

ON/OFF control system

The newly developed variable discharged volume type compressor was assembled into the 14 kW (5 HP) type GHP (two compressors built-in type) manufactured by Aisin Seiki Co., Ltd. and a comparison test with a conventional machine was conducted.

Table 3 and Figs. 7 and 8 show the test results. This ON/OFF control system was developed with the aim of cost reduction. However, it was confirmed that the efficiency improved approximately 36% at a load ratio of 16 % (rated load is determined to 100%) when averaging the cooling and heating test results.

Table 3 COP improvement effects by the ON/OFF control system

Load condition	COP improvement ratio of system (at load ratio of approximately 16%)		
	JIS cooling rating	JIS heating rating	Average
Improvement effect	26.9 (%)	44.4 (%)	35.7 (%)

* JIS cooling rating: Outdoor side 35°C (D.B)/24°C (W.B), Indoor side 27°C (D.B)/19.0°C (W.B)

* JIS heating rating: Outdoor side 7°C (D.B)/6°C (W.B), Indoor side 20°C (D.B)

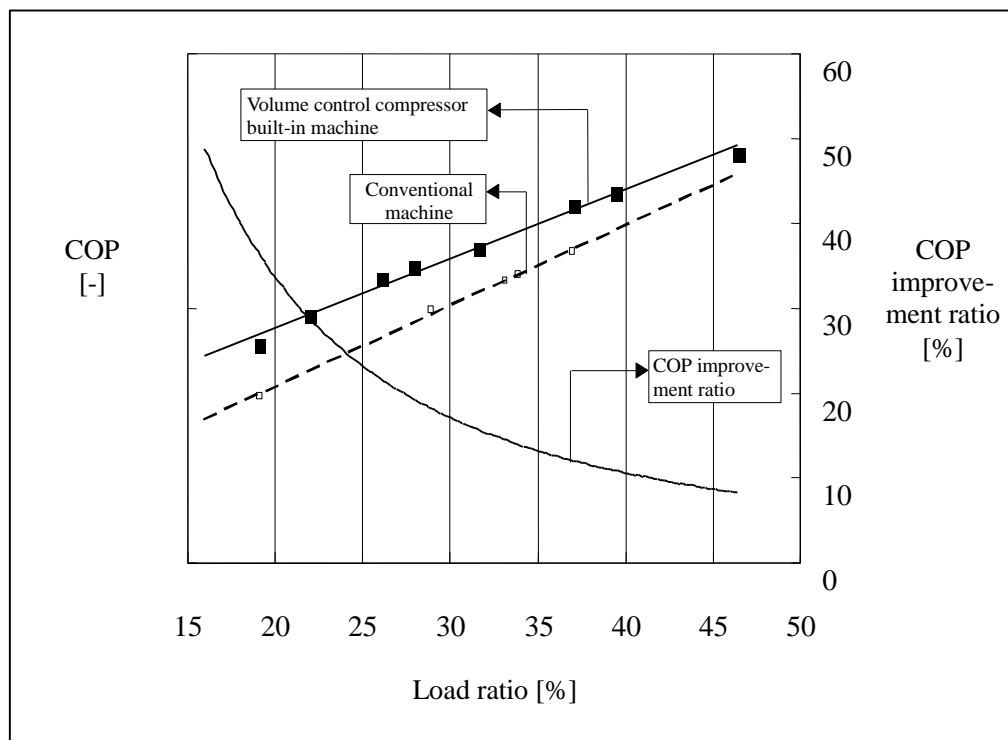


Fig. 7 Comparison of efficiency during heating

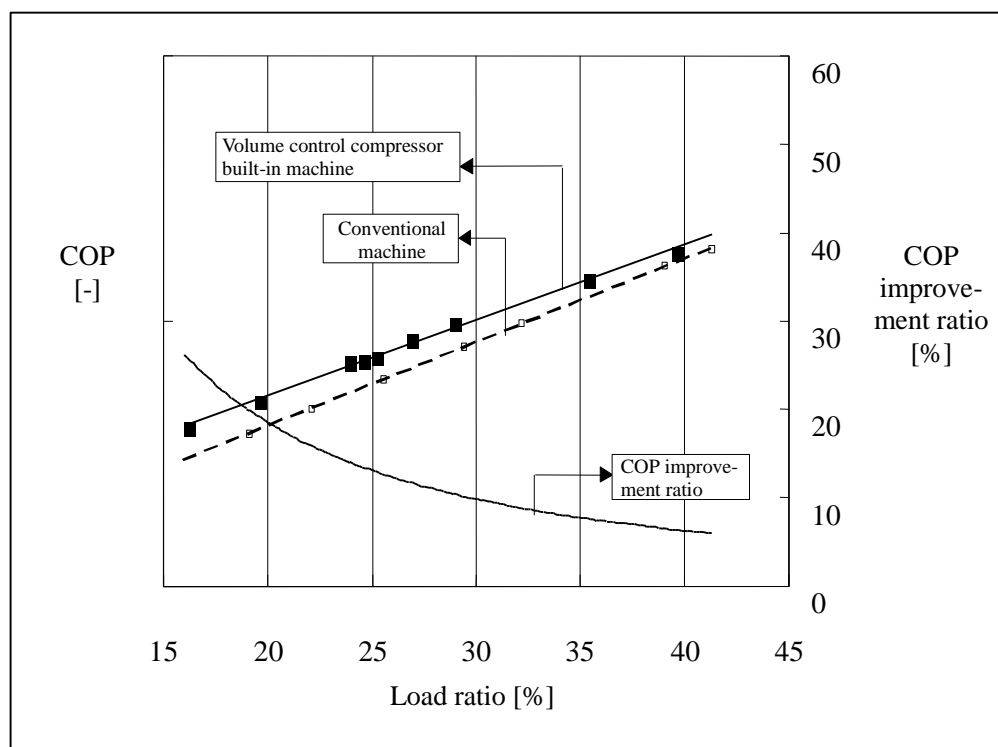


Fig. 8 Comparison of efficiency during cooling

4-2. CALCULATION RESULTS OF ANNUAL ENERGY SAVING EFFECTS WITH THE VARIABLE DISCHARGED VOLUME TYPE COMPRESSOR MOUNTED

Table 4 shows the calculation results of the annual energy saving effects between the variable discharged volume type compressor (ON/OFF control system) built-in machine (14 kW) and the conventional machine.

By mounting the variable discharged volume type compressor, energy equivalent to 5.6% of the annual gas consumption (704 kW/year) could be reduced.

For the calculation conditions, we utilized the annual load ratio of a general business building in Tokyo as the operation pattern.

The following shows the calculation conditions used for the above comparison.

[Calculation conditions]

Operation time: 2,000 hours/year

The ratio of the cooling operation to the heating operation was determined at 60%: 40% according to the past operation results.

Operation pattern (See Fig. 9.)

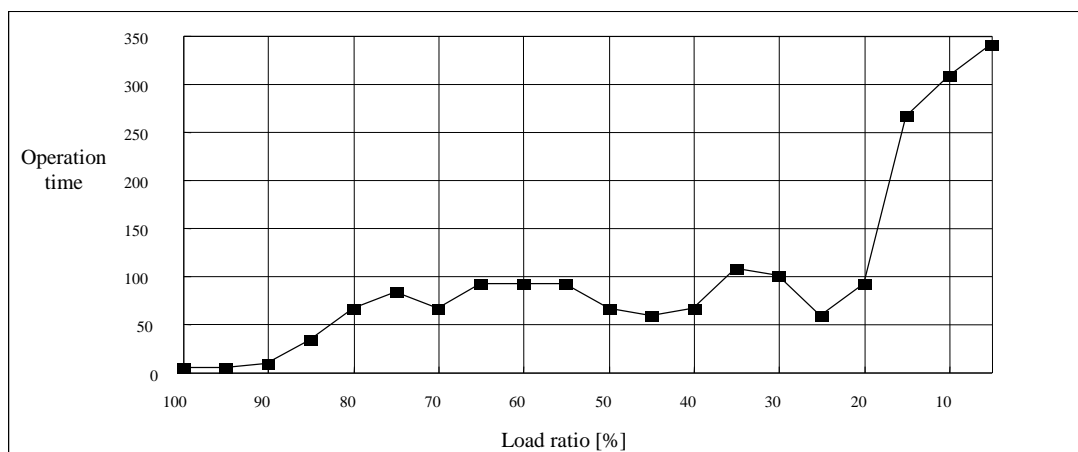


Fig. 9 Operation pattern

Table 4 Calculation results of annual energy saving effects

Conventional machine	12,573 kW/year
Machine with variable discharged volume type compressor mounted	11,869 kW/year
Reduction volume of gas consumption	704 kW/year
Reduction ratio of gas consumption	5.6%/year

4-3. DURABILITY OF THE VARIABLE DISCHARGED VOLUME TYPE COMPRESSOR

In the variable discharged volume type compressor, it was thought that the swing scroll part could be excessively worn out since the reduce ports are made in the fixed scroll part.

Therefore, a 2,000-hour durability test was conducted at 100% volume and minimum volume under high load conditions. As a result, excessive wear could not be observed on the swing scroll part. According to this result, it was estimated that the durability of the variable discharged volume type compressor is the same as that of the conventional compressor assuming that the service life of the GHP is 20,000 hours.

CONCLUSION

Use of the newly developed variable discharged volume type compressor has achieved improvement of the COP in the low-load area of the GHP. In particular, the proportional control compressor has improved the development target by 50%. From the viewpoint of price, as the cost of the volume regulation valve (proportional valve) has been reduced, the price has been suppressed to a level lower than the estimated level. It is planned that this variable discharged volume type compressor using the proportional control system is to be mounted on the highly efficient GHP (COP = 1.3 will be launched on the market in 2002), which is currently being developed.