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ABSTRACT

Recently building energy saving has been becoming one of big attentions due to global warming among EU, US and other industrial countries. As one of these building energy saving strategies, LG Electronics has developed the high efficiency high side shell (HSS) scroll compressor for a Building Multi Air-conditioning Systems (VRF: Variable Refrigerant Flow system), which are commonly used in Asia and Europe.

For high efficiency in VRF system, new oil return mechanism is developed. As the bypass loss caused by an existing oil return mechanism to low pressure side is eliminated through newly developed oil return mechanism, which is the world first structure, the system efficiency has been improved by 15% in part load condition and 5~7% in rated cooling/heating conditions. Accordingly, this novel mechanism can reduce annual building HVAC energy drastically. In addition, by employing a vapor injection structure the heating capacity in cold climate (-15˚C) has been increased by 27% and the system efficiency has been improved by over 10%.

This paper presents not only the novel oil return mechanism but the new structure of LG Electronics' HSS scroll compressor including the high efficiency brushless DC motor.

1. INTRODUCTION

As energy saving has been one of big issues due to global warming over the world, HVAC energy saving has become one of noticeable solutions for energy management in commercial buildings and skyscrapers. Thus, the demand of Building Multi Air-conditioning Systems (VRF: Variable Refrigerant Flow system), which has advantages such as energy saving and user comfortability, is steeply increasing since it enables individual operation such as independent temperature setting and control only in residing places. [1]

A compressor, one of critical components in VRF system, can seriously influence the reliability and performance of VRF system. VRF system usually employs rotary compressor or scroll compressor. Here, the scroll compressor can be classified into low side shell (LSS) compressor and high side shell (HSS) compressor up to its motor cooling type. LSS scroll compressor has compression process after motor cooling by intake low pressure refrigerant. Thus, LSS scroll compressor has the strength of motor efficiency and the weakness of volumetric efficiency. Besides, since supplied oil is completely discharged, compression chamber has the disadvantage of sufficient oil supply. On the other hand, HSS scroll compressor has motor cooling process by compressed high pressure refrigerant. Hence, HSS scroll compressor has the disadvantage of motor efficiency. However, since the refrigerant flows directly into the compression chamber, HSS scroll compressor can have enough oil supply and doesn't have any drop of volumetric efficiency by motor heating. Also, supplied oil can be separated in the compressor shell. Furthermore, HSS scroll compressor has the advantage of higher heating capacity in cold climate since there is no decline of volumetric efficiency by motor heating in high compression pressure ratio. It has easier oil management by discharge superheating control as well.

Now, the VRF system of LG electronics possesses the enough qualities of energy saving product through new HSS scroll compressor with novel oil return mechanism. In order to eliminate the energy loss during oil return operation in VRF system, a novel oil return mechanism to high pressure side returns the separated oil to compressor inside (oil sump) of high pressure, not to suction line of low pressure side. Accordingly, employing the newly developed HSS scroll compressor ensures performance enhancement in part load operation and reliable oil management. Also, through the application of vapor injection to compressor, heating capacity and efficiency in cold climate can be enhanced. Employing the structure of intermediate back pressure ensures high performance and reliability over entire operating envelope. Moreover, employing brushless DC motor of variable rotational speed in wide range guarantees the compactness of VRF system.

2. HIGH-SIDE SHELL SCROLL COMPRESSOR WITH HiPOR^{TM}

2.1 Outline of Compressor

Figure 1 shows the cross sectional drawing of HSS scroll compressor with new oil return mechanism to high pressure side (HiPOR^{TM}). Also, Table 1 draws up the list of principal specifications. The main process in the compressor can be explained as follows. Low pressure refrigerant through suction pipe at the upper side of compressor body flows directly into compression chamber and then is compressed. Compressed refrigerant drawn to gas guide positioned at the side of case inside is divided into the upper side and the lower side of motor. Then, the divided flows of refrigerant are discharged through discharge pipe after cooling down the stator. Oil is separated by oil separator from discharged refrigerant. Finally, refrigerant exits to cycle and oil is returned to compressor by oil recovery pump. Oil reserved in the oil sump at the bottom of compressor is provided to journal bearings in main frame pocket by oil supply pump. The part of oil in main frame pocket is provided to compression chamber by oil supply pocket positioned on the back side of orbiting scroll and the other part of oil is returned to oil sump by oil discharge guide

The HSS scroll compressor includes the applications of oil return structure to high pressure side (HiPOR^{TM}), which is the world first development, back pressure structure by intermediated pressure, vapor injection and brushless DC motor.

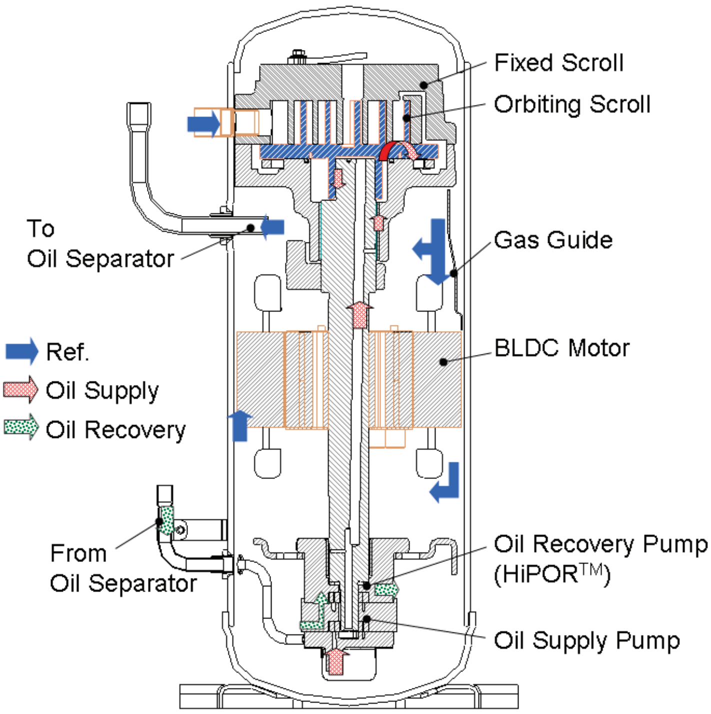


Figure 1 High-Side Shell Scroll Compressor with HiPOR^{TM}

Items	Specifications
Displacements	50.2cc/rev
Operating Speed	20~120Hz
Refrigerant	R410A
Characteristics	• HiPOR™ - High Pressure Oil Return Mechanism • HSS (High Side Shell) • Vapor Injection • BLDC Motor

Table 1 Specifications

2.2 Oil return mechanism to high pressure side (HiPOR™)

1) Oil Separator

Figure 2 shows the concept of general oil return mechanism in VRF system. In building multi air conditioner (VRF), on account of the long distance between outdoor unit and indoor unit or high elevation gap between outdoor unit and indoor unit, the amount of oil in a compressor can be dropped below minimum level before discharged oil returns to compressor. Thus, oil separator attached on discharge pipe of compressor returns oil separated from discharged refrigerant to compressor. The principle of oil return and separation can be explained that collisions between oil droplets or collisions to internal surface through cyclone flow of oil separator inside result in oil droplet's escaping from discharged refrigerant.[2] Oil separated from oil separator usually returns to suction line by pressure differential (oil return mechanism to low pressure side).

2) Drawbacks by oil return mechanism to low pressure side

High pressure refrigerant bypassed through capillary to suction line can cause system EER reduction. Oil and compressed high pressure refrigerant can be bypassed together through capillary in normal operation since the capillary capacity is designed to handle oil discharge at start-up and oil discharge at high speed operation. Accordingly, Oil return mechanism to low pressure side results in the drop of system performance by energy loss. Especially, the performance reduction in lower speed operation, which has low OCR, becomes larger.

3) Oil return mechanism to high pressure side (HiPOR™)

The concept diagram of oil return mechanism to high pressure side is described in Figure 3 and the internal structures of novel oil return mechanism are depicted in Figure 4. In order to eliminate the loss by oil return mechanism to low pressure side, the novel mechanism returns oil to high pressure side. In this case, since the internal pressure of compressor is slightly higher than the pressure of oil separator inside, it is impossible to return oil to compressor without any device. Thus, the pumping mechanism for oil return and piping system to transport oil from oil separator inside to compressor are developed.

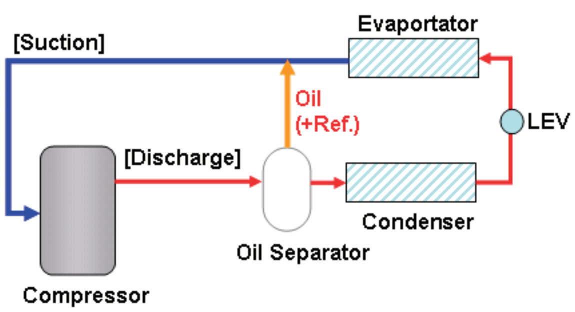
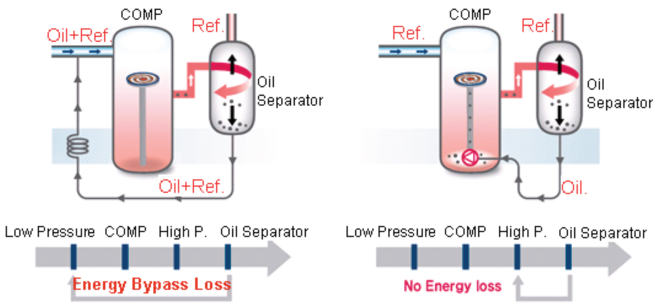


Figure 2 Conventional VRF cycle with Oil Separator



1) Conventional 2) HiPOR™

Figure 3 Oil Return Mechanism

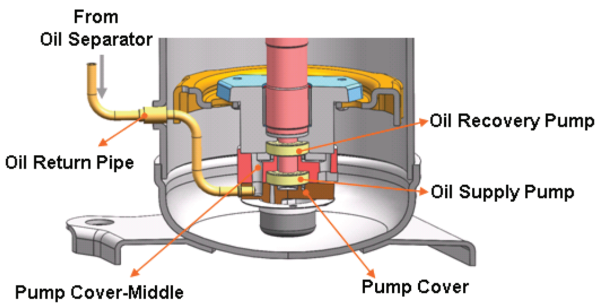


Figure 4 Compressor Structure with HiPOR™

Figure 5 shows the result of performance evaluation in ARI condition[3] along oil return mechanisms such as no oil return mechanism (compressor only), conventional type (oil return mechanism to low pressure side) and HiPOR™ mechanism (oil return mechanism to high pressure side). In the case of oil return mechanism to low pressure side, the cooling capacity is lower than compressor only case by energy bypass loss in low speed operation. On the other hand, in the case of oil return mechanism to high pressure side, the performance can be improved by 20% in low speed operation since cooling capacity does not drop and enhanced by 6% in high speed operation since volumetric efficiency increases by OCR reduction. The capacity of oil return is proportional to operation speed since oil return pump is linked to crankshaft together. Hence, oil return mechanism to high pressure side can enhance the reliability of compressor oil management

4) System performance in cooling/heating standard conditions

Figure 6 shows the composition to evaluate system performance by HiPOR™ in cooling/heating standard conditions and the result of system evaluation is shown in Figure 7. In order to evaluate the effect of HiPOR™, the both of oil return mechanism to high pressure and to low pressure side are evaluated in same 5hp (cooling capacity 14.5kW, heating capacity 16.3kW) system with a 5.5Hp (4.6RT at 60rps) inverter compressor. Since the consumed electric power of compressor is decreased by lower frequency operation (cooling: 49→45rps, heating: 53→ 49rps) for same capacity as shown in Figure 7, the system COP with HiPOR™ in cooling and heating operation could be improved up to 6.7% and 5.4% , respectively.

5) Efficiency simulation in part load conditions

Conventional oil return mechanism to low pressure side drops the performance in partial load condition drastically since bypass loss becomes larger in low rotational speed. Figure 8 shows the results of IPLV (Integrated Part-Load Value: AHRI 1230[4]) simulation in 8 hp(cooling capacity 23.2kW) system, including fan input power. 5% improvement in full load condition, in which a compressor are operated at maximum speed operation, and 7~15% improvement in 25~75% load condition, in which system is mostly operated by end user, result in IPLV 8.7% improvement. Thus, the annual electricity fee of end user can be reduced.

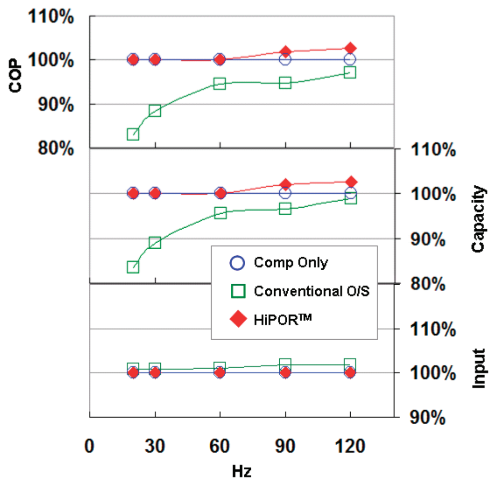


Figure 5 Efficiency with HiPOR™

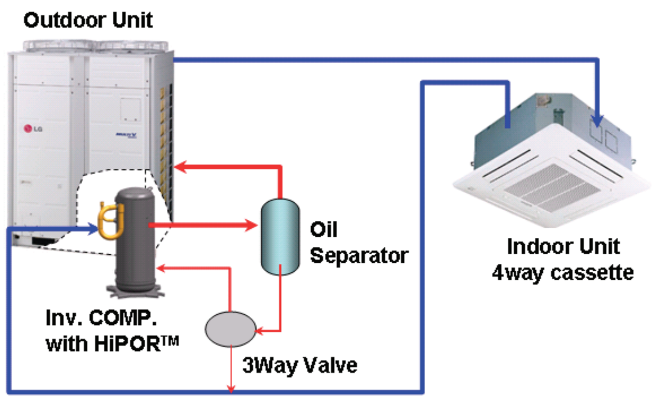


Figure 6 Configuration of Test System

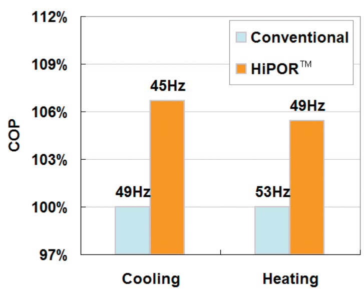


Figure 7 System COP

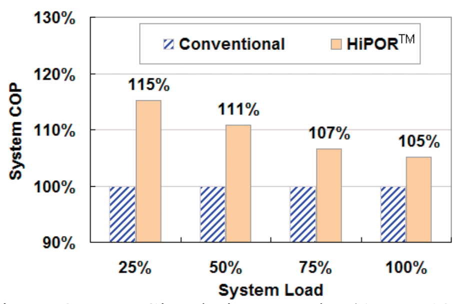


Figure 8 IPLV Simulation Results (AHRI 1230)

2.3 Back Pressure Mechanism

High side shell (HSS) scroll compressor has advantage to apply the structure of leakage prevention through back pressure, which is applied to the back side of orbiting scroll. The back pressure is formed by the discharge pressure filling shell inside. The structure of leakage prevention by back pressure, which prevents communication between compression chambers through pushing orbiting scroll toward fixed scroll tightly, has the better effect of leakage prevention and higher reliability to high temperature than tip seal type. Back pressure type of HSS scroll compressor can reduce thrust force to main frame through offsetting gas force with back pressure and intermediate pressure while, in case of tip seal type of LSS scroll compressor, gas force is supported by the only thrust bearing of main frame[5] [6]. Figure 9 shows the structure of back pressure for HSS scroll compressor of LG Electronics and Figure 10 shows the principle of back pressure formation. Intermediate pressure proportional to suction pressure ensures the stability of back pressure control and enables back pressure to work below the limit of thrust force over entire operating envelop for enhanced performance and reliability. Thus, the efficiency of compressor could be improved by 10% higher than previous scroll compressor of LG Electronics.

Since intake refrigerant does not include enough oil by HiPOR™ mechanism, it is desirable to set up a specific oil supply mechanism for compression chamber. That is, oil is provided to intermediate pressure chamber through installing oil supply pocket on the back side of orbiting scroll. Oil can be supplied to compression chamber as intermediate pressure chamber is communicated back and forth with two compression pockets (A/B pocket). Accordingly, employing the structure of intermediate pressure ensures sufficient oil supply to compression chamber.

2.4 Vapor Injection

While heating load increases as outdoor temperature goes down, the heating capacity of building multi air conditioner (VRF) decreases as evaporating pressure goes down. In order to break this bottleneck, there are several solutions such as the application of supplemental heater, high capacity compressor and booster unit. The most popular way to expand heating capacity is the application of vapor injection.[7] Figure 11 shows the structure of vapor injection port and Figure 12 shows the effect of heating capacity expansion by vapor injection and HiPOR™. Through HiPOR™, heating capacity in cold climate could be increased up to 7% and through the application of vapor injection to compressor, heating capacity and COP could be increased by 20% and 10%, respectively.

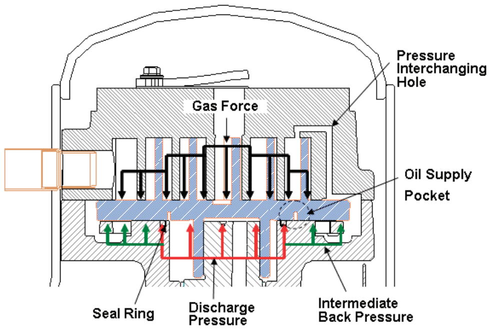


Figure 9 Back Pressure Structure

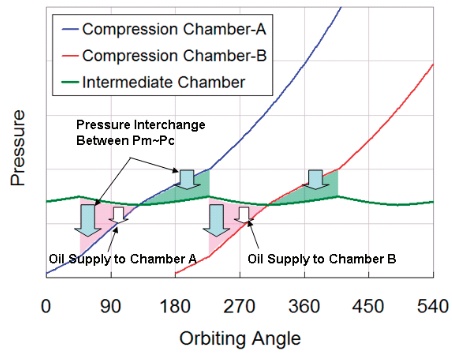


Figure 10 Mechanism of Intermediate Pressure Setting

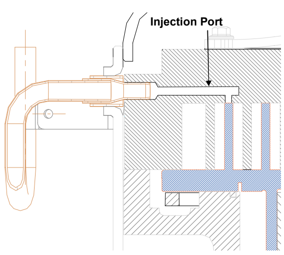


Figure 11 Vapor Injection Structure

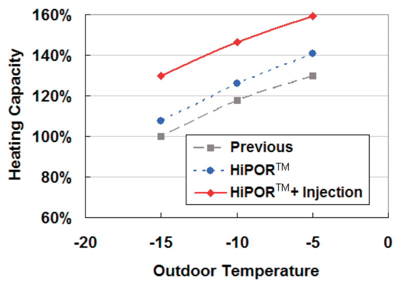


Figure 12 Heating Capacity with Injection

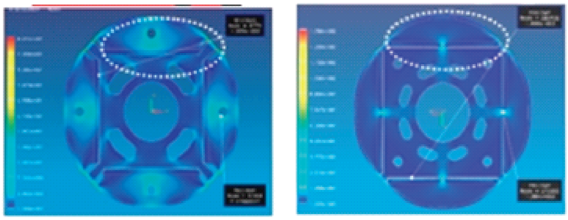


Figure 13 Rotor Stiffness Analysis Results

2.5 Brushless DC Motor

Brushless DC motor is employed for the high efficiency, compactness and wide operation range of compressor. Brushless Motor has divided magnetic to prevent the escape of permanent magnetic and reinforced ribs to avoid the damage of rotor rib in high speed operation. The shape of bridge is optimized to minimize the leakage of magnetic flux. Figure 13 shows the result of rotor stiffness analysis. On the other hand, in order to cogging torque and torque ripple generating noise and vibration, Uneven air gap is employed and flux barrier angle are optimized. Torque ripple and cogging torque could be decreased up to 68% and 60%, respectively.

3. CONCLUSIONS

Through HiPOR^{TM}, the annual consuming electricity power could be reduced as efficiency enhancement in rated load efficiency and partial load (actual operation condition) efficiency are improved by 6% and 15%, respectively. Axial leakage prevention and optimized oil supply by communication back and forth with two compression pockets ensures 10% enhancement of compressor efficiency. By applying vapor injection, heating capacity in cold climate (Outdoor temperature: -15℃) can be increased by over 20%. Besides, employing brushless DC motor operated in the wide range makes compactness of VRF system possible.

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