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ABSTRACT

Building multi air conditioners (VRF: Variable Refrigerant Flow system) are commonly used for buildings in Asia and Europe. It has several advantages compared to conventional central air conditioning, that is, higher efficiency, low maintenance cost and easy installation.

For high efficiency and reliability, DC compressor was developed. Oil injection mechanism was adopted for low rpm and part load operation. By the control of oil circulation in the compressor, oil discharge rate was reduced. A plate heat exchanger was used for higher sub-cooling of refrigerant and high rise installation. For easy maintenance, automatic fuzzy based refrigerant charging and charge check-up function were developed with accuracy of ±10%.

As a result, the newly developed building multi air conditioner provides more energy saving, installation flexibility and maintenance easiness for building owners and administrators.

1. INTRODUCTION

More than 2 decades has been passed since first VRF system introduced to the world. Since then VRF system has been evolved to increase the system performance, which is lower energy consumption (COP), ease of installation, ease of maintenance, and robustness. To make energy saving VRF system, high performance compressor and heat exchanger were introduced and to give a high freedom of installation limitation, high capacity sub cool heat exchanger unit was applied (Yoo, P., 2000).

System reliability is main concern for many building owners. Suspended air conditioning service may reduce income and even degrade the building value. In recent decade, many researchers have investigated the method for fault detection and diagnosis (FDD) to prevent sudden failure of the HVAC system in a building. FDD is intended to ease of the maintenance of the HVAC system. For small house may not need FDD system in their air conditioner but for commercial or big residential buildings require maintenance plan. Common maintenance is carried out by using maintenance company. If HVAC systems can diagnose by itself, maintenance cost drops down and also energy efficiency increase.

Unfortunately classical FDD theory does not work well in VRF system because the system characteristics are vary with installation site (Cho, S., 2005). Degree of freedom in commercial VRF system installation is large. 3~4 outdoor unit(s) can handle up to 64 indoor units. Furthermore, height difference between indoor units and outdoor units can exceed 50m. Various refrigerant pipe connection types are also arise problem. Therefore, the only way to establish FDD theory to VRF system is customize to each building. In the manufactures view point, customizing to every building is not possible. By narrowing down fault detection scope and concentrates only on the outdoor unit, installation effects such as pipe length, and compressor frequency can be eliminated. With these restrictions, logic might lose resolution but general FDD can be obtained.

The new system with most of features described above has produced in 2007. Its technological breakthrough will be described in the following section.

2. COMPRESSOR & INVERTER CONTROL

2.1 DC inverter scroll compressor

2.1.1 Overview of a new inverter scroll compressor

Improved type of inverter scroll compressor as a novel development shown in Figure 1. This compressor has 16.5 KW rated cooling capacity at 60 RPS, operating in 25 -105 RPS. This compressor has improved efficiency in the whole operating range through employing DC motor and the optimized scroll shape for specific refrigerant. Also the oil discharge rate is minimized by using oil discharge reduction structure, which can keep the sufficient oil level to maintain reliability at high speed range. Moreover, it has highly improved efficiency through oil injection mechanism in the low speed range, which is especially important to part load efficiency and reliability

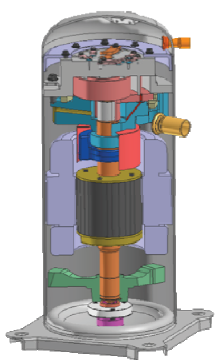


Figure 1 NEW DC Inverter

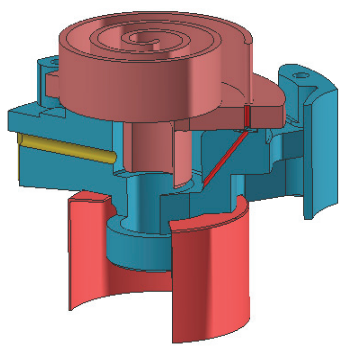


Figure 2 Oil Injection Mechanism

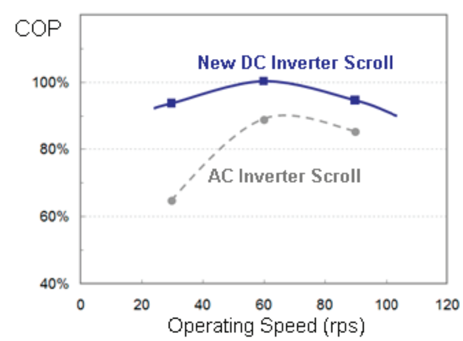


Figure 3 COP Improvement

2.1.2 Oil injection mechanism

It is necessary to have an adequate radial sealing force in the whole range of operating speed to improve the efficiency and reliability in inverter scroll compressor, which is usually used for a building multi air-conditioner. Radial sealing force is determined by the difference between gas force and centrifugal force by orbiting scroll. However, it is difficult to keep enough sealing force since slow operating range has low centrifugal force. In order to complement the sealing force, the way to give tangential gas force through adjusting the degree of crank pin running driving bush has been used. This method makes sealing force excessive in high speed range even if it guarantees pertinent sealing force in low speed range.

A new developed compressor employs a novel method to improve the reliability and efficiency in low speed range. The degree of crank pin running driving bush is designed to keep adequate sealing force considering the efficiency and reliability in whole operating speed range. Also, oil injection directly into a compressor pocket is presented to prevent radial leakage loss in low speed range.

Figure 2 shows a new developed oil injection mechanism. Oil is supplied from oil pump, which are installed in the bottom part of compressor, to the journal bearing of the orbiting scroll and the main frame along crank shaft. And then, this oil is collected in the pocket of the main frame and circulates through an oil drain. Oil, which is pressurized by orbiting scroll boss, is directly supplied from the pocket of main frame to compressor pocket through oil injection hole and orbiting scroll. The oil injection hole of orbiting scroll is connected intermittently with the oil supply path of main frame to supply the adequate amount of oil into the compressor pocket. This oil supply procedure makes the efficiency and reliability improved in whole operating speed range. Besides, oil circulation path is optimized by oil skirt to prevent sucking excessive oil mixed with refrigerant and reduce oil discharge rate in high speed range. Figure 3 shows the COP improvement of a new developed compressor, comparing with previous AC inverter scroll compressor.

2.2 SynRM for Compressor motor

Synchronous Reluctance Motor (SynRM) has been adopted for VRF system with several considerations as following. Main point for motor choice are high efficiency compared with conventional AC induction motor for energy saving, low vibration and higher reliability (CF, demagnetizing or drive protection at high EMF voltage).

The cost of SynRM is 3.5% higher than AC induction motor but shows 3~10% higher efficiency. As SynRM does not have conduction materials in a motor, there is no copper loss and the efficiency of SynRM is higher than that of induction motor which has conduction bar in a rotor.

The SynRM specifications and costs are compared at Table 1. The rating power and the max power of the two motors are about 4.2KW and 9KW. Figure 4 is the designed SynRM rotor structure with the high magnetic reluctance and low torque ripple. Figure 5 is the comparison of motor performance.

Table 1 Comparison of specification and cost

Items	AC IM	SynRM
Stator size(mm)	Φ179x72	Φ179x80
Rotor size(mm)	Φ84.5x72	Φ92.1x80
Number of poles	2	4
Cost($)	100%	103.5%

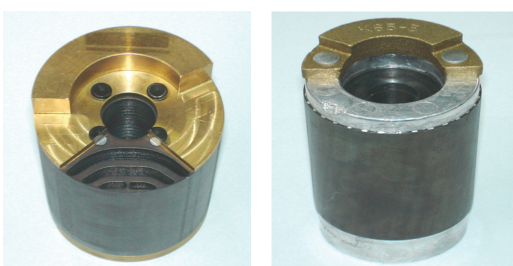


Figure 4 SynRM and AC IM

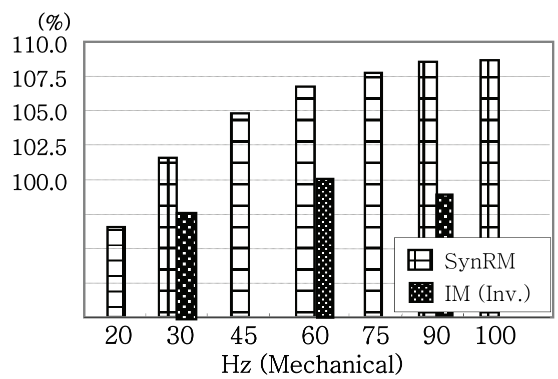


Figure 5 Motor Efficiency

2.3 Inverter Control for SynRM

Synchronous Reluctance Motor (SynRM) requires the sensor-less control because motor is inside of compressor with high temperature and circulating gas. Sensor-less algorithm consists of two parts. One is the high frequency signal injection method which has reliable position estimation in starting and low speed operating. It makes reliable start-up performance under various load condition of multi air conditioner. The other is the flux observer based magnetic modelling.

The information for this flux observer is motor current and input voltage. Generally, as motor speed is higher, induced motor voltage is also higher. So the position estimation by flux observer becomes more accurate as speed increase. Therefore, this hybrid sensor-less method guarantees adequate speed and current control at overall speed range. Figure 6 shows the overall control block diagram for SynRM.

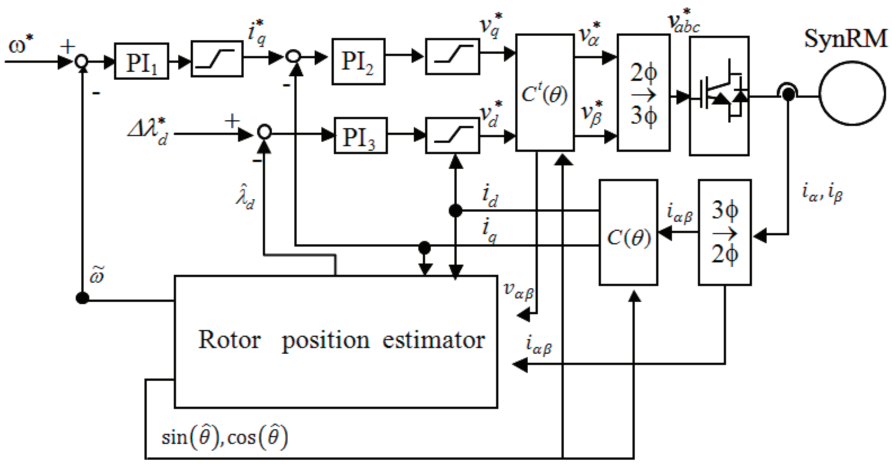
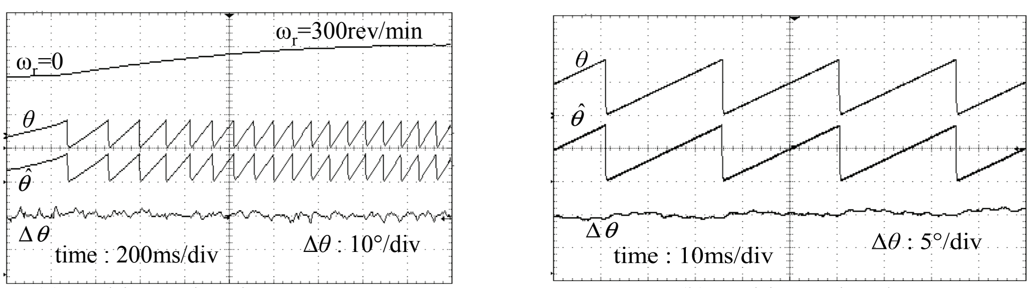


Figure 6 Block diagram of SynRM Control

Speed Control with hybrid sensor-less control is verified by error of position estimation. Signal injection method at 5Hz and flux observer at 20Hz are verified. Errors of position estimation is below ±5° in both cases.
Following Figure 7 shows the estimated position and error.



(a) position estimation at 5Hz (b) position estimation at 20Hz

Figure 7 Position error according to signal injection and flux observer

3. SUB COOL HEAT EXCHANGER

3.1 Sub Cool Plate Heat Exchanger Design

In high-rise building, outdoor unit of VRF system usually located at ground floor or top floor. It means that long pipe installation and large height difference between units are unavoidable when installing VRF system. These harsh installation conditions may cause problems such as flushing, indoor unit noise, and lower performance. To prevent problems caused by height difference, system should provide enough sub-cool which enables to deliver liquid phase refrigerant to indoor units.

Required sub-cooling can be calculated from the pressure difference between outdoor and indoor unit. When liquid refrigerant flows from outdoor to indoor units, refrigerant undergoes two types of pressure drop which are caused by friction and gravity. Following equation (1) descries the relations.

$$\Delta P = f\frac{L}{D}\frac{\rho V^2}{2} + \rho g H \qquad (1)$$

Where, f is friction factor, L is pipe length, D is pipe inner diameter, V is flow velocity, H is height difference between outdoor unit and indoor unit. For the 190m pipe length and 90m height, 20℃ of sub-cooling were required.

Plate heat exchanger was selected as a sub-cooling heat exchanger because it occupies small volume and is easy to change its capacity.

Plate heat exchanger performance was measured in the ARI standard test condition. As shown in Figure 8, when the number of plates increases, sub-cooling increased but its difference was less than 3℃. The effect of bypass flow rate was much higher than that of number of plate.

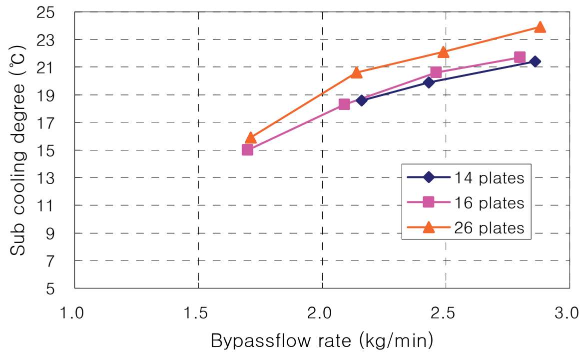


Figure 8 Effect of number of plates and bypass flow rate on sub-cooling

4. HIGH EFFICIENT HEAT EXCHANGER

For higher energy efficiency and lower material cost, the high efficient heat exchanger was used in the outdoor units. This fin-tube heat exchanger was composed of the round tube of 7mm outer diameter having several internal grooves inside it and newly designed louver fins. The design parameters for louver fin structure such as louver angle, louver pitch and fin spacing was shown in Figure 9. The louver angle and louver pitch were optimized by the 2-dimensional CFD analysis. Although newly designed louver fins have a low fin spacing of 14FPI compared to conventional corrugate fins of 17FPI, it has the higher heat transfer performance due to the enhanced air-side heat transfer characteristics as shown in Figure 10 (Hsieh, C., 2006). Figure 11 shows the comparison of air side performance with fin shapes. New louver fin of 14FPI has higher heat transfer coefficient of 27% and higher air side overall performance of 5% compared to the corrugate fin of 17FPI on the dry surface condition.

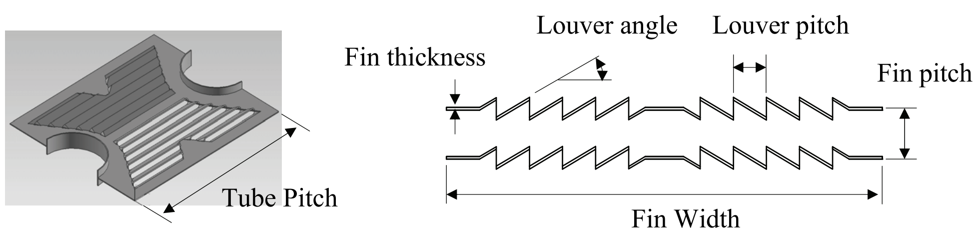
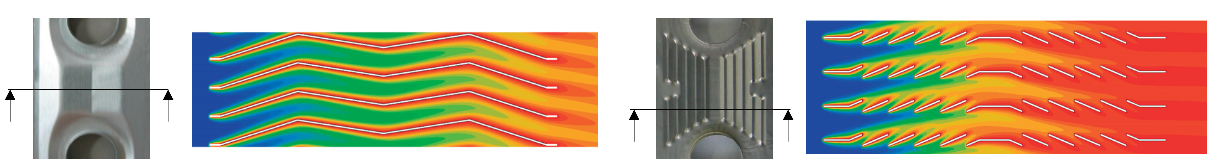


Figure 9 Design parameter for louver fin structure



(a) Conventional corrugate fin (17FPI)

(b) Newly designed wide louver fin (14FPI)

Figure 10 Comparison of temperature fields with fin shapes

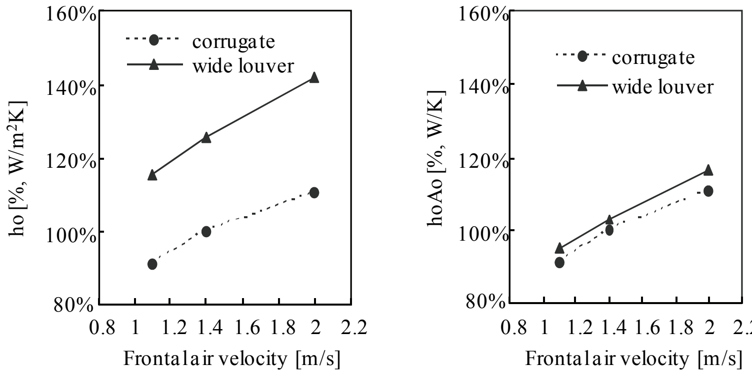


Figure 11 Comparison of Air side performance with fin shapes

The heat exchanger with louver fin has the high performances in the overall operating ranges of multi air conditioner. At 35℃ DB/24℃ WB cooling condition, the system efficiency was increased by 7% with new louver fin. System efficiency at 7℃ DB/6℃ WB heating condition of was also increased by 2%. In case of frost dominant heating condition, wide louver also has a higher system efficiency of 8%.

5. REFRIGERANT FAULT DETECTION

Most VRF system require sufficient refrigerant to avoid mal-function. If refrigerant are under or over charged, problem may occur. For the overcharged condition, cooling (or heading) may not be possible and in heavily overcharged condition, liquid compression is also possible which causes compressor damage. In case of undercharged system, electric energy consumption increases and compressor discharge temperature rises. Either overcharged or undercharged, charged amount of the refrigerant in VRF system is critical to performance and stability. Common refrigerant charging method for VRF system is to measure precise pipe length to calculate charge amount. Therefore, there are possibilities of refrigerant charging fault for inexperienced installers

5.1 Refrigerant fault detection

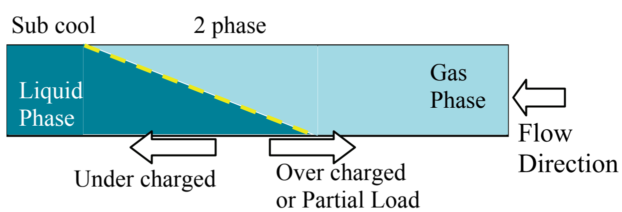


Figure 12 Refrigerant distributions in heat exchanger

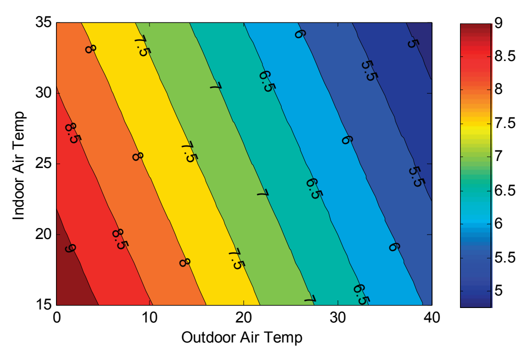


Figure 13 Sub-cool vs. temperature condition

Figure 12 shows general refrigerant distribution in a heat exchanger. In theory, optimum refrigerant charge can be detected by measuring sub cool (Langley, B., 2002). But in real life VRF system sub cool itself does not gives enough refrigerant charge information. As the ambient temperature changes, sub-cool also changes as seen in Figure 13 because of the efficiencies in the heat exchanger. Of course, if system is charged with very small amount of refrigerant, sub-cooling itself can be a good refrigerant fault detection logic. To determine precise amount of refrigerant in the system, parameter clustering is needed as in FDD (Cho, S., Yang, H., 2005).

Common FDD require full understanding of system dynamics for a specific system. The dynamic equation for the VRF system is not possible and system response is different by installation. Therefore, the VRF system with FDD is not easy. FDD function in the VRF should be fool proof. Miss-judgment could be directly related to customer complaints. To eliminate complexity and false detection, only outdoor data with following restrictions were

investigated. 1) Steady state response (equilibrium point). 2) Full load operation. 3) No extra refrigerant in indoor unit. With these restrictions, data response shows more outdoor unit characteristics.
There are two major classification methods in FDD. The one is neural network based clustering and the other is fuzzy based clustering. Among those two, fuzzy logic based classification was applied because fuzzy logic based classifier can incorporate system knowledge from VRF developer more easily. Following Figure 14 is fuzzy logic based classifier.

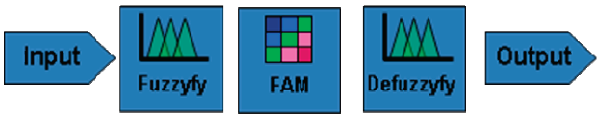


Figure 14 Classification

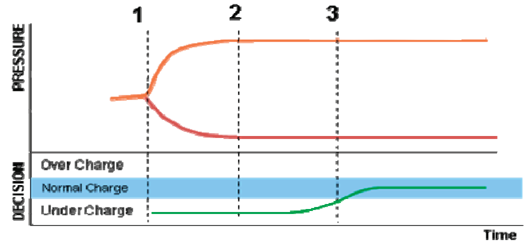


Figure 15 Time vs. fault decision

Most important factor in developing FDD logic is parameter selection. If selected parameters do not show enough system characteristics, logic performance decreases. For example, compressor discharge temperature is commonly known factor for refrigerant shortage. If system is under charged, compressor discharge temperature increases. But in real experiment shows that discharge temperature is affected by charged refrigerant amount but other system conditions such as outdoor temperature variation contribute more to the discharge temperature. Therefore discharge temperature itself cannot be the FDD logic parameter.

Reference data were collected with various temperature conditions, with various installation configurations, and with various refrigerant charge conditions. Certain blackout range of resolution exists in the system. VRF system can handle certain amount of over or under charged refrigerant. Therefore, if system is charged correctly, small amount of refrigerant fault cannot be seen.

Refrigerant fault detection logic should be confined to use only at steady state as shown in Figure 15. Refrigerant fault detection logic with signal filters which detecting steady state showed promising results. Regardless of the installation condition, refrigerant fault detection logic gives resolution up to 10% of the total refrigerant over or under charged in the system.

7. CONCLUSIONS

VRF system has many attractive features. Recently developed a new VRF system save more energy and easy to maintain using following advanced technologies:

- Compressor with SynRM motor increases energy efficiency.
- Efficient plate heat exchanger enables VRF system to be installed more height difference.
- High efficient heat exchanger improved efficiency by 2~7%
- Refrigerant fault detection logic can determine charged refrigerant with 10% resolution.

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