Development of the high efficiency and low noise swing compressor for CO₂ heat pump water heater

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ABSTRACT

Recently, from the viewpoint of global warming, natural gas CO_2 is more and more attention in the refrigeration and air conditioning industry. Otherwise, a CO_2 is the refrigerant that operating pressure and density is very high. Therefore, it is difficult to maintain efficiency and reliability. We already commercialized CO_2 heat pump water heater supply units, for these problems we came using a swing compressor in order to solve these problems.

We have developed the improvement the higher efficiency of 106% compared with our commercialized swing compressor.

This paper explains about development of the high efficiency and low noise swing compressor by a new concentrated winding motor and by a minimize of a re-expansion capacity and by a new motor stator fixation method.

1. INTRODUCTION

In recent years, the concern for natural environment such as ozone layer depletion and global warming becomes more and more growing. One of the issues is the use of HFCs refrigerants as substitutes for CFCs and HCFCs. However, the HFCs global warming potential GWP is high, accordingly HFCs is designated as a gas restricted to release. Therefore, natural refrigerants such as CO_2 , HC and ammonia are drawing attention as substitutes for HFCs. Under these circumstances, the residential CO_2 heat pump water heater supply units have been launched into the market since February 2002 by Daikin industries Ltd.

However, CO_2 refrigerants have characteristics of high pressure and high refrigerating capacity; the working pressure is extremely high and the working high-low pressure difference is high and the refrigeration capacity per a unit volume is large compared with R410A refrigerants. As a result the displacement of CO_2 compressor becomes small and the influence of a leak for performance becomes great. On the other hand, CO_2 heat pump water heater supply units are driven all night through a year, and then CO_2 heat pump water heater supply units are demanded low noise from air conditioning equipment.

We have developed the improvement CO_2 swing compressor. We applied technology of air conditioning of a motor; we developed concentrated winding motor for CO_2 compressor and let the efficiency and reliability up. And we developed technology of minimize of a re-expansion capacity; we used a FEM and pursued a limit of the discharge port height. And we developed a new quiet motor fixation method.

2. SELECTION OF THE COMPRESSOR TYPE FOR CO₂ REFRIGERANT

Figure 1 shows a rotary compressor mechanism and swing compressor mechanism. A rotary compressor puts a cylindrical roller in the cylinder which there is a cylindrical hole, and a blade which pushes to a roller by a spring and gas force forms compression room. The contact place of a blade and a roller is a leak point and a friction with a blade and a roller becomes a severe lubrication state. On the other hand, a swing compressor, because of a blade and a roller are unified and form a piston, there is no leak point and there is no severe lubrication state such as a rotary compressor. In particular CO_2 refrigerant, the working high-low pressure difference is near 10MPa or more than that, for the high efficiency and high reliability we selected swing compressor for CO_2 refrigerant.



3. FEATURES OF THE SWING COMPRESSOR FOR CO₂ REFRIGERANT

3.1 Explanation of the compressor structure

Figure 2 shows cross section of the CO_2 swing compressor. Its basic construction and the flow of refrigerant and oil are identical to that for R410A. Our CO_2 swing compressor is the high pressure shell and one stage compression.



Figure 2 : Cross section of the CO₂ swing compressor

3.2 Specification compares improved compressor with an original

Table 1 shows the several specifications of the CO₂ swing compressor.

	Original compressor	Improved compressor				
Compressor type	Swing	Swing				
Motor type	Distributed winding motor	Concentrated winding motor				
Displacement	3.7cc	4.2cc				
Discharge port height	5.0mm	2.5mm				
Motor stator fixation method	One section welding	Two sections welding				

Table 1: Specifications

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3.3 Concentrated winding motor

Figure 3 shows the stators of the distributed winding motor and concentrated winding motor. The distributed winding motor shown in this figure is a 4-pole 24solots and the concentrated winding motor shown is a 6-pole 9-slot IPM synchronous.





Distributed winding motor (original) Figure 3: The exterior x

Concentrated winding motor (improved)

Figure 3: The exterior view of the motor stators

As for the oil used for a CO_2 compressor, viscosity is high; for example, it is 18 from 20 cSt at 100 degrees, so that the oil which is collected in part of upper a motor, returns to oil collect where is part of under a motor, the oil overcomes viscosity resistance, and it is necessary to fall by oil own weight. As an index to evaluate oil return, an area of the core cut which is an oil return passage, we took in hydraulic mean depth. Table 2 shows a result of an oil return characteristic with an actual machine.

Table 2: Oil return characteristic

hydraulic mean depth : m [mm]	0.9	1.0	1.7	1.9	2.1
an oil return characteristic	×	×	0	0	0

×: oil accumulate on a motor, and oil does not return to collect

o: oil does not accumulate on a motor, and oil return to collect

$$n = \frac{S}{l}$$

$$\begin{cases} m & z \\ S & z \\ l & z \end{cases}$$

r

(1)

i : hydraulic mean depth*i* : cross section

l : length of a circumference

Figure 4 shows the analytical results of the relationship between the back york length of a motor and the motor efficiency ratio. If we will take an oil return passage, the back york length becomes long, there is a problem that the motor efficiency falls down. We decided that the hydraulic mean depth is 1.9mm and the back york length is 9mm, for motor stators outside diameter 112mm. Figure 5 shows the experimental results of the relationship between the operating speed and the motor efficiency ratio. Our developed concentrated winding motor efficiency is 103% higher than our original distributed winding motor.



length and the motor efficiency ratio



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3.4 Minimize of discharge port height

Because a gas density of CO_2 is very high, to minimize of a re-expansion capacity is one of a key technology for a high efficiency swing compressor. A re-expansion capacity is formed by a discharge port area. If a discharge port diameter becomes small, a re-expansion capacity becomes small, but the resistance of discharge becomes large, and then over-compression loss becomes large. We have to make discharge port height low in order to make a re-expansion loss small. Figure 6 shows the FEM displacement model of a front head and a cylinder, and Figure 7 shows the analytical results of the relationship between the discharge port height and the front head displacement. Original compressors discharge port height is 5.0mm, and displacement hardly changes to 2.5mm of discharge port height, and displacement suddenly increases when less than 1mm. Then we selected discharge port height was 2.5mm, a volt cannot fix a valve, we fixed a valve with a rivet (Figure 8). Figure 9 shows the experimental results of the relationship between the operating speed and the volumetric efficiency ratio. We have developed higher volumetric efficiency of 102-106% compressor compared with our original.



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3.5 Performance of the total efficiency

Figure 10 shows the experimental results of the relationship between the operating speed and the total efficiency at condition 1. From the mentioned above of the motor and the volumetric efficiency improvement, we have developed higher total efficiency of 106-115% compressor compared with our original.



Figure 10: Relationship between the operating speed and total efficiency ratio (condition 1)

4. NOISE REDUCTION

If the ratio of a operating pressure and a pulsation pressure in chamber is the same as R410A, because of a CO_2 refrigerant operating pressure is very high, a pulsation pressure in chamber becomes large, then a fluid noise becomes big. We can calculate resonance frequency in a chamber with Equation (2). In this Equation, c is a sonic speed; ex. 280m/s at 12MPa and 120 degrees, v_1 is a volume of space under a motor (our compressor: 370ml), v_2 is a volume of space upper a motor (our compressor: 820ml), S_0 is a cross-section area of a passage connecting v_1 and v_2 (our compressor: 1670mm²), L is a cross-section length of a passage connecting v_1 and v_2 (our compressor: 70mm), then f is a resonance frequency (our compressor: about 430s⁻¹). Then a compressor vibrated by resonance frequency in an up and down direction, and driving sound tended to become big by the 400Hz band sound. We have found the element which a compressor went up and down by this resonance, and we solved a driving sound problem of 400Hz band sound with stopping top and bottom vibration of the element.

$$f = \frac{c}{2\pi} \sqrt{\frac{S_0}{L} \left(\frac{1}{v_1} + \frac{1}{v_2}\right)}$$

$$\begin{cases} f : \text{resonance frequency} [s^{-1}] \\ c : \text{sonic speed} [m/s] \\ v_1, v_2 : \text{volume} [m^3] \\ S_o : \text{cross section} [m^2] \\ L : \text{length} [m] \end{cases}$$

$$(2)$$

$$V_2$$

$$V_1$$

Figure 11: resonance model

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Because CO₂ refrigerant have characteristics of high pressure, a press fitting cannot hold a motor stator to a shell pipe, conventionally we welded it on a one section to fix a motor stator. But the motor stator laminating steel plate are easy to vibrate in a up and down direction, and the characteristic value of vibration of our original motor and one section welding is about 400Hz. Because the frequency was very near to resonance frequency in a shell, the motor stator vibrate to up and down, and the driving sound became high. Then we have welded the motor stator on two sections to fix the motor stator laminating steel plate (Figure 13). Figure 12 shows the experimental results of the relationship between the vibration frequency and the axis direction vibration acceleration of a motor stator. In this way, the vibration acceleration of 400Hz of the two sections welding decreased in 1/4 than it of one section welding.

Figure 14 shows the experimental comparison of noise power level between one section welding and two sections welding. The resonance in a shell was not settled, but was able to confirm that driving band sound of resonance frequency fell down greatly because the part which vibrated by resonance disappeared.

Thus we developed low noise swing compressor for CO₂ heat pump water heater.



Figure 12: Relationship between the vibration frequency and the vibration acceleration



Figure 13: Cross section of motor stator fixation method



Figure 14: Comparison of noise power level

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5. CONCLUSIONS

We developed the high efficiency and low noise swing compressor for CO_2 heat pump water heater.

- We confirmed that it was necessary more than 1.7mm by a hydraulic mean depth to correct the oil which collected on a motor in oil return in a CO₂ compressor.
- The minimum height of a discharge port confirmed that it was 2.5mm in order to turn a re-expansion loss into a minimum in a swing compressor.
- We confirmed that two sections welding fixation of motor stator was effective for driving sound in order to suppress influence of characteristic value of vibration of a up and down direction of motor stator.

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