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H. Kato  
*Toshiba Carrier Corp.*

M. Hasegawa  
*Toshiba Carrier Corp.*

A. Morishima  
*Toshiba Carrier Corp.*

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DEVELOPMENT OF 2-CYLINDER ROTARY COMPRESSOR SERIES FOR LIGHT COMMERCIAL USE WITH R410A

*Hisataka Kato, Masumi Hasegawa, Akira Morishima
Toshiba Carrier Corporation First Compressor Department
336, Tadewara Fuji-shi, Shizuoka-ken, 416-8521, Japan
Tel.:+81-545-62-5642; Fax:+81-545-66-0305
E-Mail: hisataka.kato@toshiba.co.jp *Author for Correspondence

ABSTRACT
We have developed a DC 2-cylinder rotary compressor series for light commercial air conditioners using a new refrigerant R410A (HFC) for the first time in the industry.

Since it is possible to realize a higher efficiency of an air conditioner system, the new refrigerant R410A has been chosen from a standpoint of global warming prevention. On the other hand, the load to the compression elements increases because the operating pressure of R410A is about 1.6 times as high as that of R22. By adopting the 2-cylinder rotary mechanism and optimizing mechanical parts dimension, the dynamic characteristics of the bearings could be made equivalent to the conventional compressor, and we were able to secure high quality.

Moreover, this compressor series achieves 20% higher efficiency over wide speed operation range and 33 to 50% less weight than conventional compressors by the 2-cylinder rotary mechanism and a new DC motor, which consists of a rotor with a rare-earth permanent magnet and a concentrated winding type stator.

INTRODUCTION
In Japan, regulation on total consumption of HCFC refrigerant currently used in air conditioners was enacted in 1996, reduction is to start in 2004, and is to be totally phased out by 2020. To meet this regulation, introduction of air conditioners using a refrigerant that does not damage the ozone layer is being promoted to replace the HCFC refrigerant. Also, social need related to energy savings for global warming prevention has increased in the recent years and among the technological developments related to new refrigerants, the studies that pursue improvement in the efficiency is becoming dominant.

We made improvements in the efficiency in both the compressor and the air conditioner system by adopting a new refrigerant R410A in 1997 for the first time in the industry and succeeded in achieving considerable energy savings.

On the other hand, in commercial air conditioners for stores and offices, R407C was generally considered to be the first candidate. However, we chose R410A, the same refrigerant as used in the room air conditioners, since high efficiency can be obtained in an air conditioner system and is easy to handle due to its pseudo-azeotropic property. With this R410A, we are in pursuit of greater progress in the commercial air conditioners. When the new refrigerant R410A is compared with R22, the amount of volume circulation necessary for obtaining the same capacity can be less than 70% of that of R22. Consequently, the flow rate of the refrigerant becomes small and the pressure loss within the refrigerating cycle is minimized. Namely, it is a refrigerant by which lager improvement can be expected in the system efficiency as amount of circulation becomes higher. On the contrary, the operating pressure is about 1.6 times as high as that of R22, and countermeasures against high pressure in the compression mechanical part and the compressor casing are required. This report will describe
the advantages of the newly developed A2 · A3 compressor series for commercial air conditioners adopting the new refrigerant R410A, together with technical measures for solving the problems faced during the development.

**SUMMARY OF THE PRODUCT**

Figure 1 shows a cross sectional view of our newly developed brushless DC 2-cylinder rotary compressor. This compressor uses a new refrigerant R410A that does not damage the ozone layer. The compression mechanical part adopts 2-cylinder rotary structure and in the motor part, a brushless DC motor consisting of a concentrated winding type stator and a rotor embedded with rare earth permanent magnets is applied. The refrigerant oil, which is miscible with the HFC refrigerant, is used. A wide range of operation from 15s⁻¹ to 120s⁻¹ is possible by driving with an inverter.

**MAIN POINTS IN THE DEVELOPMENT**

1. **Improvement in the efficiency**

   In order to respond to the social need related to energy savings for global warming prevention, improvement in the efficiency of air conditioners is being sought each year. Conventionally, a scroll compressor that adopted R407C was used widely in commercial air conditioners. We chose refrigerant R410A, wherewith a high efficiency can be obtained in an air conditioner system. As a result of adoption of R410A, high pressure in the conventional scroll compressor increases, load in the axial direction (thrust load) also increases, and the mechanical loss becomes unacceptably large. Also, when driving with an inverter, the compression ratio is fixed to the design compression ratio in the scroll compressor. Accordingly, though the efficiency at a specific frequency is high, it is difficult to enhance the efficiency in a wide operating range. Therefore, we adopted 2-cylinder rotary structure. Also, as a result of using refrigerant R410A, improvement in the efficiency was made by modifying the dimension of the compression mechanical part and by optimizing the volume reduction in the discharge port and the compressed gas path volume.

   In order to enhance the efficiency of the compressor, enhancement in the efficiency of the motor is also necessary. A high capacity is necessary in commercial air conditioners in order to air-condition a large living area. A high power motor that accommodates this need is necessary, and rare earth permanent magnets were adopted. Four rare earth permanent magnets (neodymium – iron – boron) were disposed in the newly developed rotor. The maximum energy is about 8 times as large as that of the ferrite magnet, which is mainly used in room air conditioners and increase in power was achieved with a compact size. Also, with regards to the stator, the concentrated winding type stator was newly developed for use in this class of air conditioners. As apparent from the motor comparison diagram in Figure 2, the concentrated winding type stator can suppress the height of the coil end to be lower than in the conventional inserter winding type stator. Namely, the circumferential length of the coil can be reduced. In order to enhance the efficiency of the motor, reducing the copper loss, which causes dead heating from the coil, is an effective measure. In order to reduce the coil resistance, the circumferential length of the coil should be made as short as possible and the diameter of the coil wire as thick as possible. In the newly developed concentrated winding type stator, the magnetic flux density becomes high in parts and there is tendency for iron loss to increase when compared with the distributed winding type stator. However, it was possible to greatly reduce the copper loss by decreasing the amount of magnet wire by 40%. Therefore, a considerable improvement in the motor efficiency was achieved.

   Comparison in the efficiency between the newly developed A3 compressor series adopting the improvement item in the performance and the R22 scroll compressor of equivalent capacity that we adopted in the commercial air conditioners is shown in Figure 3. The efficiency in the figure is a ratio with the efficiency at 60s⁻¹ operation of the scroll compressor. In comparison with the conventional scroll compressor, improvement of about 9% in the mechanical efficiency ratio, about 14% in the motor
efficiency ratio, and about 20% in the overall efficiency ratio of the compressor was achieved at 60s⁻¹ operation. Also, it was possible to make a considerable improvement in the performance over a wide operating range from low rotational speed to high rotational speed. (The measuring conditions were in accordance with the in-house inverter compressor evaluating conditions.)

2. Measures against increased pressure

Due to increase in the operating pressure and enhancement in capacity with adoption of R410A, reliability of the compression mechanical part such as the shaft and bearing, becomes important. Table 1 shows the dimension of the compression mechanical part in the A3 compressor series. Locus of the shaft center was made with a non-linear axis center analysis program. The bearing load according to compression reactive force and minimum thickness of oil film between the shaft and the bearing were calculated. Accordingly a comparative study was made with a conventional model. Comparison was made based on our 6.3 kW single rotary compressor of the greatest capacity with R22 was used. In order to secure reliability in the shaft and bearing, it is necessary to minimize the bearing load. For this purpose, the dimension of the compression mechanical part was optimized such as reducing the height of the cylinder, and 2-cylinder rotary structure having low torque fluctuation was adopted. A result is shown in Figure 4. In spite of about 2 times as large capacity as the base model and the fact that the shaft diameter is identical, it was found out that the bearing load was 1.3 times as compared with the base model in the main bearing, and 1.5 times in the sub-bearing, and that the minimum thickness of the oil film was equivalent.

3. Reduction of size and weight

In addition to the compression mechanical part, pressure proof of the compressor casing is also important. In commercial air conditioners, high capacity becomes necessary so the compressor tends to become large. The pressure proof design becomes difficult when the size becomes large, so when using a high-pressure refrigerant R410A, it is necessary to make the size as compact as possible. It is for this purpose that our newly developed rotor and concentrated winding stator can be made maximum use of. By adopting this new motor and 2-cylinder rotary and optimizing the dimension of the compression mechanical part, the compressor size and weight were significantly reduced and it was possible to deal with the increased pressure of R410A. In Figure 5, the outer appearance and weight of our conventional scroll compressor for R22 used in this class of commercial air conditioners and newly developed A2·A3 compressor series are compared. Considerable reduction of size and weight to 1/2 ~ 2/3 was realized. In addition, small size and reduced weight of the compressor improve ease of installation work. Also, there are many merits such as being able to effectively utilize the space within the outdoor unit wherein the internal piping structure is complex.

4. Reliability

With regards to the gas route within the compressor, gas is taken in from the accumulator, compressed by the mechanical part, and discharged into the main case. Next, the gas flows to the upper part by passing through the space in the rotor and the stator then discharged to the outside of the compressor by the discharge pipe. At this time, a portion of lubricant reserved at the bottom of the main case enters into the cylinder along with the gas then discharged to the outside of the case through the space. The flow velocity of the discharged gas is expressed by V=G·v/A (flow rate · specific volume / passage area) and the flow velocity becomes large as the passage area becomes small. When the flow velocity of the discharged gas increases, the amount of oil blown upward to the upper part increases and the oil level may become too low.

In commercial air conditioners using the newly developed A2·A3 compressor series, the length of the piping is long and it takes a lot of time for lubricant to return to the compressor, hence minimizing the amount of discharged oil becomes important. The concentrated winding type stator can increase the passage area in the slot part of the motor. Therefore, the flow velocity of discharged gas decreases and the amount of oil blown upward to the upper part is minimized. In actuality, the newly developed
concentrated winding stator was able to increase the passage area in the slot part by about 3 times in comparison with the conventional distributed winding type stator. Comparison data for the amount of discharged oil between the concentrated winding type stator and the conventional distributed winding type stator are shown in Figure 6. As rotational speed increases, the amount of discharged oil in the concentrated winding type stator is small. Consequently, the difference between the concentrated winding type stator and the conventional distributed winding type stator in the amount of discharged oil becomes great. As a result, it is easy to keep the lubricating oil reserved in the compressor part and the shaft · bearing can be lubricated sufficiently. Also, in spite of the fact that the compressor has been made compact and the amount of oil is less, the maximum piping length was unchanged. As described above, it is evident that the concentrated winding type stator is effective for securing high reliability in the compressor.

5. Noise
A vector control system that used a DSP (Digital Signal Processor) capable of high speed arithmetic processing was adopted in the inverter that drives the newly developed compressor. With the realization of this control system, always accurate and immediate detection of the rotator position became possible and the torque fluctuation generated by the motor can be eliminated to the utmost hence a drive can be executed with greater efficiency. Also, as shown in Figure 7, it is possible to reduce the higher harmonic components in the motor current waveform and to make a current waveform approach to a smooth sine wave; hence reduction in the noise was achieved. Figure 8 shows the noise comparison when driven with the conventional inverter and when driven with the vector control inverter. A reducing effect is noticeable at frequency band of 1 kHz ~ 5 kHz and great contribution is being made even towards reduction of the applied air-conditioner noise.

A TABLE LISTING THE COMPRESSOR SERIES

Table 2 shows the inverter driven DC 2-cylinder rotary compressor series we developed. In addition to the DA91A1 series and DA130A1 series applied to the room air conditioners, newly developed DA220A2 series for cooling capacity of 6.3 ~ 8.0 kW and DA420A3 series for 11.2 ~ 16.0 kW for application to the commercial air conditioners are listed.

CONCLUSIONS

R410A was adopted as a HCFC substitute and a DC 2-cylinder rotary compressor for commercial air conditioners with cooling capacity of 6.3 ~ 16.0 kW was developed. As a consequence, considerable improvement in the performance and compactness in comparison with the conventional scroll compressor were achieved. This compressor is applied to our commercial use air conditioner “Super Power Eco”1) series and the “Smart Eco” series.
We hope to continue supplying products with even higher efficiency and higher reliability in order to respond to the need related to energy savings for global warming prevention.

REFERENCE

Fig. 1 Cross-section of optimized 2-cylinder rotary compressor

Fig. 2 Comparison of motor structures

Fig. 3 Comparison of compressor efficiency
Table 1 Optimized dimensions

<table>
<thead>
<tr>
<th>Type</th>
<th>2-cylinder (R410A)</th>
<th>1-cylinder (R22)</th>
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<tbody>
<tr>
<td>Cylinder bore</td>
<td>63 × 22</td>
<td>63 × 34</td>
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<tr>
<td>× height (mm)</td>
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<td></td>
</tr>
<tr>
<td>Eccentric of</td>
<td>5.307</td>
<td>5.307</td>
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<tr>
<td>crank (mm)</td>
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<td></td>
</tr>
<tr>
<td>Displacement</td>
<td>42.3</td>
<td>32.7</td>
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<tr>
<td>(cm³/rev)</td>
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<td></td>
</tr>
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</table>

Fig.4 Analysis results (2-cylinder/1-cylinder)

<table>
<thead>
<tr>
<th>Compressor series</th>
<th>A2 series</th>
<th>A3 series</th>
<th>Conventional scroll</th>
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<tr>
<td>Mass ratio</td>
<td>50</td>
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<td>100</td>
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<tr>
<td>(conventional ratio %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume ratio</td>
<td>39</td>
<td>61</td>
<td>100</td>
</tr>
<tr>
<td>(conventional ratio %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity (kw)</td>
<td>6.3~8.0</td>
<td>11.2~16.0</td>
<td>11.2~16.0</td>
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</tbody>
</table>

Fig.5 Comparison of compressor series
Fig. 6 Amount of the oil discharge

Fig. 7 Current waveform (motor current)

Fig. 8 Comparison of power level

Table 2. DC 2-cylinder rotary compressor line-up

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression type</td>
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<td>Hermetic rotary</td>
<td>Hermetic rotary</td>
<td>Hermetic rotary</td>
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<tr>
<td>Used refrigerant</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
</tr>
<tr>
<td>Displacement</td>
<td>9.06 cm³/rev</td>
<td>13.1 cm³/rev</td>
<td>22.1 cm³/rev</td>
<td>42.3 cm³/rev</td>
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<tr>
<td>Capacity (60 s⁻¹)</td>
<td>2.75 kW</td>
<td>4.00 kW</td>
<td>6.95 kW</td>
<td>13.4 kW</td>
</tr>
<tr>
<td>Motor type</td>
<td>Brushless DC motor</td>
<td>Brushless DC motor</td>
<td>Brushless DC motor</td>
<td>Brushless DC motor</td>
</tr>
<tr>
<td>pole</td>
<td>4 poles</td>
<td>4 poles</td>
<td>4 poles</td>
<td>4 poles</td>
</tr>
<tr>
<td>Rotational range</td>
<td>9~140 s⁻¹</td>
<td>9~120 s⁻¹</td>
<td>15~120 s⁻¹</td>
<td>15~120 s⁻¹</td>
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<tr>
<td>Weight</td>
<td>10 kg</td>
<td>10 kg</td>
<td>15 kg</td>
<td>24 kg</td>
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<tr>
<td>Outside diameter</td>
<td>Ø 116 × 274 mm</td>
<td>Ø 116 × 274 mm</td>
<td>Ø 130 × 300 mm</td>
<td>Ø 156 × 360 mm</td>
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