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Development of Large Capacity CO₂ scroll Compressor

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ABSTRACT
CO₂ refrigerant with a high operating pressure has a large difference between the suction and discharge pressures in
compressors. Because of a load increase, the high performance and high reliability of compressors are required.
Compared to the scroll compressor employing the conventional refrigerant, the thrust load increases in the CO₂
scroll compressor. Therefore the design of thrust bearing is needed to be altered. We secure the area of the thrust
bearing, causing of changing the structure of the compressor. It is the newly thrust bearing structure, considering
deformation of thrust bearing.

1. INTRODUCTION

The Kyoto Protocol, which was adopted in 1997, designated HFC (Hydro fluorocarbon) refrigerant as the material
control subject, due to the high GWP (Global Warming Potential). Therefore, using of natural refrigerant is desired
to make practicable. Especially, it is expected that nontoxic and nonflammable CO₂ refrigerant is applied on heat
pump equipments. Making use of its heating performance, CO₂ refrigerant has been used for household water heater
in Japan. Additionally development of large capacity compressor is desired to expand into commercial equipment.
The operating pressure of CO₂ refrigerant is very high and CO₂ refrigerant has a large difference between the suction
and discharge pressures. Therefore the structures of compressor components need to be improved highly
mechanical structural and the reliabilities of sliding bearings need to be ensured on the large capacities compressors.
In order to put it to practical use, we have to design compactly and reduced the cost of compressor.
Thrust and radial loads act on the wraps of scroll compressor. The thrust load acts axially downward and the radial
load acts toward driven direction of wraps. The thrust load of CO₂ refrigerant is larger than those of conventional
refrigerants. It is caused by the refrigerant property.
The simulated performance of compressor has become clear that the friction loss of the thrust load increases and it
holds 25 % of total compressor loss. It is for this reason that the formation of lubrication film is broken by
increasing of thrust load. The thrust load also becomes the cause of degrading the reliability of compressor.
In order to clear up these problems, we alter the structures of compressor parts and expand the area of thrust bearing,
without changing external size from conventional compressor. We have applied the deformation of compressor
components and made effective use of the expanded area of thrust bearing.
We have evaluated the compressor applied this thrust bearing structure and restrained the friction loss of thrust
bearing. Reliability of thrust bearing is verified by reliability test, for the whole area of the variable motor frequency.
As a result, we have developed a variable speed scroll compressor with high efficiency employing CO₂ refrigerant.
which is much larger than prior compressors employing CO₂ refrigerant on the market. The commercial use water heater whose capacity is 56Kw has been mass-produced. It is mounted the developed scroll compressor.

2. Technical feature of CO₂ scroll compressor

2.1 Structure of CO₂ scroll compressor

Figure 1 shows the structure of a CO₂ scroll compressor. Table 1 shows the basic specification of compressor.

![Fig.1 Cross section of CO₂ scroll compressor](image)

<table>
<thead>
<tr>
<th>Type</th>
<th>Hermetic scroll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement Volume</td>
<td>24 cc/rev</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>30 ~ 100 rps</td>
</tr>
<tr>
<td>Design Pressure</td>
<td>8.5MPa</td>
</tr>
<tr>
<td>Motor</td>
<td>DC inverter drive</td>
</tr>
</tbody>
</table>

Table 1 Basic Specification of CO₂ scroll compressor

Fixed and orbiting scrolls are set in a low-pressure shell. Several compression chambers are composed between the fixed and orbiting scrolls. When the gas is compressed, the suction gases in these chambers are transferred from the outside to the center of the fixed and orbiting scrolls. The orbiting scroll is driven by a crank shaft and the crank shaft id driven by a DC variable speed motor. The Oldham ring, placed between the orbiting and fixed scrolls, prevents the orbiting scroll from self-rotation. The thrust bearing, which moves with the orbiting scroll, supports the thrust load of the orbiting scroll. A flexible structure was installed on the frame, which supports the thrust load with the thrust bearing.

2.2 Thrust and Radial Loads in the scroll compressor

Thrust load and radial load act on the wraps of scroll compressor as shown in figure 2. The thrust load acts axially downward and the radial load acts toward driven direction of wraps. The thrust load of CO₂ refrigerant is larger than those of conventional refrigerants. It is caused by the refrigerant property.
2.3 The performance analysis of the CO₂ scroll compressor

Performance analysis was investigated by separating compressor input as shown in Figure 3. Compressor input was divided into loss and compression work. Loss was divided into leak loss, friction loss, motor loss, and indicate loss.

Analysis condition: \( P_s=4 \) MPa, \( P_d=10 \) MPa, \( T_s=15 \) °C. Rotational speed = 30, 60, 100 rps.
In 30 rps, the leak loss holds 48% of the total loss. In 60, 100 rps the thrust friction loss holds 25% or more of total loss. From this analysis result, the friction loss of the thrust bearing has a big influence on the performance of the compressor.

### 2.4 Structure of thrust bearing

The developed thrust bearing structure is shown in figure 5 and 7. Conventional structure is shown in figure 6. To support the very large thrust load, the thrust bearing area was increased. On a conventional compressor, Oldham ring is placed between frame and orbiting scroll. On newly CO2 scroll compressor, Oldham ring is placed between fixed and orbiting scrolls. Most area of frame side orbiting scroll was able to use for thrust bearing. In expanding the thrust bearing, it can keep the thrust pressure small. Moreover, to use expanding thrust bearing effectively, the flexible structure was installed on the frame, which supports the thrust load with the thrust bearing. For the thrust load, the flexible structure deformed with orbiting scroll. The stiffness of orbiting scroll and flexible structure were examined by FEM analysis. Figure 10 shows example. In case of without the flexible structure, a contact pressure increase on the inner area of the thrust bearing, as shown in figure 8. The bend of the flexible structure member almost accorded with a bend of the orbiting scroll. As a result, a local oil film starving can be prevented and excellent lubrication conditions can be secured, as shown in figure 7.
3. Test result of CO2 scroll compressor

3.1 Performance test result
Figure 11 shows the performance comparison result. Test condition: Ps=4M Pa, Pd=10 MPa, Ts=15 °C.
In 30 rps, compressor input was reduced 1 %, by adopting a flexible structure. On 60 and 100 rps compressor input was reduced 2 %. The Result shows that new thrust structure improves compressor performance.

![Figure 11. Performance test result](image)

3.2 Reliability test result
The long-term life test was performed on the developed compressor, and we measured wear volume of the thrust bearing (Figure 12). Without the flexible structure, abnormal wear was caused on the thrust bearing in the first stage of the test. With a flexible structure, the wear of thrust bearing was very small. As a result of a long-term life test, the reliability of a new thrust structure has been confirmed.

![Figure 12 Wear of the thrust bearing](image)
4. Application to the heat pump hot water supply system

A heat pump hot water supply system that adapted a newly developed compressor is shown in figure 13 and table 2. It features a large-capacity CO₂ scroll compressor and has a COP rated of 4.1. The rotational speed of the compressor can be controlled in the 30 to 100 rps range by controlling the air temperature and inlet water temperature. With controlling rotational speed ideally, efficient operation is possible through the year.

Figure 13. Heat pump hot water supply system and developed CO2 scroll compressor

<table>
<thead>
<tr>
<th>Nominal heating capacity</th>
<th>40 Kw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal heating COP</td>
<td>4.1</td>
</tr>
<tr>
<td>Maximum heating capacity</td>
<td>56 Kw</td>
</tr>
<tr>
<td>Nominal heating COP</td>
<td>4.1</td>
</tr>
<tr>
<td>Ambient air temperature</td>
<td>-15 to 40 °C</td>
</tr>
<tr>
<td>Outlet water temperature</td>
<td>60 to 90 °C</td>
</tr>
<tr>
<td>Inlet water temperature</td>
<td>5 to 63 °C</td>
</tr>
</tbody>
</table>

Table 2. Basic specification of the heat pump hot water system

5. CONCLUSIONS

In this work the CO₂ scroll compressor whose thrust load is very high was developed, the performances were examined and the following conclusions were obtained about new thrust bearing structure.
+ We developed new thrust bearing configuration with flexible structure.
+ New thrust bearing structure functioned effectively. The friction loss of the thrust bearing was decreased.
+ Efficient of compressor is increased 2. % with new thrust structure.
+ As a result of a long term testing, the reliability of a new thrust structure was confirmed.
NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Ps</td>
<td>Suction pressure</td>
<td>(MPa)</td>
</tr>
<tr>
<td>Pd</td>
<td>Discharge pressure</td>
<td>(MPa)</td>
</tr>
<tr>
<td>Ts</td>
<td>Suction gas temperature</td>
<td>(°C)</td>
</tr>
</tbody>
</table>

REFERENCES
