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## Development of Large Capacity CO<sub>2</sub> scroll Compressor

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### ABSTRACT

CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> refrigerant is applied on heat pump equipments. Making use of its heating performance, CO<sub>2</sub> 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 CO<sub>2</sub> refrigerant is very high and CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> refrigerant

which is much larger than prior compressors employing CO<sub>2</sub> 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 CO<sub>2</sub> scroll compressor

### 2.1 Structure of CO<sub>2</sub> scroll compressor

Figure 1 shows the structure of a CO<sub>2</sub> scroll compressor. Table 1 shows the basic specification of compressor.

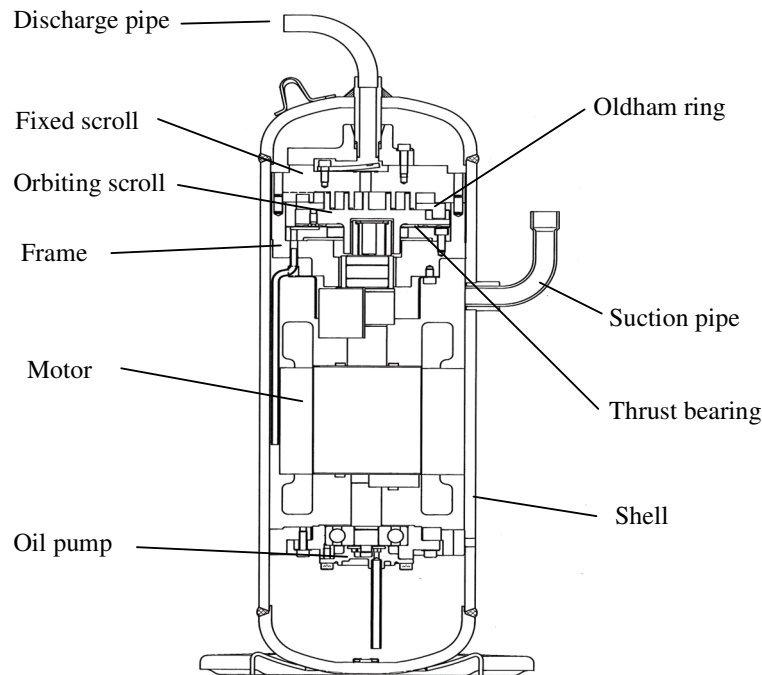


Fig.1 Cross section of CO<sub>2</sub> scroll compressor

Type	Hermetic scroll
Displacement Volume	24 cc/rev
Rotation speed	30 ~ 100 rps
Design Pressure	8.5MPa
Motor	DC inverter drive

Table 1 Basic Specification of CO<sub>2</sub> 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 is 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 CO<sub>2</sub> refrigerant is larger than those of conventional refrigerants. It is caused by the refrigerant property.

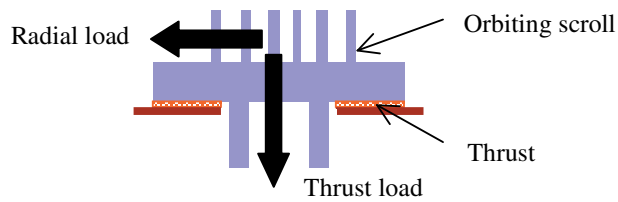


Figure 2 Load on wraps

### 2.3 The performance analysis of the CO<sub>2</sub> 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.

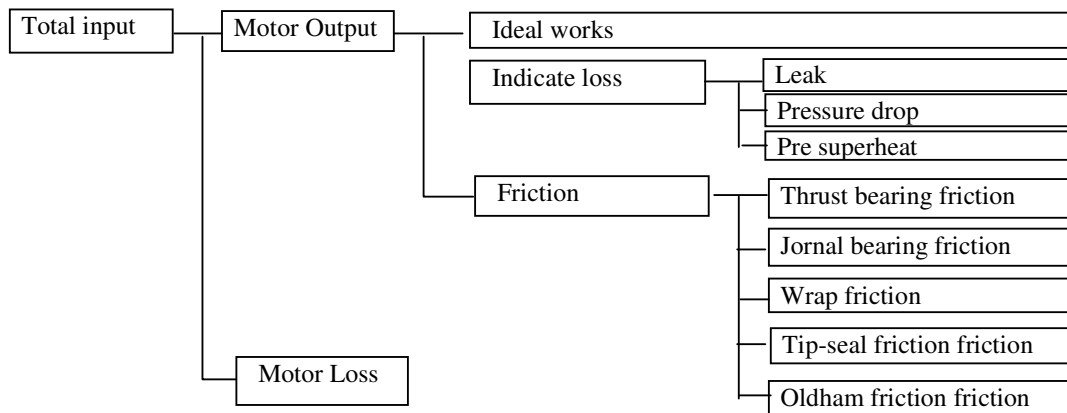


Figure 3 Performance analysis.

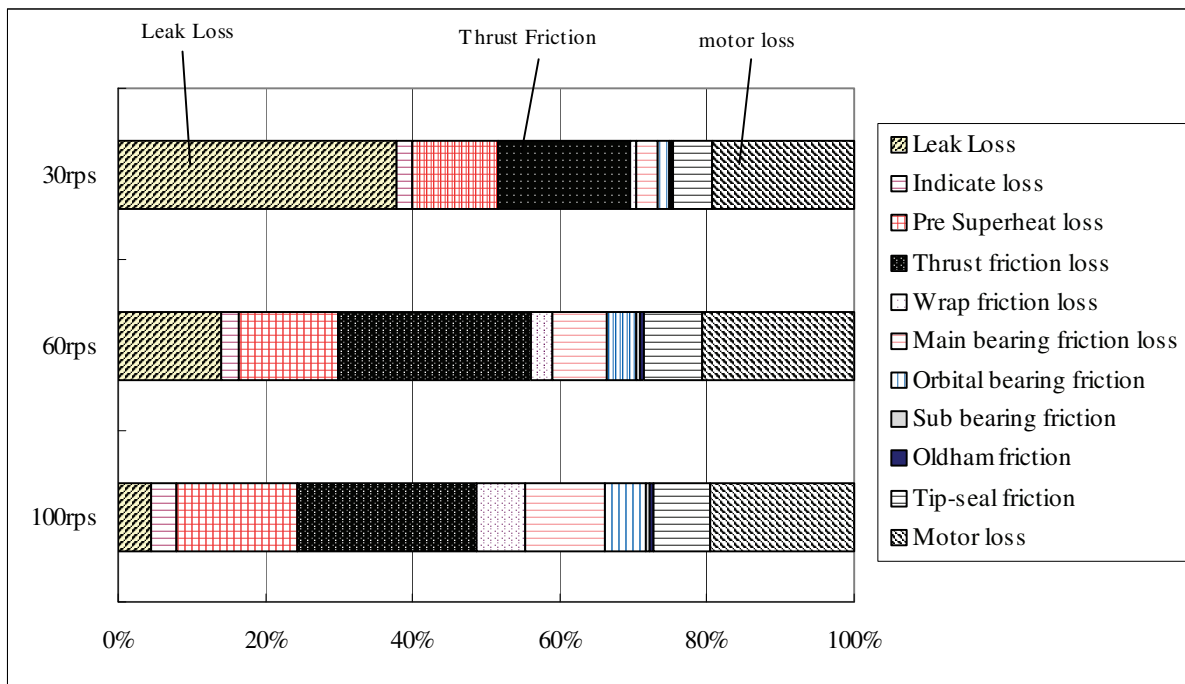


Figure 4 Breakdown of all losses.

Analysis condition: Ps=4 MPa Pd=10 MPa Ts=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

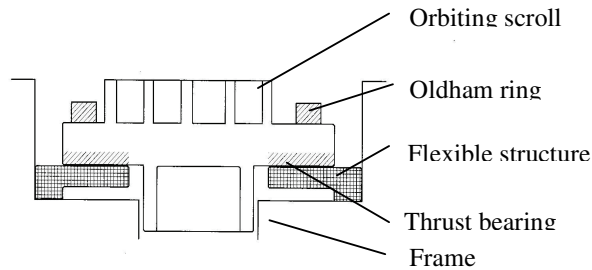


Figure 5 developed thrust structure

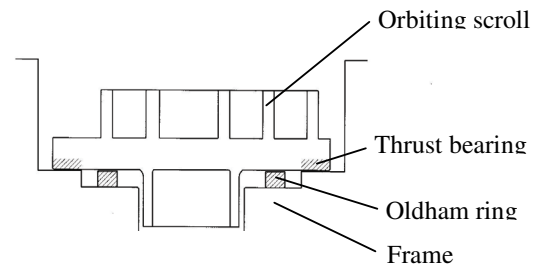


Figure 6 Conventional thrust structure

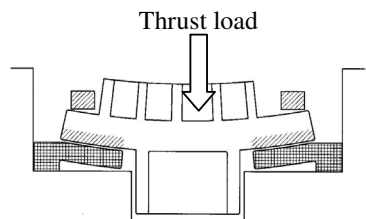


Figure 7 Deformation of orbiting scroll  
Developed structure

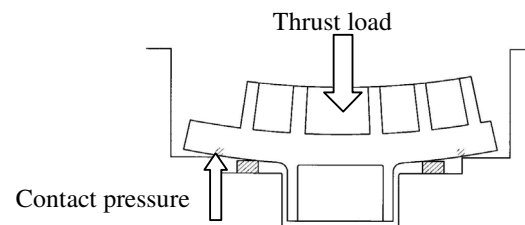


Figure 8 Deformation of orbiting scroll  
Conventional structure

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 CO<sub>2</sub> 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.

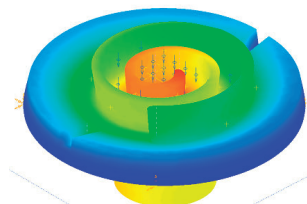


Figure 10 An example of FEM analysis

### 3. Test result of CO<sub>2</sub> scroll compressor

#### 3.1 Performance test result

Figure 11 shows the performance comparison result. Test condition:  $P_s=4\text{M Pa}$   $P_d=10\text{ MPa}$   $T_s=15\text{ }^\circ\text{C}$ . 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.

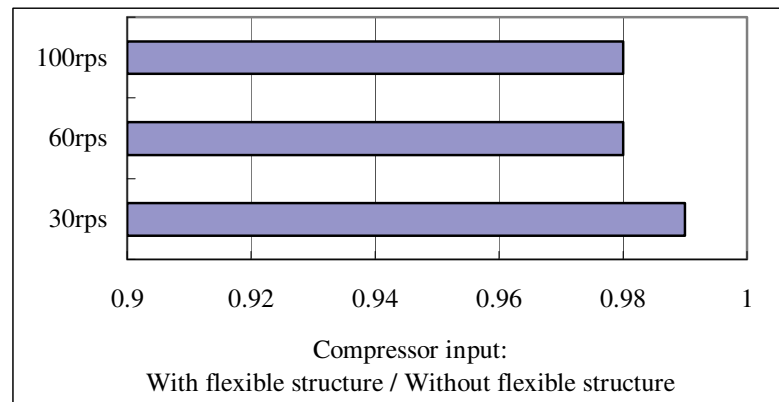


Figure 11. Performance test result

#### 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.

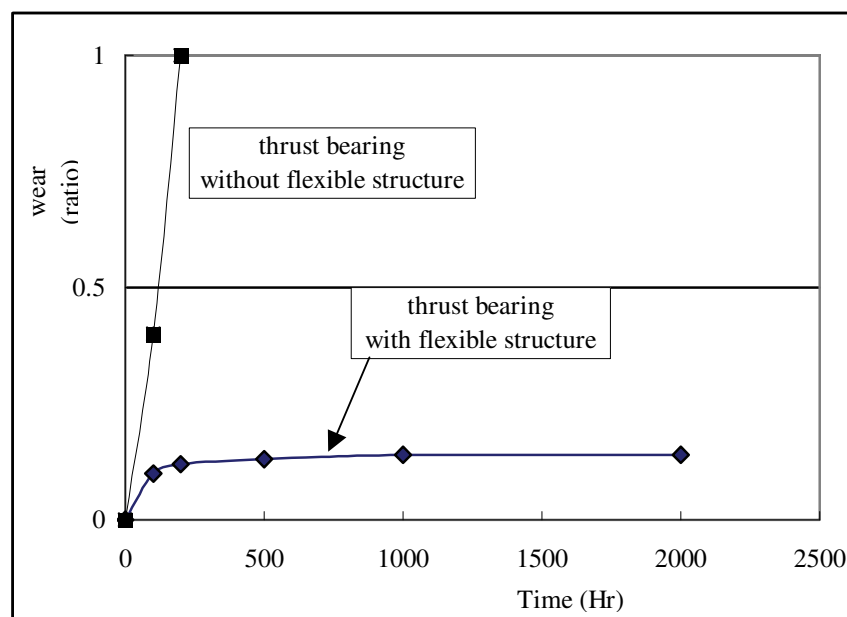


Figure 12 Wear of the thrust bearing

Test condition : Heavy load

#### 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 CO<sub>2</sub> 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 CO<sub>2</sub> scroll compressor

Nominal heating capacity	40 Kw
Nominal heating COP	4.1
Maximum heating capacity	56 Kw
Nominal heating COP	4.1
Ambient air temperature	-15 to 40 °C
Outlet water temperature	60 to 90 °C
Inlet water temperature	5 to 63 °C

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

#### 5. CONCLUSIONS

In this work the CO<sub>2</sub> 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

Ps	Suction pressure	(MPa)
Pd	Discharge pressure	(MPa)
Ts	Suction gas temperature	( °C )

## REFERENCES

Shimoji, M., Nakamura, T., 2007, Performance Analysis of Scroll Compressors Using CO<sub>2</sub> Refrigerant, *Mitsubishi Electric Advance*, Vol.120, p.17-19.



