View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Purdue E-Pubs

Purdue University
Purdue e-Pubs

International Compressor Engineering Conference | School of Mechanical Engineering

2004

# Development of High Performance R410A Scroll Compressor for Gas Engine Heat Pump

Yoshiyuki Kimata
*Mitsubishi Heavy Industries*

Makoto Fujitani
*Mitsubishi Heavy Industries*

Hiroyuki Kobayashi
*Mitsubishi Heavy Industries*

Yoshiaki Miyamoto
*Mitsubishi Heavy Industries*

Susumu Matsuda
*Mitsubishi Heavy Industries*

***See next page for additional authors***

Follow this and additional works at: https://docs.lib.purdue.edu/icec

Kimata, Yoshiyuki; Fujitani, Makoto; Kobayashi, Hiroyuki; Miyamoto, Yoshiaki; Matsuda, Susumu; and Yamazaki, Hiroshi, "Development of High Performance R410A Scroll Compressor for Gas Engine Heat Pump" (2004). *International Compressor Engineering Conference.* Paper 1644.
https://docs.lib.purdue.edu/icec/1644

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.
Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at https://engineering.purdue.edu/Herrick/Events/orderlit.html

**Authors**
Yoshiyuki Kimata, Makoto Fujitani, Hiroyuki Kobayashi, Yoshiaki Miyamoto, Susumu Matsuda, and Hiroshi Yamazaki

This article is available at Purdue e-Pubs: https://docs.lib.purdue.edu/icec/1644

# DEVELOPMENT OF HIGH PERFORMANCE R410A SCROLL COMPRESSOR FOR GAS ENGINE HEAT PUMP

***Yoshiyuki Kimata[1], Makoto Fujitani[1],Hiroyuki Kobayashi[1], Yoshiaki Miyamoto[1],Susumu Matsuda[2],Hiroshi Yamazaki[2]**

[1] Mitsubishi Heavy Industries, Ltd., Air-Conditioning & Refrigeration Systems Headquarters,
3-1 Asahimachi Nishibiwajima-cho Nishikasugai-gun, Aichi-pref., 452-8561, JAPAN
Tel: +81-52-503-9217; Fax: +81-52-501-5629
E-Mail: yoshiyuki_kimata@mhi.co.jp   *Author for correspondence

[2] Mitsubishi Heavy Industries, Ltd., Nagoya Research & Development Center,
1-Takamichi Iwatsuka-cho Nakamura-ku, Nagoya, 453-8515, JAPAN
Tel: +81-52-412-0499; Fax: +81-52-412-9162

## ABSTRACT

In order to respond to the increase of customer's demands for economical efficiency and environmental protection, we have developed a new scroll compressor using HFC-410A (R410A) for commercial gas heat pump (GHP) which is known for its energy saving and comfort.

The new scroll compressor requires high efficiency as stated above. In addition, the operating time and the life span of the GHP compressor is long about 10 years. Therefore, the GHP compressor also requires high reliability. To meet these requirements, we have developed the compressor by adopting a new scroll profile and reduction of frictional loss in the thrust bearing.

We have ensured high reliability of the strength of scroll wall and efficiency by a new scroll profile. And the loss of the thrust bearing has been minimized by the elemental friction test. By these technologies, the efficiency has been improved of 20% compared with the conventional reciprocating compressor. In addition, the reliability of the journal bearings has been improved by the oil tank installed separately from the compressor housing.

This paper shows the specification and the technology of the GHP scroll compressor, which enables high efficiency and high reliability.

## 1. INTRODUCTION

GHP system has the same air conditioning system as Electric Heat Pump (EHP) expect for the source of power. To drive compressor, GHP use an engine fueled by city gas or liquefied petroleum gas as a substitute for electric motor in compressor. Therefore, the GHP system has a number of advantages as following by difference in source of power between GHP and EHP.

Merit 1: GHP remain nearly unaffected by outdoor temperature in the heating operation. Because GHP can utilize gas engine exhaust heat as a source during the winter season.

Merit 2: GHP can use the exhaust heat as a source of power for evaporation, and maintain high evaporating temperature. Therefore, the defrosting operation of the heat exchanger in outdoor unit is not necessary.

Merit 3: The electric power consumption of GHP is less than tenth part of EHP, because no electric power expect for auxiliary machine like a fan and engine starter and so on is used.

Figure 1 shows a status of diffusion of GHP in Japan. As shown in Figure 1, GHP is widespread rapidly because of above mentioned advantages. But further efficiency improvement of GHP system is required from the viewpoint of preventing the global warming and energy saving. So, we developed a new scroll compressor for GHP.

Generally, the hermetic and vertical type compressor has adopted for the commercial air conditioner. But the compressor for commercial GHP must be open and horizontal type like that of automotive air conditioner because it is driven by gas engine. In addition, the machine life of compressor need about 10 years.

We developed a new horizontal open type scroll compressor by combining the best properties of automotive use and commercial use. We chose HFC-410A (R410A) since high efficiency can be obtained in an air conditioner system and is easy to handle due to its pseudo-azeotropic property.

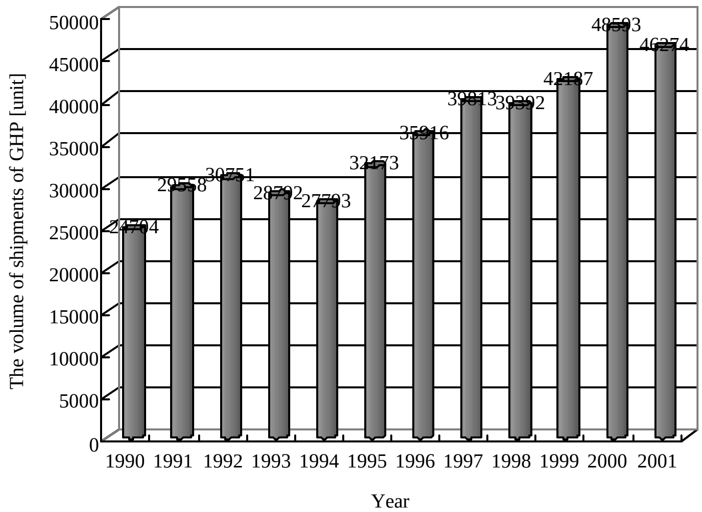


Figure 1 The volume of shipments of GHP in JAPAN[2]

## 2. STRUCTURE OF THE SCROLL COMPRESSOR FOR GAS HEAT PUMP

Figure 2 shows the cross sectional view of the new scroll compressor for commercial GHP. Engine power is transmitted to orbiting scroll by magnet clutch, crankshaft supported by main and sub bearing, and drive bearing as an eccentric motion. And this eccentric motion is converted to orbiting motion by Oldham's coupling. The journal bearings are adopted for main and drive bearing to satisfy long life. And the oil pump and the oil tank are set to supply the oil for main and drive bearing.

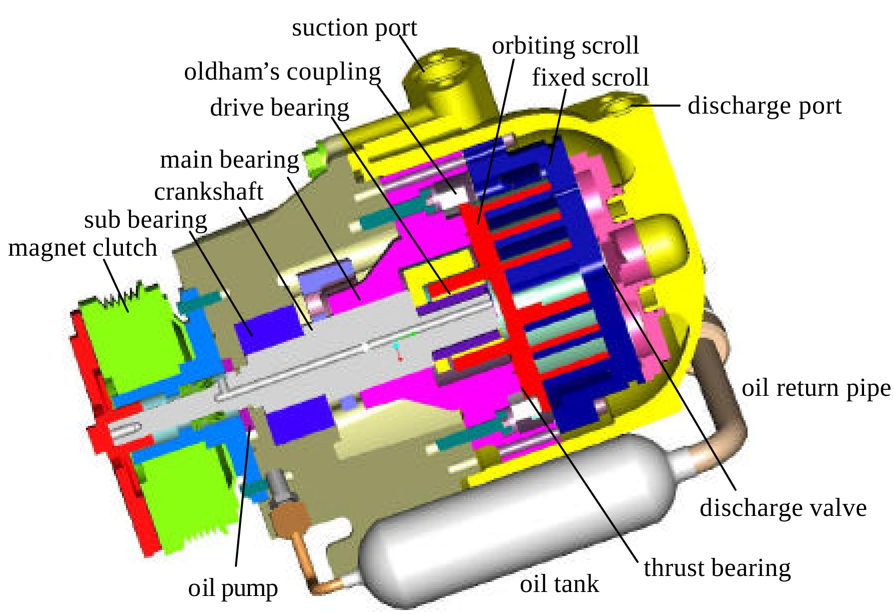


Figure 2 The cross section of the new scroll compressor

The refrigerant enters the compression chamber directly through the suction port. And the compressed refrigerant discharges through the discharge valve to the discharge port. On the other hand, the oil flows from the oil tank to the center of a crankshaft by the displacement type oil pump. The oil is distributed to main, sub and drive bearing through a crankshaft. After that, the oil is supplied to a thrust bearing. Finally, the surplus oil flows to the oil tank through the oil return pipe.

## 3. HIGH EFFICIENCY AND RELIABLITY

As remarked above, higher efficiency is required for the GHP compressor. In addition, the size is one of the important elements of the GHP compressor as much as reliability. We products the GHP air conditioner that equipped with the reciprocating compressor. In this study, our target of efficiency is 20% improvement for the conventional reciprocating compressor. To achieve the target of efficiency and to change refrigerant to R410A, we developed the new scroll compressor based on our hermetic scroll compressor series.

### 3.1 Development of the New Scroll Profile

Less than 70% of displacement volume is required for the compressor with R410A compared with that of HCFC-22 (R22). So, R410A is effective refrigerant for down sizing of the compressor. On the other hand, the operating pressure of R410A is about 1.6 times as high as that of R22, and countermeasures against high pressure for the compression mechanical part are required. Especially the stress of scroll walls is the biggest problem. The stress of scroll walls is proportional to differential pressure. Therefore, the strength of scroll walls at the R410A operating is about 1.6 times as strong as that of R22.

The stress of scroll walls is inversely proportional to the square of the height of scroll wall. Therefore, the height of scroll wall has to be decreased by 20% as against that with R22. On the other hand, to keep the displacement volume, the length of scroll has to be larger or the orbiting radius has to be larger. However, lower height of scroll wall and large orbiting radius has disadvantage in efficiency. Therefore, it is important to keep the strength without decreasing the scroll wall height.

We developed the new scroll wrap profile THREE-DIMENSIONAL SCROLL. Generally, the volume in the compression process changes two-dimensionally. But due to change the scroll height in the compression process, three-dimensional scroll was developed; the volume in the compression process is three-dimensional change. Figure 3 shows the cross sectional view of three-dimensional scroll and Figure 4 shows the compression process of three-dimensional scroll.

As shown in the Figure 3, the step of scroll wall is set. Outer height that identifies the displacement volume of scroll is high and inner height that identifies the strength of scroll wall is low. This scroll satisfies both the displacement volume and the strength of the scroll wall without setting the scroll height makes low or the orbiting radius makes large.

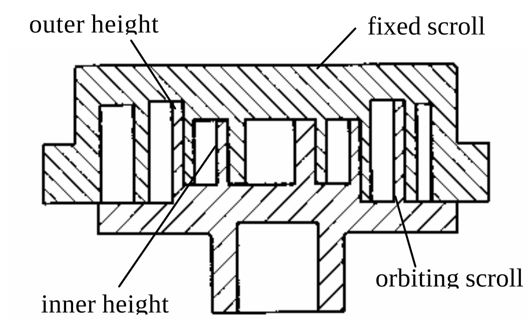


Figure 3 The cross sectional view of three-dimensional scroll

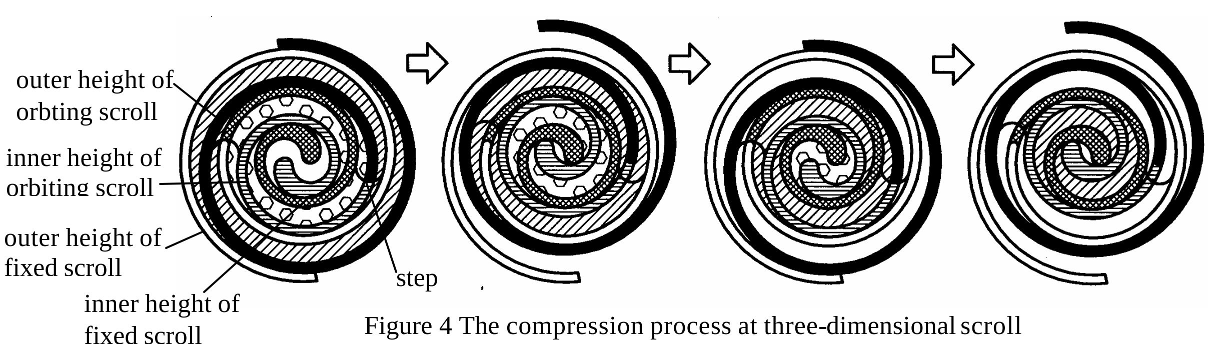


Figure 4 The compression process at three-dimensional scroll

In three-dimensional scroll, leakage loss at the step is one of the most important problems. Setting the step position outer as far as possible solves this problem. Figure 5 shows the relationship between the positions of step and the efficiency. The more step move to inner, the more efficiency goes down compared with non-step. In the case of Figure 5, we have set the step position more than 80% as against the suction angle.

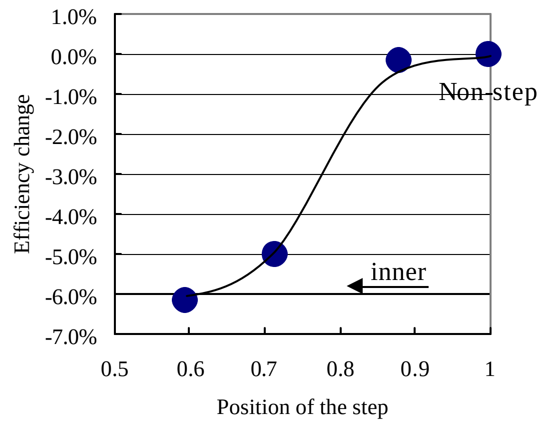


Figure 5 The relationship between the position of the step and the efficiency

### 3.2 Reduction of Frictional Loss in the Thrust Bearing

Frictional loss in the thrust bearing occupies a large part of losses in the scroll compressor. Therefore, the accurate prediction and the reduction of frictional loss in thrust bearing is one of the most important tasks in achieving the high-efficiency scroll compressor.

Frictional loss in the thrust bearing $L_{th}$ can be shown as follows.

$$L_{th} = m \cdot 2p \cdot r \cdot N \cdot F_{th} \qquad (1)$$

Where, $m$ is the coefficient of friction, $F_{th}$ is the thrust bearing load, $r$ is the orbiting radius, and $N$ is the rotating speed. It is obvious that the scroll compressor which has smaller frictional loss in the thrust bearing should be designed to make the coefficient of friction $m$, the thrust bearing load $F_{th}$, the orbiting radius $r$, and the rotating speed $N$ smaller.

As the three-dimensional scroll profile is applied in GHP scroll compressor as described previous section, it also has the smaller frictional loss in the thrust bearing. Because three-dimensional scroll make high wall possible, it has smaller orbiting radius or low rotating speed. The smaller orbiting radius also means the smaller thrust bearing load because the cylindrical pressure loaded on smaller area.

As far as the coefficient of friction in the thrust bearing, which is left in equation (1), we have investigated its characteristics by the elemental friction test simulating the actual thrust bearing in scroll compressor [(3)]. One of the test results is shown in Figure 6.

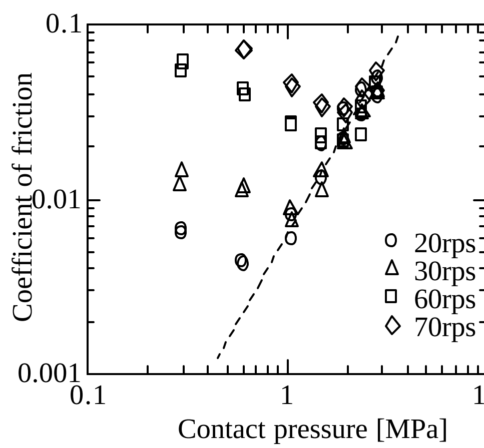


Figure 6 The variation of coefficient of friction with contact pressure
Aluminum, η=5-9mPa·s

It has been clarified that the coefficient of friction has the minimum value for the contact pressure that is the value of the load divided by the thrust bearing area. According to the elemental friction test, the area of thrust bearing has been optimized so that the loss of the thrust bearing has been minimized.

### 3.3 Improvement of Reliability

The machine life of the compressor for commercial GHP is ten times as long as that for automotive, about 30000 hours. Therefore, the journal bearings are adopted for drive and main bearing. And the displacement type oil pump is adopted for oil supplies to the bearings. It is a rotary type pump with the unrolling piston which consists of blade and rotor.

The horizontal compressor has smaller oil capacity than the vertical one. And, the horizontal compressor has higher possibility of causes slugging and damage of the scroll wall, when the oil or the liquid refrigerant is accumulated in the compressor chamber. Therefore, the new scroll compressor has an oil tank to accumulate oil. It makes oil supply path of the horizontal one much more complicated than that of the vertical one. Mizuno et al.[4] reported the merit of the horizontal scroll compressor that has the oil tank.

In addition, the discharged oil with the discharge refrigerant gas generally returns to the compressor with the suction gas. But in this compressor, the discharged oil directly returns to the compressor from the oil separator. We are able to keep the oil levels regardless of the separation by the suction flows. The oil level keeps by the throttle control (capillary size) that set in the lower differential pressure. During the differential pressure is high, the oil has discharged and keeps the lower oil levels. We clearly established the relationship between the amounts of oil return from the oil separator and the oil levels by the experiments. Figure 7 shows a result of experiments. The oil level keeps nearly constant independently of the amounts of oil return. However, when the amounts of oil return for the requirement of the oil return becomes over 100%, the oil levels decreased. We estimated to the lack of the pressure equalization between the oil tank and the compressor, because the gasification of the liquid refrigerant. The size of the pressure equalization pipe must adjust by the amounts of oil return. According to needs, it's able to keep high efficiency by changing capillary size.

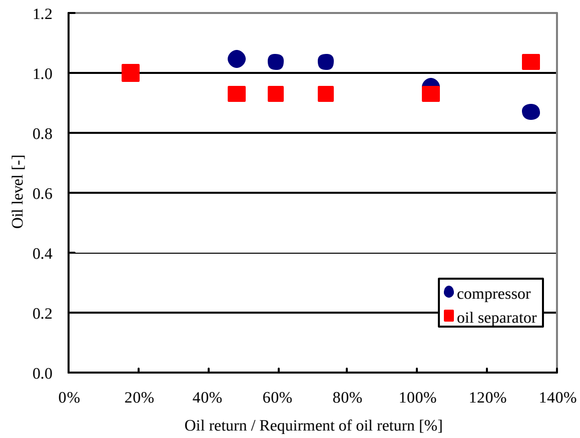


Figure 7 The relationship between the amounts of oil return from oil separator and oil tank level

# 4. RESULTS

## 4.1 Calculating Results

As referred above structure, we simulated the compressor performance by calculation program[5]. As a result, we got the possibility of 20% improvement of the compressor efficiency compared with the conventional reciprocating type. Figure 8 shows the ratio of the efficiency improvement ($?_{new}/?_{old}$) for the conventional reciprocating compressor at rating condition.

The rating speed of this new scroll compressor is 60rps. And the rating speed coincident with the efficiency peak speed. If operating speed is higher than rating speed, mechanical loss increases. And if operating speed is lower than rating speed, indicative loss increases.

Figure 9 shows the loss analysis of each part at rating condition. The indicative loss, which consists of heat and leakage loss and over compression loss, has shared 46.6% of total losses. On the other hand, the mechanical loss, which consists of thrust bearing loss, main bearing loss and flank contact loss and so on, has shared 53.4%. Heat and leakage loss accounts for about half of the total losses. And thrust bearing loss has held down 14.6% that equal to main bearing loss.

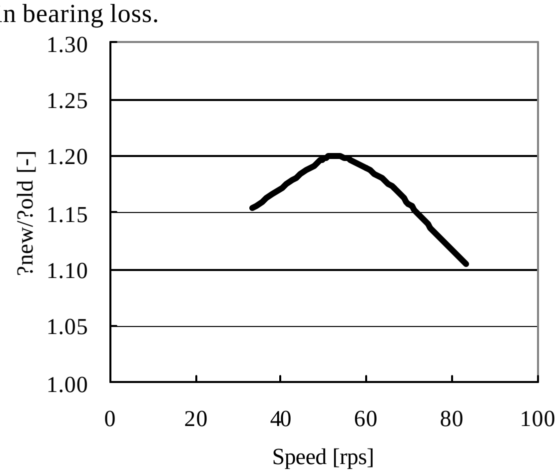


Figure 8 The ratio of efficiency improvement for the conventional reciprocating compressor at rating condition

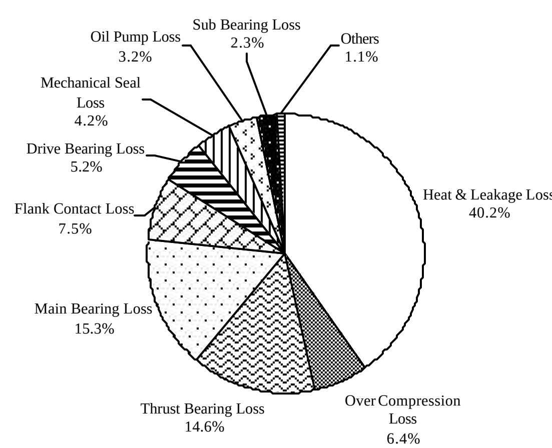


Figure 9 The loss analysis at rating condition

### 4.2 Experimental Results

Figure 10 shows the experimental results of the efficiency improvement ratio for the conventional reciprocating compressor at the rating condition. It was found that the experimental results are in good agreement with the calculating results at wide range of speed. The target, 20% improvement of efficiency compared with the conventional type, has been achieved.

The cylindrical pressure is also measured at rating condition. Figure 11 shows the measurement results of cylindrical pressure. Figure 12 shows the loss analysis of each part at rating condition. The indicative loss has shared 41.9% of total losses. On the other hand, the mechanical loss has shared 58.1%. The experimental result has good agreement with the calculating result within 5%. Heat and leakage loss decreases by 22% for calculating result. Therefore, the total efficiency is slightly higher than calculating results as shown Figure 10.

Figure 13 shows the loss analysis in each speed. If operating speed is higher than rating speed, the mechanical loss, especially thrust bearing loss, increases and the indicative loss, especially heat and leakage loss, decreases. On the other hand, if operating speed is lower than rating speed, heat and leakage loss increases and the mechanical loss decreases.

Their experimental results have been in good agreement with the calculating results.

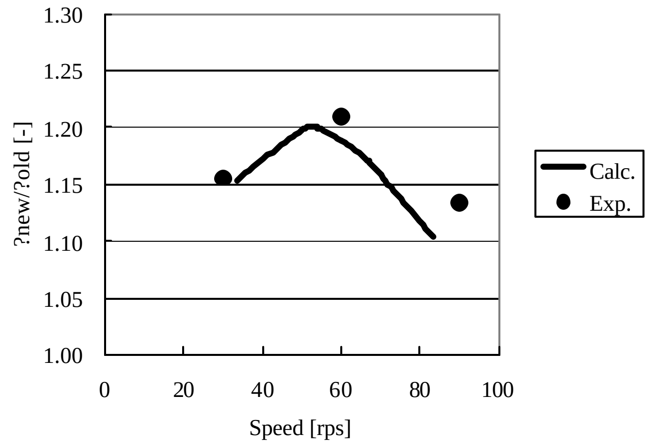


Figure 10 The ratio of efficiency improvement at rating condition

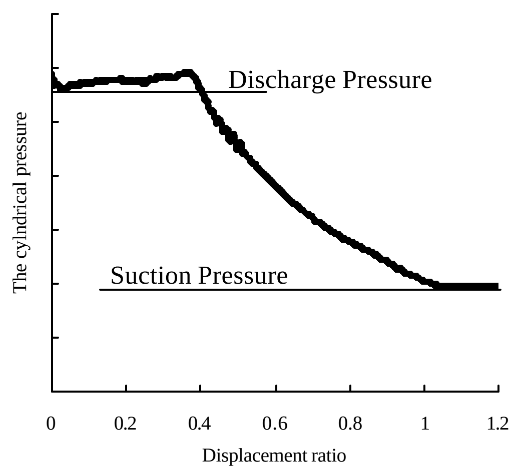


Figure 11 The measurement result of cylindrical pressure at rating condition

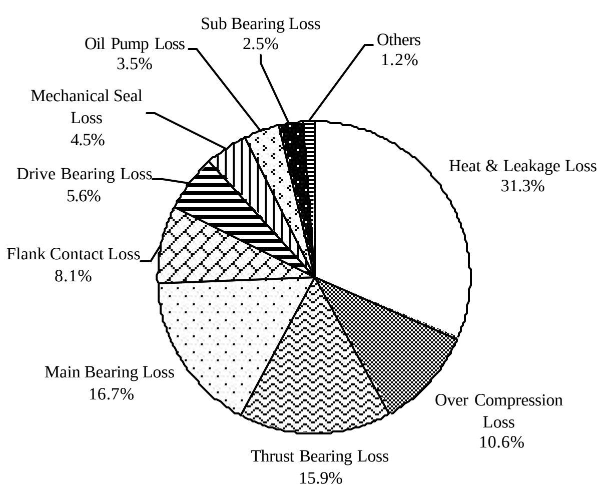


Figure 12 The loss analysis at rating condition

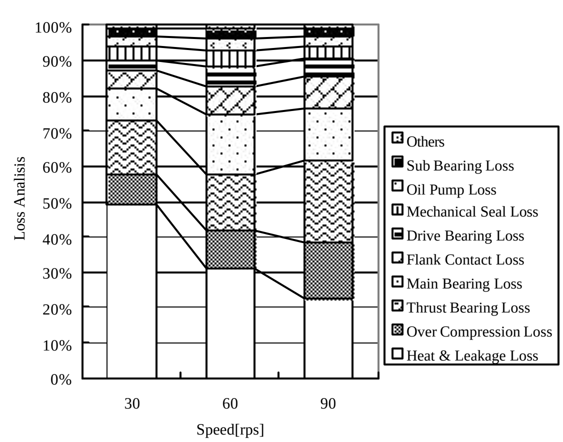


Figure 13 The loss analysis in each speed

## 5. CONCLUSIONS

We have developed the high performance R410A scroll compressor for the GHP by adopting the three-dimensional scroll and reducing the thrust bearing loss. High reliability of the strength of scroll wall has been made by the three-dimensional scroll. The loss of the thrust bearing has been minimized by the elemental friction test. By these technologies the efficiency has been improved of 20% compared with the conventional reciprocating compressor. In addition, the reliability of the journal bearings has been improved by the oil tank installed separately from the compressor housing. The new scroll compressor for GHP, which meets demands for the economical efficiency and the environmental protection, has been developed.

## ACKNOWLEDGMENTS

The authors express their gratitude to Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd. and Toho Gas Co., Ltd. for their support.

## REFERENCES

(1) Kasahara, H., et al., 2002, "High-Performance, High-Reliability Gas Heat Pump", *Mitsubishi Heavy Industries, Ltd. Technical Review*, vol.39 No.2, 62-66
(2) GHP consortium, 2002, "GAS 21", vol.9, pp. 114
(3) Sato, H., et al., 2004, "Frictional Characteristics of Thrust Bearing in Scroll Compressor", *Proc. of 2004 International Compressor Engineering Conference at Purdue*,
(4) Mizuno, H., et al., 1996, "Development of Horizontal Scroll Compressor in Air-Conditioners for Commercial Use", *Proc. of 1996 International Compressor Engineering Conference at Purdue*, pp. 573-578
(5) Yamazaki, H., et al., 2002, "High Performance Scroll Compressor with Liquid Refrigerant Injection", *Proc. of 2002 International Compressor Engineering Conference at Purdue*,