1992

A Compact Horizontal Scroll Type Compressor for Room Air Conditioners

K. Sawai
Matsushita Electric Industrial Company

M. Yamamura
Matsushita Electric Industrial Company

Y. Kojima
Matsushita Electric Industrial Company

S. Yamamoto
Matsushita Electric Industrial Company

S. Kawahara
Matsushita Electric Industrial Company

See next page for additional authors

Authors
K. Sawai, M. Yamamura, Y. Kojima, S. Yamamoto, S. Kawahara, M. Sakai, M. Tsubokawa, and N. Ishii

A Compact Horizontal Scroll-Type Compressor for Room Air Conditioners

by

Kiyoshi Sawai[1], Michio Yamamura[2], Yoshinori Kojima[1], Shuichi Yamamoto[1], Sadao Kawahara[1], Manabu Sakai[3], Masahiro Tsubokawa[4] and Noriaki Ishii[5]

[1] Chief Engineer, Air Conditioning Research Laboratory,
[2] Director, Air Conditioning Research Laboratory,
[3] Engineer, Air Conditioning Research Laboratory,
[4] Engineer, Compressor Division, Matsushita Electric Industrial Co., Ltd. (PANASONIC), Noji-cho, Kusatsu 525, Japan
[5] Professor, Faculty of Engineering, Osaka Electro-Communication University, Neyagawa, Osaka 572, Japan.

ABSTRACT

This paper presents the construction, newly developed design technologies and performance characteristics of a compact horizontal scroll-type compressor for room air conditioners. The authors were able to develop a compact variable speed horizontal scroll-type compressor with a cooling capacity of 1.8 kW, which necessitated the development of new mechanisms, namely, an axial compliance mechanism for compensating liquid compression, an oil pump mechanism for lubrication and a suppression mechanism for oil discharge. Use of the new compressor in room air conditioners made it possible to reduce the external unit of the air conditioner by about 25%. The new compressor possesses a high efficiency: about 10% higher especially at low speed operation.

1. INTRODUCTION

In recent years, in the field of room air conditioners, there has been an increasing demand for reduced equipment energy consumption as well as for lower vibration and noise. The attention of the authors was drawn to the outstanding low vibration and low noise characteristics of scroll compressors, and the authors have already developed the world's first compact vertical scroll compressor with a cooling capacity of 2.4 kW, which is used in room air conditioners that were put on the market in 1990. This paper describes efforts to develop a smaller horizontal scroll compressor, with the goal of reducing the size of the external unit of split-type room air conditioners. The cooling capacity of the new compressor is 1.8 kW, which is the most frequently used capacity for household applications in Japan.

Because horizontal compressors have up to now presented problems such as difficulty in supplying lubricating oil to the mechanisms and discharging large amounts of oil from the compressor to the refrigeration cycle, achieving this goal was considered difficult. However, by developing a new trochoid-type oil pump mechanism for lubrication and a suppression mechanism for oil discharge, completely horizontal installation was made possible. In addition, by using a radial compliance device developed by our company, high efficiency was assured when the cooling capacity was reduced. Furthermore, greater reliability was achieved by developing and adopting an axial compliance device that limits the effects of liquid compression. In this paper, the structure of the newly developed scroll compressor, as well as its features and performance characteristics, are presented.

2. OVERVIEW OF THE NEWLY DEVELOPED SCROLL COMPRESSOR

The design of the newly developed scroll compressor is shown in Figure 1, and its specifications are given in Table 1.

2.1 Internal High-Pressure Structure of the Shell

In development, emphasis was placed on compression efficiency, and thus a high-pressure shell was adopted with the aim of minimizing the degree of superheat of the intake gas and suppressing the amount of oil discharged from the discharge conduit.

Table 1 Specifications of Horizontal scroll compressor

Description			Specification
Compressor type		———	Hermetic & motor-drive
Impeller form		———	Involute scroll
Variable rotating speed		rpm	600～7800
Displacement volume		cc/rev	10.3
Built-in volume ratio		———	2.3
* Refrigrating capacity		kW	1.85
Outer dimension	Diameter	mm	110
	Height	mm	280
Weight		kg	10.6

* JIS-A requirements: Pd=2.18 MPa , Ps=0.62 MPa , Ts=291 K
N=3450 rpm (60 Hz)

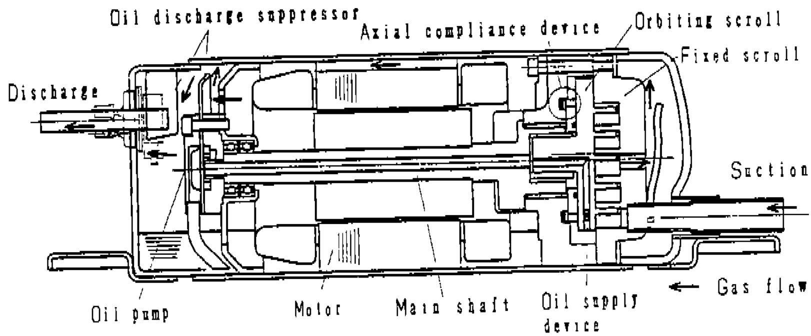

Fig.1 Construction of horizontal scroll-type compressor

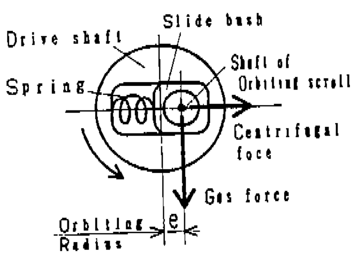

Fig.2 Slide bushing mechanism

2.2 Compression Mechanism

The refrigerant gas is compressed in the crescent-shaped chambers bounded by the wraps of both the fixed scroll and the orbiting scroll, and their end plates. The fixed scroll has an inlet on its periphery and an outlet in the center of the end plate, and is secured to the main bearing frame at the periphery. A shaft is located in the center of the orbiting scroll end plate, and is driven by the main shaft (drive shaft). As shown in Figure 2, on the one end of the drive shaft, there is a rectangular hole in the vertical cross section, which is fitted with an eccentric bearing, namely a sliding bushing, connected to the shaft of the orbiting scroll in such a way as to rotate freely. This is a Matsushita original radial compliance device, namely a sliding bushing mechanism. The eccentric bearing is pressed against the inner side wall of the rectangular hole by a spring, which is attached to the main shaft, so that the clearance between the scroll wraps in the radial direction can be maintained at a minimum value.

The gas pressure in the compression chambers acts on the orbiting scroll end plate to push it in the axial direction, away from the fixed scroll. In the new compressor, the discharge pressure is brought to the rear surface near the orbiting scroll end

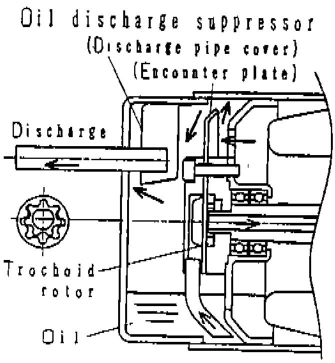

Fig.3 Oil pump mechanism and oil discharge suppressor

plate center, thereby suppressing an irregular orbiting scroll vibration in the axial direction. An Oldham ring is positioned in the space between the orbiting scroll end plate and the main bearing, preventing the orbiting scroll from rotating freely. Additionally, an axial compliance device composed of a thrust ring and a wavy spring is positioned inside the Oldham ring, preventing liquid compression from occurring in the compression chambers. The ends of the orbiting scroll wrap are also equipped with a tip seal, sealing the compression chamber in the axial direction.

The main shaft is supported by a sliding bearing on its end on the orbiting scroll side, and by a ball bearing on the other end, thus giving a design that provides double end support.

3. MAIN TECHNOLOGIES USED IN DEVELOPMENT

3.1 Oil Pump Mechanism

With horizontal compressors, the compression mechanism is generally isolated from the accumulated?? oil level, and for this reason some mechanism is required to pump up the oil and supply it to the compression mechanism. The new compressor is equipped with an oil pump, the cross-sectional view of which is shown in Figure 3. The oil pump has a trochoid volumetric rotor at one end of the main shaft, which pumps the oil and supplies it to the compression mechanism through a hole in the center of the main shaft. This provides a constant supply of lubrication for the sliding bushing, the main bearing and each sliding pair around the orbiting scroll. A portion of the oil used for lubrication is supplied to the compression chamber, but the major portion is returned to the inside of the shell.

This oil pump makes it possible for the new room air conditioner to achieve a wide operating range, ranging from a low speed of 600 rpm to a high speed of 7,800 rpm.

3.2 Oil Discharge Suppressor

With horizontal compressors, oil pooled at the bottom of the shell is agitated by the motor's rotor and dispersed. Additionally, because of the short distance between the discharge pipe and the oil surface, the dispersed oil mist is discharged from the discharge pipe to the refrigeration cycle. When the oil discharge from the compressor increases, the amount of oil within the shell decreases, and reliability-related problems such as insufficient lubrication occur. Furthermore, if there is an increase in the amount of oil mixed in with the refrigerant circulating in the refrigeration cycle, the pressure losses especially in the low pressure conduit increase, thus decreasing the cooling or heating capacity.

For these reasons, the new compressor is equipped with dual oil discharge suppressors, as shown in Figure 3. Using one method, several circular paths for refrigerant gas were made on the plate supporting the ball bearing, as well as on the fan-shaped plates at positions corresponding to these gas paths. The refrigerant gas then strikes the fan-shaped plates at high speed, and the oil mist is separated from the gas. Using another method, the discharge piping is fitted with a cover, and because the refrigerant gas is in contact with the cover until it reaches the discharge piping, the oil mist in the gas adheres to the cover and is separated.

These two methods made it possible to reduce the oil discharged from the discharge pipe to the refrigeration cycle to less than 0.5%, in terms of the mass ratio of the discharged oil to the recirculating refrigerant. When used in conjunction with the re-

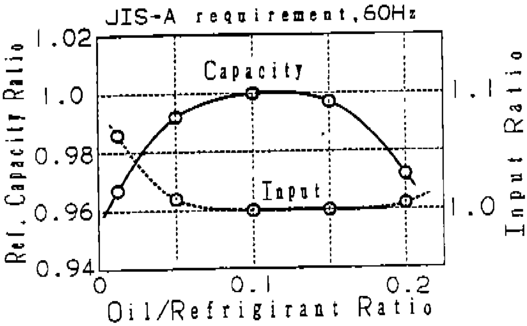

Fig.4 Effect of the amount of oil on performance

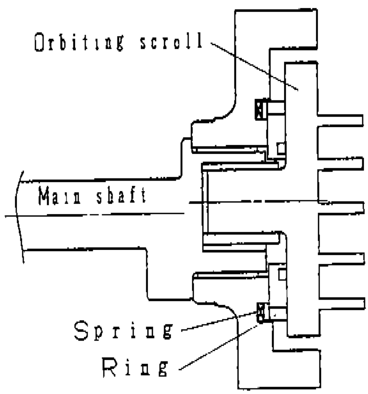

Fig.5 Axial compliance device

frigeration cycle, the oil discharge suppression mechanism made it possible to maintain cooling and heating performance equivalent to that of vertical compressors.

3.3 Sealing Technologies for Compression Chambers

In making the scroll compressor more compact, the most important issue is to develop sealing technologies to reduce gas leakage and boost compression efficiency. The gas in the compression chamber leaks through the axial and radial clearances between the orbiting and fixed scroll wraps. For the axial clearance, tip seals were mounted on the tips of the wraps to prevent refrigerant gas leakage, while a sliding bushing mechanism was used to minimize the radial clearance, and thus prevent gas leakage there.

In addition, a portion of the lubricating oil was supplied to the compression chamber via a pressure reducer embedded in the end plate of the orbiting scroll, helping to improve the seal of the compression chamber. The relationship between the amount of oil supplied to the compression chamber and the performance is shown in Figure 4. The pressure-reducing resistance was determined so as to maximize the performance coefficient within the normal range of operation.

3.4 Axial Compliance Mechanism

An axial compliance device was newly developed and adopted for this compressor to protect the compressor from excessive loads resulting from liquid compression, and to improve reliability. Figure 5 shows the structure of this device. The axial compliance device is composed of a thrust ring mounted on the rear surface of the orbiting scroll end plate, and a wavy spring supporting this ring. This wavy spring has a pre-load. When an excessive load develops within the compression chamber because of liquid compression or similar reasons, the thrust force acting on the orbiting scroll end plate overcomes the pre-load of the spring, and the orbiting scroll moves axially. This enlarges the axial clearance of the wraps, and the refrigerant liquid at high pressure

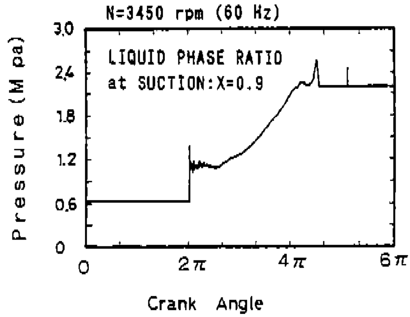

Fig.6 Calculated effect of axial compliance device

moves from this space to another compression chamber, withoutincreasing the pressure of the compression chamber above a fixed value.

Figure 6 shows the results of the calculations for evaluating the effectiveness of the new axial compliance device to limit the pressure changes within the compression chamber when liquid compression occurs.. In the calculations, it was assumed that a gas-liquid mixture is compressed. The leakage flow velocity of refrigerant from the high-pressure compression chamber, v_g, was calculated using the following expression:

$$v_g = \sqrt{\frac{\kappa}{\kappa-1} p_2 \left\{ \left(\frac{p_1}{p_2}\right)^{2/\kappa} - \frac{p_1}{p_2}^{(\kappa+1)/\kappa} \right\} \frac{2g}{\gamma_g}} \qquad (1)$$

For the fluid phase, the leakage flow velocity of the refrigerant liquid, v_l, was determined using Bernoulli's equation:

$$v_l = \sqrt{2g \frac{p_1 - p_2}{\gamma_l}} \qquad (2)$$

where κ represents the specific heat ratio of the refrigerant gas, p_1 the compression chamber pressure (high pressure), p_2 the pressure of the neighboring compression chamber (low pressure), γ_g the specific gravity of the refrigerant gas, γ_l the specific gravity of the refrigerant fluid, and g the gravitational acceleration. Through this simulation, it was determined that even when the percentage of the fluid phase is high during intake, use of the axial compliance device makes it possible to limit the compression chamber pressure to a low value, effectively protecting the compressor.

4. COMPRESSOR PERFORMANCE CHARACTERISTICS

4.1 Performance Coefficient

In Figure 7, the performance coefficient for cooling capacity of the new compressor is compared to that of a scroll compressor previously developed by Matsushita. The performance coefficient of the newly developed compressor is equivalent to that of the

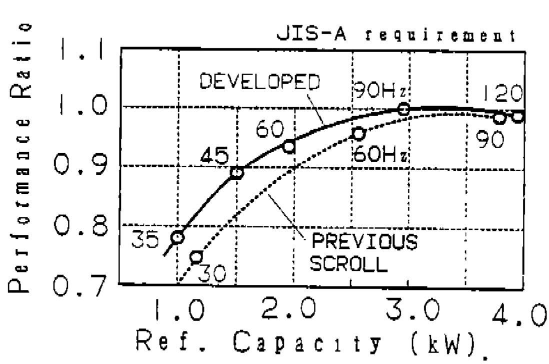

Fig.7 Comparison of performance coefficients

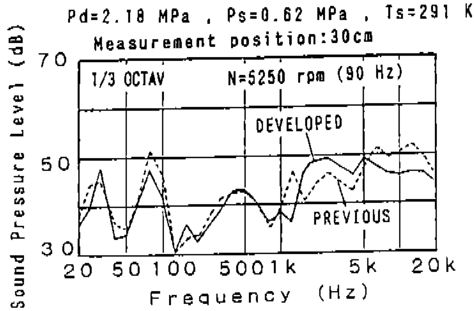

Fig.8 Comparison of sound pressure spectra

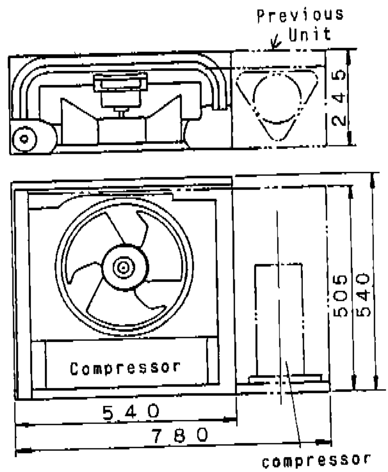

Fig.9 New smaller external unit of split-type room air conditioner

existing compressor when the cooling capacity is in the 3 kW range, and is 10% higher than that of the previous compressor in the 1 kW range. Thus, the lower the cooling capacity, the higher the performance coefficient in comparison with the existing scroll compressor. This is due to the success, in practice, of a compressor with a smaller stroke volume (reduced 30%) through the use of more sophisticated compression chamber sealing technologies, which make it possible to achieve higher operating speeds with identical cooling capacity.

Because air conditioners are frequently used at low cooling capacities during constant operation for cooling or heating, the seasonal energy consumption efficiency ratio (SEER) is directly proportional to the rate of increase of the performance coefficient at low speed.

4.2 Noise Characteristics

The noise characteristics of the newly developed compressor are shown in Figure 8. Compared with the previous scroll compressor, the newly developed compressor displays virtually the same noise level and noise spectrum. In comparison with Matsushita's rotary compressor, the noise levels of the new compressor are much lower at nearly all frequencies. However, there is a need to further reduce the level of noise below 1 kHz, because at these low frequencies, it is difficult to provide noise insulation in the air conditioner.

5. EFFECT OF COMPRESSOR ON SIZE OF THE AIR CONDITIONER

Figure 9 is a schematic diagram of the externally mounted portion of a room air conditioner in which the newly developed compressor is installed. In contrast to compressors in the external units of existing air conditioners, the new compressor is positioned horizontally, and its external diameter has been reduced from 118 mm to 110 mm, enabling the space occupied by the external unit to be reduced by 25%. This has changed the appearance of the external unit as well as its image.

6. CONCLUSIONS

By developing a lubricating oil pump and an oil discharge suppressor, the authors were able to make a horizontal compressor that can be mounted completely horizontally. Furthermore, by using a sliding bushing mechanism and optimizing the amount of sealing oil, the sealing technologies were significantly improved, making it possible to produce the world's smallest capacity scroll compressor. When this compressor is installed in an air conditioner, the size of the external unit can be reduced by 25%, thus improving its appearance as well as its image.

Matsushita has been marketing air conditioners equipped with this compressor since December 1991, and market response has been extremely favorable. Further efforts will be made to improve the efficiency of this compressor and reduce noise, boosting air conditioner energy efficiency and comfort.

REFERENCES

1. Ishii, N., Fukushima, M., Sano, K. & Sawai, K., A Study on Dynamic Behavior of a Scroll Compressor, Proc. International Compressor Engineering Conference at Purdue, Vol.3, Aug., 1986, pp.901-916.
2. Ishii, N., Yamamura, M., Morokoshi, H., Fukushima, M., Yamamoto, S. & Sakai, M., On the Superior Dynamic Behavior of a Variable Rotating Speed Scroll Compressor, Proc. International Compressor Engineering Conference at Purdue, Vol.1, July, 1988, pp.75-82; Transactions of the Japan Society of Mechanical Engineers (in Japanese), Series C, Vol. 55, No.517, 1989, pp.2436-2445.
3. Ishii, N., M., Yamamura, M., Muramatsu, S., Yamamoto, S. & Sakai, M., Mechanical Efficiency of a Variable Speed Scroll Compressor, Proc. International Compressor Engineering Conference at Purdue, Vol.1, July, 1990, pp.192-199.
4. Yamamura, M., Muramatsu, S., Kojima, Y., Yamamoto, S., Kawahara, S. & Ishii, N., Compact type Scroll Compressor for Air Conditioners, Proc. of Purdue Int. Compressor Engineering Conference, 1990, pp.140-146.
5. Shibamoto, Y., Fujimoto, S., Takano, S., Higuchi, M. & Matoba, Y., The Characteristics of Small Capacity Scroll Compressors for Residential Air Conditioners, Proc. of Purdue Int. Compressor Engineering Conference, 1990, pp.173-182.