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Compact Type Scroll Compressor for Air Conditioners

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by

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ABSTRACT

Scroll compressors possess a characteristically low level of noise and vibration, far lower than that of rolling-piston rotary compressors, and, because of this, they are being used extensively as air conditioner refrigeration compressors. Recently, Matsushita has succeeded in developing a compact scroll compressor which has a high efficiency and a low level of noise and vibration. This newly developed scroll compressor is in the 0.75 kW class, which is the major demand sector for room air conditioner use. The most significant feature of the small-size scroll compressor is the reduction in refrigerant leakage from the high pressure to the low pressure. Reduced leakage is the dominant factor in improving efficiency. In this scroll compressor, a chip seal is inserted in the slot along the top end of each impeller. To optimize the radial gap under any operating conditions, a slide-bushing mechanism was used. The slide bush mechanism reduces the bearing load and thus protects the scroll impeller from damage caused by liquid compression. To reduce the noise level, pressure pulsations in the discharged refrigerant are minimized, and noise is further reduced with a phase interference muffler. The addition of a displacement oil pump driven by the orbiting scroll makes operation possible over a wide range of rpm, further enhancing the reliability of the compact scroll compressor.

INTRODUCTION

In the field of compact air conditioners, there are strict demands for reduced energy consumption and lower levels of noise and vibration. The rolling-piston rotary compressor came into use for air conditioners about 15 years ago, because of its superior efficiency and low weight. Many efforts have been made to reduce the vibration and noise level of rolling-piston rotary compressors, for example, through multi-cylinder designs [see Refs. 1 and 2]. However, it is difficult to reduce the noise and vibration level sufficiently so as to satisfy the stringent requirements of the users.

On the other hand, the scroll compressor possesses a characteristically low level of noise and vibration [1, 3-5], far lower than that of the rolling-piston rotary compressor. The principle of the scroll compressor was discovered in 1905, and research and development work on the scroll compressor has been carried out steadily since then. Practical application, however, was not achieved for the following reasons:

(1) Very high precision tooling is required for production of the scroll compressor;

(2) A complicated process is required to assemble the parts involved in the compression mechanism.

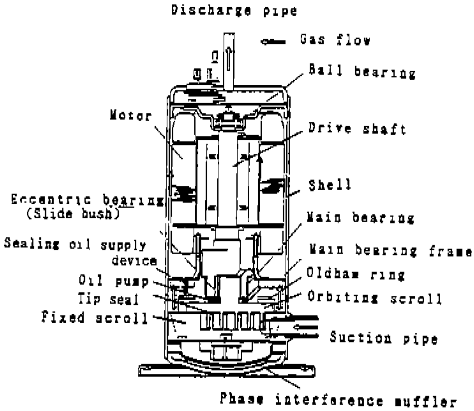


Fig. 1 Construction of compact scroll compressor

Table 1 Specifications

Description			Specification
Compressor type		—	Hermetic & motor-drive
Impeller form		—	Involutes scroll
Nominal output		W	750
Variable rotating speed		rpm	600～9000
Displacement volume		cc/rev	13.4
Built-in volume ratio		—	2.5
* Refrigerating capacity		kW	2.45
Outer dimension	Diameter	mm	117
	Height	mm	260
Weight		kg	14

* Test condition: 3600 rpm
P_d=2.18 MPa . P_s=0.62 MPa . T_s=291 K

In recent years, however, supported by steady progress in NC machine tools, precision machining has made great strides. Together with precise R&D work on scroll compressors, a variety of alternatives, including the movable crank mechanism with variable orbiting radius from America, and the self-adjusting support mechanism of the orbiting scroll from Japan [6-9], have become possible. Through this and other research, scroll compressors began to be commercialized from early 1981.

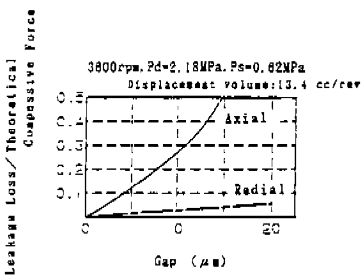
Matsushita developed low-pressure type scroll compressors in the 2 kW class (20000 BTU) and began to use them in air conditioners in 1987 [10]. It was generally believed that any further reduction in scroll compressor size would reduce the efficiency. Recently, however, Matsushita has succeeded in developing a small scroll compressor for room air conditioners, which has a high efficiency and a low level of noise and vibration. This newly developed scroll compressor is in the 0.75kW class (10000 BTU), which is the major demand sector for room air-conditioner use. This paper discusses the construction and operating features of this newly developed scroll compressor.

MATSUSHITA'S SCROLL COMPRESSOR CONSTRUCTION

The construction of Matsushita's scroll compressor is shown in Fig.1, and the specifications are given in Table 1. It is a high-pressure type structure, which encompasses the major mechanisms given below.

Compression Mechanism

Refrigerant gas is compressed in the space formed between the fixed and orbiting scroll impellers. The fixed scroll has a suction port on its periphery and a discharge port in the center of the plate, and it is secured to the main bearing frame. The shaft of the orbiting scroll is located in the center of the orbiting scroll plate. The rectangular hole in the lower end of the drive shaft holds the eccentric bearing (slide bush) which



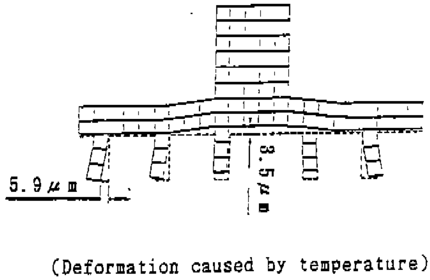


Fig.2 Calculated leakage loss through gap **Fig.3 Sample FEM diagram of orbiting scroll**

drives the orbiting scroll shaft. The Oldham ring which prevents the orbiting scroll from rotating is fitted into the key slots on the orbiting scroll plate and on the main bearing frame. During the gas compression process, the orbiting scroll is pressed up by fluctuating forces caused by the compressed gas, and this results in an undesirable motion which causes noise and vibrations. In order to prevent this undesirable motion, high pressure is directed to the back of the orbiting scroll and low pressure to the periphery. Thus, the orbiting scroll is pressed down toward the fixed scroll. In order to reduce the leakage of the compressed gas from the axial gap, a chip seal is inserted in the slot along the top end of both impellers.

Oil Pump

A displacement oil pump is mounted onto the shaft of the orbiting scroll. The lubricating oil is pumped up by means of the orbiting motion. Thus, the frictional surfaces of the main bearing, the eccentric bearing and so on, are constantly well lubricated by the oil.

Phase Interference Muffler

In general, the scroll compressors do not have a discharge valve. When the scroll compressors are operated under a designed compression ratio, the pressure pulsations are quite small. In practical operation, however, the compression ratios may vary, and a discharge pressure pulsation can result from under- or over-compression. Moreover, the gas flow discharged into the gas passage may undergo resonance. It is a matter of course that these factors will result in the production of noise. In order to prevent this problem, the new compact compressor possesses a skillfully designed phase-interference muffler which reduces effectively the discharge pressure pulsations and prevents resonance by discharging the gas symmetrically into the upper shell space to create gas standing wave interference.

Mechanism for supplying Oil to the Compression Chamber

In the newly-developed scroll compressor, a device for supplying oil is mounted in the main bearing frame, to guide the oil in the sump to a chamber on the rear surface of the orbiting scroll, from where it passes through the orbiting scroll hole and into the compression chambers. The lubricating oil which circulates in the compression chambers plays a significant role in both sealing and oil cooling [7].

MAJOR TECHNOLOGIES

Seal Technology and Establishment of an Optimum Gap

The most critical feature of the small-size compressor design is the reduction in refrigerant leakage from the high pressure to the low pressure. Reducing leakage is the dominant factor in improving the efficiency. Thanks to the technologies developed here, the gas leakage through the axial and radial gaps between the fixed and orbiting impellers is effectively reduced.

The leakage flow analysis shown in Fig.2 suggests that the axial gap has much more influence on the compressor efficiency than the radial gap. In order to reduce leakage through the axial gap, a tip seal is inserted into the slot along the top end of both impellers. An excessive radial gap also causes large leakage losses. On the other hand, an excessively small gap causes accidental impeller contact which makes unacceptable noises. For these reasons, various high-level technologies, such as the precise machining of impellers, an in-depth study of impeller deformation under various

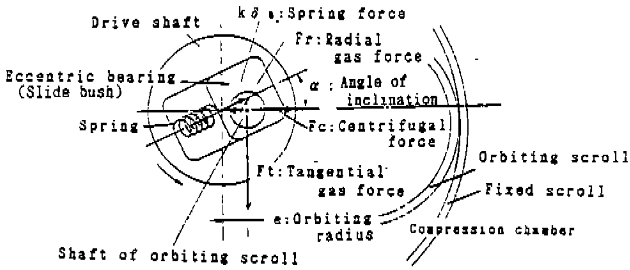


Fig.4 Slide-bushing mechanism

operating conditions and a computerized assembly technology, were required to develop the compact scroll compressor. When all these factors are taken into account, the radial gap can be optimized.

Fig. 3 shows one example of the impeller deformation studies. The deformation is caused by the temperature. The calculated results shown in this figure indicate that more distortion occurs at the periphery than at the center of the scroll impeller.

Slide-Bush Mechanism

The slide-bushing mechanism plays a significant role in reducing the bearing load. This mechanism works especially when liquid has been compressed, protecting the scroll impellers from damage caused by liquid compression. Fig. 4 shows the slide bush mechanism. The rectangular hole in the lower end of the drive shaft holds the eccentric bearing (slide bush) which drives the orbiting scroll shaft. This eccentric bearing can move along the center line of the rectangular hole, and it is pressed against an inside wall of the rectangular hole by a spring. The center line of the rectangular hole is at an angle α from the orbiting radius.

The design values for the angle of inclination α and the spring constant k can be determined from the following relationship:

$$F_t \sin\alpha + F_r \cos\alpha - (F_c \cos\alpha + k\,\delta_0) < 0 \tag{1}$$

$$F_{tm} \sin\alpha + F_{rm} \cos\alpha - \{ F_c \cos\alpha + k (\delta_0 + \delta_i) \} = 0 \tag{2}$$

where F_t and F_r represent the tangential and radial gas forces acting on the orbiting scroll during normal operation (without liquid compression), and F_{tm} and F_{rm} those during abnormal operation (with liquid compression). F_c represents the centrifugal force acting on the orbiting scroll, δ_0 the initial deformation of the inserted spring, and δ_i the movement of the eccentric bearing (slide bush) due to liquid compression. The first relationship given by (1) means that during normal operation, the resulting spring force and centrifugal force acting on the orbiting scroll should be larger than the force due to the gas pressure. In that case, the eccentric bearing remains in contact with the wall of the rectangular hole and maintains a constant orbiting radius, resulting in an optimum radial gap during normal operation.

When liquid compression occurs, the compression chamber pressure increases rapidly, and subsequently, the forces acting on the orbiting scroll increase to F_{tm} and F_{rm}. In this case, the eccentric bearing is forced to move along the center line of the rectangular hole, at an angle from the orbiting radius. The displacement δ_i of the eccentric bearing can be determined from the second relationship (2). As the displacement δ_i increases, the radial gap increases, as given by $\delta_i \cos\alpha$, and subsequently, the high pressure liquid refrigerant is released into the other compression chambers. Thus, the pressure in the compression chambers never exceeds the permissible value. F_t, F_r and F_c vary with the operating conditions for pressure and rotating speed, and therefore the angle of inclination α and the spring constant k must be selected so as to satisfy the expressions given by (1) and (2) under a variety of operating conditions. In the newly-developed scroll compressor, the design values for δ_i, α, and k were determined based on the following assumption:

$$F_{tm} = (2 \sim 3) \cdot F_t \tag{3}$$

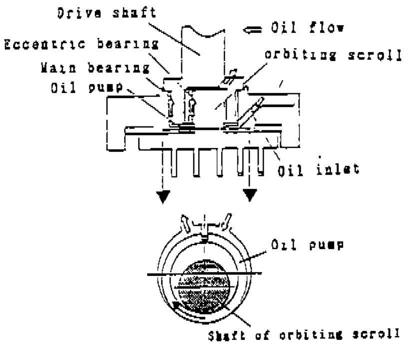


Fig.5 Oil pump mechanism

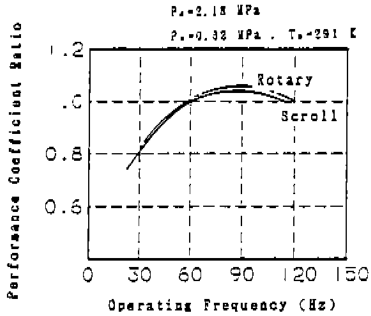


Fig.6 Comparison of performance coefficient

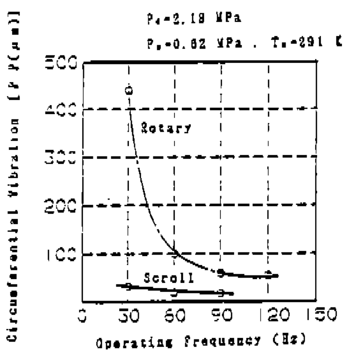


Fig.7 Comparison of vibration level

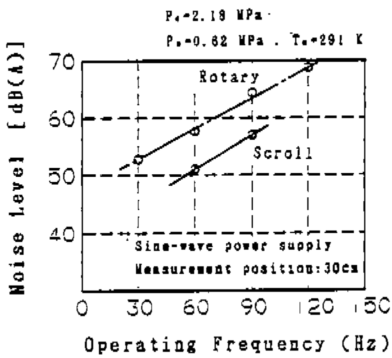


Fig.8 Comparison of noise level

Oil Pump Mechanism

The displacement oil pump is used to assure that an adequate supply of oil reaches the bearing under any operating conditions. The oil pump mechanism is shown in Fig. 5. A ring-shaped oil pump is mounted onto the shaft of the orbiting scroll, and the main bearing frame causes the pump to orbit inside the casing, resulting in a pumping action. The lubricating oil in the shell is pump up through the oil inlet, lubricates the main bearing and the eccentric bearing, and then returns to the shell. The development of this pumping makes it possible to operate the compressor over a wide range from 600 rpm to 9000 rpm, and vastly extends the variable performance range.

OPERATING FEATURES

Performance Coefficient

Fig. 6 shows the performance coefficient at various operating frequencies, for both the recently-developed compact scroll compressor and the rolling-piston rotary compressor with the same cooling capacity. The performance of the compact scroll compressor is equivalent to that of the Matsushita rolling-piston rotary compressor with the same capacity. It has been confirmed that when the compressors are actually mounted in an air conditioner, the performance coefficient of the compact scroll compressor exceeds that of the rolling-piston rotary compressor. This is due to the fact that the vibration level of the scroll compressor is so small that the pipes which connect from the compressor body to the refrigeration cycle can be shorter and thicker.

Vibration and Noise Characteristics

Fig. 7 shows the vibration level and Fig. 8 the noise level at various operating frequencies. The vibration level of the newly-developed compact scroll compressor is very small. For example, when operated in the low-speed range, the vibration level of the

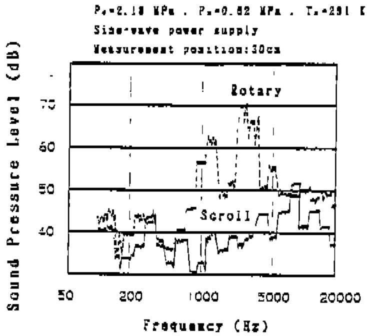


Fig. 9 Comparison of sound pressure spectrum

compact scroll compressor is about 20 dB lower than that of the rotary compressor. The noise level of the compact scroll compressor is reduced to a level which is 10 dB(A) lower than that of the rotary compressor.

Fig. 9 is the sound pressure spectrum. It is obvious from this figure that the noise level of the compact scroll compressor is lower for all frequency ranges than that of the rolling-piston rotary compressor. In particular, the noise level is extremely low for a frequency range near 1 kHz. As is well known, the noise in this frequency range is very difficult to shut out. Therefore, when such a quiet compressor is mounted in an air conditioner, there is a significant increase in comfort due to the reduction in noise. This kind of noise reduction can be achieved by using an interference muffler, which helps to prevent resonance and reduces pressure pulsation.

CONCLUSION

The newly-developed compact scroll compressor, the world's smallest, has an enhanced performance equivalent to that of a rolling-piston rotary compressor with the same capacity. The excellent performance of the compact scroll compressor was achieved through seal technology and optimum gap setting. Structural features include a reliable slide-bushing mechanism to protect the entire compression mechanism from damage caused by liquid compression; this enhances the reliability of the compact scroll compressor.

Matsushita has mounted the compact scroll compressor in a wall-mount air conditioner, and has released it for sale in February 1990. Consumer response has been excellent. However, compared to the rolling-piston rotary compressors which have been refined over decades of development, the structure of the scroll compressor is quite complicated and relatively expensive. Further technical developments will no doubt enhance efficiency, expand the line of scroll compressors and support more widespread application.

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