2022

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Sangbaek Park

Cheolhwan Kim

Kangwook Lee

Yongkyu Choi

Jungsun Choi

See next page for additional authors

Authors
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Development of Compact and High-efficiency Scroll Compressor Using Shaft-through Hybrid Wrap

Sangbaek PARK[1], Cheolhwan KIM[1]*, Kangwook LEE[1], Yongkyu CHOI[1], Jungsun CHOI[1], Seheon CHOI[1], Byeongchul LEE[1], Nara HAN[2], Sungchoon KIM[2]

[1]Disruptive Tech. Innovation Lab., LG Electronics Inc.
Seoul, Korea

[2]Component Solution Division, LG Electronics Inc.
Changwon, Gyeongnam, Korea

* Corresponding Author
Email: cheolhwan.kim@lge.com

ABSTRACT

In general, compressors used for air conditioning fields are classified into the rotary type and the scroll type. Each of these two types has different advantages and disadvantages. Rotary compressors have advantages such as simple structure and oil management because compression parts are located at the bottom side. Oil can be supplied to the friction parts easily and after compression, the oil can be separated from refrigerant at the empty upper side. Scroll compressor's continuous compression mechanism offers relatively higher efficiency and lower noise. But the compression parts have to be located at the upper side and consequently have complex structure. Most scroll compressors have additional frame below their motor and oil must be pumped up to the compression parts from the bottom reservoir. In some models, an additional oil separation device is necessary. A novel compressor, named R1, with both advantages of scroll and rotary had been developed. This new compressor has continuous compression mechanism of scroll and also simple structure of rotary. A new hybrid wrap has been applied to the compressor. The hybrid-wrap enable compression parts to be located in the bottom side because the crank shaft passed through the center of the fixed and orbiting scrolls. The shaft-through structure allows 3~17% efficiency improvement under low pressure ratio and low speed condition. With shaft-through structure, the orbiting scroll bearing can be aligned at the middle of height of the wrap. It offers a fundamental solution to scroll compressor's own problem: Tilting of orbiting can be controlled by reducing the moment arm. The back pressure can be reduced because the tiling motion of orbiting scroll can be controlled with relatively small back pressure force. The R1 compressor has simple structure by removing the sub-frame. The compression parts moved to lower side from upper side, then the empty upper space can be utilized as an oil separation space. The oil circulation ratio has been reduced by more than 70% compared with other conventional scroll compressors of LG electronics under the actual loading condition. Comparing with rotary compressor, the noise of R1 compressor has decreased by 5dB.

1. INTRODUCTION

Recently, concerns about global warming have become a major issue around the world. The air conditioning industry has been directly linked to the cause of global warming since its inception. Naturally, regulations on the energy consumption of air conditioners have become stricter as well as the regulations on GWP refrigerants. . Especially in Europe, the standard for the highest class of ErPs (energy related products) becomes higher every year, from Class A in 2013 (SEER 5.1/SCOP 3.4), to A+ in 2015 (5.6/4.0), to A++ in 2017 (6.1/4.6) and A+++ in 2019 (8.5/5.1). To meet these standards, improvement in the efficiency of the low load that is closer to the actual operation of an air conditioner is required, rather than in the efficiency of the rated load under the high load condition. Therefore, many air conditioner manufactures are using inverter compressors and have been continuously

conducting studies on expansion of the operation range to match their compressor power to the low-load as well as rated load.
Compressors account for about 90% of the power consumption of air conditioners, thus a high-efficiency compressor is essential to improve energy efficiency of an air conditioner product. In general, scroll compressors and rotary compressors are used for air conditioning products. Scroll compressors have the characteristics of high efficiency and low noise because compression occurs continuously by two interlocking scroll shapes. However, scroll compressors are costly, because an additional sub-frame is required to support the shaft due to a compression zone on the upper side of the compressor. The shaft with an oil supply path to the upper part and the design of the case comprising all those structure are also quite complex (Yoo *et al.,* 2012, Kim *et al.* 2010). On the other hand, rotary compressors have disadvantages in terms of efficiency and noise because of discontinuous compression. Compression occurs once per a rotation and it causes high fluctuation of load along the crank angle and tapping noise of valve. However, no additional sub-frame is required due to a compression zone on the lower side of the compressor. The structures could be simple, and discharged oil mixed with refrigerant gas can be easily separated using the upper space.
In this study, a novel scroll compressor, R1, has been developed by combining each advantage of the scroll and rotary compressor; it has the advantages in high efficiency and low noise of scroll compressor and also another advantage in oil management structure of rotary compressor. In this compressor, the shaft passes through the center of the orbiting scroll to stabilize the behavior of the orbiting scroll, thereby improving efficiency in the low-speed low-load condition. The structure is simplified using a lower-side-compression structure like a rotary compressor to reduce the oil circulation ratio by using the oil separation structure in upper space. The shaft-through hybrid scroll shape design, the eccentric back pressure control technology, and the oil separation technology inside of the compressor are all used in this compressor.

2. STRUCTURE OF THE DEVELOPED COMPRESSOR

The cross section view of the newly developed compressor is shown in Figure 1 and the specifications of the compressor are listed in Table 1. The external diameter of the compressor is 127.3 mm, the height is 386 mm, and the weight is 15.2 kg. The operation speed is 10–150 Hz, and the displacement is 31.6cc/rev. The fixed scroll and the orbiting scroll are made of cast iron. The fixed scroll has a discharge outlet, which has a valve to prevent discharged refrigerant from flowing back. The shaft passes through the mainframe, the orbiting scroll and the fixed scroll, and the compression zone, which is located below the motor. The refrigerant flows through the suction pipe into the fixed scroll and compressed by the orbiting scroll. The discharged refrigerant at the discharge outlet of the fixed scroll is transferred to the discharge pipe via the muffler, and through the side of the fixed scroll and the main frame. Inside of the compressor case is filled with discharged high pressure refrigerant.

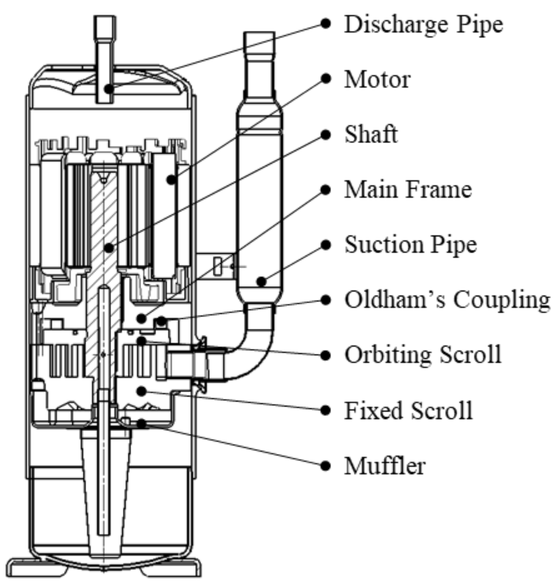


Figure 1: Cross sectional view of the R1 compressor

Table 1: Specification of the R1 compressor

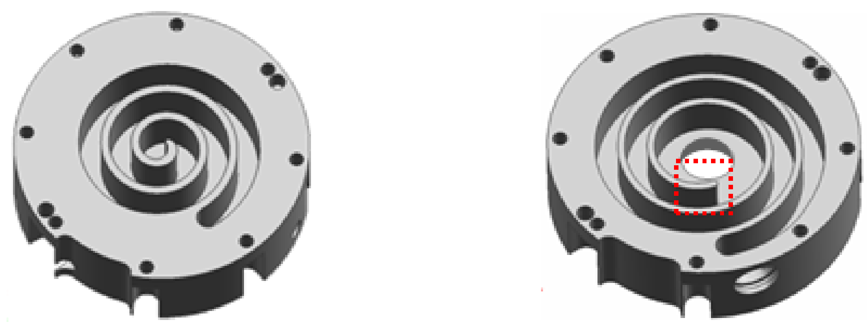
Items	Specifications
Displacement	31.6cc/rev
Weight	15.2kg
Dimensions(mm)	Φ 127.3 X L386
Operating speed	10~150Hz

3. MAIN TECHNOLOGIES

The R1 compressor is a type of scroll compressor. It has compression components on the lower side, with the shaft passing through the center of the scroll wrap. Williams et al. (1998) observed shaft through scroll compressor to eliminate overturning moment with experiment. However they reported a disadvantage that longer wrap length was required with involute design. Shaft passing through design cause lack of compression ratio due to vanished center space of involute wrap for compression. In this chapter, we will describe major technologies including the shaft-through hybrid scroll design technology that solved this problem.

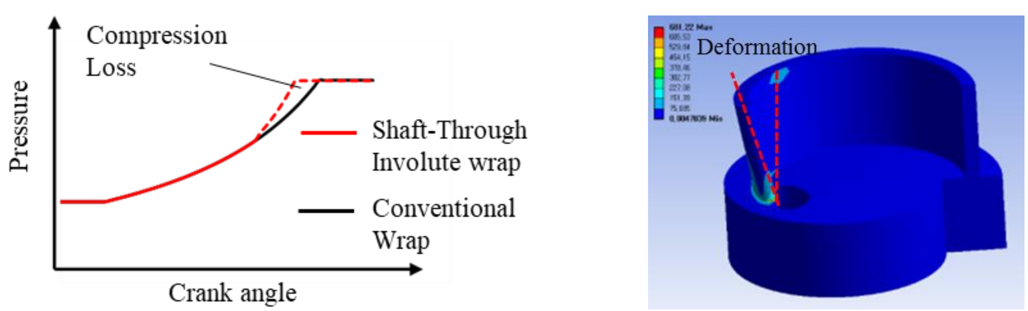
3.1 Shaft-through Hybrid Scroll Wrap

If the involute scroll wraps as shown in Figure 2 (a) is applied to the shaft-through structure, the wrap will have a shape as shown in Figure 2 (b) and be unable to be compressed to the target pressure ratio as shown in Figure 3 (a). This would cause a decrease in compression efficiency, and stiffness of the wrap at the center, as shown in Figure 3 (b), could cause a reliability issue due to deformation. Therefore, a design technology for new wrap shape is required for the shaft-through structure.



(a) involute scroll wrap (b) shaft through scroll wrap using involute

Figure 2: Conventional involute scroll wrap



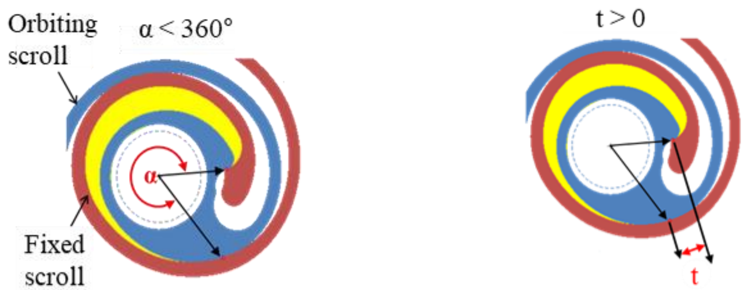
(a) Decline of compression efficiency (b) Deformation of wrap

Figure 3: Problems of conventional involute scroll wrap with shaft through structure

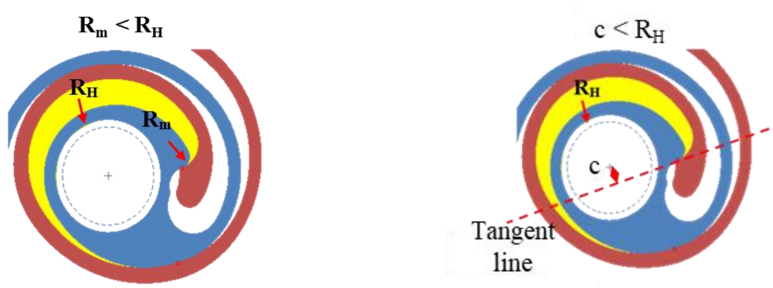
A hybrid scroll profile technology have been developed for the shaft-through structure. To increase the volume ratio, the concept of α, l was introduced to the hybrid scroll wrap as shown in Figure 4 (a). α is defined as the angle between contact points in the last compression pocket based on the coordinate of orbiting scroll center, and l is defined as the distance between the normal vectors of wrap geometry at the contact points. At this time, α was made to be less than 360, and l was made to be bigger than 0 to reduce the compression pocket space of the final discharge space more rapidly than involute. The end of the A path wrap was rolled, as shown in Figure 4 (b), to delay sealed-off, thereby increasing the volume ratio right before the discharge. To this end, Rh is the radius of the center that is assembled with the crank shaft, and Rm is the radius of the curvature of the wrap right before. c is the distance between the tangent line of the contact point right before the discharge and the wrap origin. Rm was designed smaller than Rh, and c was set to smaller than Rh. As a result, the volume ratio, similar to that of the existing involute wrap, was obtained using the shaft-through hybrid scroll wrap, as shown in Figure 5.

To solve the reliability issue caused by deformation at the center part of the wrap, the wrap envelope (which caused deformation because the wrap at the center part was thin) was adjusted as shown in Figure 6. As a result, the thickness of the wrap at the center part was reinforced by 220% compared to that of involute wrap, and this provides enough reliable strength. The final optimal profile of the shaft-through hybrid scroll wrap obtained is as shown in Figure 7.

The newly developed shaft-through scroll structure has the following advantages: The general scroll has the problem to affect efficiency and reliability, the tilting of the orbit scroll (Ahn *et al.* 2016, Williams *et al.* 1998). This is caused by tilting moment driven by the force couple that are the gas force and bearing reaction force, as shown in Figure 8 (a). However, the shaft-through scroll in Figure 8 (b) can eliminate the overturning moment of the orbit scroll with shaft-though structure. The bearing of orbiting scroll could be located as high as the wrap in the structure, then the distance between the force couple would be negligibly small. This allows smaller backpressure force to support the orbiting scroll, and the efficiency could be improved compared to that of the other scrolls through reducing the thrust friction loss by about 50%.



(a) Reduction of final discharge space



(b) Increase of compression ratio

Figure 4: Design of the new shape scroll wrap using hybrid wrap

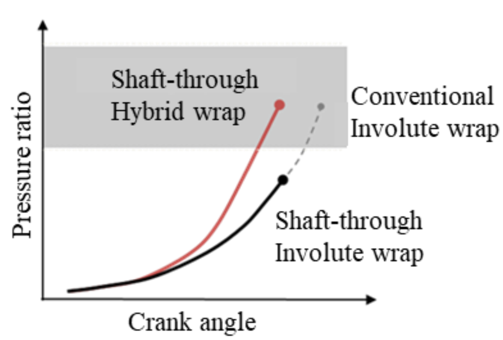


Figure 5: Pressure ratio of the new shape scroll wrap

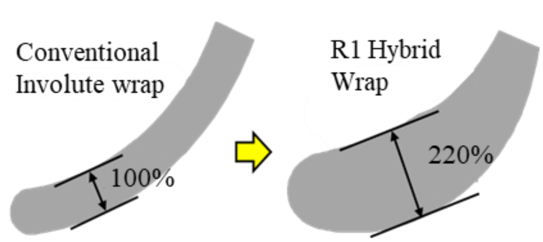
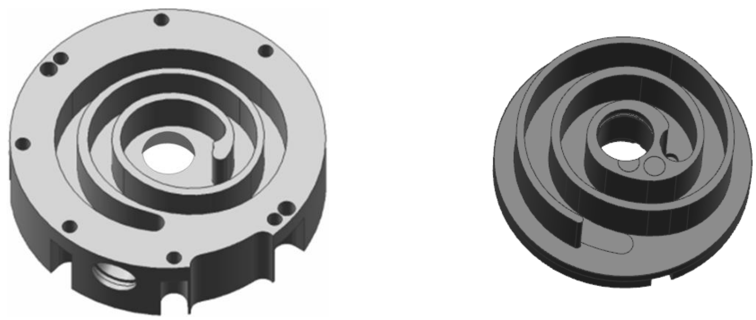
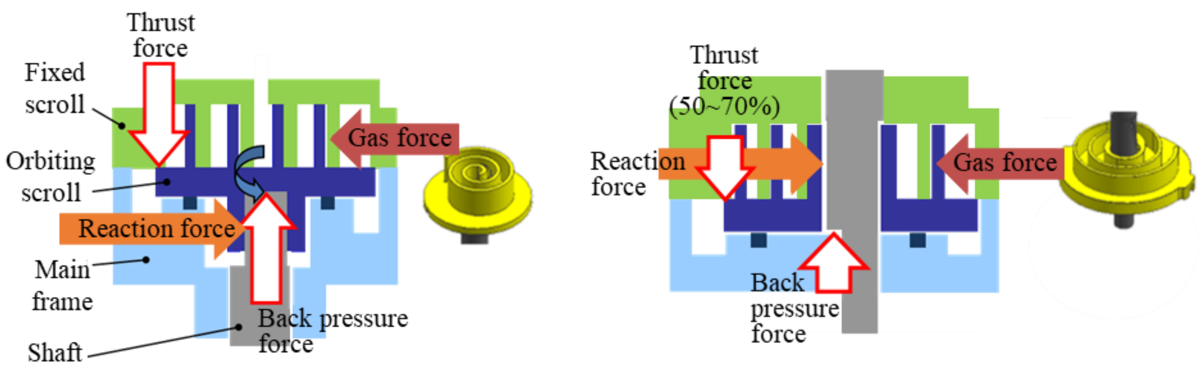


Figure 6: Thickness of center wrap



(a) Fixed scroll (b) Orbiting Scroll

Figure 7: Shaft through new shape scroll wrap



(a) Conventional (b) Newly developed

Figure 8: Position of reaction force

3.1 Eccentric Back Pressure Control

The scroll of R1 compressor has an eccentric discharge outlet because its shaft passes through the center. This makes another tilting moments since the point of action of the axial gas force deviates from the center and becomes eccentric. In order to control this moment driven by asymmetric gas force, the eccentric back pressure control method has been developed.

The simple force diagram in the axis direction at the orbiting scroll is illustrated in Figure 9. Fz means the axial gas force, Fb means the back pressure, and F thrust means the reaction force at the thrust surface under force equilibrium. The formula (1) was defined to describe the stability of the behavior by the force in the axis direction. L is the distance between the center of the orbiting scroll wrap and the point of action of F thrust, and R is the radius of the thrust bearing, *i.e.* base plate of orbiting scroll.

$$\text{Stability} = L/R \quad (1)$$

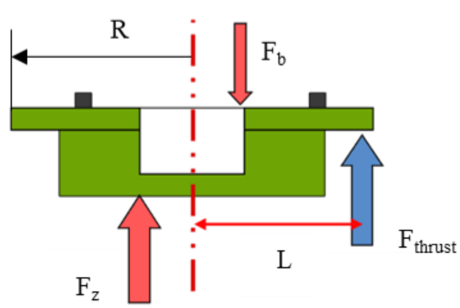


Figure 9: Axis direction force of orbiting scroll

According to the characteristics of the high-pressure compressor, a back pressure force should be designed adequately to reduce losses during the compression process. A seal has to be installed between orbiting scroll and main frame to make proper back pressure by separating high discharge pressure and intermediate pressure. The location of the seal groove is two considerable components, main frame or orbiting scroll. The point of action of axial gas force and back pressure force in the two cases are illustrated in Figure 10. To reduce tilting of the orbiting scroll, the location of the back pressure seals should be selected to minimize the moment by axial gas force. In case of main frame seal groove, the tilting moment increases because the back pressure becomes as eccentric as the orbiting radius. However, in case of seal at the orbiting scroll, the tilting moment would decrease because the distance becomes shorter.
Figure 11 shows the results of a comparison of stability prediction using formula (1) between the two cases. The stability in case of orbiting scroll seal shows smaller than main frame seal. The orbiting scroll is more proper for the seal install location than the main frame because of a lower behavior stability value. Therefore, as shown in Figure 12, pressure seals were located at the back of the orbiting scroll and their positions and sizes were optimized to minimize friction loss and leakage loss.

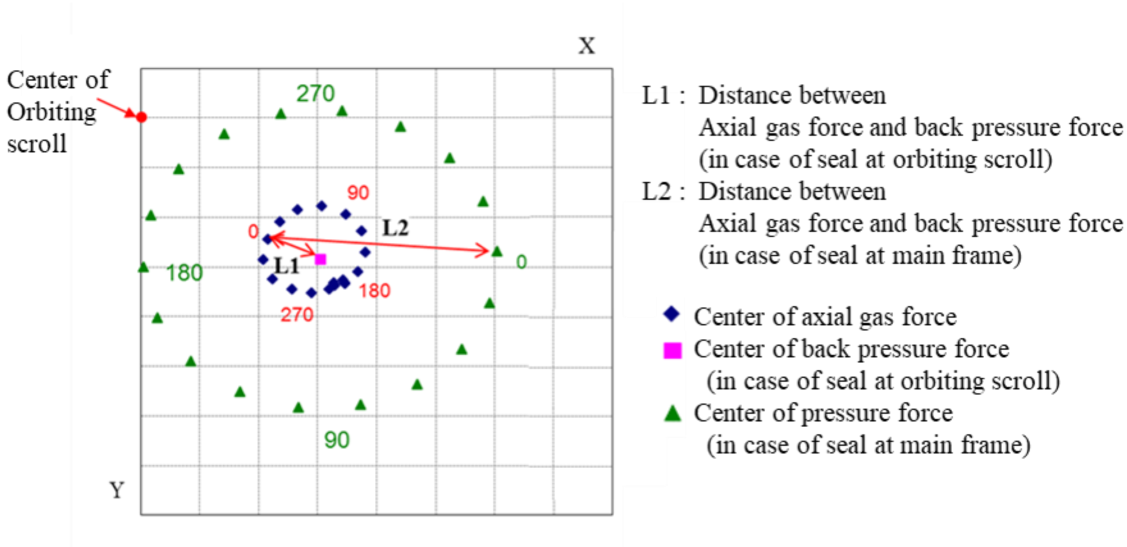


Figure 10: Force action point according to position of backpressure seal

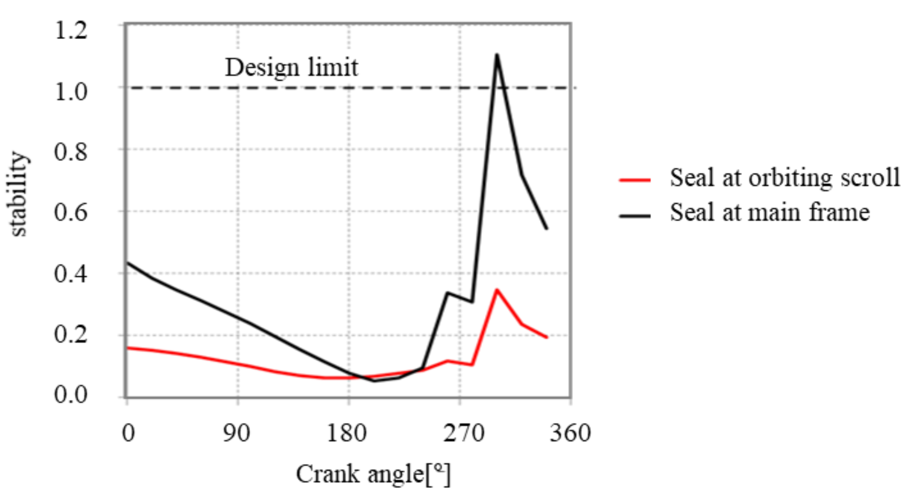


Figure 11: Comparison of stability according to position of back pressure seal

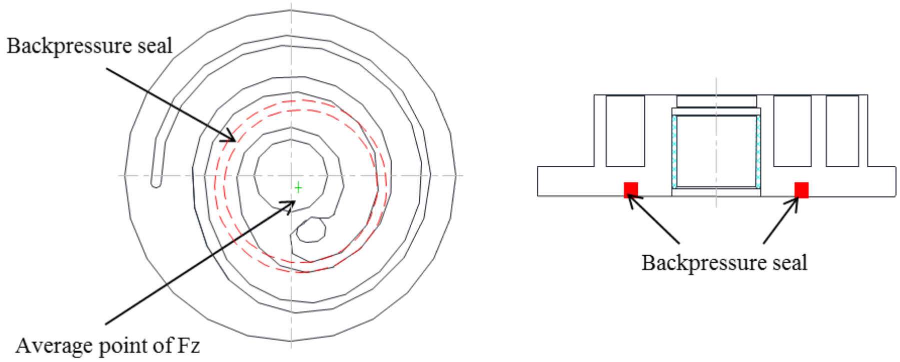


Figure 12: Eccentric back pressure seal

3.3 Oil Separation Technology

Because commercial air conditioners have long pipes in outdoor units and indoor units, the compressor is occasionally operated with rare oil supply, because all the oil from the compressor sometimes comes out before returning to the compressor. Especially during high-speed operations, the oil circulation ratio increases because the oil is discharged together with the refrigerant gas, causing lack of oil in the reservoir space of compressor inside and it can cause failure of compressor. Therefore, the technology to keep the oil in the case of compressor is crucial.

The R1 compressor has a compression components on the lower side of the compressor, thus oil can be easily separated using the upper space. The upper space is designed to guide the mixture fluid after compression flow in circulated path as in Figure 15. The gas discharged from the fixed scroll is transferred from the muffler to the upper part via the side flow path of the fixed scroll and the main frame, and then passes through the air gap of the stator and the rotor to the discharge pipe. While the gas is moving up through the motor, some of oil is separated from the mixture by centrifugal force driven by the rotation of the rotor. Much of oil is separated at the upper space, where the mixture fluid flows like cyclone around the discharge pipe. In the cyclone, some oil particles crashed to the wall and others crashed to each other, and then oil and refrigerant are separated due to the density difference. The separated oil flows down to the lower part reservoir via side path near the wall to be recovered.

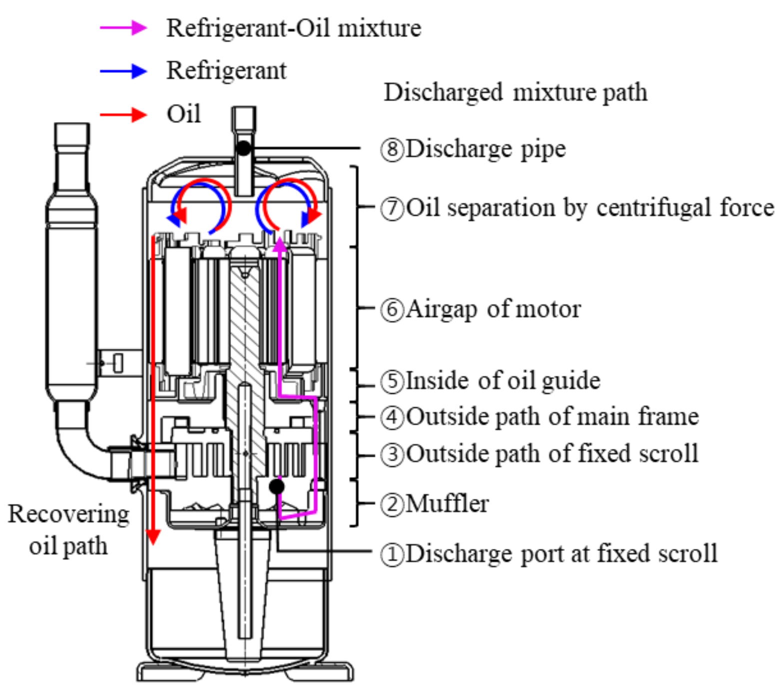


Figure 13: circulated path of the oil and refrigerant

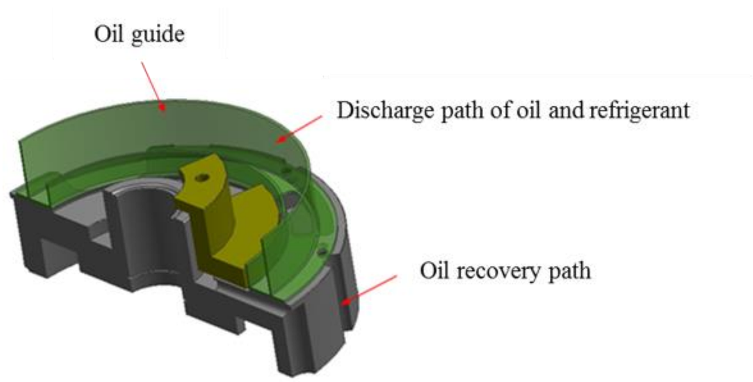


Figure 14: Oil guide

The core technologies of the oil discharge reduction can be summarized into two parts. The first is optimization of the volume of the upper space and the length of the discharge pipe and the second is the independent path design for two different flow, *i.e.* mixture path to upper side and oil recovery path to the bottom side. An oil guide has been developed to separate the two paths shown in Figure 16.

4. EVALUATION OF EFFICIENCY, NOISE AND OIL CIRCULATION RATIO

4.1 Evaluation of Efficiency

Figure 17 shows the results of evaluating and comparing the efficiency of another compressor of LG electronics and the R1 compressor under the actual loading condition of the AC products. The R1 compressor showed higher efficiency in every operation area. In the low-speed low-load condition, efficiency was improved by 17% because of reduced tilting of the orbiting scroll.

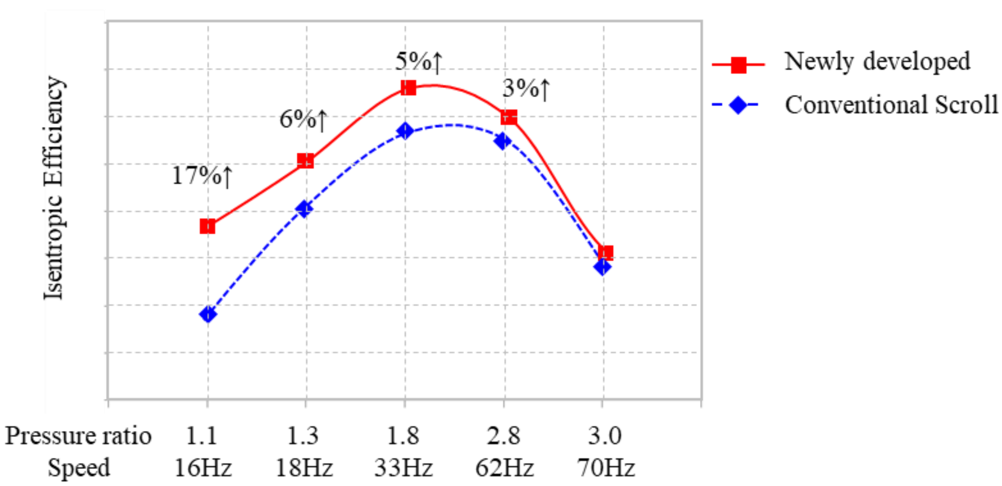
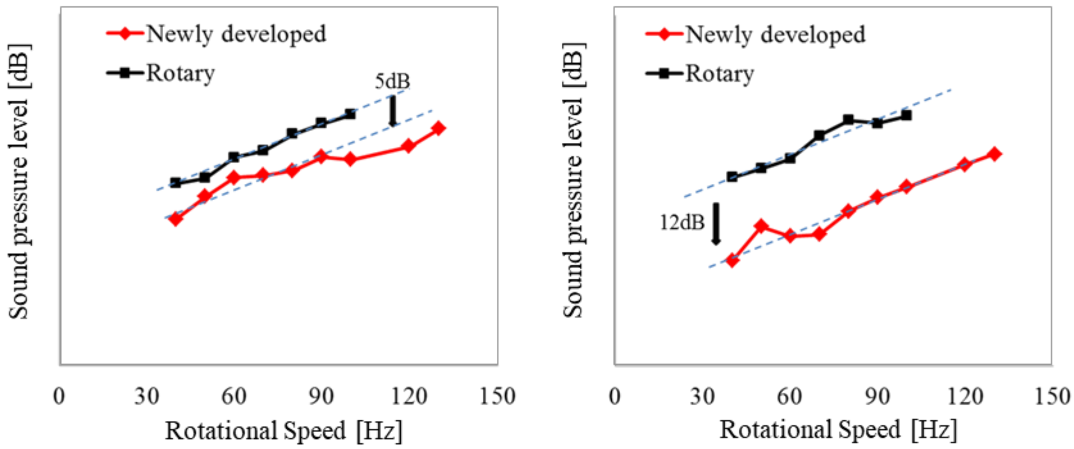


Figure 15. Comparison of efficiency with the scroll compressor

4.2 Evaluation of Noise

The heating condition in the ANSI/AHRI STANDARD 540 was used to measure the noise. Figure 18 shows the results from a noise comparison with another rotary compressor with same capacity manufactured by LG electronics. The overall noise was decreased by 5 dB in all operation areas compared to that of the rotary compressor. Noise of not exceeding 1 kHz, where a soundproof is not effective, was decreased by 12 dB in average, reducing the noise of the AC product substantially. Using this low-noise characteristics at high-speed, R1 could replace a rotary although its displacement volume is smaller than rotary. Finally this downsizing provides reducing the minimum capacity by 50% compared to the rotary compressor, which increased the efficiency of the actual-load operation.



(a) Total noise

(b) Noise under 1kHz

Figure 16. Comparison of sound pressure level

4.3 Evaluation of Oil Separation

Figure 14 shows the results of comparing the oil circulation ratios in AC system with the rotary compressor, the scroll compressor, and R1 compressor, according to their operation speed. The conventional scroll system has a high oil circulation ratio because it cannot separate the oil inside since its compression zone is in the upper part. However, the R1 compressor reduced the oil circulation ratio by 70% at 120 Hz compared to that of general scroll. This results shows that the oil separation technology of R1 is effective.

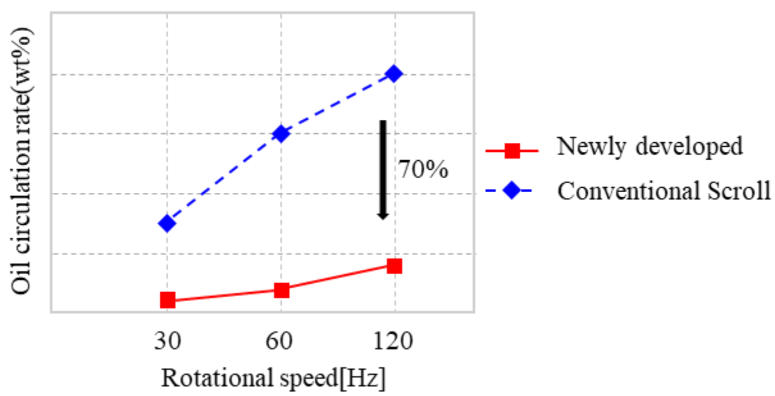


Figure 17. Oil circulation rate

5. CONCLUSIONS

To boost the efficiency of an air conditioner, efficiency in the low-load condition (which is the actual load condition) is crucial. In this study, annual operation efficiency was improved via expanding the variable capacity range by downsizing with speed-up of the compressor. Furthermore, the shaft-through structure was used to solve a chronic problem of the scroll–the tilting moment of the orbiting scroll. As a result, a compressor with a lower-side compression structure which has the oil separation technology was developed. The features of the R1 compressor are as follows:

1) Using the shaft-through scroll structure, efficiency was improved by 17% compared to the general scroll compressor under the low-speed, low-load condition.
2) The overall noise was decreased through 5 dB compared to a rotary compressor with the same capacity.

3) The effective oil separation technology reduce the oil circulation ratio by 70%, and therefor contributes to downsizing with speed-up of the R1.

NOMENCLATURE

F_z	axial gas force	N
F_b	back pressure force	N
F_{thrust}	thrust force	N
L	distance F_{thrust} from center	m
R	radius of orbit scroll plate	m
t	tangential distance between two contact points of a chamber	m
c	radial distance to last contact point of A path from wrap center	m
α	angle between 2 contact points of a chamber	°

REFERENCES

Ahn, S., Oh, J., Park, J., Choi, S., Lee, B., (2016) Development of compact and high-efficient scroll compressor with novel bearing structure, 16th International Refrigeration and Air Conditioning Conference at Purdue, (No. 1482)

Kim, C., Choi, S., Cho, U., Lee, B., Yun, J., Ha, S., Eom, K., Kim, S., (2010) Development of High-Side Shell Scroll Compressor with Novel Oil Return Mechanism, International Compressor Engineering Conference at Purdue, (No. 1412)

Williams, J. R., Hill, J. T., Fields, G. M., (1998) Scroll compressor with no tipping moment, International compressor engineering conference, (743-748)

Yoo, B., Choi, S., Won, I., Park, I., Lee, B., Eom, K., Kim, J., (2012), Development of new high-side shell scroll compressor with real-time oil level sensor, International Compressor Engineering Conference at Purdue, (No. 1418)