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Wataru Iwatake
Mitsubishi Electric Corporation, Japan, Iwatake.Wataru@bk.MitsubishiElectric.co.jp

Raito Kawamura

Keisuke Narumi

Daisuke Kudo

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A Study of "OVAL" Scroll Compressor for Capacity Increase

Wataru IWATAKE[1]*, Raito KAWAMURA[2], Keisuke NARUMI[3], Daisuke KUDO[4],

[1, 2] Mitsubishi Electric Corporation, Advanced Technology R&D Center,
8-1-1 Tsukaguchi-Honmachi, Amagasaki, Japan
Phone: +81-6-6497-3499, Fax: +81-6-6497-7285,
[1] Email: Iwatake.Wataru@bk.MitsubishiElectric.co.jp
[2] Email: Kawamura.Raito@cj.MitsubishiElectric.co.jp

[3] Mitsubishi Electric Corporation, Air-Conditioning & Refrigeration Systems Works,
6-5-66 Tebira, Wakayama, Japan
Phone: +81-73-436-2121, Fax: +81-73-428-9022,
Email: Narumi.Keisuke@aj.MitsubishiElectric.co.jp

[4] Mitsubishi Electric Corporation, Shizuoka Works,
3-18-1 Oshika, Suruga-ku, Shizuoka, Japan
Phone: +81-54-287-3258, Fax: +81-54-287-3127,
Email: Kudo.Daisuke@ah.MitsubishiElectric.co.jp

ABSTRACT

In recent years, there has been demand for a large-capacity scroll compressor to reduce cost and improve performance. To increase the capacity of the scroll compressor, technology to expand the stroke volume without increasing the shell size is required. To expand the stroke volume, expanding the wrap height in the axial direction is most effective. However, the higher wrap height raises the stress on the wrap and causes the orbiting scroll to overturn. So, we started to study a new shape of wrap to expand the stroke volume in the horizontal direction. The base plate of an orbiting scroll is usually circular. However, the trajectory of the fixed scroll on the base plate of the orbiting scroll is not circular, so wasted space that is not useful for compression exists on the base plate. We devised an oval wrap to make the trajectory of the fixed scroll on the base plate circular and reduce this space. The radius of basic circle was constant regardless of the involute angle in the conventional wrap. On the other hand, we can make the wrap shape "oval" by changing the radius of the basic circle sinusoidally (every 180 degrees). In this conference, we will present the geometric theory of our new oval wrap and the experimental result of the prototype. The results are follows: (1) It is possible to increase the stroke volume by more than 20% with the oval wrap. (2) A prototype with the oval wrap operates stably, and compressor efficiency is equivalent to the conventional wrap.

1. INTRODUCTION

In scroll compressors, technologies to increase capacity without increasing compressor size are required toward improving performance and reducing cost. Technologies to increase capacity are classified into two types, technologies that increase the rotation speed and technologies that expand the stroke volume. However, increasing the rotation speed may increase sliding loss, and may deteriorate the compressor performance. For expanding the stroke volume, increasing the scroll wrap height is most effective. However, higher wrap height raises the stress at the scroll root, and may deteriorate the compressor performance. To cope with this problem, many studies have been performed with regard to the scroll shape in the horizontal direction, including that described in a paper by John P. Elson et al. (2008). We defined again geometric functions of scrolls forming the compression chamber, expanded scrolls in the horizontal direction, and developed "oval scrolls" to expand the stroke volume. In this paper, we will introduce the geometric theory and effect of oval scrolls, and explain the experimental result of prototypes.

2. SCROLL GEOMETRIC THEORY

Figure 2.1 shows the conventional scroll shape, and Figure 2.2 shows the oval scroll shape. The base plate of an orbiting scroll is usually circular. However, the trajectory given when an orbiting scroll performs oscillation movements is not circular, but is oval in the winding end direction. As a result, wasted space that is not useful for stroke volume is generated partially on the base plate of the orbiting scroll as shown in the figure. We thought it desirable for expanding the stroke volume to effectively utilize the space on the base plate of an orbiting scroll by making the scroll shape oval and moving the base circle center from the compressor center, and devised an oval scroll. Figure 2.3 shows an example of the trajectory of the conventional scroll, and Figure 2.4 shows an example of the trajectory of the oval scroll we devised. In these figures, an orbiting wrap is fixed and a fixed wrap is moved. The trajectory of the oval scroll is close to a circular shape as shown in the figure, and the space on the base plate of an orbiting scroll can be utilized effectively.

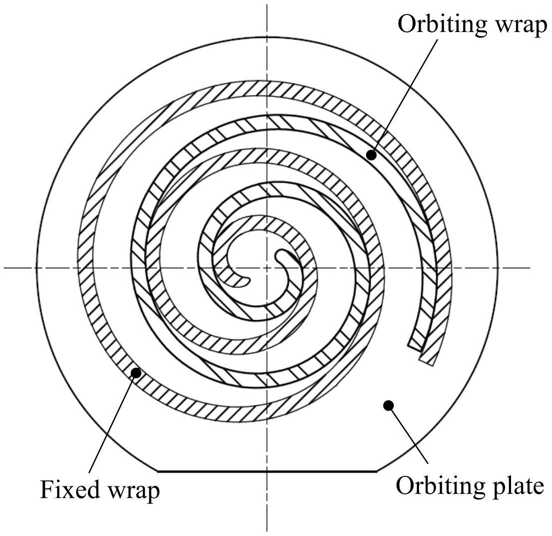


Figure 2.1: Conventional scroll shape

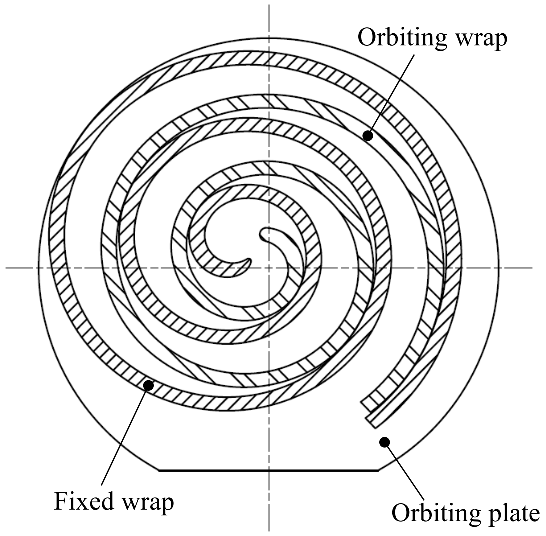


Figure 2.2: Oval scroll shape

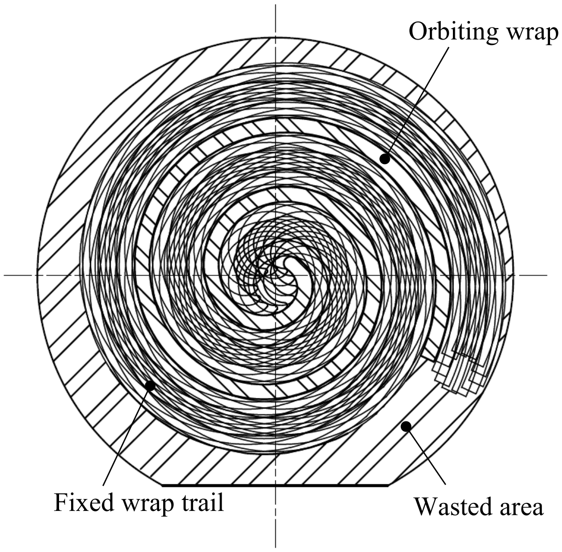


Figure 2.3: Trajectory of conventional scroll

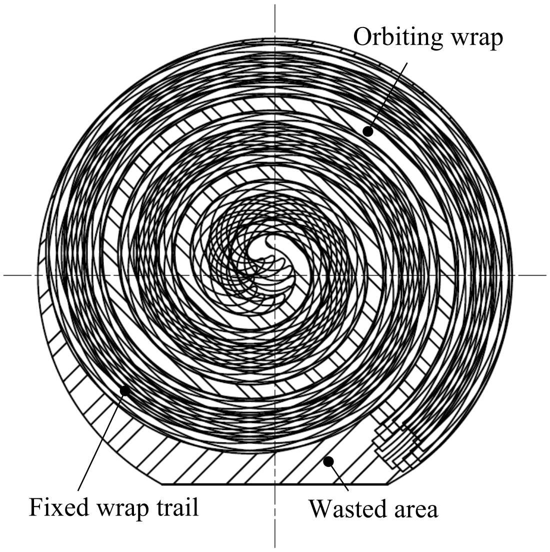


Figure 2.4: Trajectory of oval scroll

The geometric theory for the outward face of the oval scroll will be explained first. Formula (2.1) and formula (2.2) indicate the x-coordinate and y-coordinate of the conventional scroll, respectively. The conventional scroll is defined by the involute curve of a circle whose normal line is a plane curve always in contact with a constant base circle radius.

$$x = a\big(cos(\theta - \zeta) + \theta sin(\theta - \zeta)\big) \tag{2.1}$$

$$y = a\big(sin(\theta - \zeta) - \theta cos(\theta - \zeta)\big) \tag{2.2}$$

Formulas (2.3) and (2.4) indicate the x-coordinate and y-coordinate of the newly devised scroll, respectively. Here, "$a(\theta)$" is the base circle radius, and "θ" is the involute angle. Different from the conventional scroll, the base circle radius is given by a function of the involute angle "θ". Formula (2.5) indicates the base circle radius of the oval scroll, and Figure 2.5 shows changes in the base circle radius "$a(\theta)$" against the involute angle "θ". For forming an oval scroll, it is necessary to change the base circle radius "$a(\theta)$" sinusoidally against the involute angle "θ" in the cycle of "π rad". In this way, the scroll shape is made into an oval whose long diameter direction is the direction in which the base circle radius "$a(\theta)$" becomes the maximum.

$$x = a(\theta)\big(cos(\theta - \zeta) + \theta sin(\theta - \zeta)\big) \tag{2.3}$$

$$y = a(\theta)\big(sin(\theta - \zeta) - \theta cos(\theta - \zeta)\big) \tag{2.4}$$

$$a(\theta) = a_{min}(1 + \alpha \sin^2(\theta - \xi)) \tag{2.5}$$

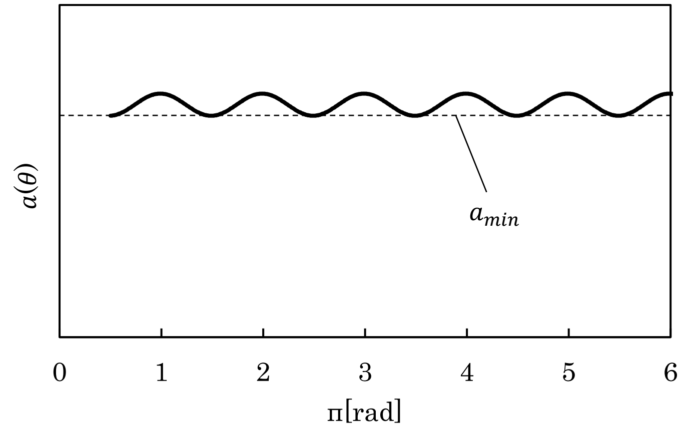
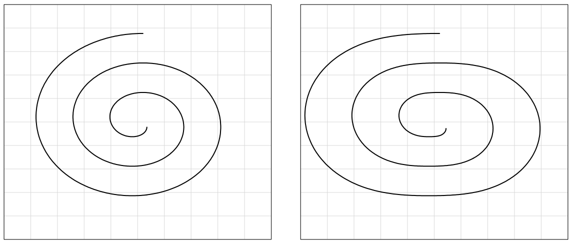


Figure 2.5: Base circle radius "$a(\theta)$" of oval scroll

Figure 2.6 shows an example of the curve of an oval scroll. The flatness "α" is 0.1 in (a), and 0.4 in (b). As the flatness "α" is larger, changes in the base circle radius "$a(\theta)$" in one cycle become larger, and the scroll becomes closer to oval.



(a) Flatness "α" = 0.1 (b) Flatness "α" = 0.4

Figure 2.6: Curve of oval scroll

The geometric theory for the inward face of the oval scroll will be explained next. Figure 2.7 shows the inward face drawing procedure. For forming the compression chamber without leakage, it is necessary that the outward face of the orbiting scroll is always in contact with the inward face of the fixed scroll at one point, and that the outward face of the fixed scroll is always in contact with the inward face of the orbiting scroll at one point while the orbiting scroll is performing oscillation movements. To meet this necessity, the inward face must be the outer envelope of a circle group whose center is located on a curve made by inverting the outward face by "π rad". When the fixed scroll and orbiting scroll have a same average wrap thickness for any π rad section, the inward face and outward face of the two scrolls have symmetrical shapes. The next section will describe prototypes of scrolls configured based on this theory.

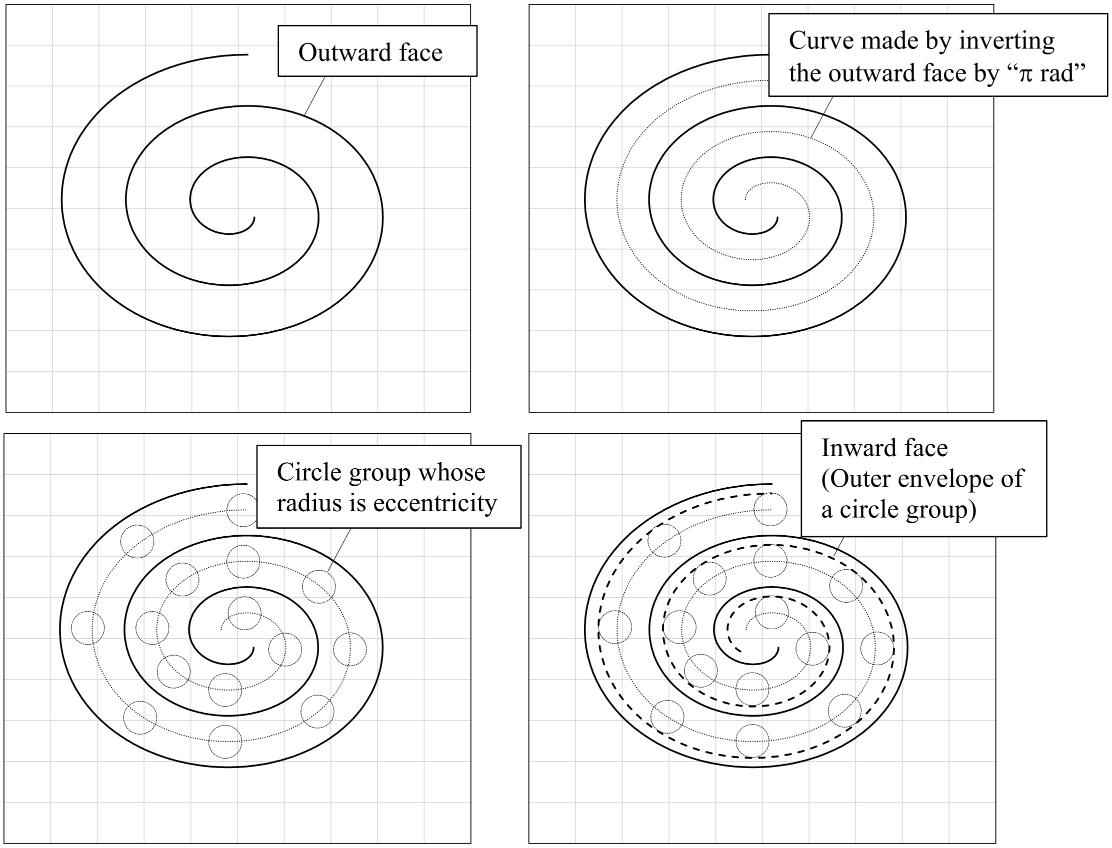


Figure 2.7: Oval scroll inward face drawing procedure

3. SPECIFICATION OF THE PROTOTYPE

3.1 Compressor Configuration

Figure 3.1 shows the entire configuration of the prototype we made, and Table 3.1 shows the basic specifications of the prototype. Used refrigerant is R290, and the stroke volume of the compressor is 36 cm^3. In the frame compliant method we adopted, the orbiting scroll floats together with the guide frame, and the compression chamber is sealed in the axial direction. We adopted a high-pressure shell whose inside is filled with high-pressure refrigerant after compression.

Refrigerant flows as follows: Low-pressure refrigerant is drawn from the suction tube into the compression mechanism. Refrigerant is compressed from low pressure to high pressure by the compression mechanism that consists of the fixed scroll and orbiting scroll, and discharged to the upper area of the compressor. After that, refrigerant flows out of the compressor from the discharge tube by way of the gap between the shell and the stator.

Table 3.1: Prototype basic specifications

Refrigerant	R290 (propane)
Stroke Volume	36 cm^3
Shell type	High pressure type

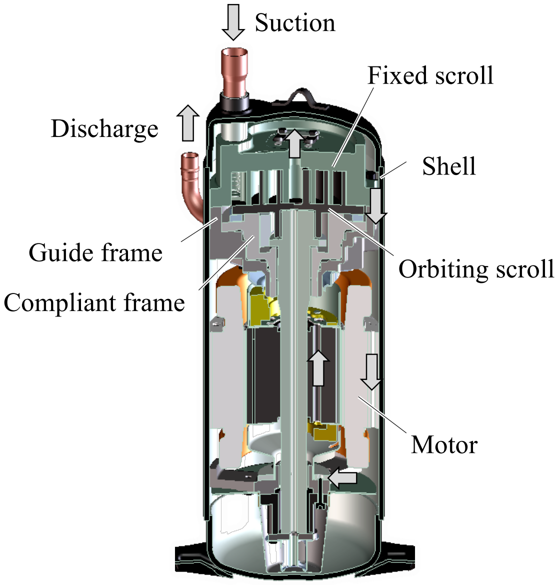
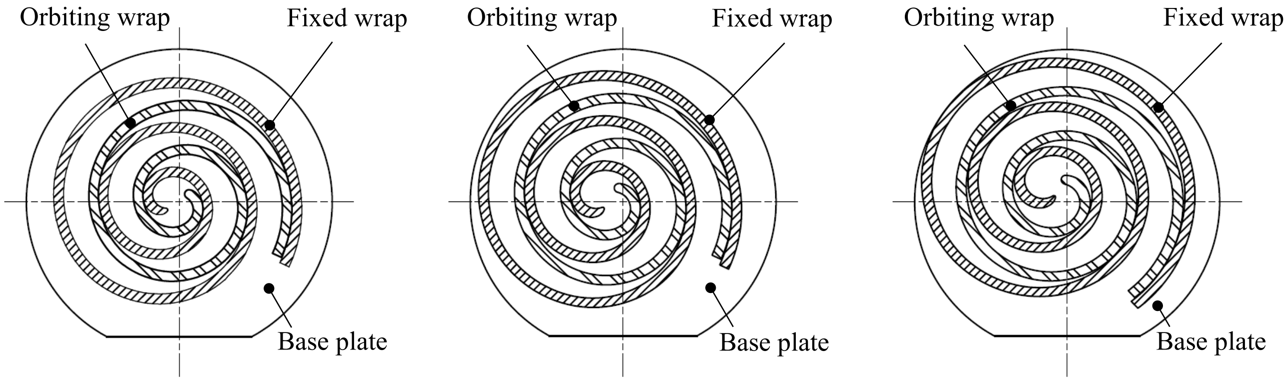


Figure 3.1: Prototype entire configuration

3.2 Scroll Shape

Figure 3.2 shows the shape of prototype scrolls, and Table 3.2 shows the specifications of prototype scrolls. It is held constant between the three prototype scrolls except for flatness, wrap height, and base circle center. (a) shows the base specifications of the conventional scroll, (b) shows an oval scroll whose flatness "α" is 0.025, and (c) shows an oval scroll whose flatness "α" is 0.050. When the wrap height is constant, the stroke volume is largest in (c). The oval scroll gives a stronger effect on expansion of the stroke volume when the base circle center is moved from the compressor center. In (b) and (c), the base circle center is moved by -2.868 mm in the x-axis direction, and by +2.233 mm in the y-axis direction. Figure 3.3 shows prototype oval scrolls whose flatness "α" is 0.050. (a) shows a fixed scroll, and (b) shows an orbiting scroll. Both the fixed scroll and orbiting scroll are made of FCD450, and machined by a general NC machine tool.

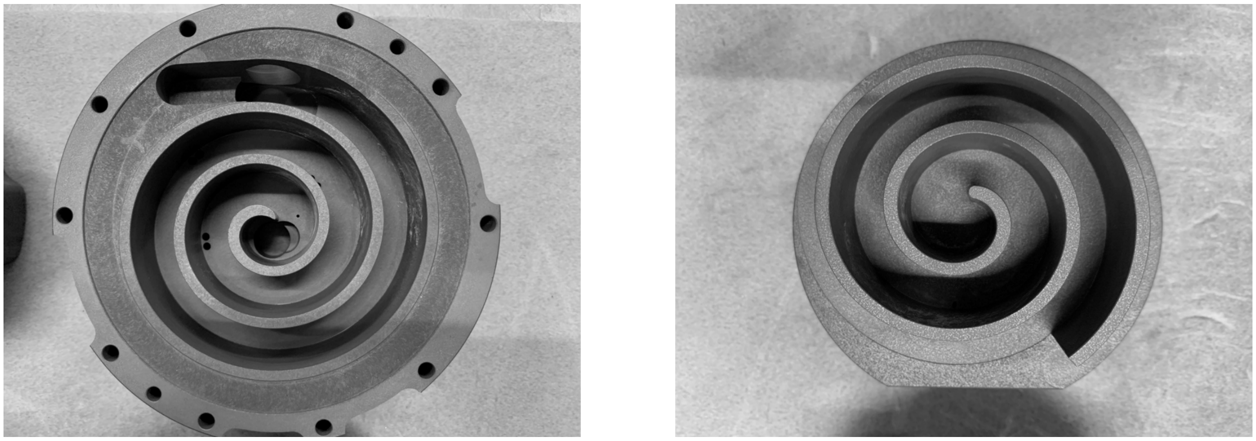


(a) Conventional scroll (b) Oval scroll ("α" = 0.025) (c) Oval scroll ("α" = 0.050)

Figure 3.2: Prototype scroll shapes

Table 3.2: Prototype scroll specifications

	(a) Conventional scroll	(b) Oval scroll	(c) Oval scroll
$\rho\ (-)$	2.30	2.30	2.30
$e\ (mm)$	4.15	4.15	4.15
$t_{ave}\ (mm)$	3.0	3.0	3.0
$h\ (mm)$	25.8	23.3	21.7
$\alpha\ (-)$	-	0.025	0.050
$(x_c,\ y_c)\ (mm)$	(0, 0)	(-2.868, 2.233)	(-2.268, 2.233)



(a) Fixed scroll

(b) Orbiting scroll

Figure 3.3: Prototype oval scrolls ("α" = 0.050)

Figure 3.4 shows the stroke volume ratio of oval scrolls. The ratio of the margin area against the base plate area is 26.0% in the conventional scroll, 17.8% in the oval scroll ("α" = 0.025), and 10.1% in the oval scroll ("α" = 0.050). By effectively utilizing the space on the base plate of the orbiting scroll, the stroke volume can be expanded by 12.0% in the oval scroll ("α" = 0.025) and by 20.0% in the oval scroll ("α" = 0.050) compared with the conventional scroll. This means that the stroke volume can be expanded while the wrap height is unchanged. However, to compare the performance together, the wrap height is designed lower in the prototypes because the scroll is extended in the horizontal direction.

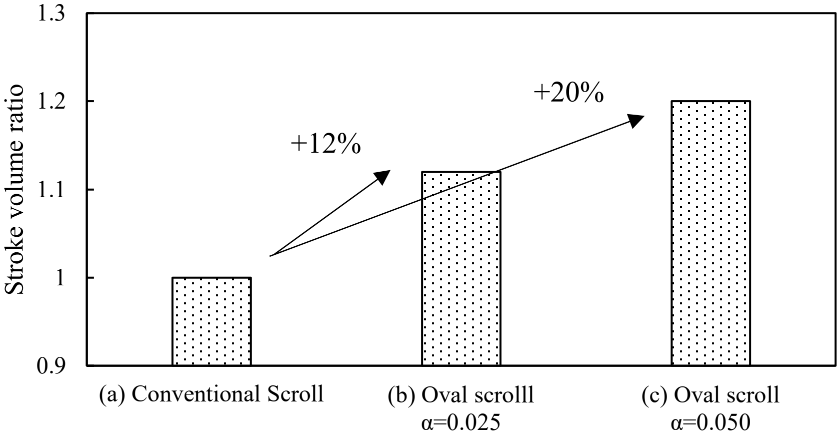


Figure 3.4: Stroke volume ratio of oval scrolls

4. TEST RESULTS

Table 4.1 shows the prototype operation condition, and Figure 4.1 shows the performance evaluation result of the prototype oval scrolls compared with the conventional scroll. Formula (2.6) indicated secondary COP.

The secondary COP (coefficient of performance) is improved by +0.6% in the oval scroll (“α” = 0.025) and by +1.7% in the oval scroll (“α” = 0.050) compared with the conventional scroll. It is estimated that the wrap height becomes lower because the oval scrolls are extended in the horizontal direction, leakage loss from the compression chamber is reduced, and then the performance is improved.

$$Secondary\ COP = \frac{W_{ref}}{W_{in}} \tag{2.6}$$

Figure 4.2 shows gas load theoretical values of the conventional scroll and the oval scroll (“α” = 0.050). It is calculated by ideal chamber pressure and geometric pressure-receiving area which change from time to time. It is assumed that gas refrigerant is mixed instantaneously when the innermost chamber is interconnected. Values calculated from REFPROP 9.1 are used for the refrigerant physical properties. Though the oval scroll is extended in the horizontal direction, conversely, the wrap height is reduced. Its gas load “$F_{g\theta}$” in the tangential direction and gas load “F_{gr}” in the radial direction are similar to those of the conventional scroll, and its sliding loss is similar to that of the conventional scroll.

Figure 4.3 shows the scrolls after operation for 50 hours. (a) shows the conventional scroll, and (b) shows the oval scroll (“α” = 0.050). It is proved that the oval scroll can operate stably without significant sliding marks in the same way as the conventional scroll.

Table 4.1: Operation condition

CT (℃)	54.4
ET (℃)	7.2
SH (K)	11.1
SC (K)	8.3
N (rps)	60

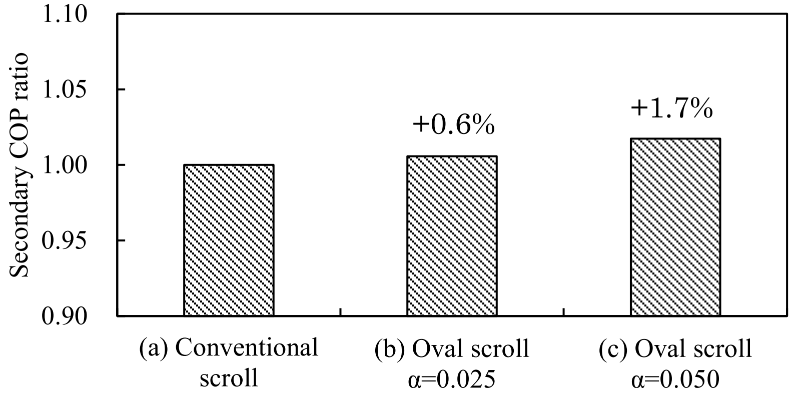


Figure 4.1: Performance evaluation result

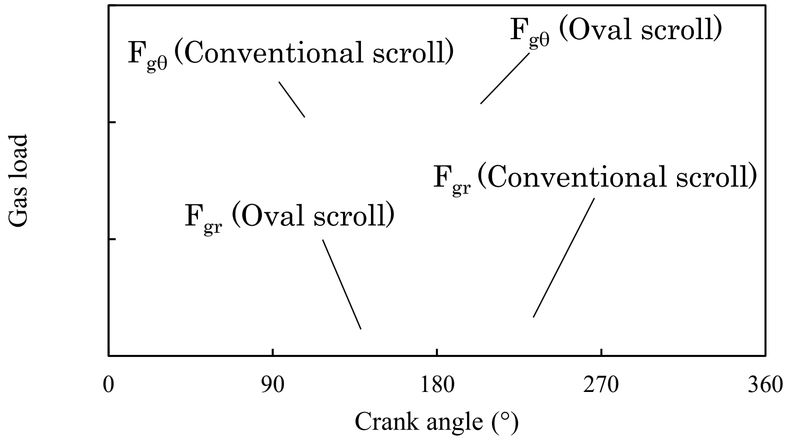
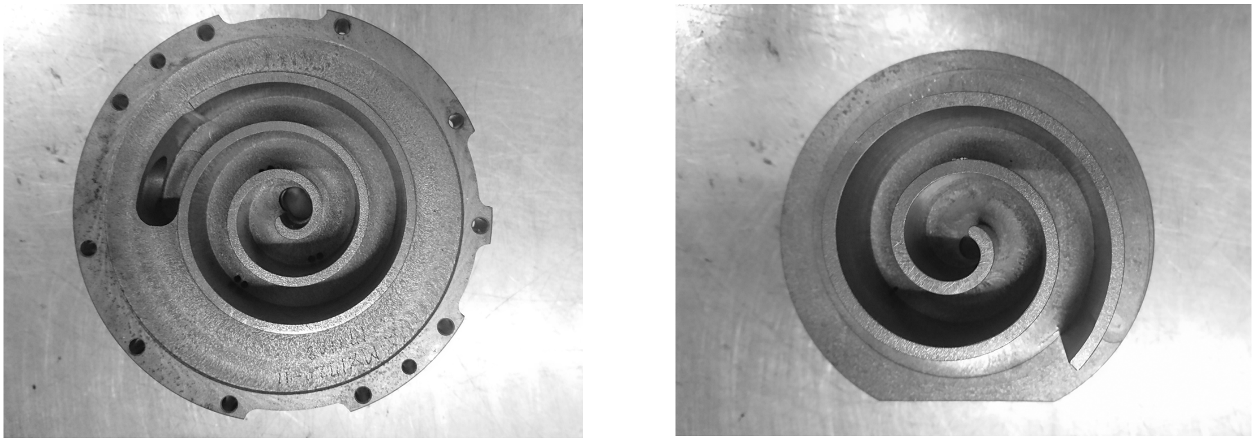
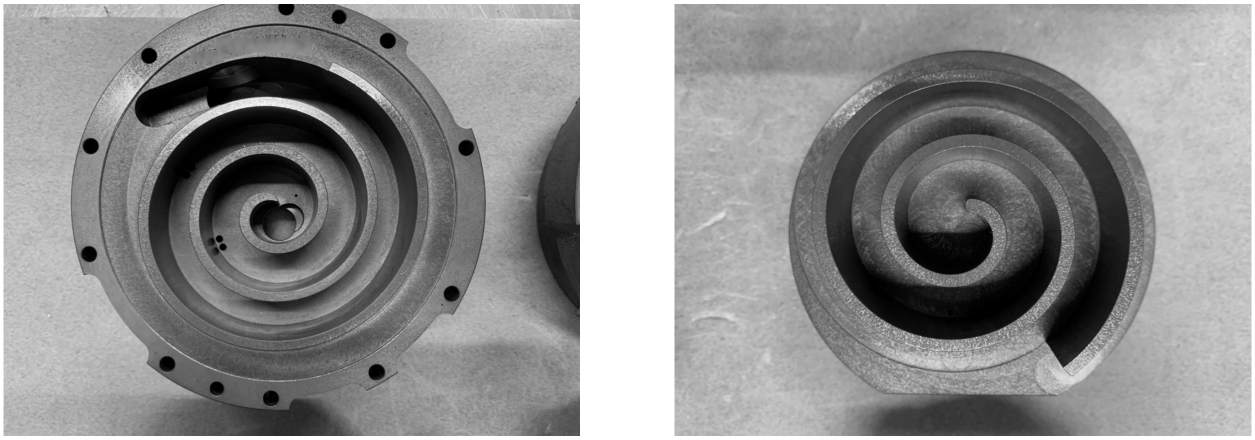


Figure 4.2: Gas load theoretical values



(a) Conventional scroll



(b) Oval scroll (α=0.050)

Figure 4.3: Scrolls after operation for 50 hours

5. CONCLUSIONS

In this paper, we have proposed an oval scroll compressor, introduced the geometric theory, and presented the performance evaluation result. We have obtained the following conclusions:

- Oval scrolls can be realized by making the base circle radius “$a(\theta)$” as a curve changing sinusoidally in the cycle of “π rad”.

- Oval scrolls can expand the stroke volume by +20% compared with the conventional scroll.

- When the stroke volume (performance) is constant, oval scrolls operate stably in the same way as the conventional scroll, the secondary COP is improved by +1.7% because the wrap height is lower, and the leakage loss is reduced.

NOMENCLATURE

x	x-coordinate	(mm)
y	y-coordinate	(mm)
a	base circle radius	(mm)

θ	involute angle	(rad)
ζ	set rotation angle	(rad)
$a(\theta)$	base circle radius (oval)	(mm)
α	flatness	(-)
ξ	angle of flat direction	(rad)
ρ	build-in volume ratio	(-)
e	eccentricity	(mm)
t	wrap width	(mm)
h	wrap height	(mm)
CT	condensing pressure	(℃)
ET	evaporating pressure	(℃)
SH	degree of superheating	(K)
SC	degree of subcooling	(K)
F_g	gas force	(N)
W	work	(W)

Subscript

ave	average
min	minimum
c	base circle radius center
θ	rotation direction
r	radial direction
ref	refrigeration
in	compressor input

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