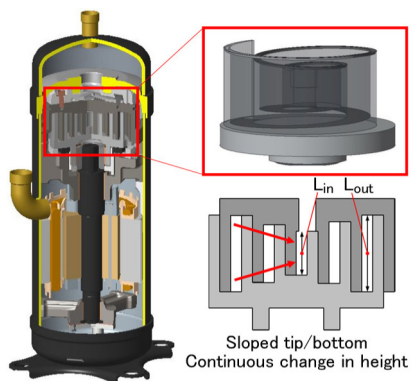


Development of Evolutionary Three-Dimensional Scroll Compressor Realizes Energy Saving in Air Conditioning and Refrigeration Equipment



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Mitsubishi Heavy Industries Thermal Systems Ltd. proposed a three-dimensional scroll (hereinafter referred to as 3D scroll* as a proprietary compression mechanism in 2004⁽¹⁾), and has been producing and selling air conditioning and refrigeration equipment featuring a 3D scroll compressor since 2007. The 3D scroll changes the height of the compression chamber during compression by providing steps at the wrap tip and bottom of the scroll to enable compression in the axial direction. For this reason, a compact and large-capacity compression mechanism can be configured in contrast to general two-dimensional (hereinafter referred to as 2D) scrolls. However, the leakage loss from the minute clearance in the step part, which is unique to a 3D scroll, was an issue for further improvement in efficiency. This time, as a solution to this issue, we have developed an evolutionary 3D scroll "e-3D scroll(Note)" compressor, which achieves a reduction in the leakage loss and improvement in efficiency, while maintaining the 3D scroll's advantages of small size and large capacity, for heat pump module chillers and VRF (Variable Refrigerant Flow) systems.

* "3D scroll" and "e-3D scroll" are our registered trademarks in Japan.

1. Introduction

From the perspective of environmental protection against global warming, energy saving in air conditioning and refrigeration equipment is being increasingly promoted. Most of the power consumption of air conditioning and refrigeration equipment is that of the refrigerant compressor, so an increase in the efficiency of the compressor is indispensable for energy saving in air conditioning and refrigeration equipment.

Scroll compressors have the advantages of high efficiency and low vibration, and have been widely adopted irrespective of application and equipment size because of the recent trend of energy conservation. To further increase efficiency and reduce the size and weight of scroll compressors, we have developed a 3D scroll compression mechanism that adds compression in the height direction to the compression principle of conventional scrolls, and have been expanding its use to various products. By adopting a 3D scroll, smaller size and larger capacity of the compressor and an increase in the compression ratio were successfully achieved. However, leakage loss from the steps installed for compression in the height direction occurred, and reducing this loss was an issue for further improvement in efficiency.

To solve the aforementioned issue, we developed an evolutionary 3D scroll compression mechanism called "e-3D scroll." This paper presents the structure and compression principle of e-3D scroll, and the development of a large-capacity scroll compressor equipped with it.

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2. Structure and features of scroll

Figure 1 shows cross-sectional diagrams of the conventional 2D scroll, 3D scroll, and e-3D scroll developed this time. The 2D scroll provides only two-dimensional compression by mesh the spiral shapes together to move the gas sucked from the outer circumference toward the inner while reducing the volume. On the other hand, the 3D scroll is characterized by adding a compression function in the height direction by changing the scroll height in steps. In the case of 3D scroll, the wrap height (L_{in}) at the inner part, which bears high pressure, is lower than the wrap height (L_{out}) at the outer circumference, so the scroll wrap strength is improved compared to 2D scrolls. In addition to this benefit, an increase in the displacement is also possible. However, since the wrap height changes in steps, it is difficult to install a tip seal that prevents leakage at the wrap tip, and leakage from this part and from the mesh clearance of the steps occurs. **Figure 2** presents a schematic diagram of the leakage clearance. **Figure 3** is a photograph of the leakage clearance of a step taken with a high-speed camera.

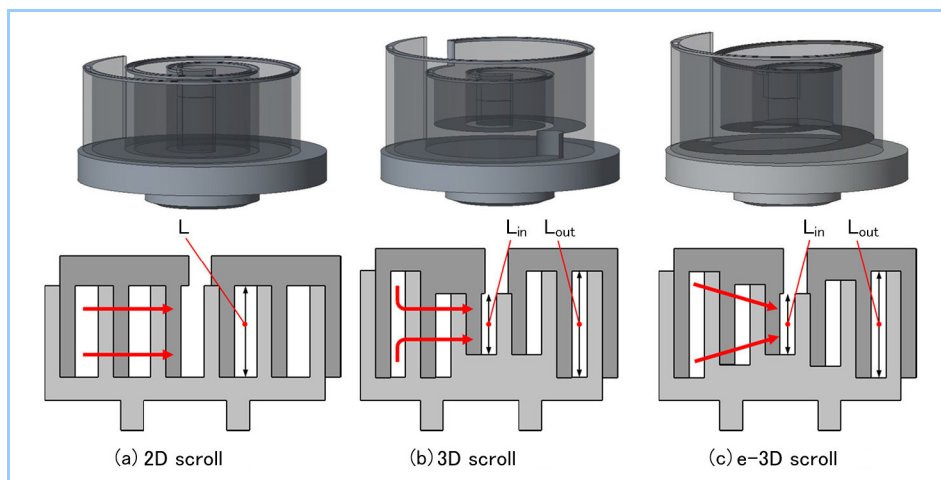


Figure 1 Cross-sectional diagrams of scroll structure

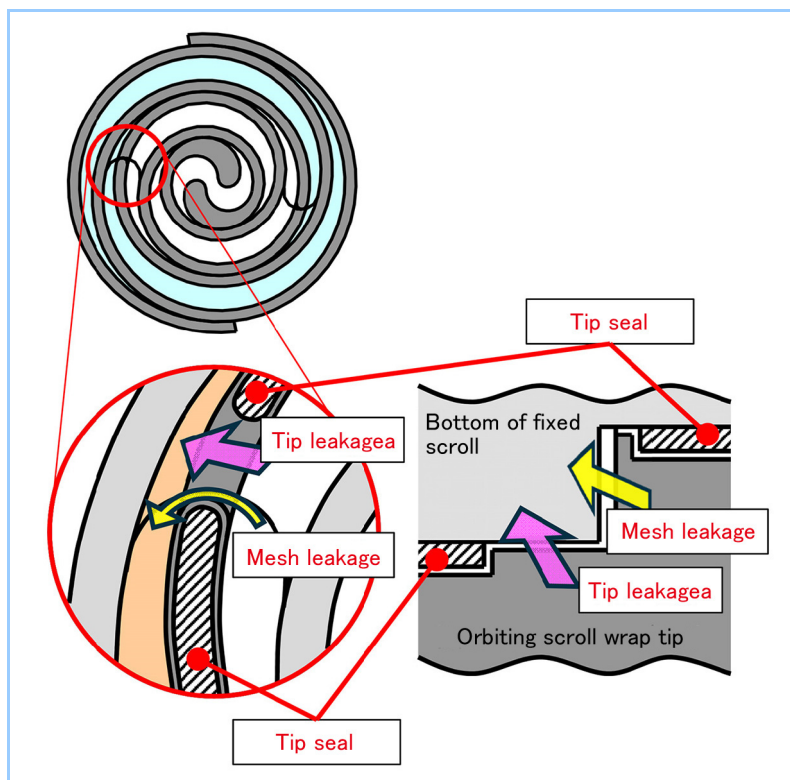


Figure 2 Schematic diagram of leakage clearance at step

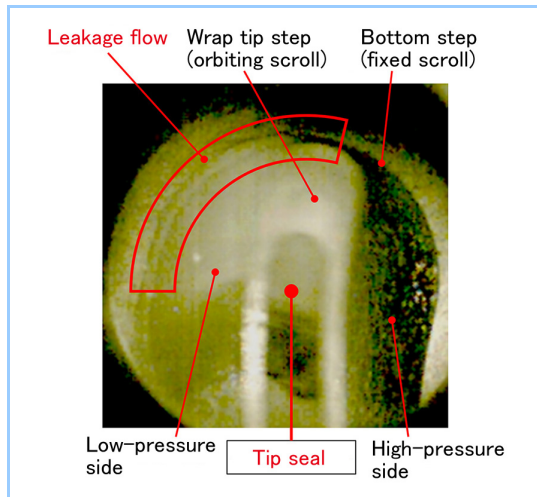


Figure 3 Visualization photograph of flow through leakage clearance at step⁽¹⁾

Until then, the leakage at the steps had been suppressed by optimizing the size of the clearance and the oil circulation rate in the compression chamber, but we determined that drastic improvement of the axial compression mechanism would be necessary for further improvement in efficiency, and started to develop a new scroll shape.

Against the above background, we created the e-3D scroll compression mechanism that solves the aforementioned issues while maintaining the advantages of conventional 3D scrolls. Figure 1 (c) gives a cross-sectional diagram of e-3D scroll, and **Figure 4** depicts a development view of the spiral. e-3D scroll is characterized by the wrap height that continuously decreases from the outer circumference to the inner circumference, while the wrap height of the 3D scroll changes in steps. One of a pair of scrolls has the same slope angle at the tip of the scroll wrap as the slope angle in the corresponding position at the bottom of the other. To make it easier to set the clearance between the fixed scroll and the orbiting scroll when assembling the compressor, the wrap tip and bottom shapes at the outermost circumference and the centermost are left flat.

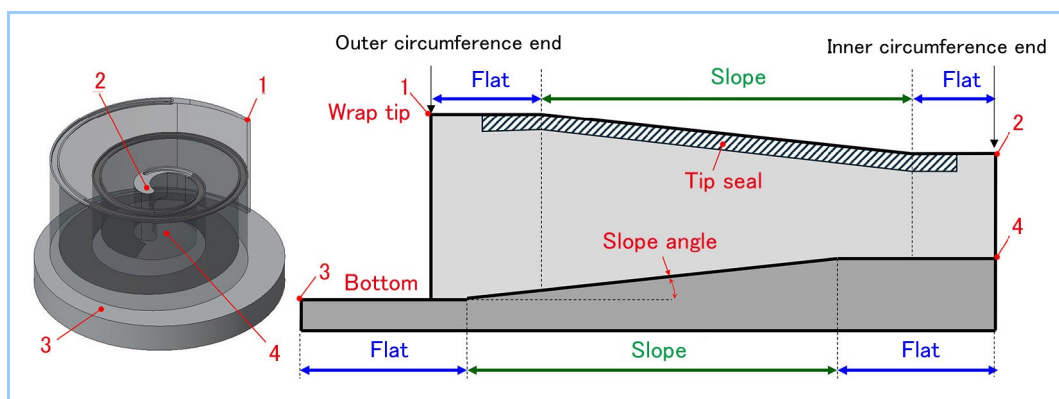


Figure 4 e-3D scroll wrap shape

Figure 5 shows a schematic diagram of the tip clearance change of 2D and 3D scrolls and e-3D scroll with respect to the orbiting movement. In the case of 2D and 3D scrolls, the movement direction of the orbiting scroll is in parallel with the wrap tip and bottom of the scroll, so the tip clearance is constant with respect to the movement of the orbiting scroll. In the case of e-3D scroll, on the other hand, since the wrap tip and the bottom are sloped, the tip clearance periodically changes with respect to the orbiting movement. The maximum value of the tip clearance per cycle is determined by the slope angle. The minimum value of the tip clearance needs to be set so that both scrolls do not make contact with each other under all operating conditions.

The tip clearance of e-3D scroll changes periodically, but the tip seal maintains contact with the mating surface following the change in the clearance, thereby preventing leakage from the tip clearance. In addition, since the tip seal is installed in a continuous manner from the outermost circumference of both scrolls toward the center, leakage at steps where the tip seal is not continuous as shown in Figure 2, which exist in the case of 3D scrolls, does not occur.

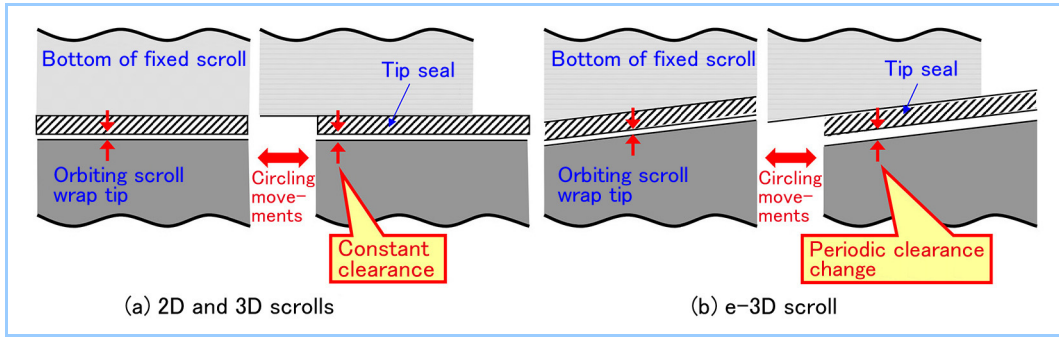


Figure 5 Schematic diagram of scroll tip clearance change

3. Effect of slope angle on efficiency

As described above, in the slope area of e-3D scroll, the tip clearance periodically changes with respect to the orbiting movement of the orbiting scroll. There are two effects involved: the effect of the change of the maximum tip clearance value per orbit depending on the slope angle, and the effect of the change of the length of the flat part depending on the slope angle. Therefore, it is expected that the amount of internal leakage changes depending on the slope angle.

To clarify the effect of the slope angle on efficiency, the degree of the effect on efficiency was confirmed using three sets of scrolls (scrolls A to C) with the slope angle depicted in Figure 6 as a parameter. Scroll A was set to have the smallest slope angle. Scroll B and scroll C were set to have slope angles larger than that of scroll A by 30% and 90%, respectively, by increasing the flat part at the outermost circumference. On the other hand, the three sets of scrolls have the same horizontal cross-sectional shape, outer circumference wrap height and slope height, so their design volume ratios and displacements are almost the same.

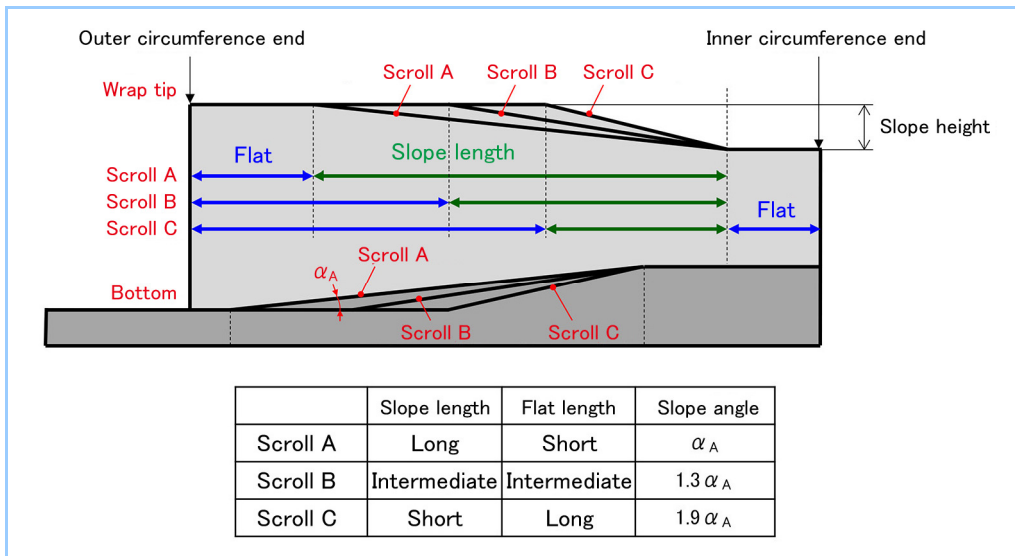


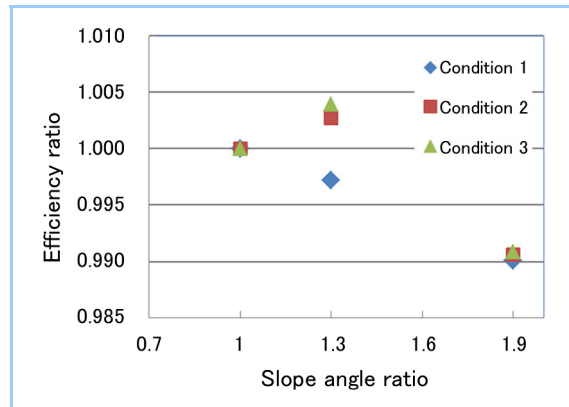
Figure 6 Slope angle of e-3D scroll

The results of performance measurement under the three conditions presented in Table 1 are given in Figure 7. The vertical axis represents the efficiency ratio made dimensionless with reference to scroll A (slope angle = 1). Conditions 1 to 3 correspond to the rated load, 50% load and 25% load, respectively. Conditions 2 and 3 have the maximum values in terms of efficiency with respect to the slope angle change. This is thought to be because during low-speed operation where the effect of the leakage amount is significant, as the slope angle increases, the leakage clearance of the slope area increases, while the slope area in which the leakage clearance increases decreases. Based on the above, the newly developed e-3D scroll compressor adopts scroll B.

Table 1 Performance measurement conditions

	CT/ET [°C]	Rotation speed [rps]
Condition 1	46/13	95
Condition 2	44/20	37
Condition 3	33/19	23

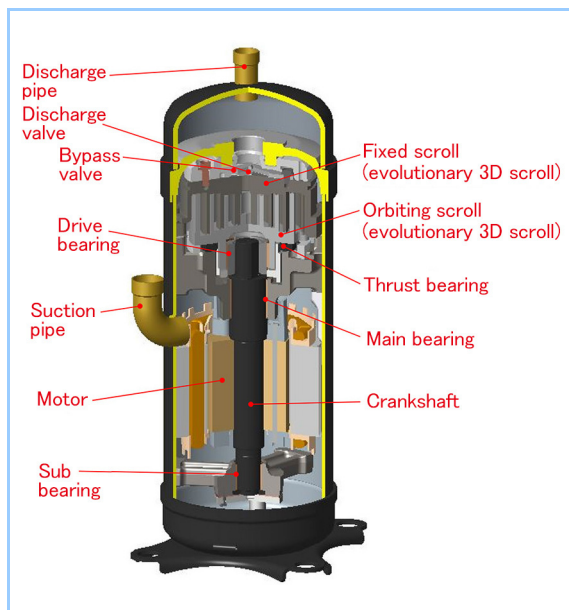
CT: Condenser outlet temperature
ET: Evaporator outlet temperature

**Figure 7 Relationship between scroll angle and efficiency**

4. Development of high-efficiency e-3D scroll compressor

4.1 Outline of developed compressor

We developed a high-efficiency scroll compressor with e-3D scroll that can be applied to heat pump module chillers and VRF systems. **Figure 8** illustrates a cross-sectional view of the developed compressor and **Table 2** lists its basic specifications. The developed e-3D scroll compressor has the same scroll spiral cross-section, outer circumference wrap height, displacement and design volume ratio as those of conventional 3D scrolls. Components other than the scroll, such as the motor and housing, as well as the refrigerant flow path in the compressor, are also the same as their conventional counterparts. Therefore, e-3D scroll can be used in current models simply by replacing the fixed and orbiting scrolls, so it is possible to improve efficiency without a significant capital investment.

**Figure 8 Cross-sectional view of developed compressor****Table 2 Specifications of developed compressor**

Application	Heat pump module chillers, VRF systems
Refrigerant/Refrigerator oil	R410A/POE
Displacement	120cm ³ /rev
Scroll shape	Evolutionary 3D scroll
Motor	Concentrated winding brushless DC motor
Outer diameter/Height	183mm/523mm

4.2 Efficiency improvement

Figure 9 shows a comparison of efficiency between the conventional 3D scroll and e-3D scroll under the operating conditions shown in Table 1. There was no difference between them under condition 1 (rated load condition), but e-3D scroll achieved significant increases in efficiency of +3.2% and +4.8% under condition 2 (50% load condition) and condition 3 (25% load condition), respectively. It is thought that under conditions 2 and 3, which were low-speed operation, the effect of the decrease in efficiency caused by leakage was prominent, so the adoption of e-3D scroll reduced the leakage loss and led to an improvement in efficiency. The contribution ratios of these conditions to annual energy efficiency measurements such as IPLV (Integrated Part Load Value)

and APF (Annual Performance Factor) are significant, so major energy savings can be expected for air conditioning and refrigeration equipment such as heat pump module chillers and VRF systems.

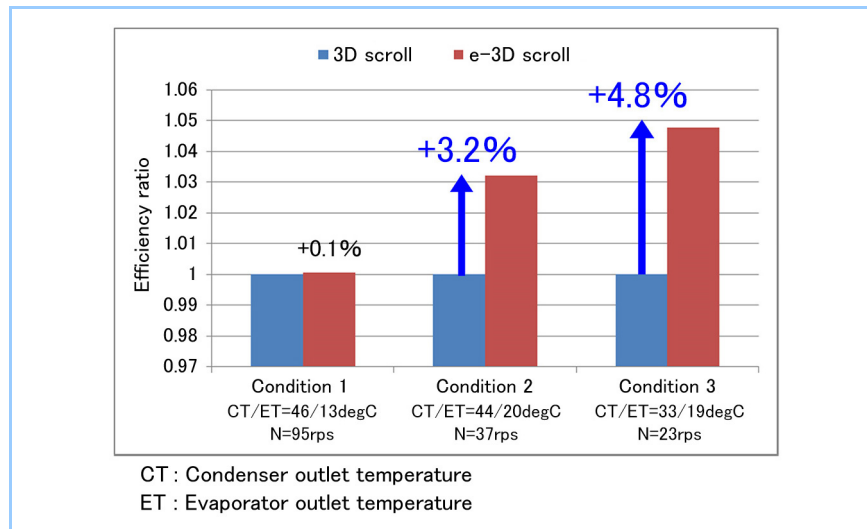


Figure 9 Efficiency comparison between 3D scroll and e-3D scroll

5. Conclusion

e-3D scroll achieves high efficiency while also offering the conventional 3D scroll's advantages of small size and large capacity, high pressure ratio, and high strength. It can be used in compressors for all types of air conditioning and refrigeration equipment. Examples include heat pump module chillers that require large capacities and high efficiency during low-speed operation and commercial air conditioners such as VRF systems, as well as refrigeration systems operated with a high pressure ratio and automotive air conditioners that must be small and lightweight.

We plan to gradually adopt e-3D scrolls for compressors for various types of air conditioning and refrigeration equipment in the future. We will contribute to energy conservation and global environmental protection by improving compressor performance.

References

- (1) H Sato, et.al. ,Efficiency improvement technology for 3D scroll compressor, *Proc. of 2005 JSRAE Annual Conf.*, C310