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Development of High Efficiency Rotary Compressor by Adopting a New Manufacturing Method.

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ABSTRACT
Reduction of leakage loss by reducing the height of the cylinder is an effective method to improve efficiency in a rotary compressor. There are, however, few challenges we must face by doing so. Below are some problems for reducing the height of the cylinder.

1) In order to keep the same stroke volume, the diameter of the rolling piston needs to be reduced. This change will create a space between M. plate and the compression chamber.
2) Due to the reduction of the area of suction mass flow passage, compression loss at suction side will increase.

In order to solve this problem, we have developed a new structure of suction mass flow passage and a new assembly method. We were able to achieve higher efficiency by reducing the height of the cylinder by 20%.

1. INTRODUCTION
Reducing leakage loss by reducing the cylinder height is one effective method to improve efficiency in a rotary compressor. Reducing the Cylinder height is not only effective for high efficiency but also reduces the amount of raw material used for the cylinder. We have developed CASIMEL method which reduces the deformation of the shell during fixing process of the cylinder and reduced the cylinder height. [1]

Furthermore to reduce the cylinder height, some issues existed on the assembly method of compression mechanical part and the suction structure because of the restriction of dimension. We have developed a new method to overcome this issues.

This paper introduces this new method and the use affect of the new technologies.

2. Issues of High Efficiency Compressor
2-1. Compressor Loss & Efficiency
Figure 1 shows the cross-section view of twin-rotary compressor installed in the room air conditioner. Mechanical section and motor is fixed inside a sealed shell. Refrigerant gas flows through the suction muffler. The gas gets compressed at the compression mechanical section and flows out of the shell. The Compressor is a high pressure shell type.

Figure 2 shows the compressing process of rotary compressor.
The rolling piston will rotate eccentrically inside the cylinder. The vane reciprocates in the vane slot of the cylinder. The vane will separate the chamber into suction chamber and compression chamber. The rolling piston will compress the refrigerant gas which flows into the suction chamber, out to the discharge side.
Table 1 shows the compressor loss of a rotary compressor. The efficiency of a compressor can be classified in three different items: motor efficiency, mechanical efficiency, and indicated efficiency.

Table 1 Classification of Loss Factor

<table>
<thead>
<tr>
<th>Consumption power</th>
<th>Motor loss</th>
<th>Mechanical loss</th>
<th>Indicated work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor output</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Journal loss
Thrust loss
Vane tip
Vane side

Heat loss
Over/Undershooting loss
Leak loss
Reexpansion loss

Figure 3 shows the leakage passage of the compression chamber. The leakage loss can be classified in 4 categories: vane side, vane top, piston side and piston top. Leakage mass flow is proportional to each cross section area of flow passage, compression condition, density and flow rate coefficient. It is efficient to reduce the size of the cross section area to reduce the leakage mass flow. Considering that the cross section area of the leakage flow passage is proportional to the height of the cylinder (Figure 3), reducing the height of the cylinder $h$ is also efficient to reduce the leakage mass flow.
2-2. Issue with reducing the cylinder height (at Assembly Process)

Figure 4 is the cross section view of a twin rotary compressor. The conventional twin rotary compressors are assembled by penetrating the crank shaft through the bearings, cylinders, M plate and rolling pistons. The M plate between the 2 cylinders is also assembled in the same process.

As mentioned in equation (1), (2), we must increase the eccentricity and reduce the outer diameter of the rolling piston in order to keep the same Stroke volume while reducing the height of the cylinder.

\[
V_{st} = \frac{\pi}{4} \left( D^2 - d^2 \right) h \quad (1)
\]

\[
e = \frac{(D - d)}{2} \quad (2)
\]

\(V_{st}\) is Stroke Volume, \(D\) is cylinder inner diameter, \(d\) is rolling piston outer diameter, \(h\) is cylinder height, \(e\) is eccentricity.

Figure 5-a is the axial view of a conventional twin rotary compressor and Figure5-b is the axial view of a larger eccentricity model. Figure 6 shows the issue of conventional manufacturing process.

As shown in the Figure 5-b, in the model with larger eccentricity, the outer diameter of the rolling piston is communicated with the inner diameter of the M. plate. Therefore, the compression room cannot be formed. Hence, if we try to reduce the inner diameter of the M plate, the crank shaft will cannot be penetrated through.

![Fig. 4. Cross section of Twin Rotary Compressor](image)

![Fig. 5. Axial view of Compression chamber](image)

![Fig. 6. Issue of conventional process](image)
2-2. Issue with reducing the cylinder height (Lack of Suction Passage Area)

As indicated in Figure 7, Refrigerant gas flows into the compression room via the suction passage in the side surface of the cylinder. The friction between the wall of suction passage and refrigerant gas fluid generates suction pressure loss. Suppose that the suction gas flow is the laminar flow in the smooth surface pipe, the pressure loss can be defined in below formula based on the Darcy-Weisbach equation (3).

\[ P_1 - P_2 = \rho \cdot \lambda \cdot \frac{l}{d_h} \cdot \frac{v^2}{2} \]  

\((P_1 - P_2)\) is pressure loss generated from the friction between the length of the pipe \((l)\), \(\rho\) is fluid density, \(\lambda\) is friction factor, \(v\) is average flow rate of the fluid, \(d_h\) is hydraulic diameter

In general, the suction passage is formed in a circular form, and if the cylinder height is reduced, the diameter of the passage will also be reduced. If the flow passage area is insufficient compared to the stroke volume, suction pressure loss will reduce the efficiency of the compressor.

3. New Manufacturing Method

3-1. New Assembly Method (Scrum M. Plate)

As mentioned in chapter 2-2, when we enlarge the eccentricity of rolling piston to reduce the cylinder height, we need to reduce the inner diameter of the M. plate. However, a problem existed in the assembly process. We have developed a segmented M. plate, which can be attached together instead of penetrating the crank shaft through the M. plate. Because we do not have to penetrate the crank shaft through the M. plate, we were able to reduce the inner diameter of the M. plate.

Figure 8 shows the new assembly process. The two cylinders and other parts are assembled in the same way as the conventional method. The M. plate, however, is assembled by snapping the crank shaft with the segmented M. plate from the side and assembled together. The refrigerant gas will leak if there is a gap between the assembled surfaces. Therefore, highly accurate assembly technique and finishing technique is required.
Figure 9 shows the dimension of the mechanical parts for new assembly method. The eccentricity improved by 28% and the cylinder height was reduced by 20% compared to the conventional model by adopting the new assembly method.

3-2. New Suction Structure (Flattened Suction Pipe)

We have developed a new structure of the suction pipe between the compressor and the suction muffler. Figure 10 shows the shape of the new suction pipe. By flattening the pipe from the suction muffler to the compressor shell to an oval form, we were able to acquire sufficient mass flow area and hold down the efficiency loss. So, we were able to fit the pipe into the new cylinder height without affecting the efficiency.

Table 2 shows the comparison of suction mass flow passage between conventional model and new model. Although, we were able to reduce the cylinder height by 20% as mentioned in chapter 3-1, if we implement the same round shape suction pipe, the efficiency will decrease by 56% due to the smaller mass flow passage area. The new suction pipe structure realized to acquire sufficient efficiency while reducing the cylinder height.
Table 2. Comparison of suction area

<table>
<thead>
<tr>
<th>Cylinder Height [mm]</th>
<th>Conventional model</th>
<th>New model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13.6</td>
<td>10.8</td>
</tr>
<tr>
<td>Suction shape</td>
<td>(φ7.8)</td>
<td>(φ5)</td>
</tr>
<tr>
<td>Suction Area [mm²]</td>
<td>47.8</td>
<td>19.6</td>
</tr>
</tbody>
</table>

4. Efficiency of New Model

Figure 12 compares the cross section view of the conventional and the new model. By adopting the new assembly method, the cylinder height is reduced by 20% compared to the conventional model.

Fig. 11 Comparison of Suction pressure loss

Fig. 12 Cross section of Compressor
Figure 13 explains the breakdown of the total loss of both conventional model and new model. The leakage flow passage has been reduced due to the reduction of cylinder height, which resulted in improving the overall leakage loss. The leakage loss at vane top increased due to the increase of eccentricity. However, the total loss has decreased. Mechanical loss has also been reduced by reducing both the load at the piston and the friction width of the piston. We were able to improve COP by 3% at ASHRAE condition implementing above dimension. At APF condition, which is closer condition to the actual usage of air-conditioner in Japan, we were able to realize 2% improvement in COP.

![loss comparison chart](image)

**Fig. 13 Comparison of compressor loss (ASHRAE 60rps)**

### 5. Conclusion

1) By developing the innovative assembly method (We named “Scrum M. Plate”), we were able to realize the reduction of cylinder height by 20% compared to the conventional model with the same stroke volume.
2) The flat suction structure adapted well with the reduction of cylinder height enabling to the compressor to keep the same suction efficiency with lower cylinder height.
3) By adopting above two innovative methods we were able to reduce 20% of cylinder height and 9% of leakage loss. Adding with other reduction of leakage loss, we were able to improve the overall compressor efficiency by 3%.

### 6. References