Development Of Scroll Compressor With New Compliant Mechanism

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ABSTRACT

Increased demand of energy saving, more high efficiency compressor is required. For high-efficiency of scroll compressor, we must minimize leak-loss on the tip and thrust mechanical loss of the Orbiting-Scroll’s thrust face.

New-type scroll compressor has new parts “Compliant-Frame” that is compliant axially, in the back of the Orbiting-Scroll, and has two independent middle-pressure chambers located in the upper side and the lower side of Compliant-Frame. By optimizing the lower side chamber, Orbiting-Scroll contacts Fixed-Scroll softly and we could minimize leak-loss on the tip. By optimizing the upper side chamber, thrust load on Orbiting-Scroll is decreased and we could minimize thrust mechanical loss of the Orbiting-Scroll’s thrust face.

As a result, this new-type scroll compressor gained around 14% improvement in COP.

1. INTRODUCTION

Rolling-piston rotary compressor and scroll compressor are used for air-conditioners. Especially for package air conditioners, 3HP UNIT or more, scroll compressor is mainly used because of high efficiency, low noise and vibration. It is broadly known that leak loss and thrust mechanical loss are main in consumption power of scroll compressor.

Various compliant mechanisms (Fixed-Scroll compliant and Orbiting-Scroll compliant etc.) are used for minimizing these losses.

Anyway compliant mechanism that is able to minimize both losses has not developed as far as we know.

With the new compliant parts “Compliant-Frame”, and two independent chambers concept, both losses could be minimized effectively. Finally, the new type scroll compressor for R407C, R410A had been developed to be the practical used compressor.

This paper refers to the new technologies able to minimize both losses and the
efficiency improvement result compared with the conventional type in R407C application.

2. CHARACTERISTICS OF THE DEVELOPED COMPRESSOR

The cross section of the new-type scroll compressor is shown in the Fig.1. Mechanical parts are contained in the high-side shell. Also the new mechanical part, "Compliant-Frame" is contained. The motor output of this model is 3.2kw. The cooling capacity is 45000BTU/Hr (60Hz, ARI condition, REF. R407C)

![Fig.1 Cross section](image)

3. NEW COMPLIANT MECHANISM

The main parts of the new-type scroll compressor are shown in the Fig.2. The axially movable frame (Compliant-Frame) is contained in the fixed frame (Guide-Frame). There are 2 chambers inside the mechanical parts. One is the space between Compliant-Frame and Guide-Frame, called “The Compliant-Frame Back Pressure Chamber”. The other one is the space between Orbiting-Scroll and Compliant-Frame, called “The Orbiting-Scroll Back Pressure Chamber”. The pressure in these two chambers is separately controlled in order to minimize the leak and thrust mechanical losses.

![Fig.2 Mechanical parts](image)
3.1 Balance Of Axial Force

The movable parts of the new-type scroll compressor, Orbiting-Scroll and Compliant-Frame, are shown in the Fig.3. Also, the relation of active force of the movable parts is expressed.

The force acting on the Orbiting-Scroll:
\[ F_{orbpd} + F_{orbpm} + F_{th} - F_{gth} - F_{tip} = 0 \]  \hspace{1cm} (1)

The force acting on the Compliant-Frame:
\[ F_{frpd} + F_{frpm} - F_{orbpm} - F_{th} = 0 \]  \hspace{1cm} (2)

Where as, \( F_{gth} \) is an axial gas force, \( F_{frpd} \) is Compliant-Frame Discharge Pressure Force, \( F_{frpm} \) is Compliant-Frame Back Pressure Force, \( F_{orbpd} \) is Orbiting-Scroll Discharge Pressure Force, \( F_{orbpm} \) is Orbiting-Scroll Back Pressure Force, \( F_{th} \) is a Resultant Thrust Force, \( F_{tip} \) is a Resultant Tip Force.

Therefore,
\[ F_{tip} = F_{frpd} + F_{frpm} + F_{orbpd} - F_{gth} \]  \hspace{1cm} (3)
\[ F_{th} = F_{tip} + F_{gth} - F_{orbpd} - F_{orbpm} \]  \hspace{1cm} (4)

The force (\( F_{frpm} \)) from the Compliant-Frame Back Pressure Chamber is related on \( F_{tip} \). The leak loss across the scroll’s tip could be minimized by adjusting \( F_{frpm} \).

The force (\( F_{orbpm} \)) from the Orbiting-Scroll Back Pressure Chamber is, also, called “the thrust cancellation force”. The thrust mechanical loss could be minimized by adjusting \( F_{orbpm} \).
3.2 Control Of Compliant-Frame Back Pressure Chamber

The force caused by the back pressure of Compliant-Frame is considered as the force which lifts the Compliant-Frame and Orbiting-Scroll up. When the movable parts are lifted, until the Orbiting-Scroll and the Fixed-Scroll are contacted each other, tip clearance will become “0”. By this method, leak loss will be minimized.

3.2.1 Lifting Force

The lifting force is the force generated from the Compliant-Frame Back Pressure Chamber. If the lifting force is increased, $F_{\text{tip}}$ will be increased. On the contrarily, if the lifting force is decreased, Compliant-Frame and Orbiting-Scroll are possibly inclined. The inclination of the Orbiting-Scroll will cause the leakage across the scroll’s tooth. In addition, when the lifting force is decreased much, $F_{\text{tip}}$ from Equa.(3) might be minus value. It means that Compliant-Frame and Orbiting-Scroll cannot be lifted. Therefore, the lower limit of the lifting force must be realized.

3.2.2 Lifting Force and Performance

In the Fig.4, the relationship between the lifting force and efficiency is shown. When the lifting force is increased, the increasing of the tip loss will cause the reduction of efficiency. In order to obtain the high level of efficiency, the lifting force must be optimized.

![Fig.4 Relationship between the lifting force and efficiency](image)

3.3 Control Of Orbiting-Scroll Back Pressure Chamber

The force caused by the back pressure of Orbiting-Scroll is considered as the thrust cancellation force. This force makes the thrust load of Orbiting-Scroll reduced in order to
minimize the thrust mechanical loss.

3.3.1 Thrust Cancellation Force

The thrust cancellation force is the force generated from the Orbiting-Scroll Back Pressure Chamber. Anyway, if the thrust cancellation force is increased until the $F_{th}$ from Equa.(4) becomes minus, the Orbiting-Scroll will be separated from the Compliant-Frame. In order to prevent the instability caused from the floating of Orbiting-Scroll, the upper limit of the thrust cancellation force must be realized.

3.3.2 Thrust Cancellation Force and Performance

In the Fig.5, the relationship between the thrust cancellation force and efficiency is expressed. When the thrust cancellation force is increased, decreasing of the thrust mechanical loss of the Orbiting-Scroll’s thrust face make the compressor possess higher efficiency. Anyway, if the thrust cancellation force ratio over 100%, the Orbiting-Scroll is possibly separated from the Compliant-Frame. Therefore, the optimum selection of the thrust cancellation force is required to make the Orbiting-Scroll not separate from the Compliant-Frame in any conditions.

4. IMPROVED EFFICIENCY

4.1 Performance Comparison Between The Conventional And The New-Type Compressor

4.1.1 Standard-Type

In the Fig.6, the performance comparison between the conventional and the new-type scroll is expressed. At the ARI condition [electrical supply: 3φ200V, 60Hz and REF: R407C], the efficiency of the new-type scroll is improved 14% when comparing with the
conventional type.

4.1.2 Inverter-Type

In the Fig.7, the performance comparison of the inverter-type between the conventional and the new-type scroll is expressed. At the ARI condition [REF: R407C], the new scroll performs the superior efficiency, especially under the low frequency. According to the Fig.7, the efficiency while running at 30Hz supplied frequency is improved 27% when comparing with the conventional type.

![COP ratio of Inverter-type scroll comparison](image)

**Fig.7 COP ratio of Inverter-type scroll**
(conventional scroll=100%)

4.2 Performance Comparison Between The New Compressors For R407C and R410A

In the Fig.8, the performance comparison of the newly developed inverter-type scroll between the R407C and R410A application is expressed. The back pressure of Orbiting-Scroll and Compliant-Frame of R410A type-scroll had been optimized to be appropriate for R410A application. Compared with the R407C type, the new scroll for R410A possess higher efficiency in case of 60Hz-supplied frequency or more.

![Compressor efficiency ratio of R410A type](image)

**Fig.8 Compressor efficiency ratio of R410A type**
(R407C type =100%)
5. CONCLUSION

In conclusion, the high-efficiency compressors for R407C and R410A application had been developed by controlling two independent chambers. Furthermore, due to the minimizing of the thrust force by thrust cancellation force, the frictional wear of thrust face could be reduced significantly. In addition, when liquid slugging has occurred, Orbiting-Scroll and Compliant-Frame can be axially movable caused to prevent the high pumping pressure occurring in compression chamber.

This newly developed scroll compressor is not only the high-efficiency but also the high-reliability compressor.

Finally, we continue researching and offering the excellent compressor technology for serving any application in worldwide market.

6. REFERENCES