Purdue University
Purdue e-Pubs

International Compressor Engineering Conference

School of Mechanical Engineering

2008

Development of the New Capacity Control Technique for the High Efficiency Scroll Compressor

Kazuhiko Matsukawa
Daikin Industries Ltd.

Hiroshi Kitaura
Daikin Industries Ltd.

Shuichi Jomura
Daikin Industries Ltd.

Masahiro Yamada
Daikin Industries Ltd.

Nobuo Takahashi
Daikin Industries Ltd.

Development of the new capacity control technique for the high efficiency scroll compressor

Kazuhiko Matsukawa ,Hiroshi Kitaura , Shuichi Jomura, Msahiro Yamada and Nobuo Takahashi
Daikin Industries, Ltd. Compressor Development and Engineering Group
3-12 chikko-shinmachi , Nishiku, Sakai, Osaka , Japan 592-8331
TEL:+81-72-241-1251, FAX:+81-72-245-3740
E-mail kazuhiko.matsukawa@daikin.co.jp

ABSTRACT

Recently, from the viewpoint of global warming, we need to concentrate our effort on the improvement of compressor efficiency.
We have developed a new capacity control technique, which is a combination of inverter drive and conventional mechanical capacity control technique.
We have achieved 10% lower energy consumption compared with our conventional scroll compressor(1) by improving the efficiency for 15% when in the use of part load.
This paper explains the combination of the inverter drive and mechanical capacity control structure of the compressor and also the optimization of capacity control port with our high/low pressure housing and asymmetric scroll design.

1. INTRODUCTION

It is necessary to increase part load efficiency than full load efficiency to reduce annual power consumption of air conditioners. Inverter air conditioners move to part load operation (low capacity operation) after the set temperature is reached to improve comfort.
According to our estimation, the part load running time accounts for more than 70% of the total running time in a year.
Therefore, in annual power consumption reduction, improvement of part load operation efficiency is important.
It is important to increase the compressor efficiency at low rotating speed and at low compression ratio for the improvement of part load operation of inverter air conditioner.
Figure 1 shows relationship between capacity control ratio and efficiency of conventional compressors. Capacity control ratio 100% is rated condition as shown in Figure. We call part load condition that is less than capacity control ratio 50%.
As shown in figure 1, there is a rapid decrease of efficiency of inverter scroll compressor at lower part load compared to conventional inverter rotary compressor. The following three reasons may effect the rapid decrease of part load efficiency of scroll inverter compressor.

1) Decrease of indicated efficiency
   The over compression loss becomes higher during low compression ratio operation. This is because for a particular compressor, the volume index (Vr) is fixed even though, pressure ratio varies according to operating condition.
   Compare with rotary compressor, leakage loss at low speed operation increases because there are more leakage paths in compression chamber.
2) Decrease of motor efficiency
   Another reason of decrease of efficiency at part load is due to the decrease of motor efficiency at low rotating speed. This is due to the increase of motor copper loss.
3)Decrease of volumetric efficiency
   With axial compliance structure compressor (force orbiting scroll onto fixed scroll), leakage loss of inverter scroll increases since pressure load of the orbiting scroll becomes too small.

This paper describes a new technology which is developed to improve the part load efficiency of inverter scroll compressor. In this technology, a new mechanical capacity control mechanism is used to improve part load efficiency of inverter scroll compressor at low rotating speed. It is possible to achieve high efficiency at low cost by using this new technology.

2. NEW CAPACITY CONTROL TECHNOLOGY

2.1 Outline of new technology

Figure 2(a) shows the detailed results of conventional inverter scroll compressor below the 50% part load operating condition. Figure 2(b) shows the detailed results when we applied new capacity control technology in the same compressor.

As shown in Figure 2(a), all efficiencies (indicator efficiency, motor efficiency, volumetric efficiency) except mechanical efficiency decrease at lower part load operation.

The outline of new capacity control mechanism is simply described in the following diagram.

New capacity control
- → Decrease of swept volume → Increase of rotating speed → Increase of motor efficiency
- → Decrease of volume index(Vr)
  - → Decrease of over compression → Increase of indicator efficiency
  - → Increase of back pressure load of orbiting scroll → Increase of volumetric efficiency

In this technology, the swept volume of the compressor is decreased and motor rotating speed is increased to obtain required capacity of air conditioner. Again, the volume index is controlled mechanically to reduce over compression at part load. Furthermore, by controlling volume index, it is possible to increase the back pressure load at part load condition. By the effect of this capacity control, compressor efficiency improves 8% compared to conventional compressor at point P in Figure 2. This is because of increase of indicator efficiency, motor efficiency and volumetric efficiency.

2.2 Compressor Details, Results and Analysis

2.2.1 Compressor Details

Figure 3 shows the compressor structure which we used for the experiment to verify the effect of our new technology. We used flange type compressor that is able to change only cylinder volume ratio (capacity control ratio). The volume ratio is changed by changing only fixed scroll that is installed capacity control mechanism. Figure 4 shows the cylinder volume at full load (100%) as well as part load condition. The position of capacity control port is also shown in figure 4. Because of asymmetric scroll wrap structure, it is possible to control the capacity by using only a single port. The cylinder volume in cylinder A is different from cylinder B as shown in Table 1. In this paper, we will describe the results by using average cylinder volume ratio of cylinder A and cylinder B.

2.2.2 Results and Analysis

Figure 5 shows the experimental results when cylinder volume ratio in 100%, 86%, 80%. The experiment was carried out at part load value of 50% (shown in Figure 2).

As shown in Figure 5, we can see that the compressor efficiency is maximum when the cylinder volume ratio is of 86%. The compressor efficiency falls compared to conventional scroll compressor at 80%.

Figure 6 shows experimental P-V diagram at cylinder volume ratio 100%, 86%, 80%. The vertical axis shows the cylinder pressure and horizontal axis is cylinder volume. As shown in figure 6, the big upward cylinder pressure appears in part X (before the compression starts) at cylinder volume ratio 86%, 80%. This upward cylinder pressure is one of the important problems to apply this new capacity control mechanism to scroll inverter compressor. The improvement of this problem will be described in the following section.

2.2.3 Modification of the Compressor Structure

Figure 7 shows cylinder volume ratio control structure of new capacity control mechanism. Figure 7(a) shows before improvement and Figure 7(b) shows after improvement.

The reason of upward cylinder pressure is due to the control of capacity by using suction chamber of nearest pocket. This problem is solved by establishing the passage directly to the inlet port. The establishment of new passage is possible due to high/low pressure side shell structure.

2.2.4 Modified Structure Results

Figure 8 shows the experimental results of cylinder pressure at cylinder volume ratio of 86% and 80%. As shown in Figure 8, we can see that by using the new structure it is possible to prevent upward cylinder pressure at cylinder volume ratio 86%.

As shown in figure 9, it is seen that the compressor efficiency can be increased by decreasing the upward cylinder pressure. The impact of this new technology is clearly appeared at cylinder volume ratio of 86%. Below this range, there is still appears some upward cylinder pressure which is a barrier of increasing the compressor efficiency. This problem will be solved in the future.

3. APPLICATION OF NEW TECHNOLGY TO PRODUCTION COMPRESSOR

The developed new capacity control mechanism is now successfully applying to our products. The cross sectional view of the compressor is shown in Figure 10. Table 2 shows detail specifications of new model compressor. As shown is figure, the Hi-mech oil re-pressure structure, improvement of roughness of sliding surface and new capacity control technology are applied to the new model. As a result, as shown in figure 11, the compressor efficiency is increased up to 15% at part load condition.

4. CONCLUSIONS

We were able to clarify the following by this study

By applying new capacity control mechanism, the compressor efficiency increases as follows:

1) The volumetric efficiency is increased 3% compared to conventional compressor.
2) The motor efficiency is increased 2% compared to conventional compressor.
3) The indicator efficiency is increased 3% compared to conventional compressor.

By applying new capacity control mechanism, the Hi-mech oil re-pressure structure and improvement of roughness of sliding surface, the annual energy consumption is decreased 10% compared to conventional one. It was possible with minimum cost up.

REFERENCES

(1)N.Nojima,et,al.,"Development of Scroll Compressors for R410A" ,
International Compressor Conference at Purdue,2004

(2)T.Obitani,et,al.,"Development of Highly Efficient Compressor Series Driven by IPM Motors",International Compressor Conference at Purdue,2000

(3)S.Hagiwara,et,al.,"Development of Scroll Compressor of Improved High-Pressure-Housing" ,
International Compressor Conference at Purdue,1998

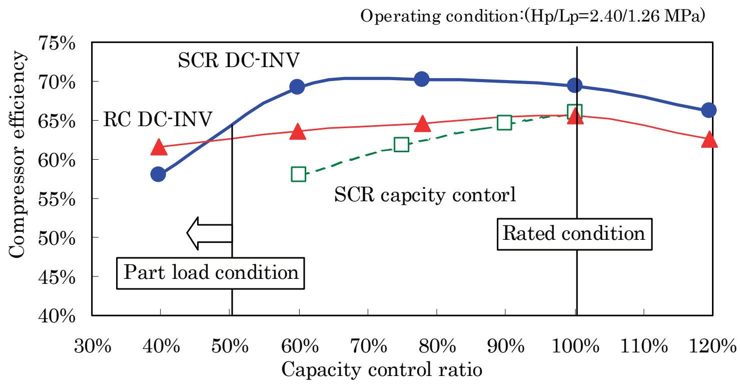
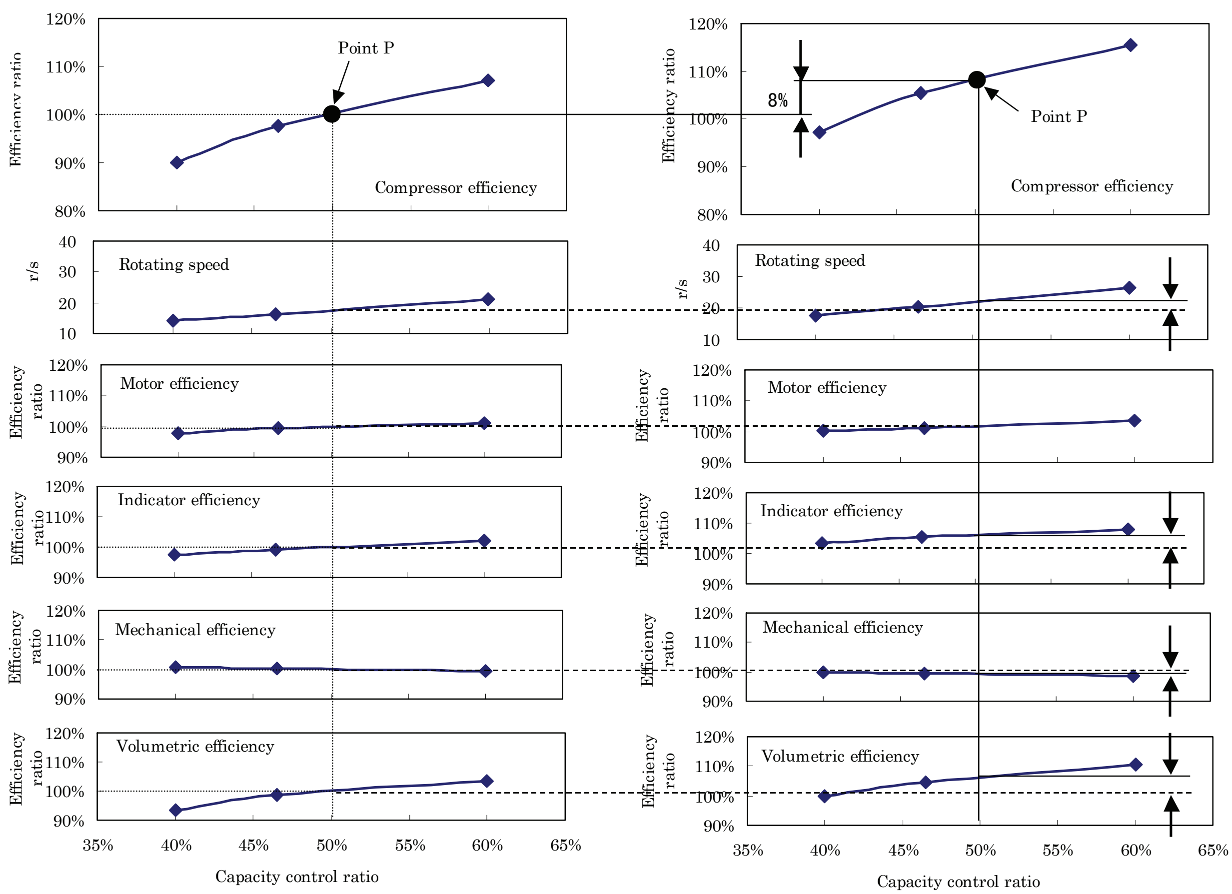


Fig.1 Comparison of conventional compressors efficiency



(a) Conventional compressor (b) New capacity control compressor (86% Cylinder volume ratio)

Fig.2 Relationship between capacity control ratio and compressor efficiency

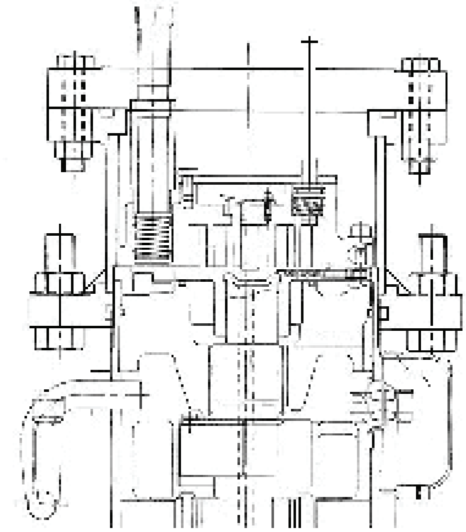


Fig.3 The structure of test compressor

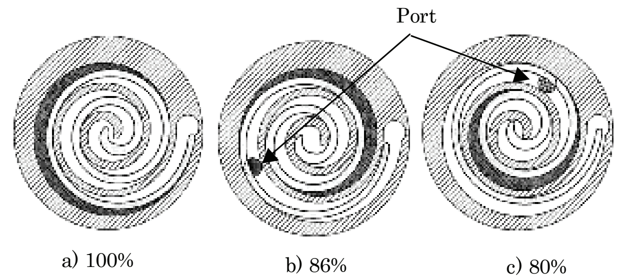


Fig4: The position of cylinder volume control port

Table 1 Design of cylinder volume ratio

Cylinder volume ratio	Cylinder volumes (cm^3/rev)		
	Total	A Cyl.	B Cyl.
100%	35.3	19.4	15.9
86%	30.4	16.7	13.6
80%	28.2	15.6	12.7

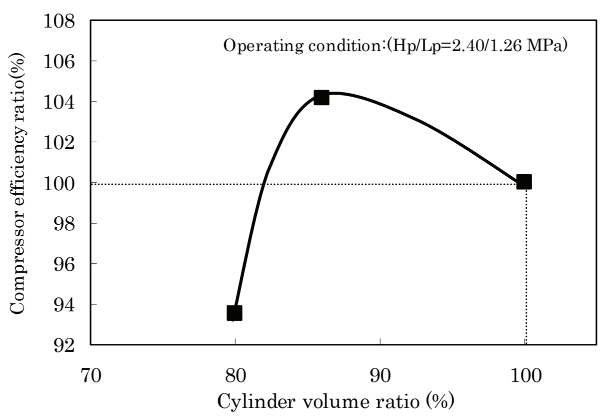


Fig.5 The measurement results of each cylinder volume ratio

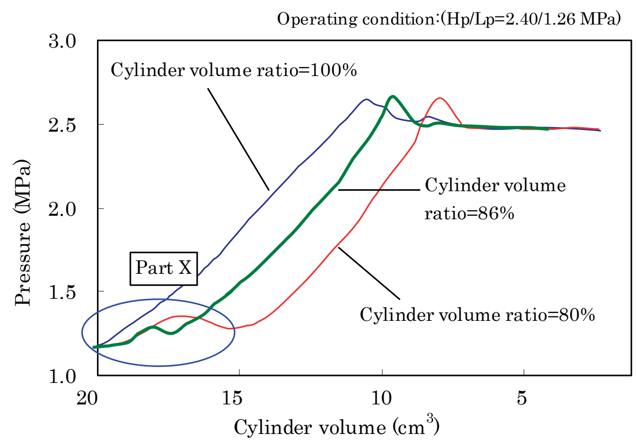
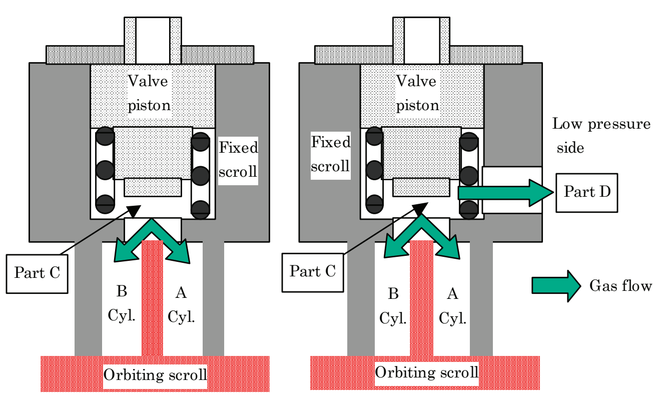


Fig.6 The measurement results of cylinder pressure



(a) Before improvement (b) After improvement
Fig.7 The structure of cylinder volume ratio control

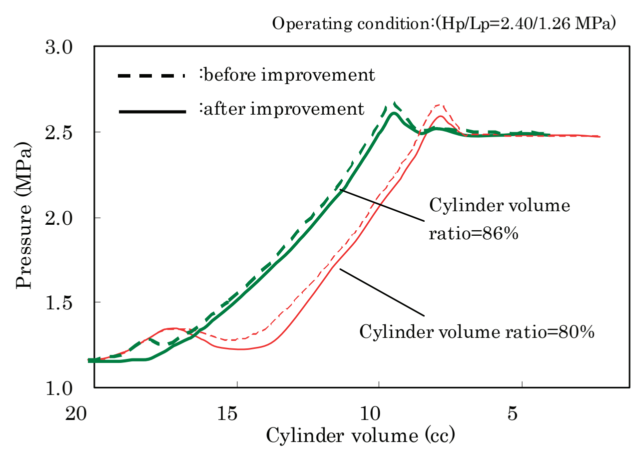


Fig8: The comparison of before improvement and after improvement

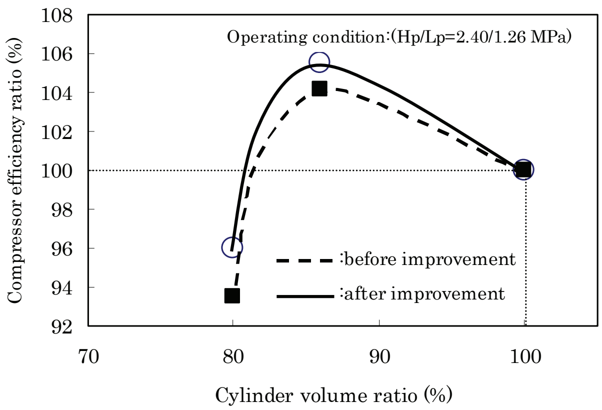


Fig.9 The comparison of before and after improvement

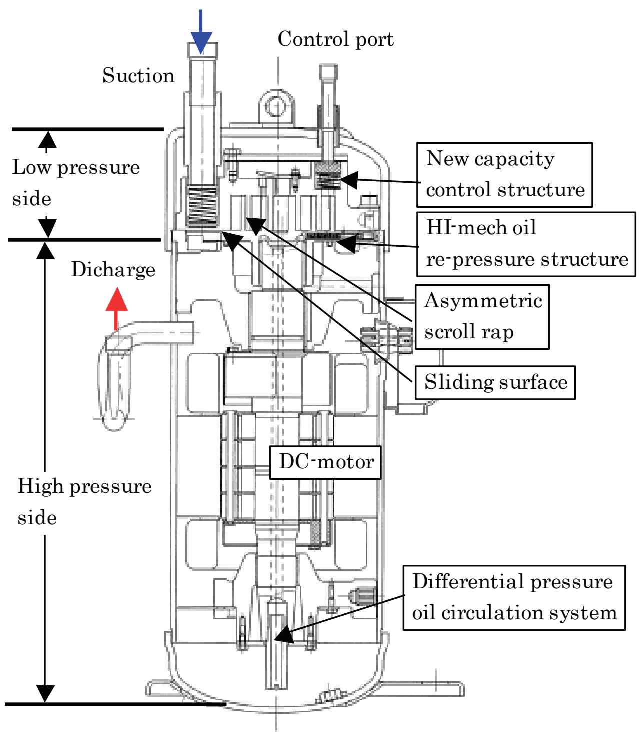


Fig.10 The structure of new model compressor

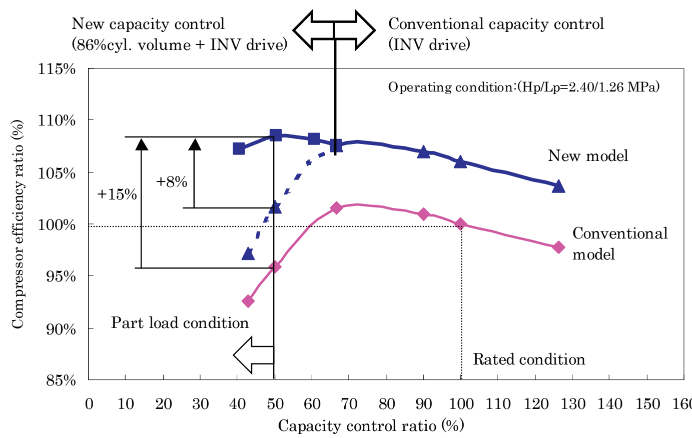


Fig.11 The efficiency characteristic of new model

Table 2 The specifications of new model compressor

Model name	Rated output	Refrigerant	Cooling capacity		
			Rated	Max	Min
JT100GVDL	5Hp	R410A	12880W (75r/s)	26700W (140r/s)	6600W (25r/s)
COP(W/W)		Cyl. volume	Weight	Size	Oil
Rated	Min				
3.48 (75r/s)	7.68 (25r/s)	35.3 cm^3	28kg	D ϕ 153 H 420	Ether oil

Note)
Operating condition
Rated : Tc/Te/Sc/Sh=46/7.5/5/8 Celsius,
Max : Tc/Te/Sc/Sh=45/5/5/8 Celsius,
Min : Tc/Te/Sc/Sh=40.5/17.1/5/8 Celsius