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DEVELOPMENT OF HIGH EFFICIENCY DUAL CYLINDER TYPE ROTARY COMPRESSOR

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ABSTRACT

We conducted numerical and experimental analysis to improve the efficiency of dual-cylinder rolling piston type rotary compressors by varying cylinder height H, diameter D and eccentricity E by developing a simulator for obtaining the optimum combination of the cylinder dimensions. As a result, the lower ratio of cylinder height to diameter tends toward higher efficiency. The experimental results correspond to the numerical analysis.

This investigation includes the reduction of superheat loss during the suction process of a compressor with a thermally isolated cylinder and the acquirement of optimum design conditions for an eccentric bearing. The numerical and experimental results show that a thermally isolated cylinder and an eccentric bearing with optimum design are effective for high efficiency.

The results show that the total efficiency of a 3/4 ton prototype dual-cylinder rotary compressor with these effective improvements is higher than that of a conventional single-cylinder type with equivalent capacity.

INTRODUCTION

In recent years, due to their low noise level and small vibration, scroll compressors are being used more and more. However, rolling piston type rotary compressors are still widely used in small capacity residential air conditioners (0.5 to 1.5 KW) in Japan. The trend of rotary compressors is currently shifting from the conventional single-cylinder type to the dual-cylinder type which has the advantages of a low noise level and small vibration due to its small torque fluctuation.

However, the efficiency of a dual-cylinder type is lower than that of a single-cylinder type with equivalent capacity, due to a large leakage loss per unit of displacement. Except for some studies on dynamic analysis [1-2], there are few studies on the improvement of rotary compressor efficiency.

This paper presents the contents and effects of improvement for obtaining high efficiency by utilizing numerical and experimental analysis. It concludes that the optimization of the cylinder dimensions and the adoption of a thermally isolated cylinder and an eccentric bearing with optimum design are effective for high efficiency.

NOMENCLATURE

Rc	= cylinder radius
D	= cylinder diameter (= 2Rc)
Rr	= piston radius
H	= cylinder height
Re	= eccentric bearing radius
E	= eccentricity (= Rc - Rr)
Ds	= suction port diameter
Ps	= pressure at suction process
Pc	= pressure at compression process
Pd	= pressure at discharge process
Vol	= compressor volume (= π H (Rc^2 - Rr^2))
CP	= radial clearance between cylinder and piston
CR	= height clearance between cylinder and piston
CB	= height clearance between cylinder and blade

Subscript

0 = value of a compressor currently in production

INFLUENCE OF CYLINDER DIMENSION ON PERFORMANCE

We numerically analyzed how cylinder dimensions such as height H, diameter D and eccentricity E affect the performance of a dual-cylinder rotary compressor by developing a simulator for optimum design (referred to as SOD). SOD consists of a main routine and some subroutines which include an automated optimization program for general purpose (AOP)[3-4]. Fig.1 shows the SOD flow chart. SOD parameters are D and E. The cylinder displacement and clearances such as CP, CR and CB are maintained constant. Table 1 shows the range of SOD parameters.

Table 1 SOD Parameter Range to be varied

(1)	$0.8 \leqq D/Do \leqq 1.2$
(2)	$0.7 \leqq E/Eo \leqq 2.0$

The target value of SOD is the maximum total efficiency under the optimum combinations of D, E and H. The SOD boundary conditions and the analysis conditions are as follows:

Table 2 SOD Boundary Conditions

(1)	Rc $\geqq$ Rr
(2)	Rr-Re $\geqq$ 3
(3)	Rc $\leqq$ 2(Rr-Re-1.0)

Table 3 Analysis Conditions

(1) Ps / Pd	= 0.58 / 2.17	[MPa]
(2) speed	= 5400	[rpm]
(3) volume	= 13.2	[cc/rev]

The sealing width mentioned in Table 2 is the minimum interface width of a piston and a partition plate between the upper and lower cylinders. Based on its structural stress and effective area for suction gas flow, the value of Ds is assumed as 0.8H. The other compressor dimensions such as the ratio of length to diameter of bearings are maintained constant.

When predicting compressor performance, it is important to take the leakages from cylinder into consideration. The analysis of compressor loss contributed to the precise prediction of performance. The related references are studies [5-7]. Here, the leakage through CP and CB is defined as nozzle flow and the leakage through CR is defined as oil viscous flow. Fig.2 shows the leakages.

Numerical Result

The results of the compressor performance analysis show the ratio of leakage through CP, CR and CB as follows:

Leakage (CP:CR:CB) = approx. 6 : 1 : 1

The CP leakage is larger than those of CR and CB and is nearly proportionate to H. The SOD shows that a compressor with large D or E and small H increases efficiency.

$$H = \frac{Vol}{\pi \cdot E \cdot (D-E)} \quad \text{-- (1)}$$

It is possible to decrease the CP leakage by decreasing H. However, small H results in large E under the condition of constant displacement.

$$E = \frac{D}{2} - \sqrt{\left(\frac{D}{2}\right)^2 - \frac{Vol}{\pi \cdot H}} \quad \text{-- (2)}$$

The SOD results show that the ratio of (H/D) tends to increase efficiency. In order to increase efficiency, it is necessary to reduce the total leakage by decreasing H. On the other hand, as the eccentricity E increases, the mechanical loss around the blade sharply increases. Therefore, it is necessary to increase D and restrain the increase of E. In addition, it is not possible to increase the diameter of a compressor currently in production. The optimum combination of the cylinder dimensions which is the simulation result is shown in Fig.3.

It is necessary to increase the diameter D and the eccentricity E by 20.0% and 51.2% respectively, and decrease the cylinder height H by 43.9%.

As a result, the volumetric efficiency and the indicated efficiency increases by 5.8% and 0.6% respectively, the mechanical efficiency decreases by 0.4% against those of compressors currently in production, and accordingly the total efficiency increases by 6.0%. Fig.4 shows the influence of cylinder dimensions on efficiency.

The following explains the reasons for the ratio of (H/D):

Volumetric Efficiency

The leakage through CP is a major leakage of the cylinder. The leakage through CR and CB is minor. As the cylinder height H decreases, the CP leakage decreases. Therefore, the total leakage decreases, and accordingly the volumetric efficiency increases. Fig.5 shows the relation of each leakage and the ratio of (H/D).

Mechanical Efficiency

As the bearing load decreases, the mechanical loss of main and eccentric bearings decreases. As the eccentricity E increases, the blade force on the cylinder slit (groove for blade) wall increases, and as a result, the mechanical loss around the blade sharply increases. As the ratio of (H/D) decreases, the total mechanical loss increases, and accordingly the mechanical efficiency decreases. Fig.6 shows the relation of each mechanical loss and the ratio of (H/D).

Indicated Efficiency

As the ratio of (H/D) decreases, the surface area of walls which surround and superheat the compressed gas decreases as well as the leakage through CR. As a result, the compression loss decreases, and accordingly the indicated efficiency slightly increases.

Experimental Result

We analyzed how cylinder dimensions affect performance by testing three different cylinder compressors. The displacement and clearances of each compressor were maintained constant. The experimental results show that as the ratio of (H/D) decreases, the volumetric, indicated and total efficiency increase and the mechanical efficiency decreases. Their tendency corresponds to the numerical results.

The experimental results also show that for obtaining the optimum combination of dimensions, it is necessary to increase the diameter D and the eccentricity E and decrease the height H at approximately the same rate of the numerical results. Fig.7 shows the numerical and experimental results of the total efficiency.

The results of the static friction tests by varying the eccentricity E show that as E increases, the frictional coefficient at the blade slit increases. Therefore, as the ratio of (H/D) decreases, the blade force and frictional coefficient at the blade slit increase, and accordingly the mechanical efficiency decreases. The study referred to is about the elasticity of flexure [8].

INFLUENCE OF THERMALLY ISOLATED CYLINDER ON PERFORMANCE

Generally speaking, the cylinders of the rolling piston type rotary compressors with high pressure side housing are immersed in high temperature lubricating oil. The heat from this oil transfers to the cylinder inside surface and to the suction gas. Therefore, the density of the suction gas decreases and the volumetric efficiency decreases. This is defined as suction gas superheat loss.

We numerically and experimentally analyzed how the dimensions and structures of a thermally isolated cylinder affect the volumetric efficiency [9].

Numerical Result

The results of the compressor performance analysis show the ratio of suction gas superheat loss through cylinder, piston and plate as follows:

Superheat Loss (Cylinder:Piston:Plate) = approx. 2 : 2 : 1

As the ratio of (H/D) decreases, the surface area of walls which surround and superheat suction gas decreases, and accordingly the volumetric efficiency increases. The results show that it is necessary to increase the cylinder diameter D by 9.1%, the eccentricity E by 38.3% and decrease the height H by 48.0%.

On the other hand, according to other analysis results, the ring type is the optimum isolation structure and the efficiency increases by 0.6%. Fig.8 shows the cylinder block cross-section of the ring type isolation. The assumed isolation conductivity is 0.13 [kcal/m/h/℃] and the width is 0.15D.

We also numerically analyzed the thermal heat balance with of cylinder being immersed in discharge gas instead of lubricating oil. As a result, the volumetric efficiency slightly increases. This is due to the decrease of the heat transfer coefficient of the cylinder outside surface. Fig.9 shows the numerical results.

Experimental Result

The test results of a cylinder with optimum combination show that the volumetric efficiency increases by 3.9% in comparison with a compressor currently in production. The results of the ring type thermally isolated cylinder with the optimum combination show that the volumetric efficiency increases by 4.4%. A thermally isolated cylinder increases the volumetric efficiency by 0.5%. The experimental results correspond to the numerical results.

Thus, it verifies that the adoption of a thermally isolated cylinder produces higher efficiency.

INFLUENCE OF OPTIMUM ECCENTRIC BEARING DESIGN ON PERFORMANCE

The numerical performance results show that the mechanical loss of an eccentric bearing is larger than the other mechanical losses.

We investigated the mechanical loss of an eccentric bearing by numerical and experimental analysis. The results show that an edge cut eccentric bearing largely reduces the mechanical loss. Hereafter, this bearing is referred to as a Woodruff bearing. Fig.10 shows the scheme of the Woodruff bearing.

Numerical Result

The results at 90Hz show that the mechanical efficiency of a Woodruff bearing is 1.0% higher than that of a normal eccentric bearing. In addition, the minimum oil film thickness of a Woodruff bearing is similar to that of a normal eccentric bearing.

Experimental Result

The mechanical efficiency increases by 1.3% in comparison with a normal eccentric bearing(Fig.11). The cut area of the Woodruff bearing contributes to reduce the mechanical loss of an eccentric bearing.

The results verifies that a compressor with a Woodruff bearing produces higher efficiency.

EFFICIENCY OF DUAL CYLINDER TYPE ROTARY COMPRESSOR

The experimental results show that the total efficiency of a 3/4 ton prototype dual-cylinder rolling piston rotary compressor with the improvements previously mentioned increases by 11.1% in comparison with that of a conventional dual-cylinder compressor currently in production.

Those improvements are effective for obtaining high efficiency. As a result, the efficiency of an improved compressor increases by 5.5% in comparison with that of a conventional single-cylinder type with equivalent capacity(Fig.12).

CONCLUSIONS

From the numerical and experimental analysis, a 3/4 ton prototype dual-cylinder compressor gives higher total efficiency than that of a conventional single-cylinder type with equivalent capacity.

The most effective improvement is to optimize the combination of the cylinder design dimensions, namely, height, diameter and eccentricity. The ratio of (H/D) tends toward higher efficiency. The optimum combination is to increase D of a dual-cylinder compressor currently in production by 20.0%, E by 51.2% and decrease H by 43.9%. The total efficiency increases by 6.0%.

The other effective improvement is the adoption of a thermally isolated cylinder and an edge cut eccentric bearing which we refer to as the Woodruff bearing.

The thermally isolated cylinder increases the volumetric efficiency by 0.5% due to the decrease of superheat loss during the suction process. Consequently a thermally isolated cylinder with the optimum ratio of (H/D) increases the volumetric efficiency by 4.4% in comparison with that of a conventional dual-cylinder currently in production.

The Woodruff bearing increases the mechanical efficiency by 1.3% in comparison with that of a normal eccentric bearing.

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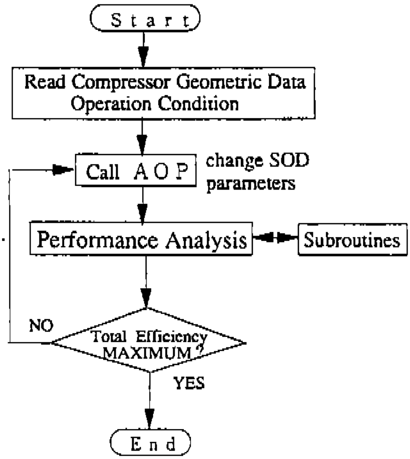

Fig.1 SOD Flow Chart

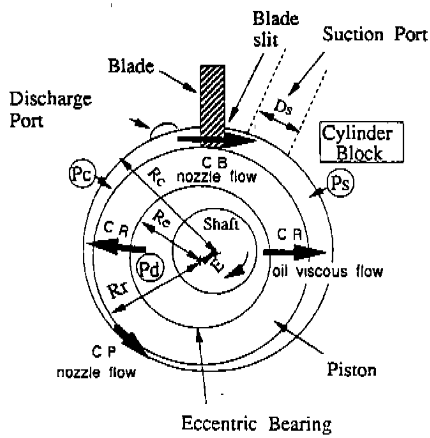

Fig.2 Leakages

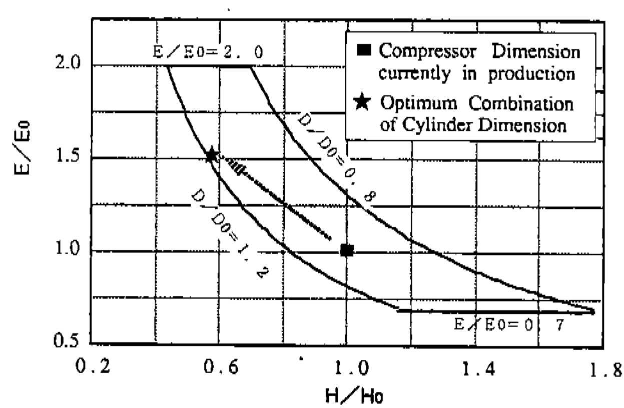

Fig.3 Range of Cylinder Diameter(D), Eccentricity(E) and Cylinder Height(H) and Optimum Combination of Cylinder Dimensions

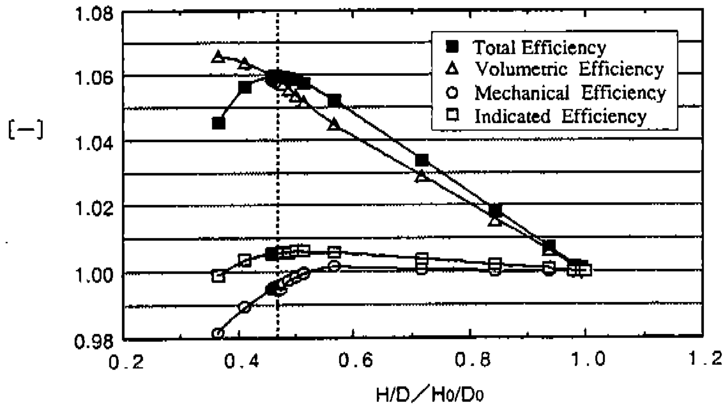

Fig.4 Influence of Cylinder Dimension on Efficiency (Calculated)

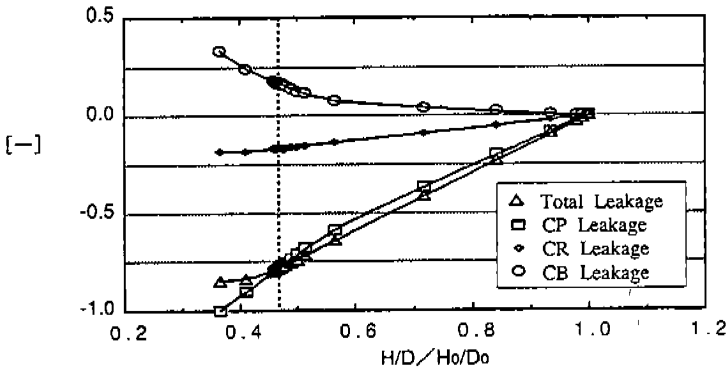

Fig.5 Relation of Leakages and H/D When Maximum Fluctuated Amount of CP Leakage equals 1.0 (Calculated)

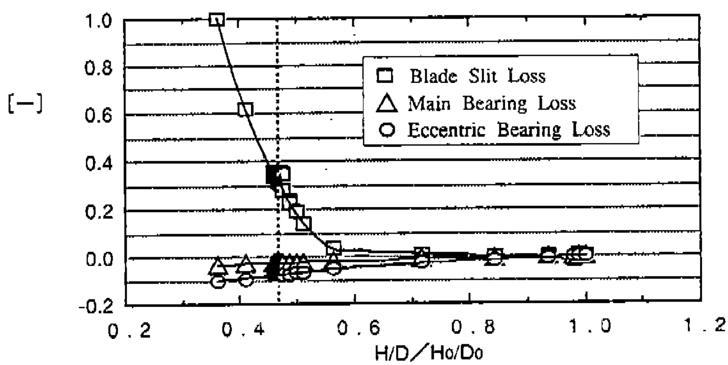

Fig.6 Relation of Mechanical Losses and H/D When Maximum Fluctuated Amount of Blade Slit Loss equals 1.0 (Calculated)

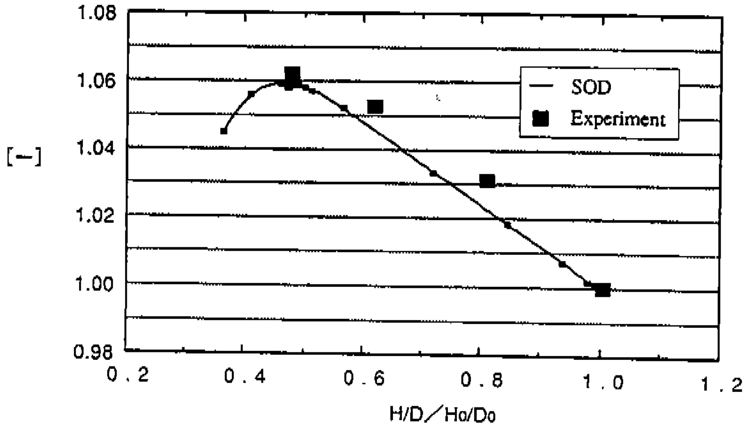

Fig.7 Total Efficiency Comparison with SOD and Experimental Results

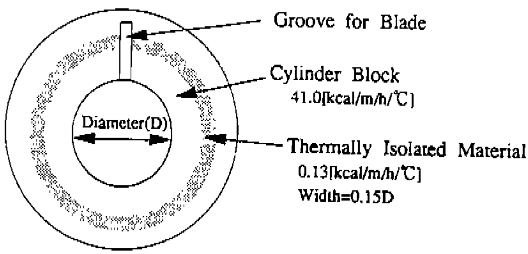

Fig.8 Cylinder Block Cross-Section of Ring Type Isolation

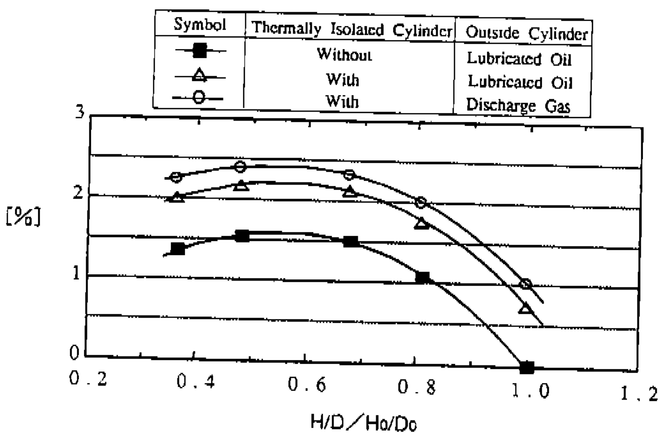

Fig.9 Influence of Thermally Isolated Cylinder and Cylinder Dimension to Volumetric Efficiency (Calculated)

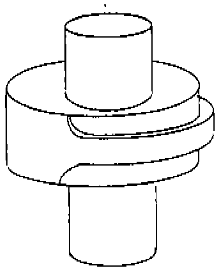

Fig.10 The Scheme of Woodruff Bearing

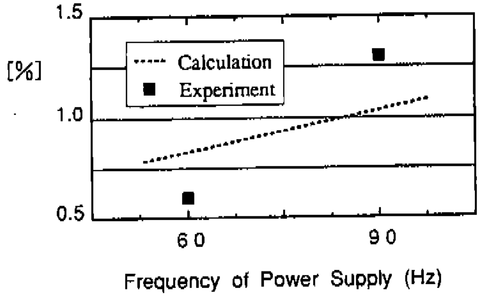

Fig.11 Influence of Woodruff Bearing on Mechanical Efficiency

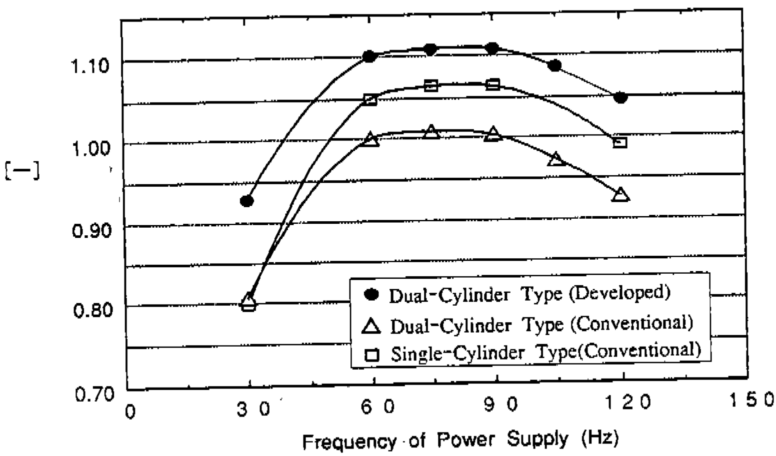

Fig.12 Total Efficiency Comparison with Single-Cylinder and Dual-Cylinder Type of Rolling Piston Type Rotary Compressor When Efficiency of Dual-Cylinder Type(Conventional) At 60Hz equal 1.0