1992

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Sa, B. D.; Kim, K. H.; Son, S. H.; Park, Y. D.; and Byun, C. H., "The Design Optimization and Experimental Behavior of the Valve for a Rolling Piston Type Rotary Compressor" (1992). *International Compressor Engineering Conference.* Paper 801.
https://docs.lib.purdue.edu/icec/801

The Design Optimization and Experimental Behavior of The Valve for A Rolling Piston Type Rotary Compressor

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ABSTRACT

The discharge valve in a rolling piston type rotary compressor is an important factor which affects the performance and noise of the compressor. We examined the valve behaviors by changing the valve thickness and retainer height experimentally, and determined the stresses on valves and designed the optimum shapes of valve and retainer theoretically by using the design optimization analysis of ANSYS (Finite Element Analysis Software).

We concluded the opening and closing times of the discharge valves were variable as to the valve thickness and the retainer height. Therefore, the optimum conditions were obtained by experience. And the result of the design optimization analysis reduced the maximum equivalent stress on valve about 33%.

INTRODUCTION

The rolling piston type rotary compressor has been widely used for domestic air-conditioners and refrigerating units, recently. The demand to improve the compressor reliability has been enhanced since the air-conditioning units could not used by the small failure in the compressor. The most important factor which has effect on the compressor reliability is the discharge valve where the highest stress occurs. Therefore, reducing the probability of failure on the discharge valve is important for improving the compressor reliability.

Some research results have already been reported regarding the behavior(1)(2)(3) and stress analysis(4)(5)(6) on valve, but the research on discharge valve from the viewpoint of changing valve thickness and retainer height has not yet been performed. Therefore, the main objectives of this paper are as follows.

(1) The discharge valve behaviors as to the change of valve thickness and retainer height will be experimentally clarified.
(2) The stress distribution on discharge valves as to the change of valve thickness and retainer height will be determined by using the finite element analysis software, ANSYS.
(3) The optimum shapes of discharge valve and retainer which minimize the stress on discharge valve will be obtained as the result of the design optimization method of ANSYS.

The compressor used for this research was the rolling piston type rotary compressor with an output of 0.61KW, and a rotational speed of approximately 3460rpm.

ANALYSES OF VALVE BEHAVIOR

In a rolling piston type rotary compressor, the behavior of discharge valve has an important effect upon the performance and noise of the compressor. Especially, the opening and closing time of discharge valve has a direct effect on the over-compression loss and re-expansion loss of the compressor. There are many parameters which have an influence on the discharge valve behavior such as the discharge pressure, the discharge port area, the valve thickness, the retainer height, and the discharge valve shape etc.

In this experiment, the discharge valve behaviors as to the change of valve thickness and retainer height were measured. Therefore, the opening and closing time of discharge valve was clarified. The experimental setup is shown in Fig.1. And the shape of discharge valve and retainer of the compressor used for this experiment is shown in Fig.2 and Fig.3 respectively. The discharge valve behaviors were measured with the eddy current type probe mounted on the retainer over the center of the discharge port. In Fig.2, the section of oblique line is the area that the discharge pressure act upon the discharge valve. In Fig.3, Hs in the table is the distance from the center of discharge port to the retainer, and R is the curvature-radius of the retainer to Hs.

The experiments were performed on three valve thicknesses(0.203, 0.254, and 0.305mm) and six retainer heights(1.6, 1.8, 2.0, 2.2, 2.4, and 2.6mm).

The testing conditions were as follows.

- Electric power : 110/60 (V/Hz)
- Discharge reference pressure : 20.86 (kg f/㎠)
- Suction reference pressure : 5.34 (kg f/㎠)

ANALYSES OF STRESS DISTRIBUTION

We determined the stress distribution on discharge valve through the finite element analysis. The stress analyses were performed on three valve thicknesses (0.203, 0.254, and 0.305mm) and four retainer heights(1.6, 1.8, 2.2, and 2.6mm). The discharge valve for this research is SANDVIK 20C steel, and its material properities are shown in Table 1.

The finite element analysis of ANSYS is performed as following steps.

Step 1. Modeling
Step 2. Generation of finite elements (meshing)
Step 3. Definition of load data
Step 4. Solution
Step 5. Display of the results

Finite element model of discharge valve and retainer was used the three dimensional shell element and the three dimensional gap element respectively.. In step 1, the modeling of discharge valve was started at the position of 8mm from the center of bolt for the simplification of analysis. Because, in real assembly of the compressor, the discharge valve was constrainted from the center of bolt to 9mm by the retainer and the bearing. And the modeling of retainer was formed by the distance between the retainer and each node point of the discharge valve center line. The number of nodes and elements of finite element model are shown in Table 2. In step 3, We used the discharge pressure acting on the area of discharge valve to be contacted with the discharge port for the load. The magnitude of the pressure was 2.6kg f/㎠, which was the difference between the discharge reference pressure and the real pressure by experiment. And the displacements of discharge valve were limited to the retainer heights. The finite element model performed from step 1 to step 3 is shown in Fig.4.

DESIGN OPTIMIZATION ANALYSIS

The behavior and the stress distribution of discharge valves are different by the valve thickness and the retainer height. Therefore, the design optimization analysis of ANSYS was performed in order to obtain the optimum shape of discharge valve and retainer to minimize the stress on discharge valve.

The theoretical basis of design optimization analysis are as follows.

- Mathematical technique

  SUMT : Sequential Unconstrained Minimization Technique

- Optimization formula

  Minimize $W(b)$

  Subject to $G(b,s(b)) \leq C_1$ (constant)

  $H(b,s(b)) = C_2$ (constant)

  where,
  $W(b)$: Objective function
  $G(b,s(b))$: Inequality constraints
  $H(b,s(b))$: Equality constraints
  b : Design variables
  $s(b)$: State variable

The modeling for optimization analysis is shown in Fig.5. The analysis type is static analysis. And the objective function, W(b) is the minimization of discharge valve mass. The state variable, s(b) is the equivalent stress on discharge valve, which is limited to 50kgf/㎟ by using the inequality constraint. The design variables are the valve thicknesses, the valve lengths, the valve widths, the valve radius near discharge port, and the retainer heights. These basis values and permitted-limits are shown in Table 3.

RESULTS

Valve behavior results

The discharge valve begins to open when the discharge pressure reachs the reference pressure(20.86kgf/㎠) and to close slowly after contact with retainer. It begins to open when the crank angle is arround 210° and close completely between 310° and 360°. The discharge valve behaviors according to the change of valve thickness and retainer height are shown in Fig.6. The opening time of discharge valve becomes earlier and its closing time becomes later as the valve is thinner.

Fig.6 (a) shows the discharge valve behavior according to the change of the retainer height(Hs) when the valve thickness is 0.203mm. When Hs=1.6mm or 1.8mm, the discharge valve begins to open rapidly when the discharge pressure reachs the reference pressure, then it begins to close slowly after contact with the retainer, and close completely at the end of discharge period. But, In Hs=2.6mm, it becomes to close rapidly after contact with the retainer, then it close very slowly around 240° of crank angle. Because the discharge valve displacement is large, it close quickly by restoration force, then it becomes to close slowly when it meets with the residual gas.

Fig.6 (b) shows the discharge valve behavior when the valve thickness is 0.254mm. Generally, the discharge valves are slowly closed after once more ascension in the midst of closing period. As the retainer height is lower, this phenomenon is more clear. The discharge valve is closed rapidly as the retainer height is higher.

Fig.6 (c) shows the discharge valve behavior when the valve thickness is 0.305mm. It shows a similar tendency with Fig.6 (b) at Hs=1.6mm. But, In Hs≥2.2mm, the discharge valve is quickly opened to the retainer, and then it becomes rapidly to close to nearly 240°, thereafter close very slowly. Because it is greatly affected by the spring coefficient of the discharge valve itself as the valve is thick.

Stress analysis results

The stress analysis results on discharge valves are shown in Fig.7, Fig.8, and Fig.9. Each figure is the equivalent stress distribution on discharge valve when the valve thickness is equal to 0.203mm, 0.254mm, and 0.305mm respectively.

In previous figures, the stress is concentrated on the neck point of discharge valve. The values of maximum equivalent stresses are shown in Table 4.

The maximum equivalent stress on valve is smaller as the valve thickness is thinner and the retainer height is lower. Because it is the discharge valve contacts well with the retainer as the valve is thinner.

Design optimization results

The analysis results of the model before optimization are shown in Fig.10. Fig.10 (a) is the stress distribution on discharge valve. The maximum equivalent stress, about 60kgf/㎟, is concentrated on the neck point. Fig.10 (b) is the displacement of discharage valve at this time.

The optimum value of design variables according to the design optimization analysis is shown in Table 5. Fig.11 (a) is the stress distribution on the optimum discharge valve. As the result, the maximum equivalent stress is reduce to 39.8kgf/㎟. And Fig.11 (b) is the displacement of the optimum discharge valve at this time and the optimum retainer shape. Therefore, in Table 5, the valve thickness(VT) is equal to the basis value(0.254mm). The valve length(VL) becomes longer 1.4mm. The valve width(VW) becomes somewhat broad and convex. Also, the basis retainer shape had one curvature-radius, but the optimum shape has one curvature radius and one straight line.

CONCLUSIONS

1. The behaviors of discharge valves according to the change of valve thickness and retainer height were experimentally clarified. There is some difference according to the valve thickness, but the reasonable retainer height is 1.6mm ~ 2.0mm.
2. We determined the stress distribution on discharge valves according to the change of valve thickness and retainer height. The thinner the valve is and the lower the retainer height is, the smaller the maximum equivalent stress on discharge valve is.
3. Through the design optimization analysis, we obtained the optimum shape of the discharge valve and the retainer. These features and values were shown in Fig.11 and Table 5. At this time, the maximum equivalent stress was reduced about 33% (39.8kgf/㎟) as compared with the basis value.

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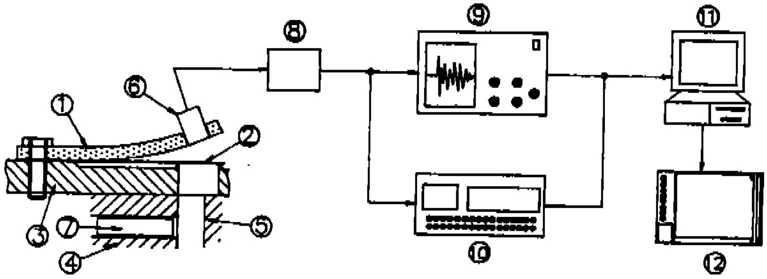
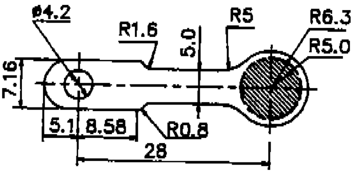


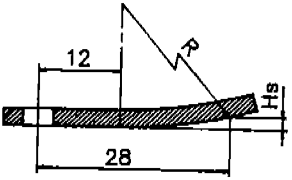
Fig.1 Experimental Set Up

1.retainer 2.discharge valve 3.bearing 4.cylinder 5.roller 6.eddy current probe 7.pressure transducer 8.proximeter 9.digital stroage oscilloscope 10.data recorder 11.386-P/C 12.printer or plotter



VT1=0.203, VT2=0.254, VT3=0.305

Fig.2 Feature of Valve



No.	Hs	R
1	1.6	80.00
2	1.8	72.01
3	2.0	65.00
4	2.2	59.28
5	2.4	54.53
6	2.6	50.53

Fig.3 Feature of Retainer

Table 1 Material Properties of SANDVIK 20C Valve Steel

Thickness mm	Tensile Strength Kgf/mm²	Yield Strength Kgf/mm²	Elastic Limit Kgf/mm²	Hard-ness HV
0.175—<0.225	205	180	155	590
0.225—<0.275	200	175	150	580
0.275—<0.375	195	175	150	565

Modulus of elasticity: 2.14×10^{4} Kgf/mm²

Density : 7.85×10^{-6} Kgf/mm²

Table 2 Number of nodes and elements of Finite element model

	Valve	Retainer
nodes	1048	25
elements	337	25

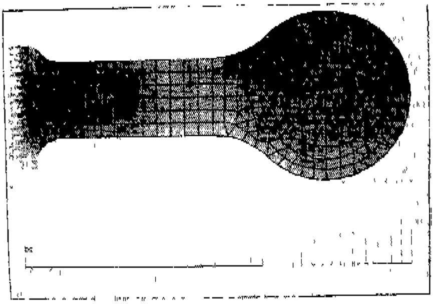


Fig.4 Finite Element Modeling for Stress Analysis

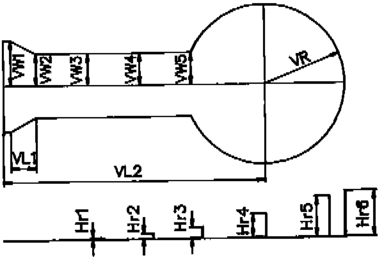
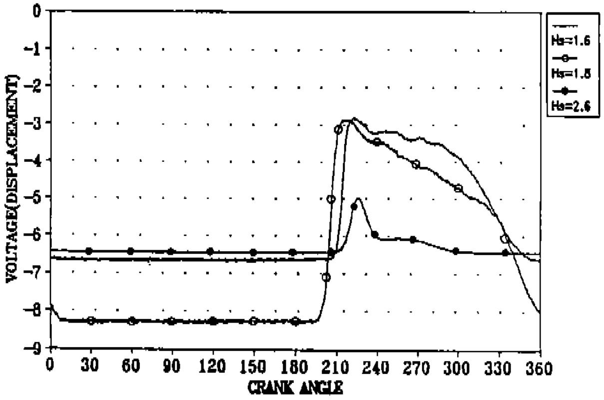


Fig.5 Model of Valve and Retainer for Optimization

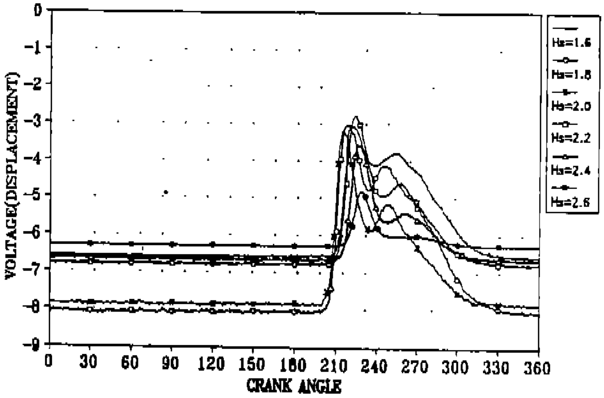
Table 3 Permitted Limit of Design Variables

unit : mm

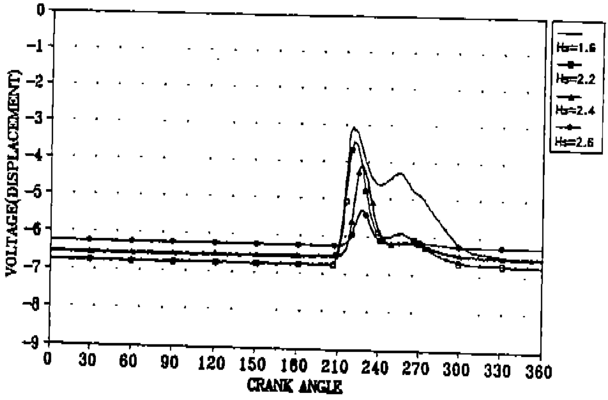
Design Variables	Basis Values	Permitted Limit		Commant
		Minimum	Maximum	
VT	0.254	0.20	0.31	Valve Thickness
VL1	2.00	0.5	3.0	Valve Length
VL2	20.00	15.0	27.0	
VW1	3.58	1.5	4.5	Valve Width
VW2	2.50	1.5	4.5	
VW3	2.50	1.5	4.5	
VW4	2.50	1.5	4.5	
VW5	2.50	1.5	4.5	
VR	6.30	6.0	7.0	Valve Radius
Hr1	0.09	0.0	0.2	Retainer Height
Hr2	0.37	0.0	0.6	
Hr3	0.85	0.5	1.4	
Hr4	1.80	1.6	2.6	
Hr5	3.13	2.0	4.5	
Hr6	3.54	2.1	5.0	



(a) When VT=0.203mm



(b) When VT=0.254mm



(c) When VT=0.305mm

Fig.6 Discharge Valve Behaviors

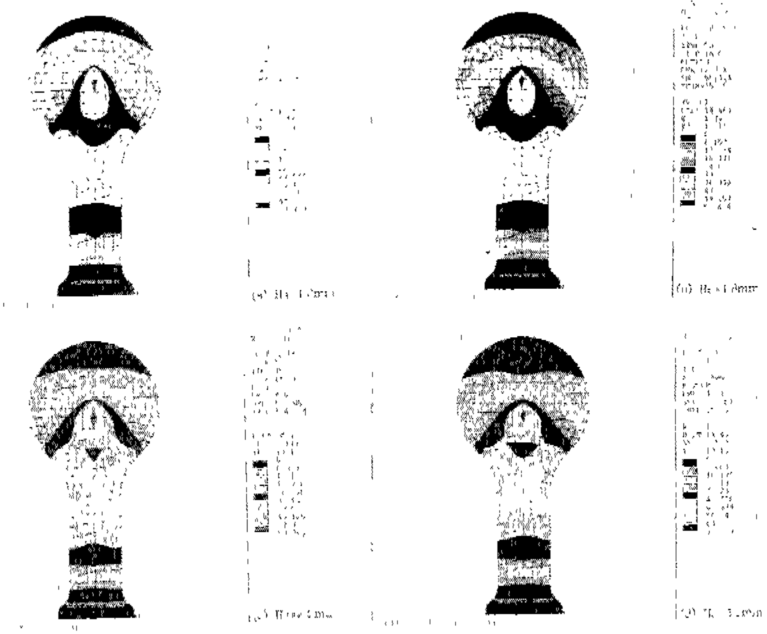


Fig.7 Stress Distribution on Discharge Valves When VT=0.203mm

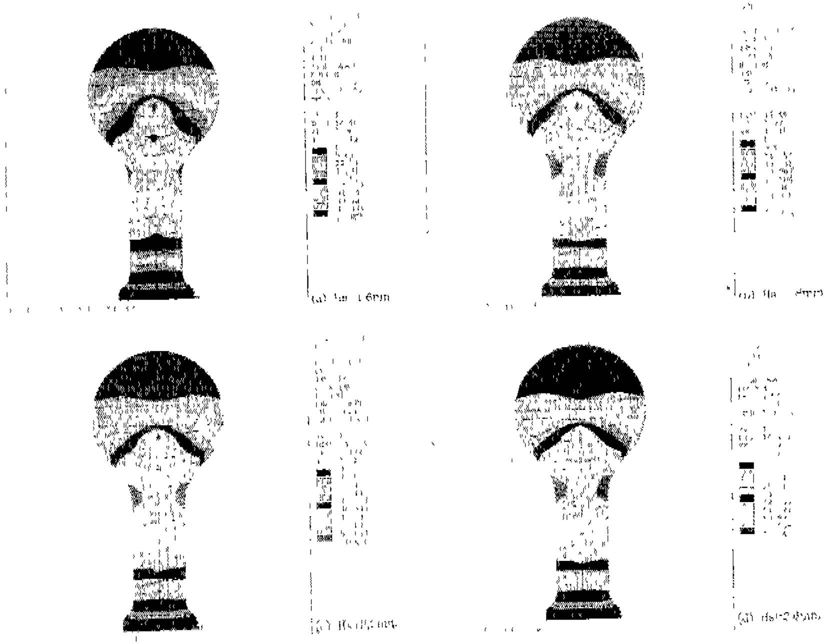


Fig.8 Stress Distribution on Discharge Valves When VT=0.254mm

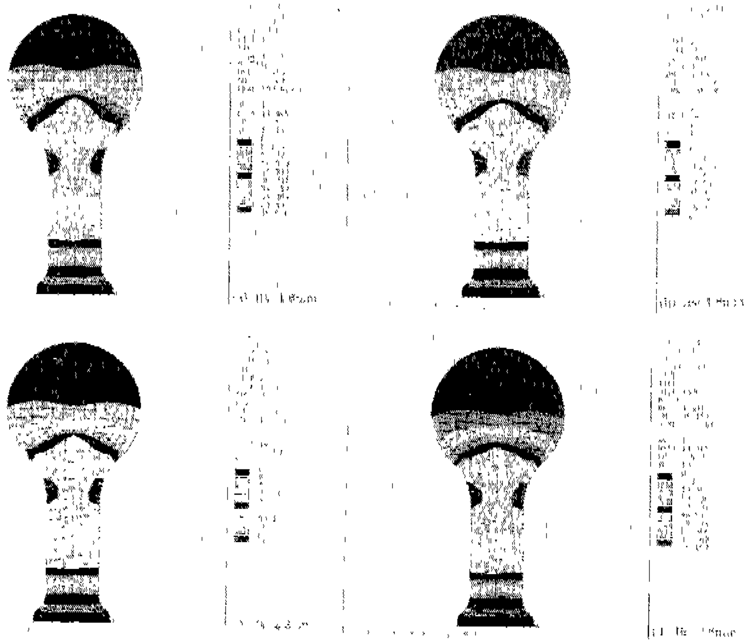


Fig.9 Stress Distribution on Discharge Valves When VT=0.305mm

Table 4 Maximum Equivalent Stress on Valves

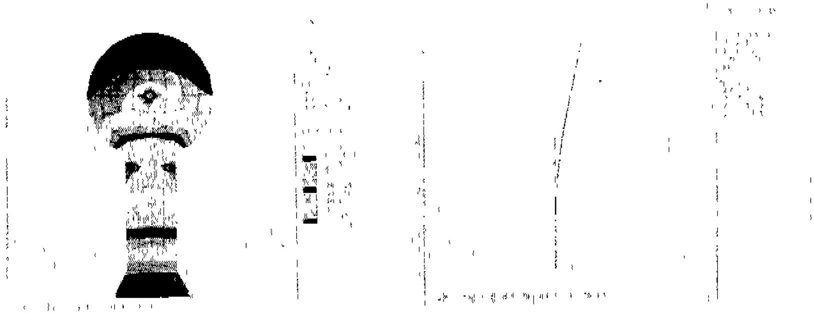
(Kgf/mm^2)

Hs / VT	1.6	1.8	2.2	2.6
0.203	49.76	55.41	59.31	72.57
0.254	51.05	53.79	66.44	77.14
0.305	55.68	62.19	75.26	88.16

Table 5 Optimum Values

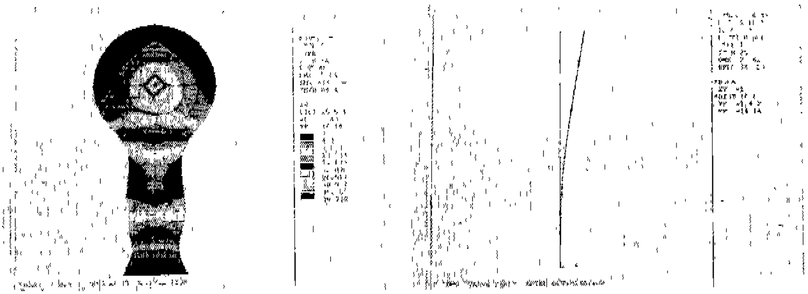
unit : mm

Design Variables	Basis Values	Optimum Values
VT	0.254	0.254
VL1	2.00	2.00
VL2	20.00	21.40
VW1	3.58	3.30
VW2	2.50	2.20
VW3	2.50	3.50
VW4	2.50	3.00
VW5	2.50	2.70
VR	6.30	6.88
Hr1	0.09	0.11
Hr2	0.37	0.43
Hr3	0.85	0.95
Hr4	1.80	1.70
Hr5	3.13	2.53
Hr6	3.54	2.84



(a) Stress Distribution (b) Displacement

Fig.10 Analysis Result of the Model Before Optimization



(a) Stress Distribution (b) Displacement

Fig.11 Result of Design Optimization Analysis