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ABSTRACT

The burst strength of rotary compressor pressure vessel directly affects the safety. Therefore, it is mandatory to ensure the strength of the pressure vessel. Major factors that determine the burst pressure of pressure vessel are stress concentration around the suction and discharge hole as well as its shape and thickness. In this study, stress concentration of the pressure vessel is investigated by means of finite element analysis. Moreover, actual hydrostatic burst test is carried out to confirm the burst pressure. Burst pressure of the pressure vessel can be increased by relieving the stress concentration around the suction and discharge hole.

INTRODUCTION

The planned phase-out of R22 refrigerant currently used in the refrigeration and air-conditioning industry is forcing compressor manufacturers to develop compressors suitable for new alternative refrigerants. The new alternative refrigerant R410A has higher-pressure characteristics than R22. Therefore, the safety must be ensured in the burst strength of compressor. And compressor shell is required to meet the safety requirement. For evaluating the safety requirement of the pressure vessel, UL sets forth the Hydrostatic Burst Pressure Test and Fatigue Test Analysis methods. [1] The present safety requirement for design pressure is that pressure vessel has no rupture at five times the maximum design operating pressure or three times abnormal pressures whichever is higher. [2]

Engineering design target pressure as well as safety requirement for pressure vessel was established in order to confirm the safety and reliability. Hydrostatic burst pressure test is performed to obtain the actual burst pressure and to find out the stress concentration in the pressure vessel. Safety and reliability for the pressure vessel can be ensured by relieving the stress concentration and by optimal design of the pressure vessel.

Burst Pressure Test

Test Procedure

Two or more samples of each type of pressure vessels are used to evaluate the burst pressure. The test specimens are filled with water and connected with a hydraulic pump. Then the pressure inside of pressure vessel is raised gradually to the required test pressure, and maintained for one minute. During that time the pressure vessel must not burst or show a visible leakage to pass the test. This test is to be continued until the burst occurs. The lowest burst pressure vessel must be taken as a representative burst pressure. The test procedure defining the step of pressure and time is given in table 1.

Table 1. Burst Test Procedure

Pressure	200 kgf/㎠·G	215 kgf/㎠·G	230 kgf/㎠·G	240 kgf/㎠·G	250 kgf/㎠·G	270 kgf/㎠·G
Holding Time	60 sec	60 sec	60 sec	60 sec	60 sec	60 sec

Test Specimen

The pressure vessel for rotary compressor is composed of two main parts; lower shell containing motor and pump assembly, and upper shell with the discharge tube hole and terminal hole.

Table 2 Specification of Test Specimen

Test ID	Specification of test specimen	
	Upper Shell	**Lower Shell**
Test #1	With discharge and terminal holes	With suction hole
Test #2	Without discharge and terminal holes	With suction hole
Test #3	Without discharge and terminal holes	Suction hole with stress concentration relief
Test #4	Terminal hole with stress concentration relief	Suction hole with stress concentration relief
Test #5	Discharge hole with stress concentration relief	Suction hole with stress concentration relief

Pressure vessels are different in size according to the compressor capacity. Burst pressure also varies according to the shell structure and size. Therefore, it is necessary to evaluate the ultimate strength of the respective pressure vessels.

Further experimental evaluations were performed to find out the burst pressure for the 20 frame and 30 frame pressure vessels, which have different size and shape. Because the stress concentration and burst depends on the geometric structure of the pressure vessel, lower and upper shell with special features were tested according to Table 2. The lower shell featured strength reinforcement around the suction hole and the upper shell featured strength reinforcement around the discharge and terminal holes.

Test Results

The test results for the pressure vessels are given in Table 3 and Table 4.

Table 3 Burst Pressure for 20 frame Pressure Vessel

Test ID	Burst Pressure / Engineering Design Target Pressure (%)	Burst Location
Test #1	105.3	Between Discharge Tube and Terminal
Test #2	111.0	Around the Suction Hole
Test #3	108.7	Around the Suction Hole
Test #4	109.1	Around the Suction Hole
Test #5	Not Tested	-

Table 4 Burst Pressure for 30 frame Pressure Vessel

Test ID	Burst Pressure / Engineering Design Target Pressure (%)	Burst Location
Test #1	90.1	Between Discharge Tube and Terminal
Test #2	97.2	Around the Suction Hole
Test #3	109.3	Around the Suction Hole
Test #4	98.2	Between Discharge Tube and Terminal
Test #5	100.0	Between Discharge Tube and Terminal

In general, the experimental test results show that the lower shell ruptures generally around the suction hole while upper shell ruptures between the discharge and terminal hole. This is caused by stress concentration around the holes. The area between holes in upper shell is weaker in strength than the area around the suction hole in lower shell. The large pressure vessel in size is ruptured at low pressure due to the increase of area subjected to pressure load. By reinforcing the strength around the holes in upper shell, burst pressure is increased by 5~10% compared to the baseline of the original pressure vessel. Though pressure vessel in the 30 frame satisfies the safety requirement, it does not satisfy the engineering design target requirement.

It is unnecessary to strengthen the strength of lower shell in the 20 frame. But, In case of lower shell in the 30 frame, it is necessary to reinforce the strength around the suction hole to meet the engineering design target pressure. Actually, the burst pressure of lower shell in the 30 frame can be increased by 12% by relieving the stress concentration.

The burst pressure of 20 frame exceeds both the safety requirement and engineering design target pressure without any modification of the current shell design. Whereas, pressure vessel in the 30 frame needs both strength reinforcement design around the suction hole in lower shell and design optimization in upper shell to relieve the stress concentration.

Design Analysis of Upper Shell

Modeling for Analysis

In order to investigate the effects of design parameters on the stress concentration of the upper shell, numerical analysis has been performed using finite element analysis program ANSYS. Fig. 1 and Table 5 show the geometry and parameters of the analysis model.

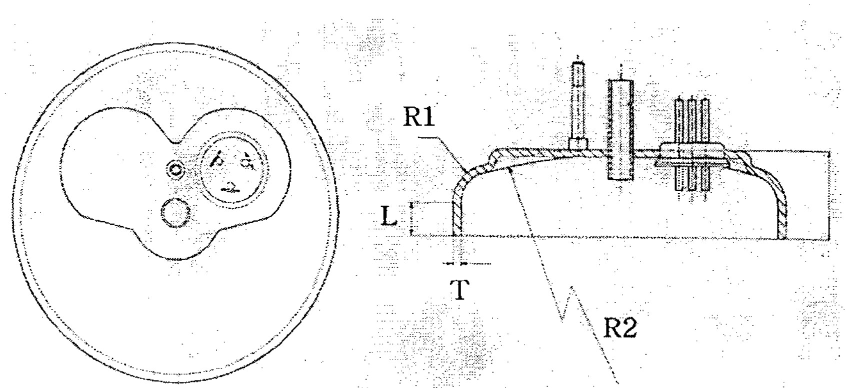


Fig. 1 Schematic geometry of analysis model

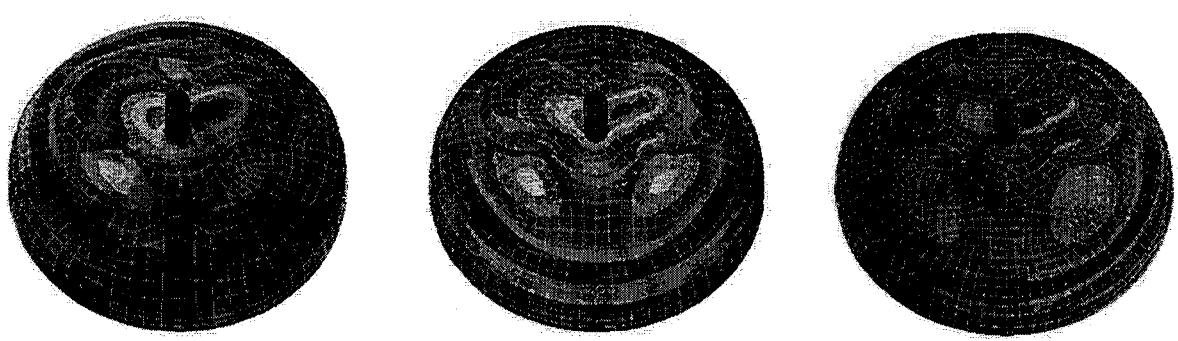
For large deformation analysis of pressure vessel with thin and uniform thickness, shell elements are adopted for the modeling. To reduce the numerical error in the analysis, welding condition on discharge tube and terminal are assumed just connected to upper shell. All degrees of freedom of welding point between lower shell and upper shell are restricted and pressure load is applied to the inside of upper shell.

Table 5 Dimensions of analysis model

ITEMS	Old Design	New Design	
	Specification (A)	Specification (B)	Specification (C)
Shell Thickness	T	T	T
	1.2T	1.2T	1.2T
1st Curvature	R1	R1	0.5R1
2nd Curvature	R2	0.7R2	0.5R2
Straight Length	L	L	0.7L
Height	H	1.1H	H

Results of the Analyses

Fig. 2 shows equivalent stress distribution according to the thickness and curvature of upper shell. As shown in Fig. 2, maximum stress concentration occurs between discharge hole and terminal hole due to the structural characteristics of upper shell. These results also coincide with actual burst test results. Other design variables such as thickness, height and curvature do not affect the position of the stress concentration, but the magnitude of maximum equivalent stress is changed.



A) Old design specification B) New design specification C) New design specification

Fig. 2 Profile of Von Mises equivalent stress of upper shell for shell Thickness T

Fig. 3 shows the ratio of maximum equivalent stress of upper shell in the 30 frame. As shown in the analysis, the increase of shell thickness alone by 20% while keeping the original shape, the maximum equivalent stress of upper shell decreases by 10%. If the height of shell with the same thickness increases by 9% like the case of new design specification (B), the maximum equivalent stress also decreases by 10%. In case of new design specification (C), stress concentration decreases by 19%.

Therefore, the changes in shape as well as thickness are the major factors affecting the burst pressure of pressure vessel. The proposed new design specification with the thicker shell ensures the strength of upper shell.

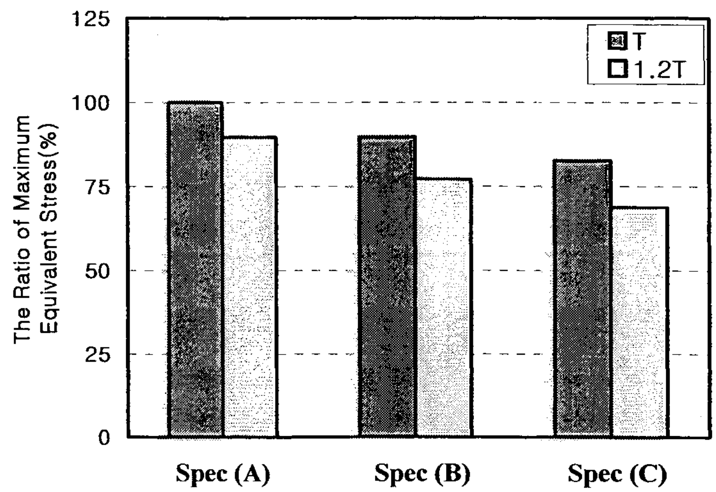


Fig. 3 Ratio of maximum equivalent stress for upper shell

Conclusion

In this study, the burst pressure of pressure vessel using alternative refrigerant R410A is evaluated and the stress concentration aspects are analyzed. The following conclusions are obtained.

- Burst of the pressure vessel usually occurs around the suction or discharge hole due to the stress concentration.
- The burst pressure of the pressure vessel can be increased to meet the target with design modification around the suction and discharge hole.
- Major factors in increasing the burst pressure of upper shell are shell shape as well as shell thickness.
- The burst pressure of pressure vessel for alternative refrigerant R410A can be increased to exceed the safety requirement.

References

[1] Refrigeration News & Notes, Underwriters Laboratories Inc.

[2] Larry Kettwich, et.al, "Pressure Strength Test Requirements for Hermetic Refrigerant Compressor Housings using Fatigue Analysis", Proc. of the 1998 Int. Comp. Eng. Conference at Purdue, vol 1.