한국기계가공학회지, 제19권, 제11호, pp. 8～15(2020.11) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 19, No. 11, pp. 8~15(2020.11) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2020.19.11.008

Hydraulic Compressor Safety Test for Hydrogen Stations

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수소충전소용 유압식 압축기 안전성 시험에 관한 연구

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(Received 11 August 2020; received in revised form 07 September 2020; accepted 08 September 2020)

ABSTRACT

The government has announced its Hydrogen Economy Roadmap to strengthen global competitiveness on the hydrogen economy by focusing on hydrogen fuel cell electric vehicles and fuel cells. In this regard, the interest on the economics and safety of the infrastructure of hydrogen stations has also increased. In this study, a test bed similar to an actual hydrogen charging facility was built, and a prototype of a piston-type compressor was modeled. In this model, the piston was hydraulically compressed to progressively test leakage, leakage rate, and durability and to check for any malfunction. Moreover, the leakage rate, cylinder leak performance, and compressor operation durability were evaluated for safety; it was confirmed that there were no abnormalities. Nevertheless, an investigation of the long-term use and operating pressure of the compressor is necessary to verify the safety of developing a100-MPa domestic compressor in the future.

Key Words : Hydraulic Compressor(수소압축기), Hydrogen Stations(수소충전소), Safety(안전성), FCEV(수소연료전지차)

1. Introduction

With the announcement of the hydrogen economy roadmap in South Korea, there is an increasing interest in the hydrogen charging infrastructure to increase global hydrogen competitiveness through the expansion of the hydrogen economy and implementation of hydrogen-electric vehicles. By initiating governmental policies to lead the hydrogen economy focused on hydrogen-electric vehicles and fuel cells, the South Korean government is promoting the hydrogen economy with great industrial effects in the effort to prevent serious natural disasters resulting from global warming and reduce greenhouse gases. The hydrogen economy roadmap aims to cumulatively produce 6.2 million hydrogen-electric vehicles by 2040, and 1,200 or more hydrogen stations. This policy intends to revitalize the industry and increase public access by expanding and installing charging infrastructures according to the distribution of vehicles [8]. Furthermore, it is possible to target overseas export markets through technological advancements.

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Regarding the distribution of hydrogen-electric vehicles, the construction of charging infrastructures should be continuously expanded mainly to ensure their economic feasibility, increase their convenience, and improve their safety.

For this purpose, the dependency on mostly imported compressors, which are key components of hydrogen stations, has been lowered, and domestic compressors with excellent performance in terms of capacity and pressure are being developed. According to the research results of the development of hydraulic compressors for hydrogen stations, suitable materials for a high-temperature and high-pressure environment have been selected, and the mechanical performance has been confirmed through structural analysis [1,4]. Previous studies have evaluated the environment for testing as well as the methods for the safety certification of hydrogen compressors to ensure the reliability and safety of the compressor prototype fabricated based on the result [1].

In this study, a testbed similar to an actual hydrogen charging facility is constructed and a piston compressor prototype is modeled in which the piston is compressed by hydraulically operating the piston without lubrication to check for operational abnormalities by conducting stepwise tests to determine leakage rates, leaks, and durability [1,5]. This study further intends to present a safety verification method for the long-term operation of hydrogen compressors that are currently used in charging facilities and do not possess any safety verifications due to the lack of an appropriate test method.

2. Piston Compressors for Hydrogen Stations

Diaphragm, ionic, and piston compressors are the types of compressors used in hydrogen stations. Piston compressors, which are widely used in overseas hydrogen stations, have a compact structure without a rotating shaft. Thus, in South Korea, high-purity gas can be obtained by injecting a high-temperature and high-pressure gas into the gas compression unit without lubrication. A piston compressor with a simple internal structure that is easy to maintain and repair is under development. As shown in Fig. 1, the piston compressor uses a two-stage compression system in which the gas is primarily compressed in the left and right cylinders and the compressed gas is secondarily compressed by moving the piston to the hydraulic drive unit when a low-pressure gas is supplied [2,5]. The internal piston seal is responsible for the internal leakage between the cylinders, and this leakage in the cylinders is crucial because high-pressure hydrogen is temporarily stored inside the piston [3]. Thus, this study investigates the internal seal, leak, as well as the operational performance of the compressor. Table 1 shows the specifications of the tested piston compressor prototype.

Table 1 Prototype compressor specification

Model	Min. P_S (MPa)	C (Nm^3/h)	Design. P_S (MPa)	C (Nm^3/h)
	Max. P_S (MPa)	C (Nm^3/h)	Max. P_D (MPa)	Po. (kW)
GH2S 110-90	3	108	10	350
	20	532	90	110

※ P_S : suction pressure, P_D : discharge pressure

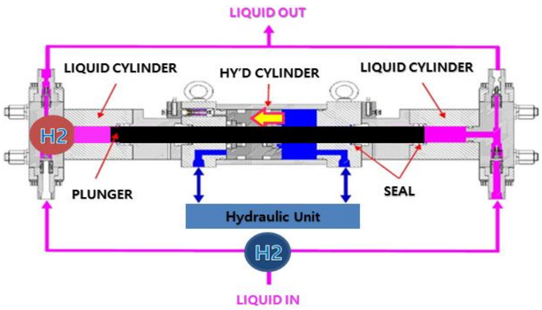

Fig. 1 Piston compressor composition

Fig. 2 Hydrogen compress equipment

3. Hydrogen Compressor Safety Test

This study examines the safety of a hydrogen compressor, as shown in Fig. 1, through three test items that include a leakage rate test to identify the leakage rate of the piston seal, an leak test of the cylinder, and an overall operation durability test of the compressor.

3.1 Leakage Rate Test

The leakage rate test is a test to check the presence or absence of gas leakage from the inner seal and fitting portions by pressurizing the module part with a booster after closing the compression module (Cylinder & Piston) at the high-pressure side of the compressor with a cover flange. The test equipment in Fig. 2 is used to test a compression module by pressurizing hydrogen to 50 MPa and is configured to simultaneously supply a nitrogen line for hydrogen purging.

3.1.1 Test Procedures

1) After tightening the high compression module, pressurize to a pressure of 10 MPa, check for gas leaks with soap bubbles at different locations including the cover flange, inner seal, piping, and fittings.
2) If there is a gas leak, check the connection, and if there is no leak, maintain the pressure at 50 MPa or more for a certain time (at least 30 minutes).
3) If the pressure gauge and transmitter values are maintained as constant, maintain the pressure for at least one hour and collect data through the data logger after setting the pressure to 50 Mpa or higher.
4) Analyze the stored data to check the leakage rate of the seal inside the piston through the measurement of the pressure and calculations.

3.2 Leak Test

The Leak test is a test in which the hydrogen supplied from the hydrogen compressor testbed to the tube trailer is compressed with the prototype compressor to store the pressure from the piston area at the front end of the high-pressure tank and further confirm any gas or pressure leakage in the compressor piping, fittings, and piston area. Fig. 3 shows the schematic diagram of the entire testbed. The testbed was constructed such that 20 MPa of hydrogen was supplied through a tube trailer, and the hydrogen was compressed at high pressures through a compressor and filled into a low-pressure tank using a differential pressure. The once-used hydrogen gas should be vented before restarting the testbed for safety reasons.

3.2.1 Test Procedures

1) Check the normal supply of the 10-MPa hydrogen from the tube trailer to the front end of the

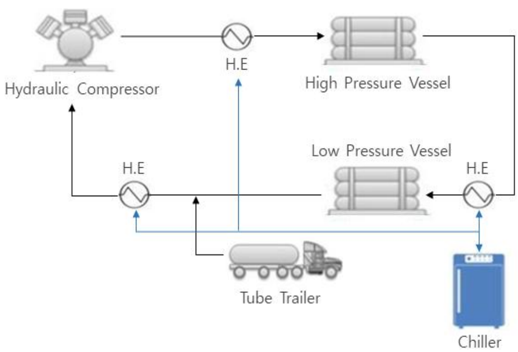

Fig. 3 Schematic image of testbed

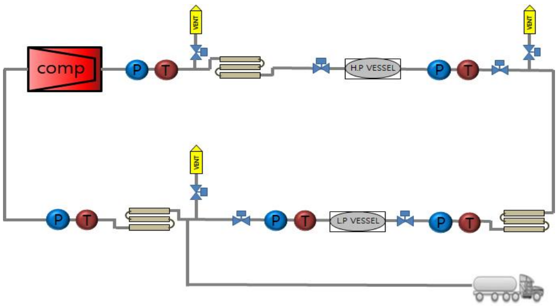

Fig. 4 Testbed control panel

compressor.

2) After starting the compressor and checking whether the discharge was performed at the discharge pressure of 82 MPa, open the valve of the high-pressure tank to restart the compressor and charge the high-pressure tank to 82 MPa.
3) After charging is complete, shut off the hydrogen supply by ceasing the operation of the compressor and closing the valve.
4) Check the leak of the gas with soap bubbles.
5) Measure and compare pressure values one hour before and after shutting off the hydrogen supply.

3.3 Durability Test

The durability test is a test in which, as shown in Fig. 3, hydrogen is supplied from a tube trailer to a testbed with an environment similar to a hydrogen station. The compressed hydrogen is stored in a high-pressure tank as in an actual charging cycle to determine any operational abnormalities by setting the cycle from the low-pressure tank to the charging station using differential pressure as one cycle and repeating the cycle five times[6]. This test can be controlled through the control panel shown in Fig. 4 to check the pressure and temperature in real time [7].

3.3.1 Test Procedures

1) Check whether hydrogen is supplied from the tube trailer to the front end of the compressor at 10 MPa.
2) Check that the discharge pressure is 82 MPa in the discharge piping gauge after operating the compressor.
3) Shut off the hydrogen supply after charging the high-pressure tank to 82 MPa.
4) Fill the compressed hydrogen into a low-pressure tank at 20 MPa.
5) After checking the charging pressure and closing the valve, cease the test operation and vent.
6) Repeat the tests a total of five times to determine whether the target pressure of the high-pressure tank (82 Mpa or more) is reached and whether the operating standards are met at 65 ℃ or less during operation.

4. Hydrogen Compressor Safety Test Results and Evaluation

In this chapter, three tests are performed for the developed piston compressor prototype by applying the test method previously defined. The obtained results are presented in the following sections.

4.1 Leakage Rate Test Evaluation

The test was conducted according to the test method in Section 3.1.1 to determine whether repetitive leakage due to the internal piston seal would occur, as shown in Fig. 5, by blocking the high-pressure compression module (Cylinder & Piston). The primary test results, as shown in Fig. 6, indicate that the pressure sharply dropped when the module was pressurized at 10 MPa. In the secondary test after reassembly, as shown in Fig. 7, the pressure was maintained and no bubbles were generated. After reaching 50 MPa, the pressure decreased to approximately 0.1 MPa per minute for the initial 30 minutes. As the prototype was operated according to the seal characteristics, the seal thermally expanded, and the leak performance improved. Thus, the

Fig. 5 High pressure module (cylinder & piston)

Table 2 Piston & Cylinder test conditions

Gas	Value	Unit	Cylinder	Value	Unit
Test Gas	H_2		Inside diameter	0.06	m
Molecular weight	2.016	kg /kmol	Length	0.36	m
Test Pressure	50.22	MPa	Area	0.002827	m^2
Test Temperature	17	℃	Volume	0.001018	m^3

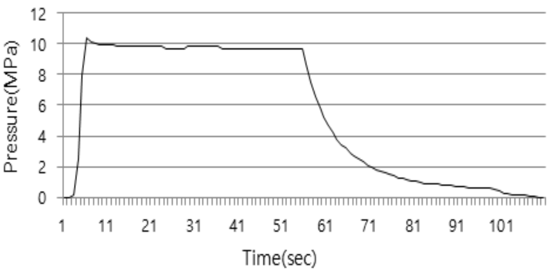

Fig. 6 First leak test result

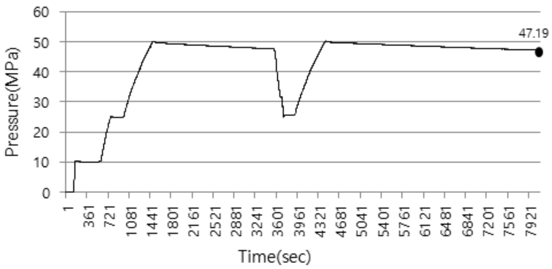

Fig. 7 Second leak test result

pressure was reduced by 0.05 MPa per minute for the actual test time of one hour. There was a pressure drop of 3.03 MPa from an initial pressure of 50.22 MPa to a final pressure of 47.19 MPa. When calculating the leakage rate by measuring the gas mass, the conditions listed in Table 2 were applied as the physical quantity required for the calculated value. The calculation results using these conditions indicate that the leakage gas mass value is 0.00040168 m^3 and the cylinder gas mass is 0.000427471 m^3. Using these results in the following Equation (1) shows a gas leakage rate of 6%.

$$Gas\ leakage\ rate(\%) = (1 - \frac{Lakage\ Gas\ Mass}{Cylinder\ Gas\ Mass}) \times 100 \quad (1)$$

4.2 Leak Test Evaluation

In the testbed configured as shown in Fig. 3, a test, for which the procedures are presented in Section 3.2.1, was conducted for the piston of the prototype compressor shown in Fig. 8. Before the test, the pressurized states of the equipment, such as the testbed, compressor, and tank, were checked and

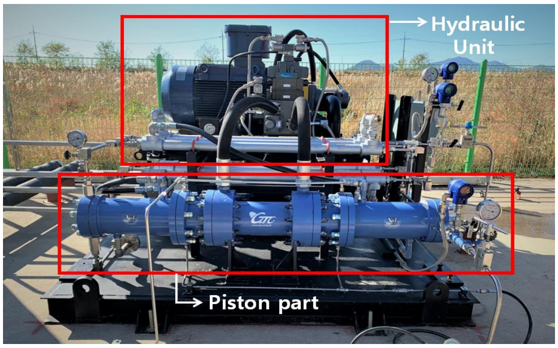

Fig. 8 Prototype of compressor

(a) Left part (b) Right part

Fig. 9 Bubble test on piston, pipe and fittings

tested. After pressurizing the compressor to 82 MPa, the valves at the front and back ends of the compressor were closed, and the target pressure value was checked through a pressure gauge, which was on the discharge side of the compressor. Furthermore, after ceasing the operation at the target pressure of 82 MPa or more, the leak was checked by spraying soap bubbles on various areas such as the piston area of the compressor, surrounding pipes, fittings, and gauges.

The initial pressure was measured as 83.4 MPa, and the final pressure value after one hour was measured as 82.8 MPa. Thus, the pressure drop was 0.6 MPa and when calculated as a percentage by the pressure difference, the leak rate was determined as approximately 0.72%. As shown in Fig. 9, no bubbles were observed around the piston area where leakage can occur.

4.3 Durability Test Evaluation

The durability test was conducted at the actual testbed site shown in Fig. 10. The test was started after adjusting the total testbed pressure to 10 MPa as the basic conditions according to Section 3.3.1. It took approximately 24 minutes to charge the high-pressure tank to 82 MPa and check the pressurization state of the initial pressure. The next test was conducted after confirming the completion of the charge. The test operation was terminated when the 20-MPa differential pressure charge from the high-pressure tank to the low-pressure tank was completed at a one-minute interval. At the end of one cycle, hydrogen gas was sequentially vented, and the test was restarted after the system pressure was adjusted to 10 MPa.

The hydrogen compressed inside the high-pressure tank was not vented, and the remaining pressure after charging the low-pressure tank was used to conduct the experiment. Thus, the high-pressure tank was charged from approximately 60 MPa to 82 MPa or more for the secondary test, and the pressurization time lasted approximately five minutes. The test was repeated for a total of five times in which Table 3 shows the resulting values. In all five tests, the target pressure reached 82 MPa, and the tests confirmed that there were no abnormalities in the operational conditions because the prototype was operated at 82 MPa or more and 65 ℃ or less as shown in Table 4.

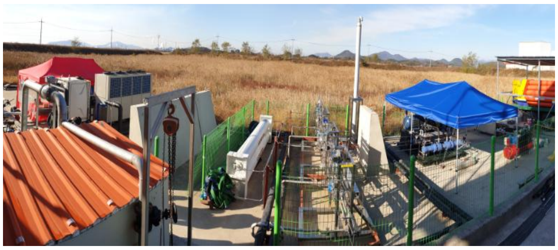

Fig. 10 Image of testbed site

Table 3 Durability test result

	Pressure(MPa)		T_{max}(℃)		
	Comp. Out	H.P Vessel Out	Comp. (In/Out)	H.P Vessel (In/Out)	L.P Vessel (In/Out)
1st	83.0	82.4	21.6 / 33.6	22.5 / 18.2	20.3 / 24.6
2nd	82.9	82.4	17.5 / 34.0	17.9 / 13.8	17.1 / 23.9
3rd	83.2	82.9	15.8 / 36.0	17.4 / 14.7	17.1 / 24.8
4th	83.2	82.8	15.8 / 35.2	17.4 / 12.8	15.6 / 24.8
5th	83.3	83.0	19.9 / 19.0	27.4 / 24.7	23.3 / 19.7

Table 4 Durability test operation condition

Requirement	Result				
	1st	2nd	3rd	4th	5th
operation	○	○	○	○	○

※ over 82 MPa and below 65℃, ○: normal △: abnormal

5. Conclusions

In this study, a testbed was constructed to investigate a safety test method for domestic compressor products. The study further conducted tests on the compressor to determine leakage rate, leak, and durability in a high-temperature and high-pressure environment. The following conclusions were obtained:

1. The results of the leakage rate test on the inner seal of the piston indicate that leakage occurred at 10 MPa in the primary test and a leakage rate of 6% occurred at 50 MPa in the secondary test. There was a difference in the leak rates of the seal according to the primary and secondary pressures.
2. The results of the cylinder leak test indicate that there were no soap bubbles at the initial pressure of 83.4 MPa. After one hour, there was a small pressure drop of 0.6 MPa; thus, the pressure measured 82.8 MPa. Therefore, the pressure leak rate after one hour was 0.72%, determining the leak performance.
3. The results of the durability test indicate that for continuous the operation of the compressor in the testbed, no abnormalities were found during the five tests. This durability test confirmed that there were no abnormalities in the operation of the compressor in an environment equivalent to that of an actual hydrogen station by repeating the charging and compression cycles.

The above test evaluation results indicate that leakage rate and leak checks at low pressures can be a method that ensures the safety of compressor use because the internal seal can show leakages at low pressures due to its expansion and contraction depending on the high-temperature and high-pressure environment. Continuous research is necessary for the appropriate use of pressure and time because this experiment was performed in the developmental stage of the compressor based on the conditions of the established testbed. However, this study will be used as a pilot test for the development of a 100MPa-class domestic compressor as well as for safety evaluation research.

Acknowledgments

“This study was supported by the 20173010041830 Research Fund for the Energy Technology Development Project of the Ministry of Trade, Industry and Energy.”

REFERENCES

1. Cho, S. M., Roh, G. G., Lee, S. K., Lyu, S. K., "Development of Hydraulic Compressor for Hydrogen Station," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17 No. 6, pp.158-163, 2018.
2. Kim, M. W., Hur, K. D., Ye, S. D., “Finite Element Analysis for the Piston Pump Tube Design”, Journal of the Korean Society of Manufacturing Process Engineers, pp. 108-109, 2015.
3. Kim, Y. H., “An Experimental Study on Oil Pressure Distribution in the Piston-Cylinder Mechanism,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 10, No. 6, pp.77-82, 2011.
4. Kim, S. K., Kim, M. K., "Development of Aluminium Alloy for Piston of Air Compresso,r" Journal of the Korean Society of Manufacturing Process Engineers, Vol. 7, No. 1, pp.9-16, 2008.
5. Kim, S. H., "A Study on the Development of Internal Components of Hydraulic Cylinder Applied to Hydrogen Compressor," A Thesis for a Master degree, Changwon National University, Republic of Korea, 2019.
6. Lee, T. H., Kim, M. J., “Experimental and numerical Study on the Hydrogen Refueling Process”, Korean Hydrogen and New Energy

society, Vol. 18, No.3, pp.342-347, 2007.

7. Shin, H. J., "CFD Analysis of an AirCompressor for a Hydrogen Electric Car," Transactions of the Korean Society of Mechanical Engineers-B, Vol. 42, No. 12, pp.853-859, 2018
8. Baek, S. W., "Propagation and Technologies on Hydrogen Fueling Station," Journal of the Korean Society of Automotive Engineers, Vol. 41, No. 2, pp. 28-32, 2019.