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# Structural Safety Evaluation of Multi-Pressure Integrated Chamber for Sport-Multi-Artificial Environment System

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# 스포츠 멀티 인공환경 시스템을 위한 다중압력 일체형 챔버의 구조안전성 평가

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**Abstract** There are several dedicated individual chambers for sports that are supplied and used, but none of them are multi-pressured all-in-one chambers that can provide a sport-multi environment simultaneously. In this study, we design a multi-pressure (positive / atmospheric / negative pressure) integrated chamber that can be used for the sport-multi-artificial environment system. We presented new chamber designs with enlarged space for the tall users and then carried out structural analysis with maximum stress and structural safety. Under the targeted allowable pressure conditions, maximum stresses occurred at the joint of the shell and the entrance, the structural safety of the chamber was evaluated with the allowable stress of its material. As a result of the structural analysis of the multi-pressure integrated chamber, the maximum stress for the positive pressure and negative pressure conditions was much smaller than the allowable stress of its material. And as a result of the structural safety evaluation, it was confirmed that the design of the final prototype for the chamber was structurally safe by satisfying the safety factor of 2 or more.

**요 약** 스포츠를 위해 제공되고 사용되는 몇 가지 전용 챔버가 공급되어 사용되고 있지만 스포츠 멀티 환경을 동시에 제공할 수 있는 다기능 올인원 챔버는 개발되지 않았다. 본 연구에서는 스포츠 다중 인공 환경 시스템에 사용할 수 있는 다중 압력 (양 / 대기 / 음압) 일체형 챔버를 설계하였다. 키가 큰 사용자를 위해 공간을 넓힌 새로운 챔버 디자인을 제시 한 다음 최대 응력과 구조적 안전성검토를 통하여 챔버의 구조해석을 수행하였다. 목표로 하는 허용 압력 조건하에서 쉘과 출입구의 접합부에서 최대 응력이 발생했으며, 챔버 재료의 허용응력을 기준으로 하여 구조안전성 평가를 수행하였다. 다중 압력 일체형 챔버에 대하여 구조해석을 수행한 결과 양압과 음압 조건에 대한 최대 응력이 챔버 재료의 허용응력 보다 훨씬 작은 값이 발생되었으며, 구조안전성 평가 결과 안전율 2 이상을 만족하여 챔버의 최종 시제품의 설계가 구조적으로 안전하다는 것을 확인하였다.

**Keywords :** Integrated Chamber, Multi-Pressure, Sport-Multi-Artificial Environment, Structural Analysis, Structural Safety Evaluation

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## 1. Introduction

A multi-pressure integrated chamber is a chamber in which the pressure of the internal air can be controlled with positive pressure, atmospheric or negative pressure. In the case of regular chambers, the internal air is created in an environment with positive and high oxygen pressure, and is used for conditioning management, such as fast fatigue recovery after competition and training. It is also used for prevention and recovery of altitude sickness caused by pressure drop[1]. Negative and low oxygen pressure chambers have the advantages of improving the exercise performance of elite athletes by sports and adapting to the environment in advance. In some countries, individual sports chambers, which allow for negative pressure with low oxygen, and positive pressure with high oxygen environment chambers are supplied and used[2-4]. However, all over the world there are no multi-pressured all-in-one chambers that can provide a sport-multi environment simultaneously. There is a growing demand for developing multi-pressure integrated chambers that can meet the needs of improved performance and fast rehabilitation in various sports and reduce the cost of adaptive training overseas. Therefore, in this study, new design for chamber model of enlarged space is presented for tall users. It has a structure in which a portion of the vessel with a smaller diameter than the shell of the pressure vessel is added. Because of the welded joint in the opening at the upper part of the vessel, reinforcement for opening was applied according to ASME Boiler and Pressure Vessel Code Section VIII Div.1. Structural strength calculations for the minimum wall thickness of the pressure vessel were performed, and then, structural analysis and structural safety evaluation of the multi-pressure (positive / atmospheric / negative pressure) integrated chamber was carried out on new designed product that can be used under positive pressure and negative pressure conditions.

## 2. Design Condition of Chamber

For the calculation of structural strength of the vessel, the pressure vessel was performed and the structural strength calculations for the minimum wall thickness of the pressure vessel were done according to the requirements of the design specification ASME Section VIII Div.1[5-7].

The design conditions are as shown in Table 1, and results of strength calculations are as follows.

Table 1. Design conditions

| Parameters | Values |
|---|---|
| Design pressure | 0.3 MPa (3 bar) |
| Inside diameter of shell | 1984 mm (O.D : 2000 mm) |
| Joint efficiency | 0.85 |
| Shell Material | SA-516 Gr.70 |
| Head material | SA-516 Gr.70 |

The thickness of the shell part of the pressure vessel, which is suitable for the conditions, was obtained by:

$$t_s = \frac{PR}{SE - 0.6P} \quad (1)$$

where, $t_s$ = Minimum design thickness of shell, P = Internal design pressure, R = Inside radius of shell, S = Maximum allowable stress valve, E = Joint efficiency.

The thickness of the head of the pressure vessel appropriate for the conditions is obtained by:

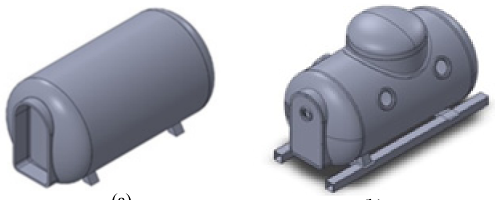
$$t_h = \frac{PD}{2SE - 0.2P} \quad (2)$$

where, $t_h$ = Minimum required thickness of head, D = Inside length of the major axis of an ellipsoidal head.

For the structural analysis conditions, the negative pressure of 0.039247 MPa at 8000 m above the sea level and the positive pressure of 0.3 MPa (3 bar) were applied.

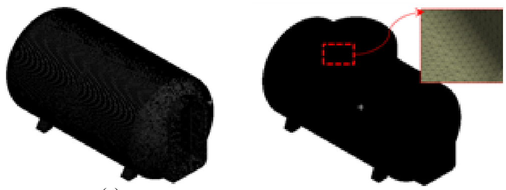
## 3. Structural Analysis and Safety Evaluation

The size of the existing vessel model is 2000 mm with outer diameter and it is somewhat smaller for tall users. Therefore, additional design model of enlarged space is presented. The additional design model has a structure in which a part of the vessel with smaller diameter than that of the existing vessel model is added to the top of the existing vessel. Because of the welded joint in the opening at the upper part of the vessel, reinforcement for opening was applied and modeled according to ASME Boiler and Pressure Vessel Code Section VIII Div.1. Fig. 1 shows the modelling of vessel used in this study and using the commercial design software of Solidworks. Fig. 2 shows the finite element model of existing and new multi-pressure vessels. Additional design models were analyzed based on the results of the previous analysis of pressure vessel readings as shown. Finite element information for the structural analysis of multi-pressure (positive / atmospheric / negative pressure) integrated vessel is presented in Table 2. Its numerical analysis was carried out by using the commercial analysis software ANSYS.



(a) (b)

Fig. 1. Geometric model of vessel
(a) Existing Model (b) New Model



(a) (b)

Fig. 2. Finite Element model of vessel
(a) Existing Model (b) New Model

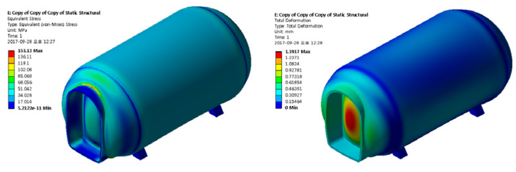
Table 2. Finite element Information

| Method of mesh generating | Patch conforming algorithm |
|---|---|
| Type of mesh | 3-D 8-Node Structural Solid (SOLID185), 3-D 4-Node Tetrahedral Structural Solid (SOLID285) |
| number of Elements | 562,089 |
| number of Nodes | 1,091,673 |

## 4. Analysis Results

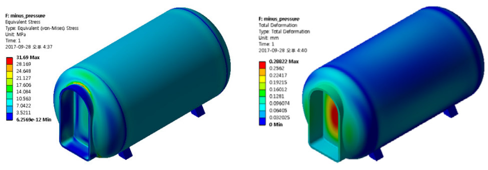
The results of structural analysis for 0.3 MPa (3 bar) of the internal pressure condition are shown in Fig. 3. The maximum stress is 153.13 MPa and the maximum deformation is 1.3917 mm for existing vessel model under the conditions of positive pressure. The maximum stress occurred at the joint of the pressure vessel head and entrance door frame and the maximum deformation was occurred at the center of the entrance door plate.

In case of the negative pressure, the maximum stress of 31.69 MPa and the maximum deformation as 0.28822 mm was occurred at the same position in case of positive pressure for existing vessel model as show in Fig. 4.



(a) (b)

Fig. 3. Results of positive pressure for existing model
(a) Stress distribution (b) Deformation



(a) (b)

Fig. 4. Results of negative pressure for existing model
(a) Stress distribution (b) Deformation

It is evident that the vessel is safe for the both positive pressure and negative pressure conditions when maximum stress is much smaller value than the yield strength of SA-516 Gr.70.

New vessel design was carried out with enlarged space for the tall users and reinforcement pads were added to the joints to reduce the maximum stress. The reinforcement pads thickness were 8.0, 12.7, and 16.0 mm, with three different cases presented as follows.

The structural analysis results of the new vessel model for the positive pressure condition show that the maximum stress is 297.97 MPa when the reinforcement pad thickness is 8.0 mm, 290.92 MPa when the reinforcement pad thickness is 12.7 mm, and 127.49 MPa when the reinforcement pad thickness is 16.0 mm are shown in Fig. 5. According to these results, The new vessel model with extended space for tall users shows that the maximum stress is lower than the yield strength of SA-516 Gr.70 and therefore it is safe under positive pressure conditions.

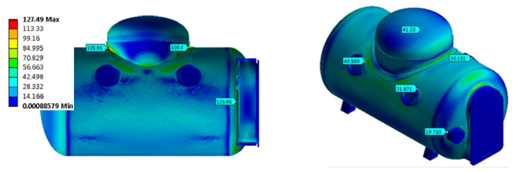



Fig. 5. Results of stress for new model (reinforcement pads thickness is 16.0 mm)

For the positive pressure condition, The results of the structural safety evaluation of the final prototype of the multi-pressure (positive / atmospheric / negative pressure) integrated chamber are as shown in the Fig. 6 and Fig. 7. The Max. at the joint between the pressure chamber body and the dome ceiling. Stress was obtained at 105.86 MPa and SA-516 Gr.70 material with yield strength of 260 MPa was used. Safety Factor was calculated to be 2.45. At the entrance of the pressure vessel and the joint of the elliptical end plate, Max. Stress was occured at 127.49 MPa, and Min. Safety Factor was calculated as 2.04. At the joint between the pressure chamber body and the nozzle, Max. Stress was occured at 49.58 MPa, and Min. Safety Factor was calculated as 5.24. In the joint between the elliptical end plate and the nozzle at the entrance side, Max. Stress was occured at 19.73 MPa, and Min. Safety Factor was calculated as 13.17. At the junction of doorway and nozzle, Max. Stress was 97.33 MPa, and Min. Safety Factor was calculated as 2.67. The results of structural analysis and structural safety evaluation of multi-pressure (positive / atmospheric / negative pressure) integrated chambers satisfy Safety Factor 2 and above, so the design of the final prototype for the product is considered to be structurally safe.

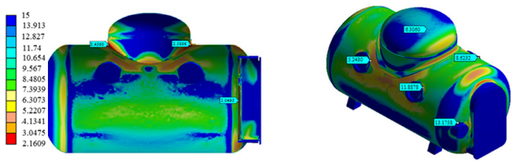



Fig. 6. Results of safety factor for new model (reinforcement pads thickness is 16.0 mm)


Fig. 7. Results of structural safety evaluation with reinforcement pad thickness

## 5. Conclusions

In this study, structural analysis was carried out on the multi-pressure (positive / atmospheric / negative pressure) integrated chamber for sport-multi-artificial environment system that can be used under both the positive and negative pressure conditions, and the results are as follows.

1) In case the new vessel model, the structural analysis was carried out for the reinforcement pad thicknesses of 8.0 mm, 12.7 mm and 16.0 mm. As a result, when the reinforcement pad thickness was 16.0 mm, the maximum stress value was 127.49 MPa, which was suitable for structural safety.
2) The results of structural analysis and structural safety evaluation of multiple pressure (negative / atmospheric / positive) integrated chambers satisfy Safety Factor 2 and above, so the design of the final prototype for the product is considered to be structurally safe.
3) By structural analysis of multi-pressure integrated chamber for sport-multi-artificial environment system, the new design of multi-pressure integrated chamber was well designed so that it can withstand the positive pressure and the negative pressure conditions.

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