Thesis for the Degree of Master of Engineering

A study on seat structure design for full seal effect of globe valve

by

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February 24, 2017

A study on seat structure design for full seal effect of globe valve (글로브 밸브의 완전 기밀 효과를 위한 시트 구조 설계에 관한 연구)

Advisor: Prof. Jae-Seob Kwak

by
Gyeong Ah Kang

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A study on seat structure design for full seal effect of globe valve

A dissertation

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Approved by:

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(Chairman) Dae-Min Kang

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(Member) Tae-Wan Kim

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(Member) Jae-Seob Kwak

February 24, 2017

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Nomenclature

A	:	Distance between top of seat and groove
B	:	Width of groove
C	:	Height of groove
D	:	Span between grooves
	:	Number of cycles to material fatigue
	:	The desired value
$x\ (k)$	:	The ideal sequence
$x_i^*(k)$	:	The generating value
min $x_i(k)$	:	The minimum value of sequence
max $x_i(k)$	:	The maximum value of sequence
ζ	:	Distinguishing coefficient
σ	:	Von-Mises stress
σ_a	:	The alternating stress
σ_{fat}	:	The fatigue limit
σ_m	:	The mean stress
σ_{ts}	:	The ultimate tensile strength of the material
$\triangle$	:	Radial deformation
$\triangle l$	:	Longitudinal deformation

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글로브 밸브의 완전 기밀 효과를 위한
시트 구조 설계에 관한 연구

강 경 아

부 경 대 학 교 대 학 원 기 계 공 학 과

요 약

글로브 밸브는 밸브의 한 종류로, 고압의 배관 내 유로를 개폐하거나 유량을 제어하는 기구이다. 글로브 밸브의 유로 개폐는 바디 내부 구조물인 시트와 디스크의 접촉으로 인해 이루어진다. 다양한 기체 혹은 액체를 운송하기 위해 내부식성이 강한 스테인리스 계 재료로 제작된 밸브는 연신율 또한 뛰어나기 때문에 고압의 작업환경에서 내부 구조물의 뒤틀림으로 인하여 시트의 파손 및 누설이 발생하기 쉽다. 또한 실제 산업 현장에서는 래핑가공 시 디스크와 시트의 접촉면에 남겨진 마이크로 단위의 요철 혹은 조립공차에 따른 축 어긋남과 같은 예기치 못한 누설이 발생하기도 한다.

이러한 문제점을 효율적으로 해결하기 위하여 본 논문에서는 시트 내부에 그루브를 설계하고, 그루브로 인한 시트의 변형에 따라 디스크와 시트가 완전히 접촉함으로써 밸브의 완전 기밀 효과를 유도하였다. 이를 유한요소해석을 통해 그루브의 형상과 치수에 따라 각 시트에 발생하는 응력과 변형량으로 분석하였다.

그 결과, 네모 형상의 그루브를 가진 시트가 디스크로부터 압력을 받을 때 시트와 디스크의 접촉부가 노치 형상이 되어 길이 방향의 변형량이 증가하고 내부 방향으로 굽혀지는 자체 보강 효과가 가장 뛰어났다. 이를 통해 시트 자체의 탄성 변형을 이용하여 시트가 유연하게 디스크와의 접촉을 이루며 별도의 장비 없이 경제적으로 밸브의 기밀성을 향상시킬 수 있음을 알 수 있었다.

또한 그루브로 인하여 시트의 강성이 약해지는 것을 고려하여 피로 해석에 대한 연구를 진행하였고, 그루브를 가진 시트가 반복적인 하중에도 충분한 수명을 보장한다는 것을 알 수 있었다.

1. Introduction

1.1 Statement of problem and significance of study

Valve is a component for controlling flow rate of pipeline. It is usually used not only in our daily life but also fuel oil system, extraction drain system, turbine, cooling water system, gas pipe, power plant and many other industries.[1, 2]

One of the control valves, a globe valve shuts the flow on and off or controls the flow rate by changing a gap between disc and seat.[3] Globe valve has both strengths and weakness for users. One of the strong strengths of it is excellent throttling ability under the high-pressure. The weakness includes a severe noise caused by irregular flow from complicated inside structure which seems like English alphabet 'S', cavitation and other stubborn structural problems.[4, 5] Also when the valve opens and closes, a stem must turn down spirally many times. It makes difficulty to find location where is complete opening and closing of valve. If the stem moves excessively, seat can get damaged. Furthermore owing to stem bending and assembly tolerance, misaligned central axis of disc and seat causes damage of seat and leakage from this is hardly predicted.[6]

User can be embarrassed and in trouble to judge when they experienced that unpredictable leakage. A major cause of this leakage is eventually bad contact between disc and seat. To maintain a valve sealing, the full contact between disc and seat is required even though when there are some unpredicted problems on contact. Most of existing disc and seat make contact at 45° chamfered edge, recently many studies are concentrating on design improvement of valve components to ensure the valve sealing. While various valve compositions are newly designed, unpredicted leakage is still beyond control.

For this reason, in this study, conventional globe valve seat was slightly modified and renovated for retaining the valve sealing. Using CAD and CAE, redesigned seat was compared with standard seat and its effect on sealing performance was analyzed. Also seat design was optimized with gray relational analysis.

1.2 Review of related literature and studies

Currently studies associated with valve are mostly divided to flow characteristic analysis and structure transformation by pressure or temperature difference. In the past, experiment was usually performed but it wasted lots of cost and time. Thus lately as a method of valve analysis, simulation using commercial software is mostly used and experiment is done depending on industrial standard at where the field of actual operation.

Fluid analysis accounts for dominant position in studies of valve. As fluid analysis, cavitation, performance improvement of valve, flow rate evaluation according to temperature or pressure difference and noise are frequently evaluated subject in detail.[7-9]

Jazi[10] investigated cavitation by observing characteristic of flow and acoustic emission. Then this study revealed that undesired cavitation came about due to pressure difference in flow and its incipient point was detectable on certain valve opening range.

In the other study, several flow characteristics are examined to predict and find out pressure loss of valve.[11] Likewise, effect of cone angle at globe valve was evaluated by Lin[12] and it had little effect on flow coefficient.

On the other hand, there were many studies about noise in a control valves. A study about aerodynamic noise according to changing the cage configuration was carried out by Sreekala[13] using a three dimensional CFD.

As stated above, most of the studies contained new designed component of valve and evaluated its efficiency concerning cavitation, flow coefficient, noise and other characteristics.

But recently, the need of Fluid Structure Interaction (FSI) analysis is rising.[14, 15] Because not only fluid analysis but also structural transformation consequential temperature and pressure difference is important in research reliability.

In accordance with necessity of FSI, stress or deformation analysis of either disc, seat or other components when the pressure was applied to valve was widely performed.[16, 17] In advance Kim[18] performed structural analysis and evaluated deformation for stability of globe valve under the pressure. Then using heat transfer model and thermal expansion model, stress and deformation of valve were investigated. Finally two methods, structural analysis and thermal expansion model, were combined for stability evaluation technique.

Though the valves used previous researches don't have theoretical problems, components of each valves are totally different with standard ones.[19-21] Therefore these valves cause additional cost to existing users and it is still vulnerable to misalignment which makes leakage.

Thus to overcome a temporal contact and respond with flexibility, a study about valve structure which ensures to tighten contact for anti-leakage is needed.

2. Theoretical background

2.1 Globe valve seat design

Fig. 2-1 shows schematized globe valve. First, external actuator works and rotates a stem. Then rotating stem has disc move down spirally toward seat. At this moment, the flow rate, throttling, opening and closing of valve can be controlled using the gap distance between disc and seat.

If the material of seat is metal, the pressure applied to seat should be high enough to uniform contact for sealing. The shape of seat is ring and it is fixed at internal baffle of valve body by form of thread. It can be partially replaced with new one. Therefore if the seat can improve sealing performance without any additional assist device, it will be the best solution in terms of saving cost and time.

To improve sealing performance of valve, thus the new designed seat has a groove inside. Modeling of conventional seat and new designed seat is shown in Fig. 2-2. When the disc press the seat if the seat has a groove inside, the seat heads to inside since bending occurred at contact region. In addition this deformation of seat increases the deformation of longitudinal direction.

These deformation changes of seat can induce tighten and uniform contact between disc and seat. It can be named the self-supporting effect and its mechanism is shown in Fig. 2-3.

In this paper, the self-supporting effect was analyzed as to shape of groove and the most effective groove shape was selected to additional simulation with respect to dimensions of groove.

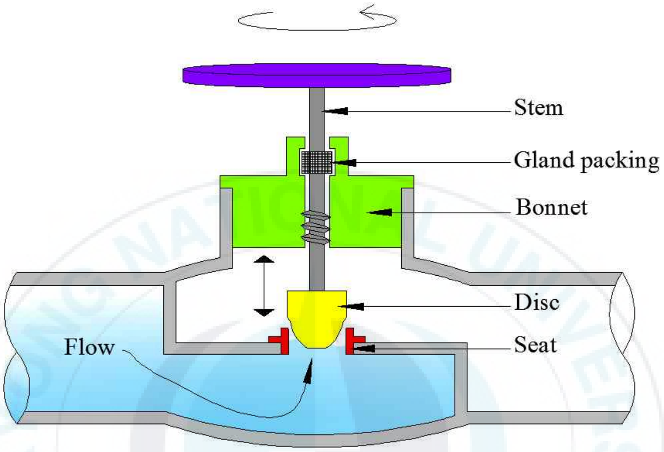


Fig. 2-1 Main component parts of globe valve

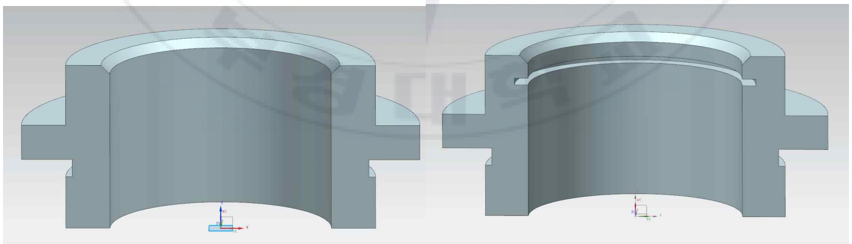


Fig. 2-2 Modeling of conventional seat and new designed seat

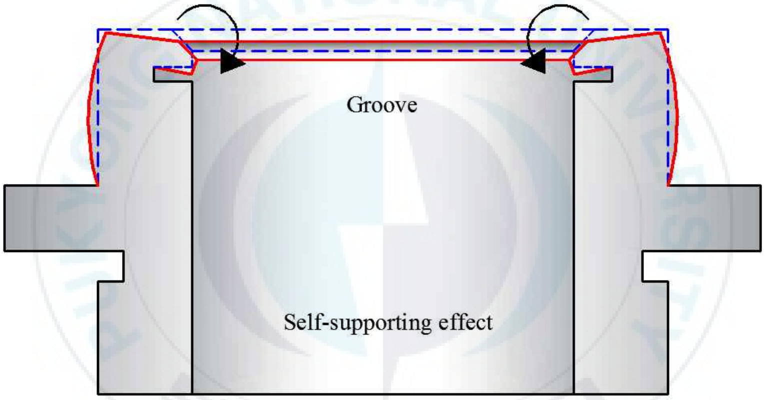


Fig. 2-3 Self-supporting effect of seat with inner groove

2.2 Gray relational analysis

The gray theory was devised in 1982. The gray theory has a system having normalized date according to its purpose. Gray means poor, incomplete and uncertain state. The aim of gray theory system is proposing an efficient solution of multi-characteristics. It has large application field of agriculture, ecology, economy, industry, material science and others which require a careful consideration on complicated problem.[22]

Among the gray theory, the gray relational analysis (GRA) not only can apply to cluster analysis but also measure their relationships. At the end of GRA calculations, gray relational grade has optimal value of multi-characteristics having different objects [23, 24]. The procedure of GRA is shown in Fig. 2-4.[25]

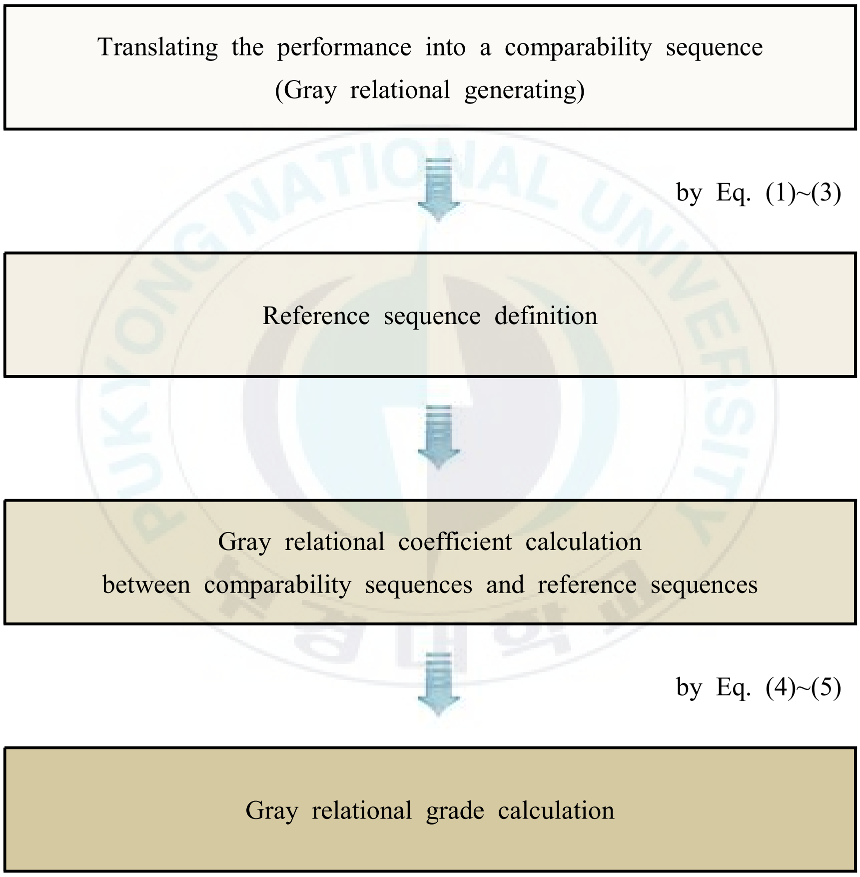


Fig. 2-4 Procedure of gray relational analysis

2.2.1. Data pre-processing

In GRA, if the date is widely distributed and standard value is tremendous, some factors will be neglected and if the direction of goals is different, optimal multi-characteristics could draw improper results.[26]

Therefore, as date pre-processing, the original date should be normalized into some sequences which are called gray relational generation. The range of the gray relational generation is between zero and one. If each original date has different object direction when sequences are normalized, they can be classified to three types.

If the target value of the date is infinite, the original date should be normalized as follows : [27, 28]

1. The-higher-the-better

$$x_i^*(k) = \frac{x_i^*(k) - min x_i(k)}{max\ x_i(k) - min\ x_i(k)} \tag{1}$$

If the target value of the date is the-smaller-the-better, then the original date should be normalized as follows:

2. The-smaller-the-better

$$x_i^*(k) = \frac{max\ x_i^*(k) - x_i(k)}{max\ x_i(k) - min\ x_i(k)} \tag{2}$$

However, if the target value should be a specific value, the original date should be normalized as follows:

3. The-nominal-the-better

$$x_i^*(k) = 1 - \frac{|x_i(k) - x|}{max\ x_i(k) - x} \tag{3}$$

Where $^*(k)$ is the generating value after date pre-processing of the gray relational analysis; min $x_i(k)$ is the smallest value and max $x_i(k)$ is the largest value of every $x_i(k)$; and x is the desired value.[28]

2.2.2 Gray relational coefficient and grade

After data pre-processing, gray relational coefficient is calculated to indicate the relationship between the ideal sequence and normalized sequences. The gray relational coefficient can be calculated as follows :

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta \cdot \Delta_{\max}}{\Delta_{0i}(k) + \zeta \cdot \Delta_{\max}} \tag{4}$$

Where $\triangle_i\, k)$ is the deviation from the target value and the each normalized date, ζ is a distinguishing coefficient, The range of the distinguishing coefficient is between zero and one, and 0.5 is generally used. The deviation can be calculated as follows : [29]

$$\Delta_{0i}(k) = \| x_0^*(k) - x_i^*(k) \| \tag{5.1}$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \| x_0^*(k) - x_j^*(k) \| \tag{5.2}$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \| x_0^*(k) - x_j^*(k) \| \tag{5.3}$$

Where $x_0^*(k)$ is ideal value. Ideal sequence which means desired value or target value is always 1 regardless of date performance characteristics. After gaining the gray relational coefficient, the gray relational grade can be obtained by taking the average of the gray relational coefficient.

In gray relational grade, if ideal sequence and comparability sequence are equal, then the value of gray relational grade will be 1.[30] Generally, a higher value of the gray relational grade means a strong relationship between the ideal sequence and the comparative sequence. Therefore, the higher value of the gray relational grade is closer to the optimal condition.

2.3 Fatigue analysis

Fatigue means structural damage from repeated loading and unloading. If the material is exposed to repeated loading, tiny crack would be formed. With stress concentration, when a crack become a bigger size, the crack will propagate gradually and the material will be crushed.

ASTM International which is standards organization defines fatigue life as , the number of cycles until fatigue is occurred. For some materials, especially steel and titanium, there is a specific value for stress amplitude called a fatigue limit, fatigue strength or endurance limit.

There are usually two methods to acquire the fatigue life of a structure: the stress-life method and the strain-life method. Stress life method is useful at high-cycle fatigue when the applied stresses and occurred deformation are elastic. On the other hand, strain life method is used for low-cycle fatigue when applied load is combined with elastic and plastic.[31]

In high-cycle fatigue, characteristic of materials is commonly shown with an S-N curve. It is a graph of a constant repetitive stress(S) according to the logarithmic scale of number of cycles to failure(N). The Fig. 2-5 shows an S-N curve for typical material. Usually S-N curves are obtained by operating a fatigue test machine with samples of the material based on standards.[32]

But the progression of fatigue test can be influenced by some internal factors and external factors like corrosion, temperature, the presence of notches and residual stresses. So to cover up these defects, enough safety factor of structure is important.[33-35]

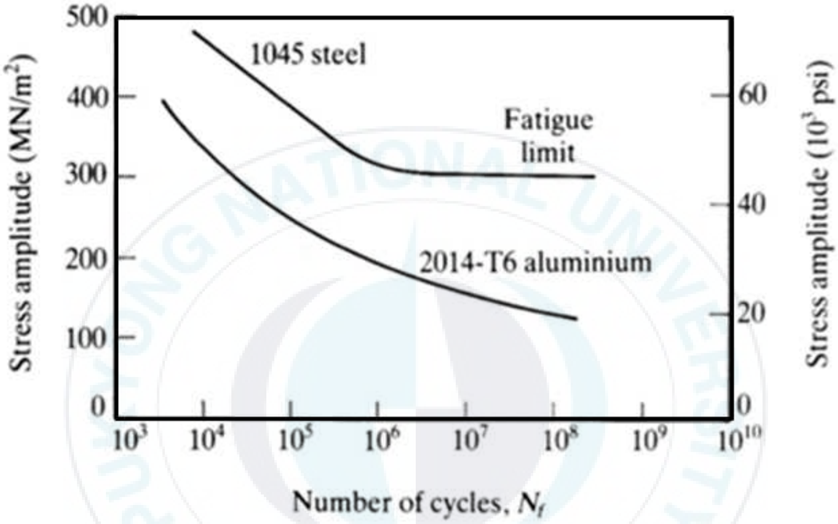


Fig. 2-5 S-N curve for typical material

3. Evaluation of new designed seat

3.1 Boundary condition for simulation

As mentioned above, this paper proposed a new type of valve seat for anti-leakage if there is a axis shift for a pressure or temperature. To show that the new designed seat can move flexibly when the pressure is applied to seat, structural analysis was performed.

Fig. 3-1 is the model for FEM simulation. Symmetry boundary condition was used for every model having different seats. The working pressure emanating from actuator is applied to disc as 3MPa. The lower part of seat is form of screw and it is fixed at internal baffle of the body. So disc contacts with top of the seat and it is role of seal performance of valve. To obtain the more accurate date, mesh of simulation model was used square form and the detailed mesh information is shown in Table 3-1.

The material for disc, seat and stem is a stainless steel(SUS 316) usually used in marine environments because of its great corrosion resistance. But one of another character of SUS 316, elongation which makes stem bent prominently under the high-pressure. Table 3-2 shows chemical composition of SUS 316 and Table 3-3 shows the material property of SUS 316.

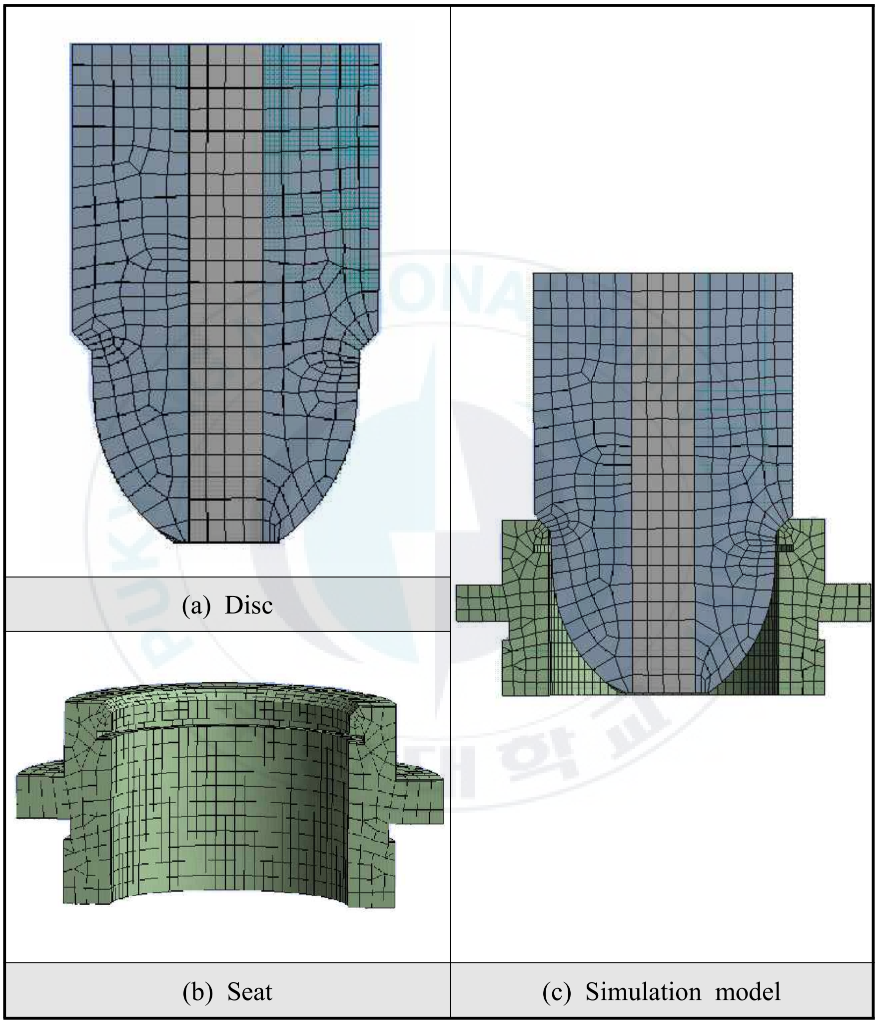


Fig. 3-1 Mesh information of disc and seat

Table 3-1 Mesh information of valve model

Number of nodes	76,381
Number of elements	16,622
Mesh size of seat (mm)	1.5
Mesh size of disc (mm)	1.5
Contact area mesh size (mm)	0.5

Table 3-2 Chemical composition of SUS316

Material	Proportion (%)
Carbon	0.08
Manganese	2.00
Phosphorus	0.045
Sulfur	0.030
Silicon	0.75
Chromium	16.00-18.00
Nickel	10.00-14.00
Molybdenum	2.00-3.00
Nitrogen	0.10
Iron	Balance

Table 3-3 Mechanical property of SUS316

Property	Value
Density(kg/m^3)	8000
Poisson’s ratio	0.27
Yield strength(MPa)	205
Tensile strength(MPa)	515
Compression strength(MPa)	170
Modulus of elasticity(MPa)	193
Elongation (%)	40
Hardness Rockwell B	95

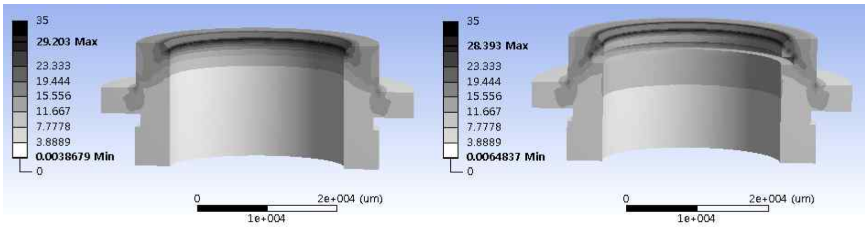
3.2 Comparing with standard seat

According to above boundary condition, the simulation results of each seat are shown in Fig. 3-2. As simulation results, Von-Mises stress, radial directional deformation, longitudinal directional deformation and contact spot between disc and seat are gained.

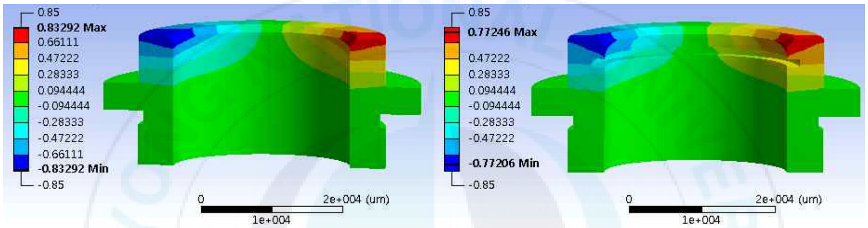
Von-Mises stress occurred on each seat were almost similar as about 30MPa and both maximum stress were shown at contact region between disc and seat.

In two directional deformation, a new designed seat had a bigger longitudinal deformation and a smaller radial deformation due to bending. Longitudinal deformation increased from 0.069 m to 0.3μm and radial deformation reduced from 0.812μm to 0.772μm.

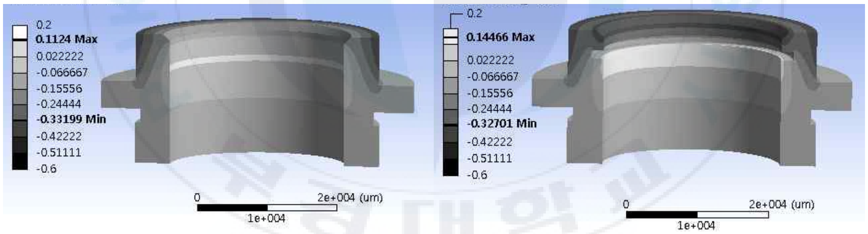
Therefore, the new designed seat can obtain tighten and uniform contact with disc from reduced radial deformation and expanded available seal area from increased longitudinal deformation. It improves the seal performance of valve. How this distortion of seat can affect valve sealing performance is schematized at Fig. 3-3.



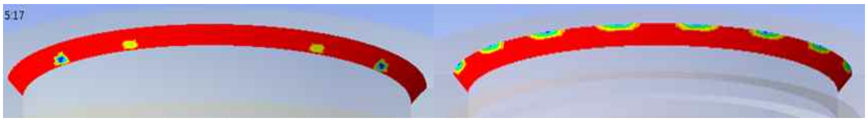
(a) Von-Mises stress



(b) Radial directional deformation



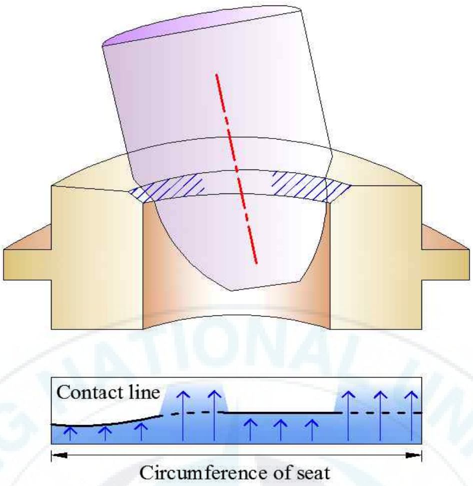
(c) Longitudinal directional deformation



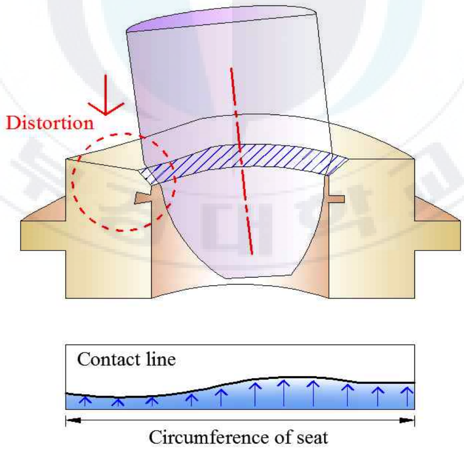
(d) Contact spot between disc and seat

Standard seat **New designed seat**

Fig. 3-2 Simulation results of each seat



(a) Standard seat



(b) New designed seat

Fig. 3-3 The full contact effect gained from designed seat

4. Optimization for improving the sealing performance

4.1 Characteristics estimation according to seat shape

4.1.1 Design of inner groove

Now we need to compare what form of grooves is the best and how much it can effect on sealing performance. For this comparison, some form of grooves are chosen. The shape of grooves were divided into 4 and those are shown in Fig. 4-1. The standard seat which is typically used also exist for comfortable comparison. As groove patterns, square, equilateral triangle, right-angled triangle, and double square, each patterns are located at same distance below from top of seat. Each constant volume removed as patterns are $100mm^2$.

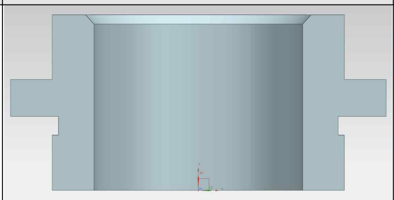
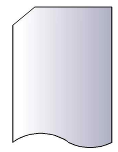
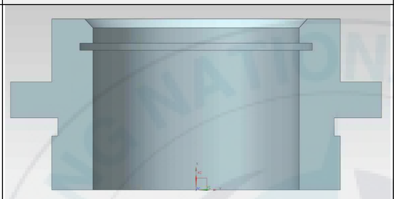
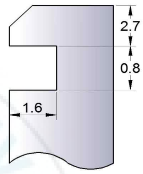
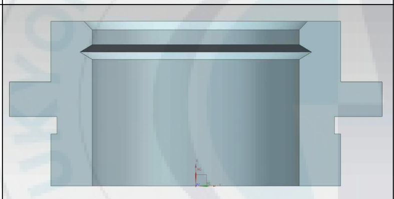
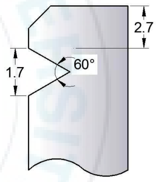
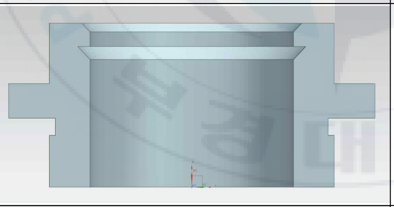
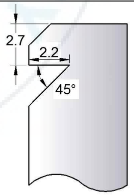
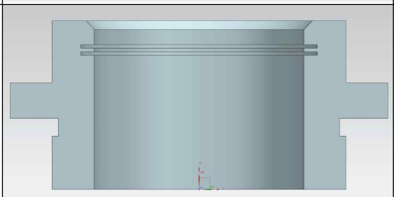
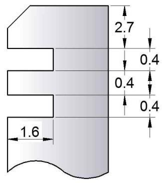
Model No.	Cross section	Groove pattern	
–		Standard	
1		Square	
2		Equilateral triangle	
3		Right-angled triangle	
4		Double square	

Fig. 4-1 Different pattern shapes of groove

4.1.2 Simulation results

As structural analysis simulation results of each seat model, Von-Mises stress and two directional deformation occurred on each seat were gained. Two directional deformation are divided into radial deformation, ΔD and Z-axis longitudinal deformation, Δl. The measurement point of two directional deformation is the end point of contact boundary and it is shown in Fig. 4-2.

Fig. 4-3 shows a graph comparing Von-Mises stress results of seat when the each seat is under the 3MPa pressure from disc. Every Von-Mises stresses occurred are below 205MPa which is yield strength of SUS 316 and have a safety factor higher than 6.

The maximum stress was occurred at contact region and it can be known in Fig. 4-4.

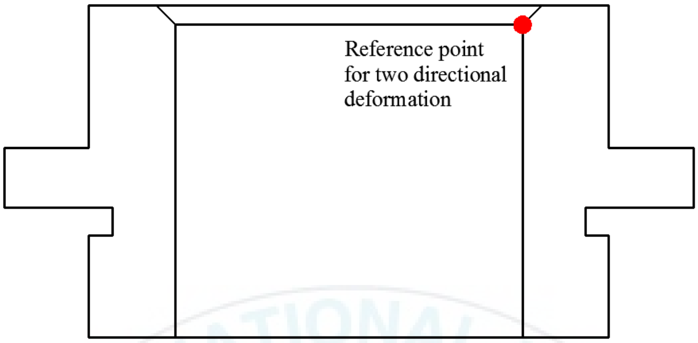


Fig. 4-2 Measurement point at seat

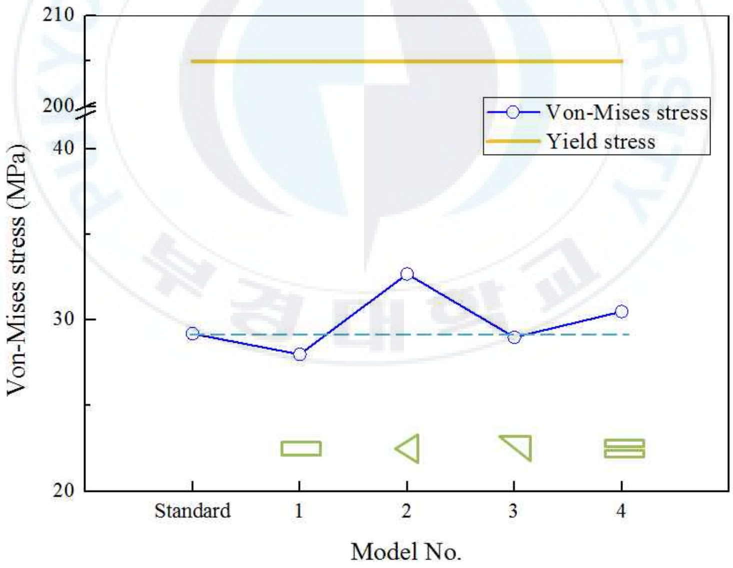


Fig. 4-3 Von-Mises stress result comparison

On the other hand, to axis-compensation, the most important thing is how to distort a seat well. Distortion means a deformation of seat. When the new designed seat is pressed, radial deformation is reduced and longitudinal deformation is increased due to bending of groove. This bending eliminates the gap in which fluid flows and would be a role of anti-leakage of valve.

In Fig. 3-5 is shown a results comparison of two directional deformation. Minimum ΔD toward outside was equal to 0.78μm at Model 1 and 5 having a square groove seat.

Maximum Δl was 0.28μm at Model 4. Considering results of Model 1, 2 and 3, it is clear that the most significant shape of groove for longitudinal deformation was a square. Detailed radial deformation results and longitudinal deformation results are shown in Fig. 3-6 and 3-7.

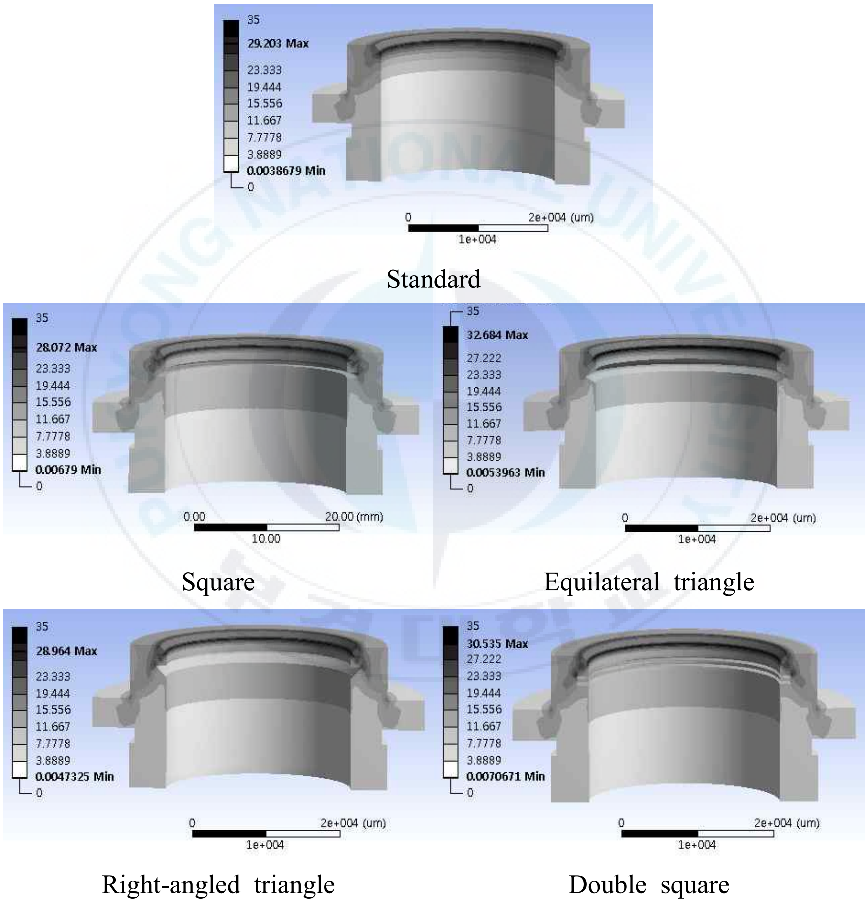


Fig. 4-4 Von-Mises stress results

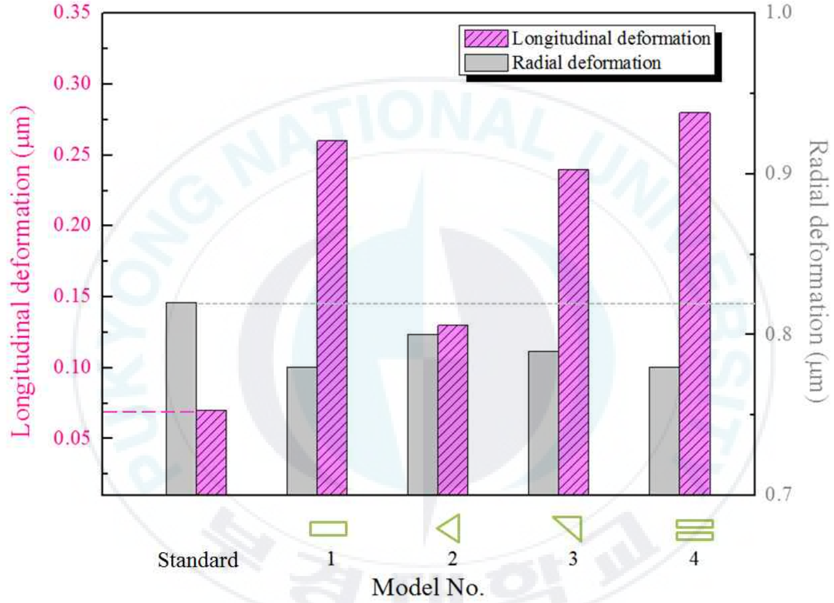
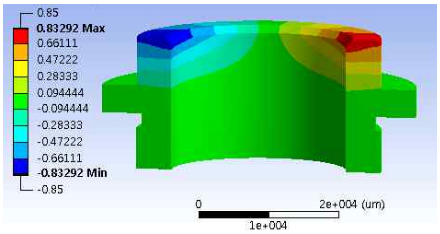
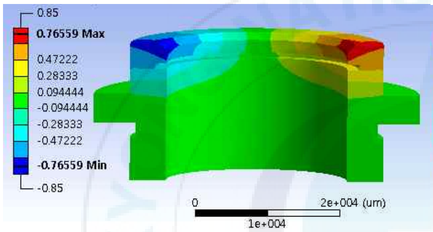


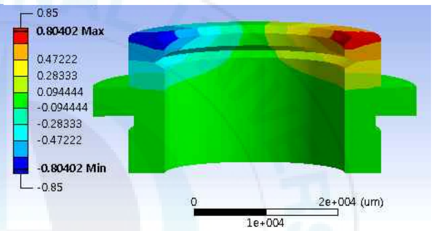
Fig. 4-5 Two directional deformation result comparison



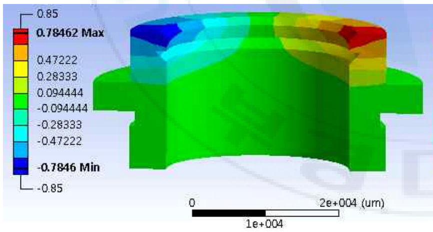
Standard



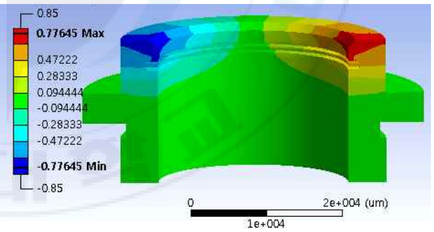
Square



Equilateral triangle

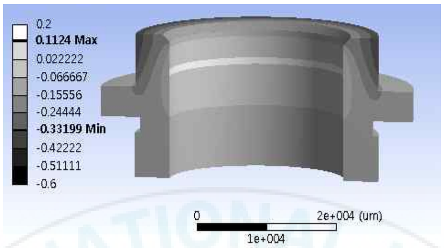


Right-angled triangle

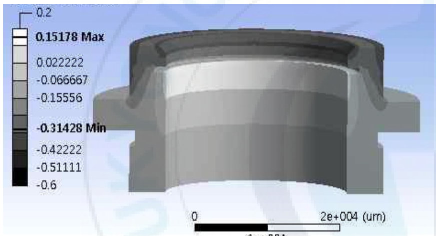


Double square

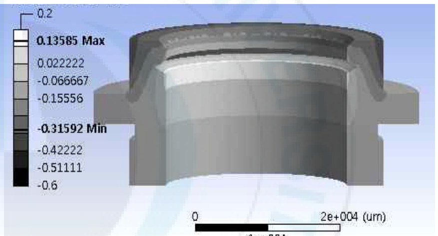
Fig. 4-6 Radial directional deformation results



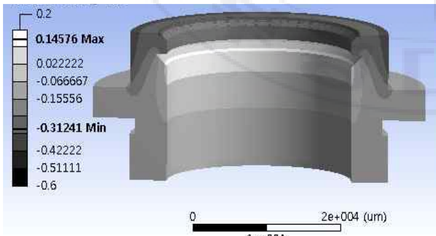
Standard



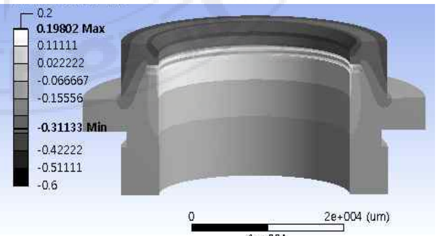
Square



Equilateral triangle



Right-angled triangle



Double square

Fig. 4-7 Longitudinal directional deformation results

4.2 Characteristics estimation according to seat dimensions

As results of preceding simulations, the seat having a square groove improves flexibility of seat more than other shape. However transform of seat also is influenced by either dimension or location of groove. Thus on the basis of preceding results, additional simulation for deformation analysis by change of groove dimension is needed.

For this, dimension factors of groove are shown in Fig. 4-8 as A(distance between surface of seat and groove), B(width of groove), C(height of groove) and D(span between grooves). Through the foundation simulation, each factor had three levels and it can be seen in Table 4-1. To investigate the effect of each factor on seat transform, simulation plan [4], such as Table 4-2, was prepared using a experiments design. Then, after additional simulations, results are shown in Table 4-3.

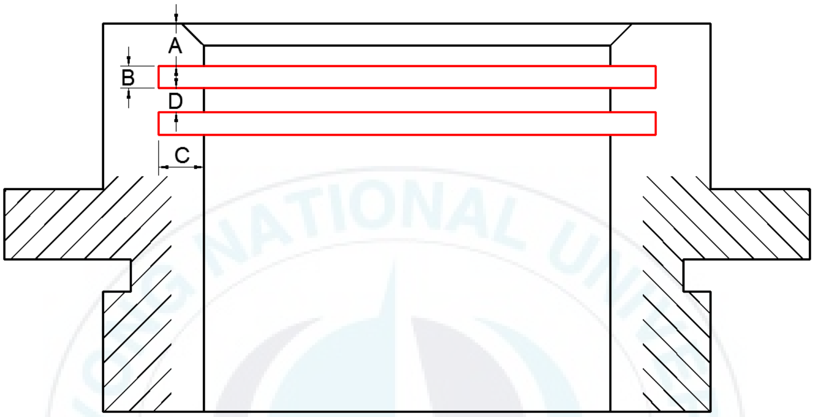


Fig. 4-8 Groove dimension factors of seat

Table 4-1 Factors and levels of groove dimension

(Unit : mm)

Symbol	Description	Level of parameters		
		1	2	3
A	Distance between upper surface of seat and groove	2	2.4	2.8
B	Width of groove	0.4	0.8	1.2
C	Height of groove	1.4	1.7	2
D	Span between grooves	0	0.4	0.8

Table 4-2 L9 orthogonal array

Simulation No.	Parameters			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4-3 Observed values of additional simulation

Simulation No.	Observed values		
	Von-Mises stress (MPa)	Radial deformation (m)	Longitudinal deformation (μm)
1	31.36	1	0.412
2	34.27	0.831	0.484
3	36.75	0.878	0.631
4	31.05	0.774	0.338
5	36.23	0.752	0.512
6	27.7	0.823	0.258
7	33.36	0.748	0.412
8	30.77	0.799	0.208
9	28.27	0.772	0.3

4.2.1 Multi-optimization using gray relational analysis

The major characteristics values of this paper are Von-Mises stress and two directional deformation. For optimizing these obtained multiple values simultaneously, a GRA is adopted.

To take GRA, date pre-processing is required. The original sequence should be normalized to gray relational generation and its range is zero to 1. Ideal value which is target value is equal to 1.

In this work, since every seats had safety factor of Von-Mises stress more than 6 times about 205MPa which is a yield strength of SUS 316, stability of seat seems not significant factor.

Therefore, multiple optimization using GRA was performed for two directional deformation on transform of seat. In date pre-processing of GRA, for flexibility of seat, radial deformation should be a smaller value and longitudinal deformation should be a higher value. Calculating these feature, the gray relational generating of two directional deformation were gained at Table 4-4 using Eqs. 1 and 2.

Also the deviation sequences of each the gray relational generating $\triangle_i$ $\triangle_{\max}(k)$ and $\triangle_{\min}(k)$ of ΔD and Δl can be calculated as follows :

1. In case of ΔD

$$\triangle_{01}(1) = \left|x_0^*(k) - x_1^*(k)\right| = |1-0| = 1$$

$$\triangle_{02}(1) = \left|x_0^*(k) - x_2^*(k)\right| = |1-0.671| = 0.329 \quad (6)$$

$$\vdots$$

2. In case of Δl

$$\triangle_{01}(2) = \left|x_0^*(k) - x_1^*(k)\right| = |1-0.482| = 0.518$$

$$\triangle_{02}(2) = \left|x_0^*(k) - x_2^*(k)\right| = |1-0.652| = 0.348 \quad (7)$$

$$\vdots$$

All results of the deviation sequences are shown in Table 4-5.

Table 4-4 Gray relational generating of two deformations

Simulation No.	Radial deformation	Longitudinal deformation
	Ideal sequence : 1	
1	0	0.4823
2	0.6706	0.6525
3	0.4841	1
4	0.8968	0.3073
5	0.9841	0.7187
6	0.7024	0.1182
7	1	0.4823
8	0.7976	0
9	0.9048	0.2175

Table 4-5 All results of the deviation sequences

Deviation sequences	$\triangle\ _{i}\ 1)$	$\triangle_{0i}(2)$
Simulation No. 1	1	0.5177
Simulation No. 2	0.3294	0.3475
Simulation No. 3	0.5159	0
Simulation No. 4	0.1032	0.6927
Simulation No. 5	0.0159	0.2813
Simulation No. 6	0.2976	0.8818
Simulation No. 7	0	0.5177
Simulation No. 8	0.2024	1
Simulation No. 9	0.0953	0.7825

When it comes to converting deviation sequences to the gray relational coefficient, the distinguishing coefficient is usually set at 0.5 and its range is 0 to 1. By applying Eq. 4, the gray relational coefficient value is noted on the Table 4-3. The gray relational coefficients of three values can be averaged to the gray relational grades. Finally grade value was normalized two different characteristics, which enables easy comparison analysis. Having high grade value means high relevance between reference sequence and comparability sequence, which means that seat deformation from bending of groove increases the full contact effect.

According to Table 4-6, simulation No. 5 gets the highest grade value. Maximum value on grade was 0.8046, and minimum value was 0.4123, which makes the difference 0.3923. To find out how much the gray relational grade value affects each seat's deformation, Table 4-7 indicates a mean response table of Taguchi method.

The major contributor on seat deformation was the height of groove, factor C. The ratio of contribution of factor C exceeded 70% of the sum of variance, occupying most of them. Contact form between seat and disc is the shape of beam due to groove.

Since the higher groove plays a role of longer beam, factor C can be the most important factor.

Factor A was the second biggest factor which accounts for 13.6%, followed by factor B with the impact of 11.4% and factor D has least impact on deformation with approximately 5%. In addition, the multi-optimum levels of groove dimensions associated with seat deformation are as follows: 2.4mm distance between upper surface of seat and groove, 0.8mm width of groove, 2mm height of groove and 0.8mm gap between grooves (A2B2C3D3).

Relationship between the gray relational grades and response is shown in Fig. 4-9. Factor C has a almost linear levels-the gray relational grade values. By comparison, factor A, B and C have a little difference in levels-the gray relational grade values and there is no consistency.

Table 4-6 Calculated gray relational coefficient and grade

Simulation No.	Gray relational coefficient		Gray relational grade	Orders
	Radial deformation	Longitudinal deformation		
1	0.3333	0.4913	0.4123	9
2	0.6029	0.5900	0.5964	6
3	0.4922	1	0.7461	2
4	0.8289	0.4192	0.6241	4
5	0.9692	0.6399	0.8046	1
6	0.6269	0.3618	0.4944	8
7	1	0.4913	0.7456	3
8	0.7119	0.3333	0.5226	7
9	0.8400	0.3899	0.6149	5

Table 4-7 Mean response table for gray relational grade

Factor level	Control parameters			
	A	B	C	D
1	0.5849	0.5940	0.4764	0.6106
2	0.6410*	0.6412*	0.6118	0.6121
3	0.6277	0.6185	0.7654*	0.6309*
Max-min	0.0561	0.0472	0.2890	0.0203
Total	0.4126			
Contribution (%)	13.60	11.44	70.04	4.92

* Optimal level

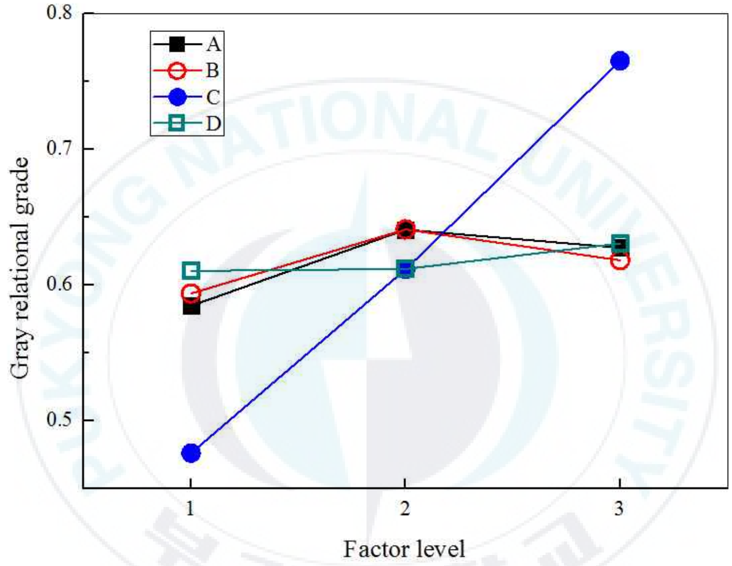


Fig. 4-9 Mean response graph of gray relational grade

A simulation for seeking the optimal combination levels associated with multi-performance characteristics was performed. Table 4-8 shows the simulation results of the optimal combination levels. A predicted gray relational grade value of optimal condition using the Taguchi design analysis makes the difference about 10% with simulation of actual optimal condition.

If there are nine experiments at 3 levels & 4 factors design of experiment, error term disappears and interaction can't be judged .[36-39] Thus an error is likely to interaction.[40] Usually when the interaction exists, only optimal combination of main effect is not working but combination of each level-main effect is meaningful.

However by analyzing results of preceding nine simulation, because simulation No. 5 is enough to bring out the advantage of groove, hence additional simulation for interaction analysis didn't be conducted. In conclusion, results of simulation No. 5 are shown in Fig. 4-10 and Table 4-9.

Table 4-9 shows Von-Mises stress values and two directional deformation values occurred on a designed seat of simulation No. 5 and standard seat under the pressure. Von-Mises stress value occurred on the designed seat was higher than that of standard seat but those are much less than 205MPa which means yield strength of SUS316.

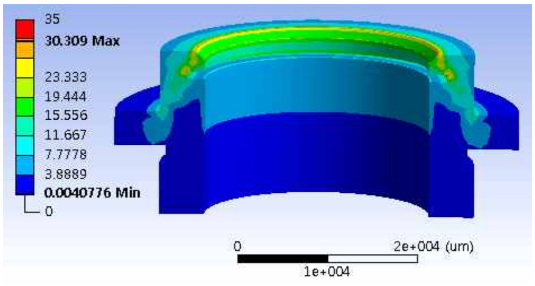
By optimizing groove, radial deformation value decreased 0.812 m to 0.752μm and longitudinal deformation value quite increased 0.069μm to 0.512μm which induces the full contact effect between disc and seat although there is either misalignment, stem bending, high pressure or assembly tolerance.

Table 4-8 Results of the confirmation simulation

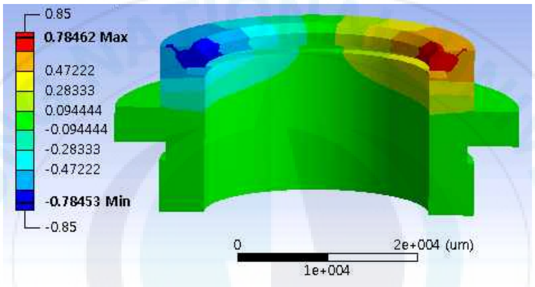
Observer values	Predicted optimal condition	Optimal combination levels of groove dimension
Setting level	A2B2C3D3	A2B2C3D3
Von-Mises stress (MPa)	-	30.98
Radial deformation (m)	-	0.752
Longitudinal deformation (μm)	-	0.414
Gray relational grade	0.8249	0.731

Table 4-9 Comparing standard seat with simulation No. 5

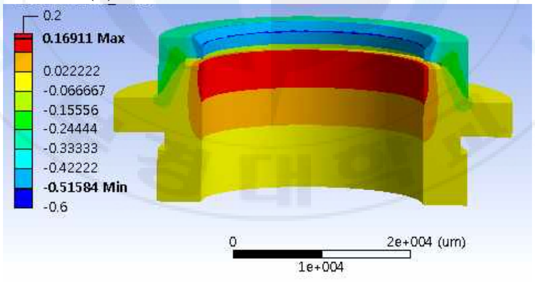
Observer values	Standard seat	Simulation No. 5
Setting level	-	A2B2C3D1
Von-Mises stress (MPa)	29.20	36.23
Radial deformation (μm)	0.812	0.752
Longitudinal deformation (μm)	0.069	0.512
Gray relational grade	0.264	0.8046



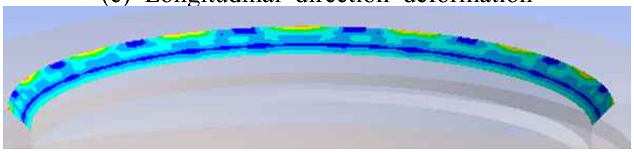
(a) Von-Mises stress



(b) Radial direction deformation



(c) Longitudinal direction deformation



(d) Contact spot between disc and seat

Fig. 4-10 Simulation result of simulation No. 5

4.3 Seat stability evaluation based on fatigue analysis

Unlike standard seat, the new designed seat in this paper has a inner groove. Earlier, this groove was used to induce a transformation of the seat and to improve the anti-leakage function of the valve. But as it received pressure from the disc, it took on the role of a beam to be used for the elasticity of the structure, thus being in constant danger of receiving damage. This is because although the seat of the groove is under stress, and even if this stress is below the yield strength of the material, a repeated application of weight on the groove leads to hairline cracks and damage. Especially when the beam becomes thinner and longer there is a big transformation, necessitating an evaluation about the safety of the beam.

As to globe valves, they are not typically being opened and shut all that often, but the applied stress is elastic and the transformation occurring on the seat is not a plastic transformation but an elastic transformation, which is why a high cycle fatigue analysis is being conducted.[41] Fig. 4-11 indicates S-N curve of

SUS 316. In high cycle fatigue analysis, usually not fewer than 0 cycle-stress amplitude is needed.

The fatigue analysis simulation, as an extension to the earlier mentioned structural analysis simulation, has the same boundary conditions as the latter. Only, the pressure directed onto the seat repeatedly is applied in a zero-based manner. As method of fatigue is the Goodman theory which suggest the Eq. (8) used and load histories of fatigue analysis is shown in Fig. 4-12.

$$\sigma_a = \sigma_{fat} \times \left. 1 - \frac{\sigma_m}{\sigma_{ts}} \right) \tag{8}$$

Where σ_a is the alternating stress, σ_{fat} is the fatigue limit, σ_m is the mean stress and σ_{ts} is the ultimate tensile strength of the material.[40]

The results of fatigue simulation are shown in Fig. 4-13. A seat having a groove has a structural capacity to an actual applied load of about 4 on both edges of the groove and the contact region with the disc, guaranteeing a long lifespan even in the HFC.

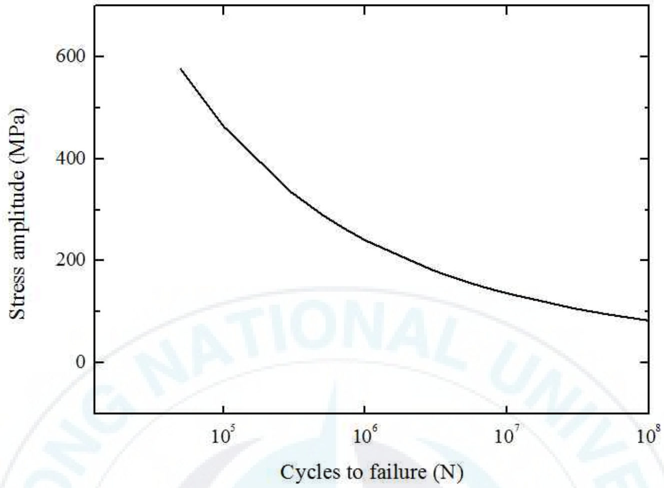


Fig. 4-11 S-N curve of SUS 316

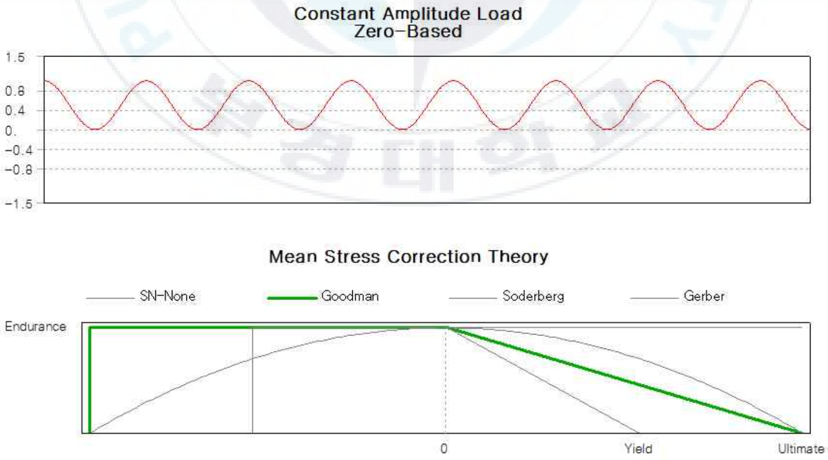
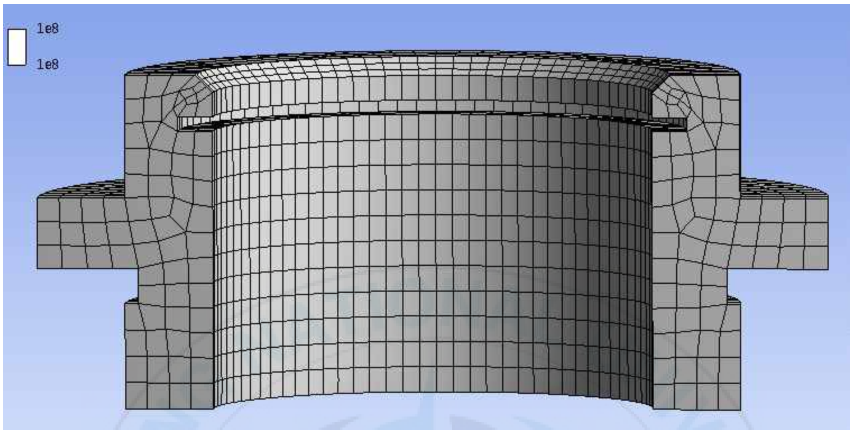
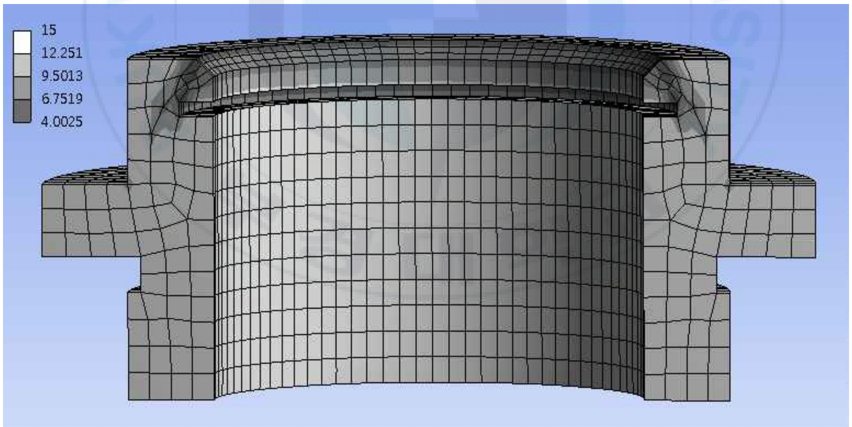


Fig. 4-12 Load histories of fatigue analysis



(a) Life



(b) Safety factor

Fig. 4-13 Fatigue analysis result at optimal condition

5. Conclusions

In this study, a standard seat is modified in an efficient way for anti-leakage of globe valve. It has a groove which let seat bend toward inside and expand available contact area with disc. Von-Mises stress and two directional deformations of the new designed seat were analyzed and conclusions are obtained as follows:

1. Compared with the standard seat, the new designed seat was subject to bending due to pressure emanating from the disc, thus leading to smaller radial deformation and to a bigger longitudinal deformation.

2. When a shape of groove is square, the contact region between disc and seat became like beam and transformation of seat was increased.

3. Analyzing the normalized two directional deformation values using the gray relational analysis, the multi-optimization dimension was 2.4mm distance between upper surface of seat and groove, 0.8mm width of groove, 2mm height of groove and 0.8mm gap between grooves. When it comes to dimension factors, factor C, height of groove had a dominant effect on transformation of seat.

4. As a result of fatigue failure, a designed seat having a groove had a structural capacity to actual applied load of about 4 each, guaranteeing a long lifespan even in the HFC.

5. By using an elastic deformation from groove, the designed seat satisfies the full contact effect with disc and improves sealing performance of globe valve.

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감사의 글

석사란 무엇일까? 라는 호기심에서 비롯하여 시작되었던 저의 대학원생활이 이제 막을 내려가고 있습니다. 처음 대학원에 들어왔을 땐, 학생과 직장인의 그 모호한 경계만큼이나 제가 해야 하는 것과 할 수 있는 일이 무엇인지 알기 힘들었습니다. 그 어느 때보다도 의구심으로 가득 차 있었던 생활이 주변인들의 도움으로 익숙해질 무렵, 저는 이 감사의 글을 써내려가게 되었습니다.

우선 제가 학부생일 때부터 지도해주신 저의 지도 교수님, 곽재섭 교수님께 감사의 인사를 드립니다. 연구뿐만 아니라 인생에 대한 조언을 아낌없이 해주셨기에 보다 더 나은 제가 될 수 있었습니다. 또한, 저의 석사학위 논문을 무사히 마칠 수 있도록 시간 내주시고 성심껏 지도해주신 강대민 교수님과 김태완 교수님께 감사드립니다. 덕분에 더욱 완성도 있는 논문이 될 수 있었습니다.

또 같이 연구실에서 생활했던 상오선배, 태희선배, 창민선배, 한성선배, 창근선배, 병훈선배, 동현선배, 주은이, 다솜이, 세영이, 수진이 그리고 여기에 미처 다 적지는 못하겠지만 초심회 선배님들, 임한석 사장님, 박진효 교수님을 비롯한 모든 분들께 감사드립니다. 기쁘기도 힘들기도 했던 다사다난한 2년이었지만 좋은 분들을 만나 값진 경험을 하게 되어 행복합니다.

마지막으로 항상 저를 믿어주시고 응원해주시는 부모님, 그리고 항상 내 편인 태환이 오빠와 선영이, 멀리서 응원해주는 소중한 친구들 모두 너무 고맙고 사랑합니다. 힘들 때마다 저를 응원해주신 여러분께 앞으로 제가 도움됐으면 하는 바람입니다.

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