

Valve Seat Design for Full Contact Effect Using Grey Relational Analysis

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ABSTRACT

A glove valve regulates the flow in a pipeline as a kind of control valve. However, when the disc and seat contact, the valve structure can be distorted and flow can leak due to the elongation of the valve material under high pressure. The surface texture is not good enough to seal the contact surface (in practice) because the lapping process is usually done manually. Furthermore, assembly performance is analyzed by structural analysis. Compared with a standard seat, the newly designed seat had a smaller radial deformation and a larger longitudinal deformation. Therefore, the newly designed seat can maintain a tight and uniform contact with the disc with a reduced radial deformation and an expanded available seal area with an increased longitudinal deformation. The seal performance of the glove valve has been improved in a cost-effective manner.

Keywords : Glove Valve(글로브 밸브), Seat design(시트 설계), Structure Analysis(구조 해석), Grey Relational Analysis(회색 관계 분석), Full Contact Effect (완전 접촉 효과)

1. Introduction

Glove valves have played an important role in piping systems conveying fluid and been widely used in industries such as mechanical, petroleum, chemical engineering and so forth.

They are commonly applied to pipe lines to control fluid flow because of throttling ability under high pressure. However, there are drawbacks in terms

of noise and leakage during operation. A severe noise level brings out cavitation and irregular flow caused by complicated structure inside valves. In addition, leakage results from mechanical problems such as excessive moving stem, assembly tolerance and misaligned central axis between disc and seat^[1]. As a consequence these factors could contribute to less life expectancy and performance to the valves.

Although majority of studies focused on impacts of flow variations and cavitation by modifying internal or external structures of various types of valves^[2-4], a few research paid the attention to the sealing

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performance, in particular changing the seat structure inside the globe valve.

Therefore, this paper aims to proposed new designed seat and evaluate four different patterns of seat shapes compared with the conventional one in terms of longitudinal and radial directional deformation using finite element method(FEM). In addition, optimal dimension parameters satisfying multiple characteristics of the selected design would be determined employing grey relational analysis(GRA) for enhancing full contact ability of the globe valve.

2. Computational Simulation

In this research, material for disc, seat and stem is SUS316 because of high level of corrosion resistance and elongation under high pressure.

Conducted standard seat which generally contacts disc at 45° chambered edge and new designed seat having a single groove patterns for anti-leakage are illustrated in Fig. 1.

Based on FEM, the effect of two directional deformation on seal performance is evaluated in comparison with the conventional type, and then direction of these two variations is analyzed.

In order to find the optimum shape for full sealing, four different groove shapes which are single square, equilateral triangle, right-angled triangle and

double squares are simulated.

Futhermore, a suitable design resulted from preceding simulations is selected and then dimension parameters of the shape are analyzed using a Taguchi's $L_9(3^4)$ orthogonal array table. After this stage, GRA is performed based on desired sequences of two directional variations induced from the previous simulation in order to find the biggest attribute among various parameters and produce the optimized seat.

The working pressure applied to the disc is about 3MPa. A measurement point of radial deformation, ΔD , and longitudinal deformation, Δl , for both models is marked in red as shown in Fig. 1.

The square mesh form of the modeling used in FEM simulation is adopted. Distribution of mesh around evaluated point is 0.5mm, which is more denser than other areas about 1.5mm to obtain precise results.

3. Result and Discussion

3.1 Effect of two directional deformation

When the disc and seat made contact under 3MPa, Von-Misses stress of both seats were nearly 30MPa which is significant lower than the yield stress of SUS316, about 205MPa. Accordingly, the effect of this factor had not influence on seal performance. With regard to single groove seat, longitudinal

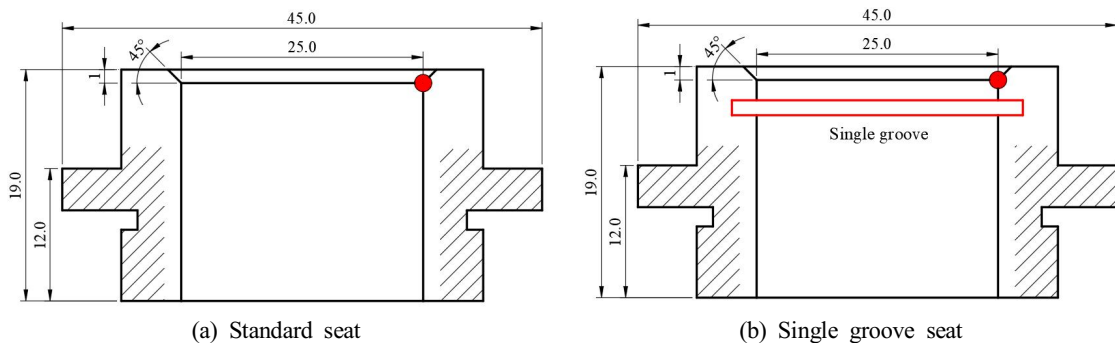


Fig. 1 Measurement point for two directional deformation

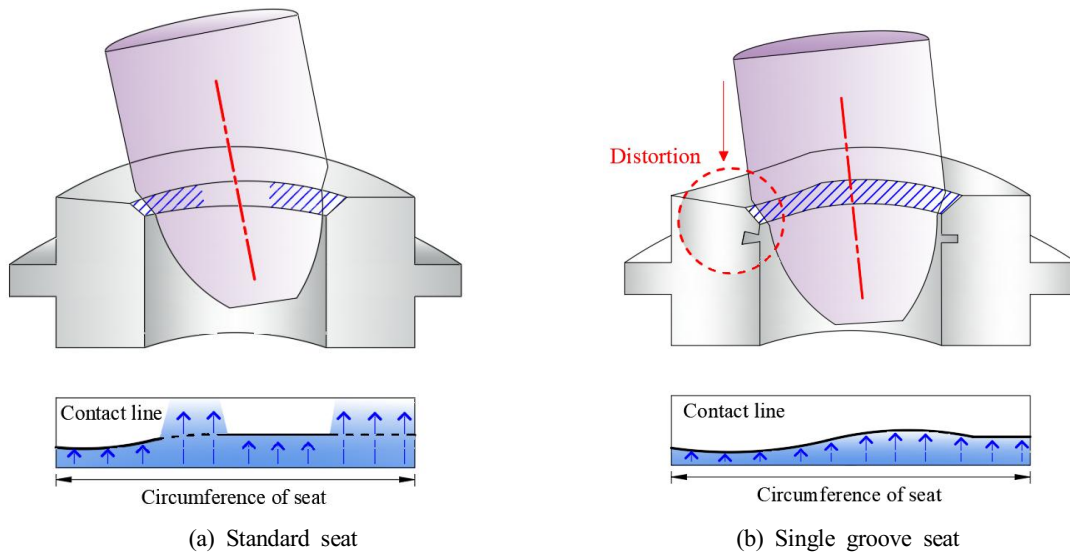


Fig. 2 Full contact effect for sealing performance

deformation increased by $0.191\mu\text{m}$ from $0.069\mu\text{m}$ to $0.26\mu\text{m}$ while radial value reduced by $0.032\mu\text{m}$ from $0.812\mu\text{m}$ to $0.78\mu\text{m}$ in comparison with standard type.

According to results, the new designed seat was expected to improve ability of the contact area between the disc and seat, since bending occurs at a contact region due to the groove. It means that these changes induce tighten and uniform contact with disc from decreased radial deformation and expanded available seal area from increased longitudinal deformation as represented in Fig. 2. The conducted effect in paper was called as self-supporting effect.

3.2 Evaluation of four patterns of the seat

As previously stated, bending induced from groove shape could prevent unexpected leakage. In other to know the effect of groove shapes on seal performance, four different types of patterns were analyzed considering two directional aspects. Table 1 shows various patterns which were single groove, equilateral triangle, right-angled triangle and double grooves corresponding to model no. 1, 2, 3 and 4

respectively. The removed volume of them was identical, about 100 mm^2 .

According to the simulation results illustrated in Fig. 3, the trend of radial variation, ΔD , dropped by approximately 4% at every conducted shapes, which were $0.78\mu\text{m}$, $0.80\mu\text{m}$, $0.79\mu\text{m}$, and $0.78\mu\text{m}$ respectively. On the other hand, longitudinal variation, Δl , increased about $0.26\mu\text{m}$, $0.13\mu\text{m}$, $0.24\mu\text{m}$, and $0.28\mu\text{m}$ respectively.


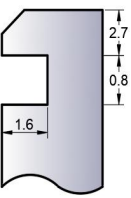
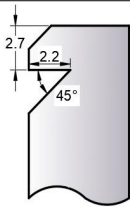
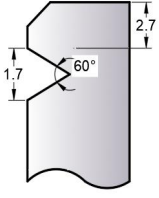
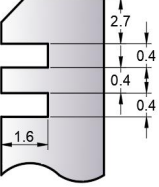
It was noted that contact ability was enhanced when the seat has the smaller radial value and the bigger longitudinal value. Therefore, the double grooves, no. 4, which had minimum ΔD and maximum Δl had the superior flexibility than other alternatives.

3.3 Evaluation of the optimized seat

According to conducted simulations, it was proved that the revised seat having double grooves pattern enhanced the sealing performance.

Therefore, in this section, four controllable dimension parameters shown in Fig. 4 were considered to find

Table 1 Conducted patterns with standard model

No.	Groove patterns	
-	Standard	
1	Single groove	
2	Equilateral Triangle	
3	Right-angled Triangle	
4	Double grooves	

the biggest contribute of the optimal seat design. The controlled factors with three levels were listed in Table 2. To analyze the effect of dimension parameters on full contact ability, all the simulations were carried out based on Taguchi's $L_9(3^4)$ orthogonal array table. As the consequence, two deformation values at each simulation were obtained as shown in Table 3.

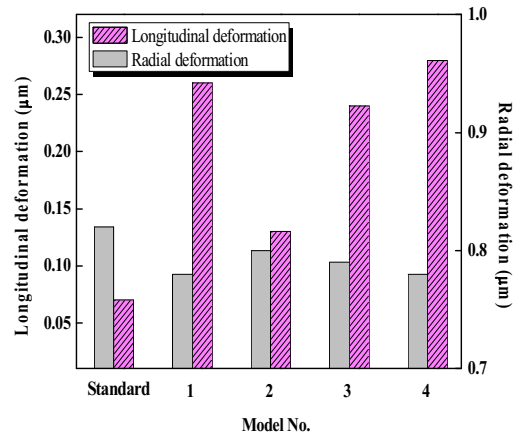


Fig. 3 Results of distortion for different patterns

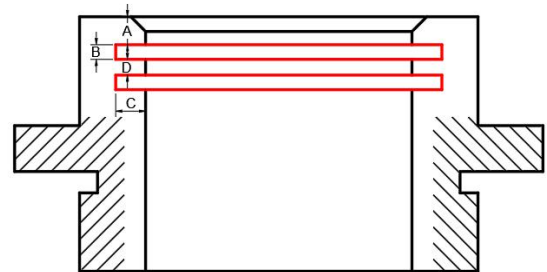


Fig. 4 Dimension factors of double groove seat

Table 2 Considered dimension parameters and levels

Description	Levels		
	1	2	3
Distance between top of the seat and groove, A(mm)	2.0	2.4	2.8
Width of groove, B(mm)	0.4	0.8	1.2
Height of groove, C(mm)	1.4	1.7	2.0
Span between groove, D(mm)	0.0	0.4	0.8

In order to investigate optimal parameters under multiple characteristics, GRA was carried out based on observed data shown in Table 3. The value of Von-Misses stress in all simulations were almost same, about 30MPa.

Table 3 The results of observed two deformation and grey relational analysis by orthogonal array table

No.	Parameters				Observed value		Grey relational generating		Grey relational coefficient		Grade	Orders
	A	B	C	D	$\Delta D(\mu m)$	$\Delta l(\mu m)$	$\Delta D(\mu m)$	$\Delta l(\mu m)$	$\Delta D(\mu m)$	$\Delta l(\mu m)$		
1	1	1	1	1	1.000	0.412	0.0000	0.4823	0.3333	0.4913	0.4123	9
2	1	2	2	2	0.831	0.484	0.6706	0.6525	0.6029	0.5900	0.5964	6
3	1	3	3	3	0.878	0.631	0.4841	1.0000	0.4922	1.0000	0.7461	2
4	2	1	2	3	0.774	0.338	0.8968	0.3073	0.8289	0.4192	0.6241	4
5	2	2	3	1	0.752	0.512	0.9841	0.7187	0.9692	0.6399	0.8046	1
6	2	3	1	2	0.823	0.258	0.7024	0.1182	0.6269	0.3618	0.4944	8
7	3	1	3	2	0.748	0.412	1.0000	0.4823	1.0000	0.4913	0.7456	3
8	3	2	2	3	0.799	0.208	0.7976	0.0000	0.7119	0.3333	0.5226	7
9	3	3	1	1	0.772	0.300	0.9048	0.2175	0.8400	0.3899	0.6149	5

Therefore, it was clearly noted that this value was not a key factor affecting seal performance so it was not considered same as other evaluations. As stated, the target value of longitudinal distortion desired the bigger values while radial distortion aimed the smaller values. Accordingly, grey generating values for longitudinal and radial deformation were calculated as follows^[5,6].

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

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

Where $x_i^*(k)$ is the generating value after data pre-processing of GRA, $x_i(k)$ denotes the experimental data, $\min x_i(k)$ and $\max x_i(k)$ are the smallest and largest values respectively.

With regard to deviation sequence, $\Delta_{0i}(1)$, and $\Delta_{0i}(2)$ for $i=1-9$, are obtained as follows.

$$\Delta_{01}(1) = |x_0^*(k) - x_i^*(k)| = 1.0000 - 0 = 1.0000$$

$$\Delta_{02}(2) = |x_0^*(k) - x_i^*(k)| = 1.0000 - 0.4823 = 0.5177$$

Grey relational coefficient converted from deviation values could be averaged to grey relational grades

Table 4 Mean response table

Level	Levels			
	A	B	C	D
1	0.5849	0.5940	0.4764	0.6106
2	0.6410*	0.6412*	0.6118	.06121
3	0.6277	0.6185	0.7654*	0.6309*
Max-min	0.0561	0.0472	0.2890	0.0203
Total	0.4126			
Contribution(%)	14	11	70	5

*Optimal level

which expressed the correlation between reference sequence and comparability sequence. It means that the highest rank of normalized grade values results in optimal combined level among the considered values. In accordance with Table 3, simulation no. 5 had the maximum grade, about 0.8046, which was close to the ideal sequences among ninth simulations.

Based on the best multiple performance characteristic acquired, the mean response variables of four controllable parameters per level were generated as reported in Table 4. Each average value was calculated by grey relational grade corresponding to the orthogonal array employed as Table 3. The highest mean response indicated the optimal level of control factors. In addition, deviation between maximum and minimum values at the same the control column was the most important factor to

determine the major attribute on experiment. As can be seen Table 4, the percentage of the factor C accounted for approximately 70% followed by factors A, B, and C which make up about 14%, 11%, and 5% respectively. Hence, it was noted that the height of groove, factor C, was the significant parameter affecting prevention of unexpected leakage.

Moreover, it was cleared that optimal parameters related to multiple performance characteristic was A2B2C3D3, which are corresponding to A, 2.4mm, B, 0.8mm, C, 2.0mm, and D, 0.8mm. In comparison with standard seat, renovated one was expected to be flexibility for full contact between the seat and disc during operation.

5. Conclusion

This paper aimed to provide the optimal seat for SUS316 considering structure deformation to improve seal performance as a cost effective way. The following results can be drawn :

1. Contact area of new designed seat having a single groove was improved by increasing longitudinal distortion, Δl , from $0.069\mu\text{m}$ to $0.26\mu\text{m}$ and reducing radial value, ΔD , from $0.812\mu\text{m}$ to $0.78\mu\text{m}$. It is noted that the revised seat bent toward inside when the disc and seat made contact, and it contributed to expanding the contact region.
2. Additional analysis for diverse patterns were carried out in terms of two directional characteristics. According to the evaluation, double squares pattern which has minimum ΔD , $0.78\mu\text{m}$, and maximum Δl , $0.28\mu\text{m}$, was the most optimized type among the conducted shapes.
3. Based on the Taguchi method and GRA, optimal dimension factors for distance between top of the seat and groove, width, height of groove and gap between grooves were 2.4mm, 0.8mm, 2.0mm, and 0.8mm respectively. When it comes to these

factors, height was the major contribution which accounted for 70% of total deviation values between maximum and minimum values.

4. It is cleared that the new designed seat could improve seal performance obtaining tighten and uniform contact with disc from reduced radial deformation and expanded available seal area from increased longitudinal deformation.

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