Investigation of the Effect of Parameters on the Tightness

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Abstract: The Center Composite Design (CCD) is built as a surrogate computationally expensive numerical simulations to improve the efficiency of the optimization design of metallic gasket. The optimization of important parameters such as wavy height, top flange thickness and gasket thickness is the goal of optimization by the CCD. Higher gasket thickness, wavy height and top flange thickness are beneficial to the improvement of sealing reliability. By comparing the optimization results with the finite element analysis results and test results, the results show that the coincidence is high and the design efficiency is greatly improved.

1. Introduction

Metallic gasket seal is widely used in the working environment including low temperature, high temperature, high pressure and other harsh working conditions. Non-metallic gasket is difficult to meet the requirements [1]. In the fields of aviation, aerospace, automobile, nuclear power, petroleum, chemical industry and construction machinery, pressure vessels, pipelines and valves, Metallic Gaskets are usually taken as the first choice [2].

It is a very difficult task to establish the relationship between the effects of various parameters on the tightness. With the development of experimental design methods, it provides us with a new analysis idea, which is to use DOE to analyse multi-parameter experimental design and their mutual influence. Saeed et al. study the influence of gasket parameters including gasket material, thickness and pressure wavy on sealing performance by taguchi method [3]. Haruyama et al. investigated the effect of contact surface width on sealing performance [4]. Research results show that increasing the contact width resulted in a lower leakage rate. From the literature review, the parameter optimization of the sealing system with metallic gaskets is still in its infancy at home and abroad [5-8]. Research results are rare and many aspects need further in-depth discussion [9-11].

The primary objective of the current numerical evaluation is to determine the optimum parameters for achieving improved sealing performance in terms of the minimum sealing pressure by CCD.

2 Response surface methodology (RSM)

The shape of the test gasket and the corrugated shape of the cross section are shown in figure 1. In order to obtain the optimal structural parameters, the influences of the wavy height, top flange thickness, gasket thickness and other factors on the sealing system were further studied by CCD.
Figure 1. Structure of metallic gasket

CCD was first proposed by Box and Wilson in 1951, which is the most commonly used second-order design in Response Surface Methodology. Compared with the traditional method, this method uses fewer experiments to study the influence of each parameter on the sealing system and the interaction between the parameters.

Table 1. The factors and levels (low and high) selected for CCD

| Variables             | Symbol | coded values |
|-----------------------|--------|--------------|
| wavy height           | A      | -α 0.26591 0 0.3 0.35 0.4 0.43409 |
| top flange thickness  | B      | 0.25 15 0.3 0.35 20 21.7045 |
| gasket thickness      | C      | 0.21591 0.3 0.35 0.43409 |

In this paper, CCD is used for experimental design. The wavy height, top flange thickness, gasket thickness were selected as the test factors (table 1), minimum contact pressure was used as the evaluation index, and a three-factor and five-level test scheme was designed based on CCD. The results are shown in table 2.

Table 2. Experimental design and results of CCD for Minimum pressure

| Run | Factor 1 A: wavy height | Factor 2 B: top flange thickness | Factor 3 C: gasket thickness | D: Minimum pressure |
|-----|-------------------------|---------------------------------|------------------------------|---------------------|
| 1   | 0.35                    | 17.5                            | 0.21591                      | 5.2                 |
| 2   | 0.35                    | 21.7045                         | 0.3                          | 6.1                 |
| 3   | 0.35                    | 17.5                            | 0.3                          | 5.8                 |
| 4   | 0.3                     | 15                              | 0.35                         | 6                   |
| 5   | 0.35                    | 13.2955                         | 0.3                          | 4.78                |
| 6   | 0.35                    | 17.5                            | 0.3                          | 5.8                 |
| 7   | 0.4                     | 15                              | 0.35                         | 6.45                |
| 8   | 0.4                     | 20                              | 0.25                         | 5.9                 |
| 9   | 0.35                    | 17.5                            | 0.3                          | 5.8                 |
| 10  | 0.43409                 | 17.5                            | 0.38409                      | 6.1                 |
| 11  | 0.35                    | 17.5                            | 0.38409                      | 7.8                 |
| 12  | 0.35                    | 17.5                            | 0.3                          | 5.8                 |
| 13  | 0.4                     | 20                              | 0.35                         | 6.66                |
| 14  | 0.3                     | 20                              | 0.25                         | 4.45                |
| 15  | 0.35                    | 17.5                            | 0.3                          | 5.8                 |
| 16  | 0.26591                 | 17.5                            | 0.3                          | 5.1                 |
| 17  | 0.3                     | 20                              | 0.35                         | 6.2                 |
| 18  | 0.35                    | 17.5                            | 0.3                          | 5.8                 |
ANOVA for Quadratic model are shown in table 3. The model results are predicted with 95% confidence and P-values less than 0.0500 indicate model terms are significant. It can be seen that the P value of the model is less than 0.0001, which proves that the model is significant at 95% confidence level. The wavy height, top flange thickness and gasket thickness are the three important parameters, and their P values are all less than 0.05. In this case, A, B, C, AC, B², C² are significant model terms. The P value of AB was 0.2800, and the P value of BC was 0.3720, indicating that there was no significant correlation between the wavy height and top flange thickness, top flange thickness and gasket thickness, respectively.

Table 3. ANOVA for the experimental results of the CCD

| Source                | Sum of Squares | df | Mean Square | F-Value | p-Value |
|-----------------------|----------------|----|-------------|---------|---------|
| Model                 | 11.53          | 9  | 1.28        | 30.70   | < 0.0001 significant |
| A- wavy height        | 1.72           | 1  | 1.72        | 41.13   | < 0.0001 |
| B- top flange thickness | 0.9384        | 1  | 0.9384      | 22.49   | 0.0008  |
| C- gasket thickness   | 7.22           | 1  | 7.22        | 173.10  | < 0.0001 |
| AB                    | 0.0544         | 1  | 0.0544      | 1.30    | 0.2800  |
| AC                    | 0.2244         | 1  | 0.2244      | 5.38    | 0.0428  |
| BC                    | 0.0365         | 1  | 0.0365      | 0.8734  | 0.3720  |
| A²                    | 0.1956         | 1  | 0.1956      | 4.69    | 0.0556  |
| B²                    | 0.4317         | 1  | 0.4317      | 10.34   | 0.0092  |
| C²                    | 0.5863         | 1  | 0.5863      | 14.05   | 0.0038  |
| Residual              | 0.4173         | 10 | 0.0417      |         |         |
| Lack of Fit           | 0.4173         | 5  | 0.0835      |         |         |
| Pure Error            | 0.0000         | 5  | 0.0000      |         |         |
| Cor Total             | 11.95          | 19 |             |         |         |

Another statistic is the F value, which indicates the importance of a parameter. The model F-value of 30.70 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The F value of gasket thickness is 173.10, indicating that this parameter is more important than the wavy height and the top flange thickness (F value <0.0001 and 0.0008, respectively).

The optimal response of each factor is further discussed by using contour map and response surface graph (figs.2-4). The gasket thickness has more influence on the minimum sealing pressure than the upper flange thickness and the upper flange thickness.

The quadratic equations of the Minimum pressure are provided below:

\[
P = 5.81 + 0.3534 \times A + 0.2621 \times B + 0.7273 \times C + 0.0825 \times AB - 0.1675 \times AC - 0.0675 \times BC - 0.1165 \times A^2 - 0.1731 \times B^2 - 0.2017 \times C^2
\]  

(1)
Figure 2. Effect of Height of ripples and Thickness of top flange on Minimum pressure
(a) 3D surface; (b) contour plot

Figure 3. Effect of Height of ripples and Thickness of the gasket on Minimum pressure
(a) 3D surface; (b) contour plot
3. Conclusions

The main conclusions of the study are listed below:

1. The influence of the wavy height, top flange thickness and gasket thickness on the minimum sealing pressure is constructed by using the center composite design method (CCD) and taking the pressure distribution of sealing belt as the evaluation index.

2. The quadratic equations of the minimum pressure are provided. The gasket thickness has the greatest influence, followed by the wavy height, and top flange thickness is the smallest. Higher gasket thickness, wavy height and top flange thickness are beneficial to the improvement of sealing reliability.

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