# Wall Thickness Design for Mine-used Explosion-proof Box

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## Abstract

Using the formula that based on thin plate theory of a small deflection to calculate the wall thickness of explosion-proof box to get the initial design of the wall thickness. The optimum wall thickness of the explosion-proof box can be derived from the simulation and the iterative calculation of plate thickness, and the thickness of the wall can be determined according to the iterative calculation results and the standard thickness of the material. The design process of the wall thickness can shorten the design cycle of the explosion-proof box and it will be a certain reference for the design of the rectangular explosion-proof enclosure.

## Keywords

Rectangular explosion-proof Box, Thickness, Simulation and Analysis, Optimal Design.

## 1. Introduction

Explosion-proof box is a kind of electrical equipment shell that used in a coal mine. With certain thickness and mechanical strength, walls of explosion-proof box have very little deformation under the explosion pressure, which can ensure that sparks inside the box can't ignite external flammable environment. So, the reliability for the wall thickness design method of flameproof box plays an essential role to its security[1-2].

## 2. Theoretical Analysis on Wall Thickness

Explosion-proof box comprises box body and cover plate with bolts connection. Box body is welded together by the bottom plate and four side plates. The thickness of the plates is far less than its width, so it can be seen as Thin Plate[3]. Because the deformation of plates subjected to explosive loading is small, based on thin plate theory of a small deflection, plates of explosion-proof box can be considered as rectangular Thin Plate whose four sides are supported and be suffered from a uniform load[4]. The thickness calculation results of plates show that their maximum stress computational formula is

$$\sigma_{\max} = \frac{M_{\max}}{W}. \tag{1}$$

where $\sigma_{\max}$ is maximum stress of the plate and $M_{\max}$ is the bending moment in the center of plate, $W$ is the bending section coefficient of plate.

Assume the plate length is 1cm, the thickness of the plate is

$$M_{max}=K_1pa^2. \tag{2}$$

$$W = \frac{d^2}{6}. \tag{3}$$

$$d = \sqrt{\frac{6K_1pa^2}{\sigma_{\max}}}. \tag{4}$$

where $a$ is the width of the plate and $d$ is thickness of the plate, $K_1$ is correlation coefficient that related to the ratio of $a$ and $b$, $p$ is the explosion pressure, $\sigma_{\max}$ is the maximum stress of the material which means $\sigma_{\max} = \sigma_s = 235MPa$ .

Table 1 The value of K1

| *a/b* | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
|---|---|---|---|---|---|---|---|---|
| $K_1$ | 0.045 | 0.043 | 0.040 | 0.037 | 0.032 | 0.027 | 0.022 | 0.018 |

## 3. The Simulation and Optimization Analysis of Plate Thickness

Thickness that calculated by the above theoretical calculation formula is often more conservative and the margin of safety is too large; they make the explosion-proof box too heavy. In order to realize the goal of minimum weight, it needs to use the simulation software to iterative computing the optimized thickness that based on stiffness and strength [5].

Before optimized designing the plate thickness, the first thing to do is establishing a simplified mathematical model of explosion-proof box, then simulate and analyze the mathematic model with the use of solidworks simulation. The conventional method for withstand voltage test of flame-proof enclosure is hydrostatic test which is applying 1MPa hydrostatic pressure on the inside face of the wall for 1min. So, during the simulation process, applying 1MPa uniform load on the inside face of the wall to replace hydrostatic pressure [6]. Thickness of plates that calculated by the theoretical formula can be checked out if it meets the strength and stiffness requirements through the simulation analysis results, and also the simulation result can provide analysis document for the following iterative calculation[7].

In the plate thickness optimization design, select $d$ as the iteration variable of the plates, define the interval iteration as: $\frac{1}{2}d_0 < d \le \frac{3}{2}d_0$, where $d_0$ is the theoretical value that calculate by formula (4); select the minimum weight as optimal design goals[8], take “stress on plate is less than the permissible stresses of materials” as constraint conditions of optimal design.

## 4. Practical Engineering Example

Using 8t mine-used electric locomotive power box that shown in fig1 to illustrate the design process of plate thickness, this box is composed of junction box, control box and battery box. Among the 3 boxes, battery box has the largest geometry size, therefore, take the battery box as an example to illustrate the design process, the design method of the other boxes is the same [9]. The material of the battery box is Q235-A and consists of two chambers, the cavity structure size of each chamber is 787mm ×476mm×295mm; two channels that welded to the bottom plate is convenient to transport; the width and thickness of flange on battery box are 30mm, the flange is connected with the cover plate by 43 8. 8 grade M12 bolts, the preload for the bolt is 50N m.

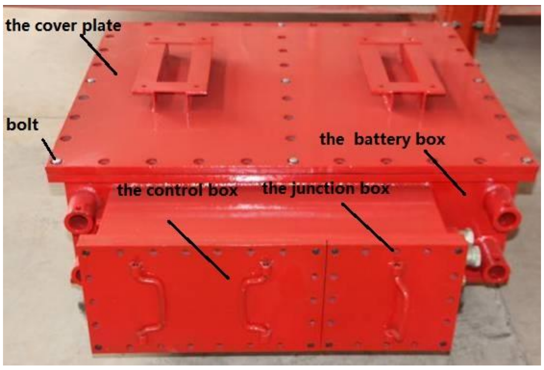



Fig 1 8t Mine-used electric locomotive power box

### 4.1 Thickness Calculation for Each Plate

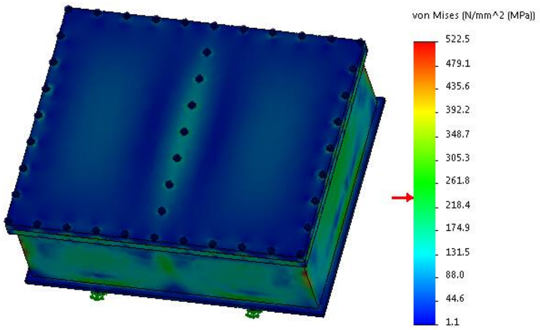
The geometric dimension of the front plate for battery box is 476mm×295mm which means $a/b$=0.62, according to table 1, using the interpolation method to calculate the value of $K_1$, put the calculation result into formula (4) and $d_1 = \sqrt{\frac{6 \times 0.036 \times 1 \times 295^2}{235}}$ =8.94mm. Similarly, the geometric dimensions of the cheek plate and bottom plate are 476mm×295mm and 787mm×476mm, so, the thickness of cheek and bottom plate are $d_2$=9.83mm and $d_3$=14.58mm. Because the cover plate is connected with the flange by bolts, make sure its thickness is the same as the flange. Calculated the iteration interval of each plate base on its thickness and sorted them together that shown in table 2.

Table 2 Parameter table of plate

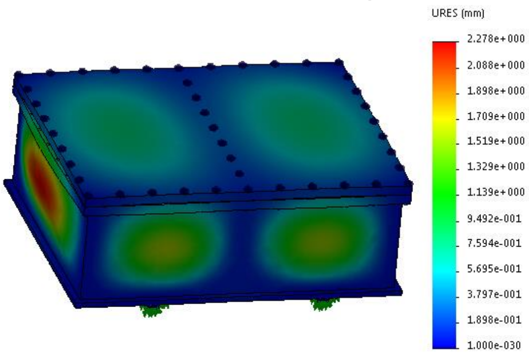
| Plate | Thickness/mm | Iterative interval /mm |
|---|---|---|
| The front plate $d_1$ | 8.94 | $4.47<d_1<13.41$ |
| The cheek plate $d_2$ | 9.83 | $4.92<d_2<14.74$ |
| The bottom plate $d_3$ | 14.58 | $7.29<d_3<21.87$ |
| The cover plate$d_4$ | 30 | $15<d_4<45$ |

### 4.2 Simulation on Explosion-proof Box

Based on the size of the battery box and its thickness that shown in table 2, establishing a simplified mathematical model of 8t mine-used electric locomotive power box. In order to accelerate the speed of analysis and improve its accuracy, the mathematical model should be simplified which means eliminate the wire connecting hole between the battery box and the junction box; using the virtual bolt joint in solidworks simulation instead of bolt assembly to connect the cover plate and the box body; The simplified model is mainly composed of a battery box (including the flange and two channels welded on the bottom plate) and a cover plate. In accordance with the requirements of the national standard, load 1MPa pressure on the inner wall of the box to simulate the stress on plates after the explosion, the simulation results are shown in Figure 2




(a) The stress nephogram




(a) The displacement contour

Fig 2 Fhe simulation results of explosion-proof box

Table 3 The stress and deformation value of plate

| Plate | Stress/MPa | Deformation/mm |
|---|---|---|
| The front plate $d_1$ | 215.2 | 1.5 |
| The cheek plate $d_2$ | 288.5 | 2.3 |
| The bottom plate $d_3$ | 98.6 | 0.12 |
| The cover plate$d_4$ | 133.2 | 0.8 |

Calculation result of the stress and deformation on each plane shows that the maximum stress and deformation appear at the center of the wall which is consistent with the theoretical analysis. The maximum stress and deformation on each plate are shown in table 3, in table 3, the maximum stress is on cheek plane and its value is 122% of yield stress of the material which means the calculated value of the theoretical thickness is too small. The maximum stress on the front plane is 92% of yield stress of the material and it indicates that theoretical calculation of the wall thickness is moderate and the material is fully utilized. The stress value of the bottom plate and the cover plate is much lower than the yield stress, which indicates that the thickness of the plate is too large. The cheek plane has the maximum deformation among all planes, the value is 0.078% of its width that meets the national standard requirements of "maximum displacement does not exceed 2% of its length", so all plates meet the design requirements of deformation.

It can be seen from the above-mentioned simulation results that thickness of the planes calculated according to empirical formula can meet the deformation requirements of the national standard, but thickness of the bottom plate and cover plate is oversized which make the explosion proof box too heavy, so, the designed thickness is not the optimal one.

### 4.3 Optimization Design and Result Analysis of Plane Thickness of Explosion-proof Tank

In order to solve the optimal thickness and achieve the goal of minimum weight, thickness should be selected as variable based on the results of the above static analysis, the iteration interval of each plate is shown in table 2. Select the minimum weight as optimal design goals, take the stress on plate is less than the permissible stresses of materials as constraint conditions of optimal design.

After 25times iterative calculation by solidworks simulation, the optimization design of thickness is obtained as shown in table 4. In the iterative process, plate thickness changes are illustrated in figure 3.

Table 4 Initial and optimum design of wall thickness

| Plate | Initial design of wall thickness/mm | Optimized design wall thickness/mm | The maximum stress of the wall/MPa |
|---|---|---|---|
| The front plate $d_1$ | 8.94 | 8.66145 | 226.85 |
| The cheek plate $d_2$ | 9.83 | 11.29929 | 220.23 |
| The bottom plate $d_3$ | 14.58 | 8.02481 | 210.51 |
| The cover plate$d_4$ | 30 | 17.94138 | 215.44 |

Thickness of plates in each iteration can be clearly seen from curve 3. According to table 4, it can be seen that after the iterative calculation, because the cheek plate of thickness increased by 0.28mm, the maximum stress of the wall plate is reduced from 288.5MPa to 226.85MPa which meet the requirements of stress. Thickness of all plates decreases and its stress increase. After optimization, the maximum stress of all the planes is more than 89% of its material yield stress and the weight of the box reduced by 29%, it means materials are fully utilized. After the optimal design, the maximum deformation of all plates is 2.02mm which meets the design requirements. It can be seen from fig 4 that the lateral displacement of Z direction of the casing and cover flange that the gap between the binding surface is very small, the max difference between these two line is 0.4886mm which meets the requirements of the national standard [10].

It can be seen from the above conclusions that with the satisfaction of the design requirements on the thickness of plate and ensure that the size of the inner cavity of the box is constant, the optimal design of the thickness can greatly reduce the weight of the box and make the material fully utilized.

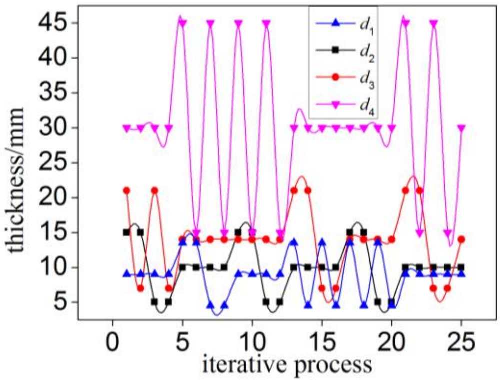



Fig. 3 The variation curve of variables in the process of optimization

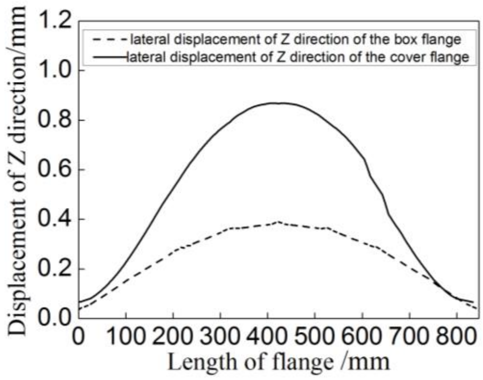



Fig 4 The lateral displacement of Z direction of the box and cover flange

### 4.4 Selection of Wall Thickness

Finally, select the optimal wall thickness based on table 4 and nominal thickness of Q235 steel plate, the final thickness of the walls are: $d_1$=10mm, $d_2$=12mm, $d_3$=10mm, $d_4$=18mm.

## 5. Conclusion

(1) This paper provides a design method of wall thickness for mine-used explosion-proof tank. In this method, using the formula that based on thin plate theory of a small deflection to calculate the wall thickness of explosion-proof box to get the initial design of the wall thickness, then establishing a simplified mathematical model based on above calculation and simulate it, the simulation result indicates that the theoretical calculation results are more conservative, it is necessary to optimize the thickness of the wall.

(2) Using concrete engineering example to illustrate the design process of plate thickness, it can be seen from the process that this design method can shorten the design cycle of explosion-proof box, improve the design precision and the ratio of material. It provides a certain reference value to the design of the rectangular explosion-proof electrical equipment.

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