Structural Design of Extruded Profiles Based on Simulation

Dezhao Qin\textsuperscript{1*}, Binxia Yuan\textsuperscript{1,2}, Jianben Liu\textsuperscript{2}, Yan Liu\textsuperscript{2}

\textsuperscript{1}Shanghai University of Electric Power, Shanghai, China
\textsuperscript{2}State Key Laboratory of Power Grid Environmental Protection, Wuhan, China
*Corresponding author: techao.chin@shiep.edu.cn

Abstract. In this paper, through the introduction of ABH related theory, a variety of optimized structures are established and compared. By changing the layout of holes in extruded profiles, the vibration characteristics of extruded profiles are studied by using the control variable method. It is found that for single extrusion profile, the through hole (the radius is 8mm to 10mm, the chamfer is 30 degrees) compared with the structure without holes, the natural frequency of the structure is increased by 7Hz from the first order to 20 Hz from the seventh order. For the spliced extruded profiles, the wedge-shaped hole structure with 8mm to 10mm has better vibration damping performance. The application of ABH structure can effectively improve the vibration characteristics of extruded profiles.

1. Introduction

In recent years, the subway has been completely integrated into human life. It is favored by people of all ages with its advantages of fast, accurate and large passenger capacity. In the process of taking the subway, it is not difficult to find the problems encountered\textsuperscript{[1-2]}. In some cases, the vibration of subway car body makes passengers unable to hear the arrival broadcast, the vibration of subway car body makes passengers unable to rest at ease, and the vibration of subway car body makes the train too bumpy. These problems also make some people not choose the subway as the primary means of travel\textsuperscript{[3-4]}. Moreover, the vibration of subway hub and floor will also reduce the service life and increase the maintenance cost. However, the emergence of subway can greatly alleviate the traffic burden of cities with large passenger flow. Subway should become the focus of most cities to develop public transport. If there is no subway, its traffic situation can't be imagined, so there is no doubt about the importance of subway. This topic is to reduce many disadvantages caused by vibration on the basis of the existing subway floor.

1.1. Model design of single ABH rib plate hole and through hole

By consulting materials, the model that can be created by extrusion process is designed. Secondly, because the model should be used as the subway floor, its size should not be too small, otherwise it will not be able to stand people. Similarly, the size should not be too large. Too large size is not convenient for optimization and calculation. The extruded profiles should be spliced to form a large plate, rather than forming a large plate. Therefore, the size design should be moderate, and then the subject assumes that 10 people standing on an extruded profile should have sufficient area. The thickness of the thin plate should not be too large, so that the effect of the subsequent ABH model is reduced by the thickness. Through these three conditions, it is finally determined that the upper thin plate of the extruded profile is 1100mm $\times$ 860mm $\times$ 5mm. Then, two points need to be considered.
for the rib plate in the middle of the extruded profile. The first parameter is the shape of rib plate, which can be designed as square, rectangle, trapezoid, etc. The second parameter is the size of rib plate, which is the key to affect the strength of the whole extruded profile. Thirdly, the size of the rib plate should be consistent with the spacing size of the adjacent rib plates. Finally, through calculation, nine stiffened plates are designed, the interval of each stiffened plate is 83mm, the thickness of the stiffened plate is 30mm and the height is 70mm, as shown in Figure 1.

Figure 1 Nonporous diagram

The structural optimization of this subject focuses on ABH theory. ABH theory is to open a hole. Holes are usually round holes, but square holes will lead to stress concentration. The size and location of holes are the key of the subject. The most basic model is an "I" word from the side. The hole can be in the bottom plate or in the rib plate, and the position of the rib plate can also be divided into penetrating the whole rib plate or passing through the side of the rib plate. Since the rib plate has been limited and cannot be changed, it is necessary to comprehensively consider 8 rib plates and 860mm thin plate width, as shown in Figure 2. The number of holes to be designed just fills the whole rib plate with the same spacing. Therefore, two kinds of rib plate holes are designed, one is r = 20mm, the interval between adjacent holes is d = 100mm, and the number is 8. The other hole r = 12.5mm, the interval between adjacent holes d = 98mm, and the number is also 8. It can be seen from the parameters of the above two models that only one variable of the rib plate hole of the two models is the radius of the hole. By comparing the radii of different holes, it is concluded that r = 20mm is better.
Place the hole on the thin plate, which is due to that someone stand on the upper plate as the premise and the hole can only be placed on the lower plate. The hole can only be opened at the interval between the rib plate and the rib plate. Since the number of rib plates is 9, the interval between rib plates is 8, and the total number of holes has been determined as 72 in the previous model, so 9 holes are opened in the direction of 860mm gap length, the radius of holes is determined as 20mm after the previous modeling, and the interval between adjacent holes is 90mm. Thus, the third model - bottom plate hole is completed.

When the distribution of holes is uneven, whether a new model can be established. The total number of holes is 72, the radius of holes is 20mm, and the number of rib plates is 9. From these three conditions, can we not let the hole to $8 \times 9$. Through calculation, the hole is designed to $3 \times 12 + 6 \times 6$, in which there are 9 rib plates in total, as shown in Fig Figure 4. With the fifth rib plate as the center line, both sides are still symmetrical, but the three outer rib plates have 6 holes and the fourth rib plate has 12 holes. In this way, the model of non-uniform hole is established under the condition of overall symmetry. The biggest problem of the model is the strength problem. Because the distribution of intermediate holes is very dense, it is likely to cause problems in the strength test of the model. However, according to the subsequent test results, the strength test passes smoothly.

After considering all the rib plate hole models, the position of the hole and penetrating the hole
through the whole rib plate were established. The thickness of the rib plate is 30mm. The models with through holes \( r = 8\text{mm} \) and \( r = 12.5\text{mm} \) are created, as shown in Figure 5. Although the through hole \( r = 12.5\text{mm} \), the hole of the model is very large and the value is very close to 30mm. If the strength test cannot pass, discard the model. If the strength test is qualified, continue the vibration simulation. As the basic model of the two through holes can compared with the better model in the rib plate hole. When the number, diameter and position of holes have been determined, these structural optimization such as the linear change of the hole and chamfer by using ABH theory will be carried out.

Through comparing the rib plate hole \( r = 8\text{mm} \), through hole \( r = 8\text{mm} \) and through hole \( r = 12.5\text{mm} \), the results show that through hole \( r = 8\text{mm} \) is better. Thus, structural optimization is considered in the through hole. At present, the ratio of the radius of the through hole model to the thickness of the rib plate is \( 8\text{mm} / 30\text{mm} \) (i.e. \( 4 / 15 \)). Taking this as the starting point, if the scale is enlarged by 3 times, the thickness of the rib plate is 45mm and the radius of the hole is 12mm. Through the test, it is found that the result is not as good as that of the through hole \( r = 8\text{mm} \). It is speculated whether the hole size does not have to be in the proportion of \( 4 / 15 \) when the rib plate = 45mm(Figure 6), and another ratio makes the vibration result almost the same as that of the through hole \( r = 8\text{mm} \). Therefore, the next model is led out, and the thickness of rib plate is 45mm and the radius of hole is 11.75mm. The model with rib plate = 45mm is not good.

Through the above structure, the radius of the hole is determined to be \( 8\text{mm} \), and then try to change the shape of the rib plate from rectangle to trapezoid. Therefore, the further optimize of the through hole is to change the shape of the rib plate. Upper bottom of trapezoid = 22mm, lower bottom of trapezoid = 44mm. The trapezoidal stiffened plates are arranged in parallel, as shown in Figure 7. The actual test shows that the result of trapezoidal rib plate is worse than that of through hole \( r = 8\text{mm} \).
It is found that chamfering is an optimization method worthy of consideration. Therefore, the third attempt to optimize the structure of through holes is to add chamfers. Chamfer itself consists of two variables, such as chamfer angle and chamfer depth. From Figure 8, 30° and 45° angles are choose, and the chamfer depth is 5mm and 2mm. Thus, there are four variables. With 5mm chamfer depth as the fixed value and angle as the variable, it is found that the chamfer angle of 30° is more appropriate through vibration simulation. Thus, only another structure of 30° and 2mm needs to be designed, and the simulation results show that the structure of 30° and 2mm is better.

The fourth structure optimization of through hole is wedge hole. In this paper, two kinds of wedge holes are selected, one end of both methods is a hole with r = 8mm, and the other end adopts two methods, such as Figure 9 and Figure 10. One is r = 10mm and the other is r = 5mm. After vibration simulation, the results show that the structure with through hole r = 10mm to 8mm is better. It is speculated that the linear change rate of the structure is about 1, but it can not be 1. Finally, a chamfer of 30° 2mm is added to the structure as the last single extruded profile structure.
2. Design of splicing ABH through hole model

Single extruded profiles are spliced to construct spliced extruded profiles, such as Figure 11 and Figure 12. The number of spliced extruded profiles is 2×5. To ensure the structural strength of the splicing, an additional rib plate is added in during the splicing process, which is consistent with other rib plates. Splicing through hole r=8mm, splicing wedge-shaped non integrated hole and splicing integrated hole are used with a chamfer of 30° and 2mm. The best structure of through hole is directly selected for splicing extruded profiles. The two structures of wedge hole are introduced in detail later. The chamfer is not made on both sides of each plate. The chamfer is only designed on the outermost layer of the splicing structure, that is, the outermost two sides after splicing of ten extruded profiles. The design idea of splicing wedge-shaped non integrated holes is to directly splice the wedge-shaped holes r = 8mm to 10mm, 8mm corresponds to 8mm, and 10mm corresponds to 10mm. However, there will be a problem. If you think of the splicing hole as a function, then the function is not a monotone function. In ABH theory, the wedge-shaped hole should be as monotonous as possible and the middle part is not blocked. Therefore, the last model of splicing extruded profiles is constructed. The idea is to splice the non porous extruded profiles first, and then open a wedge-shaped hole with r = 8mm to r = 10mm on the basis of the non porous structure, that is, after 10 extruded profiles are spliced, the large extruded profiles formed are regarded as a plate. The structure conforms to the monotony of wedge-shaped hole in ABH theory. Although the integrated hole will increase the opening cost, it is found that the maximum value in Z direction (free end) of integrated hole is not much different from that of through hole and non integrated hole, but the average deformation will be greatly reduced. Finally, the better structure of splicing hole is integrated hole.
3. Conclusion
In this paper, the noise and vibration are effectively reduced by using ABH theory on the self-designed extruded profile structure. Through changing the parameters such as different positions and radii of holes, a variety of extruded profile structures are established based on simulation, and the natural frequency and random vibration displacement between the models are compared by using the control variable method to reflect the vibration and noise reduction effect of the model. After selecting the main model, the structure is further optimized, and finally an optimized extrusion profile structure is designed.

Acknowledgement
This work was supported by the financial supports from Open Fund of State Key Laboratory of Power Grid Environmental Protection (GYW51202001548).

References
[1] Liling Tang, Li Cheng, Hongli Ji, et al. Characterization of acoustic black hole effect using a one-dimensionalfully-coupled and wavelet-decomposed semi-analytical model[J]. Journal of Sound and Vibration,2016,374:172-184.
[2] Liling Tang, Li Cheng. Enhanced Acoustic Black Hole effect in beams with a modified thickness profile and extended platform [J]. Journal of Sound and Vibration,2017,391:116-126.
[3] Deng Jie, Zheng Ling, Gao Nansha. Broad band gaps for flexural wave manipulation in plates with embedded periodic strip acoustic black holes[J]. International Journal of Solids and Structures, 2021,224:11043.
[4] Lian Xiao, Wang Shengsheng, Liu Maolin. Study on low frequency sound insulation characteristic of thin acoustic black hole[J]. Modern Physics Letters B,2021,12(35):2150198.