Study on Topology Optimization Design of Screw Extrusion Filter

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Abstract. In order to meet the needs of sludge dewatering treatment in urban areas, a screw extrusion filter with dynamic and static ring was designed. The spiral axis of the filter is simulated by finite element statics. Based on the simulation results, the structure of the spiral axis was topologically optimized, and the optimized mathematical model was established. The minimum mass was taken as the objective function, and the reasonable structure size of the spiral axis was obtained after optimization. Under the condition of satisfying the structural strength, its quality was reduced by 9.7%, and a good optimization effect was achieved.

1. Introduction

With the increase of city size and population, sludge treatment becomes more and more important. After dehydration, the volume of sludge can be reduced to 10% ~ 20% of the original volume, and the sludge after treatment is easy to store and transport, and is not easy to decay.

The screw extruder filter can save energy, reduce operating cost and improve working environment on the premise of ensuring sludge treatment effect, and its rotating and rotating ring filter has self-cleaning characteristics, which can run continuously and stably.

For the screw extruder filter designed by ourselves for the dehydration of urban sludge, the screw axis of its core component is solved by establishing a multi-constraint optimization model and transforming the multi-objective problem into a single-objective problem by using the evaluation function. With the minimum mass as the optimization objective function and the maximum deformation of the model as the constraint condition, the helical axis was topologically optimized and the sensitivity analysis was carried out. On the premise of ensuring the structure strength, the overall mass was effectively reduced.

2. Structure Design of Screw Extrusion Filter

A screw extrusion filter with sludge treatment capacity of 5t/h is designed. Its structure model is shown in Fig. 1, which is mainly composed of motor, reducer, coupling, bearing housing, feed port, support plate, rotor and stator ring filter net, backpress plate, screw shaft and bracket. Of motor and speed reducer drive system through coupling drive screw axis of rotation, the sludge from the inlet into the screw extrusion filter, through a screw axis and static ring mesh extrusion dehydration, the back is gradually increasing because of the screw axis diameter of axle, each spiral groove cavity volume decreases, the volume pressure and filtrate under the action of gravity and volume pressure by dynamic and static ring mesh filter between the discharge, set back plate, at sludge outlet by
adjusting the position of back pressure plate to change the pressure at the exit, which regulates the moisture content of sludge after dehydration.

3. Static Analysis of Screw Axis

3.1. The establishment of spiral axis model
In the process of sludge dehydration, the screw shaft is used to transport and squeeze the sludge. The screw axis is 304 stainless steel materials, young's modulus $E = 200$ GPa, Poisson's ratio $\nu = 0.3$, the density $\rho = 7850$ kg/m$^3$. With SolidWorks parameterized modeling was carried out on the screw shaft, in order to enhance the analysis efficiency, appropriate to simplify the structure of the screw axis, omission does not affect the strength of the screw axis unit (such as chamfer, fillet, etc.), screw axis by 6 mm thick screw vane welding for 25 mm in diameter of the hollow shaft, hollow shaft for whole casting, screw axis model is shown in Fig. 2.

3.2. The application of boundary conditions
ANSYS Workbench was used for static analysis of the screw axis. Since the two ends of the screw axis were restricted by the bearing bracket, and the screw axis was assumed not to move in the one-way fluid-solid coupling, the left and right ends of the screw axis were fixed, so the screw axis was fixed at both ends, and fixed constraints were imposed on both ends of the screw axis. The screw shaft is mainly subject to fluid pressure and motor torque. The left end of the screw shaft bears the maximum motor torque of $7.16 \times 10^6$ N•mm, and is also subject to the pressure of sludge fluid as a whole. The specific constraint boundary conditions are shown in Fig. 3.
3.3. Stress deformation simulation
The finite element solution is carried out for the spiral axis model. The deformation cloud diagram of
the spiral axis is shown in Fig. 4. Under load, the maximum deformation is mainly concentrated on the
left side of the spiral axis, that is, near the entrance of sludge. The deformation of spiral blade
increases from the root to the edge, and the maximum deformation of each blade is located at the edge.
The blade deformation is mainly the result of the sludge fluid pressure. The sludge fluid impacts on
the spiral axis at the inlet, and the pressure is the largest, so the deformation at the inlet blade edge is
the largest, with a value of 0.141mm.

4. Topology optimization of spiral axis
The minimum mass of the model was taken as the optimization objective function, the maximum
deformation of the model was taken as the state variable, that is, the constraint condition, and the blade
thickness and hole diameter were taken as the design variables. Therefore, the optimization of the
helical axis model is transformed into a single-objective function solution, and the established
mathematical model of topological optimization is as follows:

$$\min M(x)$$

$$s \cdot t \quad 0 \leq \delta_{\text{max}} (X_i) \leq \delta$$

$$X_i^L \leq X_i \leq X_i^U$$

(1)
Type: $M(x)$ is the maximum deformation of the helical shaft structure, $X_i$ is the design variable, $X_{i}^{L}$ is the lower limit of the design variable, $X_{i}^{U}$ is the upper limit of the design variable and $\delta_{\text{max}}(X_i)$ is the amount of deformation $X_i$ caused. The variation interval of design variables $X_i$ is shown in table 1.

### Table 1. Design variable interval.

| The design variables | Value range /mm | The initial value |
|----------------------|-----------------|------------------|
| Blade thickness      | 2~6             | 4                |
| Hole diameter        | 20~40           | 25               |

The above Optimization variables and Optimization objectives are set in Response surface Optimization, and the calculated results are shown in figure 5.

![Figure 5. Surface response cloud image.](image)

According to the Fig. 5 (a) the response of the design variables and the total deformation nephogram, along with the rising of the hollow hole diameter, the total deformation of screw axis are also increasing, the hollow hole diameter growth of 20~35 mm range, screw axis deformation rate is not big, always within the range of 35~40 mm, along with the rising of the hollow hole diameter, total screw axis deformation growth. Similarly, when the thickness of the spiral blade is in an increasing range of 2~4, the total deformation of the spiral shaft decreases rapidly. In the range of 4~6mm, the total deformation of the spiral shaft decreases slowly as the thickness of the spiral increases. According to the response cloud diagram of design variables and mass in Fig. 5 (b), with the increase of hollow hole diameter, the mass of the spiral axis decreases continuously; with the increase of the thickness of the spiral blade, the mass of the spiral axis increases continuously, and the speed changes gently. Therefore, the size parameters after optimization are shown in table 2.

### Table 2. Optimized size value.

| Parameter       | The initial value/mm | In the optimization/mm | Round/mm |
|-----------------|----------------------|------------------------|----------|
| Hole diameter   | 25                   | 36.75                  | 35       |
| Blade thickness | 6                    | 4.3                    | 4        |

According to the results in table 2, the original 3d model of the spiral axis was modified, and the static analysis was carried out again. The total deformation of the screw axis after optimization is shown in Fig. 6. The deformation of the screw axis after optimization is similar to that before optimization, and the maximum deformation is 0.1567mm. Although the deformation increases, it is still within a reasonable range. As can be seen from table 3, the weight of the optimized spiral axis...
was reduced by 9.7% compared with that before the optimization, achieving the goal of weight reduction.

Figure 6. The total deformation diagram of the spiral axis after optimization.

Table 3. Performance comparison before and after optimization.

| Project          | Before optimization | The optimized | Change the amount |
|------------------|---------------------|---------------|-------------------|
| Biggest deformation (mm) | 0.141              | 0.1567        | 11.1%             |
| Quality (kg)     | 101.35              | 91.542        | 9.7%              |

5. Concluding remarks
A screw extrusion filter for the dehydration of municipal sludge was designed. The screw axis of the filter is topologically optimized, and the optimized screw axis can reduce 9.7% of the weight under the condition of ensuring the structural strength.

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