Large Mine Hoist Drum Topology Optimization Design

Jie HU, Jia-Chun Li\textsuperscript{a,∗}, Xue HE, Ji-Chao CAO

College of Mechanical Engineering, Gui Zhou University 550025, China

\textsuperscript{a}ljcgd211@163.com

∗Corresponding author

Keywords: Mine Hoists, Drum, Topology Optimization, Variable Density Method.

Abstract. According to the 2JK type large mine hoist drum manhole, surrounding the shell cracks problems from time to time, based on the conceptual design principle of variable density topology optimization, integrated use of OptiStruct, HyperMesh software functional modules to build a 3D mesh model of the drum. Analyze its finite static element, confirm its weaknesses, then adjust the structure through topology optimization design. Ensure safe operation under normal operating conditions. The optimization design results show that, Static analysis results roughly keep fit with the hoist drum troubleshooting, the maximum stress of surroundings decreased by nearly 38.46% after structural topology optimization, distribution is more uniform, quality dropped by 5.7%, reaching the purpose of lightweight. In this paper, research methods and conclusions provide a viable reference for corporate design departments to solve the problem of drum cracking.

Introduction

With the increasing depletion of shallow resources, development of deep mining resources exploit equipment is urgently needed. In order to adapt to the deep mine development and annual constant growing demand, large-scale mine hoist development has become a main trend. Because of the large load, complicated overall structure, and the lack of mature design experience \cite{1,2}, In particular, as the main bearing parts of the drum, in the large mine hoist work in practical applications often appears the drum cracking problem due to stress concentration, affecting the normal use of equipment.

Topology optimization is a kind of structure optimization, it is a mathematical technique applied to the known design space which determines the optimal configuration of the structure shape and material \cite{3,4}, use in product development, it can shorten the development cycle, improve design efficiency, save raw materials, and reduce design costs. HyperWorks is a powerful engineering simulation finite element software, integrated excellent pre-processing software-HyperMesh, structural optimization design module-OptiStruct and powerful post processing environment-HyperView, it has been widely praised and applied in heavy equipment, aerospace, automotive and other fields. In this paper, the structure topology optimization technology is used to carry out the lightweight design of the drum structure, ensure that the reel stiffness of the structural strength to meet the requirements.

Hoist Drum Static Analysis

In this paper, taking a company research, development and production of 2JK-5 large mine hoist fixed drum as the research object, the main parameters are: drum diameter D=5000mm, drum width=2300mm, wire rope diameter d=52mm, wire rope gap ε=3mm, wire
rope maximum static tension $F_{j\text{max}}=260$KN.

Entire reel structure composed of a plurality of thin-walled plates of different thicknesses welded together, thickness value of each plate shown in Table 1.

<table>
<thead>
<tr>
<th>Part Names</th>
<th>Drum Shell</th>
<th>Brake Disc</th>
<th>Rope Guard Plate</th>
<th>Width Plate</th>
<th>Flange Plate</th>
<th>Stiffened Plate</th>
<th>Support Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>38</td>
<td>45</td>
<td>22</td>
<td>28</td>
<td>50</td>
<td>20</td>
<td>15</td>
</tr>
</tbody>
</table>

Firstly, according to the reel’s geometric parameters, use a three-dimensional CAD model software which name is SolidWorks to create the reel’s geometry solid model, as shown in Fig.1(a) below.

Import the reel’s three-dimensional solid model into the FE software: HyperMesh, extract the midsurface and do the geometry clean, and give the different respectively thickness values to the midface of each plate according to the Table 1.

Reel main material use of high strength low alloy structural steel which grade is Q345A, check the manual and get the concrete material parameters: Elasticity modulus $E$ is 210Gpa, Poisson's ratio is 0.3, Density is $7.85$g/$\text{cm}^3$, Yield limit is 345Mpa.

Complete the reel mesh, giving the material properties, the reel’s finite element model results shown in Fig.1 (b) below.

Figure 1. Reel Model.

Apply a fixed constraint to the side of the drum near the rope guard plate, leaving the other side of some radial displacement, which is only constraint y, z directions.

When the load is applying, it is assumed rope strapped to three[5].The reel forced by the rope’s radial compression force, which was converted to the uniform load acting on the cylinder housing, the set of load is:

$$Q_b=\frac{F_{j\text{max}}\alpha_n}{r(d+\varepsilon)}$$

Where $\alpha_n$ is the comprehensive influence factor of wire rope pulling force, $n$ is the number of turns of wire rope. When $n=3$, $\alpha_3=2.1$, $r$ is the average radius of the reel.

The wire rope has axial thrust to the rope, concentrated into a force, which uniform retaining on the each node of rope guard plate.

$$F_n=1.145F_{j\text{max}}\alpha e^{-0.009n}$$
Take a view of the reel's equivalent stress cloud in HyperView, as shown in Fig.2, respectively, the webs equivalent stress cloud as shown in Fig.3, it's shows that the reel shell, webs waist manhole edge exist stress concentration phenomenon, manhole edge for the maximum equivalent stress 216.303Mpa.

From the analysis results, the webs waist manhole edge exist stress concentration phenomenon, and consistent of the devices normal running fault, indicating that the method used in this paper are reasonable, and the analysis results in the phenomenon of stress concentration will lead to fatigue cracks around the manhole, which led to cracking of the reel, affect the normal use of the elevator, so it is necessary to optimize the design of drum manhole structure.

**Reel Structural Topology Optimization**

Topology optimization, which is a kind of modern design method for the optimal allocation of the structural materials in the existing design space according to the given load, constraints and optimization objectives. At present, the optimization method of topology optimization of continuum structure is the level set method, variable density method, incremental structure optimization method and so on. In this paper, by using the variable density method of topology optimization of the hoist drum manhole structure, and for an optimization problem, the design variables, constraints and optimization objectives are the main elements[6]. For optimization of this paper, the design variable is the density of the drum unit, the optimization objective is to minimize the strain energy of the web plate structure, constraint on the volume fraction of the material, construct the mathematical model of topology optimization, and its expression is:

Design variable \( X = (X_1, X_2, \ldots, X_N)^T \), optimization equation is:

\[
\text{Min: } N = F^T B \quad (3)
\]

\[
s.t: \quad g = \frac{v - v_1}{v_0} \quad (4)
\]

\[
F = KB \quad (5)
\]

\[
0 < X_{\min} < X_r < X_{\max} \quad (6)
\]

Where, \( N \) is the strain energy of web plate structure, \( F \) is the load vector, \( g \) is the percentage of reserved material, \( V \) is the volume when the whole web plate covered with material, \( V_1 \) is
the volume of a material that is less than $X_{\text{min}}$ for a unit density value, $V_0$ is the initial volume target design area, $K$ for the structural stiffness matrix, $B$ is a displacement vector, $X_e$ as a unit relative density vector, $X_{\text{max}}$, $X_{\text{min}}$ respectively unit relative density values of upper and lower limits.

Considering the condition of multiple sub cases, obtained the weighted sum of the structural strain energy of each sub working condition, the optimization equation becomes:

$$\text{Min}: N = \sum W_i N_i \quad (7)$$

Where, $W_i$ is the i-th weighting coefficients in the range of the 0~1 working conditions; $N_i$ is the i-th condition of strain energy.

Application of finite element analysis software HyperWorks to the hoist drum manhole structure topology optimization design, define the target optimization area, constraint response, and objective function in the OptiStruct module optimization panel, convergence iterative solution, based on the analysis of the results do the secondary design and performance check, finally get the best results[7]. Specific design process shown in Fig.4.

![Figure 4. Topology Optimization Design Flow.](image)

**Result of Hoist Drum Structure Topology Optimization Design**

Take the drum board as optimization area, set the volume of material constraints to 30%, the structural strain of target function to minimum, the board density value as variable, and then the optimization iterative solution, the optimized model as shown in Fig.5, through the OSSmooth panel to export the geometry, and ignore the secondary part, finally, in the three-dimensional CAD solid modeling software SolidWorks secondary design to get the optimized organization as shown in Fig.6.
Topological Optimization of Reasonable Verification

The equivalent stress distribution diagram of the overall structure of the drum and the equivalent stress diagram of the web plate are respectively as shown in Fig. 7 and Fig. 8.

In order to verify the rationality of the topology optimization design results, the finite element static analysis of the optimized drum structure is carried out in HyperWorks under the same conditions, compared with the original structure data and the optimized structure data of the drum. The specific related parameters are as shown in Table 2:

<table>
<thead>
<tr>
<th></th>
<th>Reel overall maximum stress(Mpa)</th>
<th>Manholes surrounding maximum stress(Mpa)</th>
<th>Reel overall quality(Kg)</th>
<th>Manholes shape</th>
<th>Manholes number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization Before</td>
<td>265.2</td>
<td>216.303</td>
<td>19833</td>
<td>Waist-shaped hole</td>
<td>4</td>
</tr>
<tr>
<td>Optimized</td>
<td>264.3</td>
<td>133.103</td>
<td>18707</td>
<td>Circular hole</td>
<td>8</td>
</tr>
</tbody>
</table>

As the above table shows, the maximum stress of overall drum is 265.2 Mpa before optimizing. It decreased to 264.3 Mpa after optimized, the shape of the manhole has little
influence on the drum stress, Manhole around the maximum stress before optimization for 216.303Mpa, optimized for 133.103Mpa, a decrease of nearly 38.46%. Original drum quality is 19833 kg, it declined to 18707 kg by optimizing, decreased by 5.7%. Through the above analysis result, the topology optimization method is very effective to optimal design of the drum structure.

**Summary**

Based on the 2JK-5 large single rope winding type mine hoist drum fixed as the research object, comprehensive utilization of SolidWorks, HyperMesh and OptiStruct software function modules built roll three-dimensional model, carries on the finite element static analysis, analysis confirmed its the weak link, and the drum manhole structure topology optimization design, draw the following conclusions:

(1) The results of static analysis and the common faults of the hoist drum are generally consistent.

(2) Manhole shape change has little effect on the whole drum, but it has great influence on the stress surrounding the manhole.

(3) The topology optimization module of manhole structure was optimized by OptiStruct software, after the optimization of drum plate edge of manhole maximum equivalent stress value is 133.103Mpa, a decrease of nearly 38.46%, avoided the stress concentration, reel quality also reduced by 5.7%, realize the effect of lightweight. The conclusion of this study provides a feasible reference for solving the manhole cracking problem from the design stage.

**Acknowledgments**

This work is supported by the Major science and technology projects of Guizhou Province of China which name is the Key technology research and industrialization of a new type of mine hoist (Grant No. [2013] 6018).

**References**


