Stability Analysis of Mechanical Sludge Dewatering Machine Frame Based on Numerical Simulation

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Abstract. Sludge is the inevitable product of sewage treatment plant and sewage treatment. Before sludge treatment, dewatering is generally required. Mechanical sludge dewatering machine is a common sludge dewatering equipment. Due to the complex operation conditions, the stability of sludge dewatering machine frame directly affects its reliability. In this paper, a mechanical sludge dewatering machine frame as the research object, based on ANSYS Workbench finite element analysis platform, static analysis and modal analysis. The analysis results show that: under normal working conditions, the maximum variable of the frame is 0.07mm, which can effectively ensure the normal operation of the sludge dewatering machine; the equivalent stress is 4.22Mpa, which is far less than the Xu Yong stress of the material; the vibration of the first two modes of the frame is relatively concentrated, and the corresponding motor speed under the interference frequency is 1241.4-1595.4r/min, which should be avoided in the use process.

Keywords: Sludge Dewatering Machine, Static Analysis, Modal Analysis, Reliability.

1. Introduction
Sludge is the inevitable product of sewage treatment plant and sewage treatment [1, 2]. The sludge without proper treatment and disposal will directly bring secondary pollution to the water body and the atmosphere, which poses a serious threat to the ecological environment and human activities [3, 4]. In order to further treat the sludge, it is generally necessary to dewater the sludge first [5]. At present, the commonly used sludge dewatering processes mainly include natural drying method, granulation dehydration method and mechanical dehydration method [6].

Mechanical sludge dewatering machine is one of the common equipment in mechanical dewatering, which has the characteristics of high dewatering rate, wide adaptability and low power consumption [7]. Because the load of mechanical sludge machine is large, it is easy to damage the frame. In this paper, a mechanical sludge dewatering machine is taken as the research object, and its stability is analyzed from two aspects of structural strength and modal characteristics.
2. Analysis Model

The mechanical sludge dewatering machine analyzed in this paper is mainly composed of frame, filter screen and screw rod, as shown in Figure 1. The filter screen and the screw rod are mechanically connected and installed on the frame. In the working process, a large amount of sludge enters into the dehydrator, which causes the rack to bear large gravity. Under rated conditions, the mass of this part of sludge is 340kg. Because the screw needs an external motor to provide power, it also receives the vibration excitation of the motor in the process of the sludge dewatering machine. Therefore, the stability of the frame is very important for the reliability of the sludge dewatering machine. Qste420t is used as the material of the frame, and its specific parameters are shown in Table 1.

![Figure 1. Schematic diagram of mechanical sludge dewatering machine](image)

| Material Name | Modulus of Elasticity/GPa | Poisson ratio | Yield strength/Mpa | Tensile strength/Mpa | Density kg·m$^{-3}$ |
|---------------|---------------------------|---------------|--------------------|----------------------|--------------------|
| QSTE420T      | 200                       | 0.3           | 420                | 480                  | 7850               |

In this paper, the Parametric Modeling Software Solidworks is used to establish the frame model of sludge dewatering machine, and the features such as chamfer and mounting hole that basically do not affect the accuracy of the analysis results are simplified.

3. Analysis Model

3.1. Basic Principles of Static Analysis

In statics, the dynamic equation of an object is [8]:

\[
[M] \ddot{\{X\}} + [C] \dot{\{X\}} + [K] \{X\} = \{F(t)\} \tag{1}
\]

Where \([M]\) is the mass matrix, \([C]\) is the matrix damping, \([K]\) is the stiffness coefficient matrix, \(\{X\}\) is the displacement vector and \(\{F\}\) is the force vector. In linear static structure, force is independent of time [9].

\[
[K] \{X\} = \{F\} \tag{2}
\]

3.2. Analysis Pretreatment

Firstly, the 3D model established in SolidWorks is imported into ANSYS Workbench, and the material of the model is set as qste420t. Then set fixed constraints on the four feet of the frame, and apply 3400n downward force on the top of the frame, as shown in Figure 2. Then the finite element mesh is divided.
3.3. Static Analysis Results

Through solution calculation and post-processing, the total deformation characteristics and equivalent stress characteristics of the frame are obtained.

Figure 3 is the total deformation nephogram of the frame. It can be seen from the graph that the deformation in the middle part of the frame is the largest, but the maximum value is 0.07mm. The structural deformation ensures the normal operation of the sludge dewatering machine. However, because the rotating screw shaft is installed on the rack, and the load borne by the screw shaft is large, the auxiliary structure can be added above the rack to ensure the working environment of the screw shaft.

Figure 4 is the equivalent strain nephogram of the rack. It can be seen from the nephogram that the strain distribution on the rack is relatively uniform. There are certain strains on the four vertical bars and four cross bars of the rack, but the strain value is very small, the maximum value is 4.22Mpa, far less than the allowable stress of the material, which is very safe. The subsequent optimization can be considered to reduce the amount of materials and reduce the cost.

Figure 2. Applying a fixed constraint

Figure 3. Total deformation nephogram

Figure 4. Equivalent stress cloud picture
Figure 5 is the equivalent strain nephogram of the rack. The equivalent strain nephogram and the equivalent stress nephogram are relative. The equivalent strain distribution on the rack is relatively uniform, and the strain is small, and there is no concentrated strain, so the design is more reasonable.

4. Modal Analysis of Prestressed Concrete

4.1. Basic Principles of Modal Analysis
Modal is the inherent characteristics of mechanical structure, which is a common method to study the vibration characteristics of mechanical structure. Different mechanical mechanisms have different modal characteristics, and the same mechanical structure also has countless different modes [10]. Modal characteristics are expressed by vibration frequency and modal shape, and the relationship between them is as follows [11].

\[
[K] - \varphi_i^2 [M] \{\varphi_i\} = 0
\]  

(3)

Where \([K]\) is the stiffness matrix, \([M]\) is the quality matrix, \(\varphi_i\) is the mode shape, \(\varphi_i\) is the vibration frequency.

4.2. Modal Analysis Results
The first six modes of the frame are obtained by modal analysis, in which the vibration frequency of the first four modes is shown in Figure 2. The frequency range of the first six modes is 20.69-82.144Hz, in which the vibration of the first two modes is concentrated. During the operation of sludge dewaterer, external excitation mainly comes from driving motor, according to the relationship between motor speed and interference frequency.

\[
n = 60f
\]  

(4)

Where \(n\) is speed per r/min and \(F\) is interference frequency per Hz.

It is obtained that the speed of the motor is 1241.4-1595.4r/min when the interference frequency is 20.69-26.59Hz. However, the speed of the motor is generally within this range. If the frequency of external interference is within this range, it is very easy to cause resonance of the frame and cause great damage.

Table 2. Vibration frequency of the first four modes of the frame

| Step | Frequency/Hz |
|------|--------------|
| 1    | 20.688       |
| 2    | 26.587       |
| 3    | 48.235       |
| 4    | 54.222       |
Figure 6 is the first-order modal shape nephogram of the frame. It can be seen from the figure that the maximum deformation is 9.25mm respectively, and the maximum deformation occurs in the upper part of the frame. The deformation of the main part of the frame is small.

![First order modal shapes](image1)

**Figure 6.** First order modal shapes

Figure 7 is the second-order modal shape nephogram of the frame. It can be seen from the figure that the whole frame has some deformation, and the maximum position appears above the frame, but the overall deformation of the frame is small.

![Second mode shape nephogram](image2)

**Figure 7.** Second mode shape nephogram

Figure 8 is the third-order modal shape nephogram of the frame. It can be seen from the figure that the maximum deformation of the frame occurs at the top of the frame, with the maximum value of 7.25 mm. There is also a certain deformation at the center of the lower part of the frame, but the deformation is small.

![Third mode shape nephogram](image3)

**Figure 8.** Third mode shape nephogram

Figure 9 is the fourth-order modal shape nephogram of the frame. It can be seen from the figure that the whole frame has a certain deformation, the maximum deformation is 3.5mm, and the overall deformation is small.
5. Conclusion
The working condition of sludge dewatering machine is very complex, the stability of its frame directly determines the reliability of sludge dewatering machine, and directly affects the service life of sludge dewatering machine. In this paper, through the static analysis and modal analysis of the frame of sludge dewatering machine, the following conclusions are obtained.

(1) Under normal working conditions, the maximum total deformation of the frame is 0.07mm, which can meet the normal work of the sludge dewatering machine. However, the deformation mainly occurs above the frame. Therefore, the subsequent optimization can set a strengthening structure above the frame and reduce the material consumption of the frame.

(2) In the normal working condition, the maximum equivalent stress of the frame is 4.22Mpa, which is far less than the yield strength of 420MPa, meeting the requirements. The subsequent optimization can appropriately reduce the amount of material.

(3) The vibration of the first two modes of the frame is relatively concentrated, and the corresponding motor speed is 1241.4-1595.4r/min under this interference frequency. During use, the motor speed within this range should be avoided.

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