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# Theoretical Modelling of Power for Large Inclination Screw Conveyor

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## Abstract

**At present, the research of screw conveyor focuses on horizontal and vertical models, and the inclined type is relatively few. The theoretical research has not been improved, and the existing power calculation theory of large inclination screw conveyor does not accord with the practice of large inclination screw conveyor. The motion, mechanism of materials becomes more complicated because of gravity during inclined transport. In order to help to fully understand the movement mechanism of the screw conveyor in the material of large dip Angle, seize the influence elements, design more accord with the actual model, and improve the efficiency of engineering and applied value, based on the theory of material group of medium mechanics method, large angle inclined screw conveyor power theory modeling study, gives a full theoretical calculation model of transmission power of large Angle inclination , has the very vital significance.**

## Keywords

**Large Angle Screw Inclined Conveyor, Material group method, Power calculation.**

## 1. Introduction

Screw conveyor is a continuous transport machinery, the main work objects are powder, granular and small pieces of granular materials. Its structure is uncomplicated, sealing, environmental protection, operation efficiency, is widely used in food processing, chemical and building industries such as bulk cargo transport and close to ascend, for bulk solid, is a very efficient conveyer, can better control the flow. There are many kinds of screw conveyor, big difference in structure, and many design parameters, and the design parameters are interrelated and restricted, resulting in the determination of design parameters complex, difficult, especially some of the main parameters, if the selection and combination is not appropriate, will seriously affect the production efficiency and performance of the screw conveyor.

The principle of large inclination screw conveyor is similar to that of vertical screw conveyor. Both of them use the friction force between material and contact surface to overcome their own gravity and realize the conveying function. When the rotating speed of the screw conveyor increases to a certain value, the centrifugal force of the material overcomes the friction force between it and the screw blades and slides to the inner wall of the conveying pipe, forming a new friction force. As the rotating speed continues to increase, the friction force will overcome the weight and sliding component of the material, and screw up under the continuous pushing of the blade, and begin to transport.

## 2. Theoretical modeling of free form surface

In this paper, by the method of particle group study of screw conveying mechanism, to complete the movement analysis of the screw surface material, must make the necessary motion assumption, assuming the same material on the screw radial speed, material speed does not change with the radius

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and, on the basis of the corresponding calculation model was established, the method is simple convenient, although the actual state of and material is a certain error, but the maximum close to the actual stress state of grain materials and the actual movement condition.

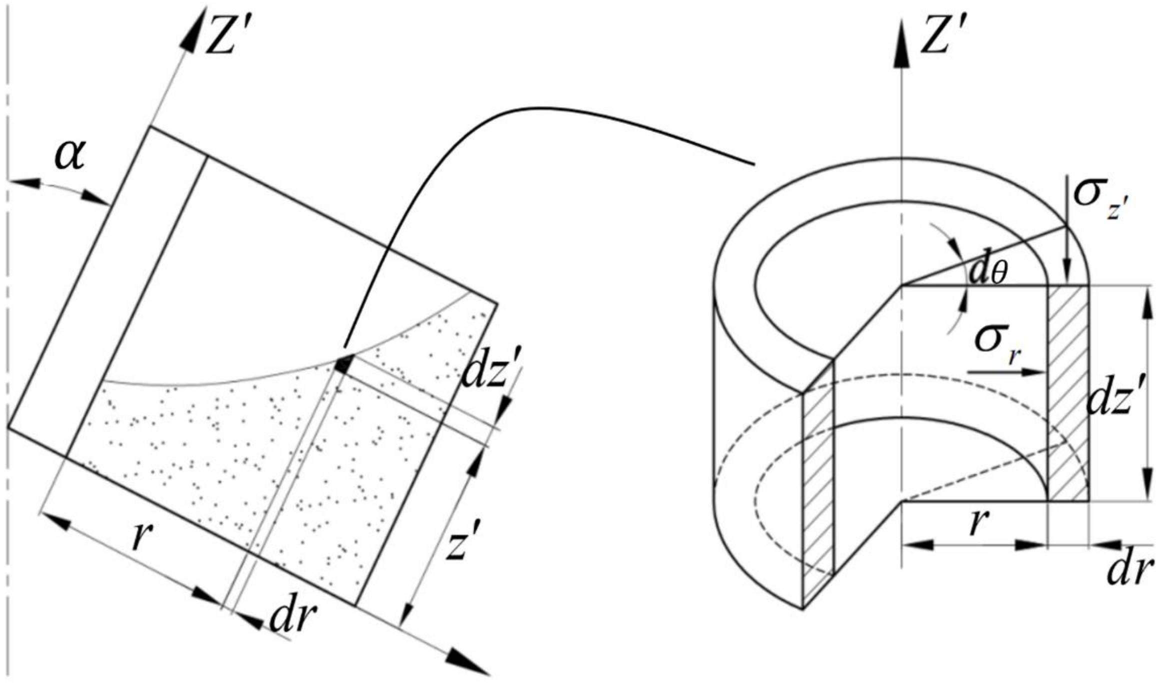


**Figure 1.** Stress analysis of micro-body of particle group

As shown in Fig. 1, take free surface radius r the particle group of body as the research object, set its quality for$\Delta$m. known by stress equilibrium conditions.

$$\sigma_r \cdot 2\pi r \cdot dz' = \Delta m\omega^2 r + \Delta mgsin\alpha \tag{1}$$

$$\sigma_{z\prime} \cdot 2\pi r \cdot dr = \Delta mgcos\alpha \tag{2}$$

Divide by two formulas, get this

$$\frac{dz\prime}{dr} = \frac{\sigma_{z\prime}}{\sigma_r}(\frac{\omega^2 r}{gcos\alpha} + tan\alpha)\omega = \xi_b(\frac{\omega^2 r}{gcos\alpha} + tan\alpha) \tag{3}$$

Integrate both sides of this equation with respect to $r$, get

$$z' = \frac{\xi_b}{gcos\alpha}\int \omega^2 rdr + \xi_b tan\alpha r + C \tag{4}$$

Substitute this formula

$$\omega = \omega_s(\frac{k_1}{r} + k_2) \tag{5}$$

into this equation, and get

$$z' = f(r) = J_1((k_1 + k_2 r)^2) + J_2 + C \tag{6}$$

Where, is the simplification coefficient, which satisfies:

$$\begin{cases} J_1 = \frac{\xi_b {\omega_s}^2}{2gcos\alpha k_2} \\ J_2 = \xi_b tan\alpha \end{cases} \tag{7}$$

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The equation$z' = f(r)$ is the curve describing the boundary of the free surface of the material on one side.The integral constant C depends on the filling rate and rotation angular velocity of the material, and can be solved by integration with the formula of filling rate. The filling rate is defined as

$$\Phi = \frac{\Omega}{P(R_0 - R_1)} = \frac{\Omega\int_{R_i}^{R_0} f(r)dr}{P(R_0 - R_i)} \tag{8}$$

Where:Ω ——the area of material within a single pitch longitudinal section.

Similar to the distribution of moving materials in the vertical screw conveyor, for different filling rates Φ and speeds of materials ω, the distribution of moving materials in the large inclination screw conveyor within a single pitch (unilateral) generally has four different surface forms, as shown in the Fig. 2.

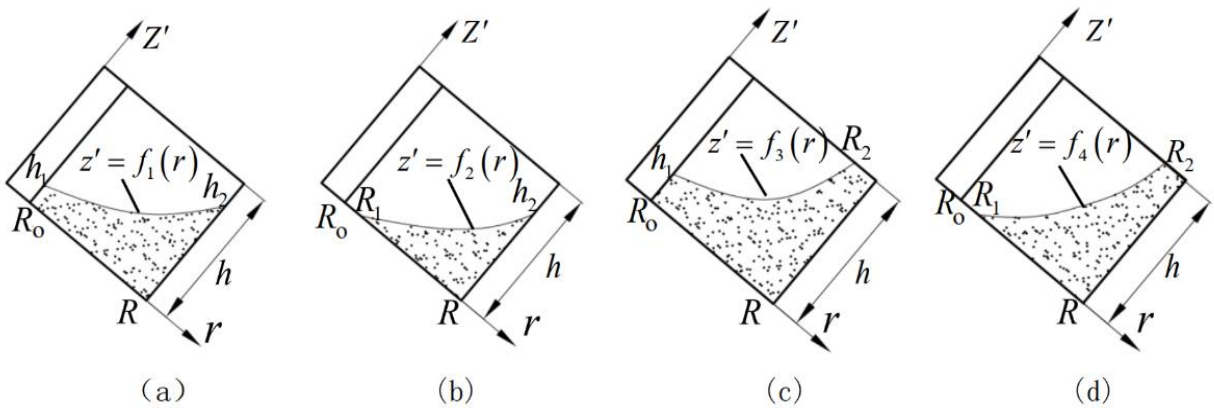


**Figure 2.** Four different types of material free surface curves

(a):The first type of free form surface(b):The second type of free form surface

(c):The third type of free form surface(d):The fourth type of free form surface

## 2.1 The first type of free form surface

The first type of free surface curve is shown in Figure (a). The corresponding curve equation is

$$z' = f_1(r) = J_1((k_1 + k_2 r)^2) + J_2 k + C_1 \tag{9}$$

The integral constant $C_1$ is calculated by the formulaΦ:

$$C_1 = \Phi h - J_1\left[\frac{k_2^2}{3}(R_o^2 + R_i + R_i^2) + k_1 k_2(R_i + R_o)\right] - J_2(\frac{R_i + R_o}{2}) \tag{10}$$

## 2.2 The second type of free form surface

The second type of free surface curve is shown in Figure (b). The corresponding curve equation is

$$z' = f_2(r) = J_1((k_1 + k_2 r)^2) + J_2 k + C_2 \tag{11}$$

Take the boundary condition $z'|_{r=R_1} = 0$ plug in to the $z' = f_2(r)$,get The integral constant is $C_2$.

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$$C_2 = -J_1(k_1 + k_2R_1)^2 - J_2R_1 \tag{12}$$

In addition, the integral constant $C_2$ is calculated by combining formula

$$\begin{cases} J_1 = \frac{\xi_b \omega_s{}^2}{2g\cos\theta k_2} \\ J_2 = \xi_b \tan\theta \end{cases} \tag{13}$$

$$C_2 = \Phi h - J_1\left[\frac{k_2^2}{3}(R_o^2 + R_1R_o + R_i^2) + k_1k_2(R_1 + R_o) + k_1^2\right] - J_2(\frac{R_1+R_o}{2}) \tag{14}$$

take this equation with respect to $C_2$, can solve for $R_2$.

## 2.3 The third type of free form surface

The third type of free surface curve is shown in Figure (c). The corresponding curve equation is

$$z' = f_3(r) = J_1((k_1 + k_2r)^2) + J_2k + C_3 \tag{15}$$

Take the boundary condition $z'|_{r=R_1} = h$ plug in to the $z' = f_3(r)$, get The integral constant is $C_3$.

$$C_3 = h - J_1(k_1 + k_2R_2)^2 - J_2R_2 \tag{16}$$

In addition, the integral constant $C_3$ is calculated by formula (13):

$$C_3 = \Phi h - J_1\left[\frac{k_2^2}{3}(R_2^2 + R_2R_i + R_i^2) + k_1k_2(R_2 + R_i) + k_1^2\right] - J_2(\frac{R_i+R_2}{2}) \tag{17}$$

Take this equation with respect to $C_3$, can solve for $R_3$.

## 2.4 The fourth type of free form surface

The fourth type of free surface curve is shown in Figure (d). The corresponding curve equation is

$$z' = f_4(r) = J_1((k_1 + k_2r)^2) + J_2k + C_4 \tag{18}$$

Take the boundary condition $z'|_{r=R_1} = 0$ and $z'|_{r=R_2} = h$ plug in to the $z' = f_4(r)$,

$$C_4 = -J_1(k_1 + k_2R_1)^2 - J_2R_1 \tag{19}$$

$$C_4 = h - J_1(k_1 + k_2R_2)^2 - J_2R_2 \tag{20}$$

Can figure out the quantitative relationship between $R_1$ and $R_2$,

$$h = J_1[(k_1 + k_2R_2)^2(k_1 + k_2R_1)^2] + J_2(R_2 - R_1) \tag{21}$$

In addition, the integral constant $C_4$ is calculated by combining formula:

$$\begin{cases} J_1 = \frac{\xi_b \omega_s{}^2}{2g\cos\theta k_2} \\ J_2 = \xi_b \tan\theta \end{cases} \tag{22}$$

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$$C_4 = \Phi h - J_1\left[\frac{k_2^2}{3}(R_2^2 + R_2R_1 + R_1^2) + k_1k_2(R_2 + R_1) + k_1^2\right] - J_2(\frac{R_1+R_2}{2}) \quad (23)$$

Take this equation with respect to $C_4$, can solve for$R_1$and $R_2$.

## 3. Literature References stress analysis

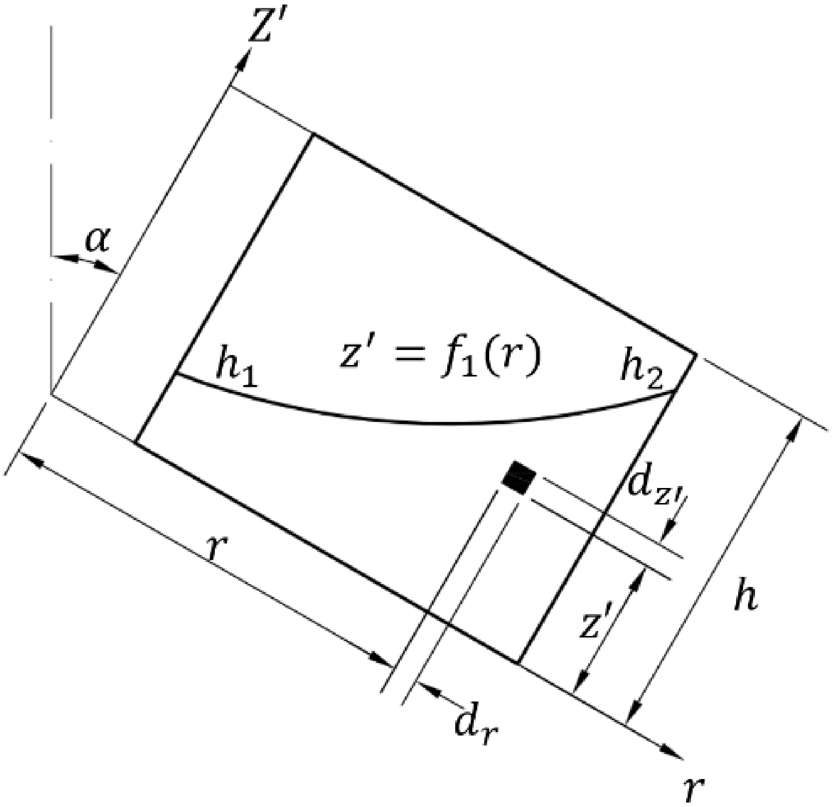


**Figure 3.** Free surface micro-unit of the first type

### 3.1 The first type of free form surface

For the first type of free surface (as shown in the figure), a micro material element is taken to analyze its stress balance by combining the curve equation of the first type of free surface and as shown in the figure. The material element is in a state of force balance, with:

$$g\rho f_1(r)dr * rd\theta sin\alpha + \tau_n rd\theta drtan\partial - \sigma_n rd\theta dr = 0 \quad (24)$$

Then the compressive stress $\sigma_n$ of the material on the screw blade is:

$$\sigma_{n1} = \frac{g\rho f_1(r)sin\alpha}{1 - f_1 tan\partial} \quad (25)$$

### 3.2 The second type of free form surface

In the second type of free surface condition, the material compressive stress on the screw blade is similar to that in the first type. The compressive stress $\sigma_n$ of the material on the screw blade is:

$$\sigma_{n2} = \frac{g\rho f_2(r)sin\alpha}{1 - f_1 tan\partial} \quad (26)$$

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### 3.3 The third type of free form surface

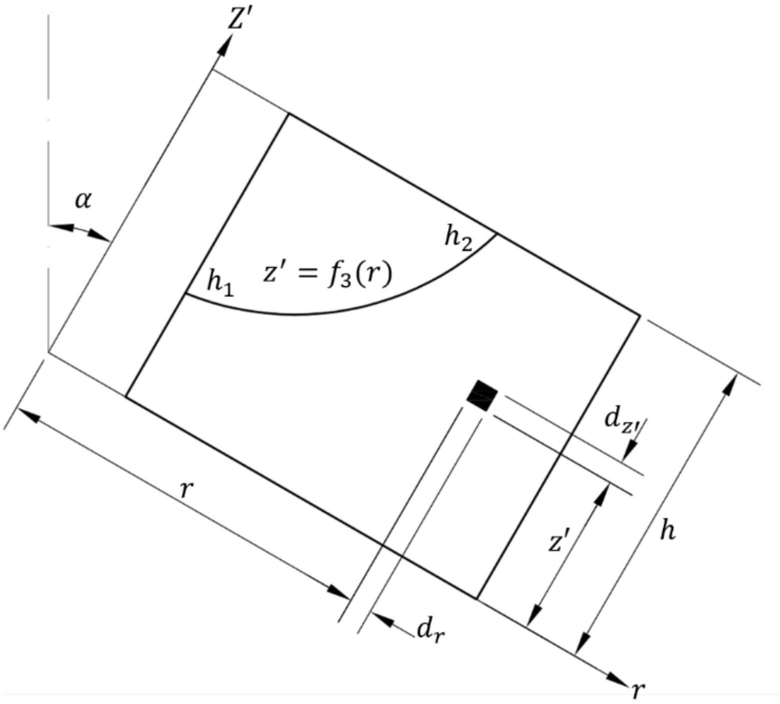


**Figure 4.** Free surface micro-unit of the third type

For the third type of free surface, as shown in the Fig. 4, the boundary pressure of the material on the screw blade when the third type of free surface is formed can be divided into and solved in two parts.

When$R_0 \leq r \leq R_2$ the pressure distribution of the material on the screw blade is:

$$\sigma_{n3} = \frac{g\rho f_3(r) sin\alpha}{1-f_1 tan\partial} \tag{27}$$

When$R_2 \leq r \leq R$ the pressure distribution of the material on the screw blade is:

$$\sigma_{n3} = \frac{g\rho h sin\alpha}{1-f_1 \frac{H}{2\pi r}} \tag{28}$$

The total pressure distribution of the material on the screw blade is:

$$\sigma_{n3} = \frac{g\rho f_3(r) sin\alpha}{1-f_1 tan\partial} + \frac{g\rho h sin\alpha}{1-f_1 \frac{H}{2\pi r}} \tag{29}$$

### 3.4 The forth type of free form surface

For the fourth type of free surface, the boundary pressure of the material to the screw blade when the fourth type of free surface is formed can be divided into and two parts.

When$R_1 \leq r \leq R_2$ the pressure distribution of the material on the screw blade is:

$$\sigma_{n4} = \frac{g\rho f_4(r) sin\alpha}{1-f_1 tan\partial} \tag{30}$$

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When$R_2 \le r \le R$ the pressure distribution of the material on the screw blade is:

$$\sigma_{n4} = \frac{g\rho h sin\alpha}{1-f_1\frac{H}{2\pi r}} \tag{31}$$

The total pressure distribution of the material on the screw blade is:

$$\sigma_{n4} = \frac{g\rho f_4(r) sin\alpha}{1-f_1 tan\partial}\frac{g\rho h sin\alpha}{1-f_1\frac{H}{2\pi r}} \tag{32}$$

## 4. The force of material and power calculation

The force of material on screw blade is divided into the pressure of material and the friction caused by pressure. Therefore, the torque of the material on the screw blade against the Z-axis is composed of two torques caused by pressure and friction. In order to simplify the calculation, when solving the torque$\partial$, the helix Angle satisfies the equation as follows:

$$tan\partial = \frac{H}{\pi(R+R_0)} \tag{33}$$

### 4.1 First type of free form surface.

When the material is in the first type of free surface state, the total torque of the force caused by the material on the screw blade to the Z axis is:

$$M_n^{(1)} = \int_{R_0}^{R} 2\pi\tau_n r^2 dr + \int_{R_0}^{R} 2\pi\sigma_{n1} r^2 tan\partial dr \tag{34}$$

And $\tau_n = f_1\sigma_n$,get:

$$M_n^{(1)} = \int_{R_0}^{R} 2\pi f_1\sigma_{n1} r^2 dr + \int_{R_0}^{R} 2\pi\sigma_n r^2 tan\partial dr \tag{35}$$

### 4.2 Second type of free form surface.

Similar to the first, when the material is in the second type of free surface state, the total torque of the force caused by the material on the screw blade to the screw axis Z axis is:

$$M_n^{(2)} = \int_{R_0}^{R} 2\pi f_1\sigma_{n2} r^2 dr + \int_{R_0}^{R} 2\pi\sigma_{n2} r^2 tan\partial dr \tag{36}$$

### 4.3 Third type of free form surface.

According to the distribution characteristics of the material pressure on the screw blade under the third type of free surface state, the moment of the screw axis caused by the material particle group on the screw blade can be solved in two parts.

(1) When$R_0 \le r \le R_2$ the moment of z-axis caused by the material particle group's force on the screw blade is:

$$M_{n1}^{(3)} \int_{R_0}^{R} 2\pi f_1\sigma_{n3} r^2 dr + \int_{R_0}^{R} 2\pi\sigma_{n3} r^2 tan\partial dr \tag{37}$$

(2) When$R_2 \le r \le R$ the moment of z-axis caused by the material particle group's force on the screw blade is:

$$M_{n2}^{(3)} = \int_{R_0}^{R} 2\pi f_1 \sigma_{n3} r^2 dr + \int_{R_0}^{R} 2\pi \sigma_{n3} r^2 tan\partial dr \tag{38}$$

The total moment to the axis caused by the material particle group's force on the screw blade is:

$$M_n^{(3)} = M_{n1}^{(3)} + M_{n2}^{(3)} \tag{39}$$

### 4.4 Fourth type of free form surface.

According to the distribution characteristics of material pressure on helical blade under the fourth type of free surface state, the moment of material particle group to z axis of helical axis caused by force on helical blade is solved in two parts.

(1) When$R_1 \le r \le R_2$, the moment of z-axis caused by the material particle group's force on the screw blade is:

$$M_{n1}^{(4)} = \int_{R_1}^{R_2} 2\pi f_1 \sigma_{n4} r^2 dr + \int_{R_1}^{R_2} 2\pi \sigma_{n4} r^2 tan\partial dr \tag{40}$$

(2) When$R_2 \le r \le R$, the moment of z-axis caused by the material particle group's force on the screw blade is:

$$M_{n2}^{(4)} = \int_{R_2}^{R} 2\pi f_1 \sigma_{n4} r^2 dr + \int_{R_2}^{R} 2\pi \sigma_{n4} r^2 tan\partial dr \tag{41}$$

The total moment to the axis caused by the material particle group's force on the screw blade is:

$$M_n^{(4)} = M_{n1}^{(4)} + M_{n2}^{(4)} \tag{42}$$

After determining the characteristic parameters of material movement, and the power of the screw shaft can be calculated by the following formula:

$$N = 2\pi n M_n^{(i)} \omega_s \quad \text{(i=1,2,3and4)} \tag{43}$$

## 5. Conclusion

In this paper, the analysis of the spatial stress state stress function, the pressure distribution on the boundary and the motion characteristics of the material is closer to the actual stress and motion of the granular material than the previous theories. The factors that affect the power of the screw conveyor include the nature of the materials, the structure parameters of the screw conveyor and the rotating speed. The function to describe these influences and its numerical calculation method established in this paper can simulate the actual conveying process with a large number of parameter changes. It can also be used as the objective function calculation model for the optimal design of large inclination screw conveyor. The research content can help master the complex working mechanism of the large inclination screw conveyor, optimize the machine performance, and provide more reliable theoretical basis for the development and design of new models and even the formulation of industry standards.

## References

[1] Liu Yan, Jiang Qiongzhu. Discussion on the material conveying behavior of the vertical screw ship unloader[J]. Journal of Wuhan Institute of Water Transport Engineering, 1985(03): 31-38.

[2] Li Yongzhi, Jiang Qiongzhu. Calculation of productivity and power of high filling rate vertical screw conveyor[J]. Hoisting and Conveying Machinery, 1996(08): 13-18.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0002

[3] Li Yongzhi, Bi Hualin, Jiang Qiongzhu. Research on the vertical conveying process of the screw ship unloader[J]. Journal of Wuhan Institute of Water Transport Engineering, 1992(02):131-136.

[4] Mei Lei. Vertical conveying mechanism and experimental research of screw ship unloader[D]. Wuhan University of Technology, 2014.

[5] Mei Xiao, Wang Wei, Liu Haiyang, Sun Yougang. Research on the movement characteristics of material particles in a large-incline screw conveyor[J]. Mechanical Design and Manufacturing, 2018(S2): 14-17+21.

[6] Mei Xiao, Zheng Ying, Liu Haiyang, Dong Dashan. Analysis of the movement characteristics of the particle group in the vertical screw conveyor[J]. Machine Design and Manufacturing, 2017(07): 26-29.