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Study on modular design and key technology of screw pressing for sludge treatment system

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ABSTRACT

In this study, the method of modular design was formed based on the requirement of modern sludge treatment system. The process of sludge treatment was studied, the operation parameter control points were analyzed and the theoretical basis was provided for each process design. The characteristics of the process of sludge dewatering were evaluated, and the function module tree based on screw press was established. The design of spiral extrusion equipment was serialized, universalized and modularized. The design model of spiral blade with known parameters such as production capacity, compression ratio and product dryness was established, and the basic structure and serial modules of spiral shaft were obtained. The design basis and characteristics of other modules were planned and the complete module design library was formed. According to the characteristics of sludge and production requirements, the database is called to combine to form the equipment.

INTRODUCTION

Water resources are indispensable natural resource for human development. At present, the world is facing severe water shortage problem. Water shortage and water pollution are becoming more prominent. Three billion people will face water shortage in the future, which restricts the development of the world economy (Jiang, 2017). Therefore, water resource is one of the important issues that is concerned by the whole society. The main factors affecting the full utilization of waste paper will be the sewage treatment of papermaking sludge.

According to the statistics of environmental protection department, a large amount of sludge is produced in the process of waste water treatment. According to statistics, the sludge of 1 m^3 will be produced every 1 t paper. In China, the total amount of sludge produced in papermaking is about 125 million t per year, and the total amount is about 25 million t (Wang et al., 2016). It is necessary to fully control the waste water of paper industry, improve the recycling rate of water resources, and completely solve the pollution of the sludge to protect the ecological environment. Green and sustainable development of paper making industry will be maintained (Yang et al., 2015). The nature of the paper mill sludge, dewatering mechanism, conditioning techniques, the relationship among the composition, distribution and sludge dewatering properties of extracellular polymeric substances (EPS), the preparation of EPS flocculants and electro-dewatering (EOD) dehydration technology were mainly elaborated.

Dewatering of papermaking sludge is one of the most economical methods in sludge reduction and recycling. The volume of sludge treated will be reduced effectively. It is also an essential part of sludge disposal, such as incineration, compost and building materials (Ge and Wu, 2012). The sludge dewaterability, flocculant consumption and costs of sludge dewatering for different wastewater treatment processes including A2/O and A2/O-MBR processes were analyzed, as well as the factors of sludge dewatering were analyzed by redundancy analysis (ＲDA) method, based on the data of one municipal wastewater treatment plant of Beijing in 2013. Results

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showed that both sludge dewaterability and flocculant consumption presented the seasonal variation, which means sludge dewatering was harder and coupled with higher flocculant consumption in the winter (Liu et al., 2015). A new type belt super-pressure filter for sludge was introduced. This device can dewater the sludgefrom 99 ~97% moisture to 55% moisture. It shows that the expected operation effect of the device has been achieved in the application for treatment of papermaking and sanitary sewage sludge, which is beneficial to bury, burnand comprehensive utilization of sludge (Lian, 2013). Natural drying and mechanical dehydration are two main methods of sludge drying and dehydration. The mechanical dewatering method of traditional paper making sludge is not ideal due to the limitation of the structure function of the machine, and the water content of the sludge is more than 70%. Sludge is difficult to be used directly. Therefore, the application of screw press to squeeze dehydration is gradually developed (Richard, 2007).

The classification of these new types of solid/liquid separating sets is made, according to the different functions of the single unit of the equipment. While the practical application of the equipments used in different industrial fields is also illustrated (Zhang and Sun, 2004). Based on the quadratic orthogonal rotating combinatorial method with three factors and five levels employed to design the experimental procedure, the effects of independent variables of screw extruded process on solid-liquid separation were analyzed. An optimum independent parameters combination for highest solid TS value of 40% was obtained with water-food ratio of 0.65, article squeeze gap of 1.5 mm and screw speed of 68 r/min. The research results can provide a reference for solid-liquid separation process of dairy manure (Guan et al., 2010). The design helical line which was applied in sludge dewatering screw press device based on theprinciple of solid material balance in the entrance and exit of the drive, the mathematical model of screw axis with equal diameter and variable pitch was derived based on dewatering parameters, and FLUENT was used to simulate the fluid model established by this mathematical model, the pressure and velocity distribution cloud of the flow field were obtained, then the results of post processing to verify the reliability and practicability of the screw press, and provide a kind of new theoretical method to design and analyze the sludge dewatering screw press device (Zhang and Qu, 2015). Application of ultrasonic waves in sludge treatment caused to reduce sludge volume and accelerate sludge digestion (Ghafarzadeh et al., 2017).

The importance of the sewage sludge treatment within the field of wastewater treatment plants (WWTPs) suggests new dimensions of analysis where the relevance of economic criteria combined with the associated environmental issues are increasing the sludge management complexity (Garridobaserba et al., 2015). Sewage sludge contains a lot of resources, such as nutrients and organic matter. At the same time, organic pollutants found in sewage sludge are attracting increasing attention. Therefore, in many European countries, incineration is the current recycling of agriculture. A multi-attribute value theory (MAVT) decision support tool (DST) is used to process sludge processing decisions (Turunen et al., 2018). An enzyme-cavitation method for biological treatment of organic wastewater and sludge treatment was proposed. However, the sludge treatment time is long and the treated sludge has certain adsorption properties (Pyndak et al., 2017). The mathematical model of screw axis was deducedwith equal diameters and variable pitches in sludge dewatering screw press device based on dehydration parameters, and the equation of the relationship between compression ratio and parameters have be established, then theparametric design of screw axis have be achieved based on the requirement of dehydration parameters (Ghafarzadeh et al., 2017). As a kind of filter press, screw press dewatering machine has the characteristics of simple structure, convenient installation and easy maintenance (Zhang et al., 2015). The problem of strength and rigidity of screw axis is solved. At present, the research of screw press is dominated by single equipment, and the research of sludge drying treatment system is not perfect. In this study, the application of modular design in screw extrusion equipment is discussed. The basic method of modular design of screw extrusion equipment is analyzed. The basic idea of system module, structure module, manufacturing module, assembly module and maintenance module is established. The spiral shaft structure and spiral blade of screw press are discussed emphatically. According to the basic dehydration parameters, the mathematical model of the spiral axis is set. Theoretical support is provided for the design of screw press. It is of great significance to establish a perfect sludge treatment system.

THE BASIC STRUCTURE TYPE PLANNING OF THE SLUDGE PRESS SYSTEM

Overview of sludge dewatering system

Sludge drying treatment is mainly to make the sewage in the process of separation, to achieve the drying requirements.The sludge treatment system is mainly composed of flocculant dissolving, sludge pond, flocculation, sludge pretreatment system, sludge crushing system and control system, as shown in Figure 1. Flocculant dissolving system completed the conversion of solid flocculant to solution, and the dissolution time was greater than 45min. In the design, this system will be controlled automatically. Sludge pond is set to ensure the

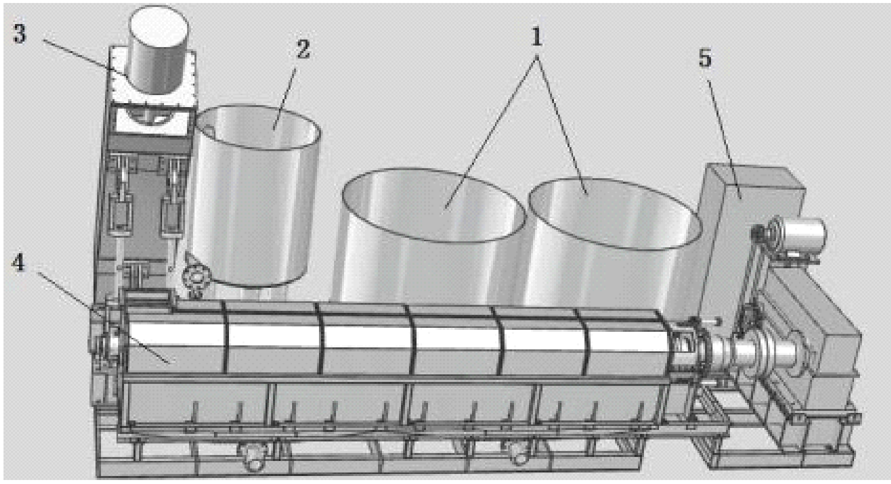

Figure 1. Schematic diagram of sludge screw press processing system. **1,** Flocculant dissolving system; **2,** flocculation system; **3,** primary dehydration system; **4,** screw extrusion dehydration system; **5,** control system.

initial sludge concentration and have sufficient volume to ensure proper system operation. The sludge pretreatment system includes sludge flocculation and pre-dehydration. The function of the flocculation part is to flocculate the sludge in turbid water, and the flocculation mass have enough strength and certain intensity. In the subsequent sieve separation, the sieve can have a larger aperture and is easy to process. The flocculation structure can be separated under certain pressure. Some free water will be separated from the sewage by the pre-dehydration section. The moisture content of sludge must meet the requirements of the follow-up process. After the pre-dehydration, the sludge will be sent to the terminal crushing system to achieve sludge dewatering and reduction requirements. The sludge drying process is mainly to realize the separation of mud and water. Water can be reused. Sludge can be reused after drying and decrement. The pollution of the sludge was eliminated. The sludge system of this study can deal with muddy water mixture with impurity content of more than 3%. Finally, it is required to get the impurity mud with the water content <50%. This will enable the reuse of sludge and filtered water. This combination design is more energy efficient than other mechanical dewatering units, and eventually the sludge moisture content will be reduced by about 10% compared to other dewatering units.

Functional structure analysis of squeezing screw

The dewatering of the terminal is completed by the squeezing screw. The speed control of squeezing screw is realized by frequency conversion to meet the requirements of different properties and water content of the sludge. With the rotation of the screw shaft, the sludge can be extruded, the flocculation is broken, and the water is extruded. The function of screw squeezing system includes feeding, pressing (support, extrusion, water discharge, mud, back pressure) and drive. The system functional structure is shown in Figure 2. According to the structure function division module, 10 modules have been obtained for the same type of products. The control module has been placed in the total control of the sludge treatment system. The control design was mainly based on the production capacity, sludge flocculation effect and the adjustment of speed. The drive function is composed of motor, reducer and belt drive or chain drive, etc., which is connected by coupling and screw shaft. Other modules are production modules for production and assembly and inspection of modules.

THE PLANNING AND DESIGN OF INTERFACE AND CONTROL MODULE

The interface module is connected pre-dehydration module and screw squeezing module. The inlet pressure of the screw press is determined by the location of the sludge in the interface. In fact, the height of the interface can be adjusted according to the sludge characteristics. Pre-dehydration yield can be controlled by sludge location. According to the global parameter configuration point, the control system is designed. Global parameters are shown in Table 1.

Output refers to the amount of sludge that is exported after the process of screw squeezing, and the unit is expressed in tons per day, that is t/d. The export

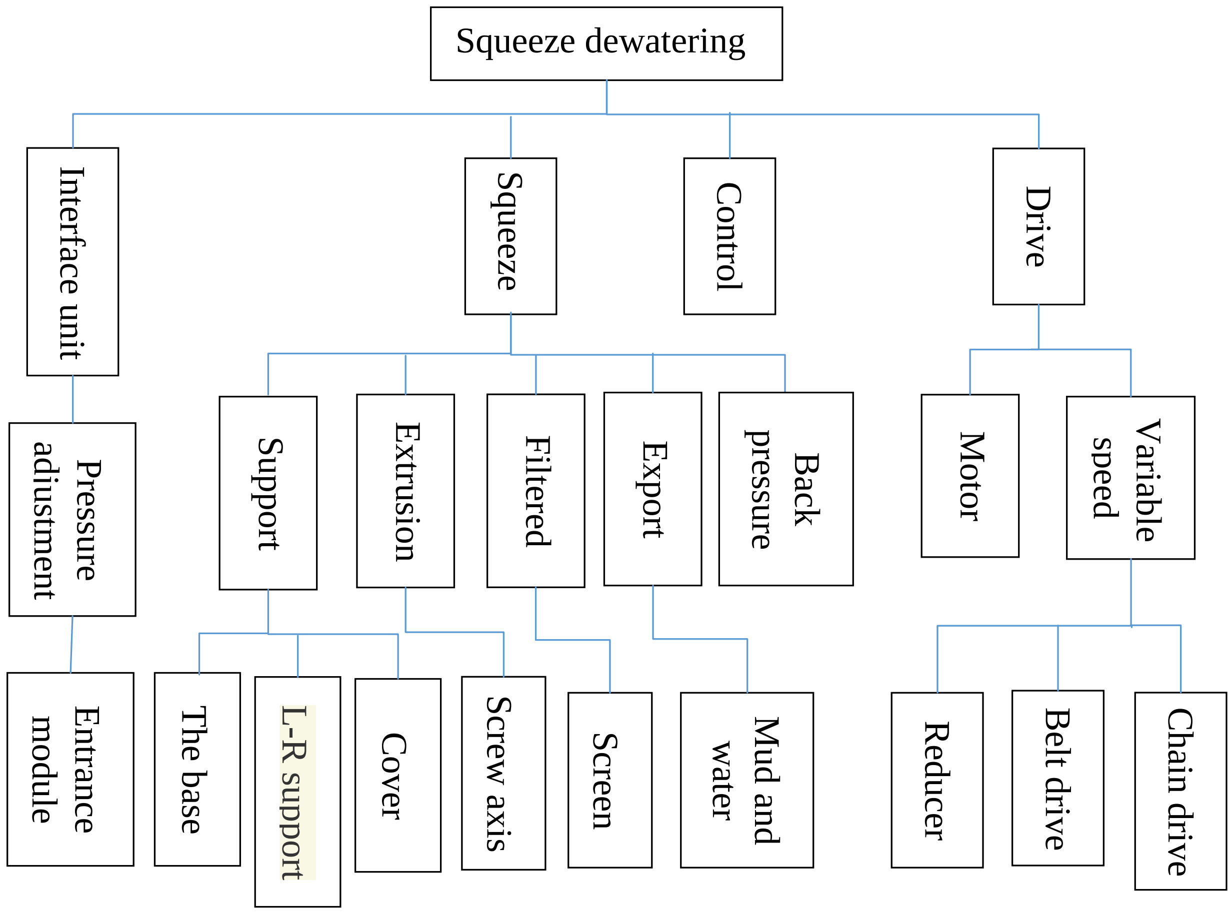

Figure 2. The functional planning of the screw squeezing dewatering structure.

Table 1. System parameter on the control points.

Output (t/d)	Export concentration (%)	Sludge concentration (%)	Sludge flow (m^3/h)	PAM flow (m^3/h)	PAM concentration (%)	PAM dose (kg/t)	PAM dissolution time (min)
10	50	5	4.167	0.446	0.2	4.28	50

concentration is the percentage of solids contained in the output sludge. Sludge concentration is the percentage of solids contained in the original sludge. Sludge concentration refers to the percentage of solids contained in the raw sludge, measured using an online sludge concentration meter. Sludge flow refers to the amount of raw sludge pumped into the system per unit time and is controlled by a flow meter. The unit is expressed in cubic meters per hour, which is m^3/h. PAM is an acronym for polyacrylamide. PAM flow refers to the amount of solution pumped into the system per unit time, which is m^3/h, using variable pump control. The concentration of the solution is 0.2%. The dosage of PAM is solid PAM mass to produce 1 tof absolute dry sludge, unit kg/t. The dissolution time of PAM means the time required for the solid PAM to completely dissolve in water, in min. The PAM dissolution system is independently controlled to ensure that enough solution is available to the system.

THE PLANNING OF DRIVING MODULE

The operation of press processing is driven by the driver module. The variable frequency motor is used as the power, and then the reducer and other transmission combinations are realized. In the sludge treatment

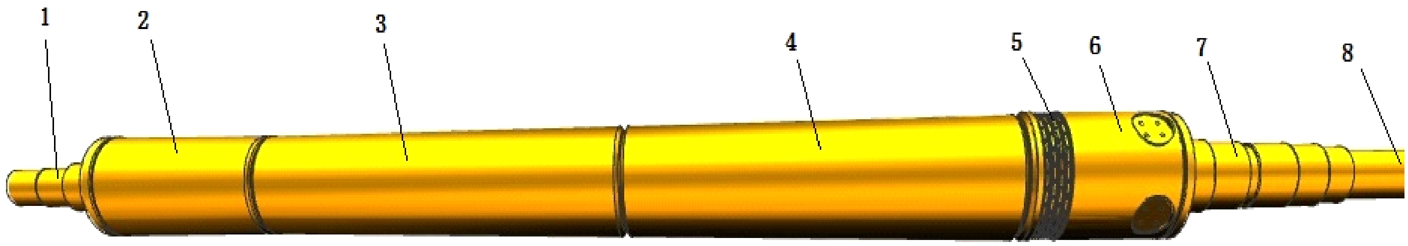

Figure 3. Basic structure of inner shaft.

system, the water content and yield of the mud are usually required. In the design, a series of modules with compression ratio changes are formed. But the drive is the same. Therefore, it is necessary to fully consider the change of screw shaft torque when driving module planning. The coordination of rotation speed and torque is realized through the change of transmission module. The combination mode is selected in series modules according to economy and space structure. In general, there are four ways.

(1) Motor → Reduce → Coupling
(2) Motor → Belt → Reduce → Coupling
(3) Motor → Reduce → Chain → Coupling
(4) Motor → Belt → Reduce → Coupling

THE PLANNING OF THE SCREW SHAFT STRUCTURE

Axis planning and design in the screw inner ring

In practice, two structural forms are used for inner shaft, equal diameter and variable diameter. For the dehydration treatment of high water content sewage, variable diameter is generally used, which is conducive to the formation of a larger compression ratio. The structure of the screw shaft is planned to be a left - right supporting section and a screw section. In the design, the structure of inner shaft is the same for the same module, and the change of compression ratio is realized by the change of blade pitch, which is beneficial to the standardization of machining module and the improvement of machining quality. The basic structure of the screw axis is shown in Figure 3.

The volume change of screw space is formed by two parts, one is the pitch change, and the other is the taper of the axis. The lateral force is affected by the taper. The smaller the lateral force is, the more difficult the sludge is to be extruded into the screen hole, which is more favorable to the production quality. The greater the taper, the greater the lateral force, the easier the sludge will be expelled from the screen holes. The greater the taper, the greater the axial thrust difference, the more unfavorable to transport sludge. In the Figure 3, the left supporting part is in position 1 and is designed according to the fixed requirements of the bearing. The sludge inlet is located at position 2 and is designed to be cylindrical. The front part of the middle part is designed to be conical at position 3. The back of the middle section is also conical at position 4. In general, the half cone angle is <3°. At position 3, the sludge has larger water content and cone angles can be chose larger. At this time, the sludge is easy to slip and the friction force will be reduced. At position 4, with the decrease of the squeezing water, the frictional resistance will increase and the cone angle will decrease accordingly. Near the sludge outlet, the pressure increase, and the double effluent structure is used, that is, the shaft screen at position 5. The structure of position 6 is designed according to the loose requirements of the mud. The structure of position 7 is designed according to the assembly requirements of the bearing. Position 8 is the power input part, which is determined according to the coupling structure. The middle shafts are designed to be hollow, that is from 2 to 6. In this way, the weight is reduced, the material is saved, and the water from the shaft screen is output at the same time. The hollow shaft thickness will be obtained by strength and stiffness analysis.

Analysis of screw blade structure

The structure and layout of the blades are shown in Figure 4. Variable pitch structure is widely used. The dehydration effect will be determined by the taper of the inner shaft and the pitch of the screw blade. In this study, the blades were designed with equal outer diameter, called equal diameter design, to simplify the design and processing of the screen. There are two parameters that affect the performance of the sludge press, namely the cone angle and the pitch. The compression ratio will be affected by the aforementioned two parameters.

Compression ratio α_i can be calculated according to the volume of the screw per turn. The total compression

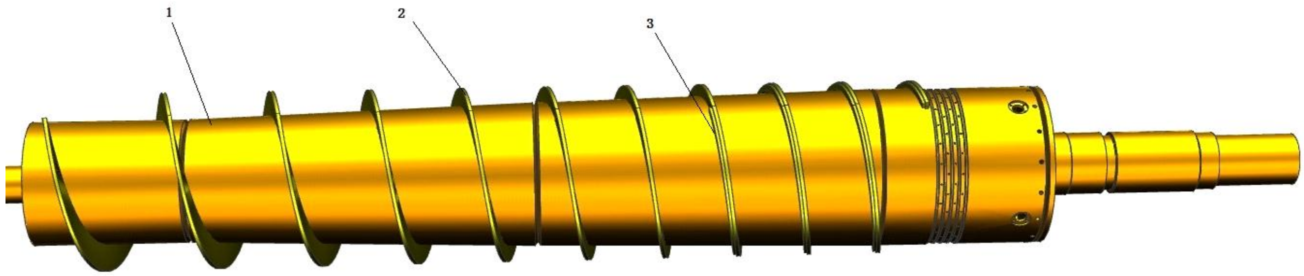

Figure 4. Structure and arrangement of the blade.
1, Shaft; **2,** blade; **3,** wearable blocks.

ratio α is defined as follows:

$$\alpha = \frac{v_n}{v_1} = \frac{v_2}{v_1} \bullet \frac{v_3}{v_2} \cdots \frac{v_n}{v_{n-1}} = \alpha_1 \alpha_2 \cdots \alpha_n \quad (1)$$

Therev_1,v_2,…v_n is the volume of 1th to nth circle. The volume of each pitch can be expressed as:

$$v_i = \frac{\pi t_i}{4}\left(D^2 - d_{cpi}^2\right) \quad (2)$$

The volume of each pitch blade is expressed as:

$$v_{yi} = b h_{cpi} \sqrt{(\pi D_{cpi})^2 + t_i^2} \quad (3)$$

Therefore, the volume of the sludge can be expressed as:

$$v_i = \frac{\pi t_i}{4}\left(D^2 - d_{cpi}^2\right) - b h_{cpi} \sqrt{(\pi D_{cpi})^2 + t_i^2} \quad (4)$$

Here: $D_{cpi} = \left(D + d_{cpi}\right)/2$, $d_{cpi} = (d_i + d_{i+1})/2$, $d_{i+1} = d_i + 2t_i \tan(\theta_i / 2)$, $h_{cpi} = \left(D - d_{cpi}\right)/2$.If the rotational speed of the screw axis is known, the production capacity can be expressed as:

$$Q_i = 60 v_i n \gamma \phi \mu / 10^{-9} \text{ (kg/h)} \quad (5)$$

The volume$v_i$in the equation is sorted.

$$v_i = \pi t_i D_{cpi} h_{cpi} - b h_{cpi} \frac{t_i}{\sin\beta_i} = \pi t_i D_{cpi} h_{cpi} - b h_{cpi} \frac{t_i \cos\beta_i}{\sin\beta_i \cos\beta_i}$$
$$= \pi t_i D_{cpi} h_{cpi} - b h_{cpi} \frac{\pi D_{cpi}}{\cos\beta_i} = \pi D_{cpi} h_{cpi} (t_i \cos\beta_i - b)/\cos\beta_i$$

In the formula, the helix angle is defined as:

$$\tan\beta_i = t_i / \pi D_{cpi} \quad (6)$$

Here:D (mm), the outer diameter of the screw blade; d_i (mm), the inner diameter of the screw blade; t (mm), screw pitch;θ(∘)–angle of cone;b (mm), blade thickness; h_i (mm), blade height; n (rpm), speed of screw shaft; γ(kg/m³), the bulk density of dry mud;ϕ, filling coefficient ;μ, the entrance concentration.

In the design analysis, the basic parameters are determined first. For example, the pitch circle number i, compression ratio α, screw outer diameter D, screw inner diameter d_1, cone angle θ and number of segments, design screw length, etc. Then, the compression ratioα_i and pitcht_i are determined according to the total compression ratio. If the compression ratio α_ι of adjacent circles is known, and the pitch t_i can be solved by Equations 1-6.

At the end of the squeeze, the pressure increases. In order to reduce the wear of the blades, the wear-resistant block is increased. At this point, the space containing the sludge will be reduced, and its reduction is expressed as follows.

$$v_j = b_{wj} \frac{1}{2}\left(d_{wj} - d_{nj}\right)\sqrt{\frac{\pi}{4}\left(d_{wj} + d_{nj}\right)^2 + t_j^2} \quad (7)$$

Here:v_j, Volume of sludge;b_{wj}, thickness of wear resistant

block and fixed plate; d_{wj}, outer diameter of wear block; d_{nj}; the inner diameter of the fixed plate; t_j, the pitch.
Thus, the volume of sludge per pitch in the position of the wear-resistant block can be expressed as:

$$v_i = \pi D_{cpi} h_{cpi} (t_i \cos\beta_i - b)/\cos\beta_i - b_{wj} \frac{1}{2}\left(d_{wj} - d_{nj}\right)\sqrt{\frac{\pi}{4}\left(d_{wj} + d_{nj}\right)^2 + t_j^2} \quad (8)$$

PLANNING OF OTHER MODULES

Other modules include support, filtered water, base and exit etc. For the same type of equipment, the interfaces of each module are the same to facilitate the processing and replacement. As the supporting base module, it mainly serves as the supporting role of other modules and the placement of the drain line. Its structure is designed to support the interface by fixing the module on it. The filter water module is designed as a segmented sieve, which includes the entrance, entrance screen and other length screen. The support module is designed by the left and right bearing to complete the positioning of the screw axis. The export module is designed according to the requirements of sludge conveying and sludge quantity. In addition, the back pressure module is designed according to the control pressure terminal sludge pressure. In general, a combination of pneumatic devices is selected to complete the pressure control.

MODULE CALLS

The design, manufacture, assembly and maintenance of serialized products can be carried out according to the principle of modularization. The function module is determined according to the serialized parameters. In design, manufacturing, assembly and maintenance management, the database can be established according to the unified module structure. In the design, the corresponding module is determined by the analysis technique. In addition, by dividing and using the hierarchical modularization, the database hierarchy is clearer and the invocation is more convenient.

The design of the structure module of this study is based on the dimension scale adjustment according to the module level. The type of the top module is determined based on the size of the screen frame. Then, the module type is selected according to the production capacity requirement. The structural modules are determined by compression ratio or final moisture content. The modular library of the spiral press equipment will be formed by combining the two.

Conclusion

The application of modular design in screw press equipment is analyzed in this paper. The basic method of modularized design and analysis is studied in combination with the screw press equipment. In the system analysis, the basic idea of system module, structure module, manufacturing module, assembly module and maintenance module must be established. At the same time, the parameter configuration of the screw press dehydration system is analyzed, and the basic control parameters are obtained, and the basic data is provided for the design of the control module. The structure of helical shaft, the main structural module affecting sludge dewatering performance, was analyzed. The calculation method of sludge space and compression ratio was established, and the basis of blade layout of spiral shaft was obtained. Therefore, the module can be automatically invoked according to the performance and requirements of the sludge. The science and automation of the design of squeeze screw dehydration equipment may be realized.

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