Research on the Design and Application of an Efficient Sisal Drying Device

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Abstract: Aiming at the problems in the traditional sisal drying process, such as the cumbersome manual adjustment of the position of drying poles, heavy labor intensity, low work efficiency, and easy damage to sisal, this study designed a new type of sisal drying device based on the principles of mechanical transmission and automation control technology. The device has a core framework composed of a left support, a right supp ort, and a fixing frame. Through a motor - driven sprocket and conveyor chain system, combined with the action of a solenoid valve - controlled paddle, it realizes the automatic transmission and position replacement of the drying poles. Practical application tests show that this device can make sunlight and air flow act evenly on sisal fibers, effectively reducing quality problems such as discoloration and mildew. The qualified rate of sisal fibers has increased by 23.5%. At the same time, it greatly reduces labor intensity, improves the drying efficiency by more than 40%, and can be extended to the drying of strip - shaped foods such as noodles and vermicelli. This device has a simple structure, convenient operation, and strong versatility. It provides a feasible solution for the mechanization and high - efficiency upgrade of the sisal drying process, and has high practical value and broad promotion prospects.

Keywords: Sisal Drying; Automatic Device; Mechanical Transmission; Position Replacement; Efficiency Improvement; Quality Optimization

1. Introduction

As an important tropical cash crop, sisal is mainly distributed in regions such as South America, Africa, and Asia around the world. Currently, countries like Brazil, China, and Mexico are major producers. China ranks third globally in terms of sisal planting area and fourth in terms of production[1]. Today, sisal fiber remains the hard fiber with the largest application volume and the widest application range in the world. Its fiber output accounts for two - thirds of the world's hard fiber output[2]. Sisal products are ubiquitous, whether in the industrial or agricultural fields, ranging from professional supplies to daily consumer goods. Due to its excellent properties such as high strength, good toughness, wear - resistance, and corrosion - resistance, sisal fiber is widely used in various fields including ropes, carpets, papermaking, and building materials. It serves as an important source of economic income for farmers in tropical and subtropical regions of China, such as Hainan, Guangxi, Yunnan, and Guangdong. The development quality of the sisal - planting industry is not only related to the stable growth of the regional agricultural economy but also of great significance for ensuring the raw - material supply of relevant downstream industries[3]. The drying of agricultural products is a crucial intermediate step and one of the important operations in the production process of agricultural products. Through drying treatment, the water content of crops can reach the requirements of processing or technological processes, ensuring the quality, storability, and processability of agricultural products[4]. Therefore, in the entire sisal industry chain, the drying process is a vital link connecting raw material harvesting and subsequent processing, directly determining the quality grade and market value of sisal fibers. The core component of sisal fibers is cellulose. However, freshly harvested sisal leaves contain a large amount of impurities such as water, gum, and sugar. If the drying is insufficient or uneven, the water content can easily cause the crops to mildew and rot, and the losses will be even greater in case of continuous rainy weather[5]. Meanwhile, these impurities can cause fiber adhesion and discoloration, which not only reduces the core properties of fibers such as strength and flexibility but also affects the smooth progress of subsequent processing. Ultimately, this leads to a significant decline in the added value of products. Statistics show that under traditional drying methods, the quality loss rate of sisal fibers due to improper drying is as high as 15% - 20%, directly affecting farmers' planting profits and the overall competitiveness of the industry.

At present, the drying methods in the main sisal - producing areas of China are still dominated by traditional models, which are mainly divided into two types: ground - flat drying and simple - bracket drying. Ground - flat drying is mostly suitable for small - scale growers. The harvested sisal leaves or semi - processed fibers are directly spread on cement floors, drying yards, or natural ground for drying. Although this method is simple to operate and requires no additional equipment investment, it has many drawbacks: (1) It is highly vulnerable to weather conditions. In rainy and humid weather, moisture can easily seep back, and mold is likely to grow. (2) The labor intensity is high. Frequent turning is required during the drying process, which can easily cause fiber breakage. (3) High requirements for the drying site. During the peak harvest period, farmers have no choice but to dry on roads, posing traffic safety hazards, risks of vehicle - rolling damage, and secondary pollution risks such as dust, insects, and benzene volatilization from the road[6,7].

For large - scale sisal plantations, the simple - bracket drying method is mostly adopted. By building wooden or iron brackets, sisal fibers are hung or laid flat on the drying poles for drying. This method has, to some extent, addressed the moisture problem of ground drying, but there are still significant pain points: First, the drying poles are arranged densely, resulting in poor ventilation inside the bracket. Sunlight can hardly cover all fibers evenly. As a result, fibers in some areas dry too quickly and become brittle, while those in some areas dry too slowly and get moldy, leading to poor consistency in fiber quality. Second, to achieve even drying, it is necessary to manually adjust the position and angle of the drying poles regularly. The operation process is cumbersome, the labor intensity is high, and the efficiency of manual adjustment is low, making it difficult to meet the needs of large - scale drying. Third, during the manual adjustment process, the handling and turning of the drying poles are prone to collide and rub against the bracket, causing damage and breakage to the sisal fibers, further exacerbating quality loss. Fourth, traditional brackets lack flexible spatial adjustment capabilities and cannot dynamically adjust the drying layout according to environmental conditions such as the angle of sunlight and wind force. The drying effect is significantly affected by the weather.

At present, certain progress has been made in the research on agricultural product drying equipment at home and abroad. However, the research on automated devices specifically for sisal drying is relatively scarce. Abroad, in countries with developed tropical cash crop cultivation, such as Brazil and Mexico, sisal is mostly planted in a large - scale and intensive manner. Their drying equipment mainly consists of large - scale drying production lines, which use hot - air drying technology to rapidly dry sisal fibers. Nevertheless, the current mechanized drying technology also has many limitations, and its widespread application in China is greatly restricted. Currently, it is mostly used in medium - and large - scale intensive production operations[8]. These limitations are mainly reflected in the following aspects: (1) The device has high energy consumption and cost. (2) The drying machinery requires a large one - time investment and has a long investment recovery period[9,10]. (3) There is a variety of items to be dried, and it is difficult to control indicators such as drying uniformity, crop quality, and breakage loss rate. High demands are placed on the performance and quality of the mechanical device[11].

In China, relevant research mainly focuses on the development of drying equipment for agricultural products such as grains, fruits, and vegetables, such as solar drying rooms, movable drying racks, and solar - powered automatic turning and drying machines. These devices have accumulated certain technical experience in structural design and automated control. However, sisal fibers have special requirements such as their long - strip shape, high toughness, and the need to remain loose during the drying process, making it difficult for existing agricultural product drying equipment to be directly applicable[12]. Some studies have attempted to improve traditional sisal drying brackets, such as adding ventilation layers and optimizing the bracket angle, but they have not fundamentally solved the core problems of cumbersome manual operation and poor drying uniformity.

Therefore, based on the actual demands of China's sisal industry, this study integrates mechanical transmission technology and automated control technology to design a highly efficient automated device specifically for sisal drying, thus promoting the mechanized upgrade of the sisal - drying process.

2. Design of the Overall Device Scheme and Key Components

2.1 Design of the Overall Device Plan and Key Components

2.1.1 Collaborative design of the overall structural layout and working principle

First, before placement, the sisal fibers need to be pre - treated to ensure that there are no obvious knots or clusters. The fibers should be combed into a loose state with a single - bundle diameter of 5 - 10 mm to avoid affecting subsequent ventilation and drying due to fiber adhesion. Subsequently, the hanging operation is carried out. As shown in Figure 1, the pre - treated sisal fibers are evenly and loosely hung on the drying pole. The spacing between each bundle of fibers should be maintained at 5 - 10 mm, and the natural drooping length of the fibers should be controlled to exceed the two ends of the drying pole by 10 - 15 cm. This not only prevents the fibers from slipping during the transmission process but also reserves sufficient ventilation space for the fibers on adjacent drying poles to avoid mildew caused by overlapping. In this high - efficiency sisal drying device, the fixed position of the drying pole is achieved through a dual design of "mechanical limit + transmission coordination", which not only ensures stability during the transmission process but also adapts to the requirements of cyclic replacement. The specific fixing methods are as follows:

The positioning of the drying rod is fixed as depicted in Figure 2. At its core, it depends on the structured limiting components of the cross - frame and the support frame. On the cross - frame, transmission rods made of nylon are arranged on the transmission chain at intervals of 300 mm. Movable rollers are installed at the ends of these rods. Once the drying rod is placed, its two ends are precisely positioned between adjacent transmission rods. The lateral obstruction of the rods restricts movement in the horizontal direction, preventing lateral displacement during the transmission process. Simultaneously, the movable rollers make rolling contact with the drying rod, minimizing frictional damage while maintaining its fixed position.

Inside the support frame, a double - guide limiting structure is formed by the ">"-shaped inlet and outlet on the shell and the guide protrusions on the guide plate. When the drying rod enters or exits the cross - frame, the guide protrusions define its moving trajectory from both sides, with a guiding error of less than 5 mm, ensuring it accurately enters the preset transmission path. In addition, the connection between the support frame and the cross - frame adopts a precise docking design. The size of the inlet and outlet is precisely matched with the diameter of the drying rod, further restricting the radial displacement of the drying rod to prevent it from falling off or getting stuck.

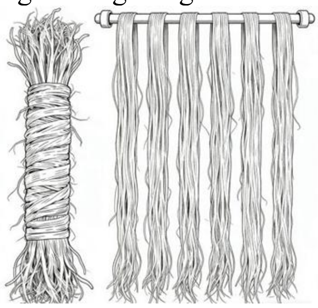

Figure 1. Schematic Diagram of Sisal Hanging Method

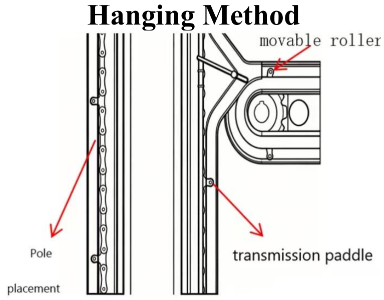

Figure 2. Schematic Diagram of the Positioning of the Drying Pole

As shown in Figure 3, the core framework of the device consists of a left support, a right support, and a fixed frame, featuring a symmetrical multi - layer "closed - frame" layout design. This design precisely matches the S - shaped cyclic transmission principle of "left support frame → upper - layer cross - frame → right support frame → lower - layer cross - frame → left support frame". Starting from point T1 of the support frame, along the direction of velocity, it is vertically conveyed upward to point T2, then horizontally conveyed to the right through the cross - frame to point T3. After that, it is conveyed to the right support frame and then downward to point T4. Subsequently, it is horizontally conveyed to the left through the cross - frame to point T5, and then vertically downward through the left support frame to point T6. The conveyance and drying from T6 to T9 are carried out in the same way.

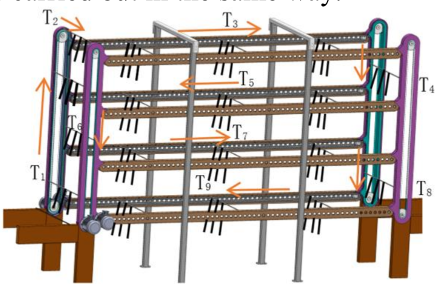

Figure 3. Schematic Diagram of the Sisal Drying Device and Its Motion Trajectory

This layout is not simply a spatial stacking. Instead, based on the drying requirements of "even sunlight exposure + efficient ventilation", sisal fibers are loosely hung on the drying poles. Through the design of multiple independent drying spaces, the drying poles alternately assume different heights and orientations during cyclic conveyance, ensuring that each bundle of sisal fibers can receive uniform sunlight and air circulation. Compared with traditional single - layer brackets or fixed multi - layer brackets, the advancement of this solution lies in the fact that traditional devices require manual adjustment of the drying pole positions frequently to achieve even drying. In contrast, through the integrated design of the structural layout and transmission path, this device transforms "manual position adjustment" into "mechanical automatic cycling". From the root of the design, it realizes the automation of the drying process, greatly reducing labor intensity while ensuring drying uniformity.

2.1.2 Innovation in modular design and multi - scenario adaptability

The overall plan adopts a modular split design. The left support, right support, cross - frame, and fixed frame are all independent modules, which are connected by high - strength bolts. The number of cross - frame layers or the distance between supports can be flexibly adjusted according to the size of the drying site and the demand for the amount of drying. This design, combined with the working principle of "steplessly adjustable conveying speed", enables the device to be applicable not only to the drying of sisal fibers but also, by adjusting parameters such as the distance between drying poles and the conveying speed, to meet the drying requirements of different long - strip materials such as noodles, vermicelli, and cotton yarn. Compared with the "one - thing - for - one - use" limitation of traditional special - purpose drying equipment, the innovation of this plan lies in achieving a breakthrough in versatility, that is, "one machine with multiple functions". Traditional sisal drying equipment is designed only for the characteristics of sisal fibers and cannot be adapted to other materials. However, through the combination of a modular structure and an adjustable transmission principle, this device not only ensures the professionalism of sisal drying but also expands the application scenarios, improves equipment utilization, reduces the investment cost for users, and meets the diversified needs of small - and medium - scale growers and processing enterprises.

2.2 Design of Key Components

2.2.1 Structure of the conveyor support frame

Collaborative Innovation in Precise Transmission and Guidance As the core component for vertical transmission, the conveyor support frame integrates the support frame motor, sprocket - conveyor chain system, guide plate, paddle, and solenoid valve control components. Its structural design is deeply intertwined with the working principle of "layer - by - layer precise transmission". The ">"- shaped inlets and outlets for the drying poles on the support frame housing form a dual - guidance structure with the guide protrusions on the guide plate. Coupled with the controllable rotation of the paddles, it enables the precise introduction and extraction of the drying poles between different cross - frame layers, with a guidance error of less than 5mm. The innovation lies in the fact that traditional drying equipment often uses a slide - rail - based design for vertical transmission, which is prone to jamming and inaccurate guidance, and requires manual assistance for pushing. In this device, the transmission combination of "motor + reduction gearbox + sprocket - conveyor chain" reduces the motor speed to 72 r/min through a reduction gearbox with a reduction ratio of 1:20, ensuring the smooth and slow transmission of the drying poles, thus preventing fiber shedding or damage. At the same time, the coordinated action of the paddle and the toggle link, controlled by the solenoid valve, realizes the automatic opening and closing of the inlets and outlets, with a response time of less than 0.5s, precisely matching the cyclic transmission rhythm of the drying poles. In addition, the design of the auxiliary rod on the outer side of the support frame, combined with the requirement of "batch feeding", can temporarily hold the drying poles to be dried. Together with the continuous transmission of the conveyor chain, it realizes batch - automated feeding, further improving operational convenience. This is also an innovative optimization of the "single - pole feeding" mode of traditional equipment.

2.2.2 Cross - frame structure

Efficient Design for Horizontal Conveyance and Stable Loading As a horizontal conveyance component, the structural design of the cross - frame is centered around the working principle of "smooth conveyance + adequate drying", consisting of a cross - frame motor, a sprocket - conveyor chain system, transmission push rods, and movable rollers. The cross - frame housing is fabricated from aluminum alloy profiles, with a top - opening design that facilitates the placement and removal of the drying poles. The edges of the opening are chamfered to prevent fiber scratching. The nylon - made transmission push rods, which are set at intervals on the conveyor chain, have movable rollers installed at their ends. This converts the sliding friction between the drying pole and the conveyor chain into rolling friction, significantly reducing friction and wear during the conveyance process. The advanced nature is manifested in that traditional horizontal conveyance equipment mostly uses belt transmission or direct sliding conveyance, which easily causes the offset and wear of the drying poles, affecting the quality of the fibers. In this device, the power combination of a "1.1 - kW motor + 1:25 reduction gearbox" outputs a rotational speed of 57.6 r/min, ensuring the smooth horizontal conveyance of the drying poles. At the same time, the spacing between the transmission push rods is set at 300 mm, precisely matching the length of the drying pole. This ensures that the drying pole remains horizontal during the conveyance process, allowing the sisal fibers to hang naturally and fully come into contact with sunlight and air currents. This design not only meets the requirement for the stability of horizontal conveyance but also provides structural support for even drying.

2.2.3 Collaborative innovation of control components and transmission system

The control components adopt a combination of a PLC (Programmable Logic Controller) and a touch - screen, which is deeply integrated with the working principle of "periodic position replacement". Parameters such as the motor rotation direction, replacement cycle (1 - 3 hours per time), and total drying time can be preset to achieve fully automated control. The collaborative logic between the control system, motors, and solenoid valves is the core manifestation of the device's advancement. Traditional drying equipment lacks the automatic position - replacement function and requires manual adjustment at regular intervals, which is inefficient and prone to omission. In this device, the PLC controller precisely controls the start - up, shutdown, and rotation direction of each motor, as well as the on - off state of the solenoid valves. This enables the drying poles to circulate along the preset S - shaped path, regularly completing up - down and left - right position replacements to ensure that the fibers on each drying pole receive uniform sunlight. The design of the overload protection device is combined with the load requirements of the transmission system. When the transmission resistance exceeds the set thresholds (50 N for the support frame and 40 N for the cross - frame), the motor automatically stops to prevent damage to mechanical components, improving the operational safety and service life of the device. This collaborative design of "control logic + transmission system" makes the device's degree of automation far exceed that of traditional equipment. The entire process of feeding, conveying, position replacement, and unloading can be completed without manual intervention.

3. Analysis of Working Principle and Core Conveyance Mechanism

3.1 Working Principle of the Whole Machine

The core working logic of this sisal drying device is to achieve the automatic conveyance of the drying poles along a preset path and periodic position replacement through the coordinated transmission of the motor - reduction gearbox - sprocket - conveyor chain, combined with the solenoid - valve - controlled guiding mechanism. This ultimately ensures uniform sunlight exposure and ventilation for the sisal fibers.

The device adopts a layered cyclic conveyance mode, where the drying poles move cyclically along an S - shaped path of "left support frame → upper - layer cross - frame → right support frame → lower - layer cross - frame → left support frame". The motor of the left support frame drives the drying poles upward to the upper - layer cross - frame. The motor of the upper - layer cross - frame then transversely transports them to the right support frame. The motor of the right support frame drives the drying poles downward to the lower - layer cross - frame, and the motor of the lower - layer cross - frame sends them back to the left support frame, completing one cycle. During the drying process, the device can automatically replace the positions of the drying poles according to a preset cycle of 1 - 3 hours per time. By reversing the operation of the motors and coordinating with the guiding mechanism, the positions of the drying poles at the bottom and top layers, as well as on the left and right sides, can be interchanged to avoid uneven drying of local fibers.

The control system utilizes an S7 - 200 SMART PLC (Programmable Logic Controller). Parameter configuration and operational monitoring are enabled through a touch - screen interface. It is capable of presenting the device's status, drying duration, and the frequency of position replacements in real - time. Through the precise linkage of the relay module with motors and solenoid valves, the system achieves high - accuracy control and a fast response, guaranteeing the harmonious coordination of transmission and guiding operations.

3.2 Key Analysis of the Core Conveyance Mechanism

3.2.1 Design and advantages of the sprocket - conveyor chain transmission system

The transmission system is the core of the device's conveying function. It adopts a combined solution of "motor + reduction gearbox + sprocket + conveyor chain", taking into account both transmission stability and load adaptability.

Parameter Matching of Sprocket and Conveyor Chain: The sprockets of both the support frame and the cross - frame are designed with 18 teeth, and the pitch is uniformly set at 25.4mm. The 16A - 1 type roller chain (with a chain plate thickness of 4mm) is selected for the conveyor chain, ensuring the coordination of each transmission unit and the interchangeability of spare parts. The sprockets are forged from 45 - steel and their surfaces are quenched to reach a hardness of HRC45 - 50, significantly improving wear resistance. The roller structure of the conveyor chain can reduce meshing friction, preventing chain jumping and derailment during operation, with a transmission efficiency of over 90%.

Precise Regulation of Power Output: The support frame motor has a power of 1.5kW and is equipped with a reduction gearbox with a reduction ratio of 1:20, reducing the rated speed of 1440r/min to 72r/min. The cross - frame motor has a power of 1.1kW, and through a reduction gearbox with a reduction ratio of 1:25, the output speed is controlled at 57.6r/min. This design of "high - power motor + high reduction ratio" not only ensures the load - bearing capacity of the transmission system but also enables the smooth and slow conveyance of the drying poles, avoiding the shedding or damage of sisal fibers caused by excessive speed.

Overload Protection Mechanism: All motors are equipped with overload protection devices. The protection threshold of the support frame motor is set at 50N, and that of the cross - frame motor is 40N. When the transmission resistance exceeds the threshold, the motor automatically stops, effectively preventing the damage of mechanical components due to overload and improving the operational safety and service life of the device.

3.2.2 Guiding and linkage control mechanism

The precise linkage between the guiding mechanism and the transmission system is crucial to ensure the smooth conveyance of the drying poles. Dual - guiding Structure: Both the support frame housing and the guide plate are equipped with a “>”-shaped guiding structure. The “>”-shaped inlets and outlets on the housing and the guide protrusions (with a height of 30mm and an inclination angle of 45°) on the guide plate form a dual - guiding system. With the assistance of gravity, the drying poles can be accurately guided into or out of the cross - frame, with a guiding error of less than 5mm, thus avoiding jamming. Electromagnetic - controlled Guiding Switching: Nylon paddles (with a thickness of 8mm) are installed on the guide protrusions through pins. The paddles can rotate 0° - 90° around the pins. Two toggle links (A and B) are driven by a two - position five - way solenoid valve (with an operating pressure of 0.4 - 0.6MPa) to achieve synchronous movement. The paddles of the guide protrusions on the 1st and 3rd layers are connected to link A, and those on the 2nd and 4th layers are connected to link B. By controlling the on - off state of the solenoid valve to rotate the paddles, the inlets and outlets can be quickly opened and closed, with a response time of less than 0.5s, precisely matching the conveyance rhythm of the drying poles.

After the parameters are set, click the "Start Conveyance" button on the touch - screen, and the device starts to operate automatically. The motor of the left support frame starts, driving the conveyor chain to move upward. The transmission push rods push the drying poles on the auxiliary rod through the inlet and outlet of the frame rod into the interior of the left support frame housing. The drying poles move upward driven by the conveyor chain. When they reach the inlet and outlet of the drying poles corresponding to the upper - layer cross - frame, the control system commands the toggle link A to move upward, driving the paddle to rotate and open this inlet and outlet. Under the combined action of gravity and the transmission push rods, the drying poles slide into the upper - layer cross - frame along the guide protrusion.

The motor of the upper - layer cross - frame starts, and the conveyor chain drives the drying pole to move towards the right support frame. During the conveying process, both ends of the drying pole rest on the transmission push rods of the cross - frame conveyor chain, maintaining a horizontal state. The sisal fibers hang naturally, fully exposed to sunlight and air currents. When the drying pole reaches the corresponding inlet and outlet of the drying pole of the right support frame, the toggle link A of the right support frame moves downward to open the inlet and outlet, and the drying pole enters the interior of the right support frame housing.

The motor of the right support frame starts, driving the conveyor chain to move downward, and transports the drying pole to the inlet - outlet position corresponding to the lower - layer cross - frame. The control system commands the toggle link B to move upward, opening the inlet - outlet, and the drying pole slides into the lower - layer cross - frame. Then, the motor of the lower - layer cross - frame starts, driving the conveyor chain to move towards the left support frame, and transports the drying pole back to the left support frame, completing the arrangement of the drying poles on the first - layer cross - frame.

Repeat the above process until all four layers of cross - frames are filled with drying poles. The device then automatically enters the drying stage, and the touchscreen displays the "Drying" status and starts timing.

3.2.3 Collaborative logic of horizontal and vertical conveyance

Vertical Conveyance (Support Frame): It is responsible for the lifting and transfer of the drying poles. The driving sprocket and the driven sprocket are installed at both ends of the support frame housing respectively, forming a closed transmission loop through the conveyor chain. The push rods on the conveyor chain push the drying poles to move along the internal track of the housing. The auxiliary rod (forming an angle of 30° with the housing) can temporarily hold the drying poles to be processed, cooperating with the conveyor chain to achieve batch feeding and improving the conveyance continuity.

Horizontal Conveyance (Cross - frame): It undertakes the horizontal transfer of the drying poles between the left and right support frames. The cross - frame housing is designed with aluminum alloy profiles, and the top opening facilitates the placement and removal of the drying poles. Nylon transmission push rods are set at intervals of 300 mm on the conveyor chain, and movable rollers (with a diameter of 20 mm and a length of 30 mm) are installed at the ends. This converts sliding friction into rolling friction, significantly reducing the surface wear of the drying poles. Meanwhile, it provides auxiliary support to the conveyor chain, enhancing the operational stability.

Collaborative Linkage: The PLC controller uniformly regulates the startup, shutdown, and rotation directions of the vertical and horizontal motors. Through a pre - set program, it achieves seamless connection of "vertical conveyance - horizontal transfer - vertical conveyance", ensuring that the drying poles move cyclically along the S - shaped path and the position replacement is accurate, all without the need for manual intervention.

4. Analysis of the Device's Advantages and Rationality

4.1 Core Advantages

High degree of automation, significantly reducing labor intensity: Through the coordinated operation of the PLC control system, motors, and solenoid valves, this device can automatically convey, replace positions, and remove the drying poles without any manual intervention. This completely replaces the cumbersome manual adjustment of drying poles in traditional drying methods. In the traditional rack - drying method, an operator can only manage the drying of about 100 kg of sisal per day and has to frequently turn and adjust the drying poles, resulting in extremely high labor intensity. However, this device can manage the drying of 200 kg of sisal per unit. The whole process requires no manual operation except for one operator to be responsible for feeding and unloading. Labor efficiency is greatly improved, effectively solving the problems of high labor intensity and high labor costs in sisal drying.

Good drying uniformity, significantly improving sisal quality: The device features a multi - layer cyclic conveying design. The drying poles can be regularly replaced in up - down and left - right positions, ensuring that the sisal fibers on each drying pole can receive uniform sunlight exposure and air circulation, thus avoiding the problem of uneven drying of local fibers in traditional drying. Low sisal loss, reducing economic losses: In traditional drying methods, collisions, frictions during manual adjustment of drying poles, and pulling during turning are likely to cause damage and breakage of sisal fibers. This device smoothly conveys the drying poles through mechanical transmission. During the conveying process, the contact between the drying poles and components is rolling friction, which has a small frictional force. Moreover, the conveying speed is slow and uniform, avoiding mechanical damage caused by manual operation.

Wide range of applications and high versatility: The design of this device is not only suitable for drying sisal fibers. According to the characteristics of the materials to be dried, by adjusting parameters such as the spacing of drying poles and conveying speed, it can also be used for drying long - strip - shaped foods like noodles, vermicelli, and yuba, as well as for the drying treatment of textile raw materials such as cotton yarn and chemical fibers. The multi - layer structure design of the device allows for flexible adjustment of the cross - frame spacing to meet the drying requirements of materials with different lengths. The conveying speed can be steplessly adjusted through the touch - screen, ranging from 0.1 to 0.5 m/s, adapting to the drying characteristics of different materials. The versatility of this device expands its application scenarios, improves equipment utilization, and reduces the investment cost for users.

Simple and reliable structure with low maintenance cost: The device adopts a modular design. Each component has a simple structure and a high degree of standardization, which facilitates manufacturing, repair, and replacement. Core transmission components such as motors, sprockets, and conveyor chains are all common standard parts available in the market, making procurement convenient and cost - effective. Structural components like the housing and brackets are made of ordinary steel and aluminum alloy materials, resulting in low manufacturing costs. The device is easy to maintain. It only requires regular cleaning of debris, inspection of the conveyor chain tension, and monitoring of the motor's operating status. This can be accomplished by ordinary operators without the need for professional technicians, leading to low maintenance costs and making it suitable for promotion and application in rural areas.

4.2 Analysis of Design Rationality

Rationality of Structural Design: The device features a symmetrical frame structure, ensuring balanced stress on the left and right supports. The multi - layer cross - frame layout not only increases the drying capacity but also guarantees the stability of the device. The connection between the support frame and the cross - frame adopts a precise docking design. The dimensions of the drying - pole inlets and outlets highly match the diameter of the drying poles, ensuring smooth conveyance of the drying poles without jamming.

The design of the transmission push rods and movable rollers effectively reduces the friction during the conveyance of the drying poles, preventing surface wear of the drying poles. The ">" - shaped design of the paddles and guide protrusions utilizes gravity to assist with guidance, improving the accuracy of the insertion and extraction of the drying poles, with a guiding error of less than 5mm. The overall height (3.5m) of the device and the cross - frame spacing (0.6m) are rationally designed. This not only ensures the convenience of material loading and unloading for operators but also guarantees the ventilation effect of each drying layer without any blockage.

Rationality of the Transmission System: The transmission system adopts a combined scheme of motor + reduction gearbox + sprocket + conveyor chain. The motor power and reduction ratio are reasonably matched, and the output speed is moderate. This ensures the stable conveyance of the drying poles, meeting the requirements of drying efficiency while avoiding fiber damage caused by excessive speed.

The collaborative control logic of the multi - layer transmission system is reasonable. The PLC controller precisely controls the startup, stop, and rotation of each motor, as well as the on - off of the solenoid valves, ensuring that the drying poles are conveyed along the preset path and the position replacement is accurate. The design of the overload protection device effectively prevents mechanical components from being damaged due to overload, improving the operational safety and service life of the device.

Rationality of the Control Scheme: The control system combines a PLC (Programmable Logic Controller) and a touch - screen. The operation interface is intuitive and easy to understand, and parameter setting is flexible and convenient, making it suitable for operators in rural areas. The preset programs cover drying parameters under different weather conditions, allowing users to make quick selections according to actual situations without complicated debugging. The system has a fault self - diagnosis function. It can monitor the operating status of components such as motors and solenoid valves in real - time. When a fault occurs, it alarms promptly and displays the fault location, facilitating rapid troubleshooting and repair.

The adjustable design of the position - replacement cycle and the total drying time enables the device to adapt to the climatic conditions of different regions and seasons. In sunny and low - humidity weather, the replacement cycle and drying time can be shortened to improve efficiency. In rainy and high - humidity weather, these parameters can be extended to ensure the drying quality.

5. Conclusion and Prospect

5.1 Research Conclusions

This study aimed to address the issues of traditional sisal drying methods, such as cumbersome operation, high labor intensity, low efficiency, and poor fiber quality. An efficient sisal drying device was designed, and the main research conclusions are as follows:

The device consists of a left support, a right support, and a fixed frame, which form the core framework. Driven by a motor - powered sprocket and conveyor chain system, and combined with the solenoid - valve - controlled paddle movement, the device realizes the automatic conveyance and position replacement of the drying poles without any manual intervention throughout the process, thus thoroughly solving the pain points of manual operation in traditional drying methods.

The device features a simple structure, stable operation, and low maintenance cost. It adopts a modular design with standardized components, facilitating manufacturing, repair, and replacement. Moreover, it has strong versatility and can be extended for drying long - strip - shaped materials such as noodles and vermicelli, with a wide range of applications.

Practical application tests show that this device can effectively improve the efficiency and quality of sisal drying, reduce labor intensity and the loss rate, bringing significant economic benefits to sisal growers and processing enterprises. It has high practical value and broad promotion prospects.

5.2 Future Outlook

Although the sisal drying device designed in this study has achieved good application results, there is still room for further optimization. In the future, in - depth research can be carried out in the following aspects:

Optimization of the Control System: Introduce intelligent sensing technologies, including light - intensity sensors, air - humidity sensors, and temperature sensors. This enables the automatic adjustment of parameters such as the drying - pole replacement cycle and conveying speed according to real - time environmental parameters, further enhancing the intelligence level and adaptability of the drying process.

Modular Design: Explore the modular design of the device. Design support modules and cross - frame modules of different specifications, allowing users to flexibly assemble them according to the size of the drying site and the required drying quantity, thus forming drying devices with different capacities. This can improve the adaptability and convenience of the device.

Solar - assisted System: Research the integrated design of a solar - assisted heating system and the device. In rainy days or when sunlight is insufficient, the solar - heating system can provide auxiliary drying energy, further shortening the drying cycle and reducing dependence on the natural environment.

Optimization of Materials and Structure: Optimize the materials and structure of the device. Select lightweight and high - strength alloy materials and surface - treatment processes with stronger anti - corrosion properties. This can further reduce the weight of the device and improve its service life in harsh outdoor environments. Meanwhile, optimize the design of easily - worn components such as conveyor chains and paddles to reduce maintenance frequency and costs.

Expansion of Application Fields: Expand the application fields of the device. According to the drying characteristics of different long - strip - shaped materials, design special drying poles and fixing devices to make the device adaptable to the drying needs of more agricultural products and industrial raw materials, further enhancing the device's versatility and market competitiveness.

In the future, with continuous technological optimization and improvement, this efficient sisal drying device is expected to be widely promoted and applied in major sisal - producing areas, promoting the mechanization and intelligent upgrading of the sisal industry and providing technical support for the high - quality development of China's tropical economic crop industry.

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