

Design and Application of Fully Hydraulic Intelligent Screw Clearing Machine for Grain Silos

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Abstract. In order to fundamentally solve the hidden danger of dust explosion in grain silos, a new fully hydraulic intelligent screw clearing machine for grain silos was studied. The rotation of the spiral shaft and the movement of the whole machine were controlled by the hydraulic system, which realized that there was no electrical component in the internal actuator and the safety was higher. This paper introduces the structure and composition of the fully hydraulic intelligent screw clearing machine for grain silos and studies its key technologies. Based on the above achievements, the first domestic fully hydraulic intelligent screw clearing machine for grain silos is developed and applied to the grain silos of Xiamen Port Hailong Wharf. The application further compares and analyzes the main performance parameters of the fully hydraulic intelligent screw clearing machine and the electric screw clearing machine for grain silos. The research shows that the fully hydraulic intelligent screw clearing machine for grain silos can effectively reduce the operation of personnel entering the warehouse and realize safer, intelligent and efficient clearing operations.

Keywords. Grain silos, hydraulic driven, screw clearing machine, dust explosion proof

1. Overview

Grain silos are the main types of grain storage silos for various grain reserves and grain-oil terminals in China. In the process of clearing and conveying the grain in the grain silo, a large amount of grain-associated dust will be generated. These dusts will continue to spread during the production process, which can easily cause dust explosions and cause great harm to the lives of personal and collective and property loss. Dust explosion has become a major threat to the grain processing and storage enterprises.

The screw clearing machine is one of the main clearing equipment for grain silos. At present, most of the screw clearing machines used for grain silos in China and abroad are mostly electric or pneumatic drives [1, 2]. The pneumatic-driven screw clearing machines has complex structure and high failure rate, and when used in humid and dusty environments, blockage of cylinders and various valves, water ingress and corrosion are often seen. Its market share is gradually decreasing. In addition, according to the explosion-proof zoning regulations of the national standard

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GB17440-2008 "dust explosion-proof safety regulations for grain processing, storage and transportation systems" [3], the interior of the silo is zone 20 explosion-proof level, and electrical equipment is not allowed to operate in such places. However, there is no motor with explosion-proof certification of zone 20. Therefore, the electric-driven clearing machine in the grain silo is contrary to the requirements of the national mandatory standards, and there are certain safety hazards. In recent years, explosion accidents have also occurred due to electric-driven clearing machine.

Some research on hydraulic drive clearing machines have been done. Huang Sulong of China University of Mining and Technology [4] researched and designed a multi-arm telescopic coal warehouse clearing robot system. The drive system is connected with the actuator of the clearing robot, and drives the actuator to work to realize the robot clearing operation. Zhong Lingling of Shandong Luban Machinery Technology Co., Ltd. disclosed a patent for a hydraulic system of a warehouse clearing machine and a cylinder hydraulic transmission conveyor [5]. The machine provides power, which can realize the smooth operation of the excavator and improve the efficiency of coal slime excavation or dredging. Fan Yang and Jiang Sihan of Wuxi Nuoliyanke Hydraulic System Co., Ltd. disclosed a patent for a screw conveying device and a clearing machine [6]. The screw conveying device in the patent includes a conveying shaft and a rotary power device that drives the conveying shaft to rotate. The power device is an electric cylinder, and a hydraulic cylinder is also set on the screw conveyor as a power booster, so that the screw conveyor can be driven by a power booster in addition to being driven by a rotary power device. When driving the conveying shaft, additional power is provided by the power assist device to ensure the continuous rotation of the conveying shaft, thereby ensuring the stability of material conveying. To sum up, at present, the research on the hydraulically driven warehouse clearing machine mainly focuses on providing power for local devices or mainly for use in coal bunker.

Therefore, in view of the above background, this paper proposes for the first time a fully hydraulic driven screw clearing machine for grain silos, which has better safety performance, stronger driving ability, and more intelligent control, can better ensure grain processing and storage and finally improve the capacity of grain storage and transportation system.

2. Design and Application of the Fully Hydraulic Driven Screw Clearing Machine

2.1. Structure Design

The fully hydraulic driven screw cleaning machine is mainly composed of body, hydraulic system and electric control system. The body mainly includes centering and rotating device, head transmission device, revolution drive device, structural support device, screw conveying device and revolution track. Among them, the centering and rotating device is installed on the center discharge port of the flat-bottomed silo, and the center of the silo is used as the rotary centering. The hydraulic system includes pump station motor, hydraulic pump [7], electro-hydraulic proportional multi-way valve, pressure sensor, screw drive motor, revolution drive motor, hydraulic filter, radiator, etc.

The screw drive motor is installed on the head transmission device and is used to drive the screw shaft in the screw conveying device to rotate, so as to achieve the

purpose of conveying and clearing materials. The revolution drive motor is installed on the revolution drive device, and is used to drive the whole machine to rotate and walk along the revolution track with the rotary centering as the center.

In the scheme, a sprocket is installed on the revolution drive device. Under the circular running track of the sprocket, a revolution track is installed, and the track is fixed and installed in the silo through embedded bolts. Each track has evenly distributed arc-shaped toothed sprocket holes of a specific size, and the whole machine can be propelled on the revolving track through the meshing between the sprocket and the sprocket holes. The revolution drive device and revolution track meshing technology ensure the compulsion, no slippage, no climbing, high reliability, and no need for manual warehousing auxiliary operations.

The screw conveying device of this scheme is mainly composed of screw shaft, screw blades, material trough, etc. Among them, the screw shaft adopts a multi-section + universal joint connection, which solves the problems of huge span, poor rigidity, and easy deformation of the screw shaft, and can realize multi-degree-of-freedom rotation adjustment and coaxiality self-adaptation. In addition, in order to reduce the stress concentration caused by the discontinuity of the structure, spherical bearings are arranged in the middle and tail sections of the screw shaft, and the two ends are connected to the screw shaft through flanges. There are keys between the flanges, which can effectively transmit the torque of the screw shaft.

The structural support device is installed on the trough of the screw conveying device, which has the effect of strengthening the longitudinal strength and rigidity of the cleaning machine. In addition, the structural support device is also provided with an up and down adjustment function to facilitate the adjustment of the gap between the screw conveying device and the local ground.

The hydraulic pump is directly driven by the pump station motor to generate high-pressure oil, which is adjusted by the electro-hydraulic proportional multi-way valve to control the direction and speed of the screw drive motor and the revolution drive motor. The hydraulic system is equipped with a large flow filter and a radiator in the oil return circuit to ensure the cleanliness and temperature of the hydraulic oil and prevent the hydraulic oil from deteriorating.

The hydraulic pump station and the electronic control system are arranged outside the belt conveyor corridor, and the screw drive motor and the revolution drive motor are driven to work by controlling the hydraulic system connected to them. The structure of the whole machine is shown in Figure 1, and the composition of the hydraulic and electronic control system is shown in Figure 2.

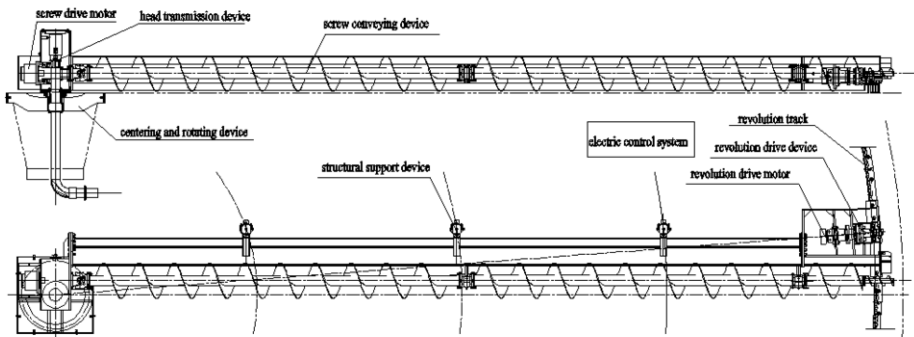


Figure 1. The structure of the fully hydraulically driven intelligent screw clearing machine.

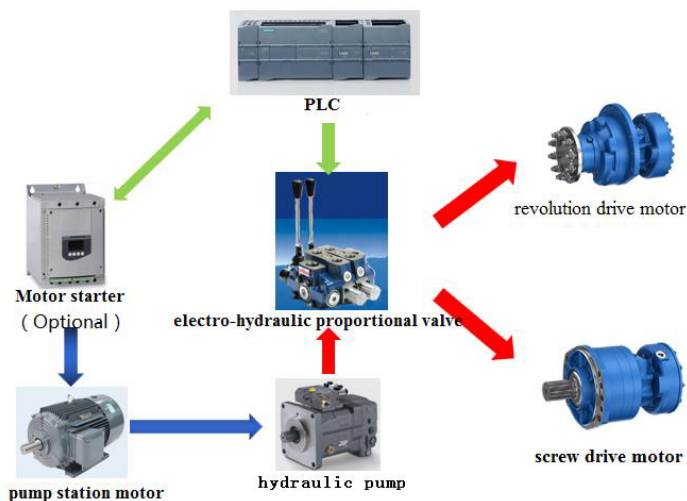


Figure 2. Composition of hydraulic and electronic control system.

2.2. Working Process Introduction

When starting, the electronic control system controls the screw drive motor and the revolution drive motor to work. The screw drive motor transmits the torque to the screw shaft to rotate, and the screw blade cuts into the grain pile. Depending on the cutting action of the screw blade and the self-flow property of the grain itself, the grain continuously enters the material trough of the screw conveyor, following the principle of screw conveying. The grain will be sent into the central grain unloading port, so as to achieve the purpose of conveying materials. When there is no grain in front of the screw blade, the whole machine will take the rotation centering as the center under the push of the revolution drive device, rotate along the revolution track, and continue to clear the grain. The remaining grain will be cleared when whole machine complete one rotation.

2.3. Key Technologies of Fully Hydraulic Driven Screw Clearing Machine

(1) Fully Hydraulic Drive

The screw cleaning machine proposed in this paper adopts the full hydraulic drive. Since the driving shafts of the screw conveying device and the revolving propulsion device have low rotational speeds and complex driving loads, the motor will be directly driven by low-speed and high-torque hydraulic motor, which can provide the drive shaft low speed and high torque. In addition, the low-speed scheme is also easy to control and adjust, with flexible layout and less space. The hydraulic motor is directly installed on the drive shaft, eliminating various transmission links between the hydraulic motor and the drive shaft, avoiding additional power loss between them and reducing mechanical noise. At the same time, the moment of inertia of the drive shaft is reduced, which is conducive to improving the adjustment quality of the system and reducing the impact of the impact load on the screw structure and the traveling structure during the clearing operation.

(2) Load-Sensing, Constant-Power Control and Load Adaptive Control Technology

The load-sensing and constant-power control technology is adopted. With the same output power, the torque output characteristics of the clearing machine are improved, the energy consumption of the hydraulic system is reduced, and the efficient operation of the motor of the pump station is ensured. The hydraulic system provides flow according to the screw speed requirement, reducing energy consumption. At the same time, when the grain is hardened, the hydraulic system will automatically increase the working pressure, increase the screw driving torque, and reduce the flow output to ensure that the motor of the pump station always works in the high-efficiency area, and the system is more energy-saving.

In addition, this equipment also adopts the load adaptive control technology. The control system can automatically adjust the screw and revolution driving speed according to the load condition of the screw, which realizes the automatic execution of the clearing operation without the intervention of the staff. When the material flow is good, it can be switched to the "automatic" mode of operation. The automatic control system automatically adjusts the revolution action according to the load condition of the screw drive: when the material is quite limited, the revolution advances, the screw speed decreases, and the screw filling rate is increased; when the load increases, the automatic control system identifies that the material filling rate is high, and the revolution stops. The screw operates at maximum speed, enabling automatic clearing operations without the necessity of human intervention.

(3) Intelligent remote monitoring technology

At the same time, this clearing machine adopts newly developed intelligent remote monitoring system. For the first time, it realizes the full remote working mode of the whole life cycle remote debugging, remote maintenance, remote monitoring and remote control of the grain silo clearing machine. At the stage of machine installation, debugging and trial operation, system programmers do not need to visit the site in person, they can conduct system program modification, program uploading and downloading, and joint debugging of programs and equipment through the online cloud platform. Controlling various remote methods such as PC terminal, mobile APP terminal, online cloud platform terminal, etc., workers can obtain information such as equipment running time, main failure frequency, spare parts maintenance cycle, specific maintenance reminders, etc., and realize 24h all-weather monitoring of clearing machine real-time operating status and fault alarms, query historical data, accurately locate fault information, and reasonably arrange maintenance work according to the actual situation on site. The mentioned remote terminals can also be used to start, stop, reset, speed regulation, manual automatic switching on the clearing machine, realizing the "zero entry" of the staff, and ensuring the work safety and personnel health under the complex operation environment of grain silos. What's more, the operation and maintenance costs will be reduced and operation efficiency will be comprehensively improved.

2.4. Development and Application of the First Fully Hydraulically Driven Intelligent Screw Clearing Machine in China

Based on the above research results, the first fully hydraulic driven screw clearing machine in China was developed (as shown in Figure 3), and it has been applied to the grain silo of Xiamen Port Hailong Terminal Co., Ltd. Based on the dimension and capacity of the silo, combined with the severity of grain hardening, the clearing machine equips with 45KW pump station motor, hydraulic motors that can meet the

maximum driving torque of 6900Nm, and other supporting hydraulic components and joints.

The hydraulic components and hydraulic joints of the clearing machine are all made of the world's top hydraulic products to avoid the phenomenon of "running, bubbling, dripping and leaking" to the greatest extent. Meanwhile, food-grade hydraulic oil certified by the US authority has been adopted to avoid contamination of the grain in the silo. At present, the equipment operation status and clearing operation effect are good, which can meet the actual needs of users, and can realize safe, intelligent, efficient and reliable clearing operations, which has been strongly recognized by users. The main technical parameters of the equipment are shown in Table 1.

Table 1. Main technical parameters of the fully hydraulic driven intelligent screw cleaning machine.

Item	Technical parameter
Conveying material	Soybeans, Wheat, Corn
Clearing Capacity	300t/h
Screw Diameter	500mm
Clearing duration	5~6h
Maximum pitch	500mm
Screw Length	11.55m
Maximum driving torque	6900Nm



(1) Clearing Operation



(2) Hydraulic Pump Station

Figure 3. Fully hydraulic driven intelligent screw clearing machine.

3. Comparative Analysis of Performance of Full Hydraulic Driven and Mainstream Electric Driven Screw Clearing Machine

3.1. Comparative Analysis of Output Characteristics

Figure 4 and Figure 5 are the output characteristic curve of the motor and the output characteristic curve of the hydraulic system, respectively. Comparing and analyzing the curves, when the working frequency is below 50Hz, the motor is in a constant torque control state. No matter how the speed is adjusted, the output torque of the motor is always constant. Only when the frequency is higher than the rated frequency, the constant power control is adopted, while the torque is reduced. For the hydraulic

system, constant power electro-hydraulic control can be performed within the allowable range of working pressure. For example, when the grain is hardened, that is, when the resistance torque increases, the output speed can be automatically reduced, thereby increasing the output torque and enhancing the driving ability. And in this working process, the motor of the pump station always works at the highest efficiency point with the lowest energy consumption.

As a summary, under the same output power, the hydraulic system can improve the torque output characteristics of the clearing machine, reduce the energy consumption of the hydraulic system, ensure the efficient operation of the pump station motor, and be more conducive to the efficient cleaning operation of the clearing machine under complex working conditions.

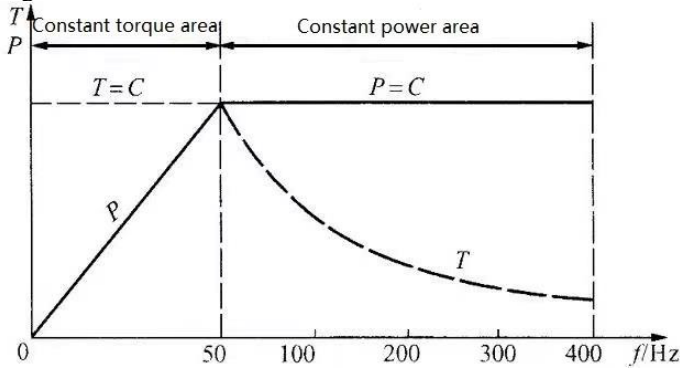


Figure 4. Motor output characteristic curve.

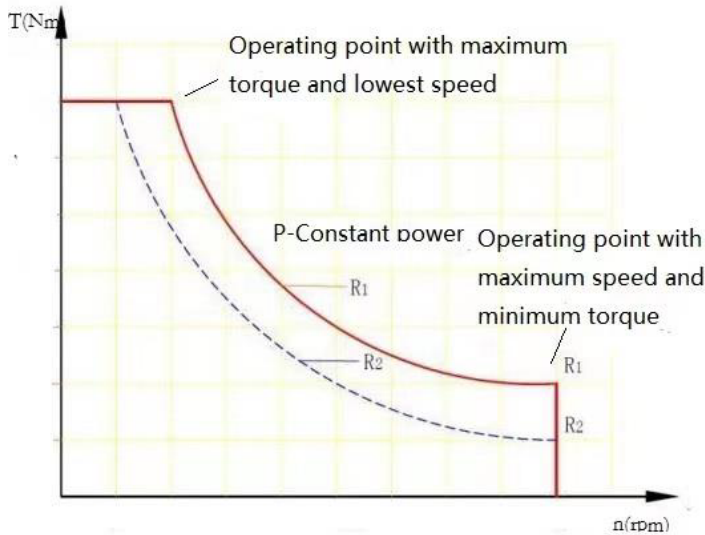


Figure 5. Output characteristic curve of hydraulic system.

3.2. Comparative Analysis of Main Technical Parameters

A comparative analysis of other technical parameters of the fully hydraulic driven screw clearing machine and the mainstream electric screw clearing machine is shown in Table 2.

Table 2. Performance comparison table of different driving modes of screw cleaning machine.

	Fully Hydraulic Driven	Electric Motor Driven
Torque under same power	Larger	Smaller
Crack breaking capacity	Unmanned clearing can be realized in light and moderate compaction conditions; in severe compaction, the rotating speed of the equipment is automatically reduced, the screw driving force is increased, and the compaction-breaking ability is enhanced.	Realize the clearing operation under separation of personnel and machine in the case of mild and moderate hardening
Transmission efficiency	Hydraulic motor direct driven, high transmission efficiency	Electric motor + gearbox drive system, loss of transmission efficiency, overall mechanical transmission efficiency is reduced
Structural form	Compact structure, flexible layout, light weight, small installation space, easy installation	Complex structure, large volume, large space occupation
Explosion-proof safety	No electrical components in the silo, the safety is high	low, potential safety hazards
Cleanliness and environmental protection	Easy to cause oil leakage, food-grade hydraulic oil must be used to avoid leakage and contamination of food.	Clean and pollution-free
Operation efficiency	Effectively improve operation efficiency and shorten the clearing time	The clearing efficiency is quite limited.
Operation and maintenance costs	Reduce the operation and maintenance of equipment such as motor reducers, which can effectively reduce maintenance costs	High operation and maintenance costs of motors and reducers

Through the above comparative analysis, the fully hydraulic intelligent screw clearing machine has the significant advantages of large torque, strong breaking capacity and high safety. However, in order to prevent problems such as "running, bubbling, dripping and leaking" in the hydraulic system, it is necessary to optimize the processing technology and solve the hydraulic sealing problem through proper selection of materials. PARKER, Rexroth and STAUFF as the world well-known brands are suggested. Their high-quality sealing materials and sealing technologies can ensure the reliability of product sealing. In addition, food-grade hydraulic oil certified by the American authority shall be used to ensure no pollution to Grain.

4. Conclusion

The research results of this paper fill the technical gap in this field in China, realize that the actuator inside the silo has no electrical components, solve the problem of dust electrical explosion-proof, and can effectively avoid serious casualties and property losses caused by dust explosion; It can reduce the number of people entering the silos, effectively reduce the long-term operation cost and labor cost, and improve the occupational hygiene level of the enterprise; at the same time, it realizes a safe, green, intelligent, efficient and reliable silo clearance operation, which can significantly improve the residual grain clearing efficiency of the grain silos, guaranteeing the normal operation of the grain processing and storage and transportation system, and further improve the turnover efficiency and storage and transportation capacity of the grain storage and transportation system. At the same time, the research results have a positive role in promoting the level of occupational hygiene in China's grain and port industries, and promoting the development of silo loading and unloading technology

and equipment industry. The research results of this paper have good social and economic benefits, and have broad prospects for market promotion.

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