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Design and Experimentation of Multi-Rod Grain Sampling Machine

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Abstract

In order to enhance grain sampling efficiency, in this work a truss type multi-rod grain sampling machine is designed and tested. The sampling machine primarily consists of truss support mechanism, main carriage mechanism, auxiliary carriage mechanism, sampling rods, and a PLC controller. The movement of the main carriage on the truss, the auxiliary carriage on the main carriage, and the vertical movement of the sampling rods on the auxiliary carriage are controlled through PLC programming. The sampling machine accurately controls the position of the sampling rods, enabling random sampling with six rods to ensure comprehensive and random sampling. Additionally, sampling experiments were conducted, and the results showed that the multi-rod grain sampling machine simultaneously samples with six rods, achieving a sampling frequency of 38 times per hour. The round trip time for the sampling rods is 33 seconds per cycle, and the sampling length direction reaches 18 m. This study provides valuable insights for the design of multi-rod grain sampling machines.

Keywords

Grain Sampling, Sampling Efficiency, Truss-Type Sampling Machine, PLC Control

1. Introduction

Grain sampling plays a crucial role in the processes of grain procurement, processing, and storage [1] [2]. It not only ensures fairness in transactions but also involves the safety of stored grains and quality control in subsequent processing. Effective grain quality inspection promotes the healthy development of the grain market and is essential for ensuring the safety of the national grain quality [3].

Currently, some grain enterprises mainly rely on manual and semi-automatic methods for sampling, leading to issues such as low sampling efficiency and heavy labor burden. In response, Chinese scholars have begun to develop automatic grain sampling machines [4]. The intelligent grain sampling machine designed by Ma Yan [5] can improve sampling efficiency and save labor costs. An innovative loose grain sampling machine, utilizing hydraulic drive designed by Anhui Yunlong, has effectively addressed the issue of slow manual sampling speeds. However, challenges such as blind sampling spots and relatively low sampling rates persist. Anhui Ju Long has developed a single-rod rotary arm grain sampling machine with broad applicability, suitable for sampling in open bulk grain transport vehicles and vehicles loaded with packaged grains. It demonstrates outstanding performance with a sampling frequency of 20 times per hour, providing a relatively efficient solution for sampling operations. While Duan Wenyuan's design of a double-rod truss-type grain sampling machine has successfully resolved blind sampling issues, its utilization of a double-rod structure results in relatively lower sampling efficiency [6]. In a bid to enhance sampling efficiency and expand the sampling range, in July 2023, the Anhui Provincial Department of Science and Technology issued a notice on the "Initiation of Agricultural Material Technology Equipment Leading Projects and Agricultural Machinery Gap-Filling Project Filing Work," prioritizing the development of multi-rod intelligent sampling machines. Specific requirements include 1) simultaneous multi-rod sampling to improve efficiency, achieving a sampling frequency of 38 times per hour; 2) a round trip time for the sampling rods of 36 seconds per cycle; 3) standard sampling carriage length less than 17.5 meters.

In this work, a truss type multi-rod grain sampling machine is designed and tested. This design aims to meet the requirements outlined in the notice for improving sampling efficiency and expanding operational capabilities. Utilizing SOLIDWORKS, one conducted three-dimensional model design, completed prototype fabrication, and integrated PLC control for relevant functionalities. This advancement enables more efficient and comprehensive grain sampling, thereby driving the upgrade and innovation of agricultural science and technology equipment.

2. Overall Mechanical Structure and Working Principle

The structural design of the multi-rod grain sampling machine is intricate, comprising pillars, three main carriage mechanisms for sampling, six auxiliary carriage mechanisms, six sampling rods, three main carriage movement devices, six auxiliary carriage movement devices, reinforced truss framework support structures, and grain suction devices, among other components. The overall configuration is illustrated in **Figure 1**. Taking the midpoint of the contact surface between the foundation and the ground as the origin, denoted as point O in the figure. The X-axis is defined along the length of the truss framework support structure, the Y-axis along its width, and the Z-axis along the height of the pillars.

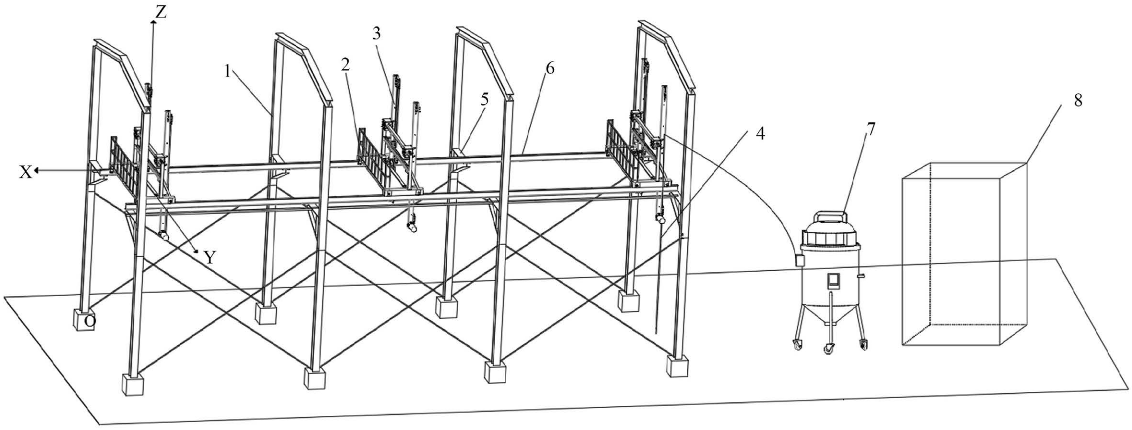

Figure 1. Structural diagram of the multi-rod sampling machine. 1. Pillars, 2. Main Carriage Mechanisms for Sampling, 3. Auxiliary Carriage Mechanisms for Sampling, 4. Sampling Rods, 5. Reinforcements, 6. Cantilever Beams, 7. Grain Suction Devices, 8. Control Cabinet.

Working Principle

The sampling process of the multi-rod grain sampling machine mainly includes the following steps: the main carriage moves to the target position, the auxiliary carriage moves to the target position, the sampling rod moves to the target position, the grain suction device operates, and the main carriage, auxiliary carriage, and sampling rod return to their initial positions.

The working process is as follows: when the grain vehicle enters the working range of the sampling machine, the controller initiates the movement of the main carriage and accurately controls it to move along the X-axis to the target X position. Simultaneously, it activates and controls the auxiliary carriage to move along the Y-axis to the target Y position. Subsequently, the sampling rod drive device is activated to precisely control the sampling rod to move along the Z-axis to the target Z position. Then, the grain suction device is activated until the sampling task is completed. To ensure operational safety, proximity switches are installed on the main carriage mechanism, auxiliary carriage mechanism, and sampling rod to effectively prevent potential collisions during their movements. Once the task is completed, the controller guides each mechanism to return to its initial position, ensuring smooth and safe operation throughout the entire process.

3. Enhanced Component Structure Design and Key Parameters

3.1. Main Carriage Mechanism

The design of the main carriage mechanism is intended for motion along the X-axis. It consists of the main carriage frame, sampling machine vertical arm, sampling carriage lateral movement upper guide, sampling carriage lateral movement lower guide, and anti-derailment device, as shown in **Figure 2**. The bottom of this mechanism is equipped with walking wheels tangent to the cantilever beam. With the action of the main carriage drive motor, torque is transmitted

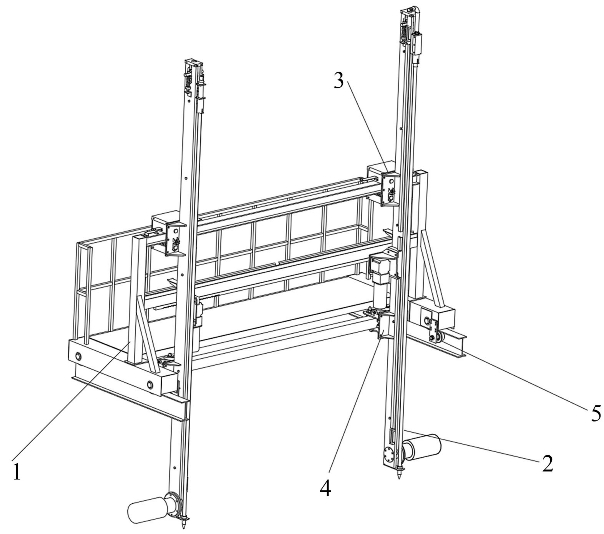

Figure 2. Structural diagram of the main carriage mechanism. 1. Main Carriage Frame, 2. Sampling Machine Vertical Arm, 3. Sampling Carriage Lateral, 4. Movement Upper Guide, 5. Sampling Carriage Lateral Movement Lower Guide, 6. Anti-, 7. Derailment Device.

to the walking wheels through gears meshing after being reduced by the reducer, enabling the main carriage mechanism to move along the X-axis. To ensure smooth motion, a targeted anti-derailment device is designed to prevent the occurrence of track deviation during operation. This device enhances equipment reliability and safety during operation, providing a reliable guarantee for the smooth operation of the entire system.

To meet the requirement of the standard carriage being less than 17.5 m in length, thus necessitating the sampling length direction to exceed 17.5 m, a truss support structure with a length of 20 meters is utilized. The sampling carriage mechanism measures 4000 mm × 1400 mm × 1500 mm (L × W × H). On all three main carriage mechanisms, proximity switches and displacement sensors are installed. Under the intelligent control of the proximity switches, the main carriage mechanisms are accurately positioned at the extreme left and right positions along the X-axis. Simultaneously, at the extreme positions where the main carriage mechanisms approach the origin of the entire machine's coordinate system, the main carriage origin is established using the displacement sensors. During its movement, precise control over the main carriage mechanisms is achieved by writing PLC-related programs that utilize the displacement sensors to obtain the actual positions of the main carriage mechanisms.

3.2. Auxiliary Carriage Mechanism

The design of the sampling carriage mechanism is intended for motion along the Y-axis and comprises components such as the main beam, upper fixed bracket on the main beam, lower fixed bracket on the main beam, walking motor bracket, and drive motor, as illustrated in **Figure 3**. The carriage mechanism is connected to the main carriage mechanism via the upper fixed bracket on the main beam and the lower fixed bracket on the main beam. Its operation involves the following: once the main carriage reaches the target position, the sampling carriage motor, after being reduced by the reducer, transmits torque to the sampling carriage wheels through gear rack engagement, enabling the sampling carriage mechanism to move along the Y-axis.

The auxiliary carriage mechanisms are also equipped with proximity switches and displacement sensors. When the two auxiliary carriage mechanisms on the main carriage mechanism move to the extreme positions near the truss support structure on both sides, the two displacement sensors automatically zero out, setting the zero position of the auxiliary carriage mechanisms. During the movement of the auxiliary carriage mechanisms, PLC-related programs have been written to utilize the auxiliary carriage displacement sensors to obtain real-time positions of the auxiliary carriage mechanisms, enabling precise control over their movement.

3.3. Sampling Rod Structure

The sampling rod is designed for motion along the Z-axis and consists of connecting plates, roller bearings, springs, sleeves, and the sampling rod itself, as depicted in **Figure 4**. The sampling rod is connected to the auxiliary carriage mechanism via connecting plates. Under the action of the sampling rod drive motor and subsequent reduction by the reducer, an efficient and stable transmission system is formed through the engagement of sprockets and chains, thus controlling the motion of the sampling rod along the Z-axis. The design of roller bearings not only reduces friction during movement but also ensures that the sampling rod remains aligned vertically during vertical motion. The design of the sleeve facilitates easy replacement of the sampling rod. Additionally, a spring device is incorporated to provide cushioning when the sampling rod touches the bottom of the carriage.

The sampling rod is also equipped with proximity switches and displacement sensors. When the sampling rod moves to the top position of the auxiliary carriage mechanism, the displacement sensor for the sampling rod automatically zeros out, indicating the origin position of the sampling rod. During the movement of the sampling rod, PLC-related programs are written to utilize the sampling rod displacement sensor to obtain the actual position of the sampling rod, thus achieving precise control over its movement. Considering the possibility of the sampling rod failing to rebound when it touches the bottom of the carriage, to prevent damage to the sampling rod, a current transmitter is introduced into the control program. Once an abnormal increase in current is detected, the system triggers the reverse function of the sampling rod drive motor to achieve rebounding of the sampling rod. This design aims to protect the equipment from damage and ensure its robust operation.

3.4. Operating Parameters

The design parameters of the multi-rod sampling machine are shown in **Table 1**.

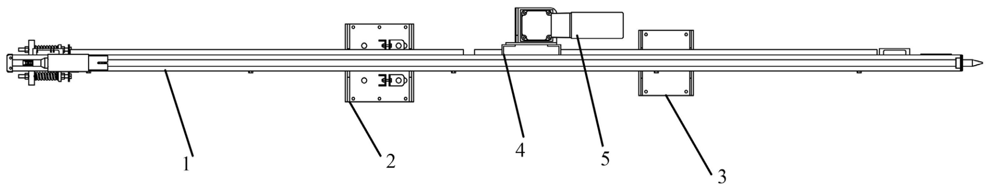

Figure 3. Structural diagram of the auxiliary carriage mechanism. 1. Main Beam, 2. Fixed bracket on main beam, 3. Fixed bracket under main beam, 4. Walking Motor Mounting Plate, 5. Walking Motor.

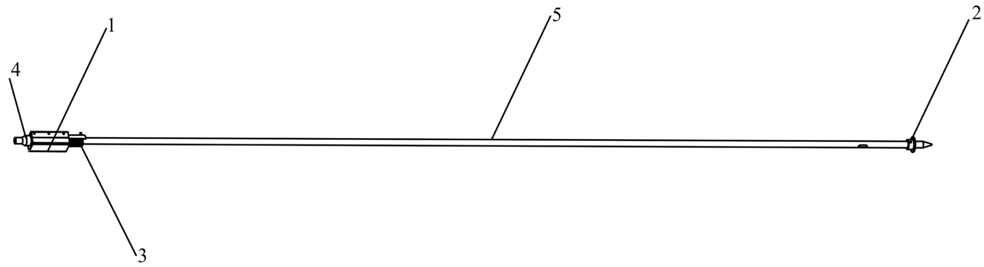

Figure 4. Structural diagram of the sampling rod. 1. Connecting Plate, 2. Roller Bearing, 3. Spring, 4. Sleeve, 5. Sampling Rod.

Table 1. Design parameters table.

Name	Unit	Value
Overall size (L × W × H)	m	20 × 7.8 × 10
Sample working width	m	18 × 3
The sample rod drives the motor	Kw	0.75
The cart drives the motor	Kw	0.4
Trolley drive motor	Kw	0.75

4. Design of Control System for Multi-Rod Spike Prototype

The control system of the sampling machine is crucial to ensuring its proper operation. During a sampling process, the machine executes commands for the movement of 3 main carriage mechanisms, 6 auxiliary carriage mechanisms, and 6 sampling rods, necessitating a control system with a large number of input and output points.

During operation, the control system must control the forward and reverse operations of both large and small mechanical components as well as the motors driving the sampling rods. The key components of this control system include PLC controllers, PLC expansion modules, motors, displacement sensors, current transmitters, power supplies, intermediate relays, AC contactors, switches, and circuit breakers. The basic control process involves ensuring that the main carriage mechanisms, auxiliary carriage mechanisms, and sampling rods return to their respective origin positions and resetting each displacement sensor to zero.

The core control component of this system is the Siemens S7-1200 PLC, characterized by modularity, comprehensive functionality, and compact structure, powered by a 24V switching power supply. Compared to the S7-200 PLC, the S7-1200 PLC supports more input and output modules and is widely used in small to medium-scale automation systems due to its high performance and scalability. In terms of communication, the S7-1200 PLC supports multiple network device types. Overall, the S7-1200 PLC meets the control requirements of the multi-rod grain sampling machine and can simultaneously control all six rods. External wiring for the PLC and expansion modules can be seen in Figure 5 and Figure 6. The CPU 1200 PLC, SM1223-1, SM1223-2, SM1223-3, and SM1223-4 mainly control functions such as origin setting, forward, and reverse operation for three main carriages, six auxiliary carriages, and six sampling rods. SM123-1, SM123-2, and SM123-3 mainly control analog signals for various displacement sensors and current transmitters.

Based on the electrical schematic diagram, I will design the layout of the electrical cabinet to produce the electrical cabinet. Due to the numerous components, the electrical cabinet is arranged on both the front and rear sides, as depicted in Figure 7.

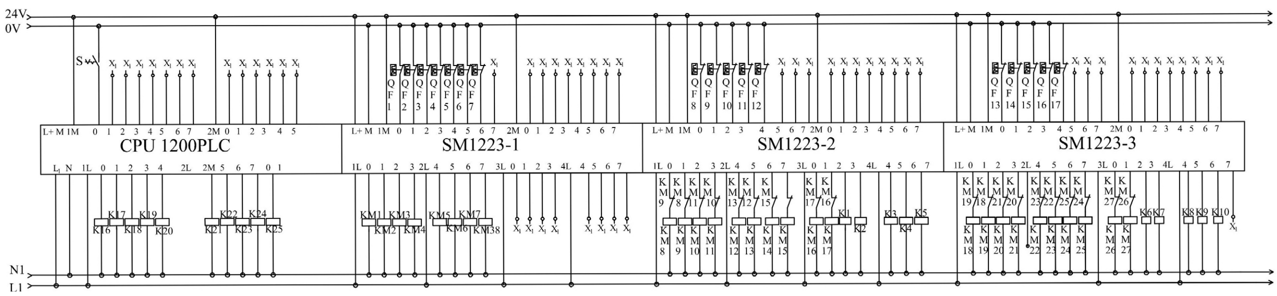

Figure 5. Electrical wiring diagram 1.

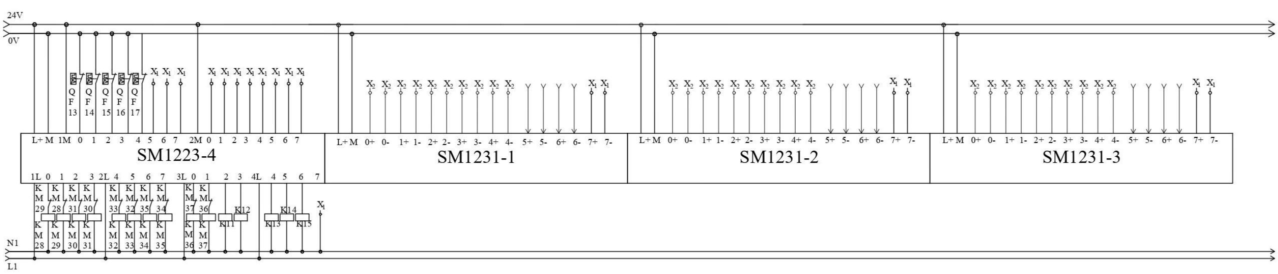

Figure 6. Electrical wiring diagram 2.

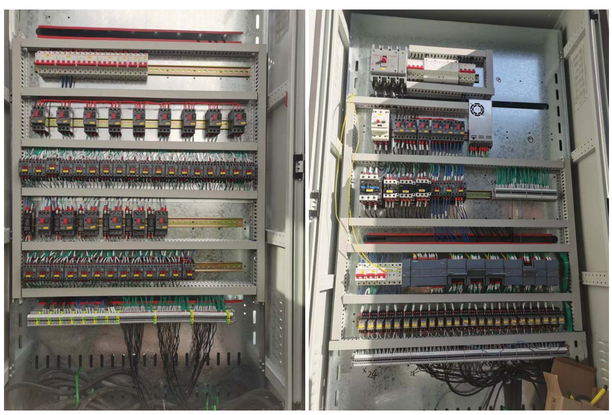

Figure 7. Electrical cabinet.

5. Experimental Validation

5.1. Test Conditions

After the completion of the assembly and fabrication of the multi-rod sampling machine, a series of tests were conducted at Jie shou Ju li Grain Machinery Co., Ltd. in Fu yang, Anhui, to validate whether the machine's mechanical performance and actual effects meet the design expectations. The test equipment is shown in **Figure 8**, and the multi-rod sampling machine designed in this paper was used for the experiments. The PLC program was downloaded to a computer, which controlled the movement of the main carriage, auxiliary carriage, and sampling rods.

5.2. Test Results

The test results indicate excellent performance of this multi-rod grain sampling machine. Specifically, the highlights include: a sampling frequency of 45 times per hour, a round trip time of the sampling rod of 26 seconds, a sampling width of 300 cm, a sampling rod stroke of 420 cm, and a sampling length of 1800 cm for the main carriage. Throughout the entire testing process, the machine operated smoothly without any abnormalities, further demonstrating the efficiency and reliability of this design. The test results are presented in **Table 2**.

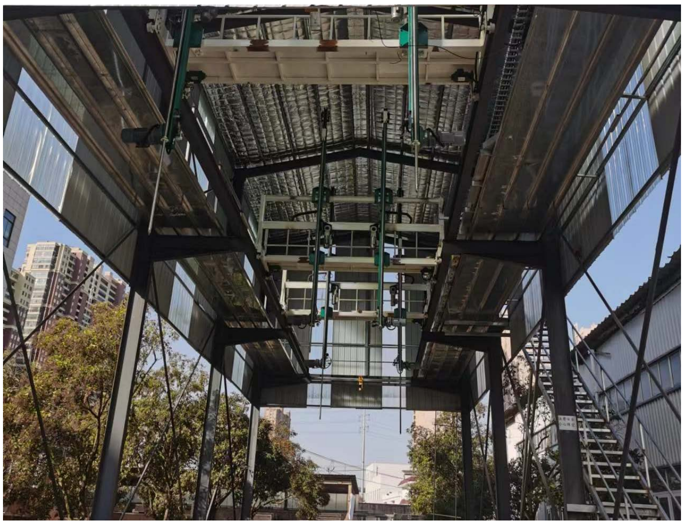

Figure 8. Multi-rod spike prototype prototype.

Table 2. Test results.

Test Parameters	Unit	Results
Sampling Frequency	Times /h	45
Sampling Rod Round-Trip Time	s	26
Sample width	cm	300
Sample rod stroke	cm	420
Boom sample length	cm	1800

6. Conclusions

1) A grain sampling machine was designed with a determined overall structure, and automatic control of the main carriage mechanism, auxiliary carriage mechanism, and sampling rod was achieved by setting up PLC-related control programs. The efficiency of sampling was significantly enhanced due to the structural design of the six rods, and the sampling operation was greatly improved owing to the design of high amplitude and width.

2) The results of the sampling tests demonstrate stable operation of the entire machine, with a sampling frequency reaching 45 times per hour and a sampling rod round-trip time of 26 seconds. The sampling length of the main carriage reached 1800 cm, meeting the requirements set by the Anhui Provincial Department of Science and Technology.

3) The research on grain suction pipe has not been designed yet, and the research on grain suction plan will continue in the future.

Fund

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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