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Design of Small Sorghum Harvesting Equipment Based on PLC for the Zunyi Mountainous Area

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Abstract : In order to meet the needs of mechanized harvesting of sorghum in the complex terrain of Zunyi Mountains, an integrated and automated small-scale sorghum harvesting equipment was designed. The equipment adopts crawler walking mechanism and DC brushless motor drive system, which can adapt to the 25° steep slope working environment, the weight of the whole machine is 400kg, and the maximum speed of climbing and flat slope is 0.78m/s and 1.1m/s respectively. It has the function of 1000mm wide harvesting table and integrated harvesting and threshing, and the theoretical feeding volume reaches 1663.2kg/h, which significantly improves the operation efficiency. Through the PLC control system to achieve automatic operation, programming control forward, backward, steering and threshing drum forward and reverse functions, and equipped with HMI touch screen human-computer interaction interface, real-time status monitoring and parameter adjustment. Combined with the compact body design, it adapts to the flexible transfer of narrow terraces. The equipment provides lightweight and cost-effective mechanization solutions for small plot sorghum planting areas, which has important reference significance for promoting the development of agriculture in Zunyi area.

Keywords : Sorghum harvester, Mechanical structure, PLC control system0 Preface

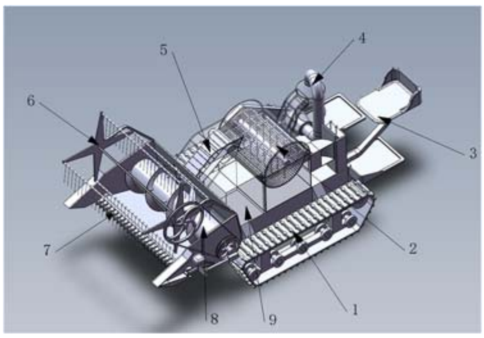
1 INTRODUCTION

Zunyi is the core production area of Maotai-flavor liquor, and liquor enterprises represented by Kweichow Moutai have a huge demand for local sorghum. As a key raw material for brewing Maotai-flavor liquor, the quality and yield of sorghum directly affect the development of the liquor industry. Meanwhile, as an important crop in Zunyi, it contributes significantly to the local agricultural economy.

However, Zunyi is characterized by complex mountainous terrain with undulating landforms, small and irregular plots, scattered sorghum cultivation, and inconvenient transportation. The diverse and complicated planting environment brings numerous difficulties to large-scale harvesting machinery: inconvenient equipment transportation, poor terrain adaptability, low operation efficiency, and the high risk of damaging the mountainous ecosystem. At present, the local area still relies on manual harvesting, which suffers from high labor intensity, low efficiency and unstable quality.

With the growing market demand for sorghum as a liquor-making raw material, it is imperative to design small-sized and highly adaptable sorghum harvesting equipment tailored to the special mountainous environment of Zunyi, in order to improve harvesting efficiency and ensure the stability of market supply.

2 MECHANICAL STRUCTURE DESIGN OF SORGHUM HARVESTER



1-CRAWLER BASE 2-THRESHING BIN 3-OPERATION SEAT 4-SORGHUM COLLECTING DEVICE 5-GRAIN LIFTING DEVICE 6-REEL 7-CUTTING KNIFE 8-AUGER 9-POWER BATTERY

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FIG 1 MECHANICAL DESIGN DRAWING OF SORGHUM HARVESTER EQUIPMENT

As shown in Figure 2, the transmission system of the sorghum harvester operates as follows: first, Motor 4 directly drives Pulley V1 to rotate, which in turn powers the threshing bin equipment on Shaft Ⅱ. Shaft Ⅰ drives Pulley V2 to rotate, thereby actuating the grain lifting device on Shaft Ⅲ. Meanwhile, Motor 3 drives the reel on Shaft Ⅳ, and Shaft Ⅳ further drives the cutting knife on Shaft Ⅶ via gear transmission.[1][2]

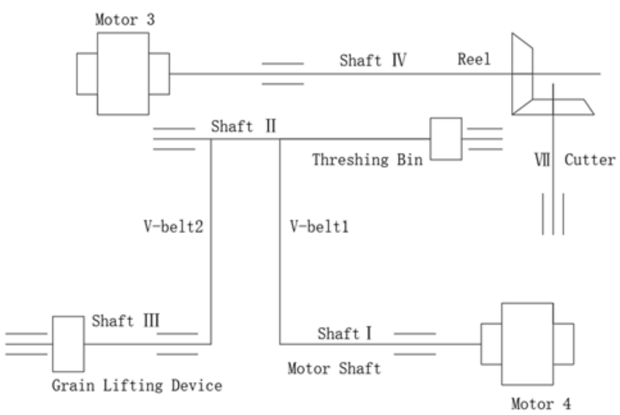

FIG. 2 DIAGRAM OF THE TRANSMISSION SYSTEM OF THE HARVESTING EQUIPMENT

3 DESIGN OF CONTROL SYSTEM FOR SORGHUM HARVESTER

3.1 *HARDWARE DESIGN OF THE CONTROL SYSTEM*

As shown in Figure 3, the circuit diagram of the hardware control system for the small-sized sorghum harvester is presented. The PLC expansion module SM1234 is adopted to control the driver with 0–10 V analog signals, so as to adjust the rotational speed of the motor and further drive the crawler base. By controlling the rotation direction and speed of Motor 1 and Motor 2, the crawler base can achieve the functions of forward and backward movement; in addition, the steering function is realized by utilizing the speed difference between the two motors. The rotation speed, start-up and stop of Motor 3 and Motor 4 are controlled to meet the requirements of the rotation speed, start-up and stop of the header and threshing bin under different working conditions.[3]

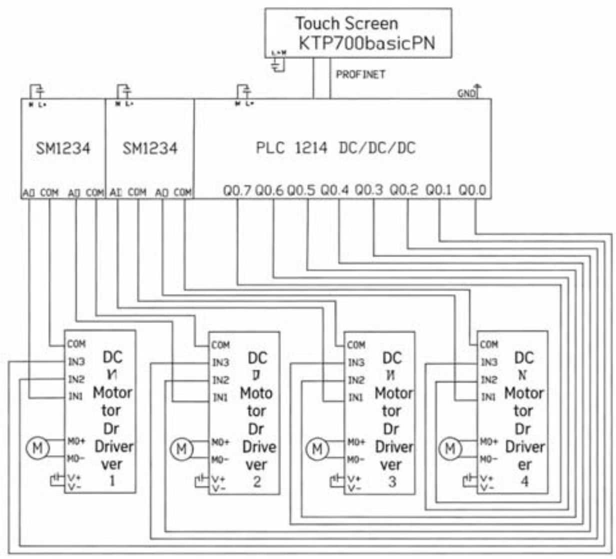

FIG 3 EQUIPMENT ELECTRICAL CONTROL CIRCUIT DIAGRAM

3.2 *SOFTWARE DESIGN OF THE ELECTRICAL CONTROL SYSTEM*

The input signals of the PLC system for the sorghum harvester are composed of the forward switch, backward switch, left turn switch, right turn switch, Motor 3 forward rotation switch, Motor 3 reverse rotation switch, Motor 4 forward rotation switch, Motor 4 reverse rotation switch, crawler base start switch, header start switch and threshing bin start switch.

The output signals of the PLC system for the sorghum harvester consist of the Motor 1 reverse rotation enable, Motor 1 forward rotation enable, Motor 2 reverse rotation enable, Motor 2 forward rotation enable, Motor 3 reverse rotation enable, Motor 3 forward rotation enable, Motor 4 reverse rotation enable, Motor 4 forward rotation enable, Motor 1 working indicator light, Motor 2 working indicator light, Motor 3 working indicator light and Motor 4 working indicator light.

The I/O address allocation of the PLC program is shown in the table.

TABLE 1 I/O ADDRESS ALLOCATION TABLE

Input Signal	Signal Address	Output Signal	Signal Address
Forward Switch	%I0.0	Motor 1 Reverse Rotation Enable	%Q0.0
Backward Switch	%I0.1	Motor 1 Forward Rotation Enable	%Q0.1

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Left Turn Switch	%I0.2	Motor 2 Reverse Rotation Enable	%Q0.2
Right Turn Switch	%I0.3	Motor 2 Forward Rotation Enable	%Q0.3
Motor 3 Forward Rotation Switch	%I0.4	Motor 3 Reverse Rotation Enable	%Q0.4
Motor 3 Reverse Rotation Switch	%I0.5	Motor 3 Forward Rotation Enable	%Q0.5
Motor 4 Forward Rotation Switch	%I0.6	Motor 4 Reverse Rotation Enable	%Q0.6
Motor 4 Reverse Rotation Switch	%I0.7	Motor 4 Forward Rotation Enable	%Q0.7
Crawler Base Start Switch	%I1.0	Motor 1 Working Indicator Light	%Q1.0
Header Start Switch	%I1.1	Motor 2 Working Indicator Light	%Q1.1
Threshing Bin Start Switch	%I1.2	Motor 3 Working Indicator Light	%Q1.2
		Motor 4 Working Indicator Light	%Q1.3

As shown in Figure 4, the ladder diagram of the PLC control program is a schematic diagram for controlling the crawler base to achieve the functions of forward movement, backward movement and steering during operation.

By turning on the Crawler Base Start Switch (%I1.0), the circuit is energized. Pressing the Forward Switch (%I0.0) will activate the simultaneous forward rotation of Motor 1 and Motor 2, thus realizing the forward function of the crawler base. Pressing the Backward Switch (%I0.1) will trigger the simultaneous reverse rotation of Motor 1 and Motor 2, enabling the crawler to move backward.

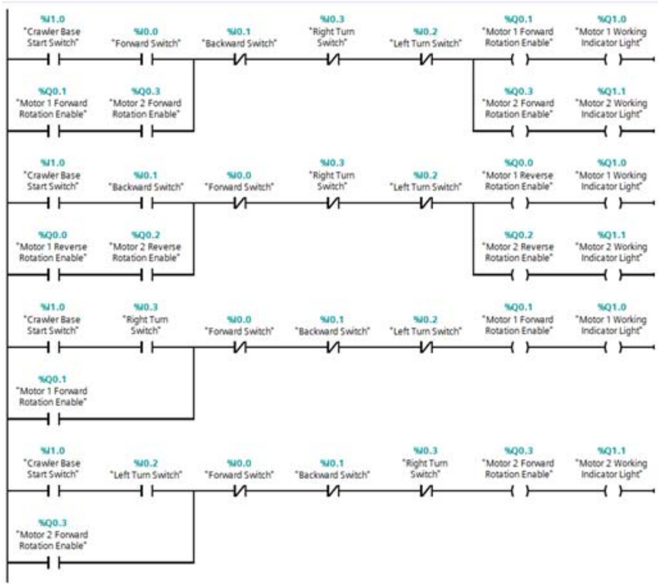

FIG. 4 LADDER PROGRAM DIAGRAM

The steering function of the crawler is achieved by the speed difference generated between Motor 1 and Motor 2. Pressing the Left Turn Switch (%I0.2) will stop Motor 1 while keeping Motor 2 in normal operation; the resulting speed difference enables left turn. Pressing the Right Turn Switch (%I0.3) will keep Motor 1 running normally while stopping Motor 2; the speed difference thus created realizes right turn.

As shown in Figure 5, this is the schematic diagram for controlling the forward and reverse rotation of the header motor. By turning on the Header Start Switch (%I1.1), the circuit is energized. Pressing the Motor 3 Forward Rotation Switch (%I0.5) will activate the forward rotation of Motor 3. If reverse rotation of Motor 3 is required under this condition, pressing the Motor 3 Reverse Rotation Switch (%I0.4) will initiate the reverse rotation of Motor 3.

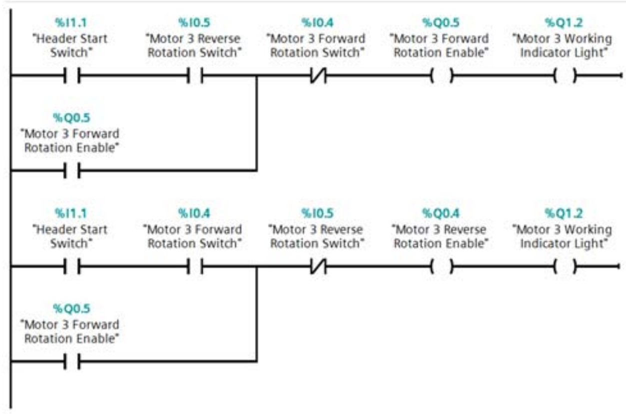

FIG.5 LADDER PROGRAM DIAGRAM

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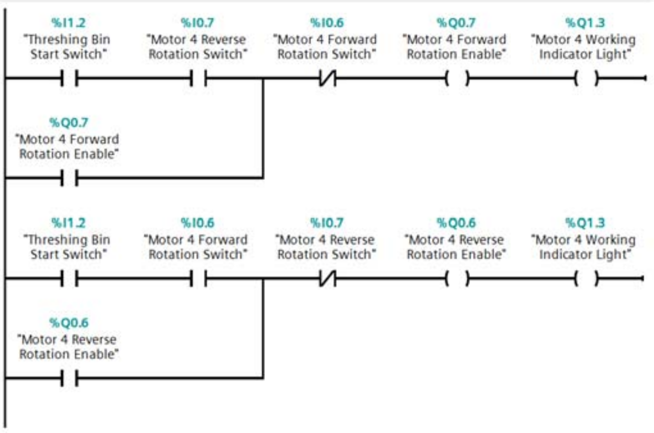

FIG.6 LADDER PROGRAM DIAGRAM

As shown in Figure 6, this is the schematic diagram for controlling the forward and reverse rotation of the threshing bin motor. By turning on the Threshing Bin Start Switch (%I1.2), the circuit is energized. Pressing the Motor 4 Forward Rotation Switch (%I0.7) will activate the forward rotation of Motor 4. If reverse rotation of Motor 4 is required under this condition, pressing the Motor 4 Reverse Rotation Switch (%I0.6) will initiate the reverse rotation of Motor 4.

As shown in Figure 7, this is the schematic diagram of the driver analog-to-digital conversion program. The maximum frequency of the AQMD6040BLS DC brushless motor driver is 50 Hz; therefore, the MIN value is set to 0 (corresponding to 0 Hz) and the MAX value is set to 27648 (corresponding to 50 Hz).

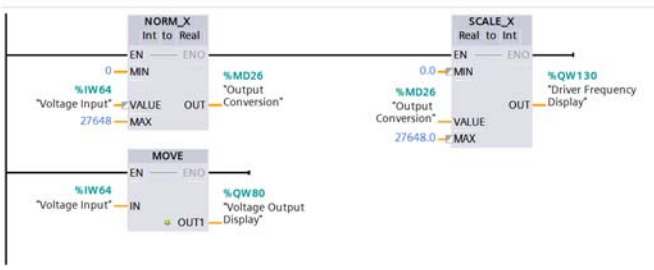

FIG.7 LADDER PROGRAM DIAGRAM

The NORM_X and SCALE_X instructions are adopted to enable the motor to adjust its frequency according to the set voltage. Then, the MOVE instruction is used to transfer the input voltage value to the voltage output display, laying the groundwork for its connection with the HMI display screen.[4]

4 ANIMATION DESIGN OF THE HMI CONTROL PANEL

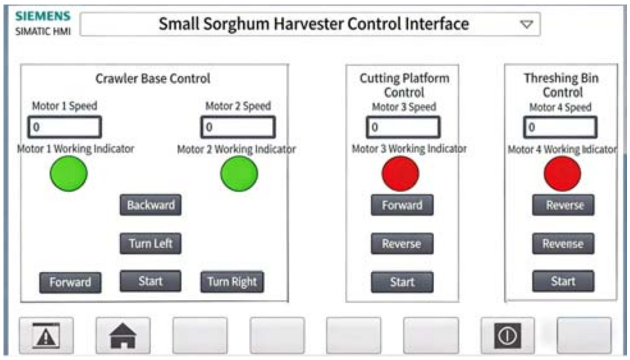

FIG.8 HMI CONTROL PANEL INTERFACE DIAGRAM

As shown in Figure 8, this is the interface diagram of the control panel. The control interface of the sorghum harvester is divided into three sections: crawler base control, header control, and threshing bin control. Each motor is equipped with a working indicator light. The indicator light remains red when the motor is not in operation, and turns green when the motor starts running, enabling the operator to monitor the equipment status in a more intuitive manner.

5 CONCLUSION

A small-sized sorghum harvester suitable for mountainous areas in Zunyi was designed. Adopting a crawler-type traveling mechanism driven by DC brushless motors, combined with a lightweight body (full load: 400 kg), this harvester significantly improves adaptability to sloping fields (maximum climbing gradient: 25°). Its maximum speeds on slopes and flat ground reach 0.78 m/s and 1.1 m/s respectively, meeting the requirements for stable operation on rugged terrain. The integrated design of a 1000 mm-wide header and a threshing unit achieves a theoretical feed rate of 1663 kg/h, which greatly improves efficiency compared with manual harvesting while reducing grain loss. Equipped with a high-capacity battery of ≥458.3 Ah, it ensures 4 hours of continuous operation. Combined with its compact structure, the harvester can move flexibly in narrow terraced fields, balancing operational efficiency and handling convenience. Theoretical calculations show that the equipment performs stably under the working conditions of 25° slopes and 400 kg load, with its operational efficiency and endurance meeting the design requirements.[5]

A PLC control system was applied to control the sorghum harvester. The forward, backward, left-turn and right-turn functions of the crawler base, as well as the forward and reverse rotation functions of the header and threshing bin, were realized via programmed control. An HMI control panel was configured to achieve human-machine interaction, making the operation of the harvester more convenient, simple and visualized. Real-time machine status feedback via indicator lights on the touch screen enables operators to conduct safer and more efficient manipulation. The rotation speed of the motors is controlled by DC brushless motor drivers, thus regulating the traveling speed of the harvester.

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