The Design of Gantry Welding Production Line System Based on PLC

Junfeng Yuan, Chenghua Tian, Hui Li, Haitao Wang, Chunlin Zhou
Beijing research institute of automation for machinery industry co., ltd., beijing, 100120

Abstract. This paper introduces the composition of the mast welding production line, and designs the process flow of the production line. With Siemens S7-300 PLC and ET200SP as the core, this paper designs a production line control system is designed. In addition, this paper expounds on the hardware design and software design of the PLC system in detail and describes the communication methods between the PLC and the robot, and programming is conducted based on modular programming, thus making the system become stable and scalable.

1. Introduction
In recent years, with the advancement of intelligent manufacturing 2025, the manufacturing model of China’s construction machinery industry, especially the forklift industry, has undergone great changes. The previous manual semi-automatic operation is gradually transformed towards the direction of automation and intelligence. Our company and a well-known forklift manufacturer have jointly developed the automatic welding production line for the outer door frame of small tonnage forklifts, which has solved the difficult production of small batches and multiple varieties of outer door frame welding. Through the integration of automatic identification system, flexible automatic tooling fixtures, welding robots, handling robots, and automatic conveyor rollers, the forklift company has realized nearly 100 kinds of flexible automatic welding of mixed lines for external masts. The level of automation and intelligence of the production line has reached the advanced level in the industry, and thus the production line has become an industry benchmark project.

The PLC system is an industrial computer system that implements control functions. Because it has strong functionality, high reliability, strong environmental adaptability and anti-interference ability, and simple programming, it is widely used in industrial sites. The network performance of the new generation PLC system is greatly enhanced. Based on the industrial Ethernet protocol and a variety of communication protocols, it can greatly facilitate the communication connection with various devices on the site with good scalability. Based on these considerations, the Siemens PLC system is used as the control center in this paper to integrate automatic identification systems, inverter systems, industrial robots and other systems, and thus a control system is designed for the production line of the outer mast welding.

2. Composition of the Outer Mast Welding Production Line
The forklift mast is the main load-bearing component of the forklift picking device consisting of a series of components such as an inner mast, an outer mast, and a fork rack. The manufacture of external masts is an important part of forklift production. In order to meet the market demand, there
are many types of forklift masts. Therefore, outer masts are typical components of multi-variety and small batch production. This production line can be adapted to weld the mast with a length ranging from 1885mm to 2885mm and a width ranging from 606mm to 692mm, covering 98% of customers’ products, with nearly hundreds of product types. The process flow of this welding production line is: door frame identification code → after assembly of the work-piece, the self-assembly mold is lifted to the conveying unit→ repair welding and information confirmation before going online (identification of outer mast) → the gantry is automatically transferred to the welding robot workstation for welding and blanking to the conveyor line →automatic gantry conveying → repair welding→ calibration tooling. The entire welding production line layout is shown in Figure 1, which specifically includes the following parts: Feeding conveyor system, work-piece secondary recognition system, transplanting robot system, seven sets of automatic welding workstation system (each set consists of 2 welding robots and 1 automatic positioner), blanking conveyor line system, and repair welding station.

![Figure 1. General Layout of Welding Production Line](image)

3. Composition of a PLC-based Control System
The control system composition of welding production line is shown in Figure 2. The master control system is the core of the entire control system. Siemens PLC was selected. The system adopts the way of head station plus remote I / O, and uses field bus for input and output expansion. The main control system is responsible for the logical control, data processing, equipment information interaction and coordination of the entire welding production line. The system can be switched between automatic, manual and debug modes. The control system includes controlling various conveyors and lifting movements, reading the bar code information of the work-piece, and performing visual recognition and comparison. Perform signal interaction coordination with KUKA robot, control the positioner fixture to automatically clamp and loosen the work-piece, and communicate with the host computer system. During the entire control process, the PLC control system communicates with the on-site touch screen and the industrial control host computer. It can display and store the status, faults, running status, switch status and various alarm information of the conveying system on the touch screen and the upper computer to facilitate process traceability.

Specifically, the welding production line system includes the following functions: control of the robot system; control of the conveyor system; communication with the host computer; switch status
and various operating alarms are displayed on the touch screen. And the control methods include debug mode, manual mode, and fully automatic mode with the functions such as switch detection and various running alarms.

![Control Block Diagram of Welding Production Line](image)

**Figure 2. Control Block Diagram of Welding Production Line**

### 4. Design of the PLC Control System

The PLC control system is in the core control position in the production line. It is responsible for the coordinated control of the work-piece loading and unloading conveyor system, the welding robot and the tooling fixture, and the operation scheduling of the handling robot. In addition, it displays status and enters information through the human-machine interface and on-site operation buttons and indicators. Through modular programming ideas, the stability and reliability of PLC program operation is greatly improved, and the project debugging progress is greatly improved.

#### 4.1. Hardware Design of PLC

The welding production line integrates a work-piece conveying system, a handling robot system, a robot automatic welding system, and a welding automatic tooling system. The input signals mainly
include a button switch, a work-piece detection sensor, and a cylinder magnetic switch. The output signals include motor start and stop, solenoid valve, robot start and stop, and field indicators. Based on the design principles of modularity and scalability, this control system combines centralized control and decentralized control. The main control cabinet selects Siemens S7-300 controller 317F-2PN / DP as the control core. The on-site input and output signals are input to the ET200SP remote control station nearby, and the main control cabinet and remote control station communicate through the PROFINET protocol. Therefore, data communication is stable, reliable, and real-time. The transmission line motor is controlled by Siemens G120 frequency converter. The frequency converter communicates with the PLC through the PROFINET protocol. KUKA robots also interact with PLC systems via PROFINET protocol. The system design block diagram is shown as in Figure 3. In addition, based on the principle of partition control, this system divides the entire production line into four functional areas, namely the on-line conveying area, the automatic welding area, the automatic off-line conveying area, and the blanking repair welding buffer area. Each area is designed with an independent console, which can be used to switch modes in this area. The control mode in the control system includes three control modes: debug mode, manual mode and automatic mode. Among the three operating modes, there is a certain order of priority. The debugging mode has the highest level, then the manual mode, and finally the automatic mode. The on-site operating platform is shown in Figure 3.

**Figure 3.** On-site Operating Platform

### 4.2. Software Design of PLC

The PLC software design is based on the modular design concept, and the same function is written as the repeated calls of the function block. For example, the control process of the conveying motor and the control process of the welding robot only need to change the corresponding input and output addresses when called, which greatly improves the programming efficiency and reduces the program error rate. The following introduces several core program modules:

#### 4.2.1. Design of Secondary Recognition Control Program for Work-piece.

In order to meet the production needs of multiple external masts simultaneously on-line for mixed line welding, the automatic welding production line barcode is used as the identity of each outer mast. Through the secondary identification system of the work-piece, the identity of the mast is obtained. Through the storage and transmission of the identity in the PLC control system, the functions of the carrying robot and the welding robot calling different execution programs are finally realized. In order to avoid the robot program calling error caused by the manual misapplication of the barcode and the collision between the robot and the work-piece, the control system designed a secondary recognition system for the work-piece. Cognex fixed bar code reader was used to read the bar code information, and the upper computer database was retrieved to obtain a program number. The Cognex high-resolution smart camera was selected to take pictures to identify the features of the work-piece and obtain another program number. Only when the program numbers obtained by the two are consistent, the work-piece identification success signal is sent, and the work-piece is allowed to flow into the feeding conveyor. When the two information is inconsistent, the system will give an alarm prompt message,
which will be confirmed by the operator before entering the next process. The program flow chart is shown in Figure 4.

![Flow Chart of Secondary Recognition of Work-piece](image)

**Figure 4.** Flow Chart of Secondary Recognition of Work-piece

4.2.2. *Design of Control Program for Feeding Conveyor Line.* The automatic feeding and conveying area is composed of seven sections of conveying rollers, seven lifting and moving chain machines, and seven stoppers. Each section of the roller table is equipped with three sensors for entering, decelerating and stopping to feedback the status of the work-piece on the roller table. Each jacking movement has ascending and descending in-position detection switches, and deceleration and in-position detection signals feedback the state of the work-piece. Each stop has a release and blocking detection switch to indicate the current status of the stop. Each section of the roller table is provided with a manual operation button box on the side of the wire body, which is used to manually run the roller table in the manual or debugging mode. Each station can be set to a disabled state. After disabling, the work-piece will not be conveyed to the loading position. The handling robot is prohibited from grasping the work-piece at the loading position until the disabling. The roller motor is controlled by Siemens frequency converter, with smooth start and stop and adjustable speed. The welding program number corresponding to each loading position is stored in the PLC program, and the work-piece type can be roughly judged by the program number. The robot calls different types of work-piece gripping programs for handling, and is used to adapt to the gripping of multiple types of work-pieces. The program flowchart is shown in Figure 5:
4.2.3. Design of Control Program for Handling Robot. The handling robot system includes a KUKA KR1000titan six-axis robot with a load of 1 ton, a set of linear guide walking mechanisms, and a set of work-piece grippers. The robot walking servo motor adopts the external axis control method of the robot. The opening and closing of the work-piece grip is controlled by the PLC system. Data is communicated between the PLC and the robot control system via the Profinet protocol. Data interaction is performed through signal mapping. After the robot is powered on, it switches to the external automatic mode and waits for the PLC to transmit the corresponding program number. The corresponding subprogram module is selected and executed by the program number. The PLC program should obtain the next to-be-executed task of the handling robot through logic control based on the current loading level, welding station, loading status, and current position of the handling robot, and calculate the corresponding program number for the robot. After the robot finishes executing, it waits for the next task. The operation flow of the transfer robot is shown in Figure 6.

**Figure 5. Flow Chart of Loading Level Program**
4.2.4. Design of Control Program for Welding Station. The welding station consists of two KUKA KR16 welding robots, a single-axis servo positioner, a fixture system, and two EWM digital welding machines. The fixture system is composed of multiple cylinders, and the opening and closing of the cylinders are controlled by PLC to complete the positioning and pressing of the outer mast. After the clamp is clamped, the PLC system transmits the welding program number transmitted by the handling robot system to the two welding robots. The two welding robots coordinate work through the Robteam software package to avoid collisions in the interference zone, and the robot and PLC communicate directly through the Profinet protocol. The two complete signal interaction through IO mapping, PLC sends program number, start and stop signals to the robot, the robot sends robot status, welding completion signal, welding fault, welding current, welding voltage and other information to the PLC. When the robot fails, an acousto-optic display is displayed on the tri-color lights of each workstation, which is convenient to remind the operator to deal with it in time. The engineering process of the welding station is shown in Figure 7:

Figure 6. Work Flow Chart of Handling Robot
4.2.5. Design of System Alarm Program. The control system is designed with perfect fault alarm and processing display procedures. There are two types of warnings and alarms according to the type of fault. When a warning occurs, it does not affect the operation of the production line, but there will be a message prompt. When an alarm occurs, the equipment in the corresponding area is shut down to ensure the safety of equipment and personnel. The fault information prompt on the human-machine interface at the scene, the operator can reset the fault after the fault handling and restart according to the information prompt. The following Figure 8 is a flowchart of the processing of a welding station failure:
5. Conclusion
The successful implementation of the production line of the forklift outer mast welding not only greatly reduces the labor burden of workers, shortens the welding time, guarantees the welding quality, and greatly improves the output. In addition, the production line has a good demonstration significance, which provides a good reference experience for the subsequent design and implementation of similar production lines. Over the nearly one year since the welding production line began to run, and the overall operation of the system is stable and reliable. There are more than 80 products on the line, which fully meet the design requirements and good customer feedback.

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