

## Research and Development on the Fault Diagnosis System of Automatic Production Line Based on PROFIBUS

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### **Abstract**

*The YL-221 automatic production line is complex in structure, low in utilization and hard to maintain, which makes it unsuitable for teaching. So a fault diagnosis system based on PROFIBUS (Process Field Bus) on the basis of original device is developed. This paper firstly introduces the structure and working principle of the automatic production line, determines the common fault points of the slave station with the blanking station being the example and then employs the PLC and touch screen technology to design and develop fault setting and diagnostic devices of the slave station to meet the working requirements of setting faults in touch screen and monitoring the operation condition. Ultimately, a centralized control on the whole system and distributed control on field devices based on the PROFIBUS bus technology is realized. Real-time data monitoring is made through WINCC interface on the host computer.*

**Keywords:** PROFIBUS, Fault diagnosis, Automatic production line, PLC, Touch screen, WINCC

### **1. Introduction**

As the result of the rapid development of programmable logic controller (PLC), the PROFIBUS has been one of the most successfully applied field buses so far. Its most salient feature is openness, which means that it is compatible with devices from different manufactures and complies with national standards [1, 2]. According to different application demands, PROFIBUS can be divided into three compatible versions, namely, PROFIBUS—DP, PROFIBUS—PA and PROFIBUS—FMS. PROFIBUS—DP applies to the communication between PLC and field distributed device and is designed for decentralized control of high-speed devices; PROFIBUS—PA is designed specifically for the process automation; and PROFIBUS—FMS is designed for solving the workshop-level communication task, providing a great amount of communication service and accomplishing the cycle and non-cycle task of moderate transmission rate [3, 4]. Since International Electro-technical Commission formulated the IEC61158 international standards in 1999, PROFIBUS has been for field use for more than ten years. Currently it is widely used in manufacturing, process control, power and transportation field. And it plays a particularly important role in automatic production lines [5, 6, 7].

The YL—221 automatic production line is a mechatronics training equipment jointly developed by Zhejiang Yalong Technology Group Limited and our academy based on the PROFIBUS—DP. It aims to provide a good training platform for students from electrical automation majors and make up for past deficiencies. To be specific, previous experimental

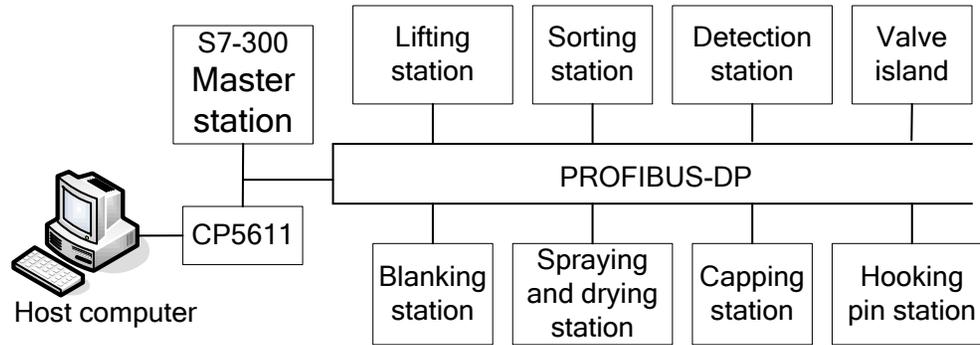
unit had poor perception and systematicness and automatic control device was only for seeing instead of operating for outdoor visits and practices. However, there are two problems in reality. Firstly, this production line is too bulky and it is difficult to conduct overall commissioning. Any fault arising from a certain workstation would probably lead to the circumstance that the system cannot run on-line. For teachers and students, applying this production line to teaching has too high threshold, so it's seldom employed in teaching and more often than not used for student and outsider visiting. Secondly, even if we apply it to actual teaching, the device damage rate is too high and device maintenance and teaching difficulty is increased accordingly as students perform the device wiring and disassembly too many times. Therefore, how to maximize the performance of original device by enabling students to get plenty of exercise in practice and equipping this device with easy operation and maintenance, repeatable non-destructive disassembly and friendly interface is an urgent problem that needs addressing currently.

Existing literature on fault diagnosis based on the PROFIBUS primarily uses the hardware test and STEP7 software for diagnosis in view of the network fault in industrial fields [8, 9]. With respect to the modification of practical teaching device, domestic scholars have studied and developed experimental devices of fault setting including CNC machine tools [10], electrical device maintenance training bench [11], fault system of EFI engines [12] and comprehensive fault setting stations of trains. These research results provide useful ideas for this design. On the basis of the existing technology of YL-221, this paper conducts extended development and designs fault settings and diagnosis settings of seven slave stations. Based on the PROFIBUS bus, the centralized control and distributed flexible control of master stations and slave stations are realized. And the WINCC interface on host computers to accomplish the real-time data monitoring and fault diagnosis control on the whole production line is made.

## 2. A Brief Introduction to Automatic Production Line

The YL-221 automatic production line consists of a master station and seven slave stations. The master station takes S7-300 PLC (CPU315-2DP) as the controller while the seven slave stations employ S7-200 PLC (CPU226) as the controller. The PLC of each slave station is externally connected to the communication module EM277 and constitutes a distributed control system with the master station through the PROFIBUS-DP [13, 14]. With the PC installed with a control card CP5611 being the host computer of the system, the master station collects data from each slave station, coordinates the operation of each station and provides data for the monitoring program of the host computer. The seven slave stations accomplish the control on blanking station, spraying and drying station, capping station, lifting pin station, inspection station, waste sorting station and upgraded storage station. The system's structure is shown in Figure 1.

Technology control process of the system includes: system startup→ loading work-piece by sending the tray into blanking stations →accomplishing the spraying and drying process after the work-piece is sent into the spraying and drying station →entering the capping station and adding caps to the work-piece →entering the hooking pin station for work-piece pin installment →entering the detection station and testing work-piece color for the judgment of product quality →entering the product sorting station for sorting (if the product is an end product, manipulators rotate the work-piece 90 degrees before sending it into the lifting station; if the product is a waste product, manipulators send the work-piece to waste transport stations) →entering the lifting station and placing the products of different colors to specified locations.

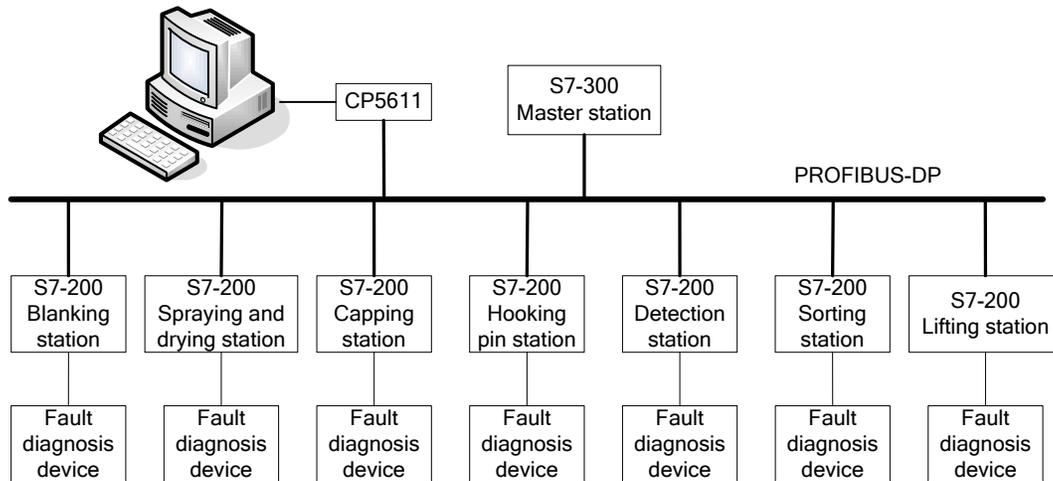


**Figure 1. The Overall Structure Diagram of YL-221 Automatic Production Line**

### **3. Fault Diagnosis System Design of Automatic Production Line**

#### **3.1 Design scheme**

The YL—221 automatic production line is a complex automatic control system combining light, mechanics, electricity and gas. Any fault that occurs in a certain aspect of the system may lead to dysfunction of the production line. Rapid troubleshooting in industrial fields according to fault phenomenon is a skill necessary to technology maintenance personnel of the automatic production line. Similarly, during the practical training process of vocational colleges, equipping students with the ability of troubleshooting is the gravity of all in practical teaching. Therefore, how to simulate the real fault phenomena conveniently, rapidly, reliably and repeatedly proves to be the significant guarantee of innovative practical teaching, which is also the starting and innovation point of this design. To start with, extract several most common fault phenomena from the technological process of seven slave stations and determine corresponding fault points. Then conduct secondary development on the basis of original device and redevelop a set of production line fault diagnosis system used for teaching which integrates fault setting and information monitoring by transforming and increasing new corresponding hardware circuit, writing the PLC program, configuring the human-machine interface and writing monitoring procedures of the host computer. We can set several faults of slave stations through the host computer and the touch screen of each slave station and then on the basis of fully grasping the working principle of automatic production line, students analyze, judge, inspect, test, find the fault point and exclude it according to these fault phenomena. Once the fault point is excluded, workstations can operate normally and the message of excluding faults successfully would occur correspondingly. By achieving the network communication between host computer, master station and slave stations through the PROFIBUS, we enable the host computer to realize real-time monitoring on all fault information of slave stations including the fault setting condition and excluding condition. The specific design scheme is shown in Figure 2.

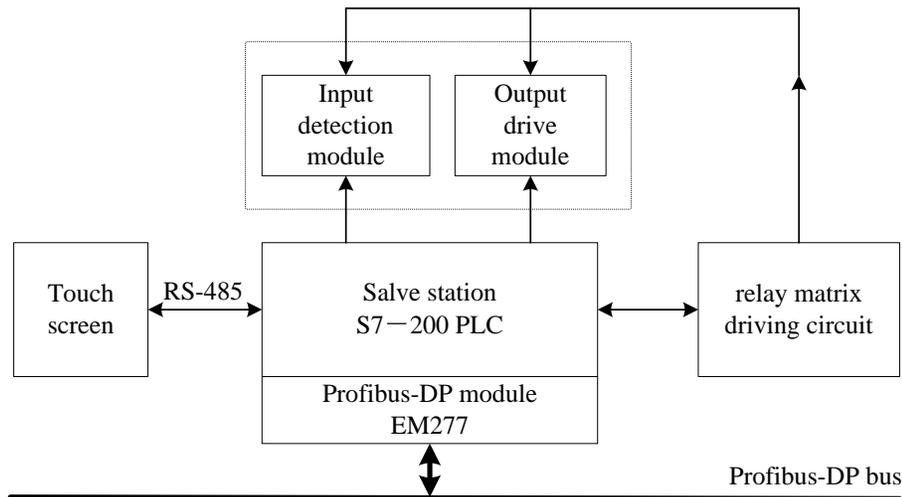


**Figure 2. The overall design scheme of the fault diagnosis system**

### 3.2 Circuit design

The fault diagnosis device of each slave station bears the functions of fault setting, information monitoring and data alarming and its circuit structure is mainly composed of PLC, touch screen, relay, freewheeling diode and RS-485 communication cable as shown in Figure 3. Employing the PLC as the controller has high operational stability and easy access to touch screen, saves costs by using the remaining I/O port of PLC slave stations for circuit design and simplifies the difficulty of system integration. As an important device of human-machine interaction, the touch screen can achieve fault difficulty selection (easy, medium and hard), single and multiple fault point settings, time setting of troubleshooting and displaying and monitoring various information produced and operated in this station. The normally open and closed contacts of relays are used for disconnecting and connecting the electrical control circuit of a certain fault point. Whether the relay coil is energized or not is controlled by the PLC output point. When we set a certain fault on the touch screen, the PLC connected with it would issue corresponding control commands to drive relay action and arouse fault phenomena by changing previous circuit connection forms.

All slave stations employ S7—200, the small-size PLC produced by Siemens as the master control unit. The input detection sector includes the start, stop, reset and emergency stop of circuits as well as various sensor signal detection circuits and the temperature detection circuit required by the production process of this station. All switch signals of that input sector are sent into the input terminals of PLC while the analog signals are sent into the input terminals of EM231 expansion modules. Output drive modules mainly include the drive solenoid valve control gas circuit, drive DC motor, drive signal display circuit and output analog signal circuit. To save costs, we directly use the PLC of slave stations as the master control unit of fault diagnosis devices and solve the problem of input/output point inadequacies by designing the relay matrix driving circuit or expanding the I/O Module (only upgrading station uses this method). To simulate the faults of slave stations, we need to set some common fault points on slave stations based on original circuits. These fault points control the on-off through relay driver circuits to determine whether faults occur or not. The touch screen adopts the TPC7062K type developed by Kunluntongtai Company and performs data communication with the PLC of slave stations via RS—485 communication cable. The PLC of each slave station is attached to the PROFIBUS—DP through EM277 module.



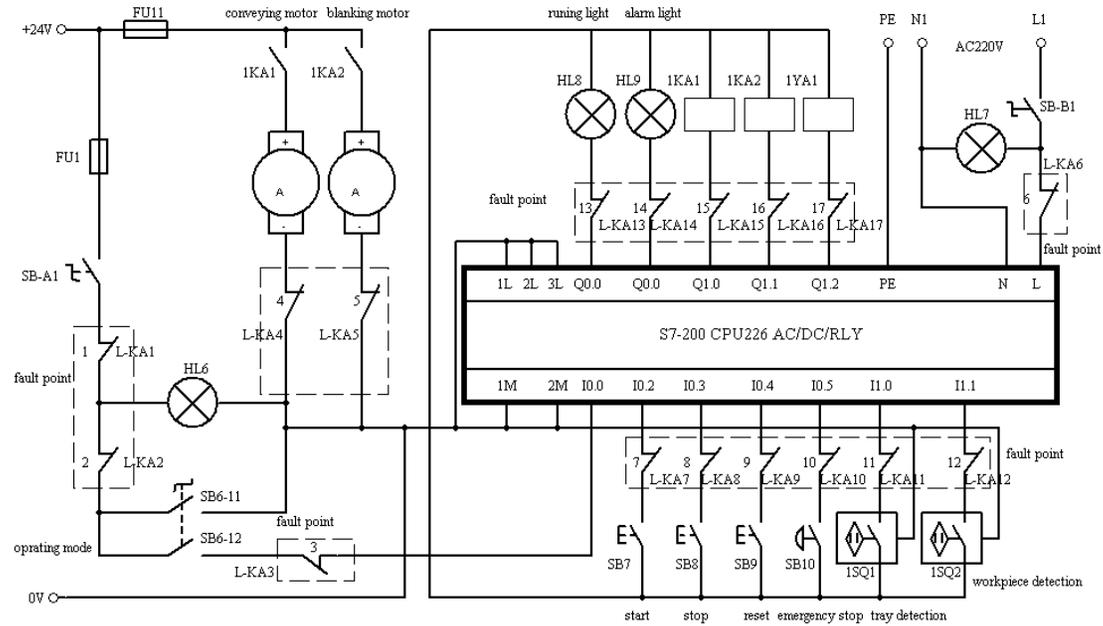
**Figure 3. The Structure Diagram of Fault Diagnosis Device of Slave Station**

The design ideas and circuit structures of the fault diagnosis device of this system's seven slave stations are basically the same. Due to the space limitation, this paper mainly sets the design of blanking stations as an example and gives a detailed discussion on the design process and method of that fault diagnosis device.

### 3.2.1 The working principle of blanking station

The electrical control principle diagram of blanking station is shown in Figure 4. Its working principle is: under normal circumstances, when the system is at the origin state, AC and DC power indicators HL6 and HL7 are turned on. If we place the switch SB6 on the on-line location and press the start button SB7 of this station or the start button of the master station, all slave stations enter the running state with the running indicator HL8 turned on and transport motors drive belts to rotate after obtaining electricity. When the tray on the conveyor belt runs to the blanking station, the limit electromagnet blocks the tray and forbids it from running. Then that unit starts a new duty cycle. At this moment, sensors detect the tray in place and the blanking motor gets started and makes the work-piece to fall by driving the pin wheel to rotate. When the sensor (1SQ2) has detected the work-piece, the blanking motor (M2) is turned off electricity and stops. Then we inspect whether the spraying and drying station is processing work-pieces: if it is processing work-pieces, we will wait until the end of the process; otherwise, the limit electromagnet (1YA1) is energized for two seconds and releases the tray and the work-piece, marking the end of a duty cycle. Under abnormal circumstances, if the blanking motor (M2) starts 60 seconds and the workpiece-detecting sensor still fails to detect the work-piece, an alarm condition occurs in this unit. If the device is under the single machine mode, the alarm light of this station will be turned on; if it is under the on-line mode, the alarm lights of this station (HL9), the terminus (HL5) and the warning devices (HL-S2) will all be turned on, which demonstrates that this unit lacks materials and needs to add

work-pieces. After adding work-pieces, once the sensor (1SQ2) detects that there are work-pieces in place, the above alarm lights will be extinguished.



**Figure 4. The Electrical Control Schematic Diagram of the Blanking Station**

The blanking station employs S7-200 series CPU226 relay-output-type PLC as the controller and the input, output and total points are 24, 16 and 40 respectively. The PLC input terminal mainly detects the field switch signal including the start, stop, reset and emergency stop information as well as the tray signal detection and work-piece detection signals which occupy a total of 6 input points and leave over 18 input points; the PLC output terminal primarily controls the motor operation and alarm display and drives three intermediate relays to control the work state of transport motor, blanking motor and workpiece-releasing solenoid valve which occupy a total of 5 output points and leave over 11 output points. The signal distribution and its function of each input and output point is shown in Table 1.

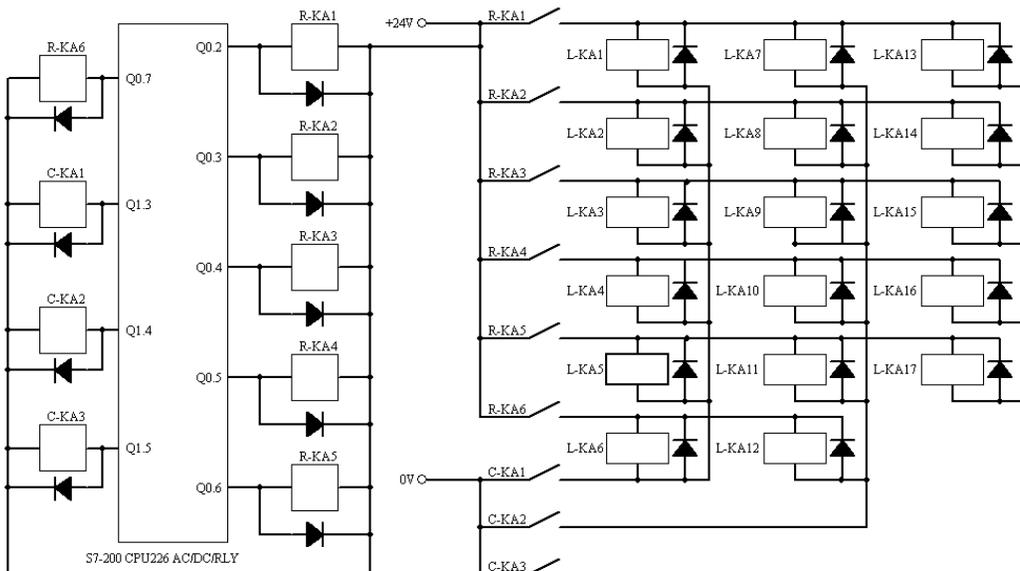
**Table 1. PLC's Input / Output Port Functions of the Blanking Station**

No.	Input address	Input signal function	Output address	Output signal function
1	I0.2	start	Q0.0	running light
2	I0.3	stop	Q0.1	alarm indicator
3	I0.4	reset	Q1.0	transport motor
4	I0.5	emergency stop	Q1.1	blanking motor
5	I1.0	tray detection	Q1.2	release solenoid valve
6	I1.1	workpiece detection		

### 3.2.2 Circuit design of the blanking station

According to the working principle of the blanking station and in conformity to the practical operation, 17 common faults are pointed out (as illustrated within the dotted line in Figure 4). For instance, PLC doesn't work, input/output modules don't work, on-line operation is not available, it can't be started, it can't be stopped, the button for emergency stop doesn't work, blanking is not available, and the tray can't be released. Among all these faults, the most significant one is switch fault. If 2 fault points out of 17 are combined, there will be 136 fault combinations. The number is much bigger when three or more than three fault points are combined together.

Here is the working principle of the circuit: in normal conditions, when the normally closed contact of the relay (in correspondence to the fault point) closes, the circuit will work normally. Nevertheless, a fault arises when the normally closed contacts are cut off and then the circuit starts to be disconnected. The connection and disconnection state of the 17 fault points are decided by the normally closed contacts of 17 relays. When the contact is connected, a fault then occurs; vice versa. Each normally closed contact is controlled by an independent relay. Therefore, 17 relays are called for. If a relay's coil is controlled by one PLC output point, then 17 PLC output points are called for, which surpass the number of CPU226 PLC physical output points. However, this issue can be solved through expanding PLC digital output module. To lower costs, this system takes advantage of the matrix circuit principle to design relay matrix output circuit, which not only lowers costs but also meets the design requirements[15]. The relay matrix drive circuit is illustrated in Figure 5.



**Figure 5. The Relay Matrix Drive Circuit of the Fault Diagnosis Device**

The circuit uses the matrix form of 6 (rows)  $\times$  3 (columns), with 9 PLC output points controlling 17 relays. It solves the problem of lacking PLC output points, for the circuit can at most control 18 relays. If the matrix form of 5 (rows)  $\times$  4 (columns) is used, 20 relays at most

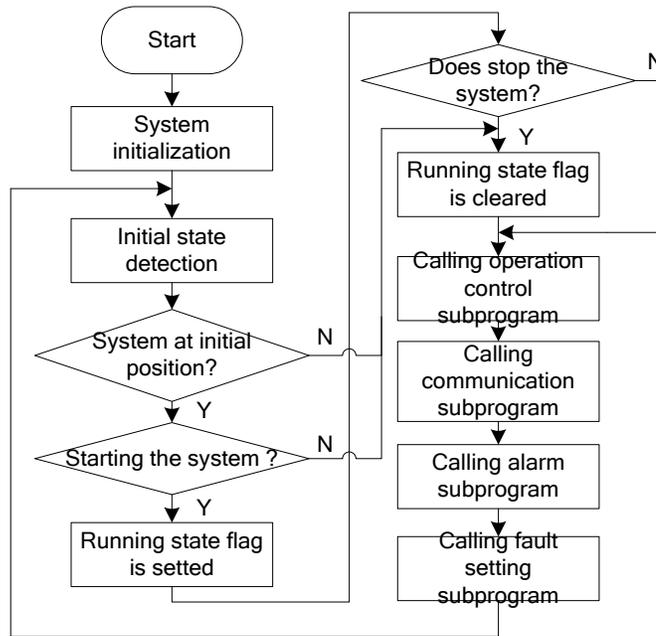
can be controlled. In the Figure 5, Relay R-KA1~R-KA6 controls the row level of the circuit, while C-KA1~C-KA3 controls the column level. If any row relay is energized, its normally open contact is closed, making its row level value DC24V. Whether the relay connected to that row can be energized depends on whether the column relay can be closed. For example, when level value of PLC output point Q0.2 is 0V, Relay R-KA1 is energized, with normally open contact closed and level value of the first row DC24V. If level value of PLC output point Q1.3 is 0V which is effective, it can lead to that the column Relay C-KA1 is energized, resulting in the close of normally open contact, and that level value of the first column reaches 0V, resulting in the disconnection of normally open contact of Relay L-KA1. Then Fault point 1 appears (as is shown in the Figure 4). Similarly, we can get the controlling relationship between the 17 fault-control relays and PLC output points shown in the Table 2 (“Y” is for effectiveness of PLC output relay, while “N” for its ineffectiveness).

**Table 2. Controlling Relationship between Fault-control Relays and PLC Output Points**

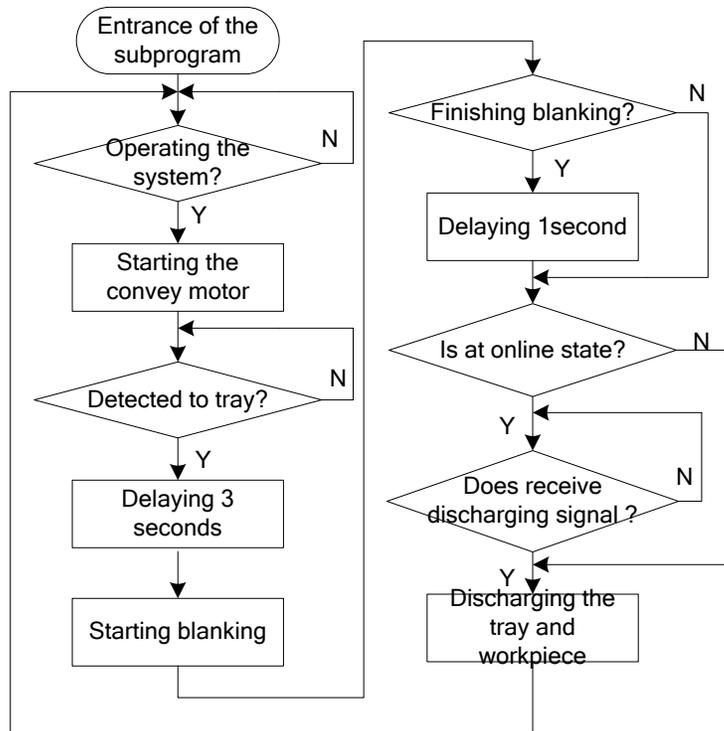
No.	Q0.2	Q0.3	Q0.4	Q0.5	Q0.6	Q0.7	Q1.3	Q1.4	Q1.5	Fault-control Relay
1	Y	N	N	N	N	N	Y	N	N	L-KA1
2	N	Y	N	N	N	N	Y	N	N	L-KA2
3	N	N	Y	N	N	N	Y	N	N	L-KA3
4	N	N	N	Y	N	N	Y	N	N	L-KA4
5	N	N	N	N	Y	N	Y	N	N	L-KA5
6	N	N	N	N	N	Y	Y	N	N	L-KA6
7	Y	N	N	N	N	N	N	Y	N	L-KA7
8	N	Y	N	N	N	N	N	Y	N	L-KA8
9	N	N	Y	N	N	N	N	Y	N	L-KA9
10	N	N	N	Y	N	N	N	Y	N	L-KA10
11	N	N	N	N	Y	N	N	Y	N	L-KA11
12	N	N	N	N	N	Y	N	Y	N	L-KA12
13	Y	N	N	N	N	N	N	N	Y	L-KA13
14	N	Y	N	N	N	N	N	N	Y	L-KA14
15	N	N	Y	N	N	N	N	N	Y	L-KA15
16	N	N	N	Y	N	N	N		Y	L-KA16
17	N	N	N	N	Y	N	N	N	Y	L-KA17

### 3.3 Software Design of the Blanking Station

Designing procedures of the blanking station includes 1 main program and 3 subprograms. The main program is mainly responsible for system initialization and initial state detection. In every scanning circle, it calls operation control subprogram, communication subprogram, alarm subprogram and fault setting subprogram.



**Figure 6. Main Program of the Blanking Station**

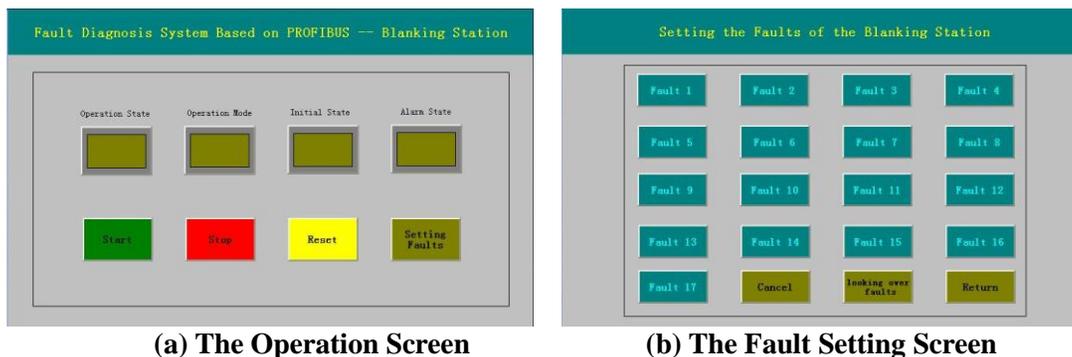


**Figure 7. Operation Control Subprogram of the Blanking Station**

After the main program is energized, initialize the output image register, sequence control relay, relative timer and counter. Then check whether the system is on initial state, which should be based on the following conditions: (1) there is no workpiece in the blanking station; (2) emergency stop button is not pressed; (3) the system is in halted state; (4) operation control subprogram is in the initial state. After these conditions are met, the system enters the ready state, meaning it can be started. After the start, the main program in every scanning circle calls operation control subprogram, communication subprogram, alarm subprogram and fault setting subprogram, as is shown in Figure 6. Operation control subprogram is a process of sequence controlling, responsible for starting the conveyor, checking whether the tray is in place, blanking and discharging the workpiece, as is shown in Figure 7. Alarm subprogram is mainly responsible for sending out signals when abnormal conditions occur, such that time of blanking and discharging exceeds 300 and 60 seconds respectively. Communication subprogram is in charge of sending information instantly to the main station, such as starting, stopping, operating, emergency stopping, and alarming of the blanking station, state of the workpiece, conveying, blanking, discharging and the stand-alone or on-line mode. It also provides data for the main station to monitor the operating condition of slave stations. Fault setting subprogram is used to set fault of the system, with its programming based on Table 2.

### 3.4 The Human-machine Interface Configuration Design of the Blanking Station

The human-machine interface is an important part of the fault diagnosis device for blanking station. It uses true color TPC7062K touch screen developed by Kunluntongtai Company, which is connected to the S7-200 PLC communication port through the RS-485 communication cable for controlling and monitoring of the industrial processes[16]. On one hand, the touch screen can be used to control the running state of the slave station by setting arbitrary faults and issuing different orders like start, reset, stop and emergency stop. On the other hand, the touch screen stores large data including the real-time and historical data and warnings of the slave station etc. The configuration screen in this article is composed of the operation screen, fault setting screen, and looking out fault screen, which is shown in Figure 8.



**Figure 8. The Human-machine Interface configuration screen of the Blanking Station**

#### 4. The PLC Programming of the Master Station

The master station uses STEP7 software for programming. It is a software developed by Siemens for 300/400 series PLC with functions including hardware configuration, parameter setting, communication, start-up, maintenance and diagnosis, *etc.* [17]. The first step of programming is to design the hardware configuration in the STEP7 development environment. Like the on-state hardware configuration, it connects the S7—300 PLC with the EM277 communication module of 7 slave stations via the PROFIBUS bus. Its structure is shown in Figure 9.

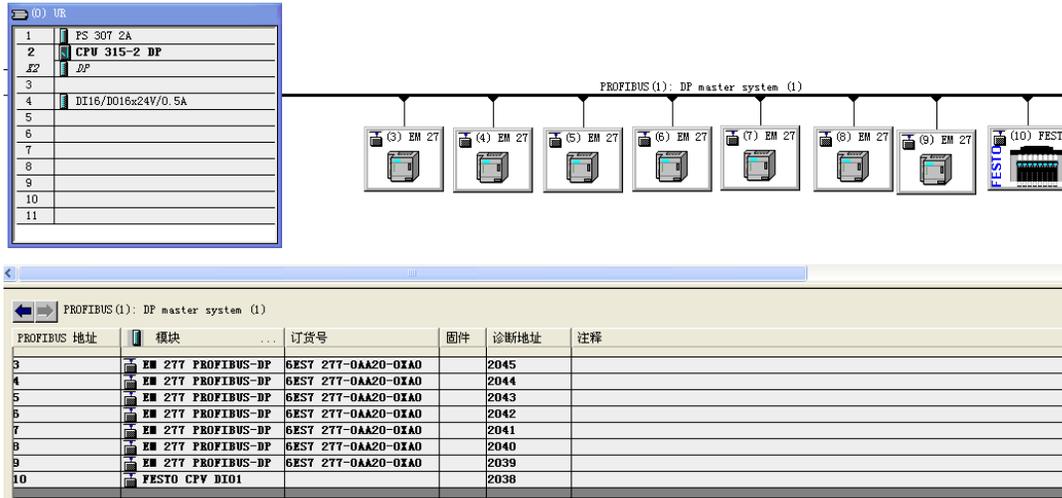
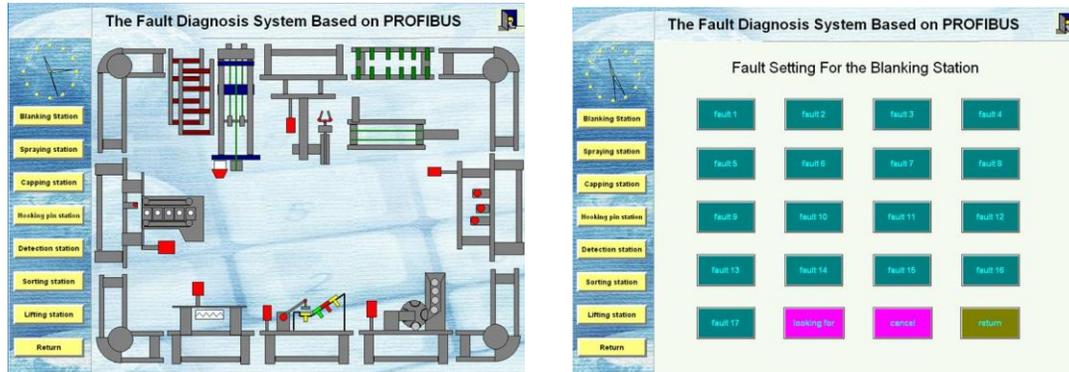


Figure 9. The Hardware Configuration of the System

This design uses the ladder programming. The master station as “the commander” in the organization block OB1 conducts the logic control and analog adjustment of all the 7 slave stations by constantly calling their function blocks (FC1~FC7) for controlling and collecting the field signals.

#### 5. The WINCC Monitoring and Control System on PC

Automatic production line is a complicated control system. In order to get the real-time running data of the slave stations, a high-performance computer is chosen as the host computer with Siemens WINCC V6.0 configuration software as the monitoring software, as it has powerful graphics and thus makes man-machine interaction more friendly and intuitive [18, 19, 20]. The host computer and the slave computer S7-300 and S7-200 (equipped with EM277 module) PLC, via the CP5611 communication card, form a PROFIBUS distributed control system for data communication, including sending and collecting data and monitoring warning information *etc.* After the system starts, the main interface appears. One can see the running state of the whole system on the screen or by pressing different buttons, enter different workstations to know all their fault setting information and dynamic operation. The degree of automation is thus greatly enhanced, as is shown in Figure 10.



(a) The Main Interface (b) The Fault Setting Interface of the Blanking Station

Figure 10. The WINCC Monitoring and Control Screen

## 6. Conclusion

Based on a simulated YL—221 automatic production line, 7 slave stations are transformed according to actual teaching needs. This article introduces the fault setting, hardware design of diagnostic devices, PLC programming and human-machine interface configuration design in the case of blanking station. To make the host computer monitor all the defaults and other data in the slave stations, a distributed control system based on PROFIBUS has been built, which is composed of one master station and 7 slave stations. The PLC hardware configuration and software programming has also been designed for the master station. Combined with WINCC 6.0 software, it can monitor the real-time data and set the defaults of the slave stations.

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