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Research Article

Research on the Simulation of Chemical Reactors Utilizing the PCS7 Platform

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ABSTRACT

The rapid development of industrial control and its systems since the 1960s has been mainly due to the remarkable progress of key process control theories, which are increasingly used in the field of science and technology. Often, there are multiple potential risks in a factory environment, so people tend to use remote and precise control methods. This study using PCS7 remote control software to simulate the chemical reactor process, and through the PID adjustment to ensure the rationality of the results of simulation and accuracy.

1. Introduction

The normal functioning of human society depends on the support of chemical reactions, which are carried out in special containers called chemical reactors. These devices play a vital role in many fields such as chemical, pharmaceutical and energy, and are designed to ensure efficient production while producing quality products.

Although the operating environment of chemical reactors may contain a variety of hazardous substances that pose risks to human health and the ecological environment, with the advancement of technology, we have been able to reduce direct contact through remote control technology, thus ensuring operational safety. This control method not only improves the safety of operation, but also makes the control of the reaction process more accurate.

In this study, PLC-SIM is used as the simulation controller, and the remote control process of chemical reactor is simulated by PCS7 software. This paper first introduces the architecture and operation interface of PCS7 software in chemical reactor simulation, and then uses CFC and SFC modules to build a simulation model and realize the automatic control of the reactor. By adjusting the PID control strategy, we optimize the performance of the simulation system and ensure the accuracy and reliability of the simulation results. Finally, we show the change of key parameters in the simulation process, which provides an intuitive reference for remote control of chemical reactors.

2. PCS7 Project Basic Framework

In most industrial automation projects, common system components include ES (engineer station), OS (operator station), AS (automatic station), and the communication bus between them. Each of these sites has a unique set of tasks and functions, as shown in Fig. 1.

In simple terms [1], the ES station usually acts AS the central node for project configuration and monitoring, the OS station provides real-time data display and user interaction interface, and the AS station is directly connected to the production process and executes specific control logic. In addition, the communication bus acts as a link for information transmission, ensuring data

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synchronization and instruction transmission between stations. This structural design not only improves the reliability and flexibility of the system, but also facilitates remote monitoring and fault diagnosis, thus optimizing the operation efficiency and maintenance management of the entire project.

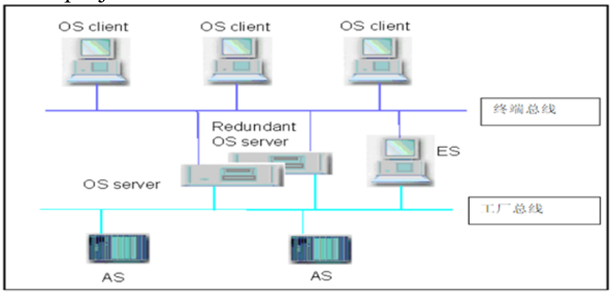


Fig. 1 PCS7 framework

2.1. Engineer station

The engineer station (ES station) has the core function of creating and modifying project files, but also coordinates the data exchange and communication between the automation station (AS station) and the operator station (OS station). Under normal circumstances, the configuration of ES station is realized through SIMATIC Manager software, which is mainly divided into two key steps: The first is the configuration of automation station, which involves the control logic and hardware Settings; The second is the configuration of the operator station, which is related to the user interface and data presentation.

For the configuration of automation stations, it covers multiple levels of work, including but not limited to the drawing of continuous function diagrams (CFC) and sequential function diagrams (SFC), which are key tools for describing the flow and sequence of operations of industrial processes. In addition, factory-level design is included to ensure that the automation system matches the layout and needs of the entire plant; Hardware configuration, ensure that all hardware devices are correctly set up and work together; And communication network configuration, establish a stable and reliable data transmission path.

In the design of operator stations, the focus is on creating intuitive and easy-to-use process monitoring and operation interfaces that not only present real-time data, but also provide operators with the necessary means of control. At the same time, the operation station is also responsible for the archiving management of data to ensure the safe storage and easy retrieval of historical data. Protocol design is also an important part, which defines the rules and formats of data exchange to ensure compatibility and effective communication between different systems and devices. Through these integrated designs and configurations, the operation station becomes an important hub for monitoring and controlling industrial processes.

2.2. Automation station

The Automation station (AS station) forms the core of the Siemens distributed control system and consists of several key components, including the rack, the power module (PS), the central processing unit (CPU) and the input/output (I/O) module.

In PCS7 systems, the CPU 400 series is widely used, and they are installed in racks (racks). In addition to CPU modules, the rack also contains communication processor (CP) modules, which are specifically responsible for communication tasks with other systems. In addition, some CPU modules are also integrated with communication functions, such as having PROFIBUS DP interfaces or as serial communication modules, thus enabling direct communication with other devices.

The automation station uses fast industrial Ethernet technology to connect to the entire system, ensuring high-speed data transmission and processing. At the same time, the engineer station is connected to the ET200 distributed I/O station through the Profibus-DP fieldbus, which not only improves the flexibility of the system, but also enhances the real-time data acquisition and control. In this way, the engineer station can efficiently monitor and control I/O devices distributed in different geographical locations, enabling precise management of the entire automation process. Note: The "block" in PCS7 is very critical, it is related to the work of the CPU in the software STEP7, the specific utility is shown in Table 1.

Table 1 Utility of blocks

Block	Utility
Tissue block (OB)	The function is responsible for sequentially storing the user's master program and control logic.
System Function Block (SFB) and System Function Call Block (SFC)	These programs and control logic are stored in the S7 CPU to ensure that some built-in retention

	functions can be performed.
Functional Block (FB)	It is used to store custom designed program blocks.
Function call block (FC)	This is a subroutine that consumes no additional memory resources and can be called multiple times.
Background Data block (INSTANCE DB)	Use a function or system function blocks, the system will automatically handle their connection, without manual intervention.
Data block (DB)	The main purpose is to save user-defined data.
System Data Block (SDB)	It is used to hold data related to the hardware configuration.

2.3. Operator station

In industrial control systems, the operator station (OS station) plays an important role in the interaction between the user and the production process, which is usually implemented by computer systems. The design and configuration of these operator stations is done by the engineer station (ES station), so their function and setup is an integral part of the ES station project. In a distributed operating system environment, an operator station can be divided into two basic components.

Operator station server: This component acts AS a hub for data forwarding, transmitting real-time program values to the connected operator station client, and is also responsible for transmitting the display content of the operation interface to the relevant functional modules of the automation station (AS), ensuring real-time monitoring and accurate control of the production process.

Operator station client: The client accesses the data on the server through the data connection established with the server, so that the operator can monitor the process and perform necessary control operations on the local or remote interface.

The design of operator stations focuses on the following aspects, such as user interface design, functional integration, field simulation display, data archiving and history. Through these designs, the operator station not only improves the ability to monitor the production process, but also provides the operator with an efficient and intuitive work platform, thereby improving the operational efficiency and reliability of the entire industrial automation system.

2.4. Factory bus and terminal bus

Automated communication in factories depends on a stable and efficient network infrastructure. In this context, industrial Ethernet came into being, which follows the 802.3 standard formulated by the International Electrotechnical Commission (IEC) and becomes the key technology to achieve factory automation communication. This kind of network technology is often used as the transmission medium in the construction of network architecture, and is favored for its high stability and anti-interference.

Industrial Ethernet not only ensures a stable connection between the factory bus and the terminal bus, but also promotes seamless docking and data exchange between different industrial communication protocols. For large-scale industrial environments, especially those with strict requirements for real-time and data transmission speed, the PCS7 system provides a high-speed and reliable communication solution by integrating industrial Ethernet technology. The system, combined with advanced fiber optic connectivity, marks a major advance in communication technology for industrial automation. The system adopts high-speed optical interconnection equipment, which not only improves the data transmission rate, but also ensures the security and reliability of communication. With this technology, the PCS7 achieves data transfer rates of up to 1Gbps, meeting the demand for high-speed communications in industrial environments.

In addition, the communication architecture of the PCS7 system supports a variety of transmission media, including industrial twisted pair (ITP) and optical cable (FOC), providing users with flexible network cabling options. This diversity enables PCS7 to adapt to different industrial site conditions, whether in environments with large electromagnetic interference or scenarios requiring long-distance transmission, ensuring the stability and efficiency of communication. By combining these technologies, PCS7 provides a powerful and flexible communication platform for modern industrial automation.

3. Mathematical Modeling and Automatic Operation of the Controlled Object

In PCS7, an engineering application, there are many ways to construct mathematical models.

3.1. CFC block

Continuous function diagram (CFC) is an advanced control strategy, which simulates the dynamic behavior of the controlled object through the construction of function blocks. These functional blocks include not only basic control algorithms such as ratio (P), integration (I) and differentiation (D), but also advanced functions such as delay and arithmetic operations, which have been integrated and pre-programmed in the PCS7 control system.

In the construction of object model, CFC block is used to define the characteristics of the object, and operation block is used to set and solve the relevant mathematical formulas, and jointly complete the mathematical modeling of the controlled object. This approach allows us to accurately model and predict the behavior of objects.

Taking the chemical reactor as an example, by referring to the experimental data and using the CFC module, we have successfully established mathematical models for key parameters such as liquid level, pressure, feed and temperature. These models not only deepen our understanding of the reactor mechanism, but also provide a powerful tool for optimizing control strategies and improving production efficiency.

1. Liquid level objects

Mainly: integral link and inertia link.

$$G(S)=\frac{3.25}{1+5.47S}*\frac{2.13}{0.97S} \qquad (3\text{-}1)$$

2. Objects of stress

Mainly: inertia link and integral link.

$$G(S)=\frac{2.78}{1+5.29S}*\frac{0.91}{5.58S} \qquad (3\text{-}2)$$

3. Feed flow

Mainly: the inertial link of its principal and subordinate reactants.

$$G(S)=\frac{1.87}{1+5.49S} \qquad (3\text{-}3)$$

$$G(S)=\frac{2.39}{1+4.68S} \qquad (3\text{-}4)$$

4. Temperature object

Mainly: the second stage of the lag time [2].

$$G(S)=0.6*\frac{1}{4.29S}*\frac{1}{3.93S} \qquad (3\text{-}5)$$

3.2. SFC block

In the process of running, the simulation system automatically executes the sequence control program, uses SFC to initialize the initial value of the control parameters required by the whole control system, and executes each control loop in turn, which is shown in Fig. 2.

After setting the initial value, each control loop of the control system automatically transitions to the stable operation mode by executing the "END" step. The switch on the operating panel allows the operator to fully control the operating mode, that is, the operator can automatically control according to the preset control target value. This ensures that after parameter initialization, all control loops can smoothly enter the automatic control state, thus realizing the automation and optimization of the process.

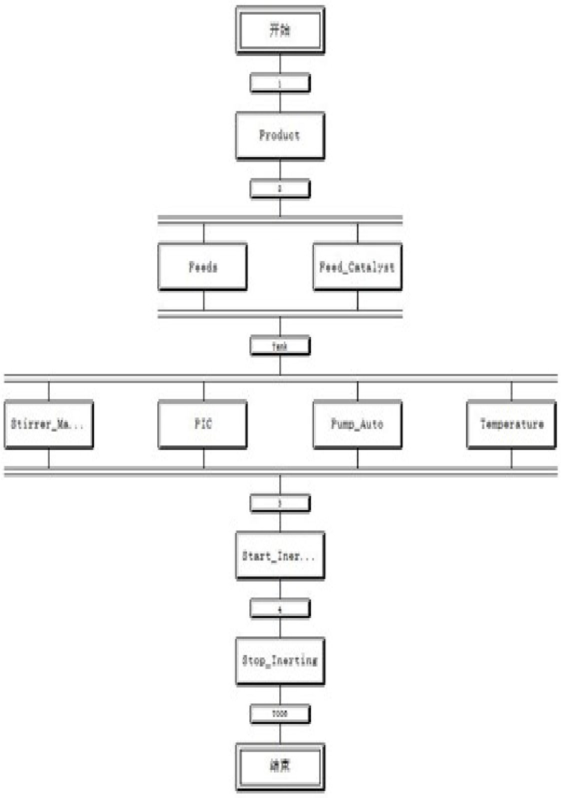


Fig. 2 Simulating the SFC starting sequence

4. Design of Advanced Control Scheme for Simulation System of Chemical Reactor

In the experiment, PID controller in APL library of PCS7 is used to realize the precise control of the reactor. The control process covers several key parts such as feed, pressure, level and temperature.

The feed part is implemented by a simple proportional module, which is divided into two sub-modules: the master module and the slave module. The main module is responsible for controlling the flow of the main reactant, while the flow of the auxiliary reactant is indirectly controlled by the set value of the main module. In addition, the proportional controller provides two PID control loops to independently regulate the catalyst portion of the reactant.

The pressure control part is handled by a separate PID module. After setting the initial setting value, through simulation tests, we ensure that when the actual operating value exceeds the preset range, the exhaust valve will automatically start to release pressure; Conversely, if the operating value is below the set value, the inert gas intake valve will be opened to replenish the pressure until the required process parameters are reached. The whole system adopts proportional-integral-differential control method to achieve accurate feedback control of pressure.

The liquid level control part also adopts an independent PID module to realize. Through these carefully designed control strategies, we are able to ensure that the reactor remains stable and efficient under a variety of operating conditions.

In the temperature part, cascade control is used. The inner ring of cascade control adopts PID module to control the flow rate of hot and cold water valves to realize the control of jacket temperature [3]. The output MV of a PID module is adopted in the outer ring as the given value of the PID controller in the inner ring.

4.1. *Liquid level control scheme*

For the control of liquid level in the loop, a negative feedback closed-loop loop is used, as shown in Fig. 3.

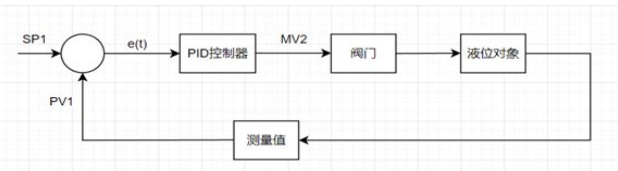


Fig. 3 Pipes and devices

In the automatic control system, the set value SP1 is one of the key parameters of the control process, which determines the target state of the process control. The value of SP1 can be obtained in two ways: one is external input, which usually comes from operator instructions or high-level control system decisions; The second is internal generation, which is usually calculated by the PID controller built into the system based on real-time process data. The PID controller adjusts the system in real time by adjusting its ratio (P), integral (I) and differential (D) parameters to ensure the stability and accuracy of the control process.

In order to achieve the best performance of the PID controller, these parameters need to be precisely tuned. The PID tuner is a specially designed tool that can automatically or manually adjust the PID parameters according to the dynamic characteristics and control requirements of the system to achieve the optimal control effect. The tuning process may include evaluation of system response speed, stability, and overshoot, as well as iterative optimization of PID parameters. In this way, the PID tuner helps ensure that the control system responds quickly and accurately to changes in the setpoint SP1, increasing the efficiency and reliability of the overall system.

The liquid level control model, as shown in Fig. 4, is built using the CFC block of PCS7.

Fig. 4 Liquid level simulation objects

For these four parts, it is usually used in a user-defined closed-loop control system set by users, integrating the input values according to the ladder rule, and output the results.

Fig. 5 shows the pipe diagram and function block of the liquid level control loop. A control loop is provided in the figure. The CFC block in Fig. 6.

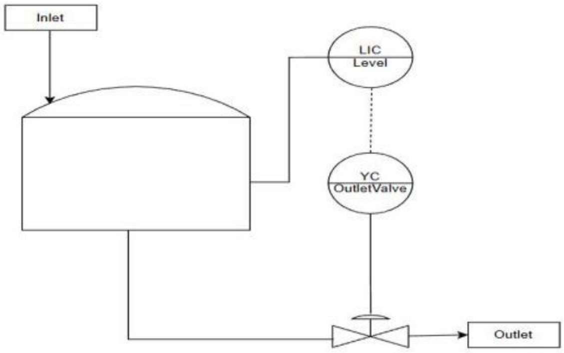


Fig. 5 Pipes and functional blocks of the liquid level control loop

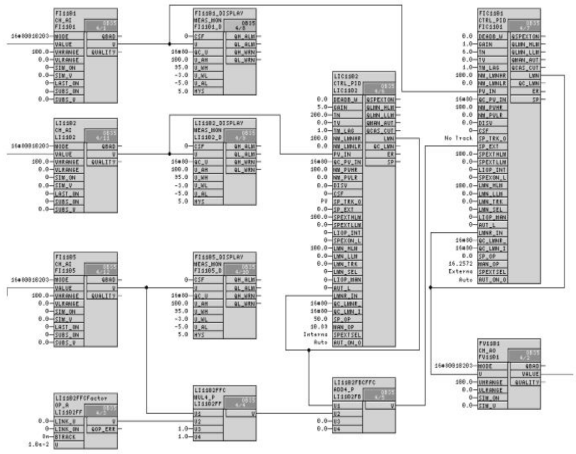


Fig. 6 Connection structure of each CFC block in the liquid level control loop

In addition, for the feed flow, pressure, temperature three parts, also to design the corresponding control scheme. Among them, the feed part is controlled by ratio, the pressure part is controlled by division, and the temperature is controlled by cascade.

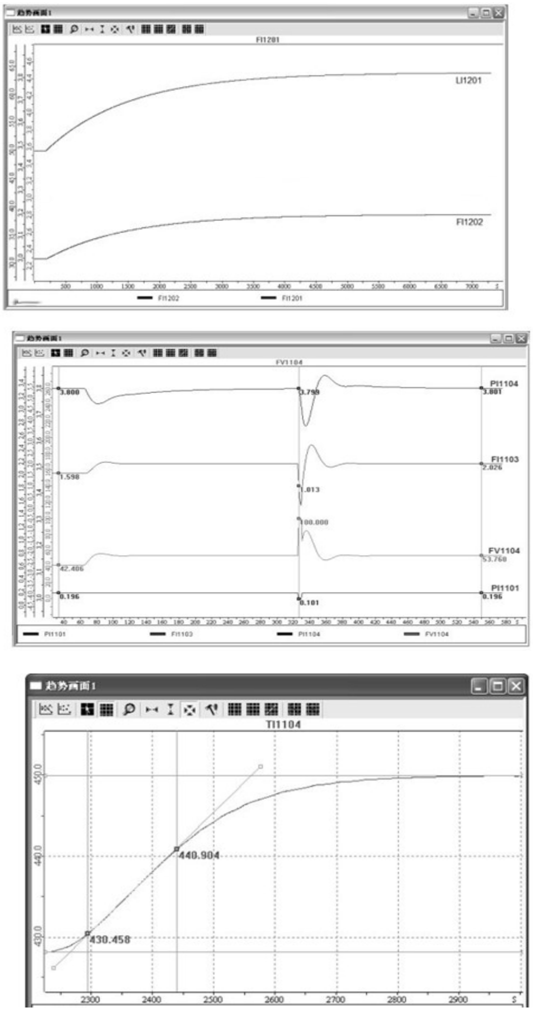
4.2. Tuning of controller PID parameters

In the automatic control system, it is very important to use PID module to control the controlled object accurately. Correct parameter setting is the key to achieve control objectives. The experiment focused on the level control loop and showed the results of 4 control loops.

We developed a PID tuner tool based on PCS7 software, which can collect and record data through the background data block of PID function block. Through the simulation test, we can obtain the ideal control data and apply these data to the controller to achieve the optimal adjustment effect under various control modes.

A notable feature of this tool is its ability to provide a simultaneous real-time data curve display of initial, median, and final values. This intuitive data display not only helps the operator monitor the control process in real time, but also clearly demonstrates the effect of the overall optimization function. With this advanced tool, we can more precisely adjust and optimize the control parameters to ensure the stability and efficiency of the control system, thus achieving our desired control effect.

Below, after proper PID tuning, the appropriate tuning pattern is obtained, which is shown in Fig. 7.



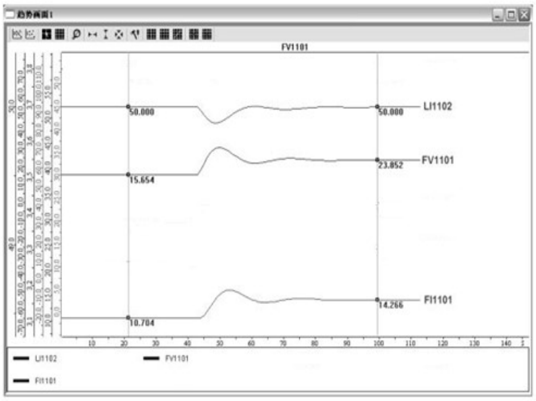


Fig. 7 Setting results of liquid level, flow rate, pressure, and temperature

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Authors Introduction

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He is a first-year master candidate in Tianjin University of Science and Technology.