# Study on Hardware-in-loop Simulation of Twin-screw Extruder Experiment System

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*Abstract*—**In order to facilitate the teaching of industrial processes and experiments on the twin-screw extruder control debugging, and be closer to the actual testing, to reduce the debugging costs and the risk of debugging process, the paper designs a hardware-in-loop simulation of twin-screw extruder experiment system which is closer to scene, low cost and high safety. The system through the establishment of twin-screw extruder's mathematical model on computer to simulate the realistic system and there is hardware practicality in the computer simulation loop. The hardware based on C8051F020 can operate in the simulation loop in real time. In computer software design, we desigh man-machine interface that is intuitive and easy to operate, can reflect twin-screw extruder main operation information vividly. Finally, twin- screw extruder's 3 heater temperature mathematical model and PID incremental control algorithm are presented.**

***Keywords- twin-screw extruder; hardware-in-loop simulation; temperature mathematical model; PID control algorithm***
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## 1 System Overview

Twin-screw extruders is one of the major mechanical equipment in food processing industry, if assemble it to the laboratory for experiment, the price is high, and there is hidden threat against safety when debugging of the equipment. The hardware-in-loop simulation technology[1] is the application of engineering simulation technology which is used very wide. It is a computer simulation loop access some kind of hardware. In this paper, a set of twin-screw extruder system is designed based on the hardware-in-loop simulation technology,this system has two pieces of hardware circuit platform，computer and relative softwares. This study is to establish twin-screw extruder's mathematical model on computer, in terms of its strong operation ability, run simulation algorithm, choose C8051F020 SCM[2] as the core of hardware circuit platform (lower computer) and computer (PC), they connect through serial communication, the lower computer sends the current control information to PC and receives PC's current state information; controller operats control algorithm to control the virtual twin-screw extruder. System principle is shown in Fig. 1.

In Fig. 1, the twin-screw extruder controller operates control algorithm and output control signals as: system on/off signal, automatic/manual signal, lubrication pump run/stop signal, injection valve on/off signal, cooling pump1、2、3 run/stop signal, main motor run/stop signal, main motor speedup signal, main motor deceleration signal,feed motor run/stop signal, feed motor speedup signal , feed motor deceleration signal, cut motor run/stop

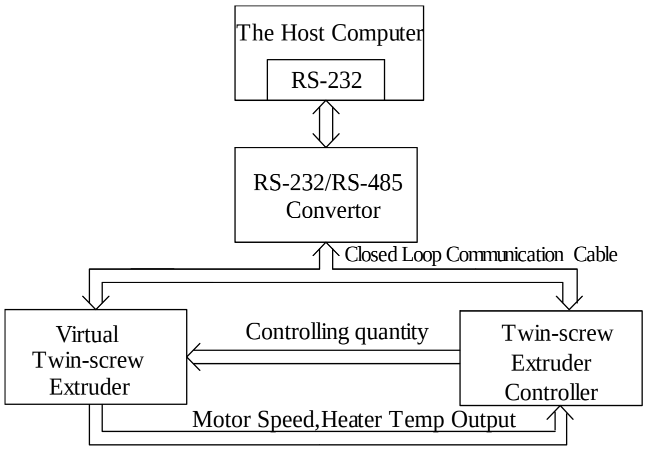


**Figure.1** Twin-screw extruder hardware-in-the-loop simulation system diagram

signal, cut motor speedup signal, cut motor deceleration signal, heater1、2、3 run/stop signal, urgent stop signal,and heater1、2、3 temperature controlled quantity. Virtual twin-screw extruder accepts signals from controller and responds to the control signals, operates related simulation algorithm,gives 3 motor speed output and 3 heater temperature sensor output. PC provides interface to show, set, modify parameters of twin-screw extruder, and reflect twin-screw extruder working condition of animation and various pictures. Twin-screw extruder hardware-in-loop simulation system real product picture as shown in Fig. 2

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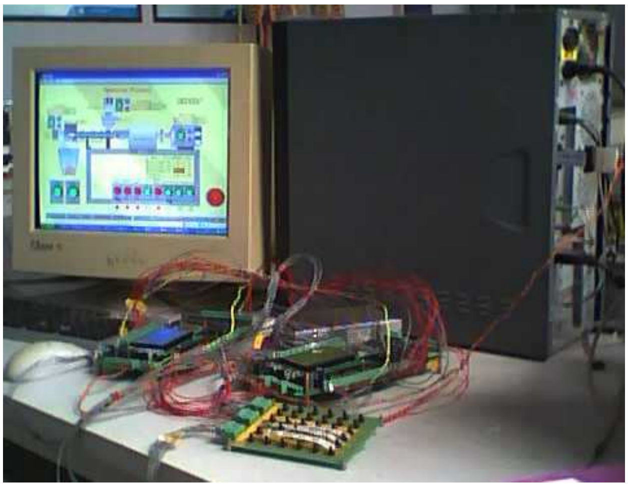

**Figure 2** Twin-screw extruder hardware-in-the-loop simulation system real product picture

## 2 Design and Realization of the System

### 2.1 Design of Hardware Platform

Hardware platform of the system is based on Cygnal's SOC single chip, and choose C8051F020 as the core. This platform consists of several parts as following: switch input and output channels can be used to simulate actual twin-screw extruder 20 buttons or states switch quantity signals; analog input channels are used to simulate twin-screw extruder's three temperature sensors on the heaters, which can acquire temperature of the target; analog output channels are used to simulate controller exporting amount of voltage control to the 3 heaters; keyboard and LCD part are used to set and display the value of a given heater temperature, the value of a given motor speed, automatic/manual work state and other parameters; RS485 communication interface for single-chip part playing the role of communications between PC and lower computer. In order to make the platform with the versatility also designs AC/DC output driver channel, storage, clock, comparator and outside oscillator circuits, etc. The system hardware platform structure is shown in Fig. 3.

### 2.2 Software Design

The characteristics of the experimental system mainly concentrated in the software, including mathematical model of virtual twin-screw extruder, system communications, a lively man-machine interface, control procedures,control algorithm. The software of the system as follows:make use of Kingview 6.5.1[3] to develop man-machine monitorial interface;found communications between PC and the lower computer through the VB programming, the lower computers' data processing and display are on PC through the VB programming, too;the lower computer's software used the compiler environment IDE, Keil c.The communication flow chart is shown in Fig. 4. Communication between KingView and VB through the DDE to achieve, VB and the C8051F020 MCU through serial interface to communicate.

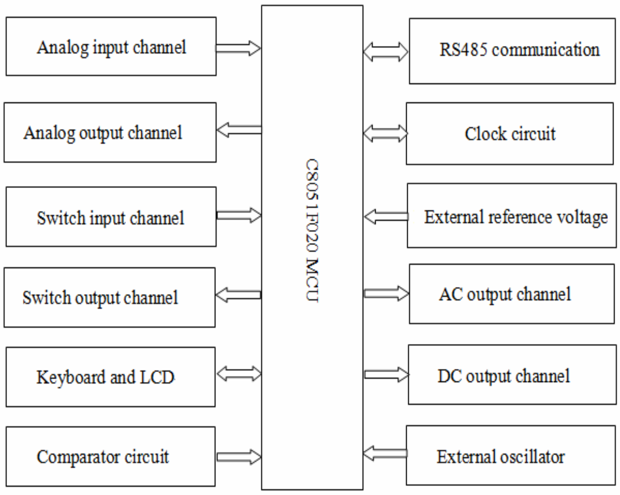


**Figure 3** The structure of hardware platform

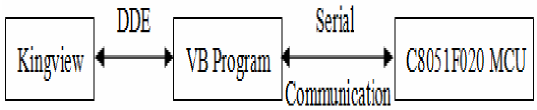


**Figure 4** Flow chart of system communication

1) Kingview software programming

Configuration software, also called monitoring configuration software (SCADA, Supervisory Control and Data Acquisition Data Acquisition and monitoring Control), refers to some special software of Data Acquisition and Control, which is a software platform and development environment that is of the primary monitoring layer in the automatic control system. SCADA is a general level of software tool,using flexible configuration mode, providing users rapid construction industrial automatic control system with monitoring function. Choose 6.5.1 Kingview to develop man-machine interface, the interface consists of curves, forms and animation that response the function state of the real equipment form and reaction equipment operation status of animation,they are: the operating parameters set and the operation of the screen, machine running screen, real-time curve of heater temperature, history curve of heater temperature, real-time curve of the pressure, history curve of the pressure, real-time curves of motor speed, history curves of motor speed, alarm screen. When the monitoring system runs, the various screen images can make use of the corresponding button in the switch under the touchview. Virtual twin-screw extruder running animation as shown in Fig. 5.

2)VB program

Because of characteristics of the visual programming VB[4], we can use it to rehabilitate various parameters from controller on CRT, such as : the main motor speed settings,

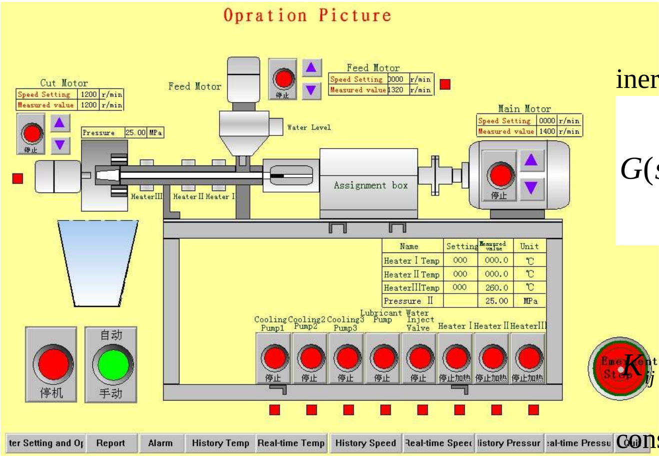


**Figure 5** Virtual twin-screw extruder running animation

feed motor speed settings, cutting motor speed settings, heater1、heater 2、heater 3 temperature set value, the proportional gain, integral time constant, derivative time constant, the current measured temperature of heater 1、heater 2 、heater 3, the current measured speed value of main motor, the current measured speed value of feed motor, the current measured value of cutting motor, sampling period, and so on.

3)The lower computer program

Twin-screw extruder controller has two work mode: manual mode and automatic mode. Manual work mode, the functions is: the lubrication pump start / stop, the heater start / stop, the motor start / stop、accelerate、decelerate, cooling pump start / stop, injection valve on / off, need to switch the keyboard by pressing the corresponding key to achieve. The shortcomings of the manual mode is that can

not control in closed--loop, and it belongs to the open- -loop control, unless it was interfered by people, or else some of the implementing agencies will not change the state of their old campaign.While in the automatic work mode, the controller of acquires real-time state information of the implementation agencies, through the port output corresponding signal to controlled-object, all the work is automatically finished, without manual intervention

Controlled-object is a virtual twin-screw extruder, including one lubrication pump, three heaters, three motors, one cooling pump, one injection valve, etc. Note. It needs to receive the control signal from controller output before running the campaign of its own model program

# 3 Heater Temprature Model 、Control and Simulation

## 3.1 Mathematical Temperature Model of the Heater

Regard the twin-screw extruder heaters as the inertia ratio tache[5], the transfer matrix is：

$$G(s)=\begin{bmatrix} G_{11}(s) & G_{12}(s) & G_{13}(s) \\ G_{21}(s) & G_{22}(s) & G_{23}(s) \\ G_{31}(s) & G_{32}(s) & G_{33}(s) \end{bmatrix} \quad (1)$$

In (1), $G_{ij}(s)=\dfrac{K_{ij}}{T_{ij}S+1}$，i=1、2、3，j=1、2、3，$K_{ij}$ is the ratio of coefficient, $T_{ij}$ is the inertial time constant, $G_{11}(s)$ , $G_{22}(s)$ , $G_{33}(s)$ are respectively the transfer function of the heater1、heater2、 heater3, $G_{ij}(s)\ (i \neq j)$ is heater i of heater j coupling transfer function. Taking the symmetry into account: $G_{ij}(s)=G_{ji}(s)$ .

Using the bilinear transformation[6] ,get heater 1, 2, 3 in Z domain output columns below：

$$\begin{bmatrix} Y_1(Z) \\ Y_2(Z) \\ Y_3(Z) \end{bmatrix}=\begin{bmatrix} G_{11}(Z) & G_{12}(Z) & G_{13}(Z) \\ G_{21}(Z) & G_{22}(Z) & G_{23}(Z) \\ G_{31}(Z) & G_{32}(Z) & G_{33}(Z) \end{bmatrix}\begin{bmatrix} U_1(Z) \\ U_2(Z) \\ U_3(Z) \end{bmatrix} \quad (2)$$

In (2), $U_1(z)$ 、$U2(z)$ 、$U_3(z)$ respectively represent to the control volume of output from the temperature controller, $Y_1(z)$ 、$Y_2(z)$ 、$Y_3(z)$ respect -ively represent heater1’s, heater 2’s, heater 3's output. Right after finish doing Z inverse transform ,heater1’s、heater 2’s、heater 3’s difference equation formula $Y_1(k)$ 、$Y_2(k)$ 、$Y_3(k)$ in the time domain is available. Among them, $Y_1(k)$ 、$Y_2(k)$ 、$Y_3(k)$ respectively represent heater1’s、heater 2’s、heater 3’s value of the temperature output at k times.

## 3.2 Heater Temperature Control Algorithm

Virtual twin-screw extruder heater 1、2、3 temperature control algorithm are same .Heater 1 is to be described as an example.

When the heater start/stop flag for the 1, running heater1 temperature control algorithm, or, the control volume of heater 1 is set to 0.

Heater1 temperature control algorithm use PID control algorithm. PID control algorithm has such advantages: the principle simple, easy to achieve, no static error, etc, can meet the needs of majority of industrial processes. After years of development and application, development from analogue controller to digital controller, performance improved constantly. Digital incremental PID control algorithm[8] as follows:

$$\Delta u(k)=K_P[e(k)-e(k-1)]+K_I e(k)+K_D[e(k)-2e(k-1)+e(k-2)] \quad (3)$$

In (3), $K_P$ is the proportional constant, $K_I$ is the integral time constant , $K_D$ is the differential time constant, $e(k), e(k-1), e(k-2)$ are respectively different values of bias at all times, and there：

$$e(k)=T_{set}-t(k) \quad (4)$$

In the formula，$T_{set}$ is heater1 temperature setting, $t(k)$ is heater 1 temperature measured value for the k moment.

The volume control $u(k)$ at k moment as following type:

$$u(k)=u(k-1)+\Delta u(k) \quad (5)$$

### 3.3 Heater Temperature Simulation Result

Under PID algorithm control, setting arbitrary temperature as long as to the extent of 300 ºC can be accurately controlled to setted-temperature. Figure 6 shows, three heater (1, 2, and 3) respectively sets 260,240, 220 degree Centigrade, after the adjust-time and the rise-time ,it can be in an stable setting value. Rise time and adjust time can be shorten by adjusting the PID coefficient or coupled-time constant of heater model.Because three heaters couple each other,the heater temperature could surpass the maximum amount of size, more than 300 ºC.But with PID control algorithm, heater temperature can reach the setted--control target. Fig. 6 is the result in the configuration software

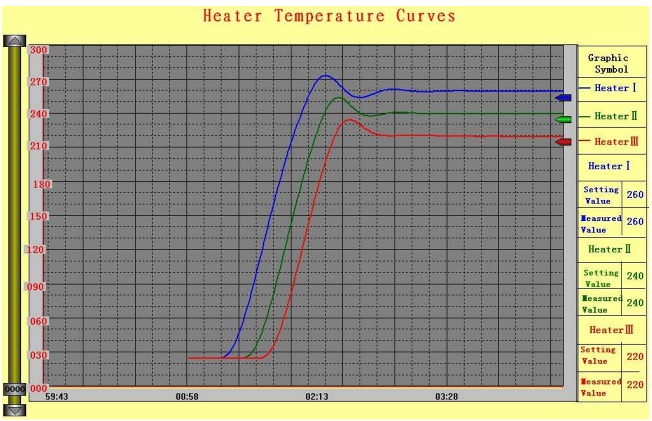


Figure 6 Heater temp curves with PID algorithm control

## 4 Conclusion and Outlook

In this paper, in virtue of hardware-in-loop simulation technology, we design a set of twin-screw extruder experiment system. The physical parts of this system are C8051F020 SCM hardware circuit platform and a computer. The software parts are configuration software, Windows advanced VB and C language. Then three heater temperature coupling model and temperature control algorithm are studied, through actual debugging, simulation and control effect are good ,can achieve actual twin-screw extruder experimental simulation.The experimental system with high simulation quality of actual twin-screw extruder, low cost and good security features, very suitable for electronic technology and computer control technology of experimental teaching.

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