ECU Hardware-in-Loop Simulation System Design for Gas Engine based on Virtual Instruments

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Abstract **- Under the severe situation of energy and environment, developing gas cars is an important way of energy saving and emission reduction at present. A new real-time simulation system using the Matlab/Simulink and virtual instruments is proposed. The software and hardware design is realized in detail based on the system overall design. Finally, the off-line simulation and the real-time simulation have been validated that the simulation system is reasonable and feasible. Moreover, the calibration equipment we have developed is connected to the simulation system, which can do better in the real-time simulation system development and ECU real-time simulation.**

Keywords - ECU; hardware-in-loop; gas engine; virtual instrument.

I. PRINCIPLE OF SIMULATION

Research on the test platform for ECU hardware-in-loop simulation of electronic fuel injection engine was given by Yubo Zhang[1]. Hardware-in-Loop simulation method for electronic stability program based on virtual integrated technology was proposed by Lifu Li[2] and J.H.SONG gave vehicle hardware system[3]. The hardware and software development of electronic control unit in the automotive engine was given by Zhen Zhang[4]. The basic theory of automotive electronic fuel injection system was proposed by He Huang[5]. The gasoline engine ECU simulation test system based on virtual instrument technology was proposed by Weibin Wu[6]. FPGA realization of energy detection based on simulation system was proposed by Kelai Wang[7]. Different types of Hardware-In-the-Loop simulation for electric drives were proposed by A. Bouscayrol[8]. Mean value modelling of spark ignition engines was proposed by E. Hendricks[9].Design of vehicle ECU hardware-in-loop simulation system for electronically controlled engine was proposed by Jianwen Li[10]. Hardware-in-loop simulation system mainly realizes creation of simulation model of the controlled object, the control of simulation model, parameter online change, real time data display and offline analysis and real-time operation of the simulation model.

The goal of the whole system is to provide a virtual controlled object and simulation environment for ECU in-loop simulation test conveniently and provide the better service for the development of ECU. The simulation system makes full use of Matlab/Simulink and LABVEIW for offline simulation and real-time simulation on the gas engine. LabVIEW SIT is used for offline simulation of gas engine model as shown in figure 1. The Host Computer is host machine is used to run the LabVIEW software. Execution Host is real-time target machine used to run engine model of Matlab/Simulink and the two computers communicate with each other via TCP/IP network. The Host Computer and Execution Host can be the same machine. The Host Computer is used to control and run the LabVIEW program and Matlab/Simulink and the output results of the engine running is showed on the LabVIEW front panel. When running the main program VI of host machine, LabVIEW program block diagram initializes the simulation, and defines the relation between parameter control/display control and engine model/signal. When changing the front panel, the following operations are carried out.

A: LabVIEW Host VI sends modified parameter value of the LabVIEW front panel to SIT Server via the TCP/IP.

B: SIT Server sends this value to engine model.

C: Engine model uses these parameter values to perform the corresponding module to update the model output value.

D: SIT Server detects model output signal connected with LabVIEW model.

E: SIT Server sends output signal value to Host VI, update the value of front panel.

Real time simulation using LabVIEW SIT is shown in figure 2. Engine model complete real-time simulation on RT target. When running the Host VI, SIT downloads Model DLL and Driver VI to RT Target and starts SIT server on the RT Target. Driver VI initializes Model DLL. When changing control values of the front panel, the following operations are carried out in turn.

A: LabVIEW Host VI sends the modified parameter value of LabVIEW front panel to SIT Server via TCP/IP.

B: Driver VI sends the value to the Model DLL.

C: Model DLL uses these parameter values to perform the model code to update the model output signal value.

D: Driver VI DLL detects output signal of Model DLL.

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E: SIT Server sends output signal value to the Host VI to update the value of the front panel.

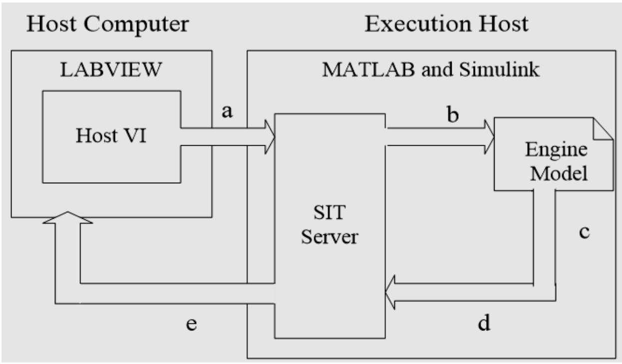

Fig. 1 Offline simulation of gas engine model.

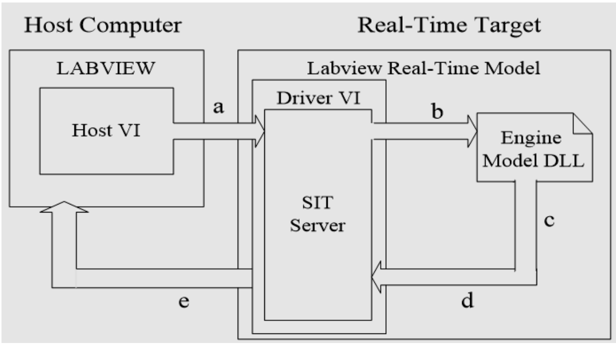

Fig. 2 Real time simulation using LabVIEW SIT.

II. ENGINE MODELLING

This article carries out hardware-in-loop simulation for CNG engine ECU and the electronic control engine model is built based on average model. Simulink provides a graphical interactive environment, which only needs to use the mouse to drag to quickly establish a system block diagram model and does not need to write a lot of code. It can combines with MATLAB, which makes users can take advantage of rich resources. In addition, Simulink has been widely acknowledged in the field of system simulation and many dedicated simulation system is supported by Simulink model, which is very helpful for code reuse and transplantation. Using Simulink can be convenient for the simulation analysis and prototype design of the control system. This paper establishes a gas engine average model in Simulink environment. This model mainly has three subsystems, the intake manifold subsystem, gas subsystem and power output subsystem. Simulation model of gas engine is shown in figure 3. Input signal of the model and output signal of model are shown in table 1 and table 2 respectively.

Modeling method is the combination of theoretical modeling and experiment. Core part includes the three subsystems of engine and the turbocharger adopts theoretical modeling, auxiliary link hardware simulation interface circuit is modelled based on the experimental data. After model is set up, offline simulation and real-time online simulation must be carried out to verify the accuracy of the model.

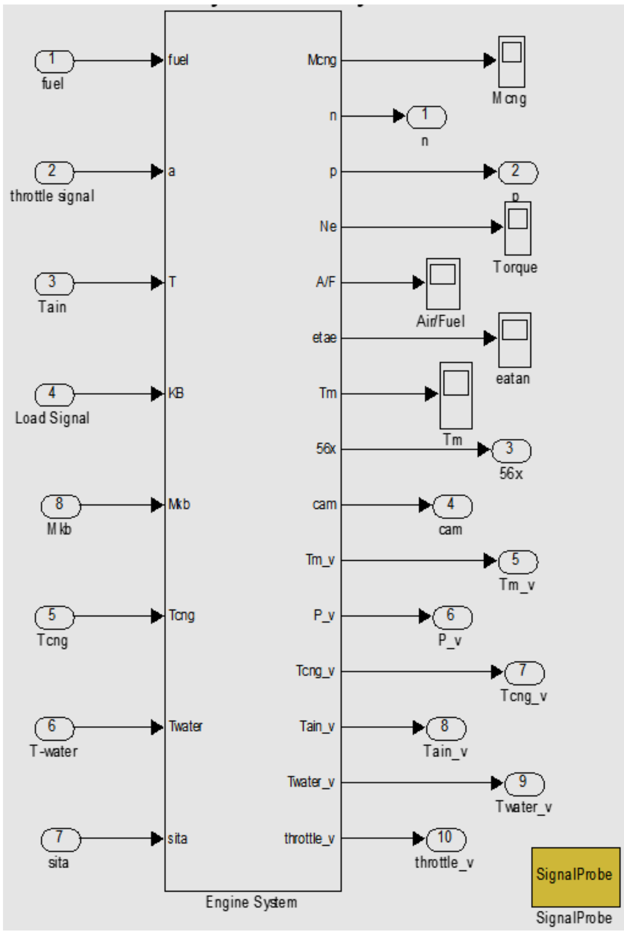

Fig. 3 Simulation model of gas engine.

TABLE. 1 INPUT SIGNAL OF THE MODEL

	symbol	meaning	unit
Input of model	fuel	Gas injection pulse width	Ms
	sita	The ignition advance angle	angle
	a	The throttle opening	V
	T	Inlet temperature	V
	kB	Load power factor	
	Mkb	Load power	Kw
	Tcng	CNG temperature	V
	Twater	Cooling water temperature	V
	Mcng	Gas injection quantity	Kg/S

TABLE. 2 OUTPUT SIGNAL OF MODEL

	symbol	meaning	unit
Input of model	n	Speed	pulse
	p	intake manifold pressure	V
	Ne	output torque	N m
	A/F	Air-fuel ratio	V
	cam	camshaft signal	pulse
	Tm	average exhaust temperature	V

III. HARDWARE DESIGN OF REAL TIME SIMULATION SYSTEM

The simulation device mainly has upper monitor machine, TCP/IP network cable, PXI-8196 real-time control system, PXI-7833R, ECU, the electric control system testing device and calibration device.

Upper monitor machine mainly realizes creation of engine simulation model, code generation, LabVIEW call of model, real-time control of model and upload of real-time simulation data. Communication between the upper control system and real-time monitoring machine is completed by TCP/IP network.

For the lower real-time system, we choose NI PXI-8196 control system. NI PXI-8196 embedded computer is a high-performance PXI/Compact compatible system controller, which adopts PXI 2.0GHz Pentium M760 embedded controller, the standard configuration 512 MB dual-channel DDR2 RAM (maximum support 2GB), 10/100/1000 BaseTX gigabit Ethernet, integrated hard drive, GPIB, serial port and other peripheral equipment. Figure 3 shows NI PXI-8195/8196 peripheral interface.

PXI-7833R board has the following characteristics.

(1)Onboard FPGA chip, use LabVIEW FPGA programmable module.

(2)user-defined trigger, timing, 25 ns resolution.

(3)8 number of analog input ports, independent sampling rate of 750 KHz, 16-bit resolution.

(4)eight number of analog outputs, independent update rate of 1 MHz, 16-bit resolution.

(5) 60 road of configurable digital lines, as the input, output, counter and logic customization, rate of 40 MHz.

(6)high data flow direct memory access (DMA) channel.

Considering that speed signal and camshaft signal is realized by FPGA, LabVIEW calls the FPGA program downloaded to the FPGA to run the program, using LabVIEW SIT for model call also uses the FPGA programming and confliction between model code download and program download of camshaft signal, two FPGA modules are used. A board is used for input and output of camshaft and speed signal, and another piece of board is used for input and output of other analog signal.

Electric control system tester is mainly used for signal connection between ECU and calibration device. Calibration device is mainly used to complete ECU calibration, but also can display data in ECU.

IV. SOFTWARE DESIGN OF REAL TIME SIMULATION SYSTEM

As mentioned above, the upper monitoring machine as a master machine of simulation system of is drive hub to control the operation of the system. Manipulator can effectively manage the whole simulation process through the human-computer interaction interface, observes the simulation results and call the other application software for various data processing work. Therefore, the monitoring system design using PC has certain requirement. It has strong modeling ability of the simulation object, friendly man-machine interface, easy maintenance and function extension. The software can operate on the underlying hardware and has a good portability. Therefore we choose Windows as the PC monitor interface development environment. At the same time Simulink is used for modelling and LabVIEW with good human-machine interface is used for simulation monitoring. The upper monitoring software design is as follows.

In the realization of the upper machine, two kinds of software can realize the function of the simulation, as shown in figure 5. One software models the engine in the Matlab/Simulink and then selects the model simulation time and simulation step size. It uses RTW for code generation. It can carry out digital off-line simulation of engine model under the environment of Matlab/Simulink to prove the validity of the model. Although Matlab/Simulink has powerful numerical computation and modeling capabilities, but it lacks in a friendly man-machine interface and hardware platform. LabVIEW provides a good man-machine interface, so LabVIEW SIT is used to call Matlab/Simulink model and realizes ECU hardware-in-loop simulation.

Peripheral	External Connector	Description	PXI- 8195/8196 Models
Video	VGA (15-pin DSUB)	Intel Extreme Graphics controller	All
Serial	COM1 (9-pin DSUB)	16550 RS-232 serial port	All
Ethernet	LAN (RJ45)	10/100/1000 Ethernet connection	All
Parallel	Parallel Port (36-pin champ)	IEEE 1284	All
USB	USB 4-pin Series A stacked receptacle	USB 2.0 capable	All
PXI trigger	Trigger (SMB)	Routing PXI triggers to or from the backplane trigger bus	All
GPIB device	GPIB (25-pin Micro D)	General-Purpose Interface Bus, IEEE 488.2	8196 only
ExpressCard/34 module	ExpressCard/34 slot	ExpressCard/34 Expansion	8196 only

Fig. 4 NI PXI-8195/8196 peripheral interface.

In LabVIEW environment, off-line simulation and real-time simulation can be carried out. In LabVIEW function block, opening the Simulink model can open a good built engine model and can set simulation time and simulation step length. Simulation model control charges pause and stop of the simulation model. Data real-time display can display ECU control signal, output signal of the simulation model and sensor signal value. Data processing and information display can shows detailed simulation information, such as name of simulation model, model storage path, simulation time, IP address of the target machine, and CPU utilization and memory utilization of the target machine.

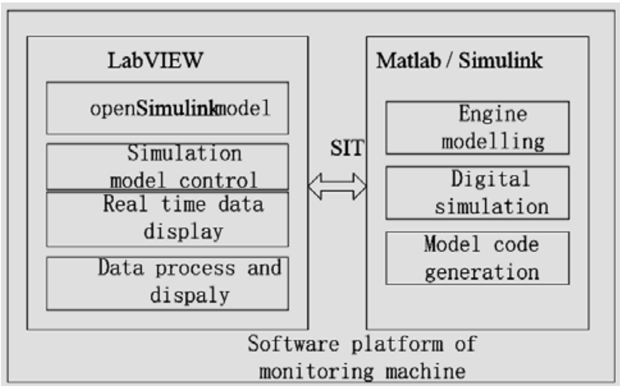

Fig. 5 Software platform structure of upper monitor machine.

The software implementation mainly refers to the implementation of upper machine LabVIEW main program. In the LabVIEW main program, it is mainly divided into two parts, the front panel and program block diagram code. The front panel mainly completes the man-machine interactive manipulation and the main implementation is the realization of program block diagram code. Each operation of front panel will corresponds to implement part of program block diagram. For the realization of the front panel, it mainly refers to module design of the upper machine as shown in figure 6.

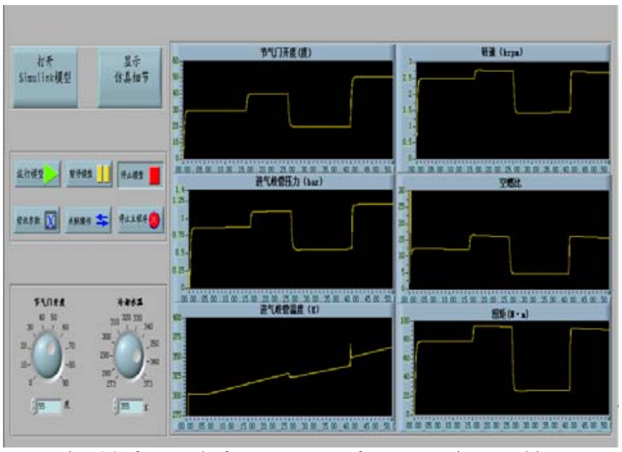

Fig. 6 Software platform structure of upper monitor machine.

Program block diagram code has four main parts: the initialization simulation code, code of setting the parameter values and updating value code of receiving simulation model, code of calling FPGA program. Figure 7 is LabVIEW code implementation. SIT initializes VI to create connection with Simulink. VI initializes connection with TCP/IP of SIT server and establishes a database connection to manage sending and receiving with the Simulink model.

After initialization, there are three threads running in parallel in the internal code of LabVIEW. The main function of three threads is to read the model parameters and the signal value periodically, update the display controls, constantly call the FPGA program code and generate the corresponding periodic serrated square wave signal.

In the first thread, multiple control values are changed. When cooling water temperature value of the LabVIEW front panel changes,LabVIEW program block diagram code deals with this event and sends the value to model code. At last, the value is sent to ECU by analog input interface of I/O board.

The second thread shows the program block diagram reading the value of Simulink model code, and display them on the LabVIEW front panel controls. In the actual engine model offline simulation and hardware real-time simulation, the while loop is used to read engine model output signal value, ECU input value and input value of other sensors, which are displayed on the host machine front panel controls at the same time.

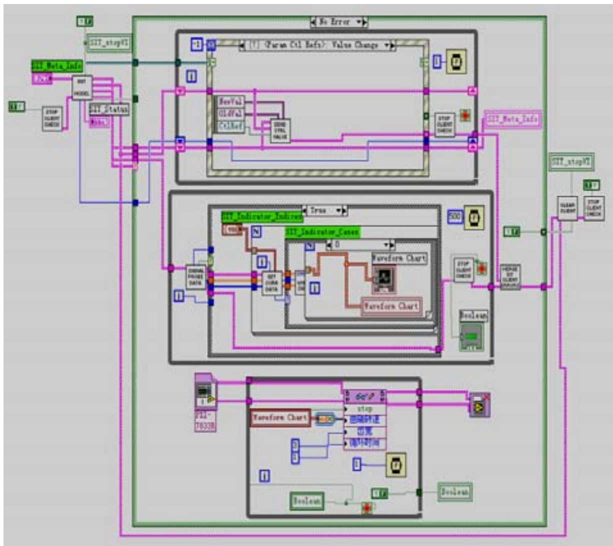

Fig. 7 LabVIEW code implementation of main program

The function of the third thread is to read engine speed value of the Simulink. The value is read into LabVIEW display control from Simulink by the second thread and the display control as a local variable is sent to the third thread. Through the call of FPGA, speed signal and camshaft signal constantly input to digital output of PXI-7833R. LabVIEW main program calling FPGA program code is shown in figure 8. ECU controls the ignition according to the two

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signal. Synchronization relationship between 56x speed signal and camshaft signal is shown in figure 9 and program of phase relationship between speed signal and camshaft signal is shown in figure 10.

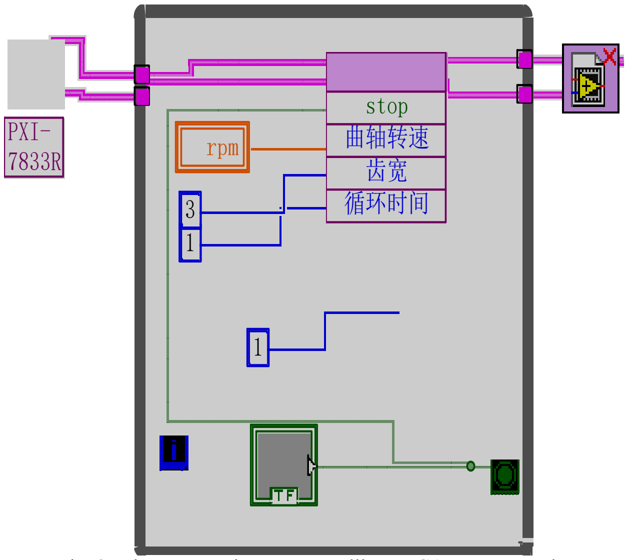

Fig. 8 LabVIEW main program calling FPGA program code.

The key signal of engine model is conversion relationship model of speed signal and camshaft signal. The sensor models mainly involved in the model are intake manifold pressure, gas pressure, Gas cylinder pressure, intake manifold temperature and cooling water temperature sensor.

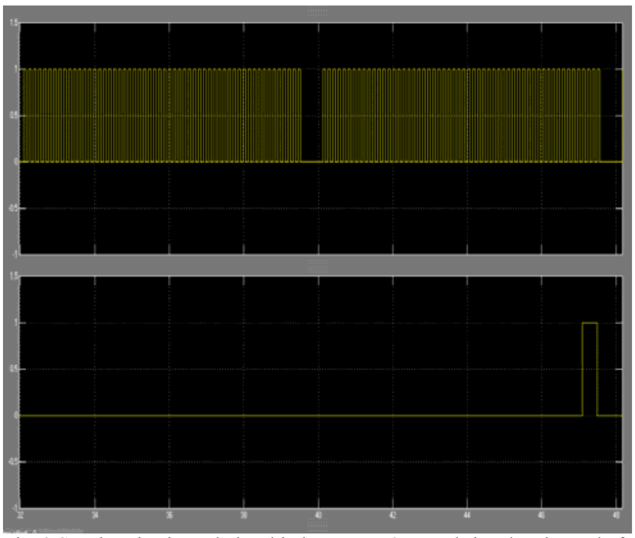
Fig. 9 Synchronization relationship between 56x speed signal and camshaft signal.

Actuator modeling mainly include the gas nozzle modeling and ignition advance angle transformation model. This paper selects 32cc nozzle model. According to the pulse signal from the ECU, firstly the injection duration is calculated, then according to the time, the injection volume is calculated. According to the injection quantity, volume is converted to injection quality as the input parameters of the engine for simulation. Nozzle flow curve is shown in figure 11.

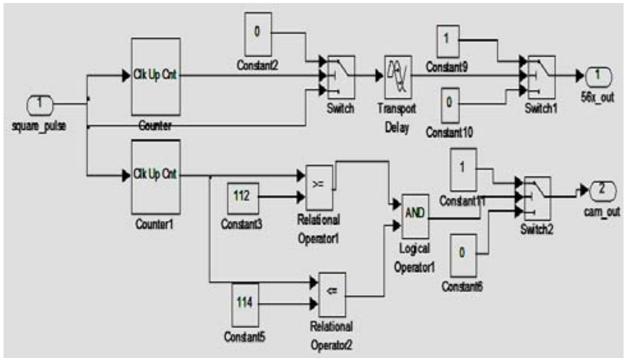

Fig. 10 Program of phase relationship between speed signal and camshaft signal.

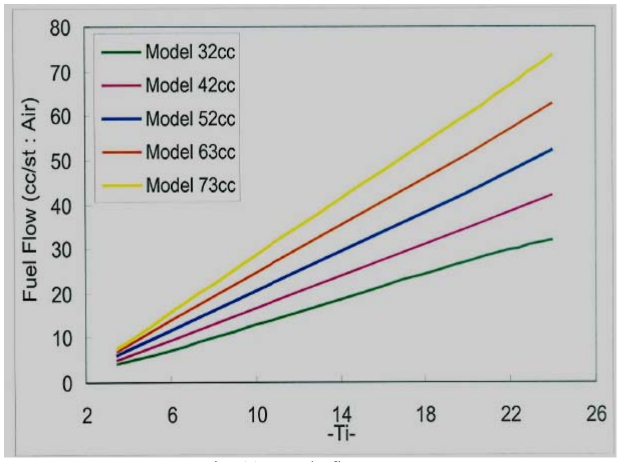

Fig. 11 Nozzle flow curve

V. THE SIMULATION RESULTS OF ECU HARDWARE-IN-LOOP SIMULATION SYSTEM

Real-time simulation model operating curve is shown in figure 12. The model running results of real-time simulation is compared with offline simulation results, and it can be seen that the tendency of the both are consistent. Through debugging of simulation system, the function of real-time simulation system is verified, which has laid a good foundation for further experiment design and research. It also provides a good platform for new ECU control algorithm. After system commissioning test, it is proved that the developed ECU hardware-in-loop simulation system is reliable, has strong practicability and has good expansibility. It can be used for hardware-in-loop simulation of other controllers of the car.

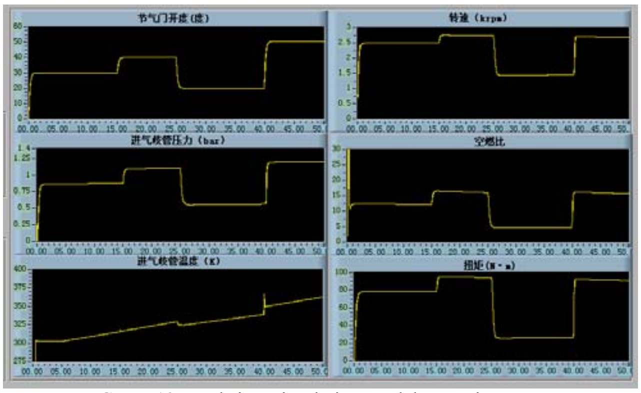

FIGURE12. Real-time simulation model operating curve

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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