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Design and Experimental Study on Digital Speed Control System of a Diesel Generator

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Abstract: This study proposed a kind of digital embedded controller for the diesel generator. Some digital circuit such as single chip microprocessor have been used in the system, therefore it can control the diesel more efficiently and accurately. Based on the theory analysis, a circuit card used in the control system has been developed by means of development tools, such as Altium10, PCB99 and Multisim. Besides, the control program corresponding to PID control algorithm has been used. The experiment results show that the controller is work well in the plateau low-temperature environment and normal environment. We are sure that our embedded controller offers a wide scope of application in the field of digital controllers in the diesel generator industry.

Keywords: Diesel generator, digital embedded controller, PID algorithm

INTRODUCTION

The role of the diesel engine speed controlling system is that the diesel engine can be automatically adjusted to ensure steady operation under a specified speed by adjusting the fuel amount automatically, when the diesel engine loads are changed.

Fuel Supply Quantity is decided by digital controller, while injection timing is decided by the gears of diesel engines. The double closed loop system based on microcontroller has been developed. This digital control system is made up of a regulating unit, an executive device and a measurement unit. The real speed value of diesel engine and some other working condition parameters are measured by the measurement unit. The principle of external control loop is following: The speed error between the real speed value and the goal speed value is computed and processed by the regulating unit, to get an intermediate control signal which is equal to the given fuel rack position. In the inner feedback loop, the regulating unit rectifies the rack position according to the position error which is computed between the given fuel rack position and the real rack position. The injection quantity is adjusted by executive device. Thus the speed of diesel generator has been controlled automatically. The algorithm of the digital speed control system can be seen from Fig. 1.

The College of Power and Energy Engineering has liaise with Shan Xi Diesel Engine Industry Corporation to completes this project. This research want to find out a way to make diesel generator work more steady and economically. Compared with the traditional analog electronics speed control system, digital control system can bring down the cost of fuel and make the generator react faster. The major indications in the control system are transient speed regulation and speed recovery time.

Technical norm: The main target technology indicators as shown intensity (Ma *et al*., 2008):

- Transient speed regulation ≤7%
- Speed recovery time ≤3s
- Steady state speed regulation 0-5%

The system functions as shown:

- Engine speed control
  - Keep the diesel engine speed in a stabilized state when the load is changed
  - Make the real speed value follow the goal speed value by adjusting the fuel amount
- Whole range fuel amount control
- Acceleration rate/deceleration rate (Ac/Dc Rate) and steady state speed regulation is adjustable
- The goal speed value can be changed by changing the state of buttons
- The diesel engine can be stopped by the governing system
- The parameters of control and state can be real-time displayed
- It has alarm function

CONTROL STRATEGY AND PRINCIPLES

A precise dynamic simulation model for the diesel generator is hard to be established because of the power system is a highly nonlinear time varying system. in all working conditions working environment is full of noise and the temperature is range from -40~70°C Only the basic control parameters are not enough with

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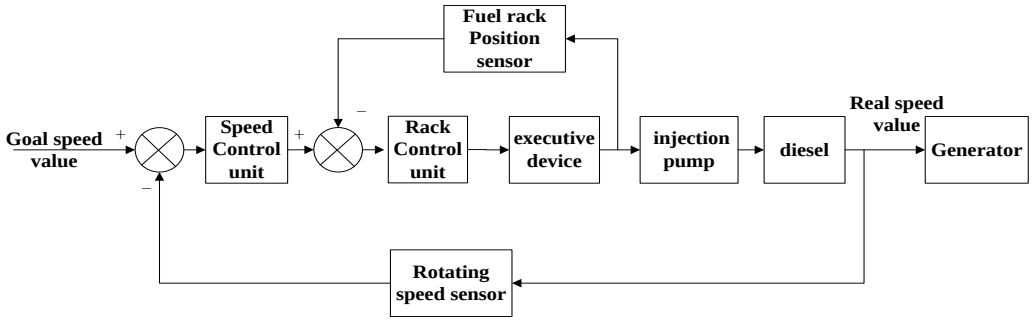

Fig. 1: The block diagram of digital control system

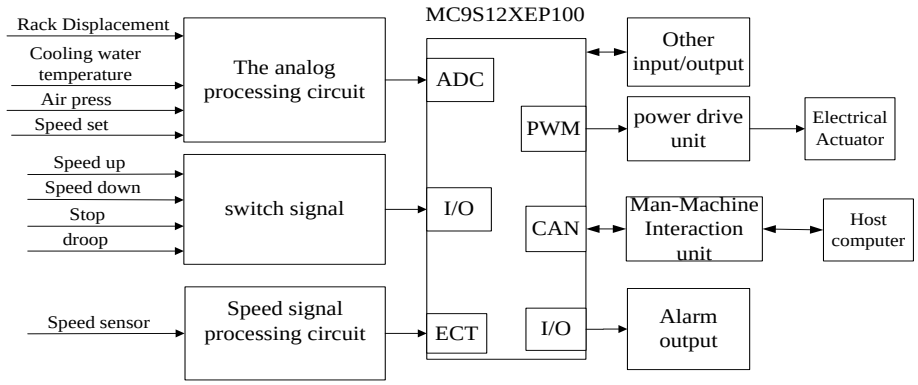

Fig. 2: Entire system block diagram

all the working conditions especially work in the plateau low-temperature environment. To get excellent performance of stable and dynamic state, using non-linear variable gains and dynamic gain adjustment can be obtained under any working conditions. The digital speed controller of diesel generator change the injection quantity by change the rack position so as to keep the diesel engine speed in a stabilized state when the load is changed.

Two methods have been used for real-time adjustment diesel engine control parameters. First, a kind of adjustments has been made using the LCD and three buttons -1 select buttons, 1 up buttons and 1 down button. The controller has a built in user interface. And the second, CAN bus communication protocol has been embedded into the system so we can use the PC to Calibration parameters and analyze data.

Controller hardware design: The hardware part of ECU2-GK controller is mainly made up of the processor MCU, the speed signal conditioning circuits, analog signal conditioning circuitry, switch processing circuit, power driven circuit, man-machine interface and power components.

The MC9S12XEP100 has been selected as the control chip. MC9S12XE family delivers 32-bit performance with all the advantages and efficiencies of a 16-bit MCU (MC9S12XEP100 User's Manual ver1.0, Freescale Semiconductor, Inc., 2006).
The features of the control chip are as follows:

- XGATE co-processor capable for build virtual peripherals and boost the overall performance
- Flexible programmable hardware emulated EEPROM
- System integrity support with the memory protection unit and supervisor/user modes
- S12X CPU at 50 MHz bus speed
- ADC 12-bit resolution and 3 μs conversion time
- Enhance Capture Timer (ECT)
- Pulse Width Modulator (PWM)

The structure of controller is shown in Fig. 2.

A Hall-type sensor is used as speed sensor. When the teeth of the rotor, which is made of magnetic material, alternately get through the gap of the permanent magnet, there will be a variable magnetic field acts on the Hall element (semiconductor material) and then a pulse signal is generated by Hall voltage. The Sine-Like signal is sent into the microcontroller for

countering after being converted by the speed conditioning circuit, so the rotation speed can be detected according to the number of pulses generated.

In the hardware circuit design, the components are used to build the logic circuit, the output signal automatically stops when the speed signal is lost, which is to protect the diesel engine and prevent speeding.

The rack position sensor is integrated in the inside of the actuator and generates a voltage signal between 0V and 5V, corresponding to the zero position and the maximum position. The signal has been sent into the microcontroller's ADC module after conditioning by the circuit so as to get rack position.

A communications circuit is made up of the CAN controller which is inside the microcontroller and the external CAN transceiver. The host computer uses the circuit mentioned above to communicate with the controller, in order to exchange data including controller parameters and diesel status parameters.

Control program design: The program is an important part of the control system. The main program of the control system is used to complete initialization of hardware chip system and manage the control processes. Tasks with lower requirements in real-time is completed by the subroutine in the main program, such as speed up and speed down, shutdown, communication, failure handling, man-machine interaction and control process. Tasks with higher requirements in real-time such as speed calculate and rack displacement feedback signal acquisition PID computed output is realized by the interrupt control mode. Detailed algorithm of PID c-means is proposed by Song (2004) and Yao (2006).

The application program for the controller is created by using the C language. Figure 3 shows the flow chart of the main program. The process includes the following steps: system Function initialize, control parameter initialization, acquisition speed setting and rack position, I/O port initialize, communication, Man-machine dialogue subroutine, alarm processing.

In the main program, operation after power on the system is following:

First, each module in the hardware is initialized and then the control parameter of the control program such as the PID parameters is initialized.

The target speed and the real rack position of the diesel have be collected to provide an initial value for the control process.

Enable interrupt program and make interrupt program works.

Judge whether the communication request exits or not in the main loop, if it exits the communication program executes on time, carry on the man-machine interaction to insure two-way data communication;

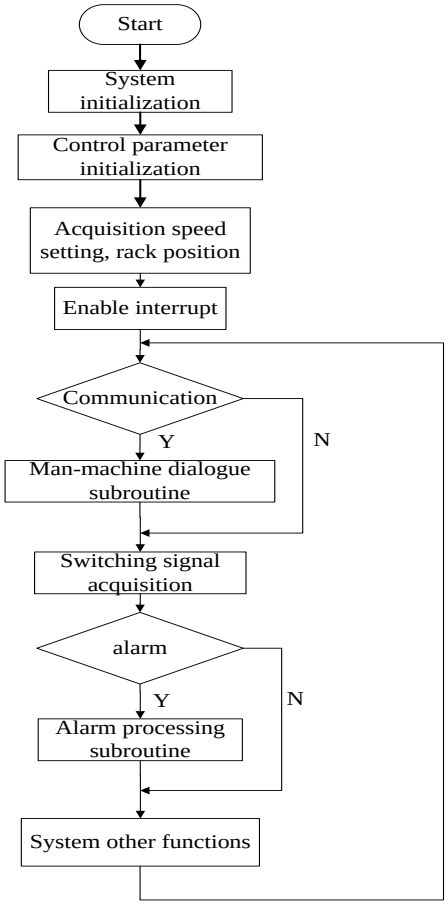

Fig. 3: Main program flow chart

otherwise jump out of the suboutime; Judge whether the information exits or not, if it exits the alarm subroutine executes, or jump out of the subroutine.

There are main two interrupts used in the program, i.e., periodic timer interrupt and input capture interrupt, the former is used for execute relevant subroutine on time and the host processor responses; the latter is used for collecting the speed pulse signal and XGATE which is the coprocessor responses, in this way it helps to reduce the mutual interference among the interrupt and the load of the main processor.

In the timer interrupt program, speed deviation is obtained by calculating the actual rotation speed and the target speed, then it is used as the input of speed loop PID, to calculate the value of target rack position; the rack position deviation is obtained by collecting actual rack position, then PWM output is calculated and then the actuator is adjusted to change the speed of diesel, finally realize the regulation of closed-loop. In this process, according to the actual rotation speed and load conditions, the control parameters of PID and the

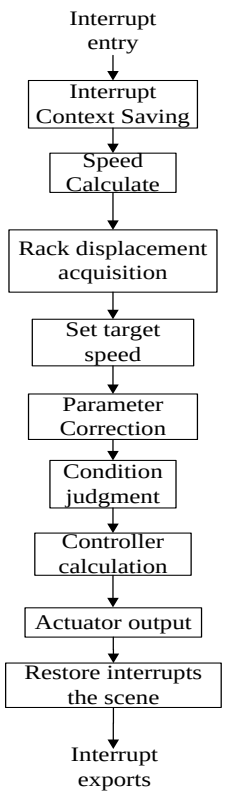

Fig. 4: Interrupt program flow chart

maximum amount of oil should be dynamically adjusted to insure that the diesel work in our expect state. Interrupt program 1 flow chart can be seen in Fig. 3.

In the input capture interrupt program, each pulse interval time is calculated according to the capture timer of the Microcontroller, the instantaneous speed of diesel is obtained through the filtering algorithms derived, then, the average speed of diesel which is acquired through smooth calculations is used for the calculation of speed loop PID. The interrupt process can be seen in Fig. 4.

RESEARCH OF EXPERIMENTS WITH DIESEL

In order to verify the functionality of the controller, ECU2 controller is used for the diesel sets generator of D6114 type to carry on the experiment. The rated power of this generator sets is 90 KW and its rated rotate speed is 1500 rpm:

- **Directly start without load in target speed:** The starting curve of the diesel in target speed, i.e., the first target speed is 700 r/min (idle speed) and then 1500 r/min, can be seen in Fig. 5 and 6, in which black line represents rotate speed. As can be seen in the figure, the diesel starts quickly and has small overshoot.
- **Add load in target speed when the diesel is in stable:** As is shown in Fig. 7 and Table 1, 100% load has been added when the speed is 1500 rpm. Several seconds later, the speed come back in 1500 rpm. And then the load has been repeal, the speed has been rise.

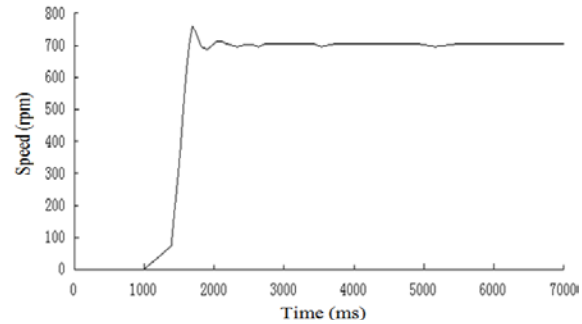

Fig. 5: The target speed is 700 rpm

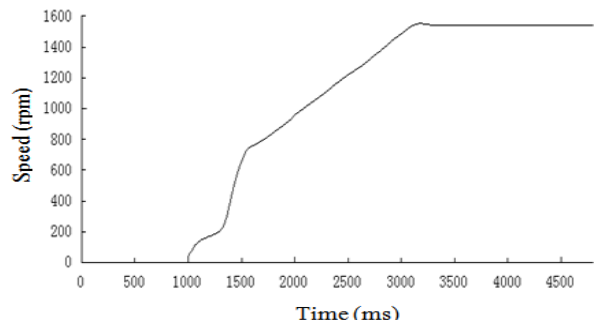

Fig. 6: The target speed is 1500 rpm

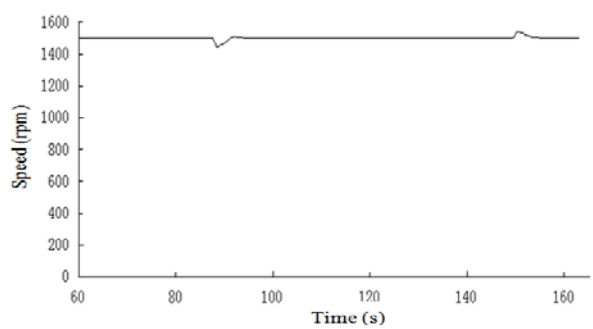

Fig. 7: Add load and repeal load

Table 1: Experimental data

	δ_d (%)	τ (s)
Add load	4.0	2.0
Repal load	4.6	1.8

CONCLUSION

This research concerns electronic controllers which effectively control diesel generators. The developed system is capable of real-time controlling and is very effective in responding to perturbation. The developed embedded controller has the following characteristics. First of all, it makes the generator work more efficiently and accurately, the digital speed control system can supply the demand of fine grade. Secondly, the host computer can communicate with the controller at any time. Finally, the diesel can be stopped immediately in cases of emergency. We are sure that our embedded controller offers a wide scope of application in the field of digital controllers in the diesel generator industry.

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