Research On and Application of Intelligentized Hydraulic Excavator

Dai Qunliang[1], Zhang Erping[2], Cai Dengsheng[2]

1. Department of Computer Science and Technology under Tsinghua University, Beijing 100084, P. R. China
2. Technology Research Institute under Guangxi Liugong Machiriery Co., Ltd, Guangxi 545007, P. R. China

E-mail: daiqunliang@163.com

Abstract For the purpose of improving the operating efficiency and reducing the energy consumption of hydraulic excavator, lightening the labor intensity of hydraulic excavator driver, strengthening the fault diagnosis and remote monitoring on hydraulic excavator, realizing the optimized configuration of plinkuctivity and meeting the needs of modern construction, the intelligentized hydraulic excavator is designed and developed. This article introduces the composition of intelligentized hydraulic excavator, and probes into the trajectory control for working equipment of hydraulic excavator, the power matching control between hydraulic pump and engine. The remote monitoring and the fault diagnosis expert system are developed. The practical application reveals that the intelligentized hydraulic excavator is highly automated, intelligentized and informationized, and enjoys the advantages such as relatively strong performance, relatively high operating efficiency and economical efficiency.

Keywords Hydraulic excavator; Intelligent control GPS/GPRS-based; Fault diagnosis.

1 Introduction

As a main-stream product of constructional machinery, hydraulic excavator plays an important role in construction of industrial and civil buildings, traffic facilities, water conservancy facilities, hydroelectric facilities and military facilities. With the sustained development of the national economy, the demands on excavator will increases by a wide margin year by year[1]. In 2004, the production volume of excavator in China reached 27500 sets, accounting for 27.8% of the production throughout the world. At present, the issues relating to environmental protection and energy conservation have aroused a great deal of public concern. As a result, higher requirements are put forward on reliability, economic efficiency, function and automation of hydraulic excavator. The hydraulic excavator presently available on the market, however, has the following disadvantages:

(1) Low degree of automation: When using hydraulic excavator to level up a field or dig a ditch, since the driver has to control the boom, arm and bucket simultaneously, the intensity of his labour is relatively high, and he is also required to be well skilled.

(2) When the hydraulic excavator is running, if the power absorbed by the hydraulic system exceeds the rated power of the engine, the engine will stall and even stop. In such case, the operational performance of excavator can't be brought into full play, and the fuel consumption will also increase.

(3) Owing to its complicated structure and the extreme operating environment, hydraulic excavator enjoys a relatively high fault rate. Whenever a fault occurs, maintenance personnel have to make great efforts to identify the cause of fault, which means the excavator will be out of service for long time and thus the user will incur huge economic losses.

(4) Since the excavator can't be brought under remote monitoring and management, the rational dispatching for excavator can't be realized and the needs of modern construction can't be satisfied.

Thanks to the extensive application of computer technology and intelligent control technology, constructional machinery has developed from hydraulically-controlled type to digitalized type which is of simplified structure, easy to control and more intelligentized. For example, the PC300 hydraulic excavator manufactured by Japan-based KOMATSU obtains 3-dimension trajectory control ability with the help of the tilted angle sensors mounted at its boom, arm and bucket; other hydraulic excavators manufactured by VOLVO, CAT, KOMATSU and HITACH obtain the remote monitoring ability thanks to the GPS mounted.

The intelligentized hydraulic excavator is highly intelligentized, automated and informationized. Its intelligence is mainly embodied in the following aspects: It can carry out automation; it realizes the trajectory control for working equipment; it realizes the self-adapting power matching control between engine and hydraulic pump; it can carry out remote data transmission, remote monitoring and remote management; it can carry out fault diagnosis and maintenance.

2 Composition of Intelligentized Hydraulic Excavator System

As indicated in Fig. 1, the intelligentized hydraulic excavator system is composed of a controller, a GPS (Global Position System), GPRS (General Packet Radio Service), a remote server, a monitor, a portable fault diagnosis system and etc.

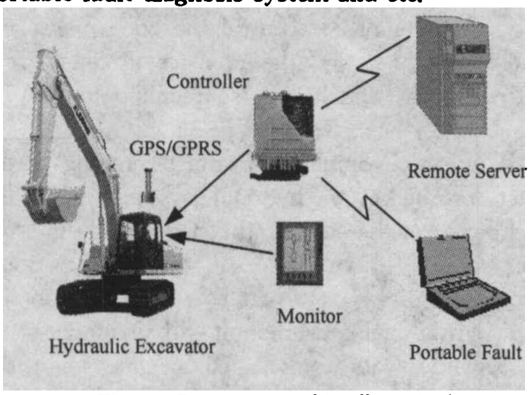

Fig. 1 Composition of intelligentized hydraulic excavator system

2.1 Controller

As indicated in Fig. 2, the controller is composed of signal acquisition module, power drive module, monitor module and GPS/GPRS module, and takes a digital signal processor (DSP) as its core control unit [2]. Its signal acquisition module measures the tilted angle, pressure, speed and temperature through peripheral sensors, and these signals are sent to the controller after going through analog-digit conversion. In this way, the real-time information about the excavator is obtained.

The monitor is used to display the main operating parameters such as engine speed, the engine oil temperature, engine oil pressure and cooling water temperature, to display fault code and give an alarm on the basis of the operating conditions of the excavator, and to display real-time information about position and gesture of bucket in the form of digit or figure.

Since the controller communicates with other parts in CAN (Control Area Network) mode, a lot of wire has been dispensed, and thus the signal-control reliability and anti-interference capacity have been improved. The CAN bus which is adaptable to the operating environment of hydraulic excavator ensures that the control can be carried out in a real time, flexible and expandable way and makes it easy for the controller to form a multi-controller network together with other peripheral devices. Since the CAN bus adopts the message-based encoding method and the priority-based non destructive bus arbitration technology, it enjoys high anti-interference capacity, high reliability and relatively high real-time capacity. The communication protocol observed by CAN bus meets SAE J1939, the physical layer of CAN bus meets SAE J1939/15, the communication rate of CAN bus is 250Kbit/s, and the terminal resistance of CAN bus is 120Ω[3].

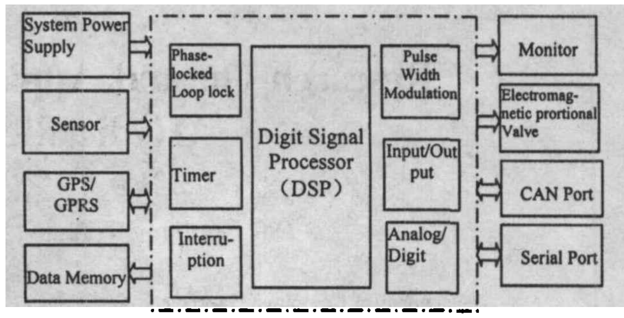

Fig. 2 Schematic diagram of controller

For the purpose of meeting the requirement on comfortable operation, the intelligent hydraulic excavator is equipped with a control handle designed in accordance with the principle of human engineering. As indicated in Fig. 3, an optical type non-contact switch is mounted on the control handle. Through the CAN bus, the signal relating to the displacement of the control handle and the signal of the optical switch are sent to the controller. The buttons on the control handle are used to select operating mode. If the manual operating mode is selected, the control handle is

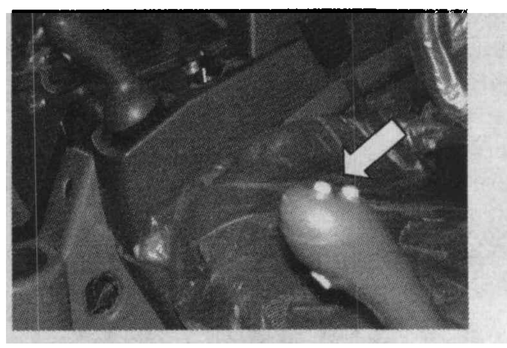

Fig. 3 Control handle designed in accordance with human engineering principle

operated in the same way as ordinary excavator. If the automatic operating mode is selected, the operator inputs operating parameters through the monitor, and then the excavator will operate in accordance with the trajectory which is determined by the controller on the basis of the operating parameters, so that the automatic control on the excavator is realized.

2.2 Remote information transmission

GPRS is a wireless packet switching technology which offers end-to-end wireless IP connection within wide area and whereby data is transmitted in packet. The structure of remote information transmission module of intelligentized hydraulic excavator is as indicated in Fig. 4. GPRS IP Modem is connected to the controller which is mounted on the excavator through RS232 port, and exchanges data with the remote server via the Internet. The controller will convert the data acquired into the format which can be transmitted by the GPRS IP Modem, and then the data will be sent to the remote server by the GPRS IP Modem via the Internet. Remote server will also send command to the controller. In this way, the remote monitoring on hydraulic excavator is realized. Between the GPRS IP Modem and the remote server is a C/S structure, which means several modems may be connected to the server for data transmission simultaneously.

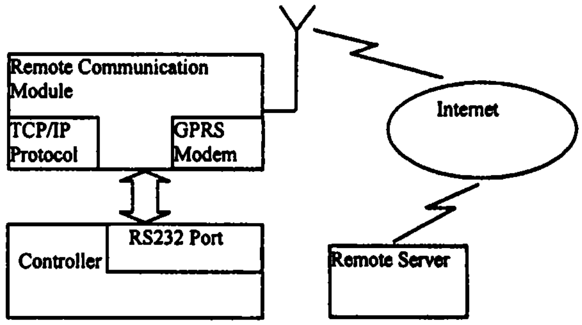

Fig. 4 Structure of remote information transimission

2.3 Application of GPS

GPS is a global wireless navigation and positioning system composed of 24 artificial satellites and earth stations. With the help of GPS and GPRS, the remote monitoring, service and management on intelligentized excavator are realized.

Besides the information about position of excavator, the controller which is equipped with a GPS/GPRS module also sends the operating parameters of the excavator such as temperature, pressure and working hours to the remote server.

Table 1 Trajectory planning and actually-measured value for excavator in slope-trimming operation

	θ_1 (°)		θ_2 (°)		θ_3 (°)	
	Expected Value	Measured Value	Expected Value	Measured Value	Expected Value	Measured Value
Group 1	45.4844	45.32	−30.8705	−30.65	−59.6139	−59.87
Group 2	47.6061	47.53	−37.9184	−38.20	−54.6877	−54.32
Group 3	49.3361	49.62	−43.4816	−43.43	−50.4445	−50.59
Group 4	50.8090	51.20	−49.1842	−49.32	−46.6247	−46.31
Group 5	52.0931	51.76	−53.9979	−54.03	−43.0952	−43.27
Group 6	53.2289	53.52	−58.4522	−58.53	−39.7766	−39.82
Group 7	54.2421	54.30	−62.6250	−62.32	−36.6171	−36.33
Group 8	55.1501	54.90	−66.5701	−66.87	−33.5799	−33.81
Group 9	55.9694	56.12	−70.3722	−70.56	−30.6382	−30.24
Group 10	56.6968	56.32	−73.9259	−74.22	−27.7708	−28.02

The position coordinates of the excavator are reflected on the map by the electronic mapping system, so as that the satellite-based positioning & tracking of excavator is realized. Getting access to the remote server via the Internet, the operator may monitor the operating conditions and obtain position information of the excavator in a real time way.

3 Intelligent control and fault diagnosis

3.1 Trajectory control for working equipment

The automatic control on excavator means to control the working equipment of excavator automatically, so as to make the bucket of the excavator move along a specific trajectory. If the excavator is controlled automatically in the course of field levelling or slope trimming, the labour intensity of driver is lightened, the operating efficiency is improved and the construction is accelerated.

The working equipment of hydraulic excavator is a linkage mechanism composed of boom, arm and bucket. The movement of each part is realized on the basis of the retraction and extension of the correspondent hydraulic cylinder. As indicated in Fig. 5, regard the working equipment as a mechanical hand with 3 degrees of freedom, regard the boom, the arm and the bucket as link 1, link 2 and link 3 respectively, regard the articulated connection between the boom and the rotating platform as Joint 1, regard the articulated connection between the arm and the front end of boom as Joint 2, and regard the articulated connection between the bucket and the front end of arm as Joint 3.

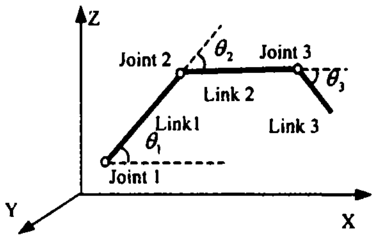

Fig. 5 Space coordinates system for working equipment of excavator

Driven by oil cylinder, link 1, link 2 and link 3 make the working equipment rotates around Joint 1, Joint 2 and Joint 3 respectively.

In accordance with the robot theory, there are many methods which can be used to set up a link coordinate system for studying the displacement relationship among these links. Among these methods, the most widely used is the Denavit-Hartenberg Method (D-H Method[4]), whereby a 4 4 homogeneous transformation matrix is used to describe the spatial relationship between 2 adjacent links and then an equivalent homogeneous transformation matrix is derived to determine the reference coordinate system for bucket teeth. The relative position relationship between link i and link i-1 can be described by a 4X4 homogeneous coordinates transformation matrix A_i as follows.

$$A_i=\begin{bmatrix}\cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i\\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i\\ 0 & \sin\alpha_i & \cos\alpha_i & d_i\\ 0 & 0 & 0 & 1\end{bmatrix} \quad (1)$$

In this equation, θ_i means the included angle between the 2 links, a_i means the length of link i (namely the length of common normal), α_i means the included angle between the 2 joints which are vertical to the a_i plane, and d_i means the distance between the 2 common vertical lines of link i's axial line. n, o, a and p refer to position vectors of the bucket.

$$^0T_4=A_1A_2A_3A_4=\begin{bmatrix}n_x & o_x & a_x & p_x\\ n_y & o_y & a_y & p_y\\ n_z & o_z & a_z & p_z\\ 0 & 0 & 0 & 1\end{bmatrix} \quad (2)$$

The transformation matrix $^0T_4$ represents the pose of bucket teeth's coordinate system {4} relative to its reference coordinate system {0}, namely the kinematical equation of bucket.

Carrying out trajectory planning and trajectory control for working equipment of excavator means to control the relative angle of boom, arm and bucket. After the moving trajectory of bucket teeth is pre-set, the angle θ_0 of each joint at start point and the angle θ_f of each joint at stop point can be determined by solving the inverse kinematical equation of working equipment, and then the moving trajectory can be represented by a smooth interpolating function $\theta(t)$.

In the course of real-time control, the sensors will measure the angular displacement of each joint in the working equipment, and the controller will compare the angular displacement acquired with the pre-set target value and then determine the driving amount on the basis of the result of calculation. Therefore, the working equipment will move along the pre-set trajectory. Take the slope-trimming slope of excavator for example, the tilted angle of bucket over the ground is set at 30°, the slope angle $\alpha=60°$, the operating height $H=3000$mm, and the expected value and actually-measured value of trajectory in slope-trimming operation are listed in Table 1. The test result reveals that the maximum deviation in trajectory which is limited to 30～50mm meets the requirements on operating performance.

3.2 Power matching control between hydraulic pump and engine

Under the precondition that the engine runs at rated power, the power matching controller in the intelligentized hydraulic excavator will, adopting the engine-pump integrated control mode, control the displacement of pump on the basis of the engine speed so as to make the engine and pump match with each other rationally. Therefore, the power of engine is brought into full play, the operating efficiency is improved and the fuel consumption is reduced. The model of power matching control is as indicated in Fig. 6.

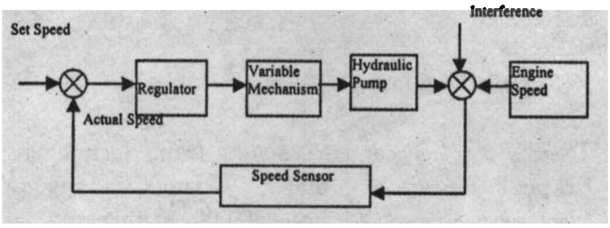

Fig. 6 Power matching control of excavator

Tested under different operating conditions, the engine always operates around the optimum operating point, which means the power of engine is brought into full play on one hand and engine stalling is effectively avoided on the other hand. The result of hydraulic pump & engine speed control test is as indicated in Fig. 7.

Therefore, the purpose of energy saving is realized because the speed adjusting device of the engine is controlled on the basis of actual operating conditions so as to make the engine run at a state of low fuel consumption. When the excavator does not work, it can reduce the engine speed automatically. Four to six seconds after the control handle is turned to the neutral position, the engine will enter into idle state automatically, so as to prevent the energy loss of hydraulic system and the wear of engine and thus reduce fuel consumption and noise of engine. As soon as the excavator works again, the engine will return to normal running state within one to two seconds, so as to ensure the normal progress of work.

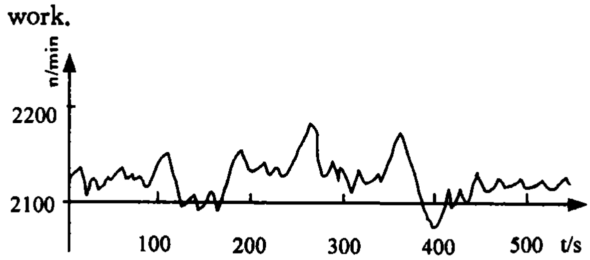

Fig. 7 Testing curve of hydraulic pump & Engine speed control

3.3 Fault diagnosis

Since many additional electrical control systems are intlinkuced into the hydraulic excavator, identification of fault cause becomes more difficult. Therefore, it is necessary to monitor operating conditions of and carry out fault diagnosis for excavator. In consideration of the features of hydraulic excavator, the fault diagnosis includes diagnosis on faults of engine management system, hydraulic system and electrical control system. Adopting the fault tree based diagnosis algorithm, the fault diagnosis system can identify the cause of fault quickly and accurately, assess the operating conditions of excavator on the basis of the expert database and help maintenance personnel to clear the fault.

The fault diagnosis system gets its application software programmed with the object-oriented programming language and Microsoft sql sever 2000 or Microsoft access database, and its functional structure is as indicated in Fig. 8.

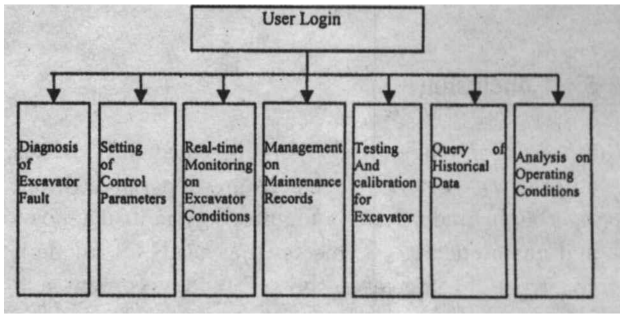

Fig. 8 Functional structure of fault diagnosis

The portable fault diagnosis system corrects the parameters in the controller until the excavator works at the best state, monitors the operating conditions of the hydraulic excavator in real time, reads the data measured by controller in real time, and displays the operating conditions of the excavator such as engine speed, fuel level, engine oil pressure and cooling water temperature in the form of digit or figure. Meanwhile, the fault diagnosis system can test each system and part, maintain and manage information, store and analyze historical information, so as to help maintenance personnel clear fault accurately and quickly.

4 Example of application

The CLG920C and CLG925C intelligentized hydraulic excavator have entered into the stage of mass production. Fig. 9 shows the field-levelling operation of intelligentized hydraulic excavator. The practical application reveals that: The intelligentized hydraulic excavator has relatively strong performance and relatively high operating efficiency; the stoppage of excavator caused by engine stalling is effectively avoided; the fuel consumption is obviously reduced; the capacity to diagnose and clear fault is greatly improved so that the out-of-service duration caused by maintenance and repair is shortened; the remote monitoring and management on excavator are realized.

Fig. 9 Field-levelling operation of intelligentized hydraulic excavator

5 Conclusion

Since the intelligentized hydraulic excavator realizes automation, gets its fuel consumption reduced and is brought under remote monitoring, fault diagnosis and maintenance, it meets the needs of modern construction, increases the technology content and international competitive power of enterprise's products, pushes the automated degree and intelligent degree of enterprise's products onto a new stage. With the development of science and technology, the information technology, automation technology and artificial intelligent technology will be applied to constructional machinery more and more widely, and intelligentized constructional machinery will surely become the developing direction.

Acknowledgement

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