

## The Implement of Hydraulic Control System for Large-Scale Railway Maintenance Equipment Based on PLC

Junfu YU, \* Hairui WANG

Information and Automation Building, Kunming University of Science and Technology,  
Chenggong District, Kunming, Yunnan Province, China  
E-mail: milady987@163.com

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**Abstract:** Programmed Logic Controller (PLC) is the digital calculation operation system, which is specially designed for industrial working environment. This paper proposed the implement of hydraulic control system for large-scale railway maintenance equipment based on PLC. This implement pursued the purpose of accurate control of hydraulic working units of large-scale railway maintenance equipment. Large-scale railway maintenance equipment should always work in efficient statement. Focusing on this requirement, the reliability design of hardware for current leakage and impulse current which is proposed in the paper is necessary. This paper proposed Triple Modular Redundancy (TMR) for relative horizontal check of working units linking bridge. This paper also proposed the method to prevent the current leakage and impulse current. As for hydraulic valves, this paper proposed PID algorithm to realize the control of Analogue Closed-Loop. Copyright © 2014 IFSA Publishing, S. L.

**Keywords:** Large-scale railway maintenance equipment, Hydraulic control, PLC, TMR, PID.

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### 1. Introduction

A Programmable Logic Controller, PLC or Programmable Controller is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLCs are used in many industries and manufacture industries. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed-up or non-volatile memory. A PLC is an example of a hard real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result.

In the late 1960's, PLC's were developed to eliminate the large cost involved in changing complicated relay based machine control systems. These systems were inflexible and complicated, which their major rewiring or complete replacement was necessary every time as the production requirements changed and control sequences had to be modified. Frequent requirement changes made the cost unacceptable. In this situation the thought of replacing relay systems with flexible microprocessor based on Programmable logic controllers (PLC) was a revolutionary step in the industrial control area. The real PLC which is selected as the implement of the system in this paper is shown in Fig. 1.

PLC's have been used for several years at different areas' applications. They are the main control elements of several subsystems which require relatively slow data monitoring: the radiation control,

personal safety, fire and smoke alarm. All these subsystems are very effective and have great reliability.



Fig. 1. MITSUBISHI F1-40MR PLC.

Large-scale railway maintenance equipment is mainly used for the construction of concrete pouring and railway works. Large-scale railway maintenance equipment or a ballast tamper or tamping machine is a machine used to tamp the track ballast under railway tracks to make the tracks more durable. Prior to the introduction of mechanical tampers, this task was done by manual labor with the help of beaters. As well as being faster, more accurate, more efficient and less labor-intensive, tamping machines are essential for the use of concrete sleepers since they are too heavy (usually over 250 kg) to be packed into the ballast by hand.

As the sleepers of the railway gets heavier, hydraulic control system was the way to do the heavy work. Hydraulic control system mainly about 4 parts:

- 1) The relative horizontal control of working units linking bridge;
- 2) The pressure control of hydraulic pump;
- 3) The control of hydraulic electromagnetic station valves;
- 4) The speed control of the hydraulic driven wheels; all four parts are used PLC as the control system component [1].

## 2. The Hardware Design for Reliability of Current Leakage and Impulse Current

### 2.1. The Hardware Design for Reliability of Input Current Leakage

As the sensors of limit switch of the PLC control system are used for input components, the usage of input current threshold value is 1.3 mA, as this

component had a disadvantage of current leakage as the current usage higher than the threshold value. In this situation, arranging a parallel resistance between sensors and PLC can solve this problem, shown as Fig. 2.

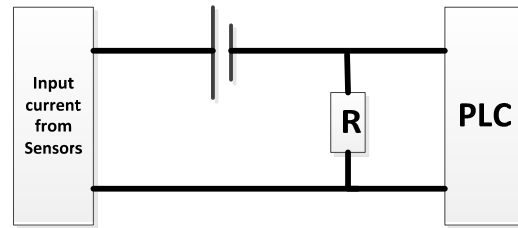


Fig. 2. The hardware design for input current leakage.

The eq. (1) shows how to calculate the resistance value and the power usage of the resistance.

$$R \leq \frac{17.15}{3.43I - 5} K\Omega \quad w \geq \frac{2.3}{R} W, \quad (1)$$

The formula shown in Eq. (1) are the resistance value and power usage calculation formulas,  $I$  represents the input device current,  $R$  represents the resistance and  $W$  represents the power usage of the resistance.

### 2.2. The Hardware Design for Reliability of Output Current Leakage

It may have some mistaken actions which cause output current leakage of the PLC load circuit. In this situation, arranging a bypass parallel resistance between load power supply and PLC can solve this problem, shown as Fig. 3.

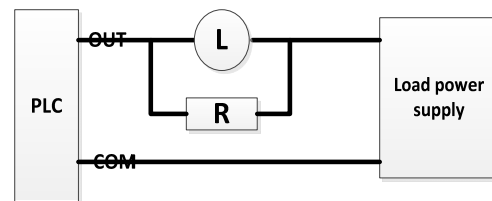


Fig. 3. The hardware design for output current leakage.

The eqn. (2) is the bypass resistance value calculation formulas,  $I$  represents the output leakage current,  $R$  represents the bypass resistance and  $U_{ON}$  represents the start pressure of the load power supply.

$$R \leq \frac{U_{ON}}{I}, \quad (2)$$

### 2.3. The Hardware Design for Reliability of Impulse Current

The transistors or bidirectional thyristor inside in PLC can suffer the impulse current 10 times than itself rated current. To forbidden too much impulse current to the load circuit, there are two ways to solve this problem, this paper proposed serials-resistance. In this situation, arranging a serial resistance between load power supply and PLC can solve this problem, shown as Fig. 4.

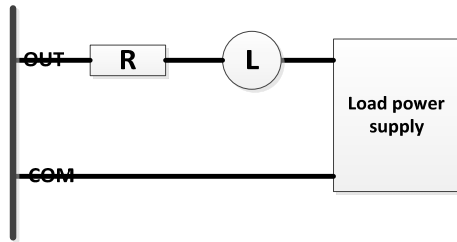


Fig. 4. The hardware design for impulse current.

### 3. The Relative Horizontal Control of Working Units Linking Bridge

As the ballast tamper working, for each rail there is a tamping unit attached to the main frame by means of vertical guide columns and a lift/lowering hydraulic cylinder. The tamping unit consists of tamping tool which is as known as arms, a hydraulic vibration motor, a vibration shaft and an eccentric flywheel. For each sleeper, a tamping unit is provided with four pairs of tamping arms: one each side of the sleeper, 16 tamping arms are used for tamping a single sleeper. All of these arms are connected to the linking bridge, shown as Fig. 5.

PLC takes the relative horizontal angle as the feedback variable, to calculate this relative horizontal angle by the control algorithm to identify the temper arming working statement information as PUSH or PULL. By the working statement information, PLC can ensure the requirement of relative horizontal angle less than  $1^\circ$ .

The relative horizontal control [2, 3] can guarantee the quality of the railway maintenance.

To secure the relative horizontal control of the linking bridge, this paper proposed to arrange two sensors for measuring the relative horizontal to the ground of the linking bridge; and arrange another two sensors at the bottom of the working car of the ballast tamper for measuring the relative horizontal to the ground of the ballast temper. PLC control system got the input signals for all the sensors to calculate the relative horizontal.



Fig. 5. The tamping unit of the ballast temper.

This paper proposed Triple Modular Redundancy (TMR) [6, 7] for data collection and Markov Model [4, 5] for testing Triple Modular Redundancy reliability. Assuming each tunnel module failure rate is a constant  $\lambda$ ; Fault diagnose scale is  $C$ ; maintenance rate is  $\mu$ ; and at one moment there was only one module failed. There are three modules in this system: 1) PLC; 2) Sensors for relative horizontal detection; 3) Hydraulic control valve. The Markov Model state process description is shown as below:

1) State 0 represents normal working state of the system;

2) State 1 represents one of the three tunnel module predicable system failure, system can decide by the principle of two taken two;

3) State 2 represents two of the three tunnel modules having predicable system failure, system could not decide the system working state, which means system could not distinguish which tunnel module has unpredictable failure, in another way State 2 also represents Failure-Success state;

4) State 3 represents one of the three tunnel modules having unpredictable failure, system can decide by the principle of three taken two, it also means reliable success state;

5) State 4 represents two of the three tunnel modules having failure, one of the two failed tunnel modules has the predictable failure and has been shut down, another failed tunnel module has the unpredictable failure, system cannot decide by the principle of two taken two;

6) State 5 represents all of the three tunnel modules having failure whether predictable or unpredictable, system is highly dangerous.

The state transition diagram is shown as Fig. 6.  $p_j(t)$  represents system State  $j$  ( $j \in \{0, 1, 2, 3, 4, 5\}$ ) at the time  $t$ ,  $p_j(t)$  initialization is  $p_j(0) = \{1, 0, 0, 0, 0\}$ , the probability of  $p_j(t)$  is calculated by matrix equation  $P'(t) = P(t)A$ .

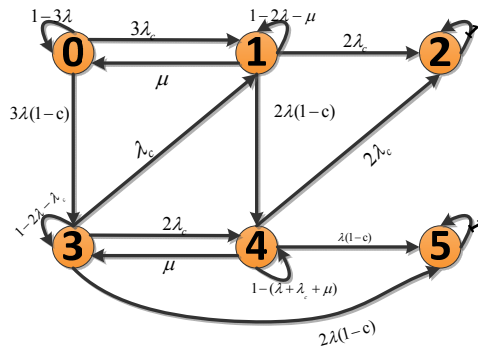


Fig. 6. The state transition diagram of Markov Module for Triple Modular Redundancy.

According to Fig. 6, the state transition diagram of Markov Module for Triple Modular Redundancy shows that State 0, State 1 and State 3 can guarantee the system reliability; State 0, State 1, State 2, State 3 and State 4 represent system at safety working state. The probability of system reliability  $R(t)$  calculation formula is shown in eqn. (3).

$$R(t) = p_0(t) + p_1(t) + p_3(t), \quad (3)$$

#### 4. The Software Design of PLC Control System for Hydraulic Pump

The hydraulic pump drives the ballast tamper tamping units' arms at the right hydraulic pressure, PLC control system for hydraulic pump is the core system of the whole PLC control system. To enhance the hydraulic pump operation pressure accuracy, this paper proposed PID algorithm [8, 9, and 10] for PLC control system. PLC control system for hydraulic pump mainly included four parts: 1) PLC; 2) the pressure sensors; 3) the proportional amplifier; 4) the proportional relief valve. The main structure of PLC control system for hydraulic pump is shown in Fig. 7.

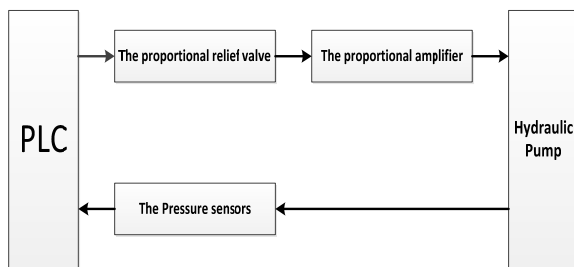


Fig. 7. Structure of PLC control system for hydraulic pump.

PLC is responsible to collect the signals from the pressure sensors. When the system starts, the pressure sensors send input signals, which represent the real pressure of each hydraulic pump, to PLC. Then PLC compares these real pressure signals with the rated pressure signals, there is a difference value ( $V$ )

of the computation. The control algorithm main processes are:

1) As  $V > 0$ , the real pressure is higher, PLC controls the proportional relief amplifier to turn the proportional relief valve down until the  $V = 0$ ;

2) As  $V < 0$ , the real pressure is higher, PLC controls the proportional relief valve up until the  $V = 0$ ;

PID represents Proportional, Integration and Differential. The PLC control system for hydraulic pumps is a close circuit control system; PID algorithm is responsible to the output control of the circuit which means PID algorithm works on controlling the signal from PLC to Hydraulic Pumps.

1)  $\varepsilon$  represents the difference value ( $V$ ) of real pressure ( $PV$ ) and rated pressure ( $RP$ ).

2)  $U$  is the output variable,  $U(t)$  is the function of time ( $t$ ), the  $U(t)$  is the combination of Proportional, Integration and Differential, its equation is shown in eqn. (4).

3)  $K_c$  represents the gains of output.

4)  $U_{initial}$  represents the initialization value of  $U$ .

$$U(t) = K_c \times \varepsilon_n + K_i \times \int_0^t \varepsilon dt + U_{initial} + K_d \times d\varepsilon / dt, \quad (4)$$

As PLC computation is discrete computation, PID equation must be discretization the discrete equation of  $U(t)$  is shown in eqn. (4).

1)  $U_n$  represents the output calculation value at the  $n$  sampling time.

2)  $\varepsilon_n$  represents the difference value at the  $n$  sampling time.

3)  $\varepsilon_{n-1}$  represents the difference value at the  $n-1$  sampling time.

4)  $K_D$  represents the coefficient of Differential.

5)  $K_I$  represents the coefficient of Integration.

$$U_n = K_c \times \varepsilon_n + K_I \sum_{i=1}^n \varepsilon_i + U_{initial} + K_D (\varepsilon_n - \varepsilon_{n-1}), \quad (5)$$

And PID algorithm program flow chart is shown as Fig. 8.

#### 5. Conclusions

This paper proposed the implement of PLC hydraulic control system for Large-Scale railway maintenance equipment. The reliability hardware designs make PLC more stable and reliable at working time. Triple Modular Redundancy for relative horizontal check of tamping units linking bridge make the linking bridge at relative horizontal, guarantee the tamping arms working at the proper status. Based on the PID algorithm PLC can accurately control the hydraulic units, which tamping arms work at the accurate step, make the whole railway maintenance process more efficiency and accurate.

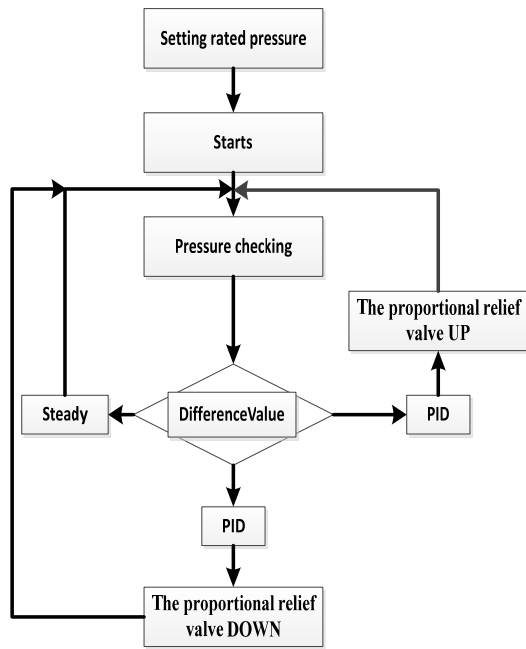


Fig. 8. PID algorithm program flow chart.

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