Design of reducer cooling system based on PLC control

Cui HuaiFeng\textsuperscript{a}, Zhang Yaxian\textsuperscript{b*}, Lin Yuanchang\textsuperscript{c}, He Guotian\textsuperscript{d}, Chen Guangping\textsuperscript{e}

\textsuperscript{a}School of Intelligent Manufacturing, Sichuan University of Arts and Science, Dazhou, Sichuan, China
\textsuperscript{b}Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing, China
\textsuperscript{c}email: chfsecond@163.com, \textsuperscript{d}email: lyc@cigit.ac.cn
\textsuperscript{e}Corresponding author’s \textsuperscript{b*}email: ZYX@sasu.edu.cn

Abstract: Combining PLC and configuration software to design the reducer cooling system, can realize the functions of reducer temperature monitoring, lubricating oil cooling, and replacement; the article puts forward the design scheme of the reducer cooling system, summarizes the various functions of the control system, analyzes and describes the realization method and key technology of the control system in detail.

1. Introduction
The reducer is widely used in various fields. The motor can provide power, and the reducer is able to reduce the output speed and increase the output torque. The reducer generally uses lubricating oil to lubricate and cool the gears. Too much lubricating oil in the reducer housing can easily lead to lubricating oil leakage; however, if the oil is too little that it can easily lead to be in poor lubrication effect; the position of adding lubricating oil in the reducer is generally one-third to one-half of the lower half of the gear. The gear meshing part is near to the middle of the gear’ tooth, and the lubricating oil level in the reducer housing is lower than level of the meshing tooth. Therefore, the lubrication of gears in the working process depends on the lubricating oil that falls from height when the gears rotate. That is, the gear lubrication of the existing reducer adopts splash lubrication, so the gear lubrication effect is poor. Since the shell of the existing reducer is a closed structure, the heat dissipation effect is poor. The frictional heat generation makes the temperature of the parts and the lubricating oil rise rapidly, and at the same time, the wear debris is continuously produced, which causes the gear surface to be damaged to different degrees, which has a negative impact on the reducer. Therefore, the filtering and cooling of lubricating oil has an important influence on improving the performance of the reducer [1-3].
2. Reducer cooling system solution

The main reason for the internal heating of the reducer is the friction of the gear meshing part, in addition, the effective lubrication and cooling of the meshing part play an important role in the performance and life extension of the reducer.

In order to achieve an acceptable cooling effect, the system, which completes the design of the reducer cooling system based on PLC and configuration software, uses PLC as the hardware platform and chooses configuration software to realize human-computer interaction.

It can be seen from Figure 1 that the reducer cooling system is composed of lubricating oil delivery part, temperature detection part, and lubricating oil cooling part. It is equipped with 5 pairs of temperature sensors and lubricating oil nozzles inside the reducer; at the same time, the temperature sensor and oil outlet are installed at the bottom of the reducer. The external lubricating oil delivery pipeline and key components include: solenoid valve, filter, oil pump 1, oil pump 2, external oil temperature sensor, oil storage tank, supercharger, flow control valve, flow sensor, etc. The lubricating oil cooling part mainly includes: water pump, water temperature sensor, plate heat exchanger, solenoid valve, water storage tank, temperature sensor, etc.

2.1 The working process of the reducer cooling system

The reducer cooling system can achieve two basic functions: Filter and replace the lubricating oil of reducer; lubricate and cool the reducer.

1) Filter and replace the lubricating oil of reducer.

When the solenoid valve at the oil outlet is turned on, the oil pump 1 start working; the oil pump drives the lubricating oil inside the reducer goes through the oil pipe and enters the waste oil storage tank via the solenoid valve, filter, oil pump, flow sensor, temperature sensor, pressure sensor, plate heat exchanger.

2) The cooling process of reducer
a) When the reducer starts working, the cooling system starts up. The PLC reads the data of each sensor in real time. When the temperature monitoring value of each point in the reducer exceeds the set value, the nozzle of the corresponding point will start to spray. The nozzle fuel injection start-up process: the solenoid valve corresponding to the position is turned on, the parameters are calculated according to the speed of the reducer (w) and the position temperature (T), the flow control valve parameters are set, then the oil pump 2 starts, the cooling oil is drawn into the supercharger and goes through the flow control valve, solenoid valve and flow sensor; the lubricating oil enters the reducer through nozzle, which has the effect of lubricating and cooling the reducer.

b) The controller calculates the volume of lubricating oil inside the reducer in real time by reading the flow sensor data V1 and V2 of the oil inlet and outlet pipes. When the volume exceeds the upper limit, the control system starts the pumping procedure to keep the lubricating oil volume at a set level.

c) The cooling water circulation system starts. When the temperature of the outlet of the plate heat exchanger exceeds the set temperature upper limit, the cooling water circulation system starts up, the cooling water inlet and outlet solenoid valves are turned on. At the meantime, the water pump works, it makes that the cooling water is injected into the plate heat exchanger and cool the lubricating oil.

The host computer accesses various data of the cooling system and reducer in real time; the data include: reducer speed (w), lubricating oil temperature (T), detection temperature (t) at each location, injection flow (M) and pressure (P) at each location, and oil volume (V) in the reducer housing; it can provide data support and experimental verification for subsequent cooling system parameter optimization.

2.2 Structure of the control system

The control system structure of the reducer cooling system is shown in Figure 2.

![Figure 2. Structure diagram of reducer cooling control system.](image)

Siemens S7-200 PLC CPU224 is selected as the controller. The controller has 14 digital inputs and 10 digital outputs, but it also needs 3 EM235 analog input/output expansion modules [4].

The reducer cooling system consists of a computer (PC), PLC, temperature sensors, pressure sensors, solenoid valves, flow control valves, flow sensors, supercharger, water pump, oil pumps, etc. The PLC hardware control system is composed of a power supply module, a CPU module, a digital input module, a digital output module, an analog input module, and an analog output module. The PLC is connected with the host computer through a 485 serial communication interface [5].

2.3 I/O port allocation

The input part of the reducer cooling system includes: temperature sensor, pressure sensor, flow sensor. The output part of the reducer cooling system includes: inverter, solenoid valve, supercharger, flow control valve, etc. The I/O port allocation is shown in detail in the table 1.
Table 1. I/O port allocation.

| Input/output | Address | Function                                      |
|--------------|---------|-----------------------------------------------|
| Digital input| I0.0    | Automatic/manual switch                       |
|              | I0.1    | Stop switch                                   |
|              | I0.2    | Start switch of solenoid valve 1~5            |
|              | I0.3~I0.6| Start/Stop switches of solenoid valve 6~9     |
|              | I0.7    | Start/Stop switch of water pump               |
|              | I1.0~I1.1| Start switches of oil pump 1~2                |
|              | I1.2    | Fault confirmation                            |
|              | AIW0~AIW14| Temperature sensors 1~8                      |
|              | AIW16~AIW18| Flow sensors 1~2                             |
| Analog input | AIW20   | Liquid level sensors                          |
|              | AIW22   | Pressure sensors                              |
| Digital output| Q0.0~Q1.0| Intermediate relays 1~9                      |
|              | AQW0/AQW4| Inverters 1~2                                 |
| Analog output| AQW8    | Flow control valve                            |

3. Design of Control Process of Reducer Cooling System

3.1 Control process
The control process of the reducer cooling system mainly includes two parts: lubricating oil circulation and cooling. The judgment condition for controlling the lubricating oil circulation is to detect the temperature of various locations inside the reducer, the volume and temperature of the lubricating oil. As for cooling water, it’s judgment condition is the temperature of the outlet of the heat exchanger. By filtering and cooling the lubricating oil discharged from the reducer, the lubricating oil entering is low temperature and free of impurities. Figure 3 shows the flow chart of the system.
3.2 Design of Human-Machine Interface of Host Computer Configuration Software

The host computer (PC) chooses YANHUA IPC-610H, and adopts the kingview6.60sp2 software of Beijing Yakong Technology Co., Ltd. as the software platform of the reducer cooling system. Kingview software has the functions of communication, device connection, device configuration, database construction, graphic interface design, animation connection, etc. So it can achieve to display, record, store, and process real-time data in the monitored device or system, besides it is able to meet various monitoring requirements [6].
Figure 4. Monitoring interface of reducer cooling system.

The monitoring interface of the reducer cooling control system mainly realizes the management of the peripheral equipment of the cooling system and various key parameters. It provides some functions, such as real-time data acquisition and display, data analysis and processing, real-time control, definition configuration, statistical storage, screen display, query printing, communication; the key parameter information of the cooling system of the reducer can be displayed graphically or in text mode, and historical data can be inquired. The design of the configuration software interface is friendly to achieve the functions of the system’s monitor and control.

4. Conclusion

The design adopts multi-point temperature monitoring and lubricating oil external circulation cooling system to achieve the effects of high-efficiency cooling and lubrication of the reducer; it plays the role of lubricating oil to a greater extent. The system not only reduces the adverse effects of the lubricating oil temperature rise of the reducer on the bearing, gear and motor bearing grease, but also effectively reduces the safety hazards of the equipment. The reducer cooling system, which can be adjusted according to different working conditions, meets different usage requirements. It plays an important role in improving the reliability of the reducer.

Acknowledgments

This work was supported in part by the National Key R&D Program of China under Grant 2017YFB1300600, in part by the National Key R&D Program of China under Grant 2017YFB0108103, in part by the CAS "Light of West China" Program, in part by the Chongqing Research Program of Technology Innovation and Application under Grant cstc2019jscx-zdztxx0046 and cstc2018jzx-cyzzx0041, in part by the Sichuan University of Arts and Sciences 2019 research base and platform special general project, project number 2019PT006Y, in part by the Sichuan University of Arts and Science's general research project in 2019, the project number is 2019KZ002Y.
References

[1] Tang, HB. (2013). Analysis on the heating problem of ring reducer and its improvement measures. J. Mechanical and Electrical Information., 18: 74–75.

[2] Wang, XL., Liu, L., Guo, LS. (2019). Analysis of the Failure of the Graphite Sealing Bowl of the Main Reducer. J. Industrial Technology Innovation., 06(02): 24-27.

[3] Wu, KS., Lian, D., Chen, M., Zhang, W. (2014). Calculation method of lubricating oil flow distribution in star reducer. J. Lubrication Engineering., 39(08): 99-102+107.

[4] Gao, AB., Dong, ZS., Wu, HB. (2012) Newly compiled machine tool electrical and PLC control technology. China Machine Press Publishing, Beijing.

[5] Liu, ZQ., Wang, HZ., Yang, K. (2016) Siemens PLC programming technology and application cases. Chemical Industry Press Publishing, Beijing.

[6] Wu, MF., Cheng, ZM., Dong, L., Liu, HL., Zhu, JC, Wu, K. (2010). Design and development of performance test system for submersible push-flow mixer based on Kingview. J. Control and Instruments in Chemical Industry.,47:523-526+562.