Design of thermal protection system for Marine Motor

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Abstract: The abnormal heat fault of marine motor frequently occurs for the bad working environment. And the navigation safety and reliability of the ship had been affected seriously. The heat transfer path of the motor is analyzed theoretically from the point of view of heat transfer in order to solve this problem. The relationship between the surface temperature and the internal temperature is established. The surface temperature of the motor is measured in real time by the temperature acquisition module. And the measurement results are transmitted to the host computer through RS485 communication interface. The inner and outer surface temperature quantitative relationship is used to judge whether the inner temperature of the motor is abnormal or not, and the real-time alarm is carried out to realize the thermal protection of the motor.

1. Introduction
As one of the most important equipment on the ship, motor’s reliability directly affects the safety of the ship. Many of the motor failure caused by a long time of abnormal heat or high temperature work. Therefore, the thermal monitoring of the motor is a prerequisite to judge its ability to work for a period of time in the future, and is a necessary measure to ensure the reliability of the motor. But it is very difficult to measure the inner winding and insulating material temperature of induction motor. So it is difficult to carry out thermal protection of induction motor. Wang used the L-M algorithm to carry out the inverse heat conduction calculation by measuring the air temperature on the surface and the end of the motor. And the internal temperature of the motor and the relevant parameters are obtained, which provides a new idea for thermal protection of the motor\textsuperscript{1,2}. A two-dimensional heat conduction model was established, and the relationship between the internal temperature rise of the stator and the ambient temperature and the surface temperature of the case is analyzed by Xue\textsuperscript{3}. Based on the analysis of the temperature detection module and the signal processing module commonly used in motor thermal protection, the design of motor thermal protection system is discussed by Gao\textsuperscript{4}. A new strategy to estimate the stator winding temperature of permanent magnet synchronous motor online proposed by Liu, and the temperature of the stator winding can be estimated online based on the linear relationship between the temperature and resistance of stator winding\textsuperscript{5}. Wang and his companions have carried out theoretical analysis and experimental research on the temperature rise of the inner
parts of high power density permanent magnet motor\cite{6}. The temperature field and temperature rise of PMSM windings with high current density are studied by Huang, which provides theoretical basis for thermal protection of PMSM\cite{7}. The research on thermal protection of asynchronous motor which is used most on the ship is relatively few according to the current research. Based on the theoretical analysis of the temperature distribution of marine motor in the early stage, the design of thermal protection device of marine motor is studied in this paper, which provides measures to improve the reliability and safety of marine motor.

2. The relationship between the temperature of the motor shell and that of the winding

It is easy to obtain the surface temperature, but it is difficult to measure the internal temperature directly for Most Marine asynchronous motors. The insulating material is coated on the coil and embedded in the iron core. The measured surface temperature is lower than the actual temperature of the insulating material. The temperature of the coil is usually estimated by the surface temperature of the motor in general. And this estimate is rough for different types of motors.

Theoretically, the temperature of the coil can be calculated accurately from the surface temperature of the motor by finite element simulation\cite{2}. For the temperature field on the cross section of the motor core, the following mathematical model is used:

\[ T(x, y) = \iint_{\Omega} \frac{\lambda}{2} \left[ \left( \frac{\partial T}{\partial x} \right)^2 + \left( \frac{\partial T}{\partial y} \right)^2 \right] \, dx \, dy + \int_{\Gamma} h \left( \frac{1}{2} T^2 - T_f T \right) ds \]  

(1)

Where:
- \( T_f \) is the medium temperature;
- \( h \) is the heat transfer coefficient between the medium and the shell;
- \( \lambda \) is the thermal conductivity of the shell metal.

Based on the basic structure of the motor, as shown in figure 1, the two-dimensional model can be simplified to a one-dimensional problem:

\[ \frac{dT}{dx} = \frac{h}{\lambda} \]  

(2)

Then the temperature inside the core at the point of D is:

\[ T_p = T + \frac{hD}{\lambda} \]  

(3)

The thermal conductivity \( \lambda \) of the shell metal in the formula (3) can be found in the relevant manual; while the shell coil depth D is a constant value for the motor, and the shell surface temperature \( T \) is the measured data. But the heat transfer coefficient \( h \) between the medium and the shell is an indeterminate value (it varies with the medium flow, temperature and surface condition). The experimental data is usually used to determine the heat transfer coefficient \( h \).

3. Design of general scheme

The temperature of each part of the motor was measured in real time through the temperature sensor. And which was pretreat processed by the lower computer and transmit to the upper computer through the communication bus. The state of the motor is judged and the conclusion is fed back to the motor control system to realize the thermal protection of the motor through the theoretical analysis. As shown in figure 2, for the overall system design schematic diagram. The whole system is composed of
temperature acquisition module, communication module, lower computer, upper computer and memory card.

Figure 2. Diagram of system overall scheme

4. Component design and selection

4.1. Temperature acquisition module
TC77 digital temperature sensor is used in the temperature acquisition module according to the field environment and the structure of the motor. TC77 is a series of accessible digital temperature sensors, temperature data time can be converted into 13-bit binary complement at any. And communication through the SPI and MICROWIRE compatible interface; MCU control slice signal, can read the temperature of each sensor. Then the temperature is interwoven into data frame, and bus upload to the host computer by RS485 at last. The temperature acquisition module circuit schematic is shown in figure 3. The range of measured temperature by acquisition module is -55°C ~ 125°C, and the accuracy of normal temperature (25°C ~ 65°C) can reach ± 1°C.

Figure 3. Circuit schematic diagram of temperature acquisition module

4.2. Host computer system
The host computer consists of a PIC 16F877A and a communication chip 65LBC184. The main circuit is shown in figure 4. The main task of the host computer is to control each acquisition module to upload and receive the data, and at the same time to form the temperature field mapping in the memory. This mapping is stored in the data storage area Bank1, Bank2 and Bank3 of Pic16f877a in the form of Data Matrix. The three storage areas respectively store the temperature field of different 3 times acquisition. And the temperature field of motor is analyzed by the host computer. An alert is sent out according to the result of analysis. The maximum difference of the data and the maximum temperature are detected by scanning the temperature field stored in the data memory card. And then the insulation
level of the motor is set to indicate whether the motor is overheated or not by compared with the ambient temperature. If the value is less than the set value, the motor can be judged to be out of order, and LED display and alarm.

![Figure 4. Schematic diagram of upper computer circuit](image)

### 4.3. Communication module

The temperature acquisition module communicated with the host computer by RS485. RS485 bus module adopts standard differential data line transceiver 65LBC184 and equipped with high energy transient noise protection device, which can effectively combat transient noise on data synchronous transmission cable and improve system reliability. The design of the differential driver integrates the output of the slept-rate controlled to meet the transmission rate requirement. The communication adopts RS485 half-duplex mode. The host computer sends the address number of the temperature collection module to RS485 bus, and then the module answers the temperature values of each temperature collection point in the module in sequence (T1 ~ T11). The specific communication format is shown in Table 1.

| B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 | B12 | B13 | B14 | B15 | B16 |
|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|
| 06H | 05H | 00xH | 044H | 078H | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 |

#### Table 1. RS485 communication protocol of the system

5. Software design and implementation

The software of the system is divided into temperature acquisition module software, host computer software and PC software. The function of temperature acquisition module software is to control the temperature acquisition and A/D conversion of each TC77, control the SPI bus to read the converted data of each TC77 and interweave the data. When the polling of host computer arrived, which sends out the data. The temperature data at each point is stored in an 8-bit byte and numbered (01H ~ 0BH) geometrically from the point near PIC 16F877a, and sequentially in the data memory address 061H ~ 06BH; When communicating, the data in 061H ~ 06BH address is sent out in turn. The definition of SPI bus and TC77 slice signal are shown in Table 2.

| TC77 Pin | SCK | SI/O | CS1 | CS2 | CS3 | CS4 | CS5 | CS6 | CS7 | CS8 | CS9 | CS10 | CS11 |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| PIC16F877a Pin | RD6 | RD5 | RD4 | RB0 | RD7 | RB1 | RB2 | RA4 | RA3 | RB3 | RA2 | RB5 | RB4 |

#### Table 2. Definition of SPI bus and TC77 slice signal
The host computer software is in charge of polling each temperature acquisition module, analyzing the temperature data, showing the temperature anomaly, and recording the temperature data. The highest temperature value and the environmental temperature data are detected by scanning the temperature field stored in the data memory card. Fig.5 shows the experimental test diagram of the developed motor thermal protection system.

Figure 5. Experimental test diagram

A standard platinum resistance thermometer was used as the comparison standard. The results show that the resolution of temperature acquisition is 1℃, the accuracy is ±1℃. The reading time of temperature acquisition module is less than 32ms/11 points; And the time of temperature acquisition system is less than 290ms. The data processing time of host computer is less than 120ms. The operating temperature range of the system is -10℃~80℃, and the operating temperature range of the temperature acquisition module is -10℃~125℃. Fig.6 presents the results of measured. The results show that the difference between the stator winding temperature and the surface temperature is about 16℃. The middle temperature of stator winding is lower, and the temperature of both ends is higher. But the surface temperature of the motor is high in the middle and low at both ends. The middle temperature difference between the stator winding temperature and the surface temperature is small, the temperature difference between the ends is large.

6. Conclusion
In this paper, the marine asynchronous motor thermal protection system is developed by using 11 temperature sensors TC77, PIC16F877A MCU, RS485 bus and VB application software. By measuring the surface temperature of the motor, using the basic theory of heat transfer of the motor and pushing back the internal temperature of the motor. The system can monitor the internal temperature of the motor in real time, monitor the thermal state of the motor in real time, and control the operation of the motor, realize the protection of the motor. The system resolution is 1℃ and the sampling time is less than 290ms, which can meet the need of engineering.

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