Design of High-Efficiency Refrigerator Test System for Industrial Internet of Things

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Abstract. Smart homes are developing rapidly, and refrigerators are an indispensable part of “smart homes”. Therefore, the research efficiency and quality assurance of refrigerators are highly valued by home appliance companies. Refrigerator test is required in both research and production processes. At present, the quality test of refrigerator has a high degree of manual participation, such as the selection of the stable operating range of refrigerator and the conversion of test stage require manual determination, which cause low test efficiency and high electric energy consumption. In order to solve these problems, this paper design a High-Efficiency Refrigerator Test System (HERTS) for Industrial Internet of Things (IIoT). The core test data intelligent analysis module realizes timely determination of test data and automatic transition of test stage. The proposed HERTS increases the efficiency of automate refrigerator test and greatly reduces the power consumption.

1. Introduction
The development of IIoT is the key of transformation and upgrade of manufacturing industries. With the proposal and development of industry 4.0 [1,2] and “Made in China 2025” [3], higher requirements are proposed for the manufacturing industry. The manufacturing industry develops from the original automation to intelligent and unmanned [4]. The rapid development of smart homes is prompting home appliance manufacturers to continuously develop new products to seize the market [5,6]. Refrigerators are an indispensable part of “smart homes” [7]. Therefore, the research efficiency and quality assurance of refrigerators have been highly valued by home appliance companies [8]. In the research and production process of refrigerators, test is required. However, the current refrigerator test system [9,10] only realizes semi-automatic testing of refrigerators, and only realizes basic functions such as sensor data acquisition, data display, and data management. With the development of intelligent factory oriented to robot, the refrigerator test industry is faced with inefficient problems.

The selection of refrigerator operation stability range and the transformation of test stage need to be judged manually. GBT8059[11] as China's refrigerator product test standard stipulates that in the test of refrigerator energy consumption, the data of refrigerator which continuous operation stable for 6 hours or more should be chose as the test data. However, the selection of stable data requires the tester to check the collected refrigerator data periodically [12]. And the tester needs select the possible stable interval to calculate whether it meets the criteria for stable operation of the refrigerator. According to the freezing capacity test of the refrigerator, each refrigerator compartment should be loaded with the freezing load after the stable operation state. At the same time, the time difference of refrigeration load from 25°C and -18°C should be recorded. The temperature rise test stipulates that the refrigerator
power should be cut off after stable operation, and the time difference of the load package from -18℃ to -9℃ should be recorded. But the switching of different test phases requires manual determination and operation. At present, refrigerator product test are over-reliant on manual, which waste manpower, and manual operations are not timely enough to increasing the test cycle [13].

In daily life, the refrigerator will work in different temperature and humidity environments [14], which is the maximum simulation of the actual working environment of the refrigerator, so the laboratory test environment will be maintained under specific conditions. Inefficient refrigerator testing increases the test cycle and wastes a lot of energy.

To address the problems faced by the current refrigerator test industry mentioned above, this paper presents the design of High-efficiency refrigerator test system. The method of judging and marking the stable state of refrigerator product test data based on feature selection and the method of intelligent test switching are presented.

2. HTRES Design and Implementation

The refrigerator test system can be divided into three parts: the refrigerator to be tested, the intelligent sensing device, and the refrigerator test software. The connection structure is shown in figure 1. Sensors are arranged on the refrigerator to be detected to sense the running state of the refrigerator, and the refrigerator test software collects sensor data and performs analysis processing.

![Figure 1. Framework of refrigerator test system.](image)

2.1. Function module of refrigerator test software

The functions module of the refrigerator test software include sensor data acquisition module, nameplate information input module, test data management module, data storage module, data curve display module, test data intelligent analysis module, test report generation module. Functional module workflow is shown in figure 2.

![Figure 2. Functional module workflow](image)
Sensor data acquisition module can automatically collect data from the sensor. Nameplate information input module can be used to input refrigerator test tasks information and refrigerator attribute information. Test data management module manage the data transferred by the sensor data acquisition module and nameplate information input module and call other modules to process the data. Data storage module can store sensor data and nameplate information into a database. Data curve display module enables the sensor data to be plotted into an intuitive curve according to time. Test data intelligent analysis module can be used to analyze and judge the collected sensor values according to the standard of refrigerator test. Test report generation module can generate test report according to test data intelligent analysis results and push it to refrigerator tester.

2.2. Intelligent Analysis Module

Aiming at the problem of more manual participation in test data analysis. We analyse the sensor data according to the refrigerator product test standard. Then we design the fast location stability interval algorithm based on eigenvalues and the intelligent switching test method, which are used to realize the function of the test data intelligent analysis module. As a result, the sensor data of a refrigerator test can be analysed quickly and intelligently, and the test results of a refrigerator test are obtained in time. The cycle of the refrigerator operating is defined as the time for the temperature of the refrigerator from peak (or trough) to peak (or trough), or the time for compressor power starts running until it stops running, and then the next time it starts running, it is recorded as Tcycle. The standard specifies the energy consumption test for the stable operating condition. It is necessary to select a continuous operating interval. This interval includes 3*n cycle (n=1, 2, 3 ...), and the interval duration is greater than or equal to 6 hours, less than or equal to 30*Tcycle. The interval is divided into three segments according to the number of cycles, interval A, interval B, and interval C. The average of the temperature calculations of the three intervals $\overline{T_A}, \overline{T_B}, \overline{T_C}$, the average of the power calculations of the three intervals $\overline{P_A}, \overline{P_B}, \overline{P_C}$, the length of time of the three intervals $t_A, t_B, t_C$. Meet the requirements (1)(2)(3)(4) formula.

\[
\frac{\text{ABS}(\overline{T_B} - \overline{T_A})}{\frac{t_A + t_B + t_C}{2}} < 0.025K / h
\]

\[
\frac{\text{ABS}(\overline{P_B} - \overline{P_A})}{(\frac{t_A + t_B + t_C}{2}) \times \text{P}_{\text{max}(A,B,C)}} < 1\%
\]

\[
\frac{\text{ABS}(\overline{T_B} - \overline{T_A})}{\frac{t_A + t_B + t_C}{2}} < 0.25% / h
\]

\[
\frac{\text{ABS}(\overline{P_B} - \overline{P_A})}{(\frac{t_A + t_B + t_C}{2}) \times \text{P}_{\text{max}(A,B,C)}} < 1\%
\]

$\text{ABS}$() is calculating the average value, $\text{P}_{\text{max}}$() is calculating the maximum value of power, $\text{P}_{\text{min}}$() is calculating the minimum value of power, $\text{T}_{\text{max}}$() is calculating the maximum value of temperature, and $\text{T}_{\text{min}}$() is calculating the minimum value of temperature.
Figure 3. Stable operating condition data

Figure 4. Unstable operating condition data

The manual method steady state interval selection is whether the power and temperature of each operating cycle are similar. Figure 3 shown stable operating condition data, and figure 4 shown unstable operating condition data. Therefore, each cycle can be used as a whole to judge the stability of data between cycles. Extract the characteristic value set of the refrigerator operating data curve \( F \).

\[
F = \{(t_1, T_{w1}, T_{i1}, T_{r1}, t_{h1}, P_{a1}), (t_2, T_{w2}, T_{i2}, T_{r2}, t_{h2}, P_{a2}), \ldots, (t_n, T_{wn}, T_{in}, T_{rn}, t_{hn}, P_{an})\}
\]

Where the \( T_w \) is temperature peak, \( T_i \) is temperature trough, \( t_r \) is start-up time (compressor operation), \( t_h \) is downtime (compressor standby), \( P_a \) is power average of each cycle. In statistics, the standard deviation can determine the stability of the data. Performing standard deviation calculation for each characteristic value, and then finally sum.

\[
\sigma_j = \frac{1}{n} \left( \sum_{i=1}^{n} (T_{wi} - \mu_{T_{wi}})^2 + \sum_{i=1}^{n} (T_{ti} - \mu_{T_{ti}})^2 + \sum_{i=1}^{n} (t_{hi} - \mu_{t_{hi}})^2 + \sum_{i=1}^{n} (P_{ai} - \mu_{P_{ai}})^2 \right)
\]

(6)

Among them, \( \frac{2}{T_{cycle}} \leq n \leq 30 \). The interval with the smallest standard deviation is locked depending on \( \min(\sigma_j) \) instead of manual selection the steady state interval.

Refrigerator test software obtains the test information through the Nameplate entry module, data acquisition module to provide data collection, the stability judgment method locates the refrigerator operation stability interval, and we design the test analysis algorithm to realize the unmanned test of the refrigerator. 

Test analysis algorithm steps are described below.

Step 1 Input the sensor data marked by the label.
Step 2 Extract sensor data feature values
Step 3 Find the standard deviation of the feature point values separately and obtain the minimum standard deviation interval.
Step 4 Determine whether the interval compliances with the steady state standards, if yes, jump to step 5; if no jump to step 2 and continue to run the test without meeting the standard; if the interval is more than 108h, jump to step 9
Step 5 Judging the type of test (energy consumption test, freezing capacity test, temperature rise test, etc.)
Step 6 If the energy consumption test is carried out, calculate the power consumption of the stable interval
Step 7 If the freezing capacity test is carried out, record the time difference between 25 °C and -18 °C of the load temperature. If the time exceeds 24 h, skip to step 9.
Step 8 If the temperature rises test is carried out, cut off the power supply, and record the time difference of the load package from -18 °C to -9 °C
Step 9 Submit a test report
3. HTRES Power economy

In the refrigerator test, the energy consumption for running the refrigerator is low, but the test is carried out under specific working conditions, and large amounts of electricity is needed to maintain the working conditions. According to the actual statistics of a household appliance enterprise in Qingdao, it is usually applied 7.5 kW∙h to maintain the test working condition. Table 1 shows the energy consumption statistics of three types of refrigerator tests conducted manually.

Table 1. Manual refrigerator test energy consumption

| Test type              | Average test time (h) | Working condition energy consumption (kW∙h) |
|------------------------|-----------------------|------------------------------------------|
| Freezing capacity test | 48                    | 360                                      |
| Energy consumption test| 30                    | 225                                      |
| Temperature rise test  | 28                    | 210                                      |

Instead of manual operation, the HERTS automatically selects the stability interval and switches the test stages, which improves the test efficiency, shortens the test period and effectively saves electricity consumption. Tables 2 shows the energy consumption statistics of the three types of refrigerator tests conducted by high-efficiency refrigerator test system.

Table 2. HTRES test energy consumption

| Test type              | HTRES average test time (h) | Reduce time (h) | Working condition energy consumption (kW∙h) |
|------------------------|-----------------------------|-----------------|------------------------------------------|
| Freezing capacity test | 32                          | 16              | 240                                      |
| Energy consumption test| 20                          | 10              | 150                                      |
| Temperature rise test  | 19.5                        | 8.5             | 146.25                                   |

From table 1 and table 2, it’s obvious to find that the energy saving for each refrigerator test of the laboratory. The freezing capacity test save 120 kW∙h, the energy consumption test save 75 kW∙h, and the temperature rise test save 63.75 kW∙h. If the three types of refrigerator tests do 50 times annually, 0.129 million kW∙h of energy consumption can be saved.

4. Conclusion

In this paper, we present the high-efficiency refrigerator test system, which leads to the realization of the unmanned operation of refrigerator test under the working environment of robot. The high-efficiency refrigerator test system achieve unmanned operation, improve the efficiency of refrigerator test and save energy consumption. It has been applied by household appliance enterprise in Qingdao. In a typical application scenario as shown in figure 5. It realizes the timely selection steady state interval and transition of test stage. It improve the production efficiency.
Figure 5. The test scenario of HERTS.

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