Design of TR module aging control system based on adaptive filtering algorithm

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Abstract. As an important part of active phased array radar, the working stability of TR module has a direct impact on the detection performance of radar system. This paper designs a set of TR electrical aging test system, for batch component aging test at the same time. Based on the principle of spontaneous heating under full power operation, the test environment was designed. The design of wave control board circuit met the excitation requirements in the work of the components. Meanwhile, the adaptive filtering algorithm and classical control theory were combined to control the TR working temperature, which realized the requirements of stable aging test of batch TR module. This system can accurately monitor whether the TR component products fail in the process of electrical aging, and at the same time can more accurately control the working temperature of the tested products within the required temperature range. It also provides a technical basis for further analysis and improvement of TR component product performance parameters. This design method can also be applied to the aging screening of other electronic board cards or components with high reliability requirements.

1. Introduction

With the development of radar technology, phased-array radar has been used more and more widely. Among them, the Transmitter and Receiver (TR) component constitutes the array function module. One end of the T/R component is connected to the antenna, the other end is connected to the IF processing unit, which constitutes a wireless transceiver system, and plays the core role of phased-array radar.

TR module is mainly used to amplify the transmitted signal, amplify the received signal, and control the amplitude and phase of the signal [1]. It is composed of low noise amplifier, power amplifier, limiter, phase shifter, etc. An active phased array radar contains tens of thousands of TR modules, and the cost of TR modules generally exceeds 50% of the total cost of the radar [2]. The success of its design determines the cost, productivity and system performance of the whole radar. Therefore, TR module can work normally and stably, which directly affects the working stability of the whole radar system.

2. Research content

The aging test of TR module is particularly important for the manufacturing integration of phased-control radar. This paper, by using the TR component full power work under the principle of spontaneous heat TR component wave control circuit board design, provide excitation signal components and test environment, and USES the adaptive filtering algorithm and classical control algorithm, temperature control and adjustment of TR module work, implements multiple TR component under the prescribed length of charged burn-in test requirements of the test system.
3. System design
TR module electrical refining system is structurally divided into four areas: electrical refining unit area, power supply instrument area, man-machine interaction area and multi-function area. It adopts the cabinet frame type fixed structure, which is composed of three units. The cabinet body bears the fixtures and all the instruments needed in the process of assembly aging. According to the function distribution of the system, the overall structure of the system is shown in Figure 1.

Among them, the electrical aging unit area is the core unit of the system, including TR module control board module, TR module tested products, temperature sensor and cooling fan. The main function of the unit area is to provide working excitation conditions for TR module products, collect TR module temperature and control cooling fan work. Thus, the aging temperature of TR module is controlled within 70°C±2°C.

4. Hardware Design

4.1. Control Panel Design
The control board in the TR component's electrical experience test system is designed using ARM+FPGA architecture. The circuit unit module of the control board is composed of the following functional circuits: Ethernet interface, 1-channel PWM output, 4-channel TTL input, 16-channel TTL output, 4-channel MOS tube (analog relay), 1-channel PWM, 1-channel temperature, 1-channel current, 4-channel voltage acquisition.

4.2. Key Hardware Design

4.2.1 ARM controller
The ARM controller is based on a high-performance ARM Cortex-M432-bit RISC core and operates at up to 180MHz. The Cortex-M4 core uses floating-point unit (FPU) single-precision support for all ARM
single-precision data processing instructions and data types. It also implements a set of DSP instructions and memory protection unit (MPU) to improve the security of the application \[3\]. The appliance contains high-speed embedded memory (up to 2Mbyte of flash memory, up to 256Kbytes of SRAM), up to 4Kbytes of backup SRAM, and extensively enhanced I/OS and peripherals connected to two APB buses, two AHB buses, and a 32-bit multi-AHB bus matrix.

4.2.2 The FPGA controller
Cyclone IV E series of Altera is selected as FPGA module. This series of chips have great power consumption and cost-effective advantages. It has 10320 logic units, 414Kbits of embedded storage resources, 23 18×18 embedded multipliers, 2 universal phase-locked loops, 10 global clock networks, 8 user I/O banks and a maximum of 179 user I/O. Communication with ARM controller via SPI, clock rate 10Mbps \[4\].

4.2.3 Input/output signal controller
4 channels TTL level signal output and 16 channels TTL level signal input are provided through the driver chip. The test bench control board line box uses SN74LVC8T245PWR to realize the input and output drive.

4.2.4 Design of temperature acquisition module
The test platform is designed with a temperature acquisition sensor PT100, which has a good uniform temperature-resistance conversion characteristic. In order to eliminate the resistance interference introduced by the measuring wire, the three-wire PT100 temperature sensor is selected in this scheme, which is converted into digital signals through the MAX31865 chip and transmitted to the ARM controller through SPI.

According to the old smelting temperature and the current product temperature conditions, the output power of the cooling fan is controlled to achieve the temperature control function, to ensure that TR products work within the rated temperature range, the temperature control accuracy is ±1℃, to meet the system control accuracy requirements.

5. Control Software Design
Modular design idea is adopted in the software of TR module test system. Specialized design is carried out according to the technical characteristics of the system, and combined design is carried out by calling different functional modules to realize the design and development of the whole software.

As the human-machine interface of the system, the system software realizes all the users' access to the system, provides a comfortable and practical interactive interface, and improves the experience of automatic operation.

The system software is mainly designed with the following functional modules:
(1) man-machine interface: the user's most direct operation and observation window.
(2) Parameter configuration: including system configuration information, aging conditions, parameter limits and other information. The aging condition is used to configure the component environment during the aging process. The parameter limit sets the critical value of the system automatic protection and alarm.
(3) Equipment control: including the program control of the parameters of each instrument and meter in the system, and the management of the aging process of each component operating table.
(4) Real-time display: real-time monitoring of the status of each hardware module in the system, and alarm in case of abnormal.

5.1. Temperature control function
The temperature control function module is responsible for controlling the temperature of the component, and adopts the double closed-loop control strategy to adjust the temperature of the component to keep it within a certain range. The double closed-loop regulation schematic diagram is shown as below. The
control board collects the temperature value of TR component in real time through the temperature acquisition module, and uploads it to the upper computer. The upper computer control software adjusts the cooling fan by analyzing the difference between the acquisition temperature and the set temperature, so as to realize the temperature control of TR component and keep it within a certain range. When the cooling fan power reaches the maximum value, if the TR component temperature is still beyond the control range, the power consumption of the TR component can be adjusted by adjusting the duty ratio of the output pulse, so as to achieve the function of reducing the component temperature.

![Control Module Diagram](Fig. 3: Principle of temperature regulation control)

5.2. Adaptive filtering function

Due to the influence of the test environment and the increase of circuit noise under high temperature conditions, noise interference is easy to occur in the temperature collection of TR module products, which will affect the effective real-time control strategy \[5\]. Therefore, it is necessary to filter the temperature collected.

The adaptive numerical filter is to model the collected time series by using the adaptive numerical filter, so as to get the fitting model of the measured parameters of the system, and through the analysis of its residual sequence to judge whether abnormal occurs in the system. This method has a good ability to detect the abrupt faults of the control system, and it does not need the statistical characteristics of the system noise, has a good real-time performance, and has a strong robustness to the system model mismatch.

The structure diagram of system identification using adaptive numerical filter is shown below.

![System Identification Diagram](Fig. 4: Schematic diagram of system identification with adaptive numerical filter)

Let \( W_0 \) be the input of the adaptive numerical filter, \( y_0 \) be its output, \( X_0 \) be the input of the adaptive numerical filter system, that is, the process variable to be detected, \( M \) be the order of the adaptive numerical filter, \( e_0 \) be the difference between \( X_0 \) and \( y_0 \), \( \hat{X}(t) \) is the estimate of the state \( X(t) \), and has the following relationship

\[
e(t) = X(t) - y(t) \tag{1}
\]

\[
y(t) = \hat{X}(t) = \Phi_t W_t \tag{2}
\]

Among (2):

\[
\Phi_t = [\varphi_{t1}, \varphi_{t2}, \ldots, \varphi_{tM}]^T \tag{3}
\]

\[
W_t = [\omega(t), \omega(t-1), \ldots, \omega(t-M+1)]^T \tag{4}
\]
\( \Phi_i, \quad i=1,2, \ldots, M \) is the weight of the filter at time \( t \), and its recursive formula is

\[
\Phi_{i+1} = \Phi_i + 2\gamma W e(t)
\]  

(5)

Among (5):

\[0 < \gamma < \frac{1}{\lambda_{\text{max}}}, \quad \lambda_{\text{max}} \]

represent the maximum eigenvalue of \( E[W, W^T] \).

Take the time delay \( \tau = 1 \), and the fitting model of state \( X(t) \) can be obtained as

\[
\chi(t) = \Phi_{i1} x(t-1) + \Phi_{i2} x(t-2) + \cdots + \Phi_{iM} x(t-M) + e(t)
\]  

(6)

For stationary time series \( \{e(k), k=1,2,3,\ldots\} \), the adaptive numerical filter will converge asymptotically, and it can be proved that the prediction error sequence \( \{E(k)\} \) is a zero-mean, Gaussian white noise, and has a time-invariant variance \( \sigma_e^2 \).

After the adaptive numerical filter converges to a stationary time series \( \{X(k)\} \), when the mutable element fault or abnormal data \( X(k) \) caused by sensor fault enters the system, the prediction error \( \{e(k)\} \) will change immediately and its white noise performance will be destroyed. Therefore, abnormal conditions in the system and whether faults occur can be detected according to this characteristic. In terms of detection standards, we adopt the 3\( \sigma \) criteria commonly used in industrial production [6], and the judgment method is calculated by the statistics defined below.

Defining Statistics,

\[
S_e^2 = \frac{N}{2} \sum_{\tau=1}^{P} r_{ee}^2(\tau)
\]  

(7)

The formula is the discriminant error sequence \( \{e(j), j= t-n+1, t-n+2, \ldots, k\} \) is an indicator function of white noise performance.

The sample variance of \( \{e(i)\} \), calculated by the following formula

\[
S_e^2 = \frac{1}{N} \sum_{i=1}^{N} \left[ e(k+1-i) - \bar{e}(k) \right]^2
\]  

(8)

\[
\bar{e}(k) = \frac{1}{N} \sum_{j=K-N+1}^{K} e(j)
\]

\( r_{ee}^2(\tau) \) is the self-covariance of \( \{e(i)\} \)

\[
r_{ee}^2(\tau) = \frac{1}{N-\tau} \sum_{i=1}^{N-\tau} e(t+1-i) e(t+1+i) - \left[ \bar{e}(t) \right]^2
\]  

(9)

Where, \( P \) is freely chosen, but it should be \( P \leq \frac{N}{4} \).

It can be verified that the approximately obeys the distribution and its degree of freedom is \( P \). Therefore, the white noise property of \( \{e(i)\} \) can be determined by using the distribution obeys or not. If some continuous inputs \( \{e(i)\} \) do not have the property of white noise, it can be judged that the input of the system is abnormal data, that is, the system has a fault. If some individual (or discontinuous few) data in a continuous input signal \( \{E(k)\} \) do not have the white noise property, while the white noise property of the whole data is not greatly affected, these data can be determined as poor-quality data, indicating that the system does not have a fault [7].

The workflow of the adaptive filtering software module is shown in the figure below.
6. Implementation
For TR module test in the burn-in test, and work for a long time after collection and data analysis, contrast test shows that using the adaptive filter algorithm processing of test data, can accurately reflect the TR component products in the process of electrical aging whether fails, and be able to accurately locate failure time and affect the outcome. At the same time, it is also verified that the control strategy after adding the adaptive filtering algorithm can more accurately control the working temperature of the tested product within the required temperature range.

7. Conclusion
Based on the adaptive filtering algorithm, this paper designs the electro-sophisticated test and control system of TR module, develops the hardware module of the wave control board of TR module, and develops the software of the working temperature acquisition and control system of TR module. After a long term of electrically charged smelting test and analysis of the test data, the effectiveness of the technical scheme is verified, which provides a technical basis for further improving the performance index of TR Module.

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