Design and Research of Online Measuring Device of Dielectric Loss Angle in Insulation Test Based on STM32

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Design and Research of Online Measuring Device of Dielectric Loss Angle in Insulation Test Based on STM32

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Abstract. In this paper, an online measuring device of dielectric loss angle for insulation test is introduced. Based on the detection principle of zero-cross comparison method, the device uses STM32F205RCT6 chip as the control core of signal measurement and processing, and communicates with UART interface and Zigbee module, and the hardware circuit design of signal measurement and processing is completed. It has been proved by experiments that the measuring device has high measurement accuracy and stability. In addition, after analyzing the dielectric loss angle variation curve, this paper proposes a compression recording algorithm based on curve segmentation line fitting. The simulation results show that the algorithm can effectively reduce the storage space required for recording and has certain practicability.

1. Introduction

The insulation of electrical equipment directly affects the safe running performance and life of the equipment. Dielectric loss is one of the important indicators to describe the insulation performance, and it is also an important evaluation parameter to measure the insulation degree of equipment or materials [1-3]. The dielectric loss angle is the complementary angle between the vectors of the current and voltage in the dielectric. The tangent of the dielectric loss angle can be used to reflect the dielectric loss, determine the insulation state of the dielectric, and find its potential defects and faults. This value is also a dielectric constant, which is only related to the properties of the insulating material, and is independent of the shape and size of the insulating material [4]. By measuring the dielectric loss angle and calculating its tangent value, it can reflect the degree of insulation defects and inferior quality changes of the insulating material. At present, the life test of insulating materials usually only uses the experimental loop current value to determine the life of the insulating specimen [5], which cannot fully reflect the characteristics of the degree of insulation degradation.Therefore, by incre asing the online measurement of the dielectric loss angle parameter in the test, It can reduce the error of judging the end point of insulation failure.In this paper, an online measuring device for dielectric loss angle of insulating specimens in insulation test is designed. Based on this, a compression recording method for dielectric loss angle and its variation curve is proposed to alleviate the problem of excessive data storage space.

2. Measuring principle

As shown in Fig.1,the device based on the priciple of zero-cross comparison method,the voltage U(t) and current I(t) signals applied to the insulation sample are processed by a hardware circuit to deal with the two signal phase difference of zero crossing time into the TLL level rectangular wave pulse width measurement of S_t, that is, let U(t) and I(t) be the same frequency sinusoidal signals,assuming that the phase difference between the two signals is θ, and the period is T, the corresponding rectangular wave pulse width is T_x, and the phase difference can be expressed as $\theta=T_x/T*360^\circ$, in this design, the edge trigger function of the timer input captured in the STM32 microcontroller is used, and set the operating frequency of the timer to f. When the rising edge of the rectangular wave signal comes, the trigger timer enters the interrupt and the program records the current timer count value, n1, similarly, when the falling edge comes, the timer count value, n_2, is recorded, simultaneously, the timer value is cleared by program, in addition, the program will record the Timer difference value, n_3, between every two rising or falling edges. The rectangular wave signal period T=n3/f, and the rectangular wave pulse width $T_x= (n_2-n_1)/f$, and the phase difference $\theta= (n_2-n_1)/n_3*360^\circ$, the calculation of dielectric loss Angle [6] is $\delta= 90^\circ-\theta$.

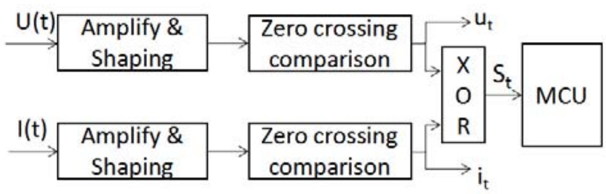

Figure 1. Signal measuring principle.

3. Hardware design

3.1. Signal Preprocessing Board

In this design, the phase difference of the measured signal is obtained by using the zero-crossing comparison method under the TTL level rectangular wave signal, Therefore, the analog signal to be measured needs to be converted into digital signal processing to reduce the noise affecting the measurement effect,Therefore, a PCB for signal preprocessing is designed.As shown in Figure 2,the specific functions are as follows:the input interface of the signal to be measured connects two sinusoidal signals to be measured; The signal conversion unit mainly converts the phase difference of sinusoidal voltage current signals of the same frequency and amplitude into TTL level rectangular wave signal output by amplifying the shaping circuit, zero-crossing comparator and or gate circuit. The signal output interface is responsible for output sinusoidal signal and rectangular wave signal before and after signal processing to the measurement control board; the battery charging circuit is responsible for charging the 18650 lithium battery pack. The 18650 lithium battery pack module is mainly responsible for providing isolated stable dc power for the signal conversion unit, and also serves as the backup power for the whole measuring device.

3.2. Measurement Control Board

The signal to be measured through the signal preprocessing board contains digital signals and analog signals. In order to collect and measure these signals, and display and transmit the measurement results, a measurement control board with STM32F205RCT6 as the main control chip is designed.With rich peripheral resources and well-functioning interfaces, the resources and interfaces mainly involved in this design are shown in Figure 3. For example, SPI is mainly responsible for communication between the external LCD display and the main control chip; ADC is mainly used to measure the sine wave in the signal to be measured. The Timer mainly USES the Timer input capture function to measure the preprocessed rectangular wave signal and obtain the phase difference between two groups of sine wave signals. The UART can be used directly to measure the real-time output of data, or it can be connected to the Zigbee network built by the Zigbee module to complete the wireless transmission of measurement data.he DMA is primarily responsible for coordinating the ADC and Timer for the transfer and processing of in-chip data. The HD35-SPI LCD module is responsible for displaying the measured data and sigbal waveforms.

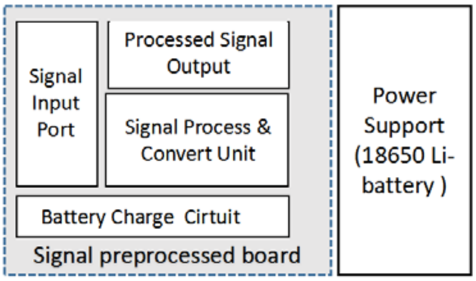

Figure 2. Signal preprocessing board.

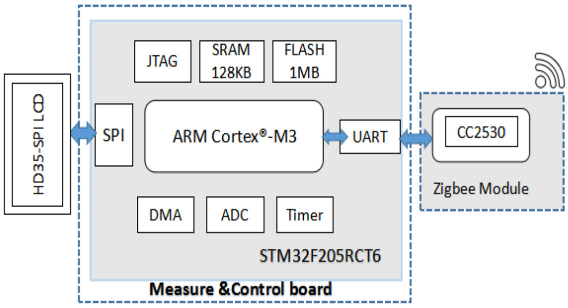

Figure 3. Measurement control board.

4. Software design

4.1. STM32 Measuring Program Design

The design uses the Keil MDK development tool to complete the program coding and debugging of STM32F205RCT6 microcontroller based on C, the specific process of the program is shown in Figure 4. In Figure 4, the initialization part mainly includes the initialization of the STM32F205RCT6 microcontroller interface, such as: System clock initialization, SPI interface, UART interface, GPIO interface, DMA data transfer interface, ADC interface and timer initialization, LCD display initialization and Zigbee module initialization.

Program analysis: The microcontroller in this design works at 100MHz.The rectangular pulse width and period of the signal to be tested are measured through the input capture function of 32-bit timer, Timer2, and the data are transmitted through DMA. Finally, the phase difference and period of the two groups of measurement signals are obtained, which are used to calculate the dielectric loss Angle.In order to display the measurement parameters in real time on the HD35-SPI-LCD module, the 12dB ADC and DMA in the microcontroller are used to sample and transmit the measured signal, and software filtering is performed to realize the display of various parameters during the measurement process..Since the dielectric loss angle online measurement is a long-term process, the measurement device has limited storage space in this design, Therefore,based on the UART interface,the program provides two data transmission methods:UART+serial converter and UART+Zigbee.

4.2. Compressed Recording Algorithm

4.2.1. Principle. In order to *obtain* the dielectric loss angle and its variation curve, it is necessary to store valid data in the measurement process before the insulation gradually fails.It is a long-term process to monitor the change of the dielectric loss angle, the measured raw data is too large to store directly. In order to reduce the storage space of records,piecewise linear fitting method is used to compress and record the variation curve of dielectric loss angle,namely,the algorithm directly record the first measurement point (δ_1, t_1) as the starting point of the curve, starting from the second measurement point. The subsequent m measurement points (δ_i, t_i) (i = 1... m) are straight-line fitted to obtain the k-th straight line (t_{KB}, t_{KE}, A_K, B_K), where t_{KB} is the start time of the straight line. t_{KE} is the end time, A_K is the slope of the line, and B_K is the intercept. If the residual squared error of the line obtained by adding a new measurement point exceeds the threshold,the previous line is saved and the next line is constructed with the measurement point as the starting point until all the measurement points of the fitting interval are fitted.

4.2.2. Symbol Description. (1) D = {(δ_1, T_1) ... (δ_i, T_i)} (i = 1, 2 ... n) is the coordinate set of the data points, where (δ_i, T_i) is expressed the value of the dielectric loss angle is δ_i at T_i moment. (2) The mathematical model for setting the curve of the dielectric loss angle is y=Ax+B. (3) $P_k = \sum_{i=1}^{n}(\delta_i - A_k t_i - B_k)^2$ represent the sum of squared residuals between the k-th fit line and the n data points. (4) The F is the reference threshold of P_k, which is the parameter used to separate the fitting lines of each segment. (5) Z={(T_{1s}, T_{1e}, A_1, B_1),...,(T_{ks}, T_{ke}, A_k, B_k)} (1<k<n), representing a data set consisting of k segmented lines, (T_{ks}, T_{ke}, A_k, B_k) represents the k-th segment fitted line, where T_{ks} is the start time , T_{ke} is the end time, A_k is the slope of line , and B_k is the intercept. (6) Compressed sequence of data W= {T_{1s}, T_{1e}, A_1, B_1, T_{2e}, A_2, B_2, T_{3e}, A_3, B_3... T_{ke}, A_k, B_k}. (7) The subscript k represents the serial number of the fitted line. (8) The n represents the number of points to be fitted. (9) The E indicates the completion identification of the dielectric loss curve for the piecewise straight line fitting. If E=1, it means completion, otherwise it is opposite.

4.2.3. Algorithm Design. **Step 1**: Take n=1000. For every n points on the curve, let the threshold F=0.311, let i=1, j=2, k=1, E=0, and add n points to the D coordinate set. **Step 2**: For the data points on the D interval [i, j], the least square method is used to obtain the k-segment fitting straight line equation: y=A_kx+B_k, and get P_k. **Step 3**: If j+1>n, let E=1, output y=A_kx+B_k, and add its information to the Z set. **Step 4**: If P_k<=F, then j=j+1, go to step 2. **Step 5**: If P_k>F, output y=A_kx+B_k, and add its information to the Z set. And let i=j, j=j+1, k=k+1, go to step 2. **Step 6**: If E=1, Z set is formed into compression sequence W through deredundancy operation, and W becomes the final compressed data. **Step 7**: Retake the next following n data from the curve and repeat steps 1 through 6.

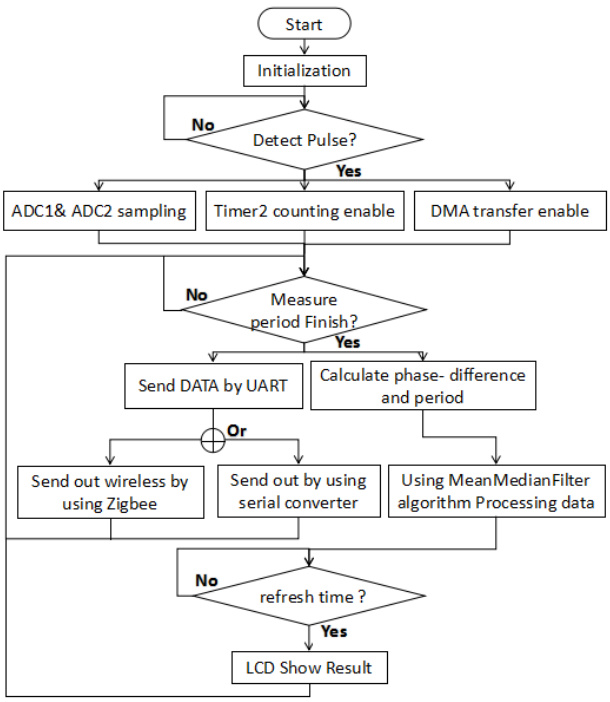

Figure 4. Flow of program.

5. Experiment and analysis

5.1. Data Transmission Test

In order to test the two data transmission modes of the design measurement device, namely: UART+ serial converter direct transmission; UART+Zigbee module wireless transmission, since the latter transmission mode includes the former,the second data transmission method can be directly tested to complete the two transmission methods above. First, the various modules and devices used in the test will be physically connected as shown in Figure 5. The flow direction of data transmission is as follows: STM32 microcontroller transmits data to Zigbee terminal node module through UART interface, and the module transmits data to Zigbee coordinator module through established Zigbee wireless network. The module transfers the data to the external computer through the UART serial port converter. Finally, the specific test results are shown in Figure 6. P=036.000 indicates that the phase difference between the two sets of measurement signals is 36˚, and T=0020.0000 represents the period of the signal is 20ms. It is concluded that the designed measuring device can transmit data through two data transmission modes above and achieve the purpose of the design.

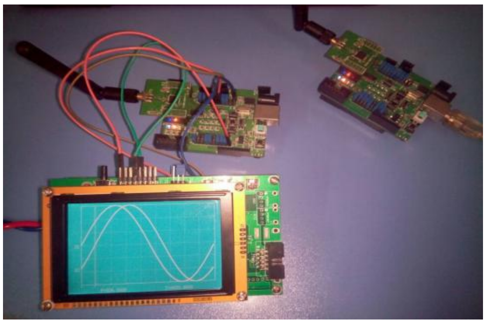

Figure 5. Physical connection of modules.

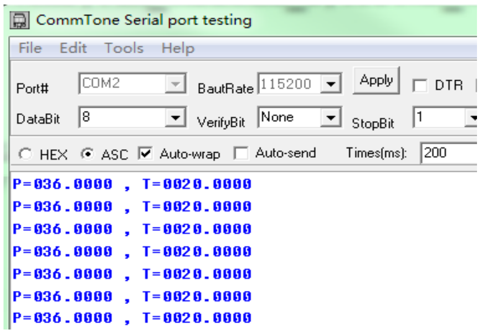

Figure 6. Result of data received.

5.2. Measurement Error Analysis

In order to evaluate the measurement performance and error of rectangular wave pulse width in this design, several sets of rectangular wave signals with different duty cycle and frequency of 50Hz are output by signal generator as the experimental phase difference analog signal source. Different duty cycle of rectangular wave represents different pulse width of rectangular wave. The measured signal is captured by timer in microcontroller. The frequency of the timer is 50 MHz, so the resolution of pulse width can reach 1/50MHz=0.02 us. If calculated by 50Hz signal, the minimum resolution of the phase difference of the signal is 0.02/ (20*1000) *360˚=0.00036˚=2pi*10^{-6} rad. After many experiments, the measurement data of different duty cycle are processed by arithmetic average. The specific measurement effect and error are shown in Table 1. The measurement error of the width of the signal pulse width can be controlled below 0.3‰ by the table, which can meet the high precision requirement of pulse width measurement and achieve the expected effect.

5.3. Simulation and Analysis of Compressed Recording Algorithm

The experiment will simulate the dielectric loss angle change of the insulating medium based on matlab,and the curve y=0.01*exp (t)+0.75+noise is used to simulate the change rule of dielectric loss angle, that is, the curve of the upper half of figure 7, where y is the corresponding dielectric loss angle (0 ~ 90˚),t is the time (0:0.01: log (8925)), and the noise is the random noise obeying the distribution of positive.According to the algorithm principle and design in Section 4.2, the program coding of the algorithm in matlab is completed, and the simulated curve of dielectric loss angle is compressed by segmented straight line fitting record, and the data is removed from redundancy. While saving the data storage space, the restored data can not affect the reconstruction of the curve of dielectric loss angle change and the judgment of the key points as much as possible.The experimental results of the recording algorithm are as shown in the curve of the lower part of fig. 8. The solid dots in the curve represents the key coordinate point required for the algorithm to record, and the line of the two solid dots represents the fitting line between the two points.In simulation experiment, the number of data points in the curve of dielectric loss angle is log (8925)/0.01≈909. If all the data need to be saved before the recording algorithm is used, we assume that each data is calculated in 4 bytes storage space.

The position of the data point (δ, t) needs the storage space of 2*909*4B=7272Byte.After using the recording algorithm, the k-segment fitting line is represented by the format of compressed data sequence W, and the required storage space is: (k-1)*3*4B+1*4*4B,for k the average value of 1000 repeated experiments is 42, the required storage space is (42-1)*3*4B+1*4*4B=(42-1)*3*4B+1*4*4B =508B, and the compression ratio of data reaches 508/7272*100%=6.9856%. The simulation shows that the compressed recording algorithm can greatly save the data storage space and has better data reproduction ability.

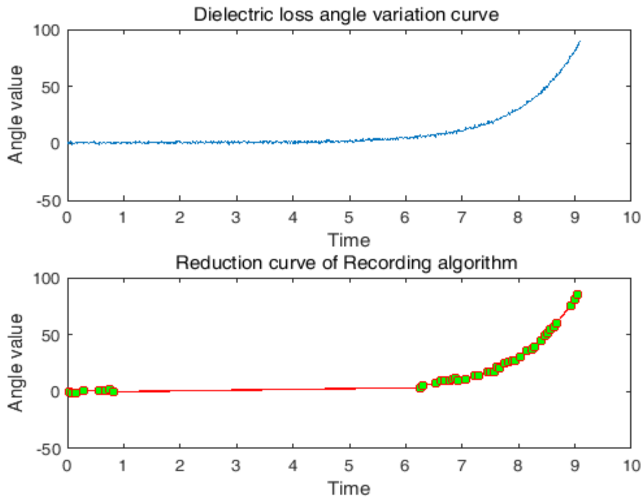

Figure 7. Simulation results of algorithm.

Table 1. Measurement of pulse width.

+Duty	Times	MAE(1)	MRE(2)
1%	5000	0.0482 us	0.2431 ‰
5%	5000	0.2111 us	0.2111 ‰
10%	5000	0.4436 us	0.2218 ‰
20%	5000	1.0802 us	0.2700 ‰
40%	5000	1.4126 us	0.1765 ‰
80%	5000	3.1087 us	0.1943 ‰
90%	5000	4.3980 us	0.2443 ‰
95%	5000	4.7731 us	0.2512 ‰

(1) Mean Absolute Error. (2) Mean Relative Error.

6. Conclusion

Online measurement of dielectric loss angle provides a powerful help for improving the reliability of power equipment and insulating media and reducing the economic loss caused by insulation faults. Based on the analog electronic and digital processing technology, this paper designs an online measurement device for dielectric loss angle based on STM32 microcontroller, and establishes a complete monitoring system for data measurement, transmission and storage, and proposes an intelligent compression recording algorithm,which can effectively reduce the storage space required for recording and has certain practicality， and the algorithm achieves the expected effect.

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