Development of Thickness Measurement Software for Aircraft Absorbing Coatings Based on Magnetic Force Measurement

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ABSTRACT

In this paper, a magnetic-force based thickness measurement model was established based on the physical properties of radar absorbing coatings that are easy to be magnetized and the experimental data obtained from the standard samples with titanium alloy substrate coatings. The experimental data obtained from the thickness measurement experiment of the standard samples with titanium alloy substrate coatings were fitted by using least squares method. A thickness measurement sensor was developed based on the STM32 microcontroller, which solved the problem that the traditional wireless design was unable to balance transmission distance, anti-interference, and power consumption. On this basis, thickness measurement software was developed based on WinCE 6.0 and measurement experiments were done. The experimental results showed that this magnetic-force based thick measurement system had the advantages of simple structure and high software reliability.

Keywords: radar absorbing coating; magnetic force-based thickness measurement model; wireless module; STM32 microcontroller; data fitting

1. INTRODUCTION

At present, in the thickness measurement of the radar absorbing coating of a certain type of aircraft, the existing measurement technology has poor measurement accuracy and on-line thickness measurements are limited by various factors[1]. For example, the thickness measurement technology based on the magnetoresistance method, which can only be applied to measuring the thicknesses of magnetic coatings, is vulnerable to interference by the Earth's magnetic field and other factors[2]. The supersonic echo method, which has poor measurement accuracy, easily produces strong scatterings on the coarse grains within materials, resulting in a lot of random scatterings during the main testing period. This affects the quality of sound waves, easily leads to misjudgments, and makes it impossible to read the measured value. Especially when the absorbing coating has a rough surface with scratches, the scattering will be more serious, which tends to make it impossible to perform measurements [3].

In order to solve the problems mentioned above, we established a thickness measurement model for the magnetic-force based measurements of absorbing coatings on the basis of the physical properties of radar absorbing coatings, and developed thickness measurement software for absorbing coatings based on the model. A stable magnetic field was formed with the aid of an electromagnet and the radar absorbing coating which is magnetic conductive. When coating thickness changed, or defects such as bumps, peeling and shedding occurred, it would inevitably lead to changes in the magnetic force between the coating and the electromagnet. The thickness changes or the occurrence of defects could be identified easily by detecting the changes in magnetic forces, which was rather suitable for defect detection and the quality testing of damage repairs. The development of thickness measurement software could offer a new technological approach for thickness measurements of this absorbing coating.

2. DESIGN OF THE THICKNESS MEASUREMENT SYSTEM FOR RADAR ABSORBING COATINGS

2.1 Modelling of the thickness measurement for radar absorbing coatings

An action model of the magnetic force between radar absorbing coatings and electromagnets, which is given in figure 1, was built based on electromagnetic theory.

The magnetic force of magnets follows from the following equation: magnetic force = magnetic force per unit volume × volume of the magnet. Because the volume of a radar absorbing coating is proportional to its thickness H, according to the above equation, electromagnet magnetic force F is proportional to the thickness of a radar absorbing coating H. The design principle of this magnetic-force based thickness measurement sensor is as follows: after an electromagnet is connected to a direct current power supply, a coating will be magnetized, resulting in a magnetic force between the coating and the electromagnet. Because the electromagnet is mounted below a tension sensor, the magnetic force is transformed to a tension acting on the tension sensor. According to electromagnetic theory, the tension is proportional to the coating thickness. Therefore, the coating thickness can be calculated, provided that the tension is measured.

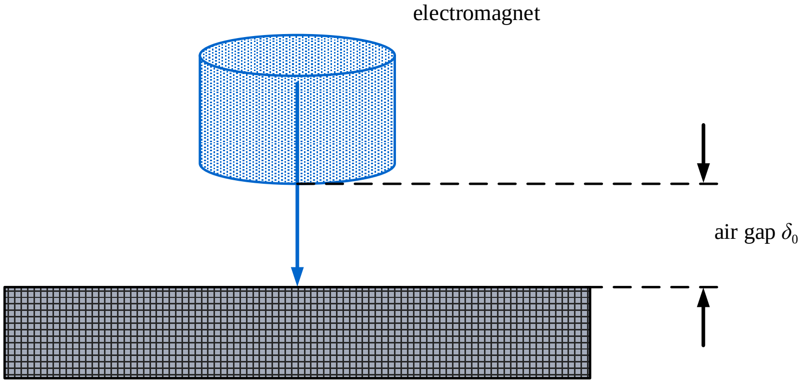


Fig.1 Model of the magnetic force between an electromagnet and a radar absorbing coating

Because the current in a electromagnet coil *I* is only related to supply voltage *U* and coil resistance *R*, the magnetomotive force (represented by *F*) between the electromagnet and the radar absorbing coating, which follows from $F = NI$, remains unchanged when the thickness of air gap δ_0 and current *I* are kept constant.

Magnetic force *F* is proportional to the square of magnetic flux Φ, and magnetic flux Φ is inversely proportional to the square of air gap according to other formulas. Thus:

$$F \propto \left(\frac{1}{\delta_0}\right)^2 \cdot H \tag{1}$$

in which δ_0 is the air gap, *H* is the thickness of a radar absorbing coating. The air gap was designed to be a constant, usually 2mm. Then magnetic force *F* was mainly determined by coating thickness *H*.

2.2 Experimental verification for the modelling of thickness measurement

During the experiment, the magnetic forces of the standard samples with titanium alloy substrate coatings were measured, the measurement results of the samples with coating thicknesses of 0.1mm, 0.15mm, 0.2mm, 0.3mm, 0.45mm, 0.55mm are given in figure 2. Fitting the experimental data by using least squares method, the computational relation between the magnetic force and the coating thickness could be obtained[4], which is described by

$$F = 532.03 \times H + 133.68 \tag{2}$$

in which, F is the magnetic force; H is the absorbing coating thickness of a coated sample. The unit of the magnetic force is g.

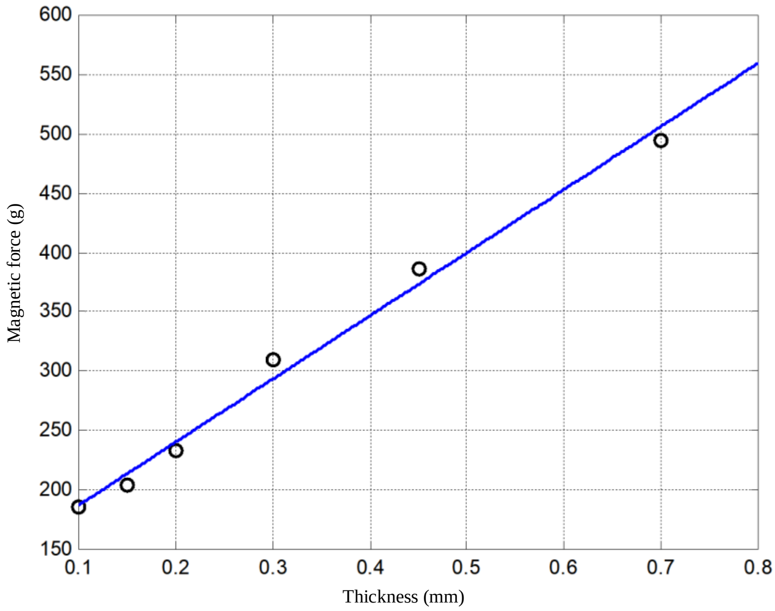


Fig.2 Relation between the magnetic forces and the coating thicknesses of the samples with titanium alloy substrate coatings

3. DESIGN OF THE THICKNESS MEASUREMENT SOFTWARE FOR RADAR ABSORBING COATINGS

3.1 Force measuring sensor module and the wireless sensor acquisition software for hand-held terminal

In order to facilitate measuring the thicknesses of various coatings on line, the wireless sensor technology was developed. The wireless sensor system is sketched in figure 3, which consists of two parts: the thickness measurement sensor and the hand-held terminal.

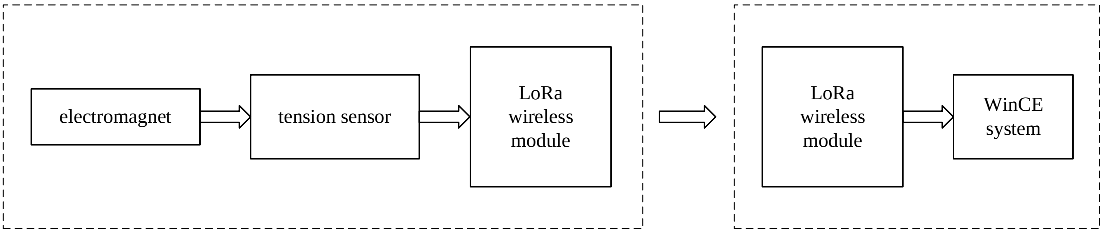


Fig.3 Block diagram of the wireless sensor system of the thickness measurement for radar absorbing coatings

In the thickness measurement sensor, the electromagnet transmits the magnetic force being acted on itself to the tension sensor. The tension sensor selected was a digital one, which can output the data in ModBus format through a serial port. Through a UART serial port, the tension sensor and other modules send the acquired data to the STM32 microcontroller which receives the data in a way of serial port interrupt receiving, and then send the data to the LoRa module through the SPI interface, and control this module to send the data to the wireless receiving module in the hand-held terminal wirelessly. The LoRa wireless receiving module, also controlled by the STM32 microcontroller, sends the received data to the WinCE system in the host computer, and then the data are received, processed, and displayed by the hand-held terminal through the serial port of the WinCE system.

The wireless module designed is sketched in figure 4. The control core of the module is the STM32 microcontroller. The tension sensor and other modules send the acquired data to the STM32 microcontroller through a UART serial port. The microcontroller receives the data in a way of serial port interrupt receiving, and then sends the data to LoRa module through a SPI interface and control this module to send the data to the wireless receiving module in the hand-held terminal wirelessly. The LoRa wireless receiving module, also controlled by the STM32 microcontroller, sends the received data to the host computer (WinCE system).

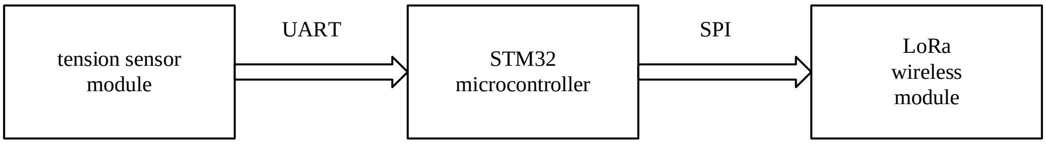


Fig 4. Block diagram of the LoRa wireless module

The experimental devices we developed are given in figure 5, in which figure 5(a) shows the magnetic-force based measurement sensor and figure 5(b) shows the hand-held terminal used for running the thickness measurement software.

(a) Thickness measurement sensor (b) Hand-held terminal

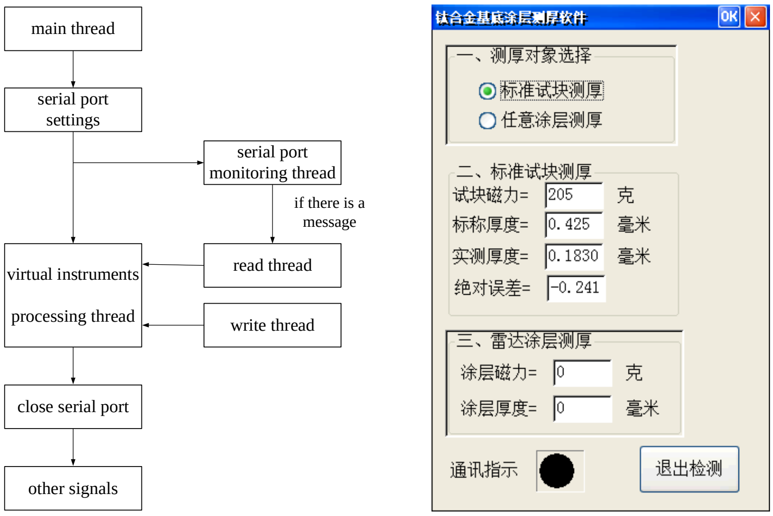
Fig.5 Experimental devices for the magnetic-force based thickness measurement

The main design work of the software for wireless sensor acquisition was the design of the receiving program for the wireless module, which was developed on a STM32F030F4P6 microcontroller with C Programming Language, and the development environment adopted here was Keil uVision5.0. The source code of the receiving portion of wireless module is as follows:

```
if((Get_SX1278_IRQ_Status() & 0x40) == 0x40) //Receiving interrupt.
{
addr = SPIRead(LR_RegFifoRxCurrentaddr); //Previous data segment address.
SPIWrite(LR_RegFifoAddrPtr,addr); //Point to the current receiving address.
packet_size = SPIRead(LR_RegRxNbBytes); // The number of bytes received during the current interrupt.
SPIBurstRead(0x00, RxData, packet_size);//// Store the received data into array RxData.
for(i = 0 ; i < packet_size ; i ++)
{
UART_send_byte(RxData[i]); /// Send the received data to WinCE 6.0 and the received data is processed by the software.
}
sx1276_7_8_LoRaClearIrq();          // Clear the interrupt flag.
return(packet_size);
}
Else
return(0);
```

3.2 Development of the application software for thickness measurement based on hand-held terminal

The main design work of the second part of the application software for thickness measurement running on the hand-held terminal included: the design of the interrupt receiving program for the received data from wireless acquisition based on WinCE serial ports; the design of the interface for the thickness measurement software and the data processing program. Both the man-machine interaction and signal transmission of the thickness measurement software were realized with serial communication. The serial communication in the WinCE6.0 system included: parameter settings (port selection, baud rate, data bit); opening ports; creating serial receiving threads and interrupt handling, etc. The serial communication was realized with multi-thread technology in WinCE6.0. The user interface thread was used as a main thread to offer a user-friendly interface and to process the data and messages, and the background thread was used for serial port read-write operation. The serial port monitoring process was used to detect whether the data was being sent to the receiver. If it was true, the monitoring thread sent a message to the read thread which was used to monitor the serial port status. When a message arrived, the read thread received the data, read it in time, and sent it back to the main thread through a callback function pointer. The thread was triggered by the thread massage sent by the main thread, and wrote data to the serial port. When user closed the application (i.e., hided the virtual instruments), the thread exited.



(a) (b)

Fig.6 Serial port operation flow and interface of the thickness measurement software for coatings

In the development of the magnetic-force based thickness measurement software for radar absorbing coatings, the development platform adopted was VS2005, and VC++ 6.0 was used as the development language. The software was developed based on the model of the magnetic force-thickness data obtained from the measurement of the samples with titanium alloy substrates. The flow chart of the operation software for receiving measurement results through the serial port is given in figure 6(a), and the operation interface of the thickness measurement software was divided into three function modules: selection of thickness measurement objects, thickness measurements of standard samples and thickness measurements of radar absorbing coatings, as shown in figure 6(b).

3.3 Testing experiment for the thickness measurement software

3.3.1 Selection of thickness measurement objects

This module was designed based on the radio button. When starting the measurement, it is necessary to select the radio button "Thickness measurement of a standard sample" first, which is mainly used for error calibration. Because after a period, the decrease in the capacity of the storage battery used for the electromagnet can lead to changes in the operating voltage of the electromagnet. These changes or those in the geomagnetic field can lead to changes in measured magnetic forces, resulting in thickness measurement errors. Therefore, it is necessary to select the function "Thickness measurement of a standard sample" for calibration.

3.3.2 Thickness measurements of standard samples

This module was used for error analysis. For example, for a standard sample with a thickness of 42mm, due to the reasons mentioned above, the measured thickness was 0.183mm instead of 0.425mm, indicating a measurement error of 0.241mm (i.e., 0.425–0.183=0.241mm). Based on the thickness measurement model described in this paper, the error was linear in theory, and a measurement error of 0.241mm occurred for each sample. More accurate measurement results can be obtained, provided that the measurement results of other samples and this deviation (i.e., the error mentioned above) are added up.

3.3.3 Thickness measurements of radar absorbing coatings

This module was used to display the thickness measurement result of an arbitrary coating. After the deviation measurement was done, just selected the radio button "Thickness measurement of an arbitrary coating" to display the interface of the thickness measurements of an arbitrary coating which is in this module.

It is necessary to perform calibration for the software with the aid of standard samples before every measurement. The calibration method is as follows: select the radio button "Thickness measurements of standard samples"→ place the thickness measurement sensor on a standard sample (the nominal coating thickness of the sample is 0.425mm)→ a "measured thickness" and an "absolute error" are displayed by the software→ select the radio button "Thickness measurement of an arbitrary coating" with a stylus pen→ place the thickness measurement sensor on the test block or structure to be measured→ the coating thickness (actual measurement result) is displayed by the software.

4. CONCLUSIONS

The measurement software for the hand-held thickness gauge described herein can be used to detect the damage on radar absorbing coatings and to measure the coating thickness after the damage is repaired. It has been shown that it is effective and feasible to measure the magnetic coating thickness using the electromagnetic force method. The measurement software obtained a more accurate thickness computational model based on fitting the experimental data with the least squares method. A more accurate measurement result was obtained by using the electromagnetic force method in measurement and correcting the error based on standard samples. This coating thickness measurement software is promising in the field of the thickness measurement of aircraft absorbing coatings.

REFERENCES

[1] Hu Zhixiong. Ultrasonic Principle and Device for Thickness Measurement of radar absorbing coating[D], Dalian University of Technology, 2013.

[2] Wang Chunguang. A Study of the Capacitive Sensor for Electromagnetic Absorbing Coating Thickness Measurement[D], Huazhong University of Science and Technology, 2006.

[3] Ye Xiuge, Fu Ming. Research on Construction Technology of Radar Absorbing Coatings[J], Modern Paint and Finishing, 2018,21(08):17-19.

[4] Li Song, Yu Haitao, Zheng Tianshui. A Technique for Thickness Nondestructive Measurement of Radar Absorbing Coatings[J], Development and Application of Materials,2012,27(05):42-45.