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STUDY ON ET TECHNIQUE TO MEASURE OXIDE THICKNESS OF RODS FOR PWR

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ABSTRACT

The ET principle for measuring the oxide thickness of rods is described in this paper, several studies have been carried out, such as: probe developing, mechanism designing, effective factors analyzing, etc. Finally, through metallurgical observation of the specimen, it is verified that the ECT results is reliable.

Key words: Probes，Effective factors，Positioning accuracy

1. INTRUDUCTION

When a reactor is running, oxide thickness will be produced on the surface of the fuel rods. This affects the heat conduction performance of the cladding seriously. And with the oxide thickness increasing, the fuel rods temperature rise unceasingly, speeding up the corrosion rate of the fuel rods, therefore the oxide thickness is one of the main parameters which affects the capability of the fuel assemblies. So it is very necessary to measure the oxide thickness termly to ensure the safe running of the rods. The examination is different from other coating examination, usually carries on in the water, which is 40 degrees to 50 degree, and the thickness is only several dozens microns, request high examination precision. Study on the oxide thickness measurement is carry out in NDT Center of NPIC to provide guidance to the oxide thickness examination of fuel rods.

2. TESTING PRINCIPLE

As shown in Figure1, when alternating current flows a coil, alternating primary magnetic field H1 will be produced around the coil. When a piece of metal is in H1, eddy current will be produced in the surface of the piece. The eddy current will produce the second magnetic field H2, the direction of H2 is opposite to the direction of H1, and H2 will be counteractive to H1, causing the impedance of the coil changing. The nearer the metal and the coil distance is, the greater the coil impedance change is, the greater the mutual inductance between the coil and metal. The equivalent circuit of the eddy current coil is also provided in Figure1.

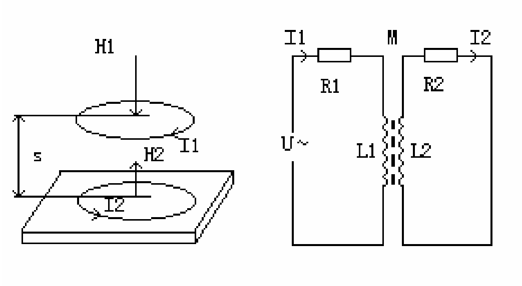


FIGURE 1.TESTING PRINCIPLE AND THE EQUIVALENT CIRCUIT

From the equivalent circuit in Fig.1, we will get the following results.
Equivalent impedance of the coil is:

$$Z= R_1+4\pi^2f^2M^2R_2/(R_2^2+4\pi^2f^2L_2^2)+j2\pi f(L_1-4\pi^2f^2L_2/(R_2^2+4\pi^2f^2L_2^2)) \qquad (1)$$

Equivalent resistance of the coil is:

$$R = R_1 + 4\pi^2 f^2 M^2 R_2 / \left(R_2^2 + (2\pi f L_2)^2\right) \qquad (2)$$

Equivalent inductance of the coil is:

$$L = L_1 - 4\pi^2 f^2 M^2 L_2 / \left(R_2^2 + (2\pi f L_2)^2\right) \qquad (3)$$

Where

R1-the resistance of the coil;
L1-the inductance of the coil;
R2-the resistance of the metal;
L2-the inductance of the metal;

From the Neumann's formula of electromagnetic theory, we can get the following expression:

$$M = \frac{\mu_0}{4\pi}\oint_{L_1}\oint_{L_2}\frac{dl_1 \times dl_2}{s} \qquad (4)$$

Where

$\mu_0 = 4\pi\times10^{-7}$H/m,is the permeability of the air;

dl_1,dl_2 is the length element of L1 and L2 respectively.

Along with the change of s, mutual inductance M will change, Z and L will change. The change of any parameter above may transform through the electric circuit as the electrical signal change, for instance voltage, electric current, frequency or phase change.

In oxide thickness examination, the probe contacts the fuel rod vertically, the oxide thickness is the distance between the probe and the substrate metal. When oxide thickness change, the probe impedance will change, the instrument will transform the coil impedance change as electrical signal, and then to carry on the examination.

3. TESTING SYSTEM

Testing system mainly include the following parts: the ET instrument and the experimental set up.

3.1 ET instrument

The ET instrument is made in EDDYSUN company, the type is EEC-35++Q. This instrument has high examination sensitivity, satisfies the oxide thickness examination demand.

3.2 Experimental setup

For the research of testing the oxide thickness, simple experimental setup has been developed. The main function of this setup is to guarantee the probe localize on the fuel rod accurately. Figure2 is the picture. It include the following parts: water tank, lift platform, probe up and down motion set, probe left and right motion set, probe ahead and backwards motion set, probe fixed set, the simulation fuel rod fixed set, draining water set.

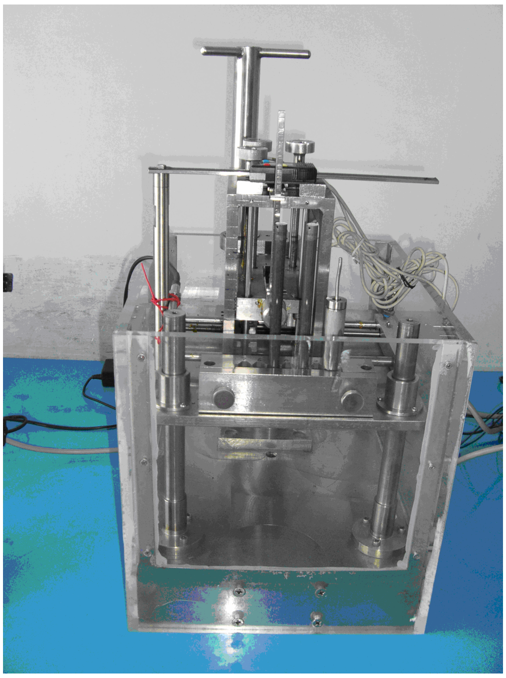


FIGURE2 EXPERIMENTAL SETUP

4. PROBE DEVELOPMENT

Block diagram of the probe is shown in Figure3. The Drive-pickup probe includes an exciting coil and a differential pickup coil. The exciting coil and the pickup coil connect the instrument separately using shielded wires. Experiments show that using this type of probe can meet the demand of the oxide thickness examination.

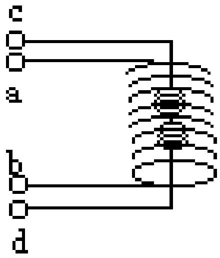


FIGURE 3.Block Diagram of the Probe

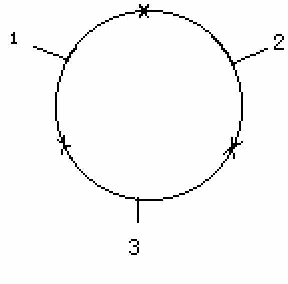
The crust of the probe using stainless steel, shields the coil not to be effected by the outside electronic signal, and in addition, enables the probe to bear the radiating environment. The interior of the probe is filled with epoxy resin, enables the probe to be waterproof.

6. TESTING PARAMETERS

When frequency is very high, in equation (3), 2πfL2>>R2, then we can get: $L \approx L_1 - M^2 / L_2$ (5), obviously, increasing excitation frequency can suppress the influence of the homogeneity of resistivity. Actually, in oxide thickness examination, uses high frequency will reduce the influence of the substrate metal, such as the homogeneity of curvature, thickness etc. However the frequency cannot be too high, because when frequency is excessively high, even if using good quality shielded wire, the influence of distributed electricity parameters can not neglect. So, the choice of frequency should compromise the two points.

7. REFERENCE STANDARD

The sketch map of the reference standard is shown in Figure 4, there are three kind of oxide thickness: 0µm, 41µm, 85µm, they distribute on the tube outer wall homogeneously. As the oxide thickness is usually between 10~60µm, the reference standard is satisfied with the demand.



1:0µm, 2:41µm, 3:85µm

FIGURE 4.SKETCH MAP OF REFERENCE STANDARD

8. EFFECTIVE FACTORS ANALYSIS

8.1 Temperature

It is the primary cause for temperature float that the resistance increases along with the temperature increase. If connecting a resistance which has the same temperature change as the resistance of the probe on the other arm of the bridge, the influence of the temperature float will be same by the two arms of the bridge, and the influence by the temperature can be eliminated. Based on this theory, a balancer is manufactured. When examination, the balancer and the probe are in the same temperature, the temperature float will be little. Figure 5 shows the experimental results.

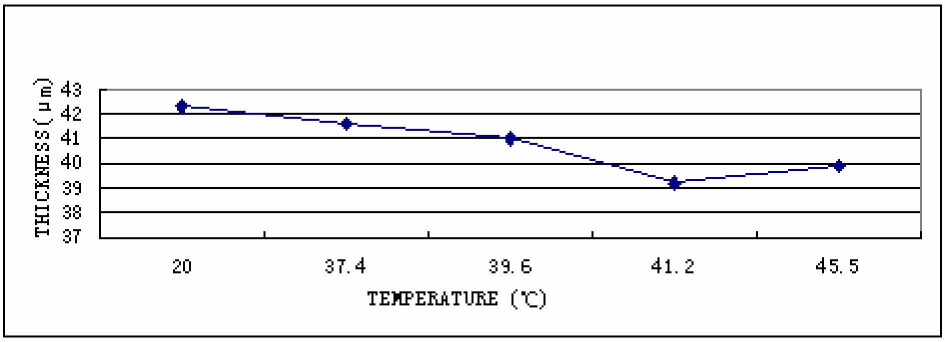


FIGURE 5.THICKNESS CHANGE WITH THE TEMPERATURE CHANGE

8.2 RELATIVE POSITION OF PROBE AND FUEL RODS

Theoretically, the probe should be vertical on the center of the fuel rod, but actually, the position always has deviation, which will affect the accuracy of the testing data. Figure 6 shows the examination results when the probe at different position. Here supposing that when the probe is on the center, the displacement is zero; when on the left of the center, the displacement is negative; when right, positive.

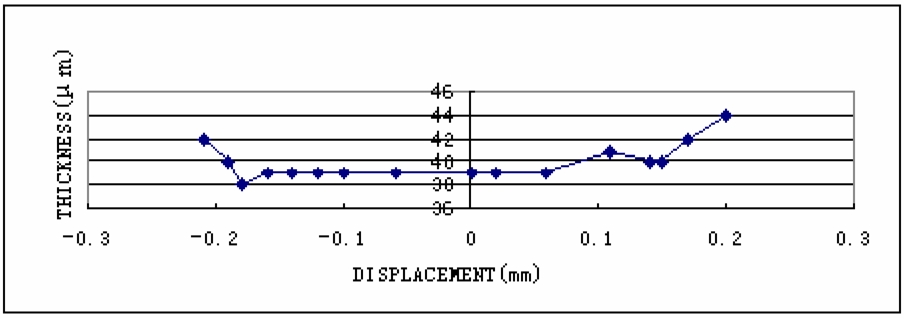


FIGURE 6.EXAMINATION RESULTS AT DIFFERENT POSITION

Figure 6.shows that the bigger the probe deviating the center, the bigger the examination error will be. Therefore, positioning accuracy should be controlled under a reasonable limitation as to guarantee the examination precision.

9. Experimental results

Finally, contrast the examination results and the metallurgical observation (MO) results to explain the testing accuracy of this method. In the experiment, four samples are tested, to each sample, examine repeatedly three times, examination results are shown in Table 1. The metallurgical observation results are also shown.

Table 1.Experimental results

Sample	Testing Result(μm)	Average(μm)	MO(μm)	Error(μm)
No.1	4.8	5.4	4.5	0.9
	5.3			
	6.2			
No.2	3.4	4.8	4.4	0.4
	4.8			
	6.2			
No.3	6.2	6.8	7.8	1
	6.9			
	7.2			
No.4	6.2	7.4	7.6	0.2
	7.6			
	8.3			

From Table 1, we can see that the testing error of this method is 2μm.