Simulation on Influence of Wall Thickness and Probe Channel Numbers on the Examination Rate of Oxides Blocking Ratio in non-Ferromagnetic Tubes

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Abstract. Oxides accumulated in the inner bend of austenite heating tubes of super critical units may cause overheating and bursting. Traditional methods could not examine oxides blocking ratio. A magnetic field simulation of the boiler tube's oxide skin blockage model has been set up in this paper. The influence of different wall thickness and different accumulation of oxide on the distribution of magnetic field was analyzed. It was demonstrated that the blockage oxide scale could be quantitatively measured by the amplitude and distribution of magnetic field.

Keywords: non-ferromagnetic heating tubes; Oxide blocking; Wall thickness; Magnetic detection; Multiple channels probe

1. Introduction

In the high temperature environment of the supercritical thermal power unit, the inner surface of the heating tube affected by water vapour oxidation may cause peeling and accumulation of the oxide film of the inner wall of the tube, leading to the local high temperature and prone to tube explosion accidents[1,2]. Therefore, the timely detection and evaluation of the accumulation of oxide is important to maintain the safe operation of the tube.

NDT methods of oxide blockage in boiler tube mainly include UT, RT, MT. UT is influenced by tube thickness, angle of ultrasonic wave and discrete state of oxide, so it is difficult to ensure the accuracy of detection[3]. RT can show the accumulation of oxide in the tube, the detection process is relatively complex, long detection time, high requirements for testing environment and great harm to human body, which is not applicable to industrial field detection[4]. Magnetic detection technique magnetizes the skin of magnetizing the magnetic field to measure the external wall of the austenitic stainless steel tube[5]. The magnetization has monolastic and bipolar mode, but both magnetization elements are located in the main magnetic flux path. When the tube oxide accumulation thickness is large, the detection signal is easy to achieve the quantification of the tube oxide[6]. This paper investigates the influence of different tube wall thickness and oxide accumulation on the magnetic field distribution. In order to eliminate the influence of tube wall thickness on oxide accumulation, a multi-channel electromagnetic detection device is developed in the paper.

2. Numerical Analysis of Magnetic Field Detection of Oxide Blockage

The simulation model of tube oxide blockage detection is shown in Figure 1, which mainly consists of magnetization, tube to be detected and oxide. The specific simulation geometric parameters are shown in figure 2. The magnetization consists of a permanent magnet and an armature, forming a π-shaped magnetization device, measuring the magnetic field elements placed on the external wall of the tube to
be measured to measure the axial magnetic field strength of the external wall of the tube. The tube material is TP347. The main composition of endooxide is Fe₃O₄. The influence of the oxide peel on the magnetic field distribution is shown in figure 3. When there is no oxide peel in the tube, the magnetism measuring element at the measuring point detects the axial magnetic field along the tube wall, as shown in figure 3 a. When oxide in the tube, the magnetic line is polarized into the oxide, the magnetic line distribution is shown in figure 3 b, and the magnetic field strength detected decreases. The axial magnetic field strength decrease will determine the blockage rate in the tube exists.

Figure 1. Simulation detection model.

Figure 2. Simulation geometry of simulation model.

Figure 3. Effect of the oxide on the distribution of the magnetic field.

3. Effect of Different Wall Thickness on the Detection Results of Oxide Blockage
Because the tube wall is austenitic stainless steel with low magnetic permeability, and the increased wall thickness corresponds to increasing the lifting distance of the magnetization, which effects the detection results. Simulation parameters are shown in Table 1.

| Titles                  | Permanent magnet | Armature iron | Stainless steel tube | oxide          |
|-------------------------|------------------|---------------|----------------------|----------------|
| Size (mm)               | Length 52.19     | Length 60     | Length 150           | Length 40      |
|                         | Width 10         | Width 40      | Width 45             | Cross-sectional 10,30 |
|                         | Height 40        | Height 10     | Height 4,8,12        | blockage ratio | 50,100 |

The measuring point of the axial magnetic field is located on a curve extending 25mm each along the axial centre of the tube with 50mm length. Stainless steel tubes with 4, 8, 12mm wall thickness of outer diameter 45mm have been simulated using figure 1 model, and the curve of the axial magnetic
field along the peripheral distribution of different wall thickness and different cross-sectional blockage is calculated, as shown in figure. 4.

![Figure 4](image)

**Figure 4.** Curves of axial magnetic field distributed along perimeter at different wall thickness and ratio of cross-sectional blockage.

It can be seen from the curve: 1) When the wall thickness is 4, 8 and 12mm, the magnetic field strength in the tube coincides along the perimeter curve, due to the low permeability of the tube wall. That is, when there is no oxide in the tube, the detected magnetic field strength detected will hardly change with the wall thickness. 2) is seen by the circumferential distribution curve of the magnetic field strength under 4mm + 30% (tube wall thickness + oxide accumulation), 8mm + 30%, 12mm + 30% and 12mm + 100%; the wall thickness has a great impact on the magnetic field distribution. As the thickness of the tube wall increases, the axial magnetic field intensity decrease is 12mm + 30%; 12mm + 100%; 8mm + 30%; and 4mm + 30%. 3) also yields that the reduction in axial magnetic field strength caused by 100% oxide blockage at 12mm wall thickness is less than 8mm + 30% and 4 mm + 30%.

Therefore, the degree of oxide blockage should be characterized according to the characteristics of different magnetic field distribution caused by different wall thickness and different oxide accumulation, and to represent different magnetic field distribution, a number of peripheral magnetic measuring elements (multi-channel) are needed to measure the peripheral distribution of the axial magnetic field.

### 4. Comparison of Magnetic Field Multichannel Detection Methods and Single-channel Detection Methods

Most commercial oxide leather blocking detectors are currently used in different forms of single-channel detectors. Some single-channel detectors also adopt the detection method as shown in Figure 1, but only the axial magnetic field at the peripheral zero point of the outer wall of the central magnetizer is detected. We discuss the difference between multi-channel detection and single-channel detection sensitivity, and analyze the necessity of multi-channel detection. COMSOL simulation
software is used to calculate the simulation model is shown in Figure 5 and the single channel simulation model is shown in Figure 5b. In figure 5a, the measurement point of the multi-channel axial magnetic field is on a curve extending each 25 mm along the axial center of the tube (at plane \( z=75\text{mm} \)) with a curve of 50mm. long. In figure 5b, the measurement point of the single-channel axial magnetic field is on a curve extending 2.5 mm each along the peripheral sides of the tube at the axial center (at plane \( z=75\text{mm} \)), with a length of 5.0mm.

![Figure 5. COMSOL simulation model of different cross sections.](image)

**Figure 5.** COMSOL simulation model of different cross sections.

Tube wall thickness is 8mm during simulation for multiple and single channel for 10%n, 30% and 50% oxides blockage. The detection area of the single-channel detection mode is small (-2.5mm~2.5mm), and the measured magnetic field intensity distribution is as shown in Figure 7. It can be seen from the figure that during the single-channel detection, the measured axial magnetic field strength is distributed in a straight line along the tube to be inspected, and it shows that the change of the magnetic field intensity distribution caused by the oxide cannot be seen, and the amount of information detected is less. The detection area of the multichannel detection mode is large (-25mm~25mm), and the measured magnetic field intensity distribution is shown in figure 7. From figure 8, the magnetic field intensity of the multichannel detection method varies from weak to strong to weak, and the change of the magnetic field intensity distribution caused by the oxide peel can be clearly recognized. When without oxidation skin, the axial magnetic field intensity on the measured point is large, the curvature of circumferential distribution is large; the curvature of the circumferential distribution is significantly smaller, and the rate of magnetic field intensity slows down with the increase of oxide blockage. Obviously, the amount of information of the multi-channel detection mode is large, which can identify the ratio of the oxide blockage in the cross section according to the size and distribution of the magnetic field.
5. Conclusion
This paper investigates the problem of inaccurate quantitative detection of austenitic stainless steel tube. Through COMSOL simulation software, the influence of different tube wall thickness and tube oxide accumulation on the magnetic field distribution is analyzed. It has been concluded that:
5.1 Austenite tube wall thickness affects the oxidation skin accumulation detection results greatly, and corresponding methods are taken to prevent it, otherwise may cause inaccurate examination.
5.2 By comparing magnetic field multi-channel detection mode with single-channel detection method, it shows that the information amount of the multi-channel detection mode is large, and the accumulation amount of the oxide can be quantitatively measured according to the size and distribution of the magnetic field.

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