

Influence of excitation current characteristics on sensor sensitivity of permeability testing technology based on constant current source

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Abstract. The permeability testing technology is a kind of non-destructive testing method, which based on the change of permeability, can detect the stress concentration state and the degree of fatigue damage for ferromagnetic samples. The detection sensor based on the constant current source has higher detection sensitivity, which overcomes the current negative feedback effect caused by the change of the magnetic circuit impedance of the ordinary constant voltage source. According to the principle of permeability detection, the influence of excitation current frequency, excitation current amplitude on the detection sensitivity were studied. The study shows that the detection sensitivity is related to excitation frequency, which exists extremes with the changing relationship of frequency; The detection sensitivity increases with the increase of excitation current, and shows a linear relationship. The research can provide reference for the development of high sensitivity magnetic permeability detector.

Introduction

Permeability testing technology is a new detection method, which can detect the stress concentration and fatigue damage of the whole or regional ferromagnetic components early and effectively evaluate its residual life[1]. Among them, the detection sensor is an important part of the detection system, its performance determines the sensitivity and detection quality of magnetic permeability detection method[2]. Therefore, the design of sensor based on magnetic permeability detection technology has an important practical significance[3]. For permeability testing technology, there are many factors that affect the performance of the sensor. For example, the excitation signal amplitude, excitation frequency, core selection, coil winding method and enameled wire selection[4].

At present, the evaluation methods of the micro-defects such as fatigue damage, stress concentration and heat treatment quality of the ferromagnetic specimen include metal magnetic memory test[5,8], Barkhausen effect test[9], acoustic emission test[10], ultrasonic stress test[11], the radiation stress detection method[12] and so on, but there are problems such as complex testing process, time-consuming and labor-intensive, high cost and other limitations in terms of detection reliability, detection resolution and practical effect, which are not enough to solve the actual problems the current industry facing and need to be further studied. This paper attempts to establish a model of the relationship between excitation current frequency, excitation current amplitude and detection sensitivity using magnetic permeability testing technology[13,14], optimize the detection sensor system from the detection signal and excitation signal, and will be of great significance to the inspection of micro-defects such as stress concentration, fatigue damage or heat treatment of the ferromagnetic components in the project.

Analysis of the relationship between the detection signal and permeability

The theoretical basis of the permeability testing technology is the microscopic force effect and electromagnetic induction principle. When the detection probe which is fed into the alternating signal approach the seized ferromagnetic workpiece, the probe and the seized ferromagnetic workpiece form a closed magnetic circuit. When there is stress concentration and fatigue damage inside the ferromagnetic specimen, according to the excitation effect, the magnetic flux density changes when the magnetic flux in the closed magnetic circuit passes through the part. According to the principle of electromagnetic induction, the output signal of the detection coil changes with the change of the magnetic flux density inside the magnetic core. By extracting the value of the induced voltage output by the detection coil, can reflect the change of the initial permeability of the ferromagnetic material. Test probe structure shown in Figure 1.

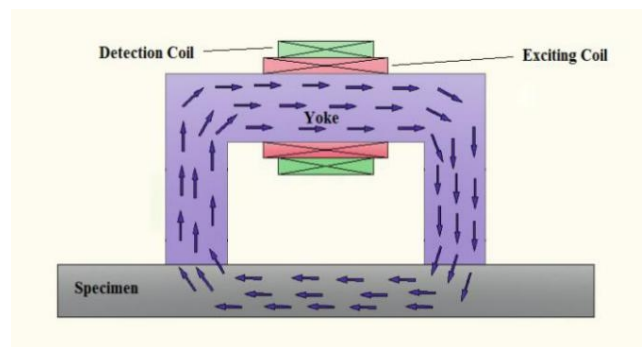


Fig. 1 Sensor structure diagram

Select the constant current source as the excitation source. Based on magnetic circuit loop theorem and magnetic Ohm's Law: $i = fR_m$, i express excitation current of the yoke, f express the magnetic flux generated by the single-turn excitation current, R_m express the magnetic resistance of full magnetic circuit. Therefore, $f = i / R_m$, R_m consist of R_{mout} and R_{min} , which expressed the magnetic resistance of air part and magnetic resistance of specimens respectively in the magnetic circuit. Therefore, $f = i / R_m = i / (R_{mout} + R_{min})$, $f = i / [R_{mout} + L / (mS)]$, m express permeability of specimen, L is the length of specimen, S express the average equivalent cross-sectional area. According to Maxwell second equation:

$$\oint E \cdot dl = - \int_s \frac{\partial B}{\partial t} \cdot ds, \text{ flux density } B = f / S$$

$$\text{output signal can be obtained: } u_{out} = N_2 \oint E \cdot dl = - \frac{N_2}{S} \int \frac{\partial f}{\partial t} \cdot ds$$

$$u_{out} = - \frac{N_2}{S} \int \frac{\partial f}{\partial t} \cdot ds = - N_2 \frac{1}{R_{mout} + L / (mS)} \frac{di}{dt} \quad (1)$$

In equation (1), N_1 and N_2 express the number of turns of the excitation coil and the detection coil, respectively. Formula (1) indicates that when the permeability m of the specimen to be changed, the output signal can change correspondingly. Negative express the phase relation of current and voltage. It can be seen that the detection voltage signal is closely related to the permeability m of the test piece and can directly reflect the differential permeability of the test piece. By detecting the induced signal, the change of permeability of the specimen can be determined, and then reflect the internal structure state of the ferromagnetic components.

Influence of excitation current characteristics on detection sensitivity

The relationship model of AC excitation frequency (f) and detection sensitivity

Select 45 steel plate as the test object, the overall dimensions of 560mm×150mm×10mm. U-shaped yoke chooses high permeability Mn-Zn ferrite material, the overall dimensions of 58mm×13mm×33mm. Select the sine wave as the current excitation source for the experiment, the excitation signal generated by the bipolar power supply BP4610, read the pick-up signal on the detection coil on the oscilloscope. Two loops were chosen in the experiment: ferromagnetic loop and air loop. When the probe is placed on the ferromagnetic specimen, the closed magnetic circuit composed of the magnetic core and the ferromagnetic specimen is a ferromagnetic circuit; Remove the ferromagnetic component to be inspected, the closed circuit formed by the probe core and the air environment is the air circuit. The difference between the detection signal of the ferromagnetic circuit and the air circuit is defined as the sensitivity of the detection technique.

Supposing that the number of turns of the excitation coil and the detection coil are both 300, the coil wire diameter is 0.2mm, the excitation coil is fed with sinusoidal alternating current of $I = 0.06 \text{ App}$. The detection signals of the ferromagnetic circuit and the air circuit, and their differences (detection sensitivity), vary with the excitation frequency, as shown in Figure 2. Figure 2 shows that within a certain excitation frequency range, the detection signal of the ferromagnetic circuit and the air circuit both increase and then decrease with the increase of the excitation frequency, and there is a maximum value. The difference of detection signal between the ferromagnetic circuit and the air circuit (detection sensitivity) has two extremums as a function of frequency. As the excitation frequency increases, the sensitivity of the detection increases first, then decreases and then increases, finally tends to a fixed value, that is, the detection probe has two optimal frequencies. The choice of the optimal frequency can be based on the characteristics of the defect to be selected, the detection of shallow cracks using a higher frequency, and the detection of deeper cracks can choose lower frequencies.

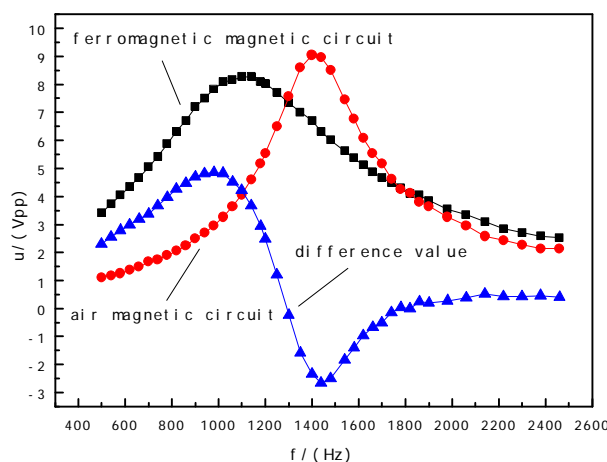


Fig. 2 The curve of signals of detection changing with the frequency

The relationship model of AC excitation current (I) and detection sensitivity

Detection sensitivity is related to excitation current, the relationship of the detection sensitivity with the excitation frequency under different excitation current conditions shown in Figure 3. It can be seen from Figure 3 that the detection sensitivity increases as the excitation current increase at the optimum frequency. When the excitation frequency is about 1000Hz and about 1460Hz, the detection sensitivity is the maximum, that is, the excitation frequency(the optimum frequency) with the highest detection sensitivity. The optimum frequency does not change with the AC excitation current. (The following experimental study are all on the optimum frequency 1000Hz)

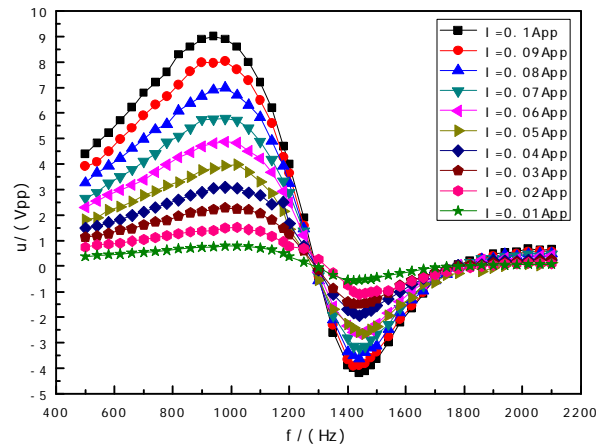


Fig. 3 The curve of detection sensitivity changing with the frequency under different excitation current

Figure 4 shows the relationship of the detection sensitivity with AC excitation current under the optimal excitation frequency $f = 1000\text{Hz}$. As can be seen from Figure 4, the detection sensitivity increases with the increase of AC excitation current, and shows a linear relationship. However, in practical experiments, the excitation current is too large, will increase the detection signal level, resulting in increased noise signal, fever and so on. The noise signal represents the square root of the signal fluctuation when a uniform ferromagnetic test piece is detected. Therefore, the selection of the probe when the number of turns of two coils are 300 can choose $I = 0.06 \sim 0.1\text{App}$, $f = 1000\text{Hz}$ AC current source as a ferromagnetic material permeability testing excitation source.

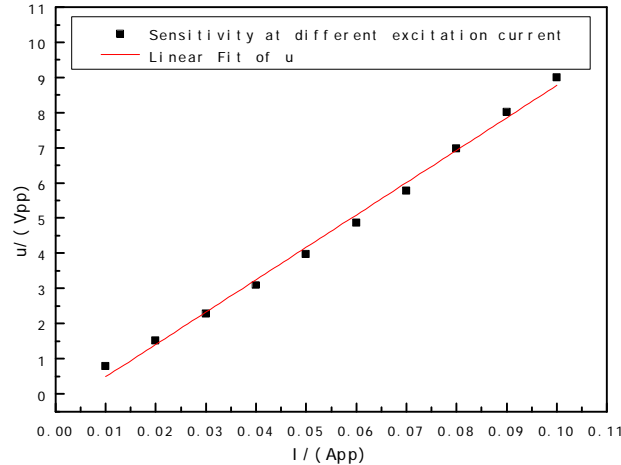


Fig. 4 The curve of detection sensitivity (at the optimal excitation frequency) changing with AC excitation current

Conclusions

Through the design of sensor of permeability testing technology, the influence of excitation current frequency, excitation current amplitude on the detection sensitivity were studied, the following conclusions can be obtained:

(1) Magnetic permeability detection sensitivity is related to excitation frequency. As the excitation frequency increases, the sensitivity of the detection increases first, then decreases and then increases, finally tends to a fixed value, that is, the detection probe has two optimal frequencies. The choice of the optimal frequency can be based on the characteristics of the defect to be selected, the detection of shallow cracks using a higher frequency, the detection of deeper cracks can choose lower frequencies.

(2) The sensitivity of magnetic permeability detection is related to the amplitude of excitation current, and increases with the increase of sinusoidal AC excitation current, and shows a linear relationship, but the signal level and noise signal also increases as the AC excitation current increase.

References

- [1] SHANGKUN, Ren, YANGCHUN, et al. Studies on stress-magnetism coupling effect for 35 steel components[J]. Or Insight, 2010, 52(6):305-309.
- [2] Ren S K, Fu R Z, Li X L, et al. Influences of environmental magnetic field on stress-magnetism effect for 20 steel ferromagnetic specimen[J]. Insight - Non-Destructive Testing and Condition Monitoring, 2009, 51(12):672-675.
- [3] Wu D, Li X, Huang Y, et al. New nondestructive test method with empirical research using local hysteretic loop characteristics[J]. Chinese Journal of Scientific Instrument, 2015.
- [4] Zeng J, Su L, Xu L, et al. Research on the stress measurement of steel plate based on inverse magnetostrictive effect[J]. Journal of Mechanical Engineering, 2014, 50(8):17-22.
- [5] Wang Z D, Yao K, Deng B, et al. Theoretical studies of metal magnetic memory technique on magnetic flux leakage signals[J]. Ndt & E International, 2010, 43(4):354-359.
- [6] Dong L, Xu B, Dong S, et al. Variation of stress-induced magnetic signals during tensile testing of ferromagnetic steels[J]. Ndt & E International, 2008, 41(3):184-189.
- [7] Dong L, Xu B, Dong S, et al. Stress dependence of the spontaneous stray field signals of ferromagnetic steel[J]. Ndt & E International, 2009, 42(4):323-327.
- [8] Shi C, Dong S, Xu B, et al. Stress concentration degree affects spontaneous magnetic signals of ferromagnetic steel under dynamic tension load[J]. Ndt & E International, 2010, 43(1):8-12.
- [9] Franco F A, Padovese L R. NDT flaw mapping of steel surfaces by continuous magnetic Barkhausen noise: Volumetric flaw detection case[J]. Ndt & E International, 2009, 42(8):721-728.
- [10] Dai G, Zhang M Y, Gao G Z, et al. Analysis and Experimental Study on Acoustic Emission Source Characteristics of Corrosion Process in Atmospheric Vertical Tank Bottom[J]. Chemical Engineering & Machinery, 2012.
- [11] Bossi R H, Giurgiutiu V. Nondestructive testing of damage in aerospace composites[M]// Polymer Composites in the Aerospace Industry. 2015:413-448.
- [12] Gao W, Hu Y, Mu X, et al. Real-time detection and segmentation of submerged-arc welding defects in X-ray radiography images[J]. Yi Qi Yi Biao Xue Bao/chinese Journal of Scientific Instrument, 2011, 32(6):1215-1224.
- [13] Tomáš I. Magnetic Adaptive Testing of Non-magnetic Properties of Ferromagnetic Materials[J]. Czechoslovak Journal of Physics, 2004, 54(4):23-26.
- [14] Vertesy G, Uchimoto T, Tomáš I, et al. Nondestructive characterization of ductile cast iron by magnetic adaptive testing[J]. Journal of Magnetism & Magnetic Materials, 2010, 322(20):3117-3121.