Detection of buried defects in steel using array TMR sensors based on ECT and MFL effects

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Abstract

The detection of small defects that are buried in ferromagnetic steel is still a challenging problem for electromagnetic non-destructive testing. This paper presents a probe with high-resolution high-sensitivity tunneling magnetoresistance (TMR) sensors for buried defects inspection. The operation principle of the probe is based on eddy current testing (ECT) and magnetic flux leakage (MFL) effects. The excitation frequency is optimized, in which way the eddy current field can penetrate through the sample. Experimental results show that the probe can detect a defect with dimensions of 5 mm (length)* 1 mm (width)* 1.5 mm (depth) buried in a 3 mm thick carbon steel plate. The proposed probe can be widely used for ferromagnetic materials inspection.

1 Introduction

Steel is widely used in the manufacture of machinery parts, vehicles and pipelines, etc. It is critical to inspect the structures during their production and usage to ensure product quality and structure safety. Eddy current testing (ECT) measures the secondary magnetic field generated by the eddy currents in the sample[1]. However, for highly permeable ferromagnetic materials, such as carbon steel, the ECT method faces challenging for buried defects inspection, because the penetration depth of the eddy current in these materials is very small. To increase the penetration depth of the eddy current, the excitation frequency should be reduced. However, for a conventional ECT probe using induction coils as the pick-up sensors, the sensitivity of the coils decreases as the frequency becomes lowers resulting in a poor signal to noise ratio. Therefore, other kinds of sensors, whose sensitivity does not drop as frequency decreases, such as hall effect sensors and magnetoresistance sensors, should be utilized to replace the coils[2]. The magnetic flux leakage (MFL) method is another widely applied technology for ferromagnetic materials inspection, which needs a strong magnetic field to magnetize the sample to a magnetically saturated state, and then detects the leakage magnetic flux caused by the defect [3]. The main drawbacks of MFL include: i) the size of the magnetization system is large and ii) it is not sensitive to small defects, especially for cracks that oriented parallel to the magnetic line.

As both the ECT and MFL measure the magnetic field, it is possible to uses them simultaneously in an inspection system to make up for each other's shortcomings. This paper presents such a probe with high-sensitivity tunneling magnetoresistance (TMR) sensors [4], which does not need saturate magnetization of the sample and the detectability for buried defects is improved.

2 Experiment Setup and Result

The schematic of the experiment setup is shown in Fig.1 (a). The probe uses a relatively weak AC magnetic field as the MFL excitation field, which is generated by a low frequency excitation coil wound on a magnetic core. According to the MFL inspection principle, the magnetic flux lines are disturbed a defect in the sample. In addition, the probe contains an air-core coil, which is

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excited by a relatively high-frequency current and induces eddy current in the sample. The probe utilizes an array of highly sensitive TMR sensors to detect the ECT and MFL signals simultaneously. A photograph of the array TMR sensors is shown in Fig.1 (b). The size of each sensor is 0.5 mm*0.5 mm, and the distance between the centers of each two adjacent sensors is 1 mm. The sensitive axis of the sensors is orthogonal to the sample surface. The signals of the sensors are amplified and filtered through multi-channel circuits. The data is processed parallel by digital lock-in amplifiers in a FPGA for fast signal acquisition.

Since the frequency of the MFL field is set to be much lower than the ECT field, the ECT signal is modulated by the MFL signal. Therefore, the magnetic signal measured by the array sensors can detect both surface and buried defects. An experimental image of a defect with dimensions length ×width×depth=5 mm×1 mm×1.5 mm, which is buried 1.5 mm from the top surface of a carbon steel sample, is presented in Fig.1 (c). The defect can be recognized from the image.

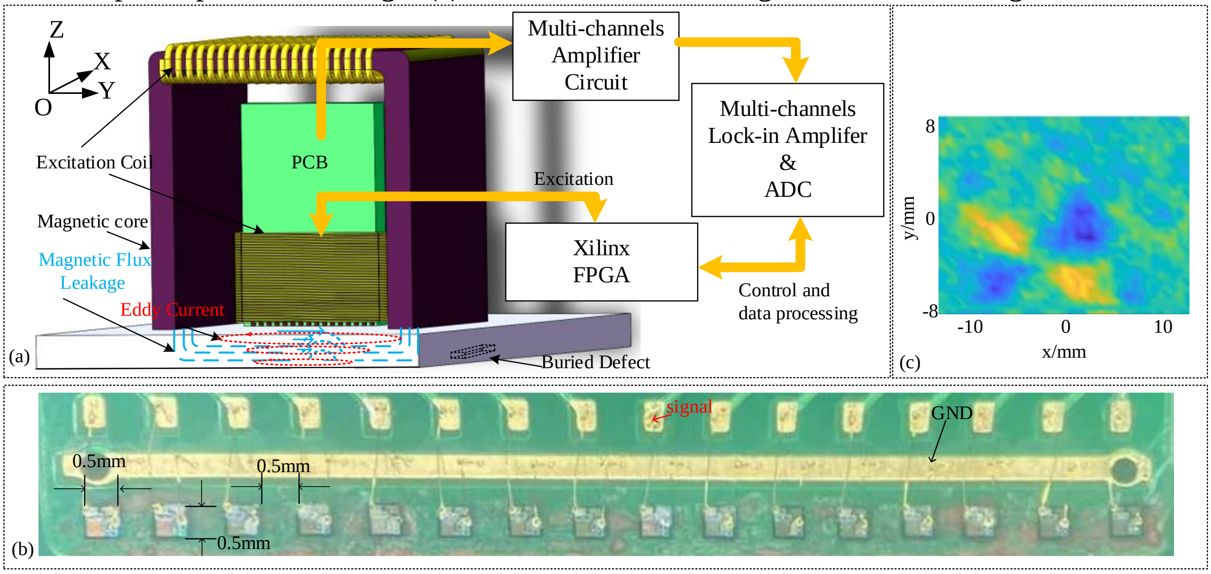

Figure 1: (a) the schematic of the experiment setup, (b) the photograph of array TMR sensors in the probe, (c) experimental result of a defect buried 1.5 mm from the top surface of a carbon steel sample.

3 Conclusion

The experimental result demonstrates the feasibility of the probe design. This design combines the characteristics of ECT and AC MFL methods, which avoiding the issue of low sensitivity in low frequency coil ECT detection and overcoming the high-power requirement in MFL inspection. Moreover, the probe enables rapid inspection of buried defects in ferromagnetic samples.

References

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