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Enhanced magneto-optic imaging system for nondestructive evaluation

Yu Hua Cheng[a], Zhao Fei Zhou[a], Gui Yun Tian[b,*]

[a]School of Manufacturing Science and Engineering, Sichuan University, Chengdu 610065, China
[b]School of Automation, Nanjing University of Aeronautronics and Astronautronics, Nanjing, China

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Abstract

An enhanced magneto-optic (MO) imaging system is presented in this paper to detect hidden and buried subsurface flaws in metallic specimens. The characters of the MO imaging system are mainly given by the parameters of the MO thin films, the magnetic excitation device and image-processing algorithms. In this paper, the choice of the MO thin films, the design of the magnetic excitation device and the development of the image processing approaches are introduced in detail. Experimental tests have been done and the method presented is evaluated by the experimental results.

Keywords: Magneto-optic (MO); MO thin films; Magnet excitation device; Image processing

1. Introduction

Nondestructive evaluation (NDE) has a wide range of applications in many safety-critical industries such as transportation, aerospace, automotive, manufacturing, petrochemicals and defense. Established NDE technologies such as ultrasound, radiography, eddy current (EC) and infrared thermograph have been extensively used by these industries over the past five decades. Although NDE is now a relatively mature field, today's heightened safety expectations mean that there is a requirement for regular, low-cost and accurate inspection and that we must also be able to detect hidden subsurface flaws, material microstructure and defect distribution, particularly for complex and small components, e.g. NDE for microsystems and complex samples are emerging as a challenge. Inspection of steel rails, oil pipes and aircraft components is a particular case where regular, large volume, low-cost inspection is essential and where detection of subsurface flaws could have prevented fatalities and serious industrial disruption. Electromagnetic methods such as EC techniques and magnetic flux leakage (MFL) for NDE have the distinct advantage of not requiring a coupling medium, which is a potential problem of using ultrasonic as the sensing modality. For electromagnetic NDE, one of the most important techniques is to measure and image the magnetic field distribution with high accuracy and efficiency. The traditional approaches are to use multiple coils [1,2] or solid state magnetic sensors, e.g. giant magnetic resistance (GMR) [3–6] for the measurement and imaging of magnetic field distribution.

Magneto-optic (MO) imaging appears as a good alternative to conventional EC and MFL, and their sensor arrays [5] for inspecting the surface and subsurface defects in metallic specimens. The MOI technique is based on the combination of electromagnetic effect (EC or MFL) and MO Faraday effect. In EC NDE, an excitation coil is excited with AC excitation which induces ECs in the sample. These ECs generate normal magnetic fields when encountering any defects. Thus by imaging the reflected polarized light through the MO thin film, defects can be imaged [7]. The magnetic fields from subsurface defects are distorted and will reflect the defects hidden by the magnetic domains and other noise. The modulated magnetic field is normally weak. It is necessary to eliminate the noises from the image and to enhance the image modulated by the defects. Therefore, in addition to

*Corresponding author. School of Electrical, Electronic and Computer Engineering, Newcastle University, Newcastle NE1 7RU, UK.
E-mail addresses: cyh365@yeah.net (Y.H. Cheng), g.y.tian@ncl.ac.uk (G.Y. Tian).

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application of appropriate MO thin films, image-processing approaches need to be developed to overcome this problem. This paper is to introduce an enhanced MO imaging system for sensing and imaging magnetic fields of NDT and E.

The paper is organized as follows: Section 2 introduces the system configuration; Section 3 reports the image-processing algorithms; Section 4 analyzes the experimental results and conclusions are derived at the end.

2. The system design and components

As illustrated in Fig. 1, an MO imaging system for pulsed MFL detection is constructed. To be able to measure subsurface defects, pulse excitation mode is applied [8].

During the MO imaging system design, a strong magnetic excitation device is utilized to magnetize the specimen. For its high magnetic permeability and high temperature stability, the ferrite magnetic core is widely used. In the experiment, the magnetic excitation device consists of a U-type ferrite magnetic core and exciting coils of certain turns. When the excitation coils are excited by alternating current (AC) or pulses, flux leakage will be produced in the specimen if defects exist. Compared with other methods, the magnetic excitation device can be designed to be smaller. The device is excited by AC, and has been proved to have high recognition ability for subsurface defects by experiment results.

MO thin film is one of the core elements of the system, whose performance is mainly defined by the MO properties. So the MO thin film should be analyzed according to its MO properties and be chosen carefully to obtain MO images of high resolution.

MO sensitivity and its stability as important parameters rely on a variety of factors such as MO rotation ratio etc. According to the real detection equipment, the MO thin films should meet the following requirements to assure the validity of the detection.

(1) High MO rotation ratio to enhance the contrast of the MO image.
(2) High temperature stability to maintain the reliability of the testing process.
(3) Approximately linear MO response curves to gain succinct adjustment.

With the above characteristics, garnet MO film becomes the most effective MO sensor for MO imaging testing. Because the Faraday rotation of pure yttrium iron garnet (YIG) film is much smaller and its saturation magnetization is much higher, pure garnet film cannot be manufactured in small sizes and integrated. According to the research results, co-doped YIG film improves the MO properties greatly, especially the novel Bi-substituted YIG (Bi-YIG) and Ce-substituted YIG (Ce-YIG). Bi-YIG becomes the ideal MO material for its smaller saturation magnetization (0.04 T), specific rotation coefficient (300°/mm), high ovality (32 dB) and effective transmission. A sensitive MO garnet film ($Y_{2.3}Bi_{0.7}Fe_5O_{12}$) with 1.0 mm thickness of φ15 mm is selected in our present experiment.

There is strong reflectivity on the surface of the garnet film, and the transmission ratio is depressed. The reflected light can also affect the extinction ratio and Faraday rotation, so antireflection coating is plated on the surface of the garnet film.

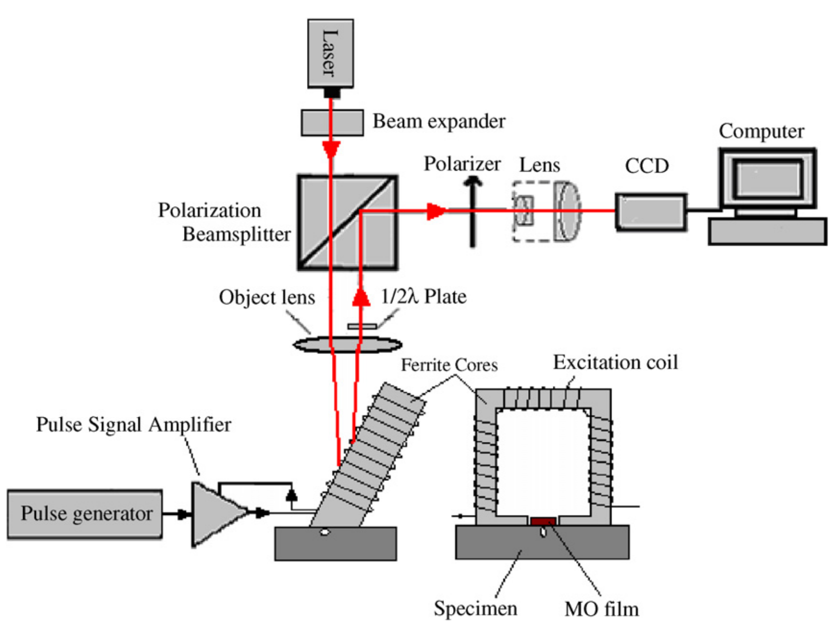

Fig. 1. The experimental setup.