Examination of Surface Flaw Detection by Eddy Current Technique using Magneto-Impedance Sensors

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Abstract
Eddy current testing (ECT) has been utilized for the surface flaw detection of jet engine components. It is necessary, however, to obtain high sensitivity for small flaws. This paper reports on the feasibility of ECT probes using Magneto-Impedance (MI) sensors for the surface flaw detection of titanium alloys. The high sensitive MI sensors were employed for sensing magnetic field change instead of the conventional pick-up coils. The electro-magnetic simulation was introduced to design the excitation coils and sensor configuration, and experimental results were obtained on the specimen with minute electric discharge machined (EDM) notches. As the experimental results, the minute notch detection with high Signal-to-Noise Ratio (SNR) was achieved, and the concept of the array sensor systems was proposed.

Keywords: Magnetic sensor, titanium alloy, Magneto-Impedance sensor, amorphous wire

1. Introduction
Low conductivity metals such as titanium alloy or nickel-based heat resistant alloys are widely used in many industrial components, such as aircraft engines. ECT is commonly used for detecting surface flaws in these components. It is difficult, however, to obtain high sensitivity for small flaw detection, while also achieving high inspection throughput because of trade-offs between sensitivity and probe size.
ECT probes using MI sensors offer the possibility of achieving higher sensitivity and wider range of flaw detection than conventional probes because of the sensitivity and the size. MI effect consists in an abrupt variation of the impedance of amorphous wire (hereinafter MI sensor) when applying high-frequency current to the wires under small magnetic fields [1-2]; MI sensors are more sensitive than GMR sensors (fig. 1) that have been used in NDT [3]. MI sensors are a few millimeters in general; these are bigger than GMR sensors that are a few dozens to a few hundreds micrometers. We have reported ECT probes using Giant Magneto Resistance (GMR) sensors [4]. The paper showed that the probe using GMR sensors could detect minute flaws in high sensitivity. It is necessary, however, for broadening range of flaw detection to apply array probes. ECT system that has much number of channels is complexity, so it is better for simplicity to broaden the range of flaw detection with one sensor.
This paper reports on the feasibility of ECT probes using MI sensors for the surface flaw detection of titanium alloys. To design ECT probes that have wide range of flaw detection, the electro-magnetic simulation was introduced and experimental results were obtained on the specimen with minute EDM notches. From these results, the concept of the array sensor systems was proposed.

Fig. 1 Comparison of magnetic sensors
2. ECT probe using MI sensor
ECT probe using MI sensor and schematic image of experimental setup are shown in figure 2. The excitation coil was produced by the method with flexible printed circuits (FPC), and a Co-Fe-Si-B bulk amorphous wire was put on the coil as a detector. Magnetic perturbation is detected as the voltage change of the amorphous wire.

A titanium alloy specimen with the EDM notch was prepared. The notch size is 0.30mm-long by 0.15mm-deep. Figure 3 shows the experimental configuration. The frequency of AC current was 6MHz, and scan speed was set at 17mm/s in this examination.

Figure 4 shows the experimental results. The probe detects the notch with 5.3 Signal-to-Noise Ratio (SNR). The range of flaw detection was 0.6mm, obtained from the full width at half maximum of amplitude for X direction. It should be dependent on the length of amorphous wire and distribution of eddy current.
3. Optimisation of the probe by simulation

To improve the range of flaw detection, eddy current has been simulated so that the excitation coils generate the uniform eddy current density. ECT probes using large excitation coils should have wider range of flaw detection. However, large probes increase noise signals because of the lift-off (the distance between the specimen and the probe). In addition, it is not easy to scan on curved surface smoothly.

The example of design of excitation coils is shown in Fig. 5(a), and the simulation result of eddy current density are shown in Fig. 5(b). The excitation coils consist of two coils for the opposite current direction each other, and the MI sensor is arranged on between centers of these coils. The excitation coils generate eddy current almost uniform density about 1mm wide. As shown fig 5(b), combination with excitation coils should improve the range of flaw detection.

The improved ECT probe is shown in figure 6(a), and experimental results are shown in figure 6(b) and 6(c). In this examination, all conditions are same as mentioned before. The range of flaw detection is 1.0mm; it was found that the probe has wider range of flaw detection than that of single probe.

In order to increase the range of flaw detection, the excitation coils that consist of opposite coils on one another were proposed (fig. 7). MI sensors are arranged on three coils and are connected either in series or in parallel. MI sensors that are connected in series should offer the wide range of flaw detection by use of conventional ECT systems.

![Fig. 5 The example of the excitation coils](image)

![Fig. 6 The improved ECT probe and experimental results](image)

![Fig. 7 The concept of the ECT array probe](image)
4. Conclusions
This paper presents the feasibility of ECT probes using MI sensors for titanium alloy. To design the excitation coils and sensor configuration, the electro-magnetic simulation was introduced. As the experimental results, the minute notch detection with high Signal-to-Noise Ratio (SNR) was achieved, and the concept of the array sensor systems was proposed. In the future, we will fabricate array probes using MI sensors, and make sure that the probes are industrially effective through the examination.

References