2-D Image of Eddy-Current Testing and Dependence of Shape for Notch inside of Narrow Hole by Needle-Type Probe

2-D Image of Eddy-Current Testing and Dependence of Shape for Notch inside of Narrow Hole by Needle-Type Probe

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Eddy-current testing (ECT) has a large contribution to the maintenance of apparatus with a high reliability both in the past and the future. The needle type magnetic probe with the giant magneto-resistance sensor made it possible to inspect minute defects in narrow spaces (groove and hole). Moreover, the high resolution and sensitivity of the detection methodology could observe the ECT signal image inside of hole and groove. In this paper, we discuss the 2-dimensional signal recognition of magnetic fields and distinguish the relationship and discrepancy between a shape of notch inside of narrow hole and a signal image by both experimental and calculated results.

Key words: nondestructive testing, eddy currents, needle probe, narrow space, notch, ECT image.

1. Introduction

Eddy-current testing (ECT) is one functional method of non-destructive inspections for conductive materials. It is effective especially for detection of scratch on a surface, and is used as an effective methodology by using relative simple apparatus.

On the other hand, it is difficult for ECT execution that the ECT probe is hardly inserted inside of rivet hole and groove. It is because the distance between a sensor and defects is far away so that spatial resolution and sensitivity become poor[1)-3)]. We have focused that giant magneto-resistance effect sensor (GMR sensor) is a ultra-compact high-sensitivity magnetic sensor [4), 5)]. It have been proposed that the magnetic sensors are mounted on the tip of thin ceramic needle in order to detect notchs in a narrow space such as minute groove or hole[6)-8)]. The previous paper has reported that it is possible to inspect notchs inside of a narrow space by using the needle-type probe[9)].

To recognize the quality of a notch accurately, it is necessary to grasp the position and shape of a notch by analyzing and data-processing the signals. The high resolution and sensitivity brought by the needle probe enable us to observe the fine ECT image. In this paper, we analyze the structure of signal and discuss the relationship between 2-dimensional image and shape of notch inside of a hole.

2. Eddy-current testing inside of hole

2.1 Eddy-current testing apparatus by using needle-type magnetic probe

(1) Process of eddy-current inspection

Fig. 1 shows the data process of eddy-current inspection of our system[9)]. At the data acquisition, it is important that the needle type probe must be driven inside of narrow space correctly, and scanned around an inner wall by 2-dimensional movement. Although an offset depending on the eccentricity of the probe scanning is not avoidable, the effective data processing of the offset signal is indispensable on the ECT inspection. The output of the probe also includes an electromagnetic noise from the outside environment, then it is necessary to remove the noise signal by a lock-in amplifier. The lock-in amplifier outputs an amplitude and phase of the ECT signal. The two informations are drawn as 2-D ECT image.

(2) Configuration of needle-type magnetic probe

We have developed the needle-type probe mounted by GMR sensor elements. Fig. 2(a) shows the SV-GMR sensor is located at the tip of ceramic needle and two terminals are connected with two printed wires along the needle. We used the spin-valve type GMR with linear sensing characteristics on a zero point [10)]. This probe has only one sensing direction.

Fig. 2(b) shows the composition of needle-type probe, exciting coil, and test sample. As shown in the figure, the directions of r, θ, and z are defined on the basis of center of hole of the sample. In this study, we

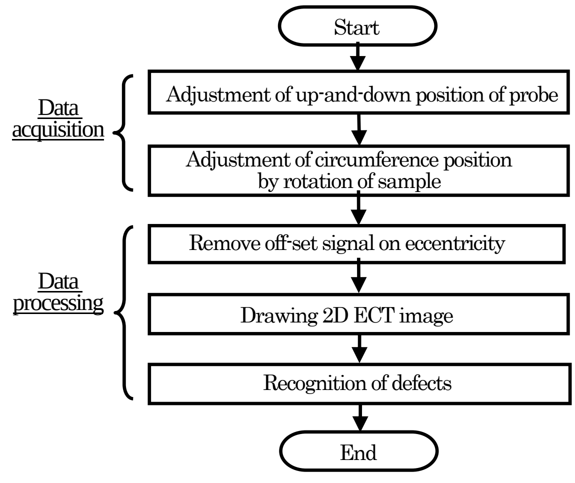
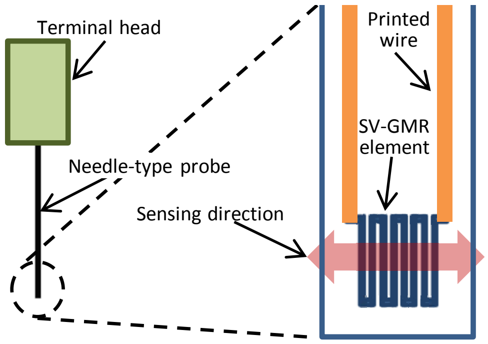
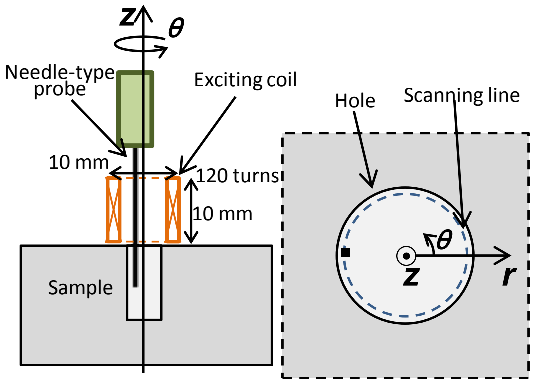


Fig. 1 Process of ECT inspection.



(a) Arrangement of GMR sensor on needle probe.



(b) Composition of probe, exciting coil and test sample.

Fig. 2 Structure of probe and arrangement of the probe, exciting coil and test sample.

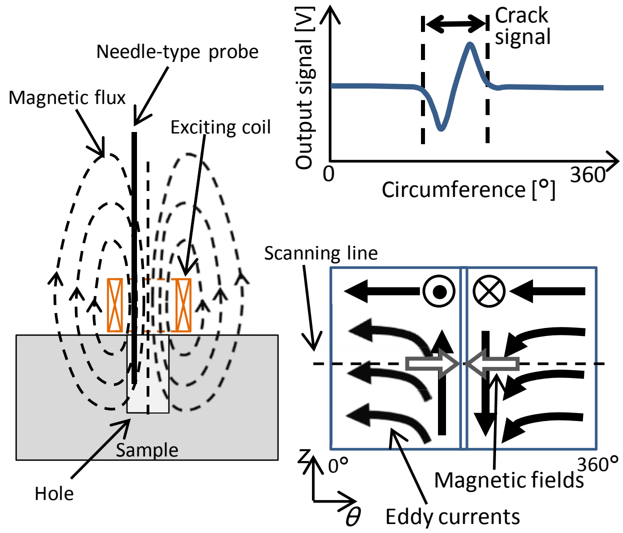


Fig. 3 Principle of inspection inside of hole.

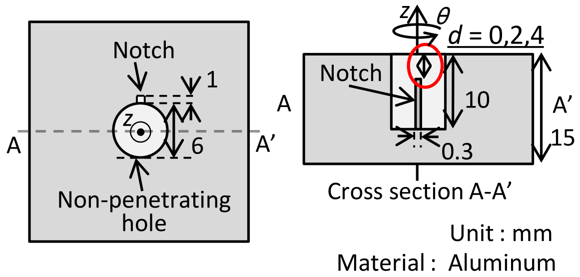


Fig. 4 Test sample with hole structure.

use a toroidal exciting coil to produce magnetic fields and needle-type probe with a magnetic sensor. The sizes of the coil are 10 mm in height, 10 mm in diameter, and 120 numbers of turns. To produce higher magnetic fields, the coil must be located on the surface of the sample concentrically with a hole. On the other hand, a needle-type probe is inserted inside of hole so that the sensor on the tip of the probe is made to stick to the inner surface of hole very much. The sensor can catch local magnetic fields because the sensor area is 40 × 40 μm². The cross-section of the probe is 400 × 400 μm². Therefore, we can insert needle-type probe inside of a hole of mm-order diameter, and it is possible to scan a probe around an inner surface of a hole.

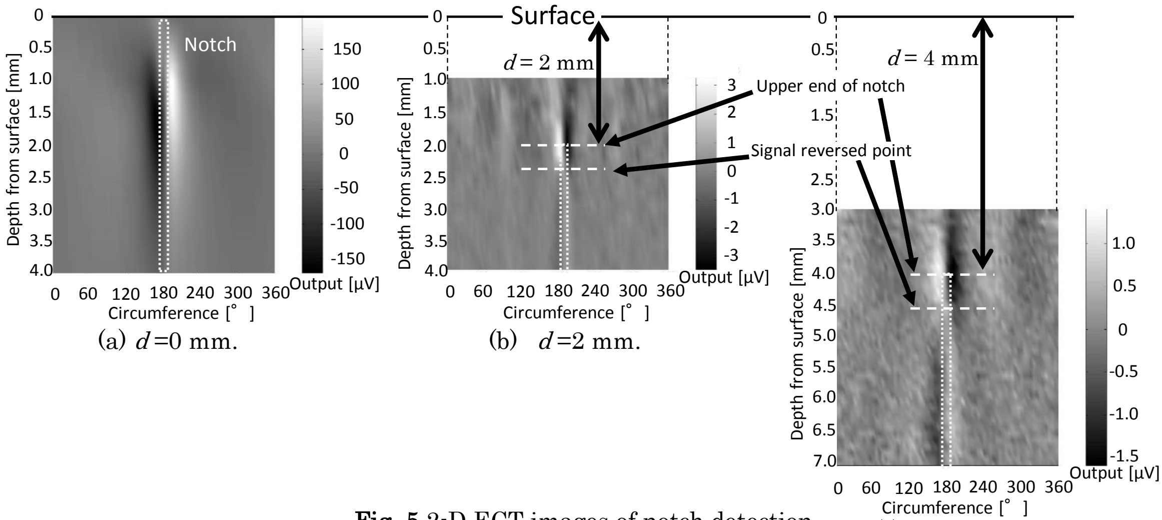
2.2 Principle of eddy-current inspection inside of hole

The principle of eddy-current testing for the notch inside hole is shown in Fig. 3. When the probe is inserted inside of hole, magnetic fields with the direction of z is generated by exciting coil. In the position away from the coil, the magnetic fields of the direction ingredient of r appear. When magnetic fields are penetrated in the hole, eddy currents flow around the surface of a hole. When there is no notch, eddy currents flow in the θ-direction, and then there is no θ-direction magnetic field.

On the other hand, when there is a notch, eddy currents change the flowing direction in the direction of z from θ-direction along a notch. The magnetic field B_θ of the direction of θ appears near a notch by eddy currents which flow in the direction of z. The output voltage of the magnetic field B_θ is measured by making the sensing direction into the direction of θ because SV-GMR sensor has sensing direction. The sensor is hardly subject to the influence of a magnetic field of the direction of r and z generated by the exciting coil. Therefore, the probe is scanned along a hole with the sensing direction of the sensor fixed to the direction of θ. signal with a peak-to-peak signal is output from a probe when a probe passes on a notch. Since the signal amplitude changes with the skin depth of eddy currents and the notch depth, exciting frequency is decided in consideration of both.

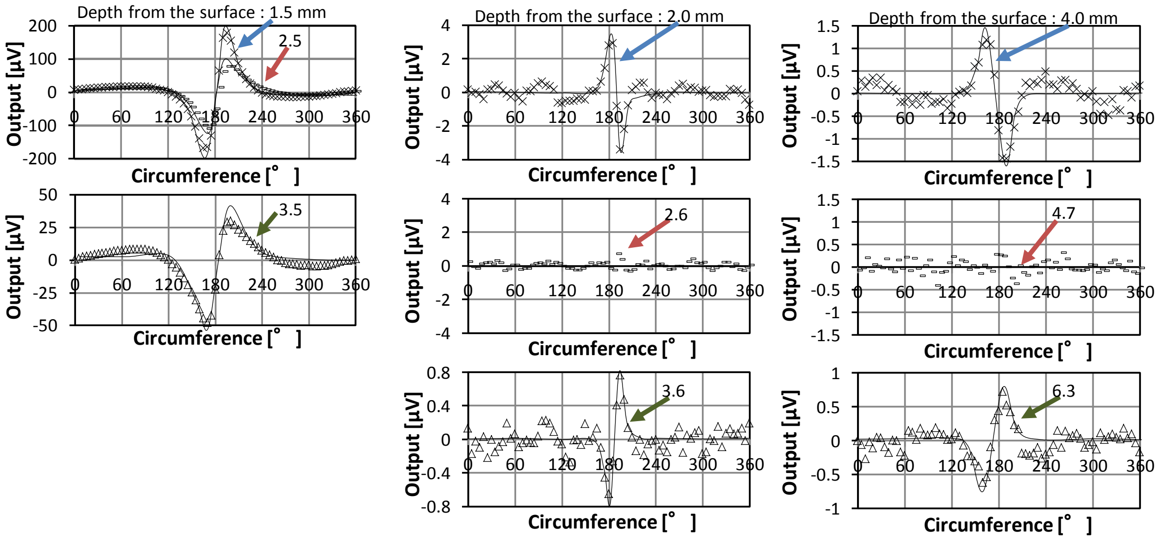
2.3 Test samples

We assume the defect of the side inside a hole as the test sample. Test samples are shown in Fig. 4. The aluminum piece of thickness 15.0 mm has the hole of diameter 6.0 mm and depth 10 mm. The sample has notch of width 0.3 mm and depth 1.0 mm in the inner surface of a hole. The depth from the surface of the position which the notch has produced was set to d, and we used three samples with d= 0, 2 and 4 mm.



(a) d=0 mm. (b) d=2 mm. (c) d= 4 mm.

Fig. 5 2-D ECT images of notch detection.



(a) d=0 mm. (b) d=2 mm. (c) d=4 mm.

Fig. 6 Strip chart of ECT signal near notch.

3. Notch detection inside of hole

3.1 Dependence of magnetic-field distribution on shape of notch

We measured the experimental ECT data of notch inside of a hole by using the test samples in Fig. 4. The exciting frequency is set to 25 kHz. The skin depth, d_s of aluminum material is 0.52 mm, and is smaller than notch depth of 1 mm. The driving current of SV-GMR is set to 1.5 mA. The driving current of the exciting coil is set to 200 mA. Scanning pitch of the direction of z is 0.1 mm and scanning pitch of the direction of θ is 5 °. The liftoff height between the sensor and the side of a hole is set to 100 μm. The test sample has been arranged so that a notch may be located near the circumference position of 180 °.

Fig. 5 shows the 2-D ECT images for three notches with different depths obtained by the measurement. In the figure, a horizontal axis is an angle and the vertical axis is the depth from the surface. Fig. 6 shows the strip charts of ECT signal at each position of the depth. Figs. 5(a) and 6(a) show that the notch is observed near the circumference position of 180° in the sample for d = 0. The notch signal has the maximum near the depth of 1 mm from the surface, and the ECT signal decreased near the surface and the deeper position. It is thought that eddy currents near the notch mainly flows in the direction of r instead of the direction of z near the surface as shown in Fig. 7(a).

On the other hand, both of (b) and (c) in Figs. 5 and 6 show the results of the samples for d = 2, 4 mm. These results show that the ECT signal of the notch is detectable like the sample for d = 0. However, two different images are observed compared with the tested sample for d = 0. One is that the notch signal is clear above the notch. Another is that the polarity of the signal reversed under the upper end of notch near the surface although a notch continues to the bottom of the hole. The depth at which the polarity of the signal reversed is defined as signal reversed point. The middle figures of Fig. 6 (b) and (c) are at the depth. The analysis results by FEM in the case of d =1, 3 mm also shows the same images as shown in Fig.8. The width and depth of the notch and conductivity are set to the same value as the test samples.

In the case of d = 0, eddy currents flow into the depth at the upper end of a notch as shown in Fig. 7(a). On the other hand, the distribution of eddy currents is shown in Fig. 7(b) when a notch exists inside of hole. The eddy currents flow separately to both of the upper end and the deeper position of the notch. Then the signal image was reversed at the upper end of the notch. In the sample for d = 2, 4 mm, the notch images were observed clearly at the upper part of a notch. The ECT signal decreases gradually from the upper end of the notch near the surface.

3.2 Estimation of notch depth

The relationship between the depth of notch and the signal reversed point of the signal is shown in Fig. 9. We can observe that the relationship has a linear characteristic, and the signal reversed point of the signal is deeper by 0.5 mm than the end of a notch. It is noted that the upper end of the notch near the surface of the testing plate is on about 0.5 mm from the signal reversed point. The distance is deeply related to the skin depth (d_s = 0.52 mm) under the measurement condition.

4. Conclusion

We discussed the dependence of the eddy-current image on the shape and position of notch in a hole. When a notch exists inside of a hole, the signal was reversed in the middle of a notch. The relationship between the depth of the reversed signal and the position of notch becomes clear. Future, we will examine what will happen to a signal for a complicated shape of crack.

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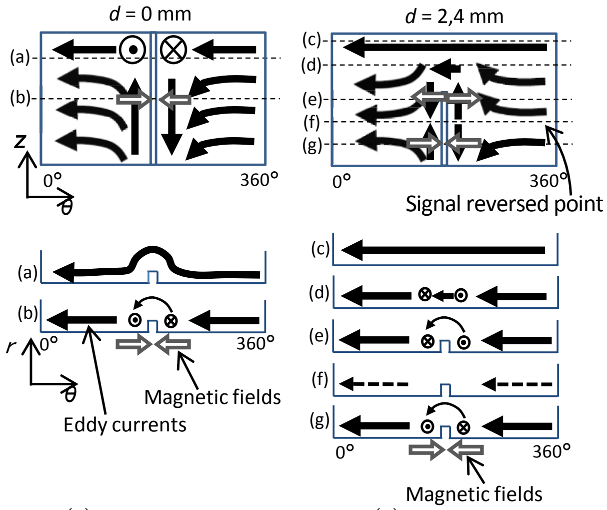
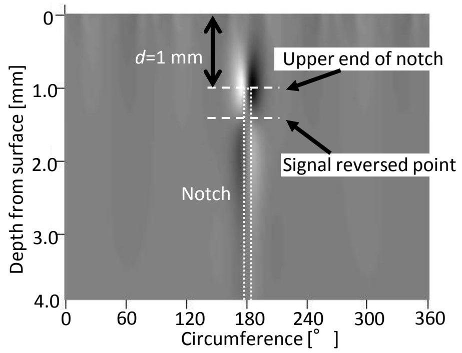
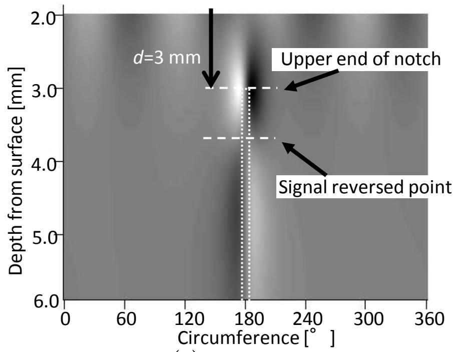


(a) d = 0 mm. (b) d =2, 4 mm.

Fig. 7 Flow pattern of eddy currents near notch



(a) d = 1 mm.



(b) d = 3 mm.

Fig. 8 Analysis results of magnetic fields

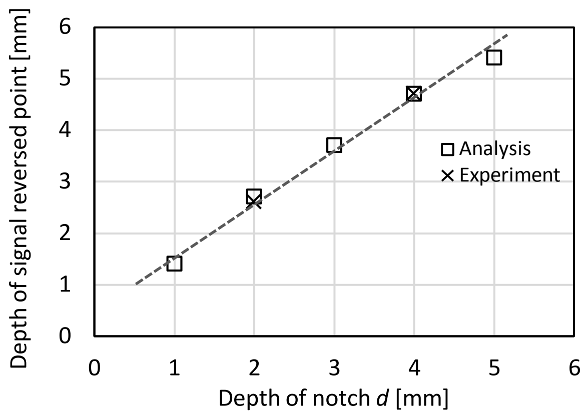


Fig. 9 Dependence of depth of notch and signal reversed point.