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Application of Eddy Current Testing to SCC Detection for Canisters in Concrete Cask System

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Abstract

In order to apply a concrete cask storage system in Japan, it is necessary to take measures against the occurrence of SCC (stress corrosion cracking) on the canister surface, since the atmosphere in storage facilities contains salt. One of the measures to prevent SCC is applying a treatment that causes compressive residual stress to the canister surface. However, considering the possibility of degradation of the preventive effect due to aging, in-service inspections may be required. We have been working on development of an SCC inspection method for the canister surface by ECT (eddy current testing). To apply ECT to the inspection of canisters, it is necessary to reduce the magnetic noise in the welding zone and improve the heat resistance of the ECT device. It is possible to reduce the magnetic noise with a permanent magnet, but strong permanent magnets have decreased magnetic intensities at high temperatures and cannot reduce magnetic noise. We created strong magnets with high heat resistance and a high magnetic intensity by combining a high heat–resistant magnet and high magnetic intensity magnet. Use of the combined magnets reduces the influence of the magnetic noise by more than 90%, and they can be applied to detection of early-stage SCC.

Background

A concrete cask storage system is more economical than a metal cask storage system, and it is expected to be applied in Japan. Japan is surrounded by seas, and storage facilities will be built near coasts. Since salt air contacts the surface of canisters made of stainless steel, there is a risk of SCC occurrence. In the worst case, SCC reaches inside canisters, and radioactive materials leak out. Therefore, it will be necessary to apply measures against SCC to concrete cask storage systems in Japan. Occurrence of SCC relies on three factors, i.e., the welding residual tensile stress, environment, and material. Removing just one of these factors can prevent the occurrence of SCC. For example, the occurrence of SCC can be prevented by bringing the canister surface into a compressive residual stress state by a peening treatment. However, the preventive effect may degrade due to the effects of aging; therefore, we have been considering introducing periodic inspections for SCC to our concrete cask system during long storage periods.

SCC detection method for the canister surface

We have been trying to apply ECT (eddy current testing) to detect SCC of the canister surface. ECT is a method of inspecting a defect by generating an eddy current in a specimen using an electromagnetic induction phenomenon and detecting the eddy current distortion due to the defect. ECT can inspect the state near the surface of the specimen regardless of the internal structure and is suitable for this kind of application. However, general ECT is difficult to apply to SCC inspections of the canister surface because of the following three main issues.

(1) The welding zone has tensile residual stress and is a place where SCC tends to occur. However, since there is a disturbance in the magnetic field inside the welding zone, magnetic noise is detected in the output signal. Therefore, the ability to detect defects is reduced.

(2) Since the temperature of the surface of the canister is high, it is necessary to improve the heat resistance of the sensor.

(3) It is necessary to automate testing because the testing is performed in a high-temperature and radiation-exposure environment.

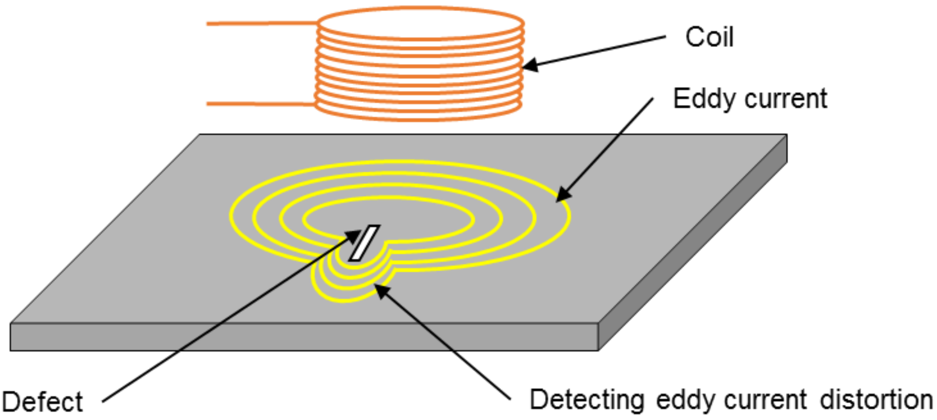
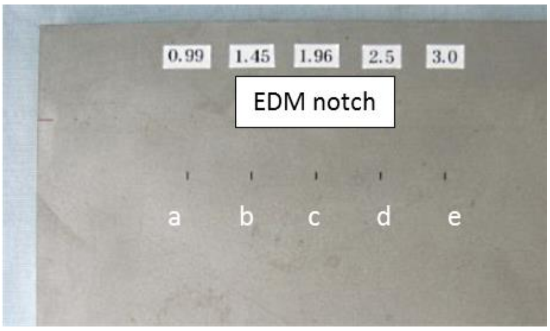


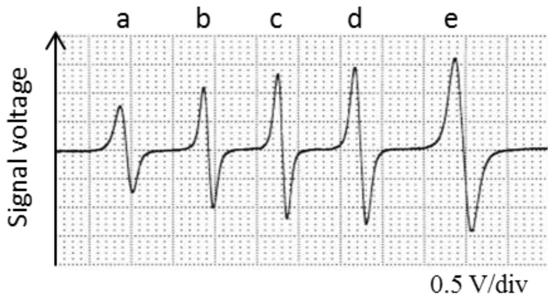
Figure 1. Principles of ECT

Investigation of the influence of magnetic noise

We used two austenitic stainless-steel specimens to investigate the level of magnetization noise. One of them, called specimen A, was not welded and had three EDM (electrical discharge machining) notches. The other, called specimen B, was welded under the same conditions as the canister used in the United States. Excess weld metal was removed from specimen B. We adjusted the output signal level so that the signal voltage amplitude for an artificial defect of 3 mm in depth in specimen A was 3.0 V. As a result of inspecting specimen A, the voltage amplitude corresponded to the depth of the defect. There was no noise reducing the detection accuracy. As a result of scanning the welding line on specimen B, significant magnetic noise was confirmed in the detection signal. The magnetic noise level exceeded 1.0 V.



(a) Surface of specimen A

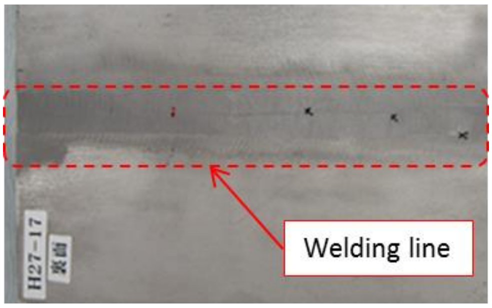


(b) Signal waveform

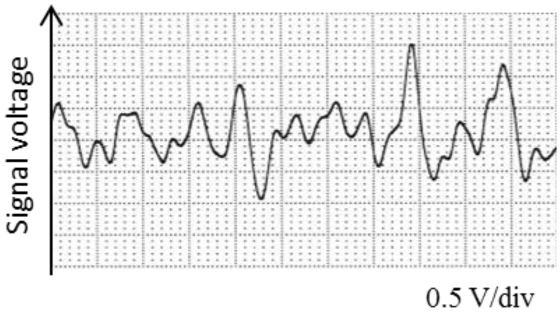
Figure 2. Specimen A

Table 1. Sizes of the EDM notches in specimen A

Notch	Width (mm)	Length (mm)	Depth (mm)	Signal amplitude (V)
a	0.3	3.0	0.99	1.5
b			1.45	2.1
c			1.96	2.5
d			2.50	2.7
e			3.00	3.0



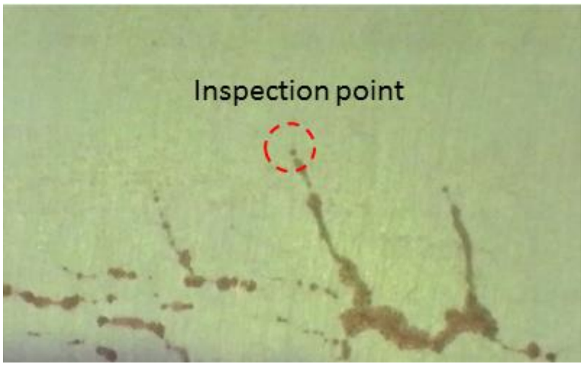
(a) Surface of specimen B



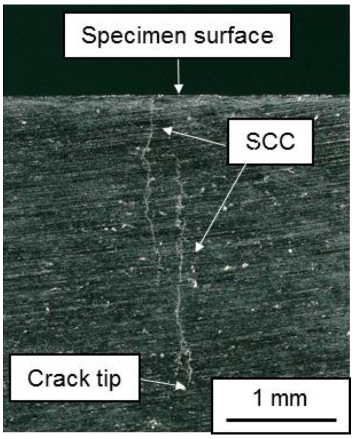
(b) Signal waveform

Figure 3. Specimen B

Basically, the ECT signal level depends on the defect volume, so SCC has a smaller signal output than the EDM defect. As an example of SCC measurement results in the case of an SCC depth of 2.68 mm, the signal voltage amplitude is about 0.54 V. That is, the SCC signal voltage amplitude is smaller than the magnetic noise level of 1.0 V, and this makes early-stage SCC detection difficult.



(a) Specimen surface after penetrant testing

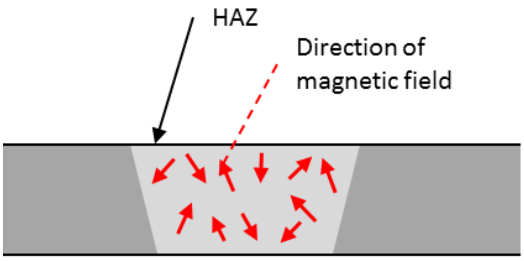


(b) Cross section of the inspection point

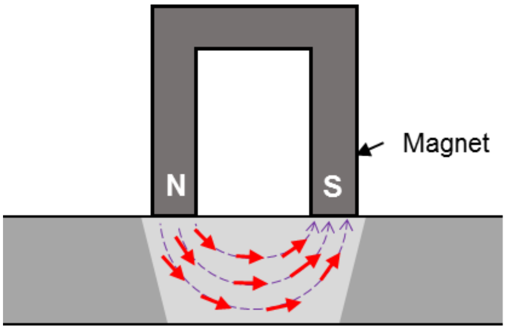
Figure 4. An example of SCC

Magnetic noise reduction method

A magnetic saturation method can be used as a measure to reduce the magnetic noise. Magnetic saturation can improve the heterogeneity of magnetic permeability by applying an external magnetic field. Since we are aiming for automated inspection, compact equipment is needed. Therefore, permanent magnets were adopted to apply the external magnetic field.



(a) Disturbed magnetic field at HAZ



(b) Magnetic field corrected by a magnet

Figure 5. Magnetic saturation method

Effect of magnetic saturation with a neodymium magnet

The stronger the external magnetic field applied to perform magnetic saturation, the greater the effect in reducing the magnetic noise. We investigated the applicability of neodymium magnets of the highest magnetic intensity from among commercially available permanent magnets. The sensor equipment was composed of an ECT sensor and a permanent magnet that sandwiched the ECT sensor, and this made it compact. As a result of inspecting specimen B with the above sensor configuration, the magnetic noise level was reduced to 0.1 V or less.

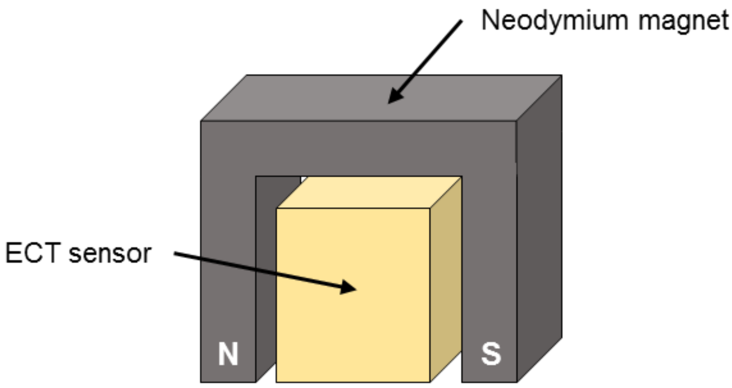
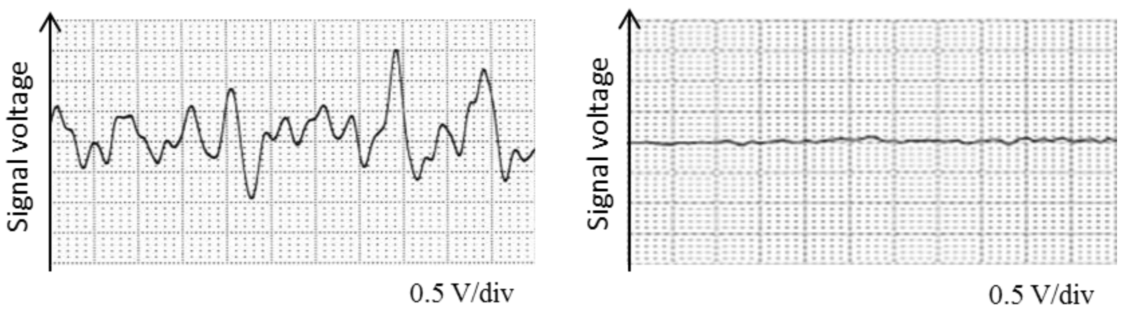


Figure 6. Device configuration with a neodymium magnet



(a) Signal waveform without a magnet (b) Signal waveform with a magnet

Figure 7. Effect of a neodymium magnet on signal waveform

Heat resistance problem of the neodymium magnet

CRIEPI (Central Research Institute of Electric Power Industry) investigated the temperature of a concrete cask when a heater simulating spent fuel with a calorific value of 15 kW, equivalent to the value immediately after the start of storage, was sealed in a canister. According to its report, the surface temperature of the canister rose to 136°C, depending on the storage method [1]. Generally, the magnetic intensity of a permanent magnet decreases as the temperature rises, and this phenomenon is called thermal demagnetization. The tendency toward thermal demagnetization depends on the type of magnet. A neodymium magnet has a high magnetic intensity, but it is a magnet that is susceptible to heat demagnetization. We investigated the heat resistance of a neodymium magnet by heating the magnet on a specimen. When the surface temperature of the specimen exceeded 80°C, the magnetic flux density of the neodymium magnet began to decrease. When the surface temperature of the specimen reached 150°C, the magnetic flux density decreased by about 30% as compared with that at normal temperature. These thermal demagnetization characteristics make it difficult to apply a neodymium magnet to inspection of the canister surface.

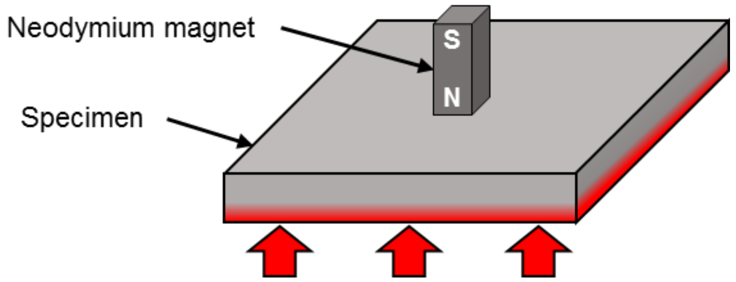


Figure 8. Heat resistance test of a neodymium magnet

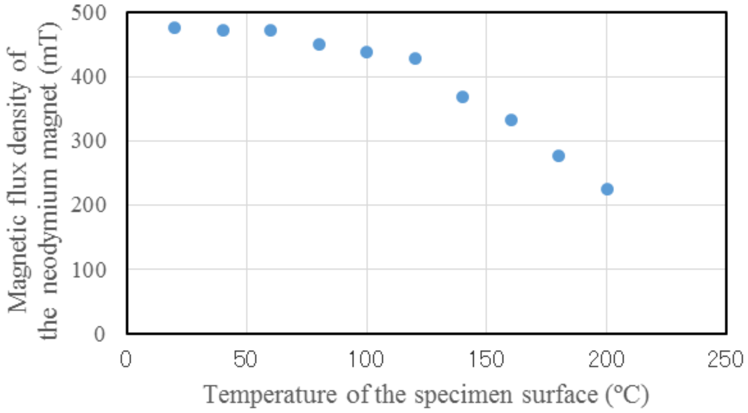


Figure 9. Relationship between temperature of specimen and magnetic flux density of neodymium magnet

Method of improving the heat resistance of magnets

A samarium-cobalt magnet has relatively high magnetic intensity and good heat resistance. However, since it has less magnetic intensity than a neodymium magnet, magnetic noise cannot be reduced sufficiently. As a result, there is about 0.5 V of magnetic noise. Considering the SCC measurement accuracy on the canister surface, this noise level is not acceptable. So, in order to produce permanent magnets with high magnetic intensity and high heat resistance, we tried the method of stacking Samarium-cobalt magnets and a neodymium magnet. Heat resistance was secured by having samarium-cobalt magnets make contact with the heated surface of the canister, and the magnetic intensities of the samarium-cobalt magnets were strengthened by the neodymium magnet stacked on top of them. As a result of inspecting specimen B with the method combining the two kinds of magnets, the magnetic noise was about 0.1 V; the magnetic noise was sufficiently reduced.

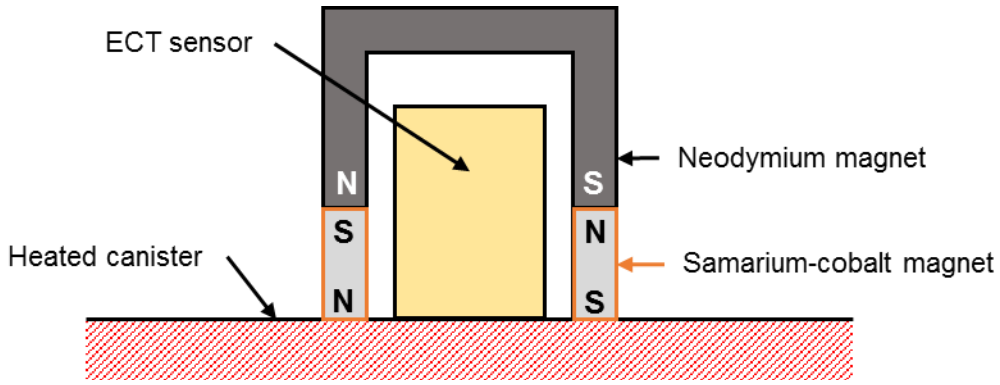
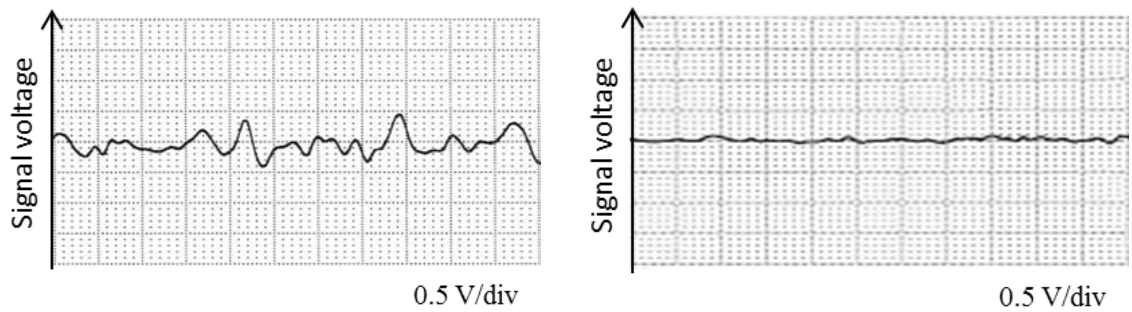


Figure 10. Method of stacking samarium-cobalt magnets and a neodymium magnet



(a) Signal waveform by using samarium-cobalt magnets

(b) Signal waveform by using the combined magnets

Figure 11. Comparison of magnetic noise reduction using the two types of magnets

Conclusion

- The level of magnetic noise is high in the welding zone of a canister, and the resulting inspection accuracy is insufficient to detect SCC in the early stage without applying a magnetic noise reduction method.
- A magnetic saturation method using strong permanent magnets can remove the influence of magnetic noise sufficiently.
- By combining two types of magnets, the combined magnets become excellent in both magnetic intensity and heat resistance and have sufficient performance to remove magnetic noise for detecting SCC on the canister surface during a long storage period.

References

[1] Shirai K, Saegusa T, Sasahara A, Hattori T, Matsumura T, Sheryl L. Morton and P.L. Winston: Ageing Characteristics of the VSC-17 Concrete Cask Storing Spent Nuclear Fuel for 15 years, CRIEPI Report N08057, 2009,(In Japanese)