Flaw Inspection System for Welded Parts Using a High-Density Flexible Magnetic Sensor Array

Eunho Choe[1], Jinyi Lee[1], and Hoyong Lee[2*]

[1]IT-based Real-time NDT Center, Chosun University, Gwangju. Korea
[2]Department of Defense Science & Technology, Gwangju University, Gwangju, Korea

[*]Corresponding author: hylee@gwangju.ac.kr

1. Abstract

Pipes welded to major components in nuclear power plants must be regularly examined by non-destructive testing to improve the reliability of plants. The liquid penetrant examination (LPE) and magnetic particle examination (MPE) are the most widely used mon-destructive testing methods for the analysis of welded structures. However, these methods suffer from limitations, such as environmental contamination and exposure of the examiner to hazardous chemicals and radiation. The present study discusses the application of the alternative surface examination (ASE) method to solve the problems associated with LPE and MPE. According to the ASE requirements, the proposed method should meet the criteria of sensitivity (either equal to or better than that of the existing methods) and reduce examination time. In this paper, an ASE method that could be applied to welded ferromagnetic pipes in the reactor coolant system (RCS) using a high-density flexible magnetic sensor array is proposed and verified.

2. Introduction

The pipes in the RCS of a nuclear power plant are connected to the reactor, steam generator, reactor coolant pump, and the pressurizer by welding. These pipes are the pressure boundaries, and prevent the release of fission products from the reactor into the environment. The probability of developing cracks at the welded zones in the pipes increases with an increase in the life of the plant. To ensure safe operation of a nuclear power plant during a planned outage, the piping system and its welding are inspected using a non-destructive examination (NDE) method.

The NDE method, which is applied to evaluate the integrity of welded pipes, is subjected to surface and volumetric examination according to ASME code requirements [1]. At present, liquid penetrant examination (LPE) and magnetic particle examination (MPE) are the most widely employed methods for surface examination. In the LPE procedure, the surface of a test specimen is cleaned and a dye penetrant is applied, so that the penetrant permeates discontinuities on the surface.

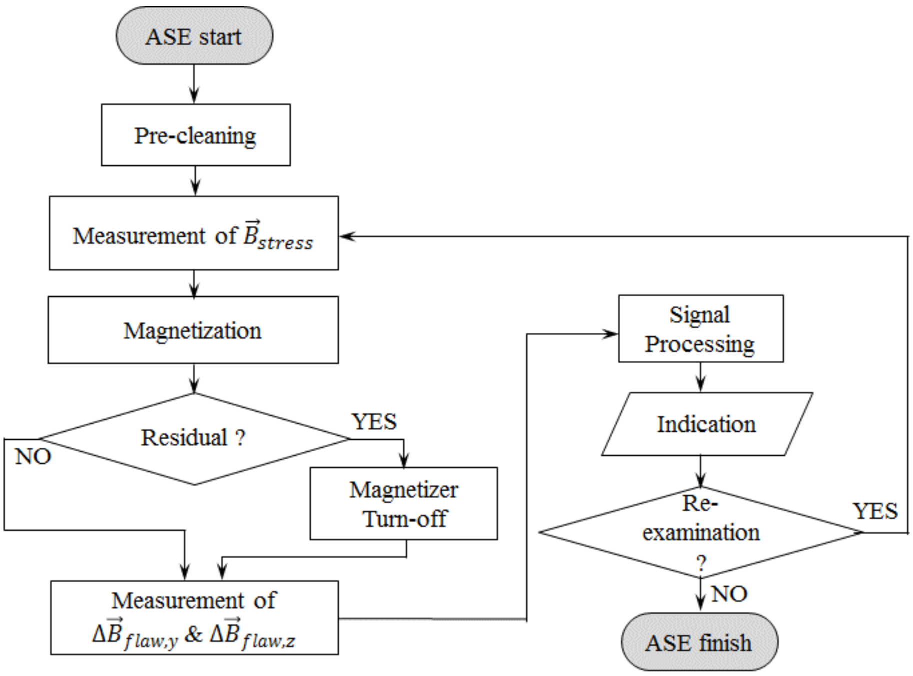

Fig. 1 Process of alternative surface examination

Subsequently, when the penetrant on the surface is wiped off and a developer is applied, the dye that has penetrated into the flaw is developed and the surface defect can be confirmed. MPE detects surface flaws in ferromagnetic materials. The test sample is magnetized using an alternating current (AC) or a direct current (DC), followed by application of magnetic particles, which reveal the flaws by detecting magnetic flux leakage from damaged areas [2]. Both LPE and MPE use several chemical substances harmful to human body. Moreover, the test time is relatively longer as compared to eddy current testing (ECT), thereby increasing the risk of the examiner to exposure to radiations. Therefore, it is necessary to develop an alternative surface examination (ASE) method to overcome these limitations.

The present study proposes an ASE method for ferromagnetic pipes (such as carbon steel and low alloy steel) with the following characteristics: (1) minimize the use of chemicals, (2) reduce the examination time by simplifying the process, (3) minimize the influence of non-uniform surfaces such as weld bead on results, (4) achieve same or higher sensitivity than that of conventional surface examination methods, and (5) store and utilize the examination results as a database.

3. Principle

Eq. (1) shows the vector of magnetic flux density produced by the magnetization vector when the specimen is under stress.

$$\vec{B}_{stress} = \frac{\mu_0}{A}\sum_{k=1}^{N} \varepsilon_{xy,k} S_k \cdot \vec{M}'_k = \frac{\mu_0}{AE}\sum_{k=1}^{N} \sigma_k S_k \cdot \vec{M}'_k \quad (1)$$

where μ_0 , $\varepsilon_{xy,k}$, S_k , and $\vec{M}'_k$ represent the permeability in the free space, strain, magnetic domain area, and magnetization vector, respectively. In other words, Eq. (1) explains that the magnetic flux density in a space is affected by the change in strain or stress on the specimen.

Excessive thermal expansion, shrinkage, and differences in local cooling rate within the specimen during welding may cause residual stress and defects in the weld. The residual stress in the weld zone induces a change in magnetic flux density distribution. Thus, welding defects can be predicted by measuring the changes in the magnetic flux density using high sensitivity micro magnetic sensors.

Fig. 1 shows the ASE process suggested in the present study. Careful pre-cleaning is essential in both LPE and MPE because the examiner visually identifies defects using penetrant and magnetic particles. However, since the ASE technique utilizes densely arrayed magnetic sensors, relatively simple pre-cleaning is required. After pre-cleaning, the residual stress distribution of the specimen, $\vec{B}_{stress}$ is measured. Next, the magnetic flux leakage density distribution, $\Delta\vec{B}_{flaw}$, due to flaws on the surface of the test specimen, is measured in the magnetized or the residual magnetization state by arrayed magnetic sensors that have magnetic anisotropy in the Y or Z axis. More details will be presented at the International Conference on Materials and Reliability (ICMR) 2019.

Acknowledgment

This work was supported by the Korea Hydro & Nuclear Power Co., LTD (No.2018-14).

References

[1] J. Kim, M. Le, J. Park, H. Seo, G. Gung, J. Lee, Measurement of residual stress using linearly integrated GMR sensor arrays, JMST, 32(2) (2018) 623-630.
[2] ASME BPVC (2019): Boiler and Pressure Vessel Code, Part V, Nondestructive Examination