Flaw Discrimination of Heat Exchange Tubes using Cylinder-Type Magnetic Camera

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1. Abstract

In this study, artificial flaws introduced into a heat exchanger (HX) tube test specimen were identified using a cylinder-type magnetic camera system and a defect characterization algorithm. The cylinder-type magnetic camera system consists of a sensor probe, a controller and an operating & analysis software. Hall sensors are arranged to be sensitive to the magnetic flux change in the circumferential direction of the tube, and the magnetic field is induced by bobbin coils that are placed on top of the Hall sensor array. The validity of the proposed system and algorithm was verified by using STS304 tube which is used in high pressure feedwater heat exchanger of nuclear power plant.

2. Introduction

Eddy current testing (ECT) using a bobbin probe is one of the most widely used non-destructive testing (NDT) methods for identifying the integrity of heat exchanger (HX) tubes [1]. HX is composed of a large number of tubes, and bobbin probe ECT is capable of inspecting the large number of HX tubes in a short time. In addition, it has an advantage that it can easily detect various types of flaws including the volumetric flaws [2-3]. However, the bobbin probe ECT has disadvantages that it is difficult to evaluate the flaw characteristics, such as discriminating flaw types between volumetric flaw and crack-type flaw and sizing flaws, and has insufficient detecting sensitivity of circumferential flaws.

After performing a NDT of a HX, tubes that have volumetric flaw within the maintenance limit can be operated without repair. On the other hand, tubes that have crack-type flaw or volumetric flaw that exceed the limit should be operated after plugging. At this time, if a crack-type flaw is mistakenly determined as a volumetric flaw and remain unrepaired, the power plant may have the risk of tube rupture during operation.

In this paper, we propose a cylinder-type magnetic camera system to overcome the limitation of conventional bobbin probe ECT. The shape of flaws in HX tubes is characterized and an algorithm for evaluating the location and depth of flaws is proposed. This study is applied to a high pressure feedwater heat exchanger tube of nuclear power plant with 13.3mm inner diameter (ID) and STS304 material.

3. Experimental setup

Fig. 1 shows the experimental setup and enlarged view of sensor probe. At the head of the sensor probe, differential-type bobbin coils are placed. Inside the excitation coil, 32 Hall sensors with a spatial resolution of 0.78mm are arrayed in the circumferential direction and 16 Hall sensors with spatial resolution of 1.56mm are arrayed in the axial direction. When an alternating current is applied to the excitation coil, an induced current is generated in the heat exchanger tube. When the radial

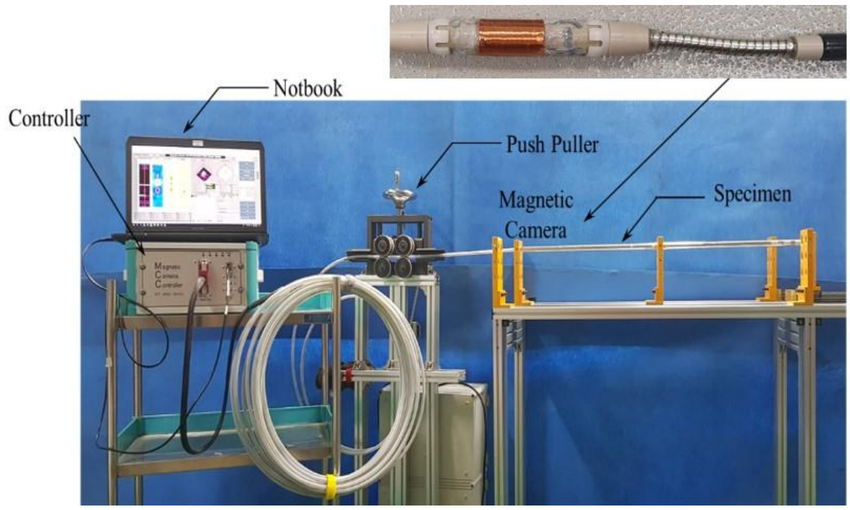

Fig. 1 Sensor probe and experimental setup

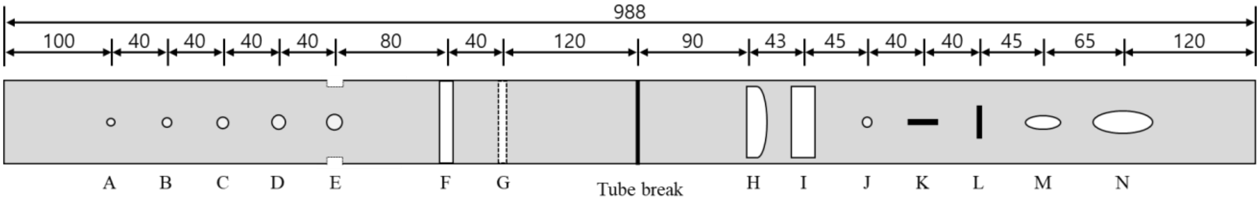

Fig. 2 Test specimen

direction of the tube is *r*, the axial direction is *z*, and the rotational direction is *θ*, the induced current in the *θ* direction and the magnetic flux density distribution in the *z* direction occur when there is no defect. In this situation, if the Hall sensors having anisotropic sensitivity in the *r* direction are arrayed in a ring shape, the magnetic flux density in the r direction is measured to the minimum. On the other hand, if there is a flaw in the tube, the induced current is distorted, resulting in a change in the magnetic flux density distribution in the r direction and this change can be measured through the Hall sensors. Each magnetic flux density change measured by the Hall sensors is accompanied by not only the impedance change but also the phase angle difference change. Therefore, it is possible to estimate the presence, position, and size of flaws by using a Hall sensor array having r-directional sensitivity.

In conventional bobbin probe ECT, as the scan speed increases, bias electromotive force is generated due to high permeability materials such as *δ*-ferrite structure, ferrous foreign object, and tube support plate (TSP). The bias electromotive force may have a positive or negative value depending on the magnetization direction, so that it is possible to recognize a flaw in a flaw-free area or to cancel a flaw signal, thereby failing to detect a flaw.

Fig. 2 shows the test specimen to verify the effectiveness of the proposed cylinder-type magnetic camera system and flaw characterization algorithm. The material of the test specimen is an austenitic stainless steel (STS304) having an ID of 13.3mm and a thickness of 1.27mm. On the left side of the specimen, flat bottom holes and grooves were introduced as ASME standard, and on the right side, tapered wear, flat wear, round hole, axial notch, circumferential notch, denting, and steam cut were introduced.

4. Results and discussion

Further details will be presented at the International Conference on Materials and Reliability (ICMR) 2019.

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