Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Array UT and ECT Systems for Inspection of Nuclear Power Components

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1. Introduction

The ultrasonic testing (UT) and the eddy current testing (ECT) are main nondestructive examination methods which are used for the in-service inspection in the nuclear power plant. The ultrasonic testing is mainly used for the inspection of welds in piping and nozzle for many components. The eddy current testing is widely used for the inspection of heat exchanger tubing like steam generator tubing. Technologies for these methods have been advanced for the reduction of inspection time and the increase of inspection reliability. Data cannot be stored during the inspection using a manual ultrasonic testing system. In steam generator tubing inspection, the rotating probe technology is regarded as the time-consuming method. Therefore, the array UT and ECT systems have been developed in order to overcome these barriers of conventional methods. The Korea Hydro & Nuclear Power Co., Ltd. (KHNP) is developing the phased array UT and multi-array ECT systems for the inspection of nuclear power components. Details of these systems are described in this paper.

2. Array Methods

Phased array UT technology allows for the generation of an ultrasonic beam with the possibility of modifying the beam parameters such as angle, focal distance, and focal spot size through software. Furthermore, this beam can be multiplexed over a large array, thus creating a movement of the beam along the array. These capabilities open a series of new possibilities; for example, it is possible to quickly vary the angle of the beam to scan a specimen or weld without moving the probe itself, phased array also allows the replacement of multiple probes, and mechanical scanning devices. Inspecting a specimen or weld with variable angle beams also improves detection of defects.

Multi-array ECT technology is high speed alternative to rotating probe and high circumferential sensitivity alternative to bobbin probe. The sensing part of the probe consists of multiple coils arranged around the probe circumference operating in transmit-receive mode. Mechanical rotation is replaced by a rotating field which rotates much faster enabling pulling speed comparable to the bobbin coil examination. The rotation of the field is provided by activating the transmission and the reception at known predefined circular patterns. Electric current injected in the transmit coil creates a magnetic field that establishes an eddy current in the test material creating a magnetic field that opposes the original one. Eddy currents are read by the receive coil. In the case of discontinuities or property changes in the test object, the flow of eddy currents is disrupted which is interpreted as variations of phase and amplitude [1].

2.1 Phased Array UT System

The phased array UT system, which is being developed by the KHNP, is composed of PA probe, pulser-receiver, AD converter, beam-former, FPGA controller, CPU board, scanner, motor drive unit(MDU), data acquisition PC, and acquisition-analysis software as shown in Fig. 1. The analog board transmits excitation signals and amplifies received signals. The digital board performs focusing beams and plays a role of post signal processing. The MDU moves a scanner with a probe for the scanning of inspection spot.

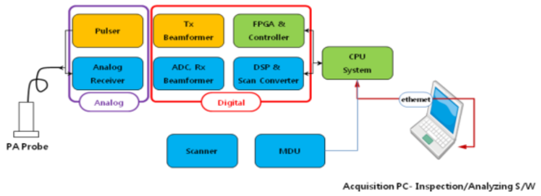

Fig. 1. Configuration of the phased array UT system

Focal law calculation algorithm is developed for beam-focusing to the specific spot using time-delay calculation of each transducer. Time-delay of an element is calculated by the following equation.

$$t_n = \frac{F}{c}\left[\begin{array}{l}\left\{1+\left(\frac{\bar{N}d}{F}\right)^2+\frac{2\bar{N}d}{F}\sin\theta_s\right\}^{1/2}\\ -\left\{1+\left(\frac{(n-\bar{N})d}{F}\right)^2-\frac{2(n-\bar{N})d}{F}\sin\theta_s\right\}^{1/2}\end{array}\right]$$

Where t_n is the delay time of an element n, d is the distance between the elements, F is focusing distance, θ_s is the steering angle and c is the wave velocity. The time delay of each element is calculated over distance and steering angle, respectively, as shown in Fig. 2.

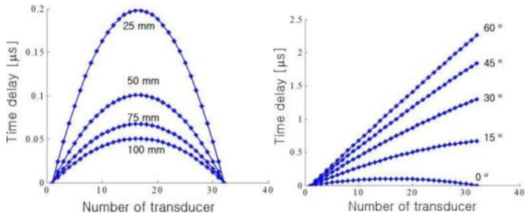

Fig. 2. Time delay of each transducer over distance and angle

2.2 Multi-array ECT system

The rotating probe technology for the inspection of steam generator tubing can be replaced with multi-array ECT technology. Multi-array ECT technology is high speed alternative to rotating probe and its schematic algorithm is shown in Fig. 3. The multimplexing switch device (MUX) is necessary for transmitting and receiving signals of many coils due to limited number of channels of the frequency generator. The design concept of the MUX is shown in Fig. 4.

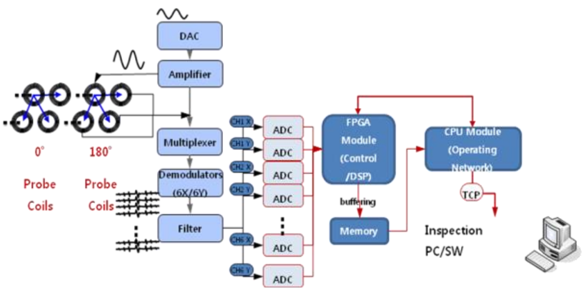

Fig. 3. Algorithm for multi-array ECT technology

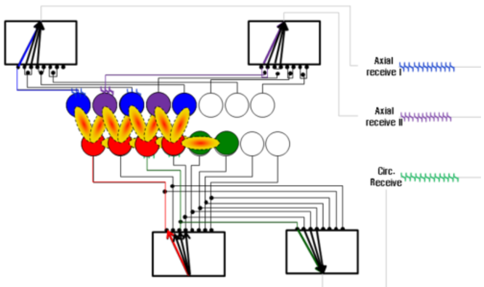

Fig. 4. Design concept of the multiplexing switch device

3. Results

The characteristics of the amplitude and frequency of the phased array UT system are shown in Fig. 5 and Fig. 6, respectively. In Fig. 5, the amplitudes are not fluctuated severely for each transducer, and the frequency characteristics for each element of the phased array UT probe are fairly good in Fig. 6. The acquired signal for calibration block from the phased array system is shown in Fig. 7. The multi-array ECT probe and its frequency characteristics are shown in Fig. 8. The acquired signal of the standard tube from the multi-array ECT system is shown in Fig. 9.

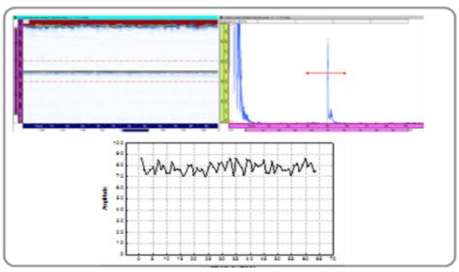
Fig. 5. Amplitude characteristics for each element of the phased array UT system

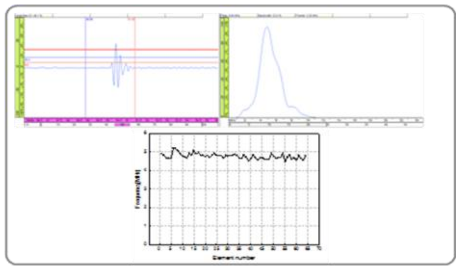
Fig. 6. Frequency characteristics for each element of the phased array UT system

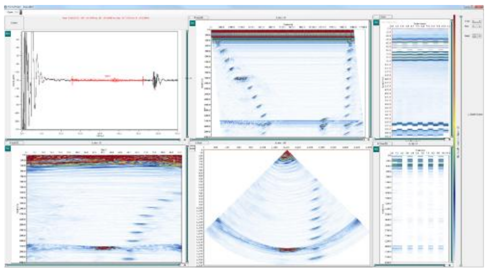
Fig. 7. Phased array UT signals from a calibration block

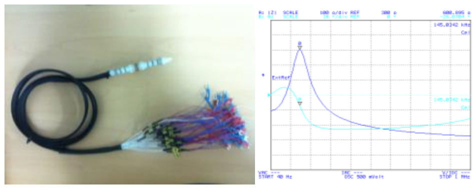
Fig. 8. Multi-array ECT probe and its frequency characteristics

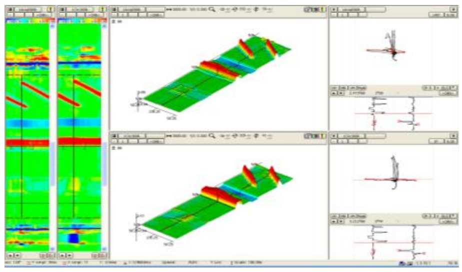
Fig. 9. Multi-array ECT signals from a standard tube

4. Conclusions

The phased array UT and the multi-array ECT systems are being developed. Amplitude and frequency characteristics from these systems are reviewed in this paper. These systems produced good results from the calibration standards.

REFERENCES

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[2] C. H. Cho, et al., Development of High-performance Phased-array Ultrasonic and Multi-array Eddy Current Testing Systems for NPPs, 2nd Annual Report Supported by KETEP, Korea Hydro & Nuclear Power Co., Ltd., 2015.