

Reliability Assessment for Electromagnetic Acoustic Resonance (EMAR) and Pulse-EMAR Methods by Statistical Analysis

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Abstract: This study proposes a reliability assessment method for two pipe wall thickness inspection techniques, the electromagnetic acoustic resonance (EMAR) and pulse-EMAR methods, using statistical analysis. The statistical analysis uses an EMAR technique with a signal processing method called the superposition of nth compression (SNC) method, which is used to calculate the normalized SNC peak value, and is concerned with the difference between the thicknesses obtained by the EMAR method and the real values. A generalized linear model (GLM) using the logistic link function overcomes the difficulties that use of ordinary linear models would cause. Finally, we build a logistic model to compare the transformed probabilities and determine the inspection method that offers higher reliability.

Keywords: nondestructive testing, electromagnetic acoustic resonance, pipe wall thinning, statistical analysis

1. Introduction

Pipe wall thinning is a common ageing problem in nuclear power plants and thermal power stations. The electromagnetic acoustic resonance (EMAR) method, a type of non-destructive testing (NDT) method, has been developed for online monitoring and thickness measurement, and offers excellent accuracy and evaluation stability [1]. The results of pipe thickness measurements in a nuclear power plant during a shutdown period indicated that the measurement results of ultrasonic testing (UT) and those of the EMAR method with superposition of nth compression (SNC) show some discrepancies. Additionally, the normalized SNC peak value can be used as a reliability evaluation parameter [2].

Statistical analysis can provide the necessary reliability assessment methods to compare these inspection methods quantitatively. In previous cases, inspection reliability assessments were conducted using electromagnetic acoustic transducers (EMATs) [3]. The generalized linear model (GLM) has been applied to crack inspection in airplanes in the United States [4].

The purpose of this study is to use statistical analysis to quantify the reliability of the EMAR and pulse-EMAR methods, based on the relationship between the normalized SNC peak values and thickness differences that are obtained

using the EMAR/pulse-EMAR methods and the real values.

2. Statistical Analysis

The generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for response variables with error distribution models other than the normal distribution. The GLM overcomes the difficulties that ordinary linear models would cause by “linking” the binary data to the explanatory variables through the probability of either outcome, which varies continuously from 0 to 1. The transformed probability can then be modeled as an ordinary polynomial function, which is linear in terms of the explanatory variables. Binary regression models explore the ways in which each independent variable affects the probability that the event will occur. In this study, we use the link functions to map $(-\infty < x < \infty)$ into $(0 < y < 1)$. We present the *logit*, which is a logistic or log-odds function used for the linking process.

$$f(X) = g(y) = \log\left(\frac{p_i}{1-p_i}\right), \quad (1)$$

which is the same as:

$$p_i = \frac{\exp(f(X))}{1 + \exp(f(X))}, \quad (2)$$

where p_i means $\Pr(a_i)$, defined as the probability that a_i will equal a specific value, and $f(X)$ is any appropriate algebraic function that is linear in terms of parameters. The

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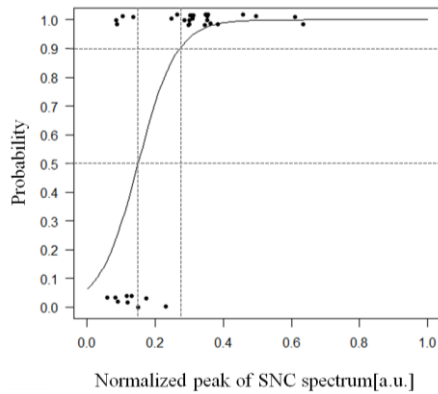


Fig. 1 Transformed logit curve – SNC peak value vs. difference (EMAR).

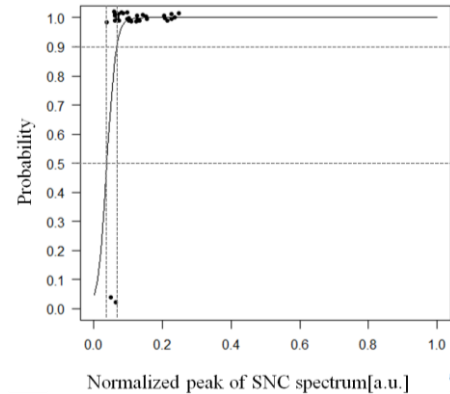


Fig. 2 Transformed logit curve – SNC peak value vs. difference (pulse-EMAR).

logit function implies a nonlinear relationship between a and the probability.

3. Experiment

Attenuation of the normalized SNC peak value is caused by changes in the shape of a pipe's inner surface by thinning. The carbon steel plates (SS400) under test have inclined bottoms with angles of 1, 2, 3, 4, and 5 degrees, and R-shaped bottoms with a two-dimensional shape depth of 2 mm are prepared as specimens. These specimens are measured by both the EMAR and pulse-EMAR methods and the results are compared.

4. Results and Discussion

The UT error is generally less than 0.1 mm, and we therefore propose that the absolute value of the difference below 0.1 mm is 1 (hit), and that for all other values is 0 (miss). Figs. 1 and 2 show the results of the analysis, which was based on transformed experimental data measured by the EMAR and pulse-EMAR methods for calculation of the probability curves. $\alpha(\text{Pr}=0.9)$ denotes the SNC peak value when the inspection has a 90% chance of “hitting” the real value. In statistical analysis, any event with a probability of 0.9 (90%) is quite likely to occur. Therefore, we compare the $\alpha(\text{Pr}=0.9)$ values of the method. The $\alpha(\text{Pr}=0.9)$ value of the EMAR method is 0.273, as shown in Fig. 1, while the $\alpha(\text{Pr}=0.9)$ value of the pulse-EMAR method is 0.066, as shown in Fig. 2.

5. Summary

This study used statistical analysis to quantify the

reliability of the EMAR and pulse-EMAR methods based on the relationship between the normalized SNC peak values and the thickness differences obtained using the EMAR/pulse-EMAR methods and the real values. The results show that the pulse-EMAR method offers higher reliability for evaluation of pipe wall thinning.

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