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A Study on the ECT Evaluation of DFMS Thimble Tube in Hanbit Nuclear Power Plant Units 1 and 2

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1. Introduction

In nuclear power plants, the digital flux mapping system (DFMS) measures the distribution of neutron flux inside the reactor [1]. By inserting and withdrawing the fission chamber, a neutron flux detector, into 50 designated thimble tubes inside the reactor, the current of the charged detector can be measured. The distribution of neutron flux inside the reactor is used as calibration data for the core power distribution analysis, fuel combustion evaluation of each fuel assembly, thermal margin evaluation, and the neutron monitoring system.

However, thimble tube may be exposed directly to the installation or coolant flow inside the reactor, resulting in vibration-induced wear and changes in shape of the crack. Therefore, during each overhaul of a nuclear power plant, eddy current testing (ECT) is conducted to verify the integrity of the thimble tube [2].

The ECT evaluation can determine the current thimble tube wear level and the corresponding action method and predict future wear rates.

There are two calculation methods for predicting wear rates of the thimble tube and the measures taken vary depending on which calculation method is applied.

In this study, the case of Hanbit 1 and 2 power plants is considered to determine a more efficient calculation method for predicting the thimble tube wear using the two calculation methods.

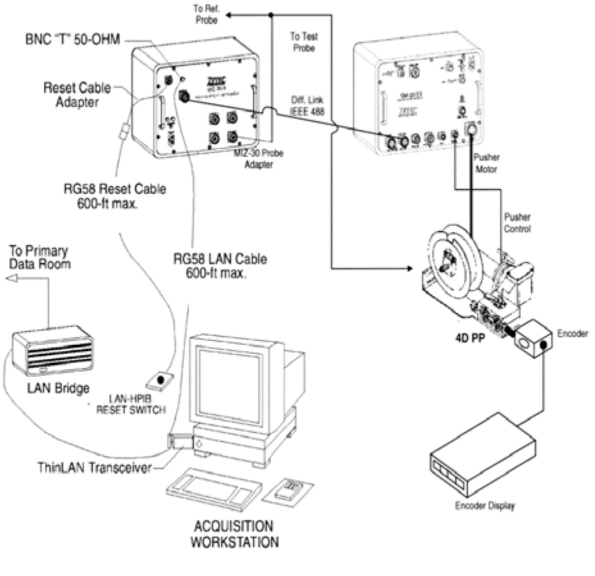

Fig. 1. ECT System of thimble tubes

2. Methods and Results

2.1. Expected wear rate of thimble tube

There are two ways to calculate the expected wear rate for a guide.

2.1.1. KNP-89-707

This method is presented in [3] and the wear depth is calculated as follows:

$$WR = (WL+10\%)/NM \quad (1)$$
$$WLP = (WL+10\%)+(WR\times X) \quad (2)$$

where

WR = wear depth per month (%/ month)
WL = ECT results (wear depth , %)
NM = number of accumulated operation months
10% = compensation value for ECT uncertainty
WLP = expected wear depth until next test (%)
X = number of months planned from ECT test to next test

2.1.2. WCAP-12866

This method is presented in [4] and the wear depth is calculated as follows:

$$W_a = W_d (N_a / N_d) n \quad (3)$$

where

W_a = expected wear depth until next test(%)
W_d = current wear depth according to ECT results(%)
N_a = number of accumulated operation months to next test
N_d = number of accumulated operation months
n = index determined by wear trend

The index is determined by the following equation:

$$n = \frac{\log(W_a / W_d)}{\log(N_a / N_d)} \quad (4)$$

where

W_a = wear depth of the first test in two consecutive test(%)

W_d = wear depth of the second test in two consecutive test(%)

N_a = until the number of accumulated operation months of the first test in two consecutive test

N_d = until the number of accumulated operation months of the second test in two consecutive test

2.1.3. Review results

In general, the best known Archard equation [5] for wear prediction is the best representation of sliding wear. This is expressed as follows:

$$V_w = K_w F_N L \qquad (5)$$

where V_w is the volumetric wear (in^3), K_w is the wear coefficient (in^2 / lb), F_N is the vertical contact force (lb), and L is the sliding distance (in).

In the above equation, the volume of wear per hour remains unchanged when the force and relative displacement are constant. Assuming that the force and relative displacement are the same as the conditions so far, the amount of wear away from the surface is the same. However, due to the geometry of the cylinder, the amount of wear per unit depth is not the same.

Although KNP-89-707 considers the increase in wear depth to be linear over time, the wear depth cannot be linear because of the geometric shape of the cylinder (the gap between the structure in contact with the guide tube becomes smaller as the abrasion progresses).

Therefore, the KNP-89-707 method that considers the increase in wear to be linear may be unclear.

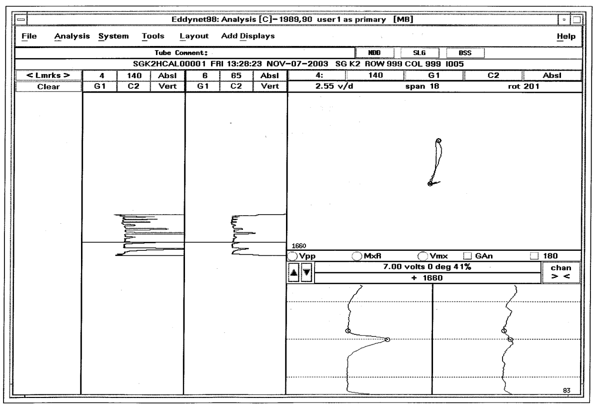

Fig. 2. ECT Result screen: location and depth of tube wear

In WCAP-12866 the wear depth for time is reviewed with field data to confirm that the wear trend of the guide is expressed as an exponential function. The wear rate of the thimble tube varies from plant to plant.

Non-destructive testing shows that the higher the number of loops, the higher the wear rate.

This means that the thimble tube wear rate of the 4 loop power plant is the highest, followed by the 3 loop and 2 loop power plants, and the wear rate is reduced.

In addition, the smaller the diameter of the internal instrumentation column, the larger the outside diameter of the thimble tube, so the greater the gap between the thimble tube and the internal instrumentation column, the smaller the wear rate.

In WCAP-12866 these plant-specific wear rates are compensated using the wear trend of the plant. Therefore, it is reasonable to apply WCAP-12866 with well-founded and geometric variables.

However, the index of Eq. (4) should be calculated using two consecutive test results (if only one test result is available, the index is 0.67).

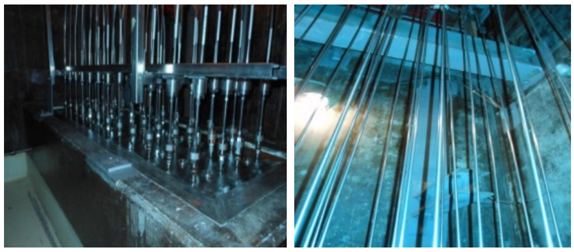

Fig. 3. Thimble tubes

To conservatively predict the wear trend, it is necessary to include ECT results performed before and when the wear rate was maximum.

2.2. ECT error

2.2.1. KNP-89-707

In KNP-89-707, a 10% ECT error is used in addition to the test result. (see Equation (1)) This is explained on the basis of ECT maximum error.

2.2.2. WCAP-12866

WCAP-12866 says that there is no need to reflect the ECT error of 10%. The actual ECT results are presented as a basis for this. The results of a thimble tube test performed using the wedge-type or flat-type reference standard thimble tubes shown in WCAP-12866 are always more conservative than the actual wear depth.

2.2.3. Review results

The usual ECT error is considered ±10%. This error is not used to predict wear depth and is used to determine the maintenance criteria. For example, the standard for plugging the steam generator tubes in a nuclear power plant is 40% wear. (According to Reg. Guide 1.121, the integrity of the steam generator tube is

maintained even when the amount of wear reaches 60%)
40% wear based on plugging the steam generator includes 10% increase in expected wear growth rate to the next test time and 10% error of ECT.

Because of the large quantity of the steam generator tubes and the various shapes of U-tubes and supports it is difficult to determine the predicted wear rate for each tube and the 10% prediction error of the wear rate is applied equally. 10% error of ECT is not added to actual test results but is used in determining maintenance criteria.

However, KNP-89-707 is required to add 10% error to ECT results. Determination of wear rate by adding 10% to the current wear value in KNP-89-707 can result in the duplicate reflection of ECT error: that is, once from the ECT results and twice from the action criteria.

On the other hand, WCAP-12866 clearly states that there is no need to consider 10% error in the ECT results of thimble tubes based on the results of the experiment. Therefore, 10% of the error does not need to be considered if the test is carried out using the two types of the reference standard thimble tube specified in WCAP-12866.

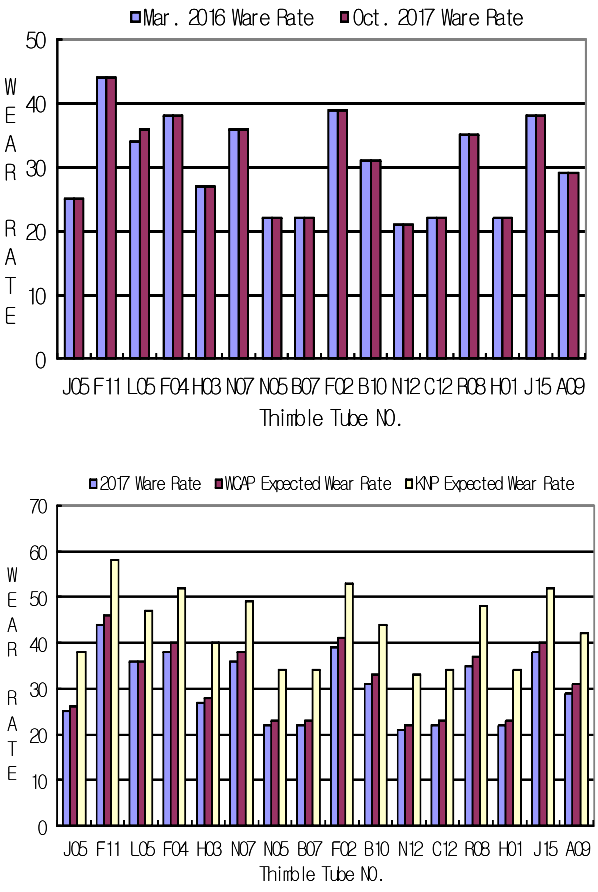

Fig. 4. Example of the expected wear rate of thimble tubes with KNP and WCAP calculation methods [6]

2.3 Maintenance criteria

Table 1 shows the comparison of KNP89-707 and WCAP-12866 methods.

Table 1. Comparison of KNP89-707 and WCAP-12866

Standard	KNP-89-707	WCAP-12866
Test cycle	- if the expected wear rate for the next test is 60% or more: After one nuclear fuel cycle - if there are no thimble tubes with an expected wear rate of more than 60% for the next test: After two nuclear fuel cycles	- ECT is continued each overhaul
Repair criteria	- wear rate of more than 60% : Thimble plugging or Replacement	- Replacement or relocation for over 80% wear during the next operating cycle
Repair standard according to expected wear rate	- 60% or more expected wear rate > Thimble tube relocation > Thimble tube plugging or replacement	- Replacement or relocation for over 80% wear during the next operating cycle

2.3.1. KNP-89-707

According to this year's ECT result, thimble tubes with a wear depth of more than 60% are plugged or replaced. Thimble tubes with a maximum expected wear depth of 60% or more will be tested after one nuclear fuel cycle, and those with a maximum expected wear depth of 60% or more will be tested after two nuclear fuel cycles.

If the expected wear rate is 60% or more and the wear length is 0.5 inches or more, a perfusion or tubular replacement is performed.

2.3.2. WCAP-12866

ECT must be performed every overhaul. To predict the next test period, the wear depth of the thimble tube must be predicted. Thimble tube expected to have more than 80% wear during the next fuel cycle should be relocated or replaced

Table 2. The pros and cons of KNP89-707 and WCAP-12866

Standard	pros	cons
KNP-89-707	Conservative assessment	About 10% overestimate WCAP-12866
WCAP-12866	Exponential wear rate calculation (considering growth of defects)	-

2.2.3. Review results

Experiments and modeling in WCAP-12866 demonstrate that the guide maintains its function even if it is worn by 80%.

The modelling also showed that wear depth has an effect on the structural integrity of the thimble tube and that wear length has no significant effect.

80% wear on the thimble tube is considered conservative and the next test period should be set based on 80% wear.

3. Conclusions

KNP-89-707 was issued in 1989 and WCAP-12866 was issued in 1991. Based on both reports issued by Westinghouse, WCAP-12866 seems to contain more new technical content. Therefore, with respect to the ECT of the neutron flux detector thimble tube of Hanbit Nuclear Power Plant Units 1 and 2, it is considered more reasonable to follow the criteria in WCAP-12866.

- It is considered reasonable to apply the wear prediction formula given in WCAP-12866 with a solid basis and a geometric variable. However, it is recommended that the index of Eq. (2) is obtained using two consecutive test results.
- If a test is carried out using two types of ECT standard test specimens as suggested in WCAP-12866, it is thought that 10% of the inspection errors are not considered.
- 80% wear on guide tubes is considered to be conservative enough and the next inspection period should be set based on 80% wear.
- The plugging or relocation of thimble tubes can be reduced if WCAP-12866 is applie. This extends the replacement time of the entire thimble tubes, thus reducing unnecessary maintenance, which is accompanied by economic benefits.

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