Uncertainty Margin of Void Packet Determination for Ultrasonic Test in NPP

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1. Introduction

In a safety related system, a void packet determination is issued by US NRC through the Generic Letter 2008-01. In case of the safety function, ECCS, CSS, and RHR systems are affected by the void packet [1-3]. The related study has been being carried out by KHNP since 2012[4, 5]. In this study, the void packet determination using a ultra sonic test method has been carried out in some sites. This paper shows the uncertainty of the method using the ultra sonic test. The key parameters are introduced and estimated. Specially, the measurement conservatism for NPP is introduced to show the uncertainty margin.

2. Methodology

2.1. Void Packet Determination

Figure 1 shows the procedure and the void packet determination.

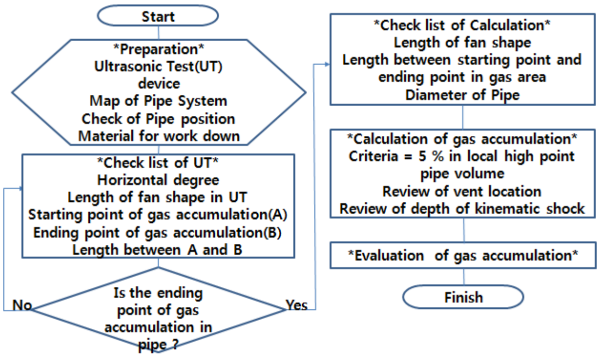

Fig.1 Schematic diagram of UT in the void packet accumulation

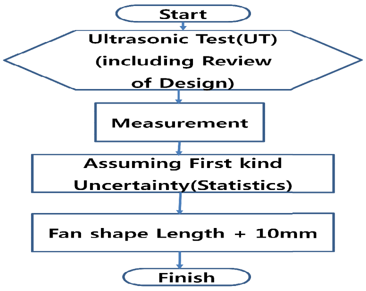

Fig.2 Assuming the uncertainty of 10mm for the fan shape length

Equation (1) is formulas to calculate the void packet volume [4]

$$\text{Void (horizontal)} = \left(\pi r^2\left(\frac{\theta}{360}\right) - r\sin\left(\frac{\theta}{2}\right) r\cos\left(\frac{\theta}{2}\right)\right)\bullet L \qquad (1)$$

Eq. (1) is used for evaluating the uncertainty of the determination of void packet. That is a general formula used in most of walk down. Here, r is the radius of pipes respectively. And L is the length of pipes. θ is the radian value by the fan shape length and the inner radius.

2.2. Uncertainty Process

Here, the uncertainty analysis process is selected from the reference of KHNP CRI's study in 2012 and 2013[4, 5]. This method has developed from the uncertainty guideline by ISO issued in late 1993, which is GUM (Guide to the Expression of Uncertainty in Measurements). Generally, uncertainty analysis includes the measured data, systematic error, the random error and so on. In Fig.3, A-type uncertainty is based on the spread of the standard deviation and the measurement statistics. The A-type uncertainty calculation is carried out by the determination of measurement standard deviation and degree of freedom in each measurement. B-type uncertainty is achieved by simple random sampling according to each distribution form.

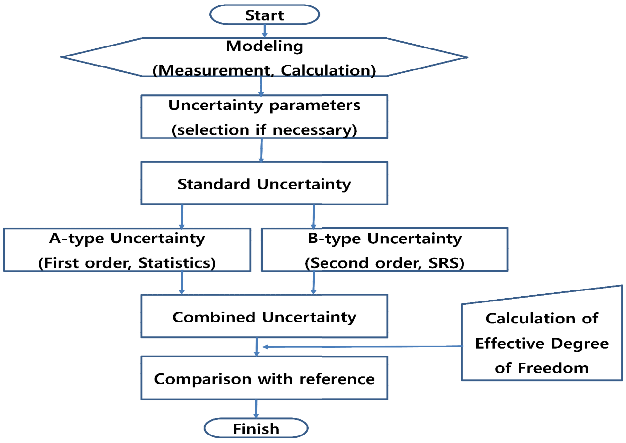

Fig.3 Procedure of uncertainty estimation

A-type is less than 30 measurements or an assumed t-distribution of sampling size less than 30. Otherwise, B-type is more than 50 sampling random numbers. Sampling standard deviation, mean standard deviation, and degree of freedom are calculated by assuming t-distribution and normal distribution.

2.3. Uncertainty Key Parameters

In this paper, the only fan shape length is selected by uncertainty key parameter. In UT, the void packet in pipes is calculated by the void length, the void fan shape, the inner diameter and outer diameter of pipe. In work down, the void packet length is conservatively used by the full length of pipe and the diameters are used by the value of design drawings.

Therefore, the conservatism of these parameters are enough. In case of the void fan shape, the measurement data is directly used. In a direct measurement, a conservative uncertainty is assumed. We assumed the uncertainty as 10mm. This value is used for work down in measuring the fan shape length. UT measurement uncertainty will be compared with the standard reference. According to Heckle's study, a general uncertainty of measurement tape is known for 2mm [6]. This value has written from trying 200 measurements when the diameter determination of the oak tree samples was measured by line tape [6]. The distribution form of these data was known as the normal distribution. A ultrasonic test equipment uncertainty was known as 0.3% [4]. Specially, this distribution is known as the log-normal distribution. We select the line tape measurement as the statistics of a normal distribution. The ultrasonic test uncertainty distribution is made from a simple random sampling (SRS) of the log-normal distribution.

2.3.1. Pipe inner diameter and Liquid area length

The void packet is also affected by the pipe diameter and the liquid area length (liquid length). In this study, a inner pipe diameter is 133mm, which is referenced from Westinghouse type design drawing in KOREA. The liquid length is directly measured by line tap, but this value is less affected than the fan shape length. In ultrasonic test, the liquid area length is scanned along the surface of pipes in order to detect the UT angle and the width of the fan shape and the length of volume. In this stage, the uncertainty of the angle is dependent on the fan shape length. And the angle is assumed as ±1.76° according to inner pipe diameter of 133mm. These parameters are included to the element of the common uncertainty.

2.3.2. Uncertainty distribution

In these work, two distributions is used for calculating the B-type uncertainty.

In order to get the B-type uncertainty, a Monte Carlo simulation is carried out using Box-Muller's algorithm. The method is shown below (2) and (3).

Normal distribution:
R1=random(0.,1), R2=random(0,1)

$$X1=\text{skew} \times \sqrt{-2\text{Ln}(R1)} \times \cos(2\pi R2) + M \tag{2}$$
$$X2=\text{skew} \times \sqrt{-2\text{Ln}(R2)} \times \cos(2\pi R1) + M$$

Log-normal distribution:
R1=random(0.,1), R2=random(0,1)

$$X1=\text{Ln}[\text{skew} \times \sqrt{-2\text{Ln}(R1)} \times \cos(2\pi R2) + Ln(M)] \tag{3}$$
$$X2=\text{Ln}[\text{skew} \times \sqrt{-2\text{Ln}(R2)} \times \cos(2\pi R1) + Ln(M)]$$

Here, R1 and R2 are uniform random numbers and Ln is natural log. In algorithms (2) and (3), m is the mean value of uncertainty. Skew is used for a non-symmetric shape, which is 1.5 in this study. In a normal distribution, the skew is generally 1.

2.3.3. Parameters and Reference

The characteristic and measurement type of uncertainty parameters are shown in Table 1.

Table 1. Uncertainty parameters and type of uncertainty distribution

Parameter	Uncertainty source	Type of Parameter (uncertainty distribution)
Pipe Area	Inner diameter	A(t-distribution)
	UT angle	B(normal)
	Fan shape	A(direct measurement)
Liquid Area	Inner diameter	A(t-distribution)
	UT angle	B(normal)
	Fan shape	A(direct measurement)
Length of Volume	Length	A(t-distribution)
Calculation method	formula	B(normal)
Ultrasonic equipment	Sonic reflection	B(log-normal)

From Table 1, the uncertainty of the ultrasonic test method is calculated and the conservatism is compared with the case results of applying Heckle's uncertainty value "2mm" into A-type parameters of Table 1.

2.3.4. Confidence interval

The uncertainty distribution is generated from some measurements and some functions. Measurement data and functions are introduced in Table 1. The calculation output by uncertainty parameter input is involved in t-distribution, normal distribution and log-normal distribution. B-type parameter is related to normal distribution and log-normal distribution in this study. The t-distribution is used for A-type parameter except the direct measurements. And the degree of freedom is calculated from t-test assumption [5]. A many kinds of the degree of freedom are merged and changed into a single normalized form by calculating the effective degree of freedom (EDF)[5].

Effective degree of freedom is used for calculating k-value, which is equal to 2σ of normal distribution.

Here, effective degree of freedom (EDF) is calculated as below [5]:

$$\text{EDF} = \frac{(\text{combined uncertainty})^4}{\sum_i \frac{(\text{component uncertainty})_i^4}{\text{degree of freedom}_i}} \tag{4}$$

In uncertainty estimation, confidence interval can be calculated by the multiplication between combined uncertainty and 95% position value of t-distribution having k-value of effective degree of freedom. Here combined uncertainty is calculated by the square root method of each component.

3. Result and Discussion

3.1. Uncertainty Estimation Results

Table 2 shows the standard uncertainty and the degree of freedom. These results are used to calculate the combined uncertainty, the effective degree of freedom, and the confidence interval.

Table2. Comparisons between UT and Heckle.

Parameter	Uncertainty source	UT (DF)	Heckle (DF)
Pipe	Inner diameter(u1)	0.5% (10)	0.5(10)
	UT angle(u2)	0.48% (∞)	0.09% (∞)
	Fan shape(u3)	2.2% (5)	0.1% (5)
Liquid	Inner diameter(u4)	0.5% (10)	0.5 (10)
	UT angle(u5)	0.3% (∞)	0.11% (∞)
	Fan shape(u6)	4.2% (15)	0.12% (15)
Volume	Length(u7)	1.2% (15)	1.2% (15)
Calculation method	Formula(u8)	0.09% (∞)	0.02% (∞)
Ultrasonic equipments	Equipment(u9)	0.3% (∞)	0.3% (∞)

In Table 2, UT is resulted from this study using the ultrasonic test and Heckle is resulted from applying Heckle's uncertainty "2mm" into A-type uncertainty such as u1, u3, u4, u6 and u7. Inner diameter, Fan shape length, volume length combined uncertainty, the effective degree of freedom, and the confidence interval. In Table2, from u1 to u9, a combined uncertainty is calculated as 4.98% in case of UT. Otherwise, from Heckle's uncertainty, the combined uncertainty is calculated as 1.44%. This mean that UT method of this study is more conservative than Heckle's uncertainty. In other hand, Heckle's uncertainty is realistic uncertainty of direct measurement. Because of that, the conservatism for the ultrasonic test of this study is more than 3.4 times in comparing with the realistic conservatism (Heckle's uncertainty).

3.2. Confidence Interval and Effective Degree of Freedom

Using Table 2 and equation (4), the result of effective degree of freedom is 24.11 at UT and 28.54 at Heckle's uncertainty. From this result, k-value is calculated through t-distribution table. The k-value is 2.042 at UT and 2.04 at Heckle's uncertainty in each degree of freedom. The degree of freedoms are 24.11 and 28.54 respectively. Also, 95% confidence interval is 10.16% at UT and 2.93% at Heckle's uncertainty. Here, the confidence interval means that the general uncertainty is extended into 95% value in assuming the statistic distribution.

4. Conclusions

In this study, the uncertainty of the void packet determination is estimated and the conservatism is reviewed by comparing with realistic uncertainty of Heckle's uncertainty. The methodology of ISO GUM is fully applied to calculate uncertainty, combined uncertainty and effective degree of freedom.

Here some results are achieved as below:

1. Combined uncertainty(UT) : 4.98%
2. Combined uncertainty(Heckle) : 1.44%
3. Degree of freedom: 5 ~ 15
4. Effective degree of freedom(UT): 24.11
5. Effective degree of freedom(Heckle): 28.54
6. K value of t-distribution(UT): 2.042
7. K value of t-distribution(Heckle): 2.04

The uncertainty of this study using UT is enough in the case of achieving conservatism when the void packet determination of the safety related system is determined. As result of this study, UT uncertainty is more conservative than the Heckle's realistic uncertainty. From these results, it is shown that UT method has the great safety margin in determining the void packet. In comparing UT uncertainty with realistic uncertainty, this study (UT) has the conservatism of more than 3.4 times. UT method is good method to determine the void packet of ECCS pipe and to achieve the safety margin.

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