Uncertainty Estimation of Void Packet Determination in Pipes of Emergency Core Cooling System using Ultrasonic Test

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1. Introduction

US NRC issued Generic Letter 2008-01 concerning the gas accumulation of the safety -related systems. The gas packet of the safety system could be the cause of the safety pump failure [1-3]. In 2012, the void packet of the safety-related pipes in Wolsung site is evaluated through the ultra sonic test by CRI of KHNP. The author's void packet determination results are estimated in the scope of uncertainty [4]. In this paper, uncertainty evaluation methodology by ISO (International Standardization Organization) guideline is developed.

2. Methodology

2.1. Void Packet Determination

Figure 1 shows the procedure and the void packet determination.

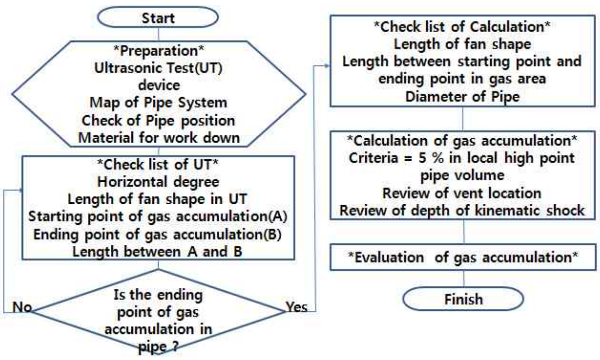

Fig.1 Schematic diagram of UT in the void packet accumulation

Eqs. (1) and (2) are formulas to calculate the void packet volume

$$\text{Void (slope)} = \frac{2\pi r^3 \sin\left(\frac{\theta}{2}\right)}{360 \cdot \tan(\alpha)} + \frac{r^3 \sin\left(\frac{\theta}{2}\right)}{2 \cdot \tan(\alpha)} - \frac{r^3 \sin\left(\frac{3\theta}{2}\right)}{18 \cdot \tan(\alpha)} \quad (1)$$

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

Eq. (2) is used for evaluating the uncertainty of the determination of void packet. That is a general formula used in most of walk down. Eq. (1) is used in the only case of slope pipes.

Here, r and α are the radius and the slop angle of pipes respectively. And L is the length of pipes.

2.2. Uncertainty Strategy

Generally, uncertainty analysis includes the measured data, systematic error, random error and so on.
Uncertainty guideline by ISO issued in late 1993, which is GUM (Guide to the Expression of Uncertainty in Measurements).

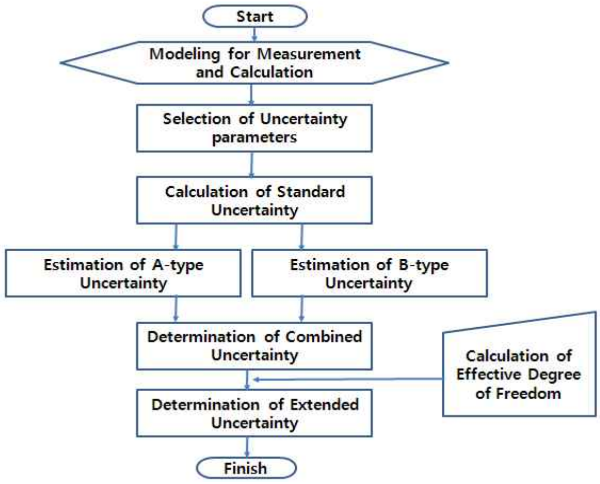

Fig.2 Procedure of uncertainty estimation

2.3. Uncertainty Evaluation

A method to evaluate the uncertainty is introduced as following (Eq. (3)):

$$\text{Void} = (\text{Pipe Area} - \text{Liquid Area}) \times L \quad (3)$$

Here L is length of Volume.
Eq. (3) is expressed to explain the concept of Eq. (2).

2.3.1. Pipe Area and Liquid Area

The void packet area is dependent on the diameter of pipes, UT angle, lengths of volume and so forth.
In Wolsung site, the common uncertainty of pipe size is 1%. In ultrasonic test, the liquid area 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 and the length is measured as the function of the normal distribution.
The common uncertainty of the angle and the length are assumed as ±2° and 1cm respectively. Here the distribution functions could be replaced with Box Muller's random generation process instead of direct measurement.

2.3.2. Length of Volume

The length of volume is directly measured with the ten-repeated measurement using the measure tape.
In this case, uncertainties are A-type data which 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 sampling standard deviation, mean standard deviation, and degree of freedom in each measurement. Sampling standard deviation, mean standard deviation, and degree of freedom are calculated by assuming t-distribution due to sampling number of less than 30.

2.3.3. Uncertainty parameters

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

Table 1. Uncertainty parameters and type of estimation

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

In A-type, t-distribution and uniform distribution are assumed. In B-type, normal distribution is assumed.
A-type is originated from measurement date and repeat measurement. Otherwise, B-type is generated from random number generation.

2.3.4. Confidence Interval and Effective Degree of freedom

The uncertainty distribution is generated from some measurement data and some functions. Measurement data and functions are based on Table 1. The calculation output by uncertainty parameter's input is involved in t-distribution and normal distribution. And t-distribution has the degree of freedom for t-test
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:

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

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

Table 2. Results of uncertainty estimates

Parameter	Uncertainty source	Standard uncertainty (degree of freedom)
Pipe Area	Inner diameter(u1)	0.5% (5)
	UT angle(u2)	0.3% (∞)
	Fan shape(u3)	1.0% (5)
Liquid Area	Inner diameter(u4)	0.5% (5)
	UT angle(u5)	0.3% (∞)
	Fan shape(u6)	1.0% (5)
Length of Volume	Length(u7)	1.2% (15)
Calculation method	Formula(u8)	0.2% (∞)

3.2. Confidence Interval and Effective Degree of Freedom

Using Table 2 and equation (4), the result of effective degree of freedom is 30.71. From this result, k-value is calculated through t-distribution table. The k-value is 2.04 at the degree of freedom 30.71. Also, using square root method, the combined uncertainty of reflecting u1 ~ u8 is 2.03%. Finally, 95% confidence interval of the uncertainty is expressed by the range of 0% ~ 4.16% using k-value.

4. Conclusions

In this study, the uncertainty of the void packet determination is estimated using ISO GUM. Here some results are achieved as below:

1. Combined uncertainty : 2.03%
2. Degree of freedom: 5 ~ 15
3. Effective degree of freedom: 30.7
4. K value of t-distribution: 2.04
5. Extended uncertainty: 4.16%
6. Confidence interval: 95%

The final uncertainty is in the range of 0% ~ 4.16% at 95% confidence level. The combined uncertainty of 2.03% is reasonable in confidence interval. The uncertainty margin of the current methodology is 2.13% at 95% confidence interval of t-distribution. The key factors are fan shapes and lengths of volume.

REFERENCES

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