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Uncertainty of Water-hammer Loads for Safety Related Systems

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1. Introduction

NRC Generic Letter 2008-01 requires nuclear power plant operators to evaluate the possibility of non-condensable gas accumulation for the Emergency Core Cooling System. Specially, gas accumulation can result in system pressure transient in pump discharge piping at a pump start [1]. Consequently, this evolves into a gas-water, a water-hammer event and the force imbalances on the piping segments [1,2]. In this paper, MCS (Monte Carlo Simulation) method is introduced in estimating the uncertainty of water hammer. The aim is to evaluate the uncertainty of the water hammer estimation results carried out by KHNP CRI in 2013[3,4,5]. In this study, the basic methodology is base on ISO GUM (Guide to the Expression of Uncertainty in Measurements) [3,4].

2. Target Phenomenon

The interesting phenomenon of this paper is water hammering in the inverted-U piping near the rupture disc in High Pressure Safety Injection System. Gas accumulation is easily occurred in this type pipes. In order to estimate the uncertainty, the gas void of 21% in the pipes volume of 4.67ft^3 assumed.

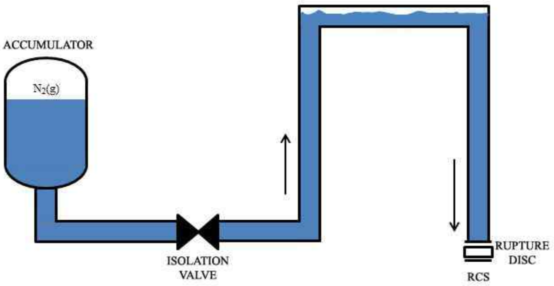

Fig.1 Condition of the High Pressure Safety Injection from reference [4]

3. Modeling Equation

In ASME code, the maximum pressure of water hammering is expressed by equation (1) in condition of the target phenomenon.

$$\Delta P_{WH} = \left(\frac{\rho_{HPECC} \bullet C_w \bullet U_s}{144 \bullet g_c}\right) = 424.586\, psi \qquad (1)$$

Here

ρ_{HPECC} : Water density at maximum flow rate

C_w : Velocity of sound in water (4,582.37ft/sec)

g_c : Gravitational acceleration

U_s : Superficial velocity for the specific pipe size and corresponding area.

Specially, U_s is specified by the accumulator linear run-up characteristic given by the equation (2):

$$U_s = \frac{Q_{HPECC,\max}}{A_{discharge}} \bullet \left(\frac{t_{shutoff}}{t_{runup}}\right) = 6.9\, ft/\sec \qquad (2)$$

In this equation, we consider following parameters

a. A maximum flow rate: $Q_{HPECC,max}$=650kg/s
b. A time required to reach accumulator pressure: $t_{shutoff}$=0.4 sec
c. A run-up interval: t_{runup}=2sec
d. A discharge piping size: $A_{discharge}$=0.6672ft^2

4. Methodology

4.1. Input quantities and characteristics

The main uncertainty parameter is U_s of the equation (2). Table 1 shows the components of U_s.

Table 1. Uncertainty Parameters of U_s

Uncertainty source	mean	Probability density function	Degree of freedom
$Q_{HPECC,max}$	650 kg/sec	Normal	∞
$t_{shutoff}$	0.4sec	t-distribution	15
t_{runup}	2sec	t-distribution	15
$A_{discharge}$	0.6672ft2	Normal	∞

First we select the measurement data of parameters in Table 1.

The data set is consistent of 16 measurements in each parameter. These values are ready to compare with the Monte Carlo Simulations.

4.2 Measurement and Monte Carlo Simulation

4.2.1. Direct Measurement

According to ISO GUM, in order to calculate the uncertainty, we select the procedure as below:

a. Selection of Modeling equation
b. Standard uncertainty calculation for components
c. Combined uncertainty calculation

d. Extended uncertainty calculation.

In the uncertainty propagation of ISO GUM, Taylor series approximation is introduced.

Applying Taylor series, combined uncertainty is equation (3).

$$u^2_c(U_s)=\sum_{i=0}^{n}\left(\frac{\partial U_s}{\partial X_i}\right)^2 \bullet u^2(X_i) \qquad (3)$$

Here, X_i is input parameters and the terms of U_s and X_i are replaced with $Q_{HPECC,max}$ and $A_{discharge}$.

Also, 95% confidence interval and 99% confidence interval are calculated by the effective degree of freedom using Welch-Satterthwait's method.

From this result, extended uncertainty is calculated.

4.2.2. Monte Carlo Simulation

Procedure of Monte Carlo simulation is below:

a. Selection of model equation
b. Selection of Probability density function
c. Extended uncertainty calculation

In Monte Carlo simulation, the steps of “a” and “b” are carried out by random generation.

Finally, the extended uncertainty calculation can be selected from the 95% position value and the 99% position value in array of data set.

5. Results and Discussions

According to ISO GUM concept, the results of measurements and Monte Carlo simulation are shown in Table 2.

Table 2 shows that the MC method is in good agreement with measurement results. Although MC method do not calculate the coverage factors (confidence intervals) directly, the 95% position value and the 99% position value from the array of the generated random numbers exactly predict the extended uncertainty of the measurement data.

Table 2. Uncertainties of the measured value and the Monte Carlo simulation

Calculation Procedure	Measured	Monte Carlo simulation
U_S Value	6.90	6.93
Combined Uncertainty	0.63	-
Degree of freedom	15	97
Confidence Interval (95%): coverage factor	2.07	-
Confidence Interval (99%):coverage factor	3.10	-
Extended uncertainty(95%)	1.30	1.34
Extended uncertainy(99%)	1.95	1.97

This result of Table 2 shows that Monte Carlo simulation is very useful method to calculate the uncertainty.

6. Conclusions

For a given gas void volumes in the discharge piping, the maximum pressure of water hammer is defined in equation (1). From equation (1), uncertainty parameter is selected as U_s (superficial velocity for the specific pipe size and corresponding area) of equation (2). The main uncertainty parameter (U_s) is estimated by measurement method and Monte Carlo simulation. Two methods are in good agreement with the extended uncertainty.

Extended uncertainty of the measurement and Monte Carlo simulation is 1.30 and 1.34 respectively in 95% confidence interval.

In 99% confidence interval, the uncertainties are 1.95 and 1.97 respectively.

REFERENCES

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