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Development of Subcooled Margin Monitor and its Uncertainty Analysis

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1. Introduction

The subcooled margin monitor is one of post-accident monitoring systems and continuously displays the margin to saturation in PWRs. It is capable of calculating and displaying temperature and pressure margin in both subcooled and superheated regions. The subcooled margin monitor should be designed to meet related standards as well as Regulatory Guide 1.97 [1].

For this purpose, Subcooled Margin Monitor (SMM) has been running since 1985 in Kori-3 & 4 Unit. Recently, Advanced Subcooled Margin Monitor (ASMM) is being designed and under design verification. In this paper, the overview of ASMM and the results of uncertainty analysis are presented.

2. System Overview

2.1 System Description

ASMM is an on-line analog/digital mixed system which uses reactor coolant process signals to provide a continuous indication of the margin from saturation conditions. As shown in Figure 1, ASMM consists of a processor rack containing three processor modules and one median module, and one display module. The temperature and pressure margins are displayed on digital panel meter and provided to recorder and plant computer. It is designed to meet IEEE 323 and 344 as a post-accident monitoring instrument.

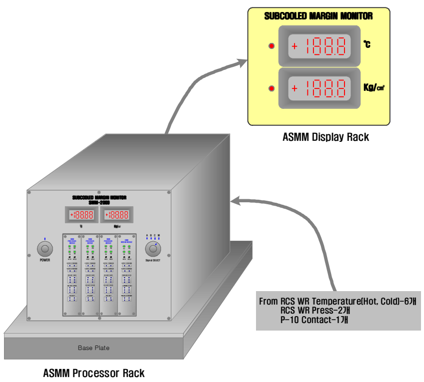

Figure 1. Advanced Subcooled Margin Monitor (ASMM)

2.2 Functional Description

A processor module is briefly represented in Figure 2. It uses temperature and pressure signals from Reactor Coolant System to calculate the saturation temperature and pressure. Three modules calculate saturation values simultaneously using the memory mapped method.

Operating temperature and pressure signals are converted to digital signals through each analog-to-digital converter. These digital signals are interfaced to a ROM as an address data. In SMM, a microcomputer has stream tables and interpolation routines from which a saturation temperature and pressure is calculated [2]. Because ASMM contains the pre-calculated steam tables in ROM, a microprocessor and calculation routines are not needed. The saturation data chosen from selected address are transfers to the next digital-to-analog converter. Eq. (1) gives the margin from saturation by comparing saturation temperature and pressure to actual coolant temperature and pressure using analog comparator devices.

$$T_M = T_{SAT} - T_{PROCESS} \qquad (1)$$
$$P_M = P_{PROCESS} - P_{SAT}$$

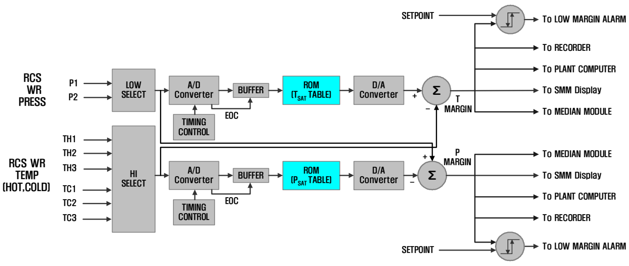

Figure 2. Block diagram of processor module

A median module selects a middle value out of three margin values comming from processor modules and transmits to a display module.

Margin is also compared to a setpoint for a low margin alarm less than 10% of reactor power.

3. Uncertainty Analysis

3.1 Sources of Uncertainty

The method applied to ASMM is a combination of statistical and algebraic methods that uses statistical square root sum of squares (SRSS) methods to combine random uncertainties and then algebraically combine the nonrandom terms with the results from [3] and [4].

Eq. (2) gives the basic formula for uncertainty calculation.

$$Z = \sqrt{A^2 + B^2 + C^2} - |F| + |L| - M \qquad (2)$$

where
A,B,C = random and independent terms. The terms are zero-centered, approximately normally distributed, and indicated by a ± sign.
F = abnormally distributed uncertainties and biases(unknown sign).
L,M = biases with known sign.
Z = resultant uncertainty.

ASMM is being designed as a mixed circuit using the analog and digital devices. Analog circuits have multiple converting stages that consist of several operational (OP) amplifiers for level conversion and a voltage reference to control zero offset. There are many sources of uncertainty in OP amplifier circuits such as input offset voltage and gain non-linearity. The input offset voltage considered as a bias term with known sign is inherent to OP amplifier device. On the other hand, the gain linearity through operating temperature ranges can be considered as a random one due to random characteristics with unknown sign. Because the gain of a OP amplifier stage is determined by fixed feedback resistors, gain variation is only affected by environmental temperature and can be considered as negligible.

Function Blocks of ASMM from signal input to margin output that contribute to uncertainty are described in Table 1.

Table 1. Function Block of ASMM

No	Function Block	Device Stages
1	High Select	3 OP Amp
2	Level Converter	2 OP Amp
3	A/D Converter	1 A/D
4	ROM	1 ROM
5	D/A Converter	1 D/A
6	Comparator	2 OP Amp
7	Display Buffer	1 OP Amp
8	Median	2 OP Amp

A/D and D/A converter have major uncertainty sources of conversion error including a gain error and a zero-scale error through operating temperature ranges. To simplify the calculation, conversion error is described as a bias term that is an algebraic sum of gain error and zero-scale error.

Function Block is a functional block that is composed of several OP amplifiers and passive devices. ASMM for uncertainty calculation can be divided into two independent blocks: preprocessor block and calculation block in the center of ROM. A preprocessor block consists of High Select, Level Converter, A/D Converter, and ROM. A calculation block includes D/A Converter, Comparator, Display Buffer, and Median.

The uncertainty of a block is defined as an algebraic sum of bias terms. Loop uncertainty also comes from SRSS of each block uncertainty.

3.2 Calculation of uncertainty

Introducing input offset voltage of an OP amplifier as 100 ㎶ and zero offset bias as 30 ㎶, the uncertainty of a preprocessor block is sum of each stage uncertainties: ±0.003%, ±0.0013%, ±0.003%. Total uncertainty of a preprocessor block is ±0.0073% or approximately ±20 Least Significant Bits (LSB) errors that can affect the selection of the saturation data in memory. From the steam table in memory, this can induce saturation temperature error less than ±0.1℃ or ±0.03%.

Uncertainty of a calculation block can be calculated in the same way of a processor block and the result is less than ±0.01%.

Loop uncertainty with SRSS is less than ±0.03% or ±0.1℃ through the operating temperature ranges.

4. Conclusion

Advanced Subcooled Margin Monitor (ASMM) is being developed for Kori-3 & 4 using pre-calculated steam table in the read-only memory without any microprocessor. It has several remarkable design features such as high reliable structure using median selection and user-friendly design improved by feedback of operation experiences.

The results of uncertainty analysis show that ASMM has smaller uncertainty than that of the previous SMM because of higher resolution hardware and more precise steam table.

REFERENCES

[1] Regulatory Guide 1.97-1983 Instrumentation for Light-Water Cooled Nuclear Power Plants to Access Plant and Environs Conditions During and Following an Accident, US NRC.
[2] Subcooled Margin Monitor Users Manual, Combustion Engineering, Inc., 1984
[3] ISA-RP67.04.01-2000 Setpoints for Nuclear Safety-Related Instrumentation
[4] ISA-RP67.04.02-2000 Methodologies for Determination of Setpoints for Nuclear Safety-Related Instrumentation