Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

Analysis of Thermal-Hydraulics of a Marine Reactor in an Oscillating Acceleration Field

Jae Hak Kim and Goon Cherl Park
Seoul National University

Abstract

In this study the RETRAN-03 code was modified to analyze the thermal-hydraulic transients under three-dimensional ship motions for the application to the future marine reactors. First Japanese nuclear ship MUTSU reactor have been analyzed under various ship motions to verify this code. As results, typical thermal-hydraulic characteristics of marine reactors such as flow rate oscillations and S/G water level oscillations are successfully simulated at various conditions.

1. Introduction

Thermal-hydraulic characteristics of marine reactor plants are influenced by various ship motions. There are six ship motions caused by various sea conditions, which are three linear motions(heaving, swaying, surging) and three rotational motions(rolling, pitching, yawing). Stationary inclination, heaving and rolling are dominant in ship motions and very important for design and operation of nuclear ship reactors. In this study, since it is impossible to analyze such thermal-hydraulic transients under various ship motions using current thermal-hydraulic analysis codes, the RETRAN-03 code[3] is modified to be capable of simulating thermal-hydraulic transients under multi-dimensional ship motions. With this code, MUTSU reactor has been analyzed under various ship motions for its validation.

2. RETRAN-03 Modification

2.1 Modified Momentum equation of RETRAN-03

Since ship motions affect on the momentum transfer, the modification is mainly implemented for the momentum equation. Modified integral momentum equation is given as,

$$\begin{aligned}\frac{1}{2}\left[\frac{L_k}{A_k}+\frac{L_{k+1}}{A_{k+1}}\right]\frac{dW_i}{dt} &= \frac{\overline{w}^2_k}{\rho_k A_k^2}-\frac{\overline{w}^2_{k+1}}{\rho_{k+1}A_{k+1}^2}+p_k-p_{k+1} \\ &-\frac{1}{A_k}F_{w,k}-\frac{1}{A_{k+1}}F_{w,k+1}-(\Delta p)_p \\ &-\left[\ \overline{\rho}_k(Z_i'-Z_k')+\overline{\rho}_{k+1}(Z_{k+1}'-Z_i')\right]\left[\ g(t)+f_v\right] \\ &-\frac{1}{2}\left[\ \overline{\rho}_k\ D_k\cos\theta+\ \overline{\rho}_{k+1}\ D_{k+1}\cos\theta\right]f_h\end{aligned} \tag{1}$$

2.2 Momentum Equation under Heaving and Rolling Motion

For the time dependent vertical acceleration under heaving motion, g_z is replaced with g(t) as in Eq. 1. For the simple periodical oscillation, g(t) can be expressed as,

$$g(t)\ =\ g_z\left(\ 1\ -\ A*SIN\left(\frac{2\pi t}{T_g}\right)\right) \tag{2}$$

$$\text{where, } A = \text{amplitude}, \quad T_g = \text{oscillation period}$$

For the given rotational angle θ as a function of time under rolling motion, f_v and f_h in Eq. 1 are given as follows,

$$\begin{aligned} f_v &= C_v - T_v = R\dot{\theta}^2\cos\theta - R\ddot{\theta}\sin\theta \\ f_h &= C_h + T_h = R\dot{\theta}^2\sin\theta + R\ddot{\theta}\cos\theta \end{aligned} \tag{4}$$

where, R is a distance between volume center and center of rotation.

For the simulation of different inlet and outlet positions in hot/cold legs in a 3-D volume as depicted in Fig. 2, new variable BOT, which indicates the volume length in the horizontal direction, is considered. According to this model, locations of center of mass and each junctions after rotation can be calculated as follows,

$$CMAS' = CMAS \cos\theta$$
$$RELZ\ l' = RELZ\ l \cdot \cos\theta + 1/2 \cdot BOT \cdot \sin\theta \quad (5)$$
$$RELZ\ r' = RELZ\ r \cdot \cos\theta - 1/2 \cdot BOT \cdot \sin\theta$$

3. Results and discussions

3.1 Normal Operation

Fig. 4 shows S/G secondary side behaviors during the heaving motion for various heaving period. As the gravity force increases, the steam generator water level decreases and the steam generator recirculation flow increases. And the longer oscillation period induces the larger variations of the S/G water level and recirculation flow.

For the simulation of the effects of the stationary inclination, initially vertical reactor linearly inclines to 30 degrees and holds that angle for a long time. As shown in Fig. 5, reactor power begins to decrease slightly at 15 sec and returns to its initial value about 100 sec. Core, hot leg, and cold leg temperatures increase very slightly and return to their initial values after the inclination. Rapid power decrease at the beginning of inclination is caused by the change in moderator temperature coefficient induced by the S/G secondary side recirculation flow and the pressure changes.

Fig. 6 shows the results of rolling test. Rolling period is set to 15 seconds and rolling angles are 5, 10, 30 degrees. Results show that, with the larger rolling angle, the magnitudes of oscillations become larger. The magnitudes of S/G water level and recirculation flow oscillations are very small compared with the results of the heaving analysis. It means that the magnitude of the water level oscillation is affected mostly by vertical acceleration.

3.2 Natural Circulation

Results of heaving analysis are shown in Figs. 7 to 8 with the periods of 4, 30 sec. As the oscillation period becomes larger, magnitudes of flow rate oscillations also become larger. For both normal operation and natural circulation state, S/G water level or loop flow rates are varying with larger magnitudes as the heaving period increases. Hot and Cold leg temperatures are remained almost constant for all heaving periods.

In the case of stationary inclination, loop flow rates in hot and cold legs are changed after inclination as shown in Fig. 9,. The loop flow rate of ascending loop(Loop 1) increases to the value of 9 kg/sec and that of descending loop decreases to nearly zero.

Analysis of rolling with the angle of 30 degrees and the period of 15 seconds is performed. The loop flow rates oscillation in each loop shows completely different phase as shown in Fig. 10. Therefore the core flow rate shows negligibly small variations.

4. Conclusions

RETRAN-03 code are improved for the analysis of thermal-hydraulics of ship reactors under various ship motions. The oscillations of S/G water level and recirculation flow mainly occur by vertical movement and their amplitudes of oscillations become larger with the larger oscillation period. For the 30 degrees stationary inclination under natural circulation, the loop flow in ascending loop increases and that of descending loop becomes nearly zero. In case of rolling, magnitudes of flow rate oscillations become larger with the larger rolling angle.

Typical thermal-hydraulic characteristics of marine reactors such as flow rate oscillations and S/G water level oscillations are successfully simulated. And it is concluded that even under the various ship motions, reactor system maintains stable thermal-hydraulic conditions for both normal operation and natural circulation states.

NOMENCLATURE

A_k = flow area of volume k

$D_{k,x}$ = length of the volume k in x-direction

$D_{k,y}$ = length of the volume k in y-direction

f_h = horizontal acceleration

f_v = vertical acceleration

L_k = height of volume k

W_i = mass flow for junction i

Z_i' = junction height above reference height z after the rotation

Z_k' = center of volume height above reference height z after the rotation

REFERENCES

[1] T.ISHIDA, T.KUSUNOKI, etc., Thermal-Hydraulic Behavior of a Marine Reactor during Oscillations, Nuclear Engineering and Design vol.120, pp213-225 (1990)

[2] Y.NARUKO, T.ISHIDA, Y. TANAKA, and Y. HUDAMURA, RETRAN Safety Analyses of the Nuclear-Powered Ship MUTSU, Nuclear Technology vol.61, pp193-204 (May 1983)

[3] RETRAN-03: A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems, Volume 1,2,3, NP-7450, 889-10, EPRI(1992)

[4] T.Ishida, I.Tomiai, Development of Analysis Code for Thermal Hydrodynamics of Marine Reactor under Multi-Dimensional Ship Motions, RETRAN-02/GRAV, JAERI-M 91-226 (Jan. 1992)

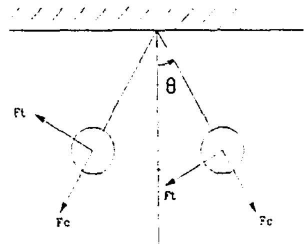


Fig.1 Centrifugal and Tangential Forces during Rolling Motion

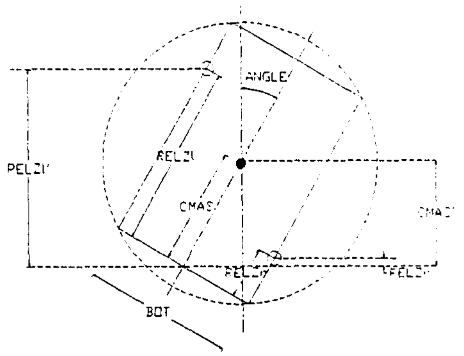


Fig.2 3-D Vol. and Junc. Elevation at Inclination

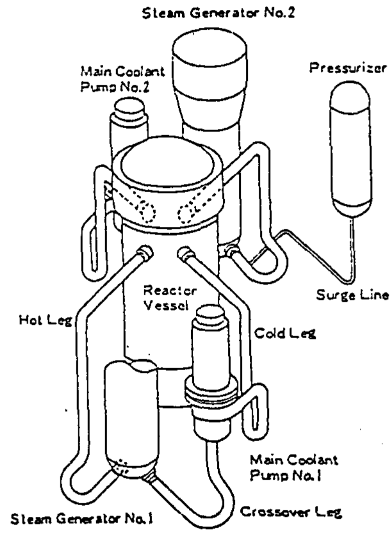


Fig.3 MUTSU Reactor Coolant Sytem

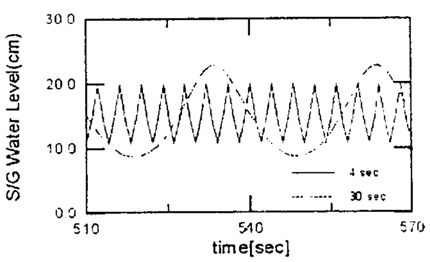


Fig. 4 Heaving Motion during N.O

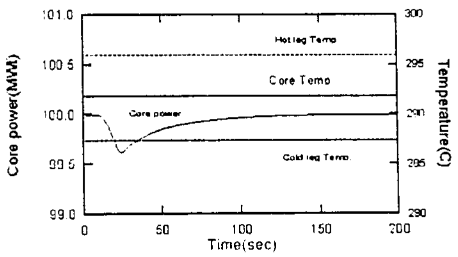


Fig. 5 Inclination(30Deg.) during N.O

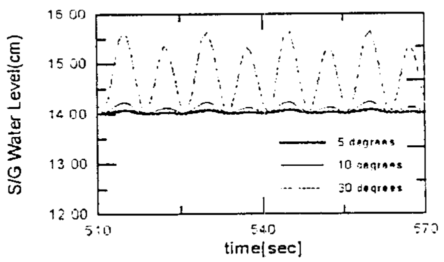


Fig. 6 Rolling Motion during N.O

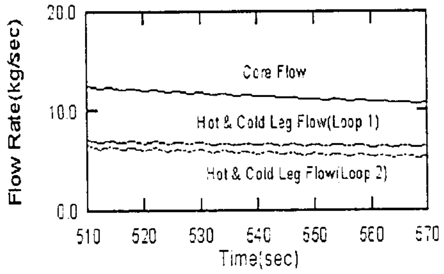


Fig.7 Heaving Motion(5sec)during N.C

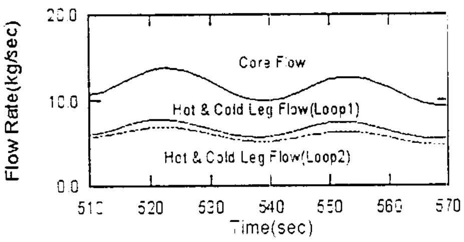
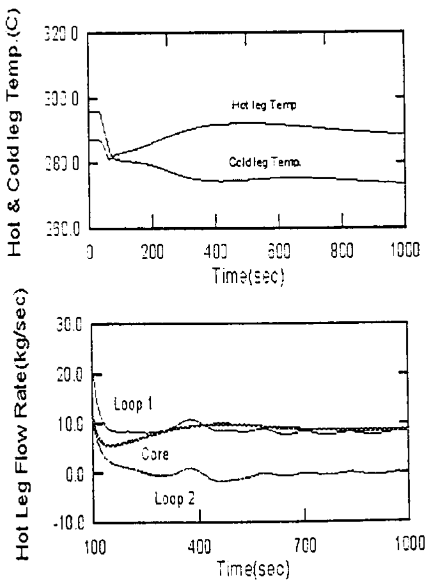


Fig. 8 Heaving Motion(30sec) during N.C



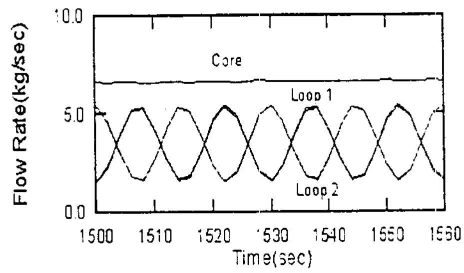


Fig. 10 Rolling Motion(30Deg) during N.C

Fig. 9 Inclination(30Deg) during N.C

(N.O : Normal Operation N.C : Natural Circulation)