Development of experimental metal sphere-mass map of reactor vessel scale models

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ABSTRACT

Loose parts in coolant systems of a nuclear power plant (NPP) can damage structural integrity of the systems and loose part signals monitoring systems (LPMS) are installed in most of NPPs. LPMS detect impact signal of a loose part and generate alarm if amplitude of the signal is over preset level. If impact signal detected, mass estimation of the loose part must be carried out in order to see the effect of the part impact on structural integrity. A metal sphere-mass map, which shows relations between amplitude and center frequency of impact signals according to mass, is essential in mass evaluation of a loose part and the map built for US NPPs has been used so far. For the purpose of precise impact analysis suitable for Korean NPPs, this work discusses the development of a mass map of Korean Standard Nuclear Power Plant (KSNP) based on experimental data for scale models of a KSNP reactor vessel as tests for real NPP vessels under operation is actually impossible. Impact tests were carried out for scale models by using metal sphere with various mass and velocity. Amplitudes and center frequencies of impact signals were investigated based on time-frequency analysis and the mass map for each models were constructed based on the results. Blind tests were additionally implemented with metal sphere with unknown mass and velocity and verified feasibility of the proposed metal sphere mass map.

1. INTRODUCTION

In most of nuclear power plants (NPP), Loose Parts Monitoring Systems (LPMS) are installed to monitor loose parts in coolant systems of NPPs. An LPMS monitors loose parts when signals over some amplitude are repeatedly measured by sensors attached on coolant systems. Once loose part signals are detected, impact location and mass of the part must be analyzed to inspect the effect on structural integrity of the coolant system. Impact point can be guessed from time delay between signals measured by multiple sensors (Olma, 1985). For mass estimation of loose parts, several techniques have been applied such as frequency ratio (FR) method (Tsunoda, 1985) or metal sphere mass map (Weiss, 1991). FR method is easy to apply because mass of loose parts can be checked from power spectrum ratio between low and high frequency band of impact signals. Recently, mass estimation based on metal sphere mass map is widely applied as it can evaluate mass more precisely, especially when mass is small. A mass map shows relation between amplitude and center frequency of impact signals according to mass and velocity of metal sphere. Mayo and Shugars (1988) presented a mass map for US NPPs based on Hertz contact theory and experimental calibration data. Kim, Lee, Jhung and Kim (2012) showed a partially built mass map based on field data for Korean NPP.

This paper presents an experimentally developed metal sphere mass map for a scale model of Korean Standard Nuclear Power Plant (KSNP) reactor vessel. Test data was measured by impacting steel balls with various mass and velocity. Time frequency analysis was carried out to investigate center frequencies of impact signals and the experimental mass map was created. Performance of the developed map was check by additional test with impact signals of different mass and velocity.

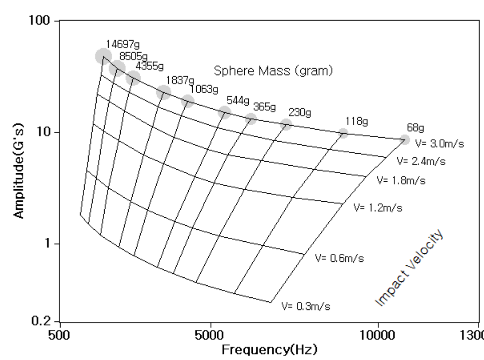
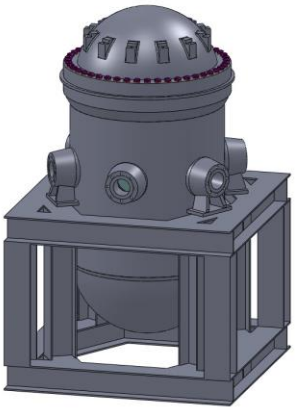


Figure 1. A metal sphere mass map (Lee & Park (2016)).

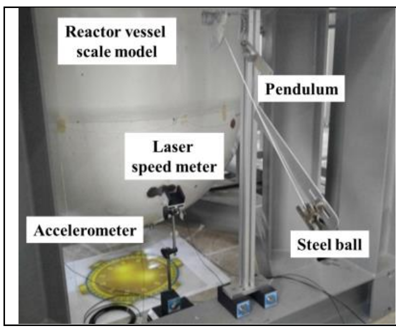
2. DEVELOPMENT OF EXPERIMENTAL METAL SPHERE MASS MAP

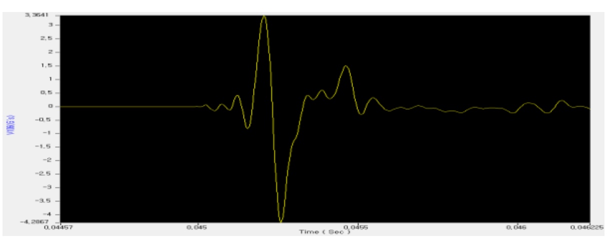


(a) CAD drawing (b) Scale model

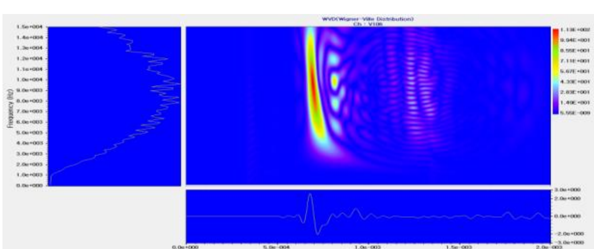
Figure 2. The scale model of KSNP reactor vessel.

Table 1. Mass of steel balls and impact velocity.

	Mass (gram)	Velocity (m/s)
	45.8 105.5 131.9 174.3 200.7 537.2	0.97 1.58 2.16 2.56



(a) A impact signal in time domain



(b) Wigner-Ville Distribution

Figure 3. A response of the scale model to impact of a steel ball.

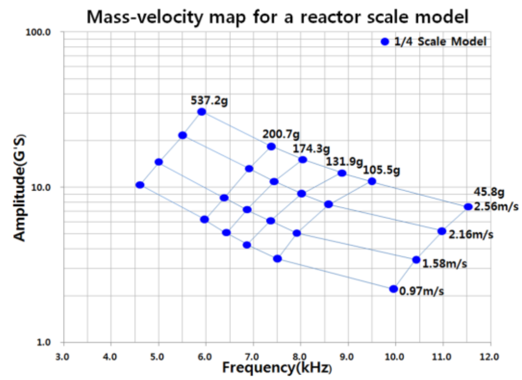


Figure 4. The experimentally developed metal sphere mass-map of the 1/4 scale model of KSNP reactor vessel.

Figure 2 (a) and (b) show the 1/4-scale model of KSNP reactor vessel in Korea Atomic Energy Research Institute. Considering the LPMS sensor calibration process stated in ASME OM S/G Part 12 (ASME, 2010), test was carried out by impacting steel balls suspended in a pendulum to lower part of the scale model. Steel balls with 6 different mass were dropped at 4 different velocities, therefore 24 different cases were tested. For each case, signals were measured five times and averaged.

Time frequency analysis, especially Wigner-Ville Distribution (WVD) (Park & Kim, 2006), was implemented to investigate center frequency of each signals and amplitude of the signals at corresponding time as shown in Figure 3. With WVD analysis results for all data, a metal sphere mass map was created for the scale model as illustrated in Figure 4, which is similar to the Mayo's map in Figure 1.

3. VERIFICATION OF THE PROPOSED MAP

To verify the working performance of the map created in this work, additional test was carried out with steel balls of unknown mass and impact velocities. Center frequencies and corresponding amplitude of signals were analyzed and plotted on the map as red points (Figure 4). Mass and velocity of each point were checked by interpolation. Assumed mass of each red point was compared to real values in Table 2, which shows that the developed map can estimate mass of a unknown loose part with error less than 8 percent.

The map built in this work cannot be directly applied to analyze actual loose part signals, however, the verification result implies that the experimental method for creating metal sphere mass map in this work is applicable to a real NPP structures with proper test or simulation data.

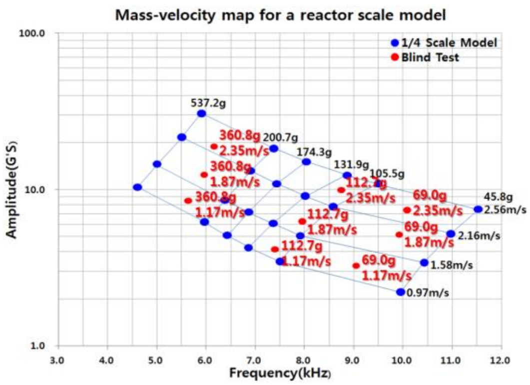


Figure 4. Verification test result for the developed mass map.

Table 2. The performance test result for the mass map.

Estimated velocity (m/s)	Mass (gram)		Error (%)
	Estimation	Actual	
1.17	74.5	69.0	7.9
1.87	70.6	69.0	2.3
2.35	75.1	69.0	8.1
1.17	116.1	112.7	3.0
1.87	113.4	112.7	0.6
2.35	119.6	112.7	5.7
1.17	344.9	360.8	4.6
1.87	354.5	360.8	6.1
2.35	393.0	360.8	8.2

4. CONCLUSION

A metal sphere mass map, which is essential in mass estimation of loose parts in NPP coolant systems, was experimentally developed for a scale model of a KSNP reactor vessel. Impact test was carried out with steel balls of various mass and velocities. The map was developed experimentally from center frequencies and amplitude of impact signals analyzed precisely by using Wigner-Ville Distribution algorithm. Additional tests were carried out with steel balls of unknown mass to verify the developed map. The result showed that the map can estimate mass of steel balls with small errors and implies that the experimental process of this work can be effectively applied for creation of a map for actual NPP coolant system with proper test or simulation data.

ACKNOWLEDGEMENT

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