Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 25-26, 2007

A Hold-down Margin Assessment using Statistical Method for the PWR Fuel Assembly

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1. Introduction

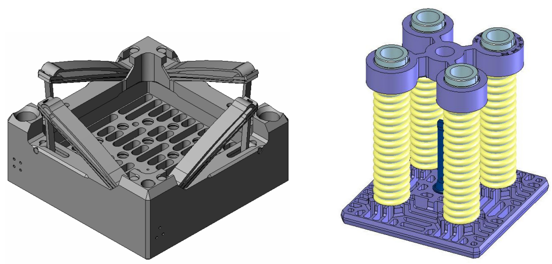
The hold-down springs provide an acceptable hold-down force against hydraulic uplift force absorbing the length change of the fuel assembly relative to the space between the upper and lower core plates in PWR. These length changes are mainly due to the thermal expansion, irradiation growth and creep down of the fuel assemblies. There are two kinds of hold-down springs depending on the different design concept of the reactor internals of the PWR in Korea, one is a leaf-type hold-down spring for Westinghouse type plants and the other is a coil-type hold-down spring for OPR1000 (Optimized Power Reactor 1000). Fig. 1 (a) shows the configuration of the leaf-type hold-down spring attached to the top nozzle of the fuel assembly[1]. There are four sets of hold-down springs in each fuel assembly for leaf-type hold-down spring and each set of the hold-down springs consists of multiple tapered leaves to form a cantilever leaf spring set. The length, width and thickness of the spring leaves are selected to provide the desired spring constant, deflection range, and hold-down force. Fig. 1 (b) shows the configuration of the coil-type hold-down spring assembled in the top nozzle of the fuel assembly[2]. There are four coil springs in each fuel assembly for coil-type hold-down spring.

In this study, the hold-down forces and margins were calculated for the leaf-type and coil-type hold-down springs considering geometrical data of the fuel assembly and its components, length changes of the fuel assembly due to thermal expansion, irradiation growth, creep, and irradiation relaxation. The hold-down spring forces were calculated deterministically and statistically to investigate the benefit of the statistical calculation method in view of hold-down margin. The Monte-Carlo simulation method was used for the statistical hold-down force calculation.

2. Analysis Method

The Monte Carlo method was used for the statistical calculation of the hold-down forces and margins. The Monte Carlo method provides approximate solutions to a variety of mathematical problems by performing statistical sampling experiments on a computer[3].

Monte Carlo method is a widely used class of computational algorithms for simulating the behavior of various physical and mathematical systems, and for other computations. Monte Carlo algorithm is often used to find solutions to mathematical problems (which may have many variables) that cannot easily be solved. For many types of problems, its efficiency relative to other numerical methods increases as the dimension of the problem increases.



(a) Leaf-type (b) Coil-type

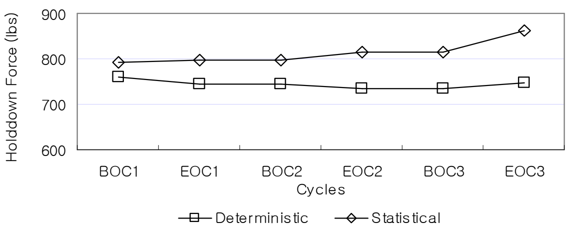
Fig. 1 Configuration of the hold-down springs attached to the top nozzles of fuel assemblies

To calculate the hold-down forces deterministically, the minimum and maximum spring deflections are established by stacking up dimensional tolerances, accounting for thermal expansion and irradiation growth effects of the fuel assembly and core support structure. The tolerance stacking is performed based on the square root of sum of squares method. The spring characteristics are determined based on a theoretical method or based on the test results of the specific hold-down spring design. The minimum and maximum hold-down spring forces are calculated using the minimum and maximum spring deflections and spring characteristics for each beginning and end of cycles.

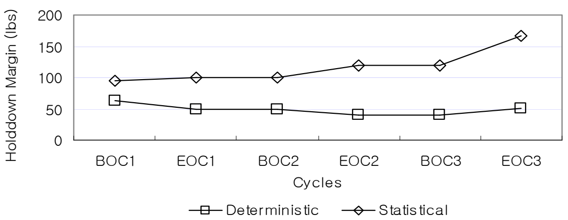
The Monte-Carlo algorithm is used for the statistical calculation of fuel assembly length change, hold-down force, and hold-down margin. To calculate the hold-down forces statistically, the statistical input variables are defined with the mean value, type of distribution, and range of sigma, etc. The fuel assembly length, hold-down spring free height, and core plate distances are considered as statistical input variables with uniform distribution for the leaf-type spring. The irradiation growth and design uplift forces are additionally considered as statistical input variables for the coil-type spring. The fuel assembly length changes and hold-down forces are determined considering the irradiation growth, irradiation creep, elastic compression, etc. based on the 95% confidence level for the coil-type spring. The hold-down margins are calculated using fuel assembly weight, lift force, buoyancy force, hold-down force, and uncertainties based on the 95% confidence level.

3. Results and Discussions

Fig. 2 (a) and (b) shows the comparison of minimum(for deterministic result) or lower 95%(for statistical result) hold-down forces and margins between deterministic and statistical results for leaf-type spring. It was seen that more hold-down force and margin exists when the statistical algorithm was applied. The min. hold-down margins with statistical method are about 30~50 lbs higher at cycle 1 and 2, 80~110 lbs higher at cycle 2 and 3 than hold-down margins with deterministic method. It was evaluated that the increase of the hold-down forces and margins are due to the statistical calculation of the fuel assembly length changes based on the 95% confidence. The hold-down forces and margins with statistical method are increased as the number of cycle increase and the hold-down forces and margins with deterministic method are decreased as the number of cycle increase. The decrease of the hold-down forces and margins are due to the minimum combination of the dimensions and tolerances, the increased irradiation relaxation, and the increased permanent set of the hold-down spring caused by the increased irradiation growth. The increase of forces and margins are the result of statistical calculation for the key dimensions and tolerances. The minimum hold-down margin take places at BOC1 when the statistical method is used and it take places at EOC2 and BOC3 when the deterministic method is used.



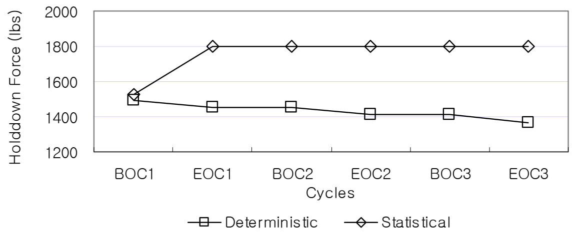
(a) Hold-down Force



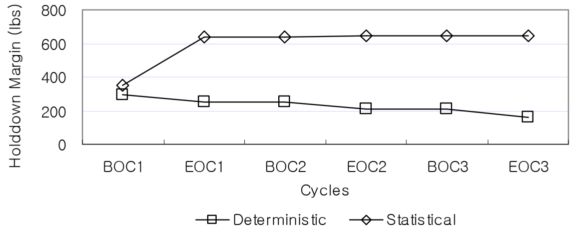
(b) Hold-down Margin

Fig. 2 Comparison of minimum hold-down forces and margins for the leaf-type spring

Fig. 3 (a) and (b) shows the comparison of minimum(for deterministic result) or lower 95%(for statistical result) hold-down forces and margins between deterministic and statistical results for coil-type spring. The hold-down margins with statistical method are about 300~400 lbs higher than hold-down margins with deterministic method.



(a) Hold-down Force



(b) Hold-down Margin

Fig. 3 Comparison of minimum hold-down forces and margins for the coil-type spring

4. Conclusion

The hold-down spring forces were calculated deterministically and statistically to investigate the benefit of the statistical calculation method in view of hold-down margin. The results are as follows ;

(1) The hold-down margins with statistical method are about 100 lbs higher for leaf-type spring and 400 lbs higher for coil-type spring than hold-down margins with deterministic method.

(2) It was seen that more hold-down margin exists when the statistical algorithm was applied, and the increase of the hold-down margins are due to the decrease of the statistical band of hold-down force calculated based on the 95% confidence level.

(3) The hold-down margins for the leaf-type spring will be increased when more statistical variables are considered.

Acknowledgement

This study was carried out under the project "Development of the Major Design Codes for a Nuclear Power Plant" which was funded by the Ministry of Commerce, Industry and Energy.

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