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A Study on the Mechanical Characteristics of Top Nozzle Holddown Spring

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1. Introduction

Top nozzle holddown springs hold a Fuel Assembly (FA) on the lower core plate firmly against the up-lift force in startup or Hot Full Power (HFP) conditions and allow the FA's length change that is caused by irradiation growth of guide tubes [1]. However, the FA might be bent if there is the excessive spring force by leaf springs. As a result of this, the holddown spring is one of the major components of FA for Pressurized Water Reactor (PWR) and a test of the holddown spring is necessary to analyze its holddown force. A top nozzle holddown spring force calculated through the load vs. deflection test of one holddown spring set has been used as a general method for fuel assembly holddown force analysis so far. Since this force has been conservatively evaluated, a new test will be performed to find a more accurate fuel assembly holddown force by pushing down the four holddown spring sets simultaneously, which describes the behavior of real fuel assembly. In this study, the mechanical characteristics of the four holddown spring sets and one holddown spring set are evaluated, respectively. And then the test results of the four holddown spring sets are compared the previous fuel assembly holddown forces calculated through the load vs. deflection tests of one holddown spring set.

2. Test Methods

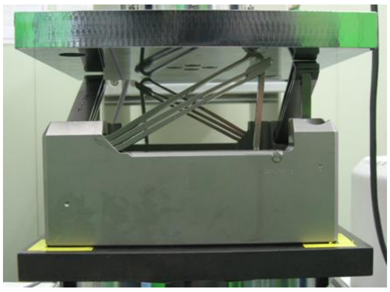
In this section some of the test procedures to get reasonable test results are described.

2.1 Test Specimens and Controlled Variables

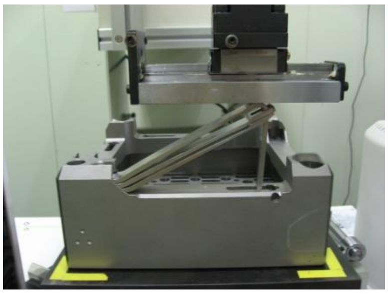
The load vs. deflection tests of the four holddown spring sets and the one holddown spring set were determined using sixteen and four test specimens, respectively at room temperature.

2.2 Test Procedure

The four holddown spring sets and the one holddown spring set were individually placed on the INSTRON universal testing machine. Loads were applied to the top surface of the holddown spring sets while the deflections of INSTRON crosshead were monitored with crosshead displacements. The holddown spring sets were deflected to the maximum compressed height and the deflections were removed slowly to reduce the dynamic effect. The setups of the tests are shown in Figure 1. Dimensional changes induced in the holddown spring sets by the installation and preloading process were within the drawing tolerances.



(a) Test Setup for Four Holddown Spring Sets



(b) Test Setup for One Holddown Spring Set

Figure 1. Load vs. Deflection Test Setup

3. Test Results

The purposes of the tests were to obtain the load vs. deflection characteristics for the four holddown spring sets and one holddown spring set. And then the test results of the four holddown spring sets are compared the previous fuel assembly holddown forces calculated through the load vs. deflection tests of one holddown spring set.

3.1 Loading Curves

The original load vs. deflection curves recorded by INSTRON universal testing machine was rough and had offset due to frictional drag between the tang and top plate. So each loading curve was regenerated to compensate for the frictional drag. Figure 2 shows the average loading curves, which were considered the offset and friction drag. These average loading curves of the four holddown spring sets were compared the previous fuel assembly holddown forces calculated through the load vs. deflection tests of one holddown spring set as shown Figure 3. The load vs. deflection curve for the four holddown spring sets showed that the average fuel assembly force for the four holddown spring sets was similar to that calculated through the tests of one holddown spring set. A small difference of the fuel assembly force between the four holddown spring sets and the one holddown spring set was because frictions between the top of the spring set and the loading device were different each.

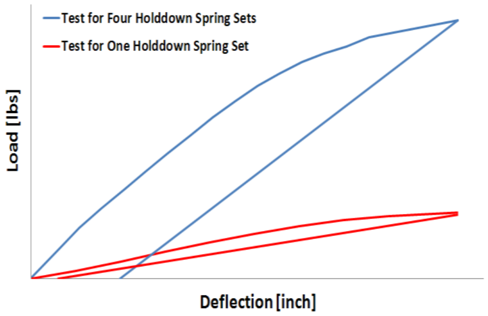


Figure 2. Average Load vs. Deflection Curves

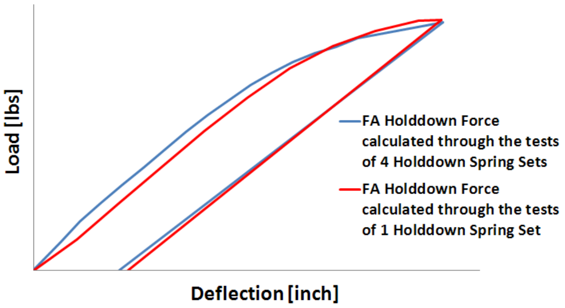


Figure 3. Fuel Assembly Holddown Force Comparison

3.2 Load Variability

The average load values for the test results were normalized. Standard deviations and 95/95 confidence values were then followed to evaluate the holddown spring using standard statistical methods. The 95/95 confidence limits on the load variability of fuel assembly were calculated using the follow equations:

$$\text{Load\_Variability}_{Assy} = (k) \times \frac{(STD\_Dev)}{2} \quad [2]$$

Where, STD_Dev is the Standard Deviation for loading and unloading of the spring sets, and k is the statistical k-factor for the population of N.

The load variabilities of the four holddown spring sets and one holddown spring set were estimated to be 2.16% and 1.02% for loading, and 1.77% and 0.83% for unloading with a 95/95 confidence level, as shown in Table 1. The loading and unloading variabilities of the four holddown spring sets were larger than them of the one holddown spring set. This was because the load variabilities of the four holddown spring sets contained height deviations of spring seating surface and loss-of-tip deflections which mean the vertical drop of the holddown spring sets caused by the spring set tail-to-clamp pocket clearance.

Table 1. Load Variability for Fuel Assembly

	Loading Variability	Unloading Variability
Four Holddown Spring Set	2.16%	1.77%
One Holddown Spring Set	1.02%	0.83%

Even though the load variabilities of the one holddown spring sets does not contain the height deviations of spring seating surface and loss-of-tip deflections, the fuel assembly holddown spring force calculated through the test of one holddown spring set has been evaluated conservatively in consideration of them as well as and other uncertainties. As a result, the general method for fuel assembly holddown force analysis calculated through the test of one holddown spring set is still available.

4. Conclusions

In this study, the mechanical characteristics of the four holddown spring sets and one holddown spring set were evaluated, respectively. And then the test results of the four holddown spring sets were compared the previous fuel assembly holddown forces calculated through the load vs. deflection tests of one holddown spring set. In summary, the four holddown spring set are characterized as follows:

- The load vs. deflection curve for the four holddown spring sets shows that the average fuel assembly force for the four holddown spring sets is similar to that calculated through the tests of one holddown spring set.

- The load variability of the four holddown spring sets is larger than that of the one holddown spring set. This is because the load variability of the four holddown spring sets contains height deviations of spring seating surface and loss-of-tip deflections.

- A fuel assembly holddown force calculated through the load vs. deflection test of one holddown spring set is still available, because it has been evaluated conservatively in consideration of the all uncertainties which show in the holddown spring tests.

REFERENCES

[1] J.S. Yim, H.K. Joo, D.S. Sohn, Analysis of Non-linear Spring Characteristics of Holddown Spring, SMiRT16, Paper #1940, 2001.
[2] J.H. Song, J.H. Park, An Introduction to Reliability Engineering in Mechanical Design, p. 91, 2007.