Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

Behavour of Hold-down Springs in Kori Nuclear Fuels

Yong Bum Chun, Kwang June Park
Korea Atomic Energy Research Institute

Abstract

The hold-down spring forces of Kori nuclear fuels were measured for seven fuel assemblies having 1 to 4 cycles of irradiation histories in the Kori Unit-1 and -2 reactor. The fuel assemblies examined had burnup from 17 to 38 GWD/MTU and the examination was conducted in KAERI PIEF spent fuel storage pool with the newly developed underwater hold-down spring force measuring device. The measurement was made within the elastic deformation ranges and the trends of hold-down spring force relaxation behavour were examined.

Introduction

There are several forces to be considered acting on the fuel assembly in estimating fuel stability during reactor operation. During normal operation, the fuel assembly structure is mainly under compressive load caused by axial forces, such as fuel assembly weight, buyancy force, hydraulic lift-up force and hold-down force, etc. Superposition of these forces produces a resultant force in the direction of coolant flow in reactor. The hold-down device of fuel assembly has to ensure that the fuels are reliably held down on the lower core support structure during operation and after the occurrence of transients. The available hold-down force is a function of the spring deflection and the gap between the fuel assembly top end piece and the upper core plate, and of the characteristic of the hold-down springs. Both quantities depends on the temperature, so that an adequate hold-down spring force to sustain the fuel assembly has to be provided reliably both for low temperature and for the operating temperature. The resultant force is determined with the coolant flow in core which produces the greatest lift-up force. The gap between fuel assembly top end piece and core plate decreases during reactor operations according to the thermal and irradiation induced expansion differences between the reactor core and Zircaloy guide thimble tubes. Quite apart from the pure axial load, the guide thimbles can also experience bending stresses from static fuel assembly bowing and from fuel assembly vibrations stimulated by the coolant flow. To minimize the flow induced vibration of fuel assembly, a special consideration of mechanical design of fuel assembly used to be placed on the determination of the hold-down spring force. The accompanying increase in spring deflection causes plastic sequent operation and the spring force will therefore be increased by the change of spring deflection. In parallel with this increase in spring force, a decrease in spring force occurs during irradiation due to the spring relaxation. It must therefore be assured that the criterion of adequate hold-down spring force is maintained throughout the entire lifetime of the fuel assembly.

Descriptions

1. Design Description of Indigenous Fuel Assembly

The fuel assemblies of Kori Unit-1 nuclear power plant (NPP) have a 14x14 rod array with 179 fuel rods, 16 guide thimble tubes and 1 instrumentation tube, whereas 16x16 rod array with 235 fuel rods, 20 guide thimble tubes and 1 instrumentation tube in Kori Unit-2 NPP fuel. The fuel rods are held by 7 or 8 spacer grids in their position. The rod diameters of Kori Unit-1 and -2 reactor fuel are 10.72 mm and 9.50 mm, respectively, with the same active length of 3658 mm. The fuel assembly is held down on the lower core plate by 4 sets of several bladed leaf springs fastened on the top end piece frame. Fully recrystallized Zircaloy-4 material is used for guide thimble tubes and instrumentation tube while Inconel 718, which is known to have the reliable properties of high yield strength, good ductility and corrosion resistance and high resistance to stress-relaxation under irradiation conditions in core, is used for the spacers, the hold-down springs and the screws of the hold-down device. The main body of the end pieces are made from stainless steels.

2. Description of Hold-down Device

The fuel assembly hold-down device is composed of four sets of springs for each fuel assembly and each comprised of several leaf springs. The hold-down device is intended to suppress reliably the lift-up of fuel assemblies caused by buyancy and flow forces during the normal operation of NPP. Each set of hold-down springs consists of from two to four tapered leaves of Inconnel 718 to form a cantilvever leaf spring pack according to the fuel design. The fixed end of the spring pack is held in place by a screw which bears directly on the uppermost leaf. The length, width and thickness of the spring leaves are designed and fabricated to provide the desired spring constant, deflection range and hold-down force. The design concepts of indigenous fuel assembly hold-down springs for Kori Unit-1 and -2 are proposed to change the leaf thickness from 4 mm to 4.3 mm with each set of three leaves to enlarge the spring forces compare to the fuels in the beginning stage of NPP. The springs are required to provide the desired hold-down spring force subsequent to the occurrence of any reactor operation conditions. The size and the geometry of the hold-down springs are established to meet specified stress criteria on the one hand and on the other hand to ensure that the spring reaction forces do not lead to a loss of preload at any time in fuel assembly life.

2.1 Thermal and irradiation expansion of FA

Thermal expansion of the fuel assembly is made up of the components of the fuel assembly top end piece, guide thimble and fuel assembly bottom end piece, which are taken into account by different temperatures according to their position. The resultant total expansion length of fuel assembly is known to be 0.745～7.606 mm at the temperature of 50 and 305 ℃.[1] The length change caused by neutron irradiation growth was investigated for PWR fuel assemblies of various reactors.[2] According to the measurement results obtained from in-pool examination executed in PIEF pool for the Kori NPP fuels, the total growth of spent fuel assemblies are about 5.0～8.42 mm.[3]

2.2 Gap between fuel assembly and grid plate

The spring deflection, and thus the spring force, depends on the gap between the fuel assembly and the reactor core plate. At the core edge, the gap is equal to the difference between installation of reactor core and fuel assembly length. In the core centre, the gap increases as a result of bowing of the core support under the weight of the fuel assembly and due to flow forces and arching of the grid plate caused by the hold-down spring forces, and also under thermal loading. Generally the spring deflections at the core edge position are 2 mm greater than that of the center position. Considering all of the factors the final spring deflection leads to the value of 20.3 mm and 10.1 mm at 50 ℃ and 305 ℃ at the beginning of life (BOL), whereas 30.8 mm and 20.6 mm at the end of life (EOL). Table 1. shows the relation of spring deflection and gap distances in the core.

2.3. Spring relaxation

Relaxation is the decrease in spring deflection as a result of a permanent deformation caused by temperature and radiation effects. This simultaneously reduces the spring forces. Generally, at the end of life, about 3 % of relaxation is used in calculation. It must be expected that the 0.2 % of yield stress and tensile strength increases somewhat as a result of neutron irradiation, thereby also reduces the permanent deformation.

3. Required hold-down force

The required hold-down force is eventually obtained from the superimposing of forces acting in different ways on the fuel assembly. The spring forces depend on the spring characteristics and the gap between fuel assembly top end piece and grid plate. There are several forces acted on the fuel assembly in the upward direction, such as the forces from the buyancy effect, upstream flow induced force and bearing force while some forces are acted in the downward direction such as the forces from gravity and from the hold-down spring. The total resultant core flow force from the flow stream is determined as a function of the flow temperature which was known to have the forces from about 1100 kN to 800 kN according to the temperature range from 50 ℃ to 300℃.[4] To determine the spring forces, the minimum permissible cold and operating characteristics were obtained by KAERI/KWU, which show about 750 N and 300 N at BOL in operation temperature of 50℃ and 308℃, respectively, whereas 940 N and 460 N are showed at EOL in same temperature conditions. This ensures that the fuel assemblies are reliably helddown at all times.

Measuring Device

A comprehensive hold-down spring force measuring device was developed in order to verify the integrity of the hold-down spring during reactor operation and even at the end of cycle. The device is designed to avoid the compressive load to be acted on the guide thimble tubes during the measurement by lifting up the fuel assembly with the removable handling tool. The handling tool is connected and disconnected to the measuring head of the device remotely. In the lower part of the measuring head, a replacable compressing adapter is mounted which can be replaced according to the number of spring leaves to be compressed. There are three force loading modes that enables to compress the spring sets separately and simultaneously. A harmonic driver mounted motor system and a precise load cell attached indicator are installed in the upper housing of the device. The equipment arrangement is shown in Fig.1. A small personal computer system controls the motor driver and load cell system, and collects the measured data in real time mode which will be processed to evaluate the spring characteristics coincidently. Double coupled mechanical seal and Nitrogen gas supplying system to give a counter pressure inside housing afford a high quality of water tightness during the 15 m depth of under water examination in service pool. The gas supplying device is equipped with pressure regulator and accumulator to control the feeding gas conditions, which is to be used in dehydrating the inside of measuring device after examination. The stroke of compressive motion is 45 mm which can be adjusted before starting the measurement in setup mode and the applied load limit also can be set easily. It takes about 10 minutes to measure and analyse the hold-down spring forces in forward and backward mode.

Experiments

To ensure the integrity of hold-down spring forces during the operation lifetime, the hold-down spring force characteristics of spent fuel measured after the end of cycle is also

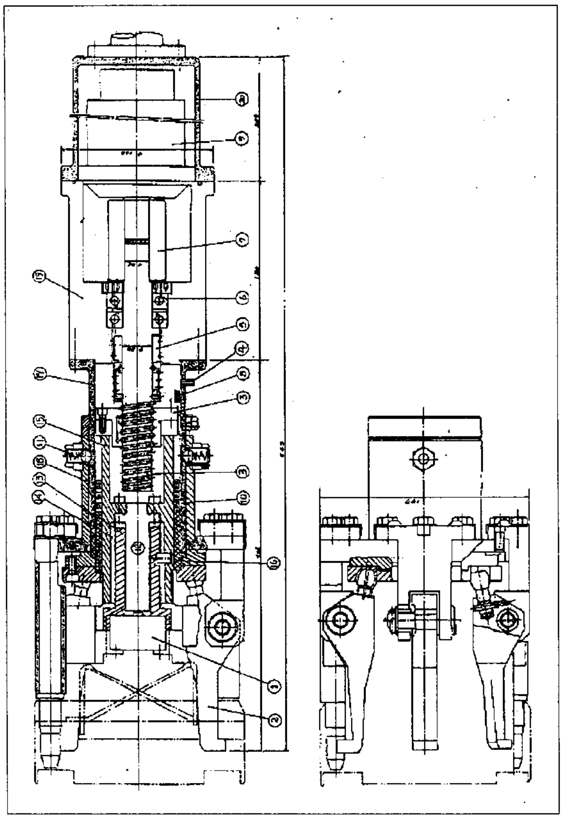

Fig. 1. An Arrangement of Hold-down Spring Force Measuring Equipment

important to estimate the spring conditions. The load-displacement characteristics of the hold-down springs for six 14x14 PWR type fuel assemblies and one 16x16 PWR type fuel assembly having 1 to 4 cycles of irradiation histories in the Kori Unit-1 and -2 reactor were examined in PIEF pool. For the determination of the spring characteristics, the top end piece of fuel assembly was connected to the head of the hold-down spring force measuring device as shown in Fig.1. In order to measure the spring forces in the elastic region, the compressive stroke of spring deflection during the examination was set to the range of 0-20 mm. Spring constants were determined in compressive mode and releasing mode.

Results and Discussion

The results of the characteristics determination of the hold-down springs irradiated in Kori NPP fuel assembly are graphically depicted in Fig.2. As is shown in figure, the spring constant remains in linear states irrespective of the type of fuel assemblies and/or irradiation conditions. The spring deflecting depicted in the figure shows different compression distance from about 13 mm to 19 mm according to the plastic deformation remained in the springs after reactor operation. The fuel assemblies used in the examination is classified in three groups according to the design and fabrication states. The first one includes J44 fuel assembly which is 16x16 type of assembly and irradiated in Kori Unit-2 NPP for 3 cycles with a discharged burnup of 32.018 GWD/MTU and it shows a completely same trends of spring characteristics with the fresh fuel assembly in its shape. The second group including F02, G23 and J14 fuel assemlbies shows almost same characteristic curves, and those spring constants are about 43~45 kgf/mm in compressive mode while 36~37.5 kgf/mm are showed in releasing mode. The other one includes C15, A39 and A17 fuel assemblies which were loaded in the beginning stage of Kori-1 reactor operation show almost the same phenomena in their characteristic curve despite of the relatively small spring forces. Fig.3 shows the upper and lower bounds of hold-down spring characteristic curves and the lower bound shows about 11.3 %~25.2% of decreases in spring forces. Consequently, in the compressive process, the force/deflection plots show linear characteristics with the spring constants of 22~67 kgf/mm. The plots then become more curved and the slope decreases as the spring deflection approaches to the yield points. As is general and typical of such plots for the one-dimensional loading of metals, the linear portion of the plots represents the region of elastic behaviour while the deviation of the curved portion from the extrapolated linear portion reflects the occurrence of plastic deformation. But in this examination, the maximum amount of spring deflection was limited within 20 mm, so the plastic deformation of spring deflection was not shown. But the already affected plasticity of the springs can be derived from the difference of the compressive spring displacements shown in the figure. Despite of the wide range of spring constants obtained through the examination, the spring characteristics of fuel assemblies fabricated with the same design concepts showed completely same patterns in their spring characteristics. According to the design report for PWR fuel assembly prepared through the joint design between KAERI and KWU, the maximum spring deflection of fuel assembly after the geometrical change of spring leaf is about 42 mm and the set of the triple leaf springs is determined to be between 16.12 mm and 16.64 mm during operation and the applied forces to be between 3975 N and 4100 N. [5] These values are a little bit higher than the examination results of Kori Unit-1 and -2 reactor fuels before the design change of leaf spring thickess. Spring constants correlated with burnup is depicted in Fig.4 which show very slight relativities between two parameters. A17, A39 and C15 fuel assemblies loaded in the initial core of Kori Unit-1 reactor show relatively low spring constants compared to the other fuel assemblies. Those low constants may be caused by the differences of the design and fabrication of fuel assembly. The spring constants of 16x16 type fuel assemblies depicted as a first group in the figure, J44 and fresh fuel assembly, are about 50 % higher than those of second group of fuels. As a structural material, the hold-down spring characteristic doesn't seem to be affected severely by the irradiation rather than the other factors such as thermal and mechanical properties. From the cyclic loading test results, the number of load cycles to spring cracking at a mean deflection of 28 ± 6 mm was determined to be 6104 N. Compared to the shutdown cycle of NPP, the fatigue test result shows a good safe margin for the reactor operation. [6]

Conclusion

A newly developed hold-down spring force measuring device was adopted in the examination of one fresh fuel assembly and 7 spent fuel assemblies irradiated in Kori Unit-1 and -2 NPP. Even though three 14x14 fuel assemblies loaded in the initial core of Kori Unit-1 have relatively low spring constants, the hold-down spring characteristics comply with the requirements of reactor operation, namely to hold down reliably the fuel assemblies at all times during the residence period and at all temperatures of startup and shutdown. Much more examinations and data accumulation will be carried out with the equipment in order to get more precise trends of hold-down spring force characteristics.

References

1. KWU technical report RB 22/e134/76
2. Knaab; Manzel, "Dimensional Stability of Water Reactor Fuel," ANS/CNA Topical Meeting, Toronto, April (1975)
3. S.G.Ro; E.K.Kim; Y.B.Chun, et. al., "Post-Irradiation Examination of Kori-1 Fuel," KAERI/GP-77/88 Jun. (1988)
4. Somogyi, "Schriftliche Mitteilung an Herrn Aisch vom 24.4.76," written notice to Herr Aisch dated 24.5.76
5. Fuel Design Report for 14x14 Fuel Assembly, Joint Design of KAERI/KWU Nov. (1987)
6. K.N.Song, D.S.Shon, et. al., "17x17 Leaf Spring Test Report," TR-FE-GEN-91001K, KAERI, May (1991)

Table 1. Hold-down Spring Deflection and Forces in Operation

	Temp. (℃)	r = R			r = 0			Spring		Relaxation
		Core Length	FA Length	Gap (Core/FA)	Core Length	FA Length	Gap (Core/FA)	Force (N)	Deflection (mm)	Force(EOL) / Force(BOL)
BOL	50	4077.0	4057.3	19.7	4079.0	4057.3	21.7	750	20.3	1.25(50℃)
	305	4094.2	4064.2	30.0	4096.2	4064.3	31.9	300	10.1	
EOL	50	4077.0	4057.8	19.2	4079.0	4067.8	11.2	940	30.8	
	305	4094.2	4074.7	19.5	4096.2	4074.8	21.4	460	20.6	

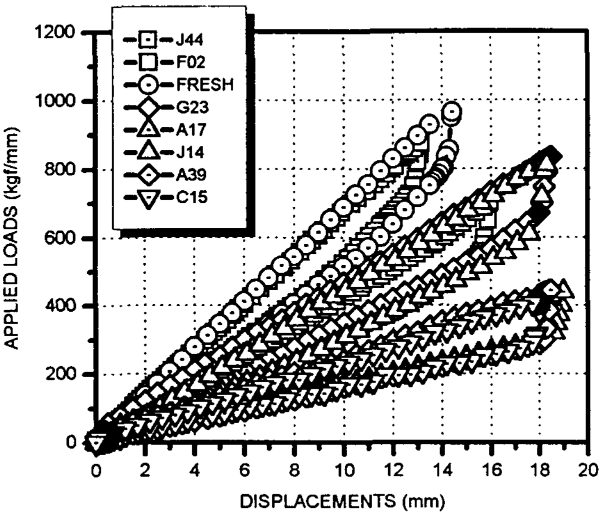

Fig. 2. LOAD-DISPLACEMENT DIAGRAM OF HOLD-DOWN SPRINGS.

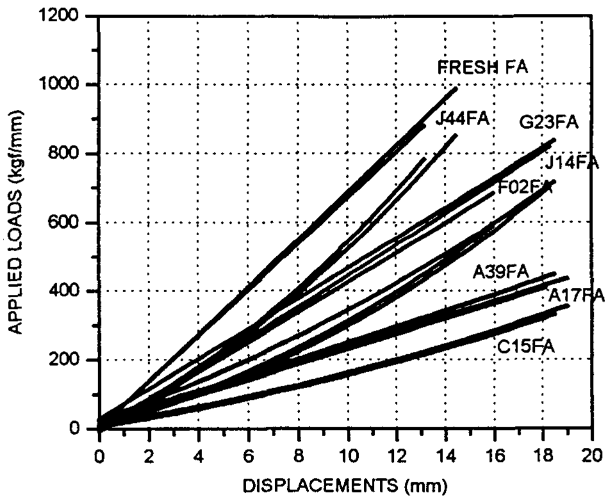

Fig. 3. UPPER AND LOWER BOUND OF SPRING DEFLECTION

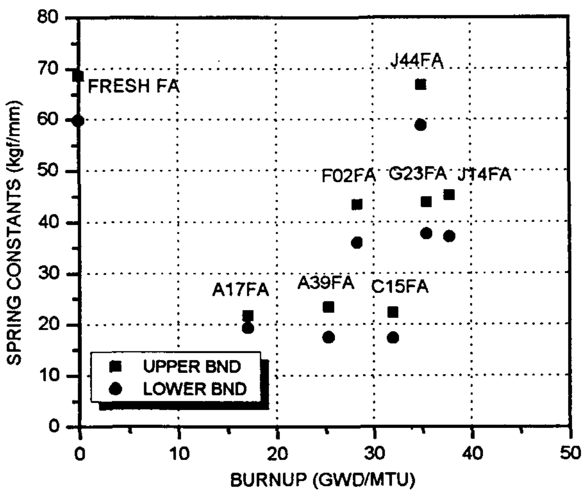

Fig. 4. SPRING CONSTANTS CORRELATED WITH FUEL BURNUP.