The Conceptual Design for a Fuel Assembly of a New Research Reactor

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ABSTRACT

A new Research Reactor (ARR) has been under design by KAERI since 2002. In this work, as a first step for the design of the fuel assembly of the ARR, the conceptual design has been carried out. The vibration characteristics of the tubular fuel model and the locking performance of the preliminary designed locking devices were investigated. In order to investigate the effects of the stiffener on the vibration characteristics of the tubular fuel, a modal analysis was performed for the finite element models of the tubular fuels with stiffeners and without stiffeners. The analysis results show that the vibration characteristics of the tubular fuel with stiffeners are better than those of the tubular fuel without stiffeners. To investigate the locking performance of the preliminary designed locking devices for the fuel assembly of the ARR, the elements of the locking devices were fabricated. Then the torsional resistance, fixing status and vibration characteristics of the locking devices were tested. The test results show that using the locking device with fins on the bottom guide can prevent the torsional motion of the fuel assembly, and that additional springs or guides on the top of the fuel assembly are needed to suppress the lateral motion of the fuel assembly. Based on the modal analysis and experimental results, the fuel assembly and locking devices of the ARR were designed and its prototype was fabricated. The locking performance, pressure drop characteristics and vibration characteristics of the newly designed fuel assembly will be tested in the near future.

1. INTRODUCTION

HANARO (Hi-flux Advanced Neutron Application Reactor), is an open-tank-in-pool type research reactor with a thermal power of 30MW. The HANORO has been operated at the Korea Atomoic Energy Research Institute (KAERI) since 1995. Based on the technical experiences in the design and operation of the HANARO, the design of A new Research Reactor(ARR) was launched by KAERI in 2002 [1~4]. The final goal of the project is to develop a new and unique research reactor model which is superior from a safety and economical aspect.

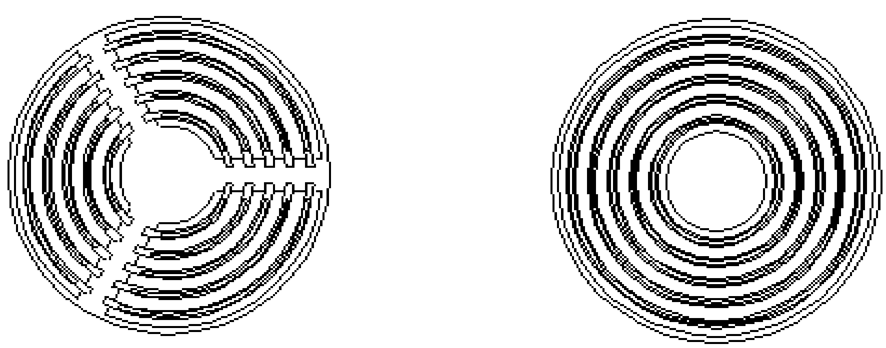
As a first step for the design of the ARR, a conceptual design of a fuel assembly and a core structure has been carried out[2,3]. For determining a fuel for a new research reactor, three typical fuel types of plate, tube and rod fuels, which have been widely used as research reactor fuels, are reviewed from various aspects such as the fuel material and fabrication, reactor physics and thermal-hydraulic characteristics, structural integrity, and their application to HANARO in the future [2].

As a result of the review of considerations on fuel selection, two tubular type fuel models shown in Fig. 1 were selected as a prototype of the fuel assembly for the ARR. One is a tubular fuel assembly with three stiffners(model A), and the other is a tubular fuel assembly without stiffners(model B).

The first objective of this work is to investigate the effects of the stiffener on the vibration characteristics of the tubular fuel. The second objective is to verify the locking performance of the preliminary designed locking devices for the fuel assembly of the ARR. The third objective is to design and fabricate a prototype of the fuel assembly and the locking devices based on the results of the modal analysis and locking performance test. For these purposes, finite element models of the tubular fuel with stiffeners and without stiffeners are developed. Then, the modal analysis was performed for the developed finite element models. For the evaluation of the locking performance of the preliminary designed locking devices for the fuel assembly, the torsional resistance, fixing status and vibration characteristics of the locking devices were tested. Then, a prototype of the fuel assembly and locking devices of the ARR were designed based on the modal analysis and experimental results[3,4].

2. MODAL ANAYSIS OF THE FUEL ASSEMBLY

As a prototype for the fuel assembly for the ARR, a tubular type fuel with three stiffeners(model A) and without stiffeners(model B) as shown in Fig. 1 were proposed. As a nuclear fuel material, U-Mo, which is known to have a higher uranium density than uranium silicide fuel, is considered.

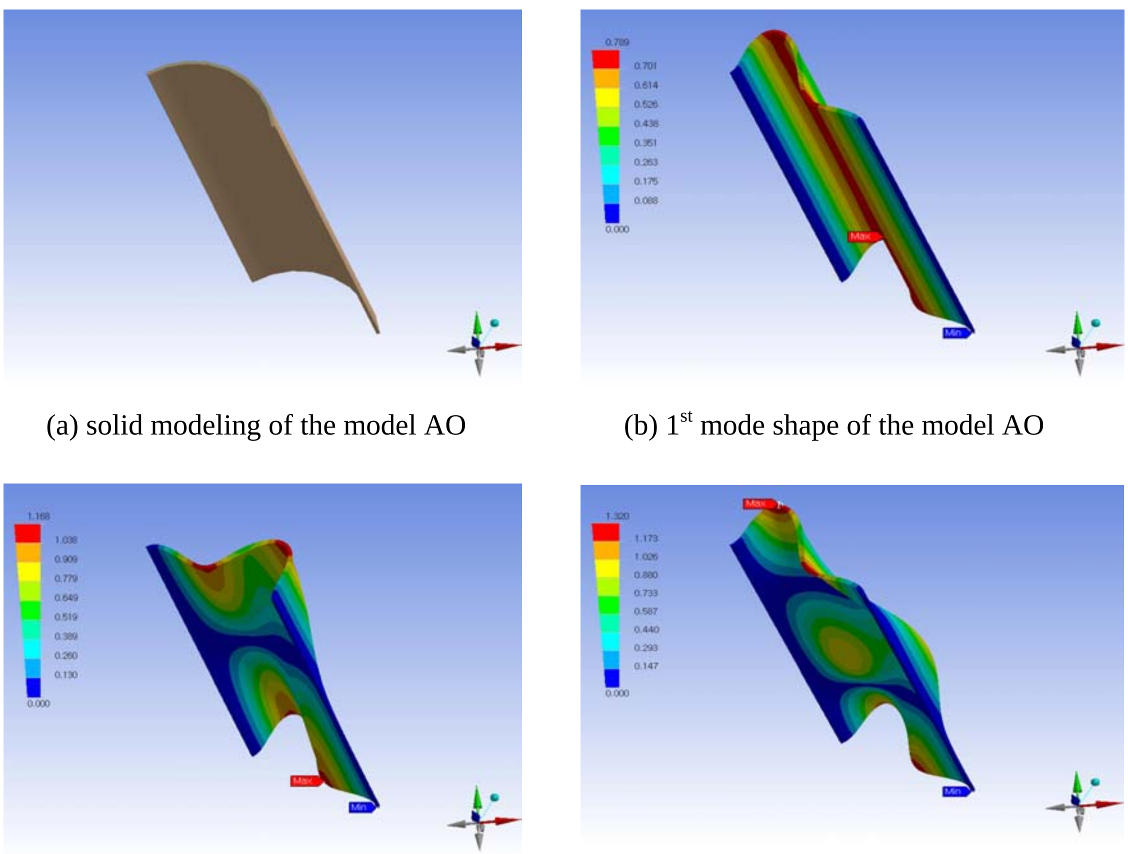


(a) fuel with three stiffeners(model A) (b) fuel without stiffeners(model B)

Fig. 1 Section view of the tubular fuel models

The structural integirity of the fuel assembly has to be proven against a fluid induced vibration through a pressure drop test, vibration test, and the endurance tests. Furthermore, the fuel assembly must be safely designed by considering the seismic loading of an OBE(Operating Basis Earthquake) and SSE(Safe Shutdown Earthquake).

In order to investigate the effects of the stiffeners on the vibration characteristics of the tubular fuel, a modal analysis was performed for the finite element models of the tubular fuel with stiffeners and without stiffeners. The modal analyses of the innermost (I) and outermost (O) fuel were performed so that the test combination lead to AI, AO for model A and BI, BO for model B. The natural frequencies and related modes were calculated using ANSYS. The height of the fuel element is 700mm and the thickness of stiffener is 6mm. As the boundary conditions, the coaxial edges of fuel model A are clamped and the top and bottom ends of fuel model B are clamped. The solid model of the outermost fuel with stiffeners(AO) for the modal analysis is shown in Fig. 2 (a) and some of its lower modes are displayed in Figs. 2 (b)~(d). The analysis model and several mode shapes of the tubular fuel without stiffeners(BO) are shown in Fig. 3. Because of the difference in the boundary conditions, the shell modes dominate in the case of model A. On the other hand, it is observed that the beam modes are dominant in the case of model B. The modal analysis results demonstrate that the natural frequencies of fuel model A are 2.4 ~ 22 times higher than those of fuel model B.



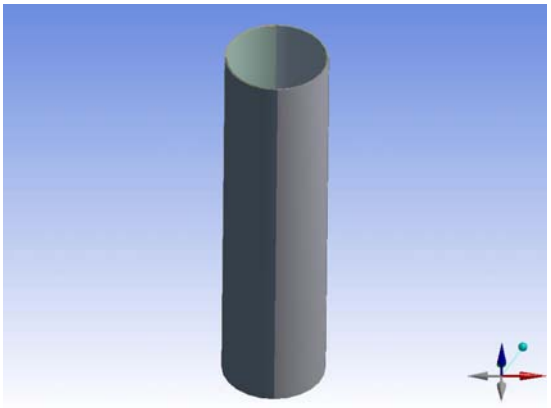
(a) solid modeling of the model AO

(b) 1st mode shape of the model AO

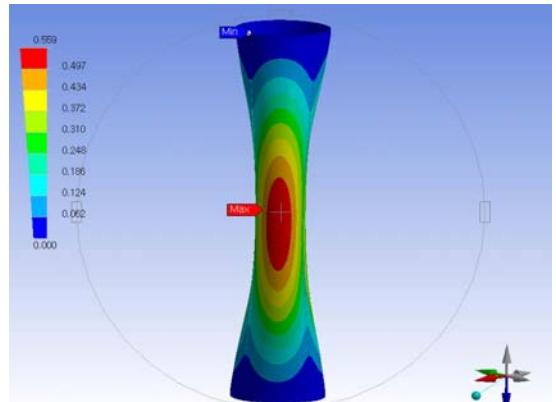
(c) 2nd mode shape of the model AO

(d) 3rd mode shape of the model AO

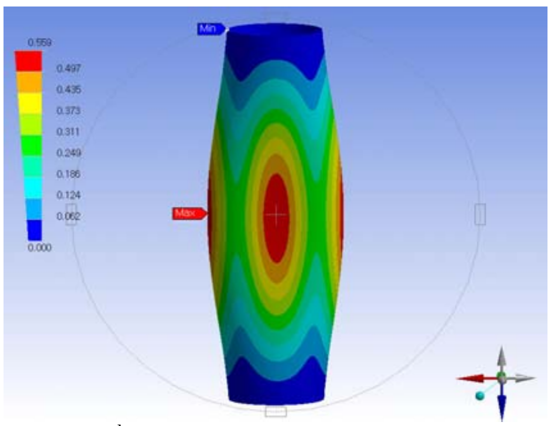
Fig. 2 Mode shapes of the tubular fuel element of model A



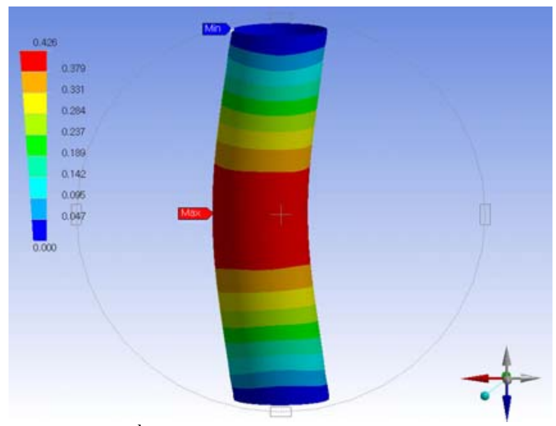
(a) solid modeling of the model BO



(b) 1st mode shape of the model BO



(c) 2nd mode shape of the model BO



(d) 7th mode shape of the model BO

Fig. 3 Mode shapes of the tubular fuel element of model B

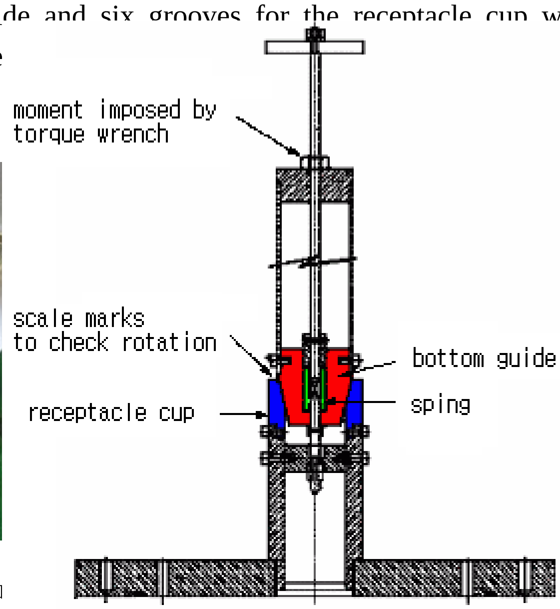
From the above results, we can confirm that the stiffener of the fuel assembly plays a crucial role on the vibration feature of the fuel assembly and the vibration characteristics of the tubular fuel with a stiffener are better than those of the tubular fuel without stiffeners.

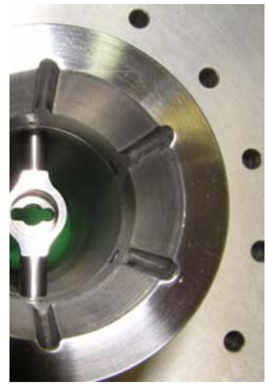
3. PERFORMANCE TESTS OF THE LOCKING DEVICES FOR THE FUEL ASSEMBLY

Considering the tubular fuel with stiffeners as a fuel assembly for the ARR, an associated locking device was preliminarily designed to lock the fuel assembly in a fuel channel. A locking device must meet several features such as the easiness of locking of the fuel assembly and the prevention of a rotation of the fuel assembly owing to an effect of the coolant flow. Also, a locking device should be designed to minimize the vibration of the fuel assembly and have a resistance against fatigue failure.

To verify the preliminary design of the locking device for the ARR, the components including bottom guide, receptacle cup and sping were fabricated. Then, tests on the loading/unloading, rotational resistance and a vibration test with the locking device were carried out.

Fig. 4 shows the bottom guide and the receptacle cup that were fabricated. To investigate the effect of the conical angle of the contact face on the torsional resistance and the structural stiffness, the bottom guide and receptacle cup were designed and manufactured with three types of angle (26°, 30°, and 36°). In addition to the surface contact type design, locking devices with six fins for bottom guide and six grooves for the receptacle cup were designed in order to reinforce the torsional re





(a) bottom gu ... cup

Fig. 4 Prel ... fins)

Fig. 5 Torsional resistance test of a locking device

3.1 Loading/Unloading Test

To check the easiness of installation of the fuel assembly and the fixing status of the preliminary designed locking device, loading/unloading tests were performed. The loading/unloading test results show that there was no trouble in loading and unloading the fuel assembly for repeated tests. However, the loose-fitting problem due to the manufacturing tolerances of the contact surfaces between the bottom guide and the receptacle cup were observed for all tested cases.

Although the loose-fitting due to the tolerances is small, it cannot support the fuel assembly during the operation period of the reactor. Even though the locking devices support the bottom part of the fuel assembly, a bending vibration at the top of the fuel assembly can be generated due to its long length. If an excessive vibration of the fuel assembly occurs, it is possible that the fuel assembly would make contact with the flow channel. Then wear defects between the fuel assembly and the flow channel can occur. The test results demonstrate that additional springs or guides on the top of the fuel assembly are needed to suppress the lateral motion of the fuel assembly. Therefore, we are going to solve this problem by adding a top guide roller at the top part of the fuel assembly so that it reduces the lateral motion of the fuel assembly.

3.2 Torsional Resistance Test

An angular moment was imposed by a torque wrench on the fuel assembly as shown in Fig. 5. Whether the bottom guide rotates or not was checked by a ruler mark on the receptacle cup whenever the torque ascended stepwise.

In the case of the locking devices without fins, scratch marks at the contact surface were observed. On the other hand, the test results of the locking devices with fins demonstrated that using the locking device with fins on the bottom guide can prevent the torsional motion of the fuel assembly.

3.3 Vibration Test

The main frequency of the coolant induced vibration called the BPF(Blade Passing Frequency) is the torsional frequency times the number of impeller blades of a cooling pump, and in fact the pressure fluctuation owing to the BPF had been detected in the case of HANARO [5,6]. The vibration of this frequency can cause the resonance when the BPF coincides with the natural frequency of the fuel assembly. Therefore the fuel assembly has to be carefully designed to avoid a resonance by the BPF.

In order to investigate the effects of the locking device on the natural frequency of the fuel assembly, the modal tests were performed. Fig. 6 represents the schematic diagram of the experimental setup for modal testing [7] of the fuel assembly. The impact force and vibration response signals from the force transducer and the accelerometers taken during each impact test were simultaneously recorded by the DAT recorder (TEAC LX-10) for the later signal analysis. Then, the recorded signals were analyzed by using the signal analyzer (B&K Pulse).

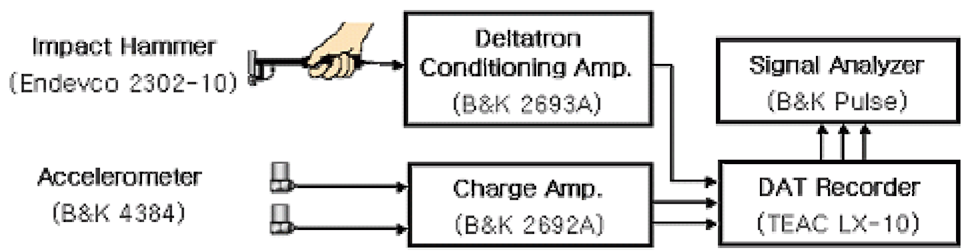
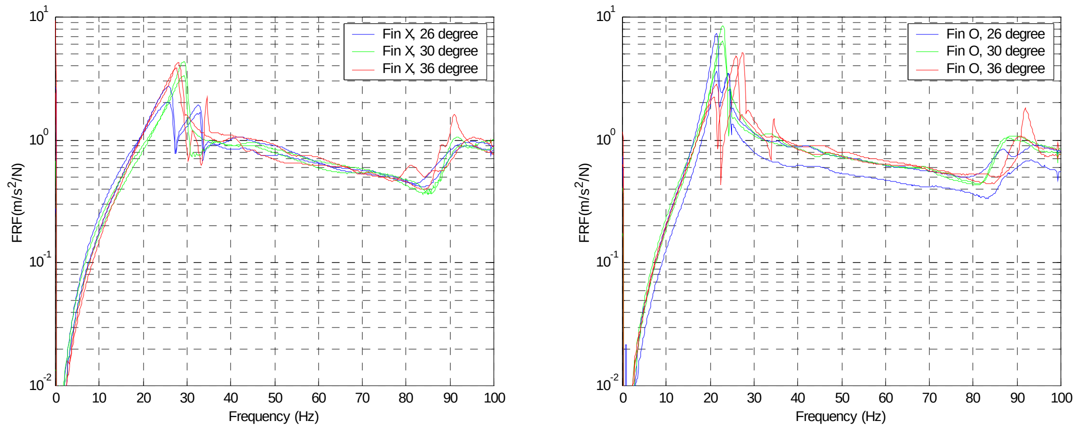


Fig. 6 Experimental setup for the modal test of the fuel assemblies loaded at the locking device

Fig. 7 shows the FRF(Frequency Response Function) obtained by the modal tests. In the case of the locking device with a surface contact type (whithout fin and groove), one can see that the first natural frequencies ranged from 25.5 to 29.9 Hz. For the case of a locking device with fins, the first natural frequencies broadly ranged from 21.4 to 25.9 Hz. In addition, by comparing Fig. 7 (a) and (b), one can observe that the fuel assembly with a surface-contact-type lockng device has a higher lateral stiffness than the fuel assembly with a fin-contact-type locking device. Because the contact surface between the bottom guide and receptacle cup can uniformly support the fuel assembly, the locking device without fins seems to be stiff and this feature has an influence on the response results. Although the vibrational characteristics are slightly preferable in the case of the fuel assembly without fins, the locking device with a fin-contact-type seems to be the better for preventing an unintentional rotation of the fuel. To increase the first natural frequency and the bending stiffness, the test result suggests that the fin-contact-type locking devices should be designed to have as large a contact area as possible.



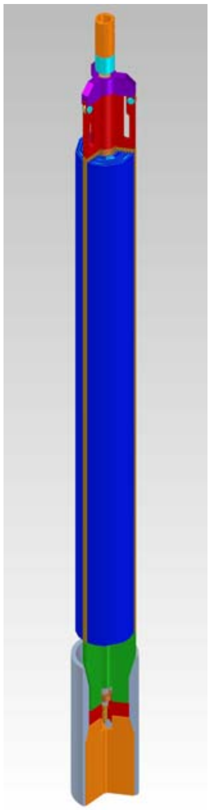
(a) FRF without a fin (b) FRF with fins

Fig. 7 Frequency response function of the fuel assemblies loaded at the locking device

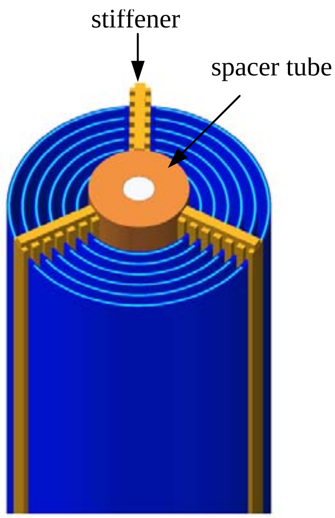
4. FABRICATION OF THE PROTOTYPE OF THE FUEL ASSEMBLY

Based on the modal analysis results of the fuel assembly and the results of the locking performance test of the preliminary designed locking devices, a prototype of the fuel assembly and the top/bottom locking devices of the ARR was designed. The flow analysis and pressure drop analysis for the coolant inlet channel were also considered in the design of the locking devices.

Fig. 8 shows the schematic diagram of the newly designed fuel assembly and the locking devices. Three stiffeners divide the cross-section into three equal parts. The fuel assembly consists of six curved plates for each trisection. Each fuel plate consists of a fuel core of U-Mo and cladding material of Al 1060. The stiffener has grooves to fix the fuel plates by swaging. Stiffeners are not directly connected to the spacer tube because it is difficult to manufacture the stiffener and the spacer tube as a whole part. The top and bottom shape of the stiffener also needs to be adequately designed to connect the top guide and the bottom guide. The design of the fuel assemblies loaded in the flow channels of the reactor core of the ARR is carrying out.



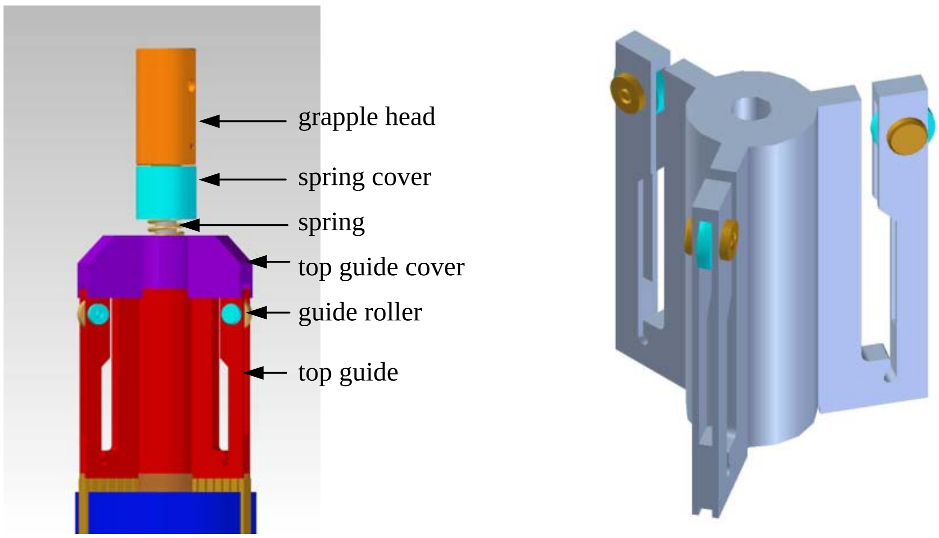
(a) fuel assembly



(b) stiffeners and fuel plates

Fig. 8 Conceptual design of the fuel assembly

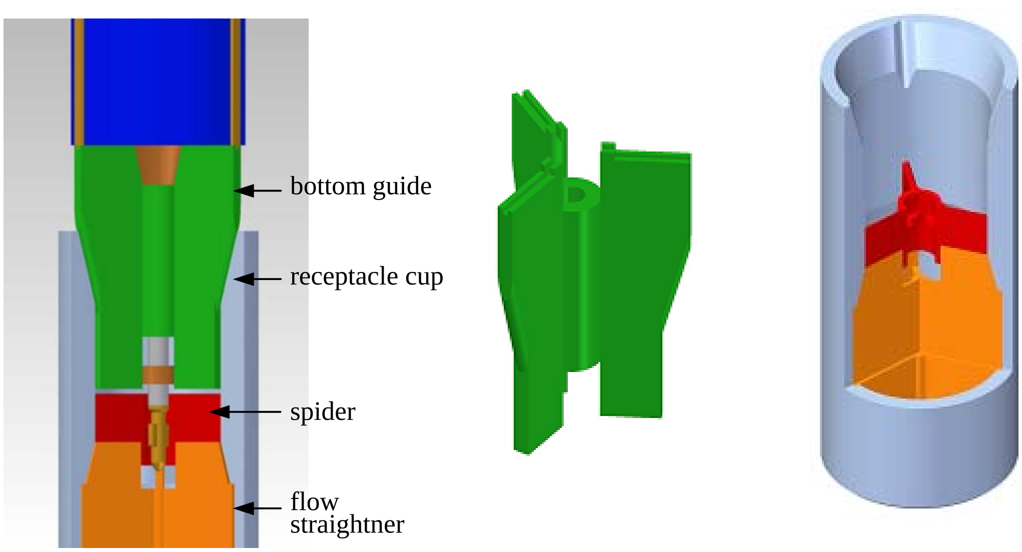
Fig. 9 represents the schematic of the newly designed top locking devices. In order to prevent a fluid induced vibration in the lateral direction of the fuel assembly, a top guide with 3 top guide rollers were designed on the top part of the fuel assembly as shown in Fig. 9 (b).



(a) top locking device (b) top guide and roller

Fig. 9 Conceptual design of the top locking device of the ARR

Fig. 10 represents the schematic of the newly designed bottom locking devices. Based on the results of the flow analysis and the pressure drop anlyasis, the thickness and configuration of the receptacle have been changed to increase the flow section area of the coolant inlet. To reduce the wake phenomena at the coolant inlet section, a flow straightner that has three wings was designed at the bootom of the locking device as shown in Fig. 10 (c). In addition, to reduce the flow resistance due to the coolant flow, the direction of the three wings of the spider and the bottom guide was designed to coincide with that of the flow straightner.



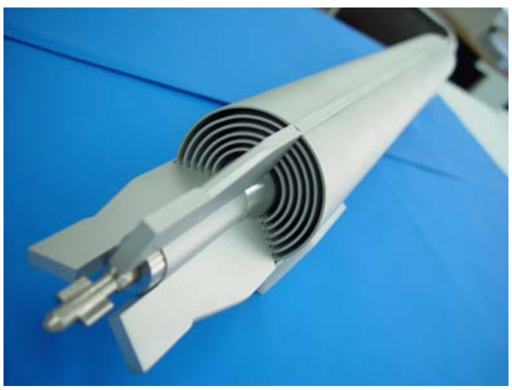
(a) bottom locking device (b) bottom guide (c) flow straightner and spider

Fig. 10 Conceptual design of the bottom locking device of the ARR

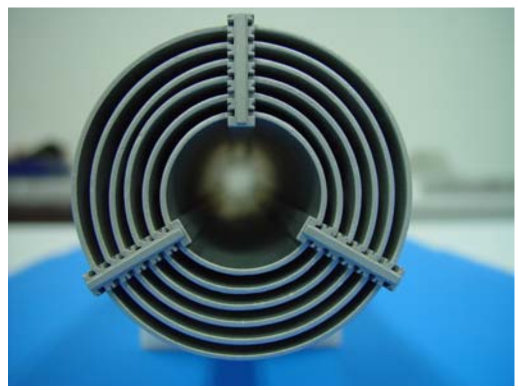
Based on the conceptual design, two-dimensional and three-dimensional drawings and a technical specification for the assembly and swaging were documented to fabricate the prototype of the ARR fuel assembly. Fig. 11 shows the prototype of the fuel assembly of the ARR. The locking performance, pressure drop characteristics and vibration characteristics of the prototype of the fuel assembly will be tested in the near future.

(a) fuel assembly

(b) top locking device



(c) bottom locking device



(d) fuel element and stiffeners

Fig. 11 Prototype of the conceptual design of the fuel assembly of the ARR

5. CONCLUSION

The conceptual design for the fuel assembly and locking devices of the ARR (A new Research Reactor) was carried out. For this purpose, vibration characteristics of the tubular fuel model with stiffners were investigated by performing a modal analysis. The analysis results demonstrate that the tubular fuel with stiffeners is better than without stiffeners from the aspect of a vibration resistance. In addition, the components of the preliminary designed locking devices were fabricated and its locking performance was investigated by the loading/unloading test, torsional resistance test, and vibration test. The test results show that using the locking device with fins on the bottom guide can prevent the tosional motion of the fuel assembly. It is observed that the fixing status of the locking device in the lateral direction is incomplete and the lateral motion of the fuel assembly can occur due to the manufacturing tolerances of the contact surface between the bottom guide and the receptacle cup. This observation demonstrates that additional springs or guides on the top of the fuel assembly are needed to suppress the lateral motion of the fuel assembly. Considering the results of the modal analysis for the fuel assembly and the locking performance tests, the fuel assembly and the locking devices for the ARR were designed and its prototype was fabricated. In the future study, the locking performance, pressure drop characteristics and vibration characteristcs of the newly designed fuel assembly and locking devices will be verified by perfoming the pressure drop test, vibration test, and endurance tests.

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