Design of the top guide of the fuel assembly for a new research reactor

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1. Introduction

A new research reactor (ARR) has been designed by KAERI since 2002 reflecting design and operation experience of the HANARO reactor. The final goal of the project is to develop a new and unique research reactor model which is superior in safety and economical aspect.

From the previous work to examine vibration characteristics of the tubular fuel model and performance of the locking device of the preliminary fuel assembly [1-2], the fuel assembly which has the tubular fuel was conceptually designed as shown in Fig. 1. As a part of the fuel assembly, the top guide plays an important role in supporting the fuel assembly in the fuel channel. Since high speed coolant passes through the channel, the flow can induce vibrating force which may do damage to the fuel assembly. The newly designed top guide functions as a beam-type spring so that it absorbs the external shock to protect the fuel assembly. Since the vertical degree of freedom is not restrained due to the top guide roller, the small vertical fluctuation is also allowed.

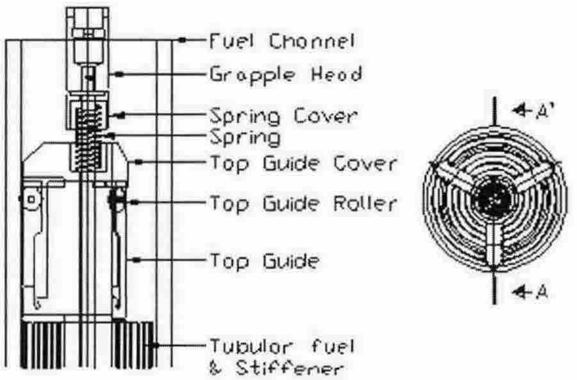

Fig. 1 Top part of the fuel assembly in the fuel channel

To reduce effect of the flow-induced vibration in view of design of top guide, we built an optimizing problem which maximized the reaction force at the top guide roller subjected to fatigue and material yield constraints. The idea is that the system should have higher natural frequency if firmly supported. It is simple analogy from end conditions for a vibrating beam since the natural frequency increase when support of the beam is changed from a simple end to a clamped one. Constraints of material failure are normalized as percentage displacement so that their relative importance and violation of feasible domain are easily checked. The commercial engineering software ANSYS 7.1 is used to analyze the structural behavior.

2. Optimum design formulation

To maximize reaction force at the top guide roller under fatigue and yield constraints, the optimum design for the top guide is formulated as follows,

$$\max R \quad \text{s.t.} \begin{cases} \delta_F > \delta_{F0} \\ \delta_Y > \delta_{Y0} \end{cases} \tag{1}$$

where R is reaction force at the top guide roller. Because displacement boundary conditions were imposed on the top guide, we formulated constraints based on displacement at the top guide roller. The notation δ_F is allowable additional deflection without violation of fatigue criteria which guarantees the top guide has unlimited life cycle, and it is defined as the equation $\delta_F = S_F / \overline{S}_m \times (1 - S_m / S_a)$. We note that the alternating stress S_a is defined by the von-Mises equivalent stress and the mean stress is defined as $S_m = \max(S_{P1} + S_{P2} + S_{P3})$ or sum of the principal stresses to reflect a fact that the tension dominated region is venerable to the fatigue failure [3]. Also the stress $\overline{S}_m$ is the von-Mises equivalent stress where S_m occurs. The formula $\delta_Y = S_Y / \max \overline{S} - 1$ is allowable additional deflection at the top guide roller without material yielding. Notations S_F and S_Y are denoted fatigue strength and yield strength of material respectively. Also δ_{F0} and δ_{Y0} are target deflections for fatigue and yield constraints.

With these formulations for the optimal design, we searched a new design profile of the top guide [4]. In the following sections, design variables for shape optimization are illustrated and results are reviewed. Also we comment difficulties in shape design of the top guide and subjects for further study.

3. Shape design for the top guide

Fig. 2 shows shape of the top guide for the fuel assembly and design variables used for optimal design. Two types (a) and (b) of section profile are considered. The profile (a) is selected to improve the original design, and the profile (b) is to search the different design from the original one. We note that the similar design with the original profile was already applied to the fuel assembly of the BR2 reactor. Given displacement 1mm, which is neutral condition when the fuel assembly is loaded into the fuel channel, is imposed on the pin hole. Also the base of one sixth of model by symmetric reduction of the model is fixed to evaluate the state variables. The capital C and T in the figure mean the compression or tension dominated region. In this study the maximum von-Mises equivalent stress generally occurs at the region C, and the maximum sum stress at the region T.

Because there is a restriction that design variables should be discrete owing to the fabricating aspect, random search approach is selected to find the optimum.

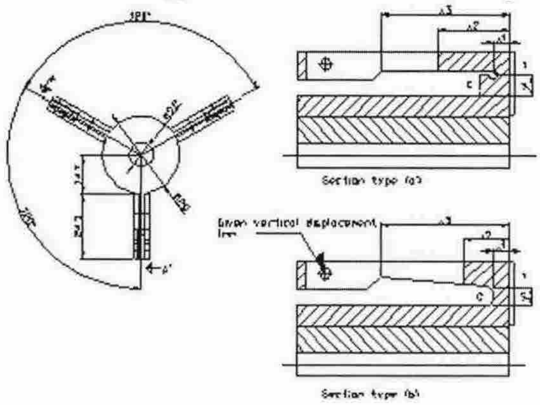

Fig. 2 Shape of the top guide and design variables

Table 1 Final results of optimum design

Model (section type)	Objective	δ_F	δ_Y
Existing design (a)	25N	0.44	0.56
Optimum O1 (a)	38N	0.40	0.43
Optimum O2 (b)	42N	0.38	0.83

Final results of optimum shape design for the top guide are listed in Table 1. Reaction force at the pin hole of the preliminary base design is 25N, but reactions for the optimum model O1 of the profile type (a) and optimum model O2 of type (b) are 38N and 42N. These objective forces improve 52% and 68% compared to that of the original model. However there is a tradeoff in view of safe deflection. For the original model, deflection at the top guide roller is neutrally 1mm when the fuel assembly loaded in the fuel channel, and it is guaranteed additional $\delta = \min(\delta_F, \delta_Y) \times 1mm = 0.44mm$ deflection which the top guide can endure by incidental shock during operation. In the other hand the model O1 and O2 can allow additional displacement 0.40mm and 0.44mm at the pin hole.

Although fatigue or yield condition is worse than before, objective gain overwhelms the loss. Therefore final designs are considered to improve and be in concord with our goal.

4. Conclusion

The optimum design of the top guide of the fuel assembly for a research reactor was carried out. We formulated the optimal design problem for the top guide with normalized fatigue and yield measures which made us easily check and compare constraints of the allowable displacement. Maximizing reaction force at the top guide roller as an objective function was selected to improve vibration characteristics of the fuel assembly. Reaction at the pin hole of the top guide increased 52% ~ 69% with minor degeneration on constraints. Conclusively, by the proposed formula for design of the top guide, we improved the performance of the top guide.

We will fabricate presented designs of the top guide to investigate effect of them on loading/unloading the fuel assembly in the fuel channel and to examine vibration characteristics of the fuel assembly as well in the near future.

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