Design of the Detachable Extension Shaft Assembly for KJRR

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1. Introduction

The Extension Shaft Assembly (ESA) of Control Rod Drive Mechanism (CRDM) [1] and Second Shutdown Drive Mechanism (SSDM) [2] for the KiJang Research Reactor (KJRR) are the component connecting the Control Absorber Rod (CAR)/Second Shutdown Rod (SSR)/Follower Fuel Assembly (FFA) to the drive mechanisms below the reactor pool. Because the upper part of the ESA can be placed near the reactor core for a long time and directly connected to the FFA, the deterioration of its mechanical properties is expected to be relatively quicker than the lower part of the ESA. The ESA is therefore composed of an Extension Shaft (ES) and an ES adapter, and the ES adapter can be detachable from the ES and replaceable by new one.

In the previous design concept, the ES adapter had four latches which can be detached from the ES in the reactor core by external pulling force, and the detached CAR or SSR, FFA and ES adapter are individually disconnected in some baskets when it is needed to replace CAR/SSR/FFA or shuffle them [3]. However, when the force to disconnect the ES adapter from the ES is too large, the CAR/SSR guide tube can be damaged. When the force is too small, the bundle of CAR/SSR/FFA and ES adapter can be unexpectedly detached from the ES. To solve the problem, we have studied another design concept which can increase the connecting force and can be easily detachable when it is needed.

2. Evaluation of the Advanced ESA Design

2.1 Advanced Design Concept

The main difference between the previous and modified designs is the shape and role of the latch and its counterpart as shown in Fig. 1. When the upper protrusion of the ES adapter latch is compressed, the lower protrusion is separated from the ES inner groove. If the upper protrusion can be compressed in a designated basket only, it is easy to increase their connecting force between the ES adapter and the ES.

When this modified design concept is adapted, the maintenance method should also be changed. As shown in Fig. 2, by using a basket, we can connect/disconnect the ES adapter to/from the ES. For this design concept, it is needed to design their proper dimensions and to calculate stresses and forces.

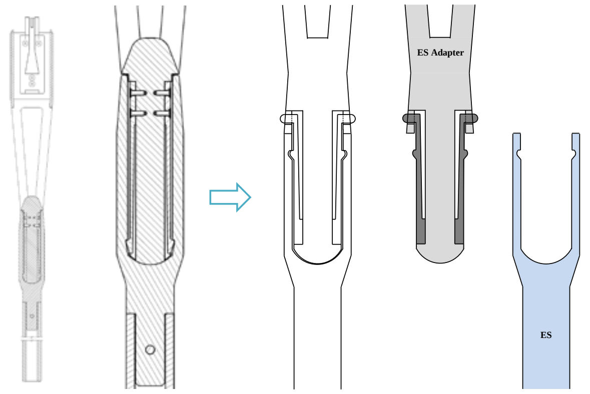


Fig. 1. Comparison of the geometry between the previous and the modified ESAs.

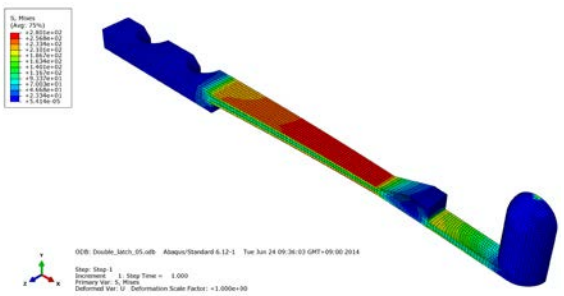
Fig. 2 Procedures for connection and disconnection between the ES adapter and the ES using a basket.

2.2 FE Analysis of the Latch for Disconnection

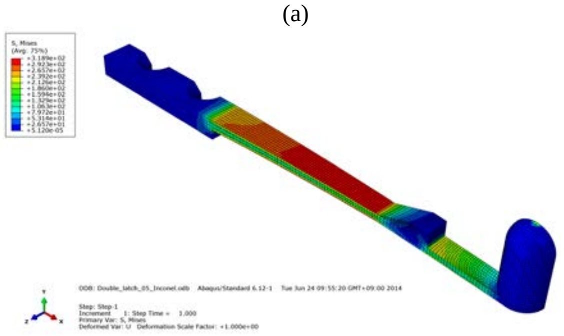
A three-dimensional FE (Finite Element) analysis for the simulation of the disconnecting the ES adapter latch from the ES has been performed using a commercial code, ABAQUS. Because of the half symmetry, only a half of the latch is simulated (Fig. 3). The eight-node brick element C3D8 is used, and the total number of elements is about 12000 ~ 17800, which depends on the geometry. The stresses and the reaction forces are calculated when the upper protrusion is fully compressed. When the protrusion is compressed by 2.5 mm, the ES adapter and the ES can be disconnected. It is, however, compressed by 3.0 mm in the analysis because the tolerance and gap between the ES adapter, ES inner groove, and basket should be considered. We assumed two kinds of materials, stainless steel and Inconel, and two kinds of latch thicknesses. The calculated maximum Mises stress and reaction force for the thinner latch are 280 MPa and 118 N for stainless steel, and 319 MPa and 133 N for Inconel as shown in Fig. 3. The calculated reaction forces are for the four latches. When we use stainless steel 630 (H1100) or Inconel 718 bar, the maximum Mises stress is lower than each allowable stress.

2.3 Vertical Force Calculation for Disconnection

The reaction forces computed in Section 2.2 are horizontal forces, so we should calculate their vertical forces when we use a basket. We have calculated analytical and FE solutions, and compared them.

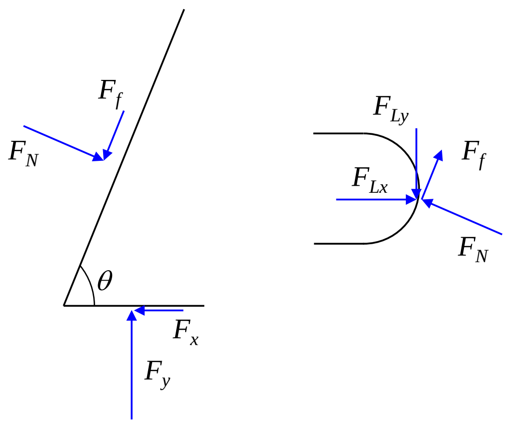


(a)



(b)

Fig. 3. Distribution of Mises stress at the maximum displacement 3 mm for (a) stainless steel and (b) Inconel latches.



(a) (b)

Fig. 4. Free body diagrams at the contact points of (a) the inclined basket and (b) the upper protrusion of the ES adapter latch.

Fig. 4 shows free body diagrams at the contact points of (a) the inclined basket and (b) the upper protrusion of the ES adapter latch. When the normal force on the surface tilted θ from the horizontal plane for the basket is F_N and the friction coefficient between two components is μ, the friction force is express as

$$F_f = \mu F_N . \tag{1}$$

When we set the vertically required force on the basket as F_y, Eq. (2) can be derived from the y-directional force balance,

$$\begin{aligned} F_y &= F_N \cos\theta + F_f \sin\theta \\ &= F_N(\cos\theta + \mu \sin\theta) \end{aligned} . \tag{2}$$

In addition, the horizontal force balance on the latch is

$$\begin{aligned} F_{Lx} &= F_N \sin\theta - F_f \cos\theta \\ &= F_N(\sin\theta - \mu\cos\theta) \end{aligned} . \tag{3}$$

Hence, we can then get the following equation from Eqs. (2) and (3),

$$\begin{aligned} F_y &= F_N(\cos\theta + \mu\sin\theta) \\ &= \frac{F_{Lx}(\cos\theta + \mu\sin\theta)}{\sin\theta - \mu\cos\theta} . \end{aligned} \tag{4}$$

Finite element simulations have been performed to calculate the vertical force for disconnection, and compared the value to the analytical solution. When the basket which is assumed to be rigid moves upward, the reaction force and stress are calculated from the contact analysis between the basket and the latch. When $\mu = 0.2$ and $\theta = 85°$ for the Inconel latch, the maximum Mises stress is 326 MPa as shown in Fig. 5, which is a little

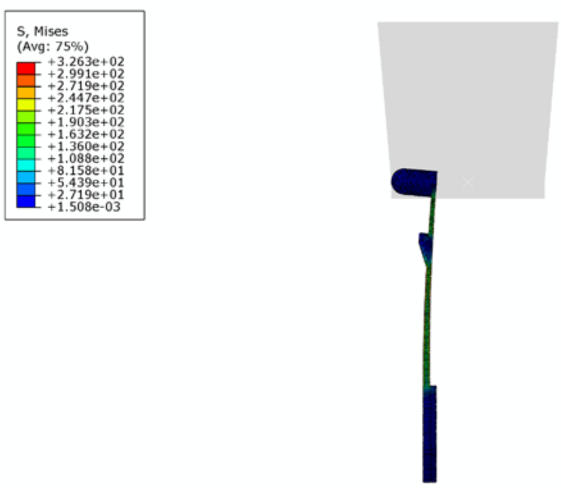


Fig. 5. Distribution of Mises stress at the maximum displacement from the contact analysis for the disconnection of the Inconel latch.

bigger than 319 MPa in Section 2.2. This small deviation of the maximum stress may be caused by the different contact points which makes slightly different displacement. The vertical reaction force from the FE analysis for four latches are 36 N. When we use F_{Lx} = 133 N (Section 2.2) and Eq. (4), the expected value F_y is 38.9 N. The difference between two values is about 8 %, which shows that Eq. (4) can be sufficiently useful to guess the disconnecting force.

The solution shows that with a very low force the ES adapter can be disconnected from the ES when the basket angle θ is 85°, so we can conclude that the designed ESA and basket are adequate to use.

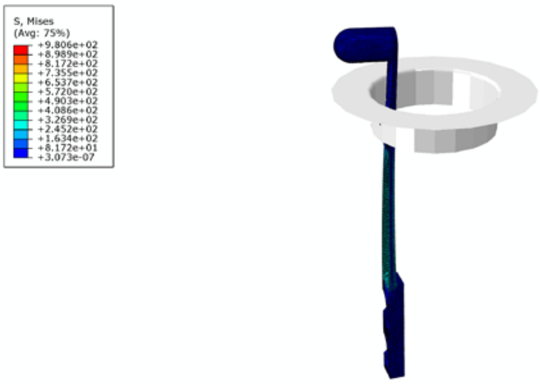


Fig. 6. Distribution of Mises stress at the maximum displacement from the contact analysis for the connection of the Inconel latch.

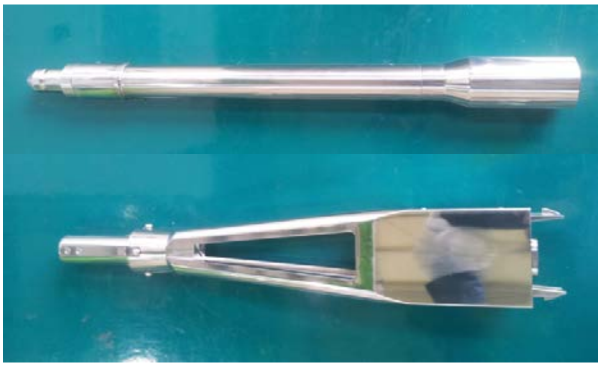


Fig. 7. Prototype of the ES adapter and shortened ES.

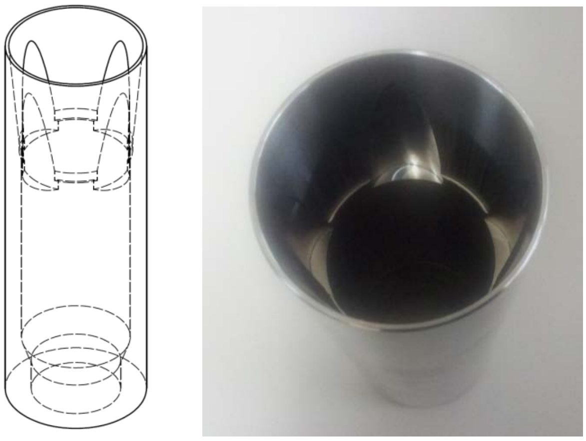


Fig. 8. Prototype of the ESA basket.

2.4 FE Analysis of the Latch for Connection

Contrary to disconnection, the lower protrusion of the latch should be directly compressed for the connection between the ES adapter and the ES. Hence, three-dimensional FE contact analysis has been performed. Fig. 6 shows the Mises stress distribution at the maximum displacement. The local maximum stress occurs near the contact surface, and it can depend on the FE mesh. It should also be noted that the latch is hardly to be bent for its lifetime, and its plastic deformation is also allowable because it does not affect its operation. The required vertical force to connect the ES adapter to the ES calculated from FE analysis is about 90 N for four latches, and it is a reasonable value to be applied.

2.5 Fabrication of the Prototype ESA and Basket

To verify these mechanisms, prototypes of the ESA and basket were fabricated as shown in Figs. 7 and 8. It was confirmed that with relatively low load the ES adapter can be connected/disconnected to/from the ES when the basket is used whereas it is hard to separate them without the basket.

3. Conclusions

In this study, we designed the ESA and basket which can increase the connecting force between the ES adapter and the ES, and can be easily attachable and detachable with the basket. The forces needed to be connected and disconnected were calculated from FE analysis, and the force to be disconnected can be guessed without FE contact analysis. The prototypes of the designed components were fabricated, and they were suitable to be used.

Acknowledgment

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