Design, Fabrication and Characteristics Experiment of a Hybrid Fuel Locking Device for Upward Core Research Reactor

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1. Introduction

It is known that the coolant flow rate in a modern research reactor can be so large that the weight of the fuel assembly is insufficient to prevent the assembly from being lifted off the core support stand.

The assembly must be held firmly against these forces, but cannot be permanently attached to the support stand because periodic refueling of the reactor requires removal or relocation of each assembly.

There are so many kinds of fuel locking devices, but they are operated manually.

As a part of a new project, we have investigated a hybrid fuel locking device (HFLD) for research reactors which is operated automatically.

Prior method of holding down the fuel assembly includes a hybrid zero electromagnet consisting of an electromagnet and a permanent magnet. The role of an electromagnet is converged to zero power for overcoming the lifting power of a permanent magnet by controlling the coil current. At this time, a HFLD is an unlocking state. On the contrary, it is locking state that only a permanent magnet works when the power of an electromagnet is off.

For these reasons, it is necessary to analyze using FEM tool that the total power of a HFLD is possible close to zero when the current of electromagnet is controlled. [1]

Finally, the HFLD was fabricated using the values determined through FEM and the operability was examined.

This paper presents the case numerical and experimental research of a HFLD for research reactors.

2. Automatic Hybrid Fuel Locking Device

A newly proposed HFLD for research reactors is composed of a hybrid zero electromagnet, guide tube, mover, stator, locking bar, split locking tube, spring, internal circular groove of fuel bottom, target, and proximity sensor as shown in Fig. 1.

Fig. 2 shows a locking mechanism of a newly proposed technique for a HFLD.

Fig. 2(A) shows the locking state of a HFLD. In this case, a permanent magnet works alone due to power cut-off. The stator and mover inside the seal tube attract each other by magnetism, thus making the mover connecting locking bar move down to the stator and the top of locking bar pushes the head of split locking tube at the same time. As a result, it is inserted the head of split locking tube into internal circular groove of fuel bottom.

Fig. 2(B) shows the unlocking state of a HFLD. In this case, a permanent magnet and an electromagnet work together. An electromagnet is converged to zero power for overcoming the lifting power of a permanent magnet by controlling the coil current. The stator and mover inside the seal tube are restored their original state because of spring force, thus making the mover connecting locking bar move up and the top of locking bar pulls the head of split locking tube at the same time. As a result, it is unlatched the head of split locking tube from internal circular groove of fuel bottom.

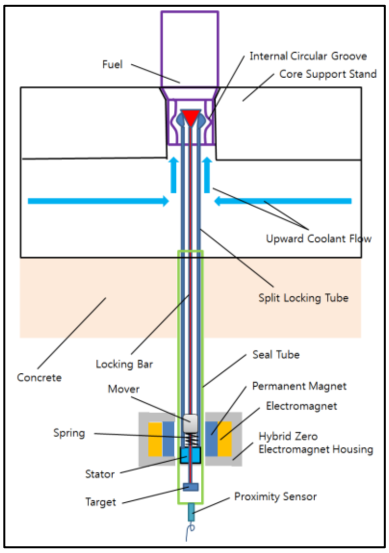
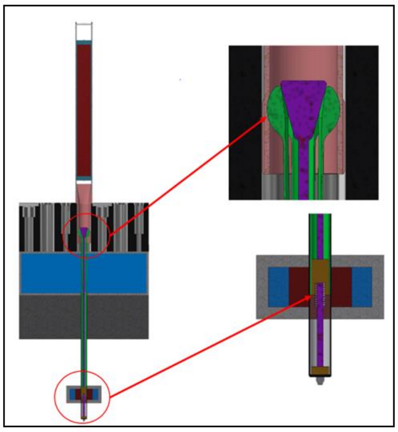
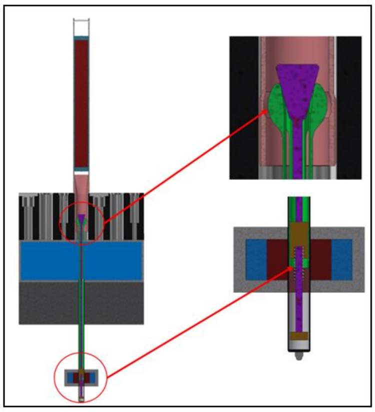


Fig. 1. Schematic of a HFLD.



(A) Locking State (Sensor-ON)



(B) Unlocking State (Sensor-OFF)

Fig. 2. A detailed view of locking mechanism of a HFLD.

3. Methods and Results

In this section the numerical magnetic field calculation with ANSYS for the optimal design of HFLD is described and compared with experimental results of fabricated proto-type HFLD.

3.1 HFLD FEM Analysis Results

The choice of the magnetic circuit (window) shape of an electromagnet will mainly depend on the designer's experience in magnetism, since the mathematical treatment of the magnetic circuit is inaccurate in most cases. As many parameters are unknown or can be predicted only with difficulty, such as the operating points of the electromagnet yoke on the hysteresis loop, the influence of small air gaps following mechanical mounting and the magnetic and mechanical tolerances of the mover, calculations of the circuit with the reluctance model, for example, will lead to only a rough approximation. [2,3]

In order to achieve a zero power electromagnet, the use of numerical field calculations by finite-element method with the aid of a computer is necessary.

Fig. 3 shows an axisymmetric HFLD model, which is composed of a permanent magnet, an electromagnet, a non-ferromagnetic spacer, housing, a mover, and a stator.

Here, the function of an electromagnet plays an important role in converging to zero power of a HFLD.

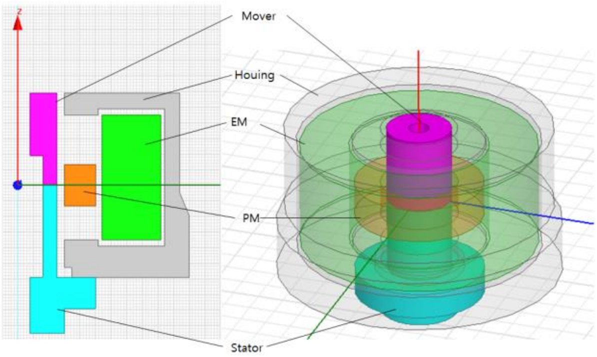


Fig. 3. FEM 2/3-D model of a HFLD.

A newly proposed HFLD for such a computation is given in Fig. 4 and Fig. 5, where the exact course of the magnetic equi-flux and latching force of a HFLD are shown.

Fig. 4 shows the locking state of a HFLD. In this case, a permanent magnet works alone due to power cut-off.

Fig. 5 shows the unlocking state of a HFLD. In this case, a permanent magnet and an electromagnet work together.

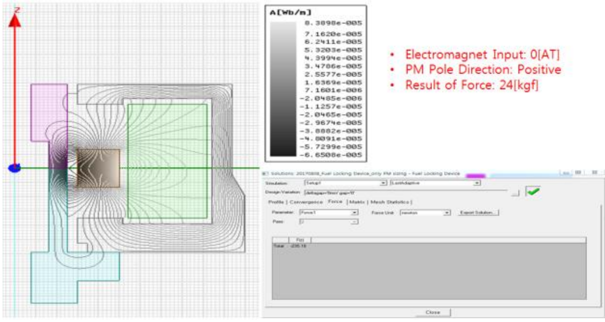


Fig. 4. FEM result of locking state.

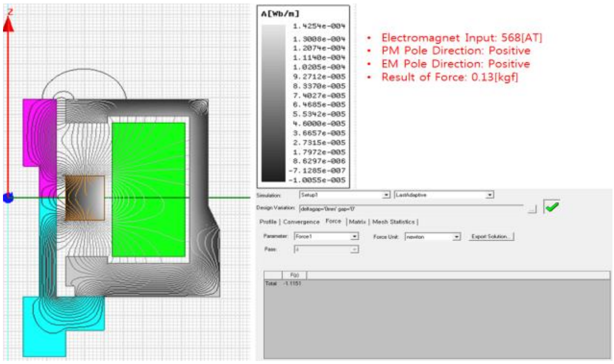


Fig. 5. FEM result of unlocking state.

Table 1 shows the input data for a HFLD FEM analysis.

Table 1: Design specification of a HFLD model.

No	Component	Material	Remark
1	Permanent Magnet	NdFe30	Hc:837kA/m Br:1.05T
2	Electromagnet Coil, mm	Copper	19x40, 568[AT] 1.0[A]x568[T]
3	Housing	STS410	Ferromagnetic
4	Stator	STS410	Ferromagnetic
5	Mover	STS410	Ferromagnetic
6	FEM solver	ANSYS-Maxwell, Axisymmetric, Transient	

3.2 Experimental Results of Proto-type HFLD

Fig. 6 shows the experimental setup for the operability of fabricated proto-type HFLD which is designed by FEM analysis result. The lifting force of proto-type HFLD is measured. As a result, it is shown that the lifting force of the proto-type HFLD has a good agreement with the result of the FEM as shown in Fig. 7.

Fig. 6. Experimental setup of proto-type HFLD.

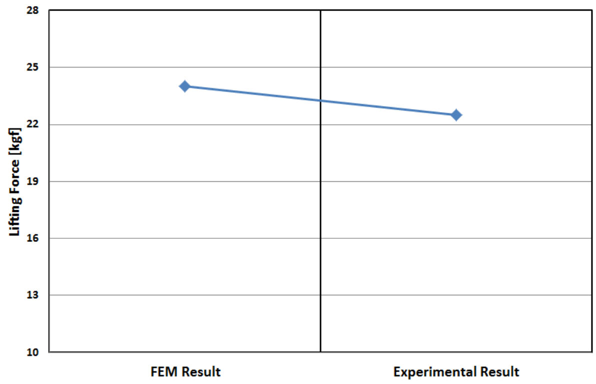


Fig. 7. Comparison of calculated and measured lifting force of HFLD.

4. Conclusion

The results of a FEM and the experiments in this work lead to the following conclusions:

(1) The FEM result for the design of a HFLD is compared with the measured lifting force of proto-type HFLD. As a result, it is shown that the lifting force of the FEM analysis results are in good agreement with experimental results within ±7%.

(2) The operability test results of a newly proposed proto-type HFLD have proven to be excellent.

(3) It is confirmed that the thrust force generated by the permanent magnet can be approached to zero power through the current control supplied to the electromagnet.

REFERENCES

[1]Hyung Huh et al., "Numerical Research on Hybrid Fuel Locking Device for Upward Flow Core-Research Reactor," Transaction of the KNS Autumn Meeting, 2016

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[3]Hyung Huh et al., "Analysis on Electromagnet Characteristics of Research Reactor CRDM for Thrust Force Improvement," Transaction of the KNS Autumn Meeting, 2010