Transactions, SMiRT-23
Manchester, United Kingdom - August 10-14, 2015
Division VI

MODAL ANALYSIS OF FUEL ASSEMBLY FOR CLEAR-I

Qingsheng Wu[1], Qian Han[1,2], Jianwei Chen[1], Huaping Mei[1], Qunying Huang[1]

[1] Key Laboratory of Neutronics and Radiation Safety, Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences, Hefei, Anhui 230031, China
[2] University of Science and Technology of China, Hefei, Anhui 230027, China

ABSTRACT

China LEAd-based Reactor (CLEAR) proposed by Institute of Nuclear Energy Safety Technology (INEST), Chinese Academy of Sciences (CAS) was selected as the reference reactor for the Accelerator Driven subcritical System (ADS). The objective of the first stage was to build a 10MW lead-bismuth cooled research reactor named CLEAR-I. Fuel assembly (FA) was one of the key components in lead-alloy cooled reactor. Considering the design specification and service environment of CLEAR-I, the design of fuel assembly was based on the principles of realistic feasibility, safety reliability and technical continuity, the mature materials and fabrication technologies were selected. The preliminary structural analysis of fuel assembly had already been completed. Meanwhile, the simulation and experimental verification of the structural analysis was underway. This work was focusing on the material selection, the configuration description and modal analysis of fuel assembly for CLEAR-I (Wu, Y. C. et al 2012, 2013, 2014).

Material selection of FA

Extensive investigations of fast reactors showed that the demonstration and commercial reactors which had already been under construction chose oxide fuel (Sobolev, V. et al 2009, Fazio, C. et al 2009, Hiroshi, S. et al 2008, Minoru, T. ey al 2008, Bortot, S. et al 2011). The investigation about enrichment of fast reactor fuels was shown in Figure 1. It was shown that the enrichment of fuels in most reactors was in the range from 10% to 30%. Combining with the Chinese domestic situation, the risk level and costs of conveyance and storage of fuel obviously increase if the enrichment was larger than 20%. However, the core volume and fuel load increase if the enrichment decreases. Therefore, 19.75% oxide fuel (UO_2) was chosen as the prime candidate for the first core fuel of CLEAR-I.

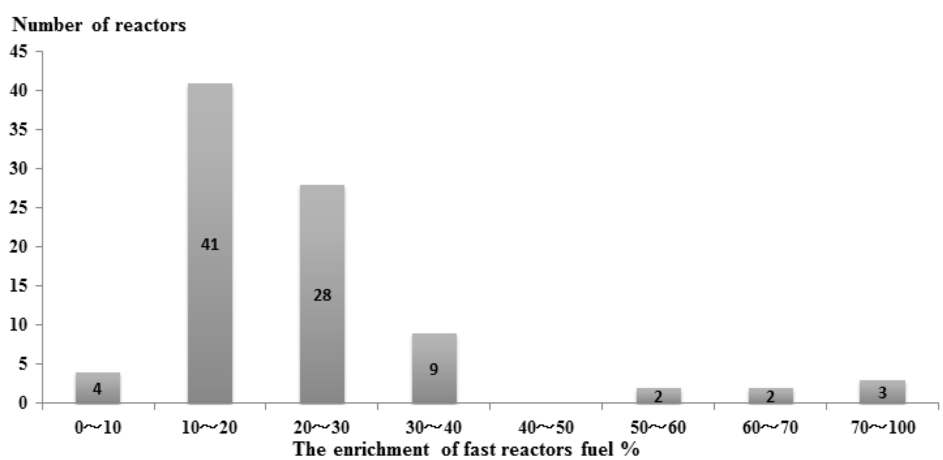


Figure 1. Enrichment distribution of fast reactors fuel.

The fuel cladding materials used in liquid metal fast reactors were mainly austenitic stainless steels and ferritic/martensitic (F/M) steels. Titanium-stabilized and cold worked austenitic stainless steels such as 15-15Ti had been used as fuel cladding in sodium fast reactors more than 30 years. However, there was no precedent to apply F/M steels as fuel cladding tubes and the qualification of F/M steels as cladding tubes was still underway. Therefore, 15-15Ti austenitic stainless steels was selected as the fuel cladding material in CLEAR-I (Huang, Q. Y. et al 2009, Azevedo, C. 2011).

Design and configuration of FA

Preliminary design of a fuel element comprised six parts, including the upper and lower end caps, the tighten spring, the upper and lower reflectors, the active zone, the gas chamber and the ballast (Zrodnikov, A. V. et al 2011). Ballast was chosen as the fixation method of the fuel assembly and the depleted uranium (DU) was chosen as the ballast material. Adjacent fuel element had been fixed by wires. The whole structure design of fuel element was shown in Figure 2. The design parameters of fuel element were presented in Table 2.

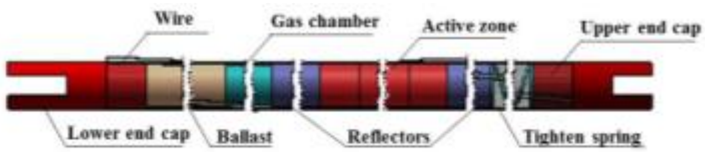


Figure 2. Fuel element design geometry.

Table 2: The design parameters of the fuel element.

Item	Value
Pin length/mm	1675
Pin diameter/mm	12
Pellet diameter/mm	10.9
Active zone length/mm	800
Ballast length/mm	510
Cladding material	15-15Ti

The preliminary structure design of FA was made up of the following six parts, including the operation head, the top nozzle, the fuel pins, the bottom nozzle, the wrapper and the coolant entrance. The whole FA was shown in Figure 3. The design parameters of FA were presented in Table 3.

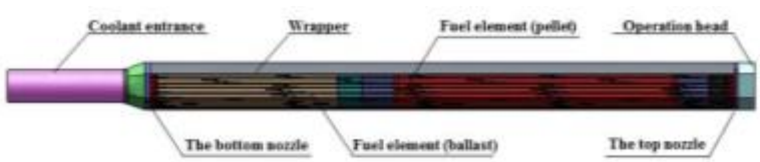


Figure 3. The design geometry of FA.

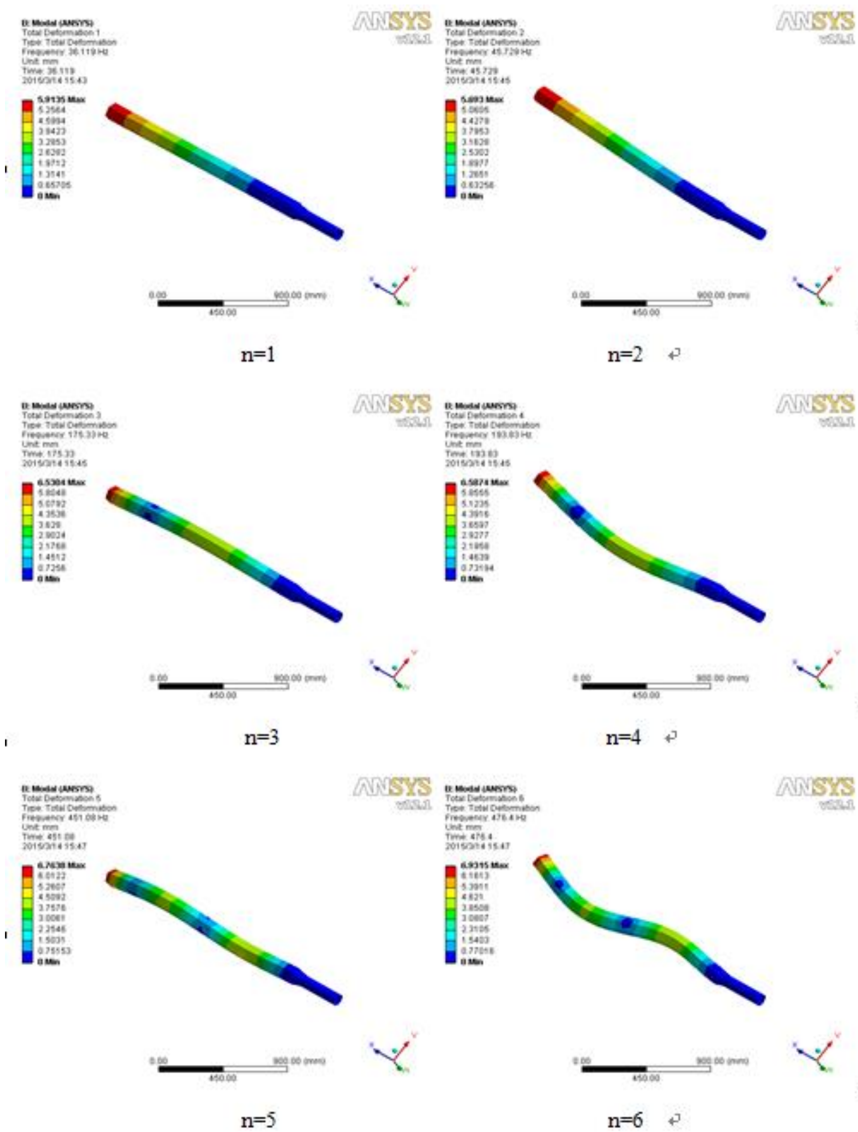
Table 3: The design parameters of FA.

Item	Value

Number of fuel pin	61
Length/mm	2110
Diameter/mm	117.2

Modal analysis of FA

In order to evaluate the mechanical behaviour of FA under external loads, dynamic characteristics of FA were studied to obtain the natural frequency and vibration mode (Hamman, K. D. et al 2011). A FE model of fuel assembly was built to predict the natural frequencies and mode shapes. The first to sixth natural modes were shown in **Error! Reference source not found.**. The natural frequencies were shown in **Error! Reference source not found.**.



Error! Reference source not found.. FA mode shapes from n=1 to n=6, respectively.

Natural frequencies could be used to predict the possibility of dynamic interferenve between the FA and other reactor internals. Meanwhile, vibration modes showed the position and numerical value of the massive vibration. Through the simulation results of modal analysis, Figure 4 showed the massive vibration was appeared at operation head, therefore, supporting pad was designed to fix the FAs.

Error! Reference source not found.: The first to sixth natural mode.

Mode	Natural frequencie (Hz)
1	36.12
2	45.73
3	175.33
4	193.83
5	451.08
6	476.40

R&D of the simulated FA

In order to verify the results of modal analysis, the simulated FA was developed and the experimental validation was realized. Figure 5 showed a picture about the simulated FAs and experimental platform.

Figure 5. Simulated FAs and experimental platform.

The first consideration adopted in the simulated FA was the verification of the model analysis. If the experimental results showed good agreement with the proposed model of FA described above, the modelling parameters could be used to optimize the design scheme. It was expected that the further experimental verification and modification can be performed effectively with the R&D of the simulated FA.

Conclusion

Based on the specifications of the CLEAR-I and the material selection, the preliminary structural design of the FA had been developed. The hexagonal type fuel assembly included 61 fuel elements, which featured a stainless steel cladding and UO_2 pellets. Ballast was chosen as the fixation method of the fuel assembly. Adjacent fuel element had been fixed by wires. The finite element modal analysis of FA was underway in order to evaluate the mechanical behaviour of FA. Further experimental modal analysis was needed to verify the proposed modal of fuel assembly. The optimization goal was to confirm the structural integrity and the design scheme of fuel assembly.

Acknowledgements

This work was supported by Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No.XDA03040000). The authors gratefully acknowledge the support of other FDS team members.

References

Wu, Y. C., Bai Y. Q., Song Y., et al. (2014). “Conceptual design of China Lead-based Research Reactor CLEAR-I,” *Nuclear Science and Engineering*, PRC, 34 201-208.

Sobolev, V., Malambu, E., Ait-Abderrahim, H. (2009). “Design of a fuel element for a lead-cooled fast reactor,” *Journal of Nuclear Materials*, Netherlands, 385 392-399.

Wu, Y. C. (2012). “Overview of China Lead alloy cooled rector development and ADS program in China,” *The 9th International Topical Meeting on Nuclear Thermal-Hydraulics Operation and Safety*. Taiwan.

Fazio, C., Alama, A., Aalmazouzi, A., et al. (2009). “European cross-cutting research on structural materials for Generation Ⅳ and transmutation systems,” *Journal of Nuclear Materials*, Netherlands, 392 316-323.

Wu, Y. C. (2013). “Conceptual design study on the China Lead-Alloy Cooled Research Reactor,” *International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13)*. Vienna.

Huang, Q. Y., Gao, S., Zhu Z. Q., et al. (2009). “Progress in compatibility experiments on lithium-lead with candidate structural materials for fusion in China,” *Fusion Engineering and Design*, USA, 84 242-246.

Azevedo, C. (2011). “Selection of fuel cladding material for nuclear fission reactors,” *Engineering Failure Analysis*, UN, 18 1943-1962.

Hiroshi, S., Yan, M. (2008). “Design study on small CANDLE reactor,” *Energy Conversion and Management*, Canada, 49 1868–1872.

Minoru, T., Shoji, U., Yoshiyuki, K., (2008). “Design study on reactor structure of Pb-Bi-cooled direct contact boiling water fast reactor (PBWFR),” *Progress in Nuclear Energy*, UK, 50 197-205.

Bortot, S., Moisseytsev,A., Sienicki, J. J. et al. (2011). “Core design investigation for a SUPERSTAR small modular lead-cooled fast reactor demonstrator,” *Nuclear Engineering and Design*, Holland, 241 3021– 3031.

Zrodnikov, A. V., Toshinsky, G. I., Komlev, O.G., et al. (2011). “SVBR-100 module-type fast reactor of the IV generation for regional power industry,” *Journal of Nuclear Materials*, Netherlands, 415 237–244.

Hamman, K. D., Barry, R. A. (2010). “A CFD simulation process for fast reactor fuel assemblies,” *Nuclear Engineering and Design*, Holland, 240 2304-2312.