

Investigation of various floating absorber for safety at transient (FAST) designs

Yong Hoon Jeong^{a*}, Seongmin Lee^a,

Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology
 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

Author: seongmeen@kaist.ac.kr

*Corresponding author: jeongyh@kaist.ac.kr

1. Introduction

Floating absorber for safety at transient (FAST) is a device to support negative reactivity feedback and enhance coolant temperature coefficient (CTC) and coolant void reactivity (CVR) values in a sodium-cooled fast reactor (SFR). The absorber region of the FAST passively inserts negative reactivity into the active core region when the buoyance acting on the FAST is smaller than gravity and vice versa. Since the FAST moves upward and downward inside the pin depending on the coolant density, the resistance applied to the FAST body determines the velocity and ultimately the reactivity of the reactor system. In this study, resistance acting on various FAST designs is presented using computational fluid dynamics code (CFD) STAR CCM+ [1].

2. Methods and Results

2.1 The FAST system description

The FAST system is suggested to improve the inherent safety by contributing to negative reactivity feedback in a sodium-cooled fast reactor (SFR) [2]. The FAST is composed of neutron absorber and the void region as shown in Fig. 1.

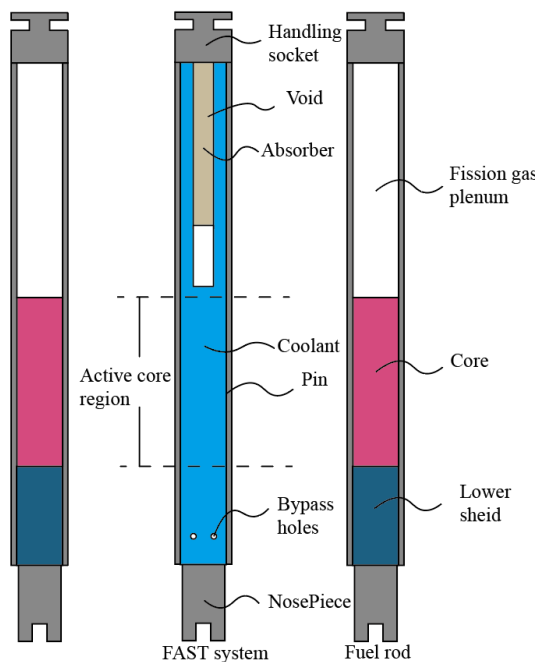


Fig. 1. Fuel rods and FAST system descriptions.

The initial shape of FAST was presented as a cylindrical shape. When the body of FAST has a cylindrical shape, it has significant advantages in the simplicity and predictability of analysis when the FAST is equipped in the fuel assemblies by replacing some fuel rods. The design of FAST can be varied in order to reliably insert the reactivity into the active core under accident or transient conditions. This study presents several possible FAST designs and compares the resistance acting on them.

2.2 Resistance acting on the FAST

The FAST is installed inside the pin and surrounded by coolant inside the pin. Therefore, buoyancy and gravity always exist regardless of the FAST movement. When the FAST moves with a velocity, drag and pressure forces are applied to the FAST body as described in Eqs. (1) and (2).

$$F_d = \mu \frac{dV}{dr} A_s \quad (1)$$

$$F_p = \frac{dP}{dz} A_f \quad (2)$$

where subscripts d , s , p , and f refer to the drag, side surface, and pressure, and frontal surface respectively. μ is the fluid viscosity and V is the fluid velocity profiles at the side region of the FAST, P is the fluid pressure, and A is the surface area.

2.3. Various FAST designs and modeling description

Fig. 2 shows the various FAST designs simulated by STAR CCM+. The FAST body in all cases is the cylindrical shape; case 1 represents the original FAST design. When the FAST moves both upward and downward, the resistance could be different for cases 3 and 4 because the geometry is not symmetrical.

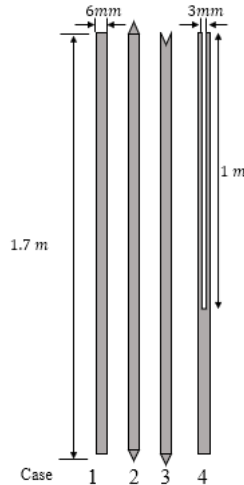


Fig. 2. Possible design options for the FAST.

In STAR CCM+, the FASTs were three-dimensionally modeled. The base mesh size for the volume mesh continuum was determined after observing the results do not change with decreasing mesh size [3]. Fig. 3 shows mesh scene created by polyhedral volume mesher, surface remesher, and prism layer method. The prism layer was used to capture accurate wall shear stress and velocity profiles near the wall.

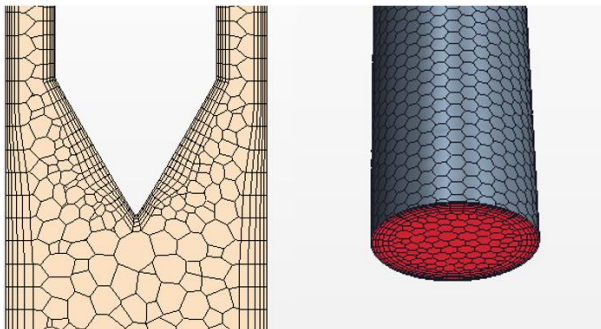


Fig. 3. Cross-sectional view of the domain (left) and mesh scene (right) for case 2.

The resistance was evaluated considering a reference frame based on the FAST moving with 6.52 cm/s of velocity. In other words, the FAST is fixed in the middle of the domain and the fluid velocity was given as the boundary condition while the no-slip condition is applied to the FAST wall. For the fluid physics continuum, laminar flow and constant density models were used.

2.4 Results

Fig. 4 shows drag and pressure forces acting on the FAST designs. The pressure force is dominant compared to the drag in all cases. There are no significant differences in the drag which mainly acts on the side surface. In particular, the case 3 and 4 shows that resistance is not affected by the different tip designs. In particular, the resistance for case 3 moving downward was calculated to be approximately 1.4% greater than the

resistance when the FAST moves upward. For case 4, the resistance was similar to case 1 because the fluid is stationary inside the 1 m of the long hole while the FAST moves. These results imply that the FAST movement is not affected even if the tip design is changed.

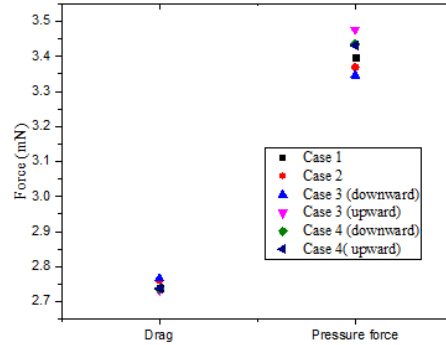


Fig. 4. Drag and pressure forces acting on the FAST body when it moves 6.52 cm/s of velocity.

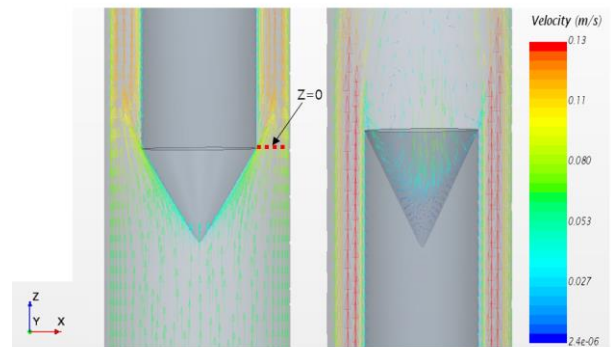


Fig. 5. Velocity field near each end of the FAST for the case 3

Fig. 5 illustrates the velocity field focusing on each end of the FAST moving downward. When the cross-sectional area expands at the height of 1.7 m, the vortex is generated behind the FAST body. The maximum velocity is found at the side region of the FAST when the fluid is fully developed.

Fig. 6 shows the velocity profiles at $z = 0$ m, 0.1 m, and 0.85 m for case 3. Note that the 0 m of height is indicated in Fig. 4. The fluid is quickly developed as soon as it enters the side region as observed velocity profiles at $z = 0.1$ m are almost similar to that at $z = 0.85$ m. Considering that the FAST length is 1.7 m, the influence of radial flow on the resistance would be negligible.

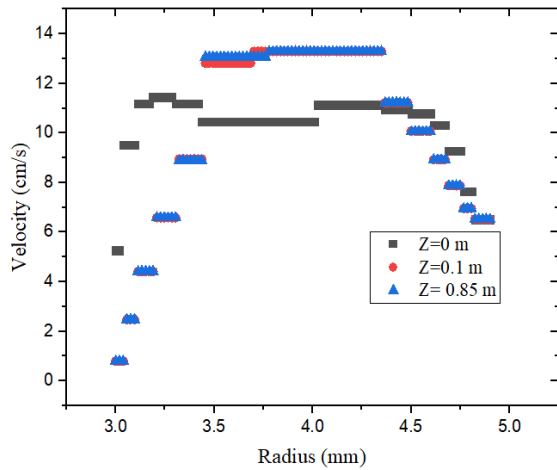


Fig. 6. Velocity profiles at the side region of the FAST

Table I explains the dependence of the resistance on the FAST length and velocity for case 3 moving upward and downward. As the velocity increases, the difference in resistance to the direction of movement increases. However, the resistance in the moving direction is not significantly influenced by the FAST length. It is because the cross-sectional area for the fluid passing through the side region of the FAST was not changed even though head designs or holes are applied to the FAST.

Table I: Resistance acting on the case 3 when the FAST moves with the 6.52 cm/s of velocity

Velocity (cm/s)	Length (m)	Upward resistance (mN)	Downward resistance (mN)
1	0.4	0.22	0.22
1	1	0.54	0.54
1	1.7	0.91	0.91
3	0.4	0.67	0.69
3	1	1.64	1.66
3	1.7	2.77	2.79
6.52	0.4	1.51	1.61
6.52	1	3.63	3.73
6.52	1.7	6.11	6.21

3. Conclusions

This study aimed to evaluate resistance acting on various FAST designs using STAR CCM+ code. Most importantly, the resistance remained almost constant even if the head shape of the FAST was different, when the FAST moves with the same velocity. Based on the simulation results, analyzing long cylinder-shaped FAST can represent FAST which have various head geometries. In addition, even if the FAST design is not symmetrical, the dependence of the resistance on the movement

direction was negligible as the difference in the resistance is below 1.7% for all cases.

The increase in the resistance can reduce the oscillatory behavior of the FAST observed in the reference [4], by suppressing the FAST movement in transients or accidents. Based on the results described here, it would be more efficient to change the resistance by other design parameters, such as the ratio of the pin diameter to the FAST diameter, rather than changing the head designs.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) (No. NRF-2017M2B2B1071971).

This work was performed with Simcenter STAR-CCM+ software provided by the Siemens Industry Software-KAIST cooperation.

REFERENCES

- [1] CD-Adapco, STAR-CCM+ Software package, Users Manual, Version 2020.2, (2020).
- [2] D. Hartanto, I. Kim, C. Kim, Y. Kim, An LEU-loaded long-life innovative sodium-cooled fast reactor (iSFR) with novel and passive safety devices, *Ann. Nucl. Energy.* 95 (2016) 86–101.
- [3] S. Lee, Y.H. Jeong, Floating Absorber for Safety at Transient Analysis Code (FASTAC): Verification And Validation Study, in: *Int. Top. Meet. Nucl. React. Therm. Oper. Saf.*, 2018: pp. 1–13.
- [4] C. Kim, Y. Kim, Potential of FAST (floating absorber for safety at transient) as a solution for positive coolant temperature coefficient in sodium-cooled FAST reactors, *Ann. Nucl. Energy.* 137 (2020) 107048.