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Numerical analysis for calculation of vacuum force of sensor transfer device for DCSS inspection

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1. Introduction

Sensor transport system(SeTS) is the wall climbing instrument developing to inspect the defects of dry cask storage system(DCSS) wall. Figure 1 shows the conceptual frame design of SeTS. It is composed of main frame, driving axle connected with electric motor, impeller connected with adsorptive motor, impeller generating negative pressure, lower chamber connected with impeller, seal generating flexibility to contact with the ground, and etc.

Important factors to decide adsorption force of SeTS in these block diagram are the shape and discharge of impeller, a lower chamber shape of impeller, and etc. Therefore, an impeller and a lower chamber of impeller were selected as the calculation area in this analysis. The analysis conditions were selected in consideration of the suction motor specification and the lower chamber of impeller was simulated in the flow range with the highest efficiency of the impeller.

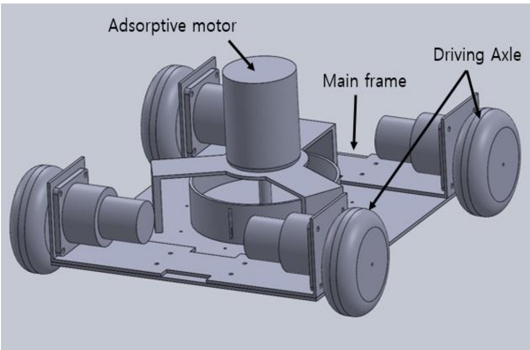

Fig. 1 Shape of SeTS

2. Governing Equation and Calculation Method

We use ANASYS CFX 17.0, which is commercial CFD program based on FVM(Finite Volume Method) in order to get the solution of RANS governing equation.

Continuity equation and momentum equation about 3-dimensional incompressible and normal turbulence flow are as below.

- Continuity equation

$$\frac{\partial U_i}{\partial x_i} = 0 \quad (1)$$

- Momentum equation

$$U_j \frac{\partial U_i}{\partial x_j} + \frac{\partial (\overline{u_i' u_j'})}{\partial x_j} + \frac{\partial p}{\partial x_i} - \frac{1}{Re} \nabla^2 U_i = 0 \quad (2)$$

In this analysis, we used $k-\epsilon$ model among generally 2-equation turbulence models and set the the convergence condition of the solution to the residual 10^{-4}.

3. Interpretation area

Air inflow into lower chamber thru SeTS impeller is ejected to upper part of chamber. As the pressure inside the chamber decreases due to the increase of rotational speed of impeller, SeTS can be attached at the wall or at the ceil. Therefore, the impeller inducing adsorption as shown in Figure 4 and the part of lower chamber were selected as interpretation area. Figure 5 depicts the distribution of pressure behavior after adsorption of SeTS with the wall. While atmospheric pressure is forcing around the chamber of impeller, adsorptive power will be generated as the pressure lower than the atmospheric pressure.

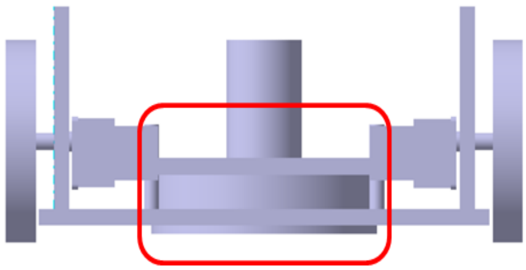

Fig. 3 Interpretation Area of SeTS

4. Interpretation Mesh

Figures 4 and 5 show the front view and the iosometric view of interpretation lattice for SeTS, individually. In order to predict the adsorptive power of SeTS, lattice systems are assumed to be unstructured lattice system, Tetra lattice. In consideration of shearing stress, lattices are located near the wall of impeller are composed as Tetra-Prism lattice. Numbers of nodes for computational lattices are 72,101 for flow field at the top of impeller, 114,564 for the flow field of impeller and 391,463 for lower chamber.

In case of impeller flow field, in consideration of vortex occuring at the tip, lattice are composed by extending the length of impeller exit in order to enhance accuracy of interpretation. Sensitivity is supposed to be analyzed on the lattice through further experiment. [2015. Jeong, Seon Yong]

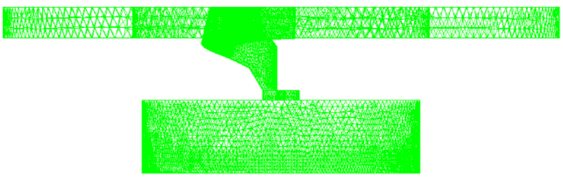

Fig. 4 Fron View of Interpretation Lattice for SeTS

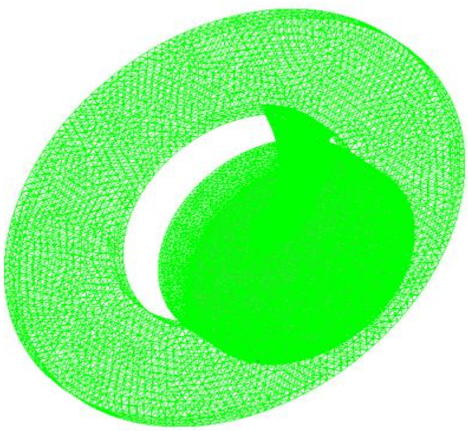

Fig. 5 Iso View of Interpretation Lattice for SeTS

Table 1. Number of Lattices Using for Each Interpretation Model

Index \ No. of Lattices	Element
Upper Flow Field	72,101
Impeller Flow Field	114,564
Lower Chamber	391,463
Total No. of Lattices	578,128

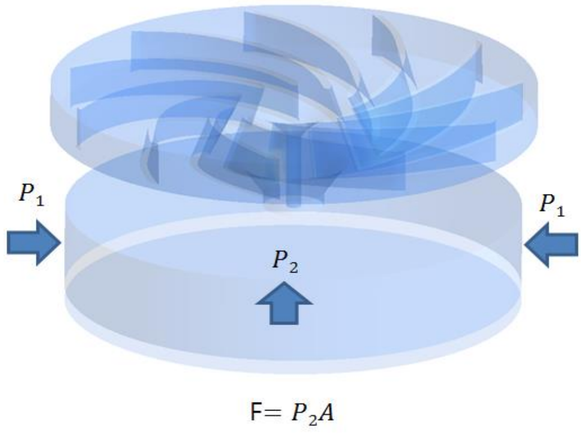

Fig. 4 Distribution of Pressure for SeTS

5. Result of Analysis

Figure 6 shows the inflow velocity vector of an impeller. As shown in the figure, pressure drop occurs at the inlet of impeller and the impeller rotation speed increases. And the flow field inside the impeller generates a complex recirculation flow and vortex due to the rapid rotation of the impeller.

The force applied to the lower part of the impeller by using the pressure and area derived from this analysis result is about 7.8kgf. Therefore, SeTS can deliver mounting up to 3.8kg of sensors and accessories excluding device to inspect the inner surface of dry storage cask wall.

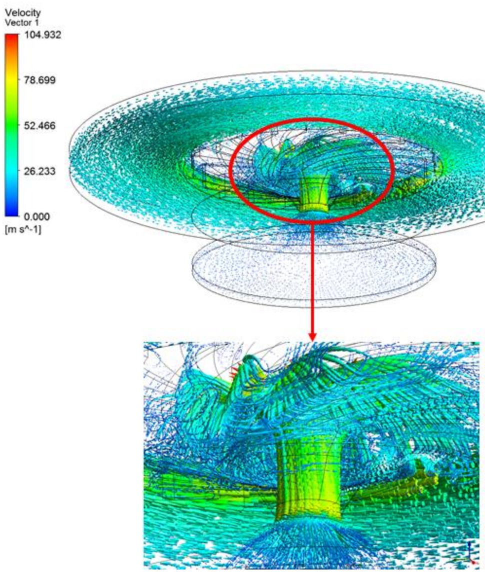

Fig. 6 Distribution of Pressure in Chamber of SeTS

6. Conclusion

In this paper, we have examined the capacity of SeTS equipped with some sensors and accessories and climbing the walls using CFD code.

As a result, the impeller with 10 blades, 7,600 rpm speed and 0.0198kg/s flow rate was evaluated to be able to mount up to 3.8kg excluding device when the gap between the wall surface and chamber is 5mm. If sensors and accessories are determined in the future, the final design will be carried out through additional analysis that reflects these conditions. And the final SeTS will also be designed to operate under high temperature and high radiation conditions.

7. References

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