Effect of unsteady flow to magnetic orientation particles in rotating container

-Visualization of flow in the rotating container-

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1. Introduction

In recent years, the development in superconducting technologies has enabled us to attain magnetic fields of up to 10 T, and as a result, orientation of feeble magnetic particles, which we have regarded as non-magnetic substances, have been tested. There are researches which aim at improving material's physical properties by controlling the direction of particles and crystals by magnetic anisotropy. In this case, it's necessary to apply rotating magnetic field to accomplish a tri-axis orientation of particles. However the superconducting magnet is too large to rotate. Therefore, in current studies, a container with particles which are dispersed in solvent is rotated in a static magnetic field to apply a rotating magnetic field (Fig. 1). However due to the rotation of container the unsteady flow of the solvent disturbs the orientation of the particles, and it might occur defects in materials.

Therefore, we have been researching the flow in the rotating container, and our previous study reported that the simulation of the behavior of fluid in the rotating container [1]. It is known that the velocity gradient of the solvent's flow is increased near the Ekman layer under unsteady state. In this study, we estimate the fluid's behavior of the two conditions that closed container and opened container (Fig. 2). We make a container which has the same dimensions as simulations, and moreover report the results of visualization experiment of the flow to verify the simulations.

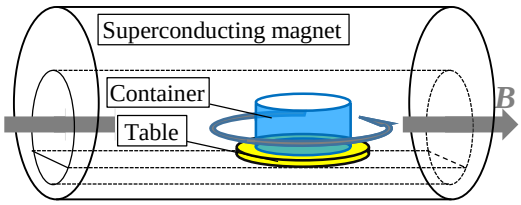

Fig. 1 Rotating container in superconducting magnet

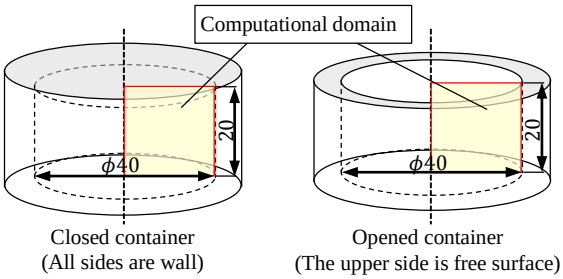

Fig. 2 Closed container and opened container

2. Simulation model

In this study, we consider the incompressible Newtonian fluid, further assume the axial symmetry flow using the cylindrical-coordinate system. We solve the continuity equation (Eq. (1)) and Navier-Stokes equation (Eq. (2)) by using the Marker-and-Cell (MAC) method [2] and three order upwind scheme for the nonlinear terms.

$$\nabla \cdot \boldsymbol{u}^* = 0 , \qquad (1)$$

$$\frac{\partial \boldsymbol{u}^*}{\partial t^*} + (\boldsymbol{u}^* \cdot \nabla)\boldsymbol{u}^* = -\nabla p^* + \frac{1}{Re}\nabla^2 \boldsymbol{u}^* , \qquad (2)$$

Here. $\boldsymbol{u}^* = (u_r^*,\ u_\theta^*,\ u_z^*)$ is the velocity vector, p^* is pressure, t^* is time. We define them by container's radius r_0, container's height h, angular velocity ω, viscosity η, density ρ, viscosity μ. We assume the flow field that the axial symmetry flow as shown in the Eq. (3). We assume the computational domain as the cross section of rotating container that has the axis of rotation on a side.

$$\frac{\partial \boldsymbol{u}^*}{\partial \theta} = \boldsymbol{0} , \quad \frac{\partial p^*}{\partial \theta} = 0 . \qquad (3)$$

In this study, we disregard particles. We assume the rotating container filled with solvent in zero-magnetic field.

3. Outlook

It is necessary that rotating magnetic field to accomplish tri-axis orientation, however, it is impossible to avoid occurrences of flow by the modulation rotation of container simultaneously. In addition, there is a possibility that the flow will inhibit the orientation of the particles. In this study, we observe the flow in the rotating container by simulations and experiments, for the purpose of the visualization of the flow. We also report the difference of fluid's behavior between the two conditions that closed container and opened container, address "Ekman layer's thickness", "the difference of the flow velocity between the wall surface and the container inside".

Reference

[1] M. Inoue, T. Ando, N. Hirota, The 62nd JSAP spring Meeting, Abstract, (2015) 14a-D11-5.
[2] F. H. Harlow, J. E. Welch: Physics of Fluids 8, 2182 (1965)