論　文　要　旨
Thesis Abstract

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主論文題名　（Title）

Experimental Investigation of Complex Behavior of Fluid Flow in a Rotating System Driven by Corotating Disks in Non-Axisymmetric Enclosure

内容の要旨　（Abstract）

This dissertation investigates the planar behaviour of a rotating flow driven by corotating disks, which are exhibited in systems like artificial hearts, turbo-machinery, astrophysics, and hard disk drives (HDDs). For HDDs, the flow must pass through the narrow spaces between the disks, the arm and shroud gap between the tip of the disk and the enclosure wall. In next-generation high-density HDDs, precise control of the actuator arm is essential to ensure position accuracy, head-disk reliability, and thermal stability. As the disk rotation speed increases and mechanical clearance decreases, complex three-dimensional structures and fluid shear occur within their enclosed casings. This becomes a critical engineering challenge. Moreover, as a result of geometric complexities and limitations of experimental access in real drives, the flow physics governing these interactions remains insufficiently understood.

The simplified model is 2.25 times the size of an HDD and features three arms, two disks, and three hubs. The flow was driven by a pair of corotating disks mounted in a shrouded enclosure with a partially open shroud. The geometry was deliberately simplified to maintain the dominant disk-driven and arm-induced flow physics based on the comparison of five commercial HDDs. Common geometry features like the actuator shroud opening, shape of the block were retained using averaged dimensions, while supplementary product-specific elements like spoilers, disk surface bypasses were excluded. The model was scaled to 2.25 to achieve the Reynolds number similarity at a lower rotational speed for improved experimental stability and measurement accuracy.

We experimentally studied the flow in the geometrically planar inter-disk region when obstructed by the arm. Two-dimensional velocity fields were measured in the inter-disk region at five planes parallel to the disk using particle image velocimetry (PIV), with respect to the arm varied at four different insertions in shallow and deeper configurations. The undistorted flow view is ensured by refractive index matching, clearing the negative effect at the optical observation. PIV was chosen for its ability to provide a non-intrusive in-plane velocity field measured over a wide spatial range, which enabled observation of a disk-driven flow and arm-induced effects in the inter-disk region.

The flow was observed to divide at a critical radius, between solid body rotation directed toward the hub and sheared flow developing toward the disk edge. In areas of solid-body rotation downstream of the arm, for the deeper insertions, it contracts while fully established. However, it spans a broader area for the shallow insertion but becomes fully established further downstream. Locally accelerated flows were observed in the constricted region between the hub and the arm, extending further downstream around the hub, with their magnitude matching and exceeding the local disk velocity due to the constricted arm-hub region for the deeper insertions and the inflow from the shroud opening region for the shallow insertions.

Upstream of the insertion, the flow decelerates toward the shroud opening, influenced by velocity gradients in both the radial and circumferential velocity components. The sudden expansion downstream of the arm–hub constriction induces adverse pressure gradients that cause flow separation and wake formation induced by the inserted arm. An indication of a secondary flow exists in the mid-plane upstream and downstream of the arm insertion as the flow moved inward in the hub direction, influenced by the cross-stream centrifugal flow in the inter-disk region. Midstream of the insertion, flow disturbances result from momentum exchange between the arm wake and the shroud opening. The flow exhibits different patterns in the inter-disk region upstream, midstream, and downstream of the obstruction, as well as the narrow channel between the hub and the arm, all of which are caused by geometric variations and the arm insertion, generating wakes and interacting with the inflow from the shroud opening.

Based on the above established flow physics, I characterized and presented an overview of the flow with respect to the inserted arm midstream. The overview can be utilized in disk-driven flow design, especially in HDDs, to understand the flow within the inter-disk region, which has an influence on the positioning accuracy of the actuator arm. The 3D flow structures, as well as the centrifugal cross-stream secondary circulations, radial momentum redistribution, and flow acceleration and deceleration induced by the arm geometry, can be predicted. This can enable the precise design of disk and arm configurations. For this reason, a controlled and predictable fluid motion that supports reliable head–disk interaction and overall drive performance can be ensured.

This study provides a physics-based framework for understanding arm-induced disturbances in disk-driven rotating flows. My findings suggest further technical improvements that can enhance HDD performance by optimizing the arm geometry-controlled shroud opening design, reducing the impact of secondary vortices, and suppressing the formation of wake in the arm-hub region. Taking these measures can

reduce the disturbances caused by the flow, enhance the position accuracy of the actuator arm, which will improve the reliability and stability of high-density HDDs.