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Numerical investigation of airflow inside an environmental chamber for HGA mechanical test and a scheme for improving the flow

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ABSTRACT

In this research, the computational fluid dynamics (CFD) was applied to simulate the airflow behavior around a head gimbal assembly (HGA) inside a hard disk drive (HDD) and the corresponding behavior inside an environmental chamber. In industrial HDD research laboratories; this type of chamber is officially used to create the desired controlled conditions for mechanical design verification test of HGA and its components. Comparison of the two simulation results showed that the airflow behavior around the HGA inside the environmental chamber was different to that inside the HDD. Therefore, an improvement scheme for conventional environmental chamber was devised and tested. Test results showed that this new scheme produced airflow pattern that agreed more closely with that in an HDD and can be used to improve the reliability of existing environmental chamber.

1. Introduction

In response to the steadily increasing demand of high-performance hard disk drive (HDD), data storage technology has also been developing rapidly. Over the past few years, the research and development in this field have focused on increasing areal density and read/write speed. HDD areal density is expected to approach 10 Tb/in^2 and its rotational speed to approach 20,000 rpm at the flying height less than 4.5 nm by 2015 (Shiroishi et al., 2009). Thailand is the country that produces the largest number of HDDs, exporting more than 40% of global HDDs worth more than US$12 billion annually. For this reason, Thailand's HDD laboratory has focused especially on the research and development (R&D) of manufacturing process while most R&D in USA and others have concentrated on other innovations in data storage technology. Generally, new HDD components are designed in USA and then transported to Thailand for mechanical design verification test for actual production. Therefore, a new HGA with a newly modified air bearing surface and/or a new slider shape must be tested for its positional accuracy, burnishing, load/unload damage, flying height, slider behavior, signal stability, etc. in order to prevent read/write failure and improve mechanical performance. Obviously, higher rotational speed can cause adverse airflow behavior leading to the HDD malfunctions. For example, airflow and air turbulence cause a structural vibration of the interior of HDD components such as actuator arm, head gimbal assembly (HGA) and slider (Sundaravadivelu et al., 2009). This type of vibration increases positional error and burnishes of magnetic head (Strom et al., 2004). Airflow behavior also varies depending on environmental conditions such as pressure, temperature and humidity (Zhou et al., 2010).

HDDs have been utilized in various environments, for example, on an airplane, on a mountain, in a forest, etc. These various environmental conditions are usually recreated in an environmental chamber called VENA. VENA is used, for instance, for testing the tribology of thin film and HDD components. In an HDD laboratory, VENA is used to create controlled environmental conditions such as pressure, temperature and humidity. Using an outside controller, VENA's spindle motor can spin a platter to a desired rotational speed. Hence, an HGA installed in VENA can be thoroughly tested under controlled conditions. For example, HGA's signal output and the efficiency of its design can be investigated. In fact, the actual layout of VENA is so similar to a completely closed system that pressure, velocity and temperature cannot be measured directly at all. Therefore, our research has focused on using computational fluid dynamics (CFD) software to simulate the airflow pattern in VENA subjected to set conditions.

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From literature review, we found that Fluent provides a comprehensive suite of computational fluid dynamics simulation. It was suitable for our simulation of airflow inside HDD because it has extensive physical modeling capabilities needed to model flow, turbulence and heat transfer for industrial applications. In Fluent, a k- ε model is a common fluid turbulence model that has been widely applied for engineering simulation of fluid flows. (Liu et al., 2011) employed a k- ε turbulence model in an investigation of trajectories of spherical and tetrahedral particles in 3.5 inch HDD. In another study, the effects on a filter's trapping efficiency of the position where particles were released, particle size, and particle density were investigated (Liu et al., 2013). For dual platter HDD, RNG k-ε model and Large Eddy Simulation (LES) models were used to investigate the flow induced vibration (FIV) (Ng et al., 2011). As an example of research on HDD manufacturing process, a standard k-ε turbulence model was used to study heat transfer and flow characteristics in an HDD tester (Naphon et al., 2009). Also, Park (Park et al., 2013) investigated the dynamic characteristics of a cold-rolled steel-plate stamped base for a 2.5 inch HDD. All of these studies reported high velocity difference and complex air turbulence in an area between two platters and around the HGA region. A k-ε turbulence model has 2 main weaknesses when applied to a practical situation. First, it over-predicts shear stress in adverse pressure gradient flow because the length scale is too large. And second, it requires a near-wall modification. However, these weaknesses have been overcome by the transition shear stress transport (transition SST), a combination between k-ε and k-ω turbulence models (Menter, 2009). Recently, we successfully employed the transition SST to simulate airflow inside a welding automation machine of HDD production line which can be applied to reduce particle contamination in HDD manufacturing process (Thongsri and Pimsarn, 2015).

As described above, this research aimed to apply the computer aided design (CAD) and the computer aided engineering (CAE) software to improve VENA's reliability and applicability in HDD manufacturing process. The transition SST turbulence model in fluent software was employed to simulate the airflow behavior inside both a VENA chamber and a 3.5 inch HDD whose platter is rotating at 15,000 rpm. The simulation results were compared and analyzed, leading to suggestions for a more reliable VENA model.

2. Theoretical background

2.1. Conservation equation

The three basic equations of fluid flow in Fluent, one of the robust turbulence models in computational fluid dynamics (CFD) software, are conservation of: mass (1), momentum (2) and energy equations (3), which can be expressed by (Fluent, 2012).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}_r) = 0, \quad (1)$$

$$\frac{\partial (\rho \boldsymbol{v}_r)}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}_r \boldsymbol{v}_r) + \rho(2\boldsymbol{\omega} \times \boldsymbol{v}_r + \boldsymbol{\omega} \times \boldsymbol{\omega} \times \boldsymbol{r} + \boldsymbol{\alpha} \times \boldsymbol{r} + \boldsymbol{a}) = -\nabla p + \nabla \cdot (\boldsymbol{\tau}_r) + \boldsymbol{F}, \quad (2)$$

$$\frac{\partial (\rho E_r)}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}_r H_r) = \nabla \cdot (k \nabla T + \boldsymbol{\tau}_r \cdot \boldsymbol{v}_r) + S_h \quad (3)$$

where $\boldsymbol{\alpha} = d\boldsymbol{\omega}/dt$ and $\boldsymbol{a} = d\boldsymbol{v}/dt$. ρ is the fluid density, t is time and ω is the angular velocity relative to a stationary frame. r is the position vector, $\boldsymbol{v}_r$ is velocity in rotating frame, H_r is relative total enthalpy, and E_r is relative internal energy. $\boldsymbol{\tau}_r$ is the viscous stress and S_h is a source term.

2.2. Turbulence equations

The turbulent flow field is obtained by solving the turbulence equations of the transition shear stress transport turbulence model. This model developed by Menter (2009) has efficiently merged the robust and accurate formulation of the model in the near-wall region from the k-ω turbulence model and of the free-stream independence from the k-ε in the far field. This model is more accurate than the (original) SST (Fluent, 2012) by improving the formulation of transport equations for the intermittency and the momentum thickness Reynolds number. The turbulence equations of the transition SST include four transport equations to represent the turbulent properties of the flow. There equations are transport equations for the turbulence kinetic energy (k), specific dissipation rate (ω), the intermittency (γ) and the transition momentum thickness Reynolds number ($\tilde{Re}_{\theta t}$). The governing equation of transport equations for the turbulence kinetic energy (k) and for the specific dissipation rate (ω) are given by

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{x_j}\left(\Gamma_k \frac{\partial k}{\partial x_j}\right) + G_k^* - Y_k^* + S_k, \quad (4)$$

$$\frac{\partial(\rho \omega)}{\partial t} + \frac{\partial(\rho \omega u_j)}{\partial x_j} = \frac{\partial}{x_j}\left(\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right) + G_\omega - Y_\omega + D_\omega + S_\omega, \quad (5)$$

where u is the fluid velocity. Γ, G and Y represent the effective diffusivity, the production and the dissipation, respectively. S is a user-defined source term. The superscript * is a modified term of k, which is defined specifically for the transition SST. However, the remaining two transport equations, the complete formulae of the intermittency (γ) and the transition momentum thickness Reynolds number ($\tilde{Re}_{\theta t}$) are not shown in this article but can be found from reference (Fluent, 2012).

In this research, fluent software in ANSYS was applied to simulate the airflow. Fluent solvers are based on the finite volume method (FVM).

3. Methodology

3.1. VENA model

In this research, a VENA currently available in an HDD laboratory was used. It was installed with a 3.5 inch single HDD platter. Fig. 1 shows (a) a solid model and (b) a simplified fluid model with electrical circuits and several inconsequential components removed. Fig. 2 shows a schematic diagram of the

VENA, in which an HGA was placed at the middle diameter (MD) position.

Using the simplified fluid model, the mesh model of VENA was created by meshing software in ANSYS 14.5. Fine meshes were created especially around the HGA regions in order to capture more accurate airflow behavior. To achieve mesh independence, several mesh models were generated. The total number of elements in each model was in the range of 6.2-8.3 million, adjusted by varying the fine mesh size of the area near the HGA. In the mesh independent analysis, it was found that the mesh model of 6.4 million elements was optimal because the difference between the air velocity obtained from this mesh model and that of the finest mesh model was only about 2%. Fig. 3 shows the mesh model of 6.4 million elements using in this simulation for (a) overview and (b) zoomed in around the HGA regions.

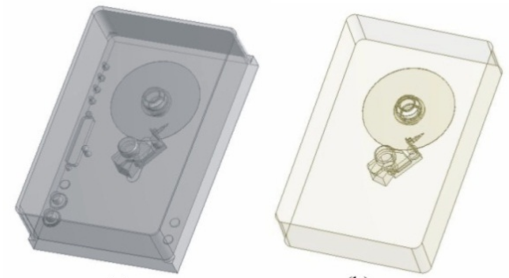

Fig. 1: VENA chamber (a) a solid model and (b) a simplified fluid model

Fig. 4 shows (a) a solid model and (b) a simplified fluid model. The locations of the HGA in VENA and in HDD were identical. Fig. 5 shows a schematic diagram of HHD. Similar to the procedure of mesh-independence analysis done on VENA, mesh size of the area near the HGA was varied. The total number of elements in each of several models was in the range of 5.4-6.1 million. We found that the mesh model with 5.9 million elements suitable because it had satisfied the mesh independence requirement.

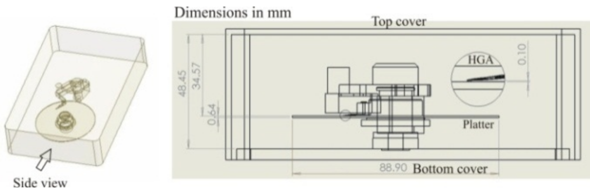

Fig. 2: A schematic diagram of VENA.

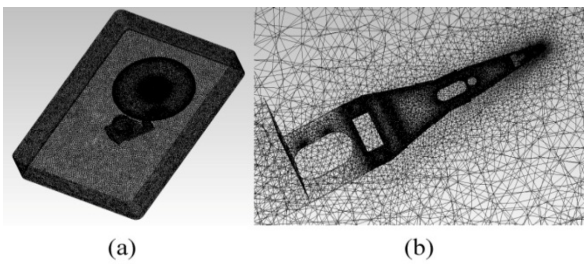

Fig. 3: Mesh elements of VENA (a) in an overview and (b) around an HGA

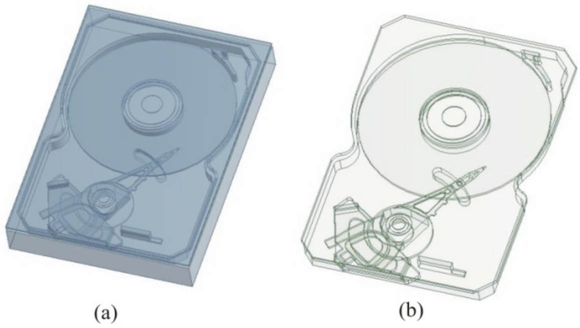

Fig. 4: HDD (a) a solid model and (b) a simplified fluid model

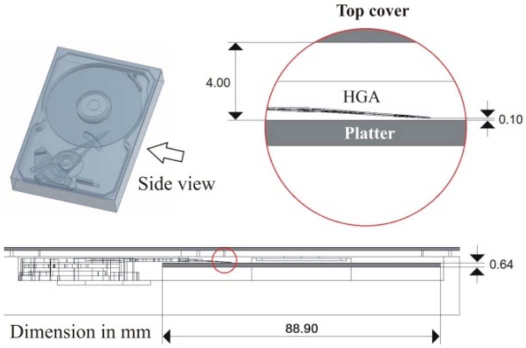

Fig. 5: A schematic diagram of HDD

3.2. Modified VENA model

In our preliminary comparison between the VENA chamber and the HDD model, we found that there was more space between the platter and the top cover of VENA than that of the HDD. This might result in very different airflow pattern between them. To make the airflow of the VENA model resemble that of the HDD better, CAD was used to modify it into a new model. This new model corresponding to industrial requirement was suggested. In modified model, a pseudo cover, covering 4 mm space over the platter was installed. This volume of space was the same as that measured in the HDD. Fig. 6 shows a modified VENA model for (a) a solid model and (b) a simplified fluid model. Fig. 7 shows a schematic diagram of modified VENA. To achieve a mesh independent model, several mesh models were generated, each with the total number of elements in the range of 4.1-8.1 million. It was found that the total element of 6.3 million was mesh independent.

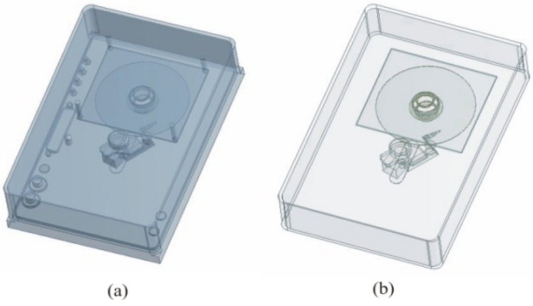

Fig. 6: HDD (a) a solid model and (b) a simplified fluid model

3.3. Fluent setup

In Fluent setup, the pressure-velocity coupling was set to couple at a rotational speed of 15,000 rpm. The spatial discretization of pressure, momentum, turbulent kinetic energy and turbulent dissipation rate was set to be second order upwind. The ambient condition for the steady state solver module was set to be at a pressure of 98,380 Pa and a temperature of 308 K. Using the settings above, a steady state solution was computed with absolute convergence criterion of 10^{-6}.

4. Results and discussion

For the three mesh independent models of VENA, HDD and modified VENA, all installed with an HGA of the same shape, size and position, Fig. 8 shows, respectively, their velocity vectors in a vertical plane normal to the HGA surface. The HGAs of all models were placed in the MD position. A comparison between the results from VENA and HDD in Figs. 8 (a) and (b) revealed that the overall airflow behavior inside VENA was markedly different to that inside HDD. This agrees with our previous assumption mentioned that there was more space between the top cover of VENA and its platter than the space in HDD. As can be seen in Fig. 8 (b), airflow generated by the rotating platter could move upward freely away from the platter. In contrast, the upward airflow in HDD was blocked by its top cover. Fig. 8 (c) illustrated that the pseudo cover provided a more resemblance airflow behavior to that of the HDD.

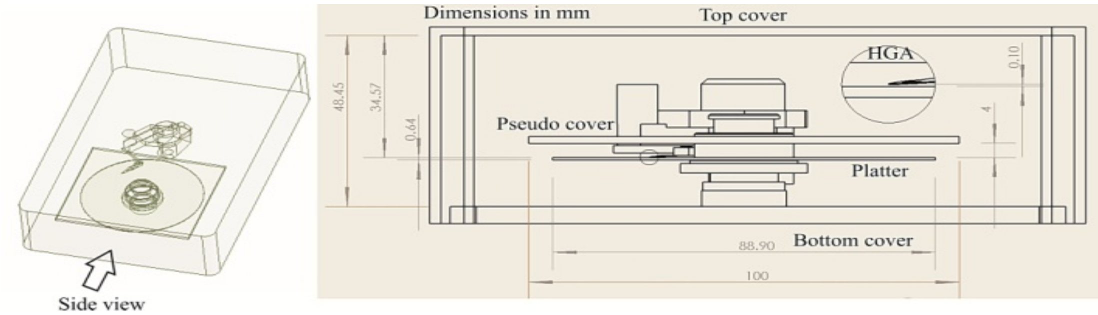

Fig. 7: A schematic diagram of modified VENA.

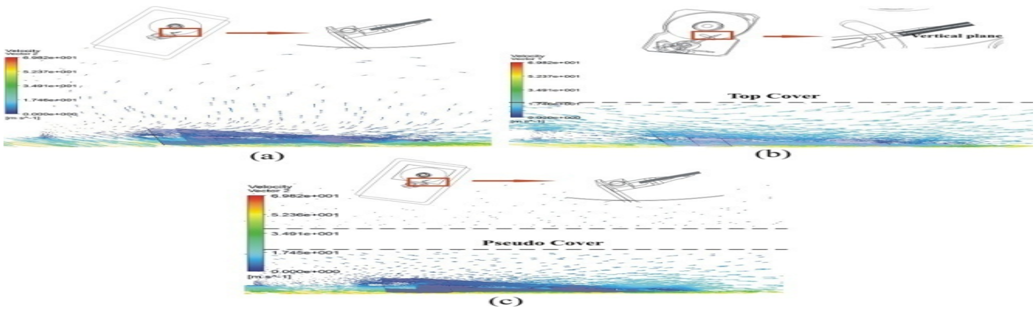

Fig. 8: Velocity vectors in a vertical plane normal to the HGA of (a) VENA (b) HDD and (c) modified VENA

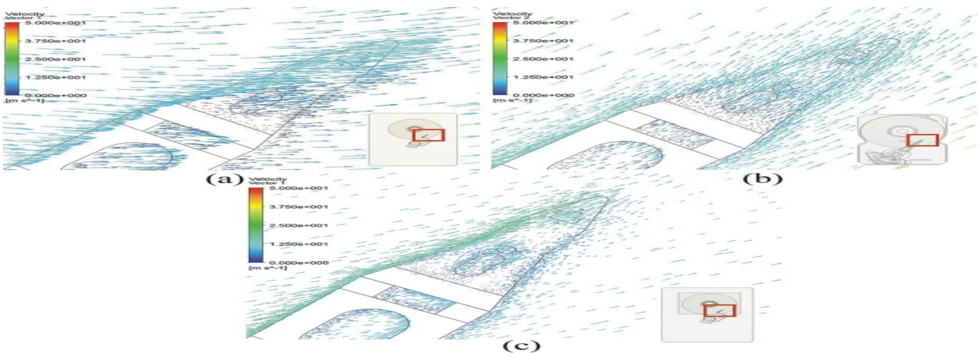

Fig. 9: Velocity vectors in a horizontal plane tangent to the HGAs of (a) VENA (b) HDD and (c) modified VENA

Similarly, Fig. 9 reports velocity vectors in a horizontal plane tangent to the HGA surface at a distance of 0.55 mm above the platter for (a) VENA, (b) HDD and (c) modified VENA. A comparison between Figs. 9 (a) and (b) shows that the overall air velocity vectors in VENA was distinctly different to that in HDD. In VENA, air could flow freely over and away from the HGA surface, unlike in HDD. This confirms that the airflow inside VENA is not comparable to that of HDD. As can be seen in Fig 9 (c), a pseudo cover was able to change the directions of airflow in VENA to resemble those in HDD more closely.

To verify the results of our simulation, we determined whether the air velocities in VENA increased when a pseudo cover was installed or not. Fig. 10 shows graphs of air velocity versus position along a given line1 projected onto the x-axis in

VENA, HDD, and modified VENA. This line is in a vertical plane that is normal to the HGA surface as depicted in Fig. 8. A comparison of these 3 graphs reveals that air velocities really increased at every position along a given line in the modified VENA. Similarly, Fig. 11 shows the same types of graphs but along a given line2. This line is in a same horizontal plane as described in Fig. 9, tangent to the HGA surface. This result confirmed that a pseudo cover can really increase air velocities in the modified VENA; a piece of confirming indirect evidences the center.

The investigation into the airflow behavior in this study is only preliminary. This work is to address only critical issues on the VENA in order to allow its operation as soon as possible to satisfy urgent demands of HGA testing. More in depth investigations of other factors such as drag force, lift force, flow induced vibration, etc. that affect the HGA should be performed to further confirm the conclusion of this study and further improve the model. All of the data in this paper had been suggested to an industrial HDD research laboratory as essential input for improving their existing VENA to better recreate the airflow inside an actual HDD. In our near future work, we will work on a new design of pseudo cover that can function even better than our preliminary design here.

5. Conclusion

VENA is an environmental chamber that creates pressure, temperature and humidity applicable for an HGA fly test in an HDD laboratory. In this study, a transition shear stress transport (transition SST) turbulence model was used to simulate the airflow inside VENA and inside a hard disk drive (HDD). A comparison between both results revealed that these two airflow patterns were not comparable, neither in the tangent plane nor in the normal plane to the HGA surface. The differences were due to the bigger space between the top cover of VENA and its platter than the space between the top cover of the HDD and its platter. Therefore, a modified VENA model was proposed. This model proved to provide much closer airflow behavior to the behavior inside an HDD.

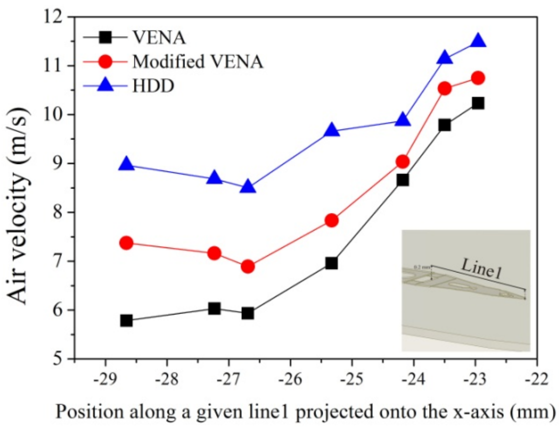

Fig. 10: Air velocity versus position along a given line1 projected onto the x-axis

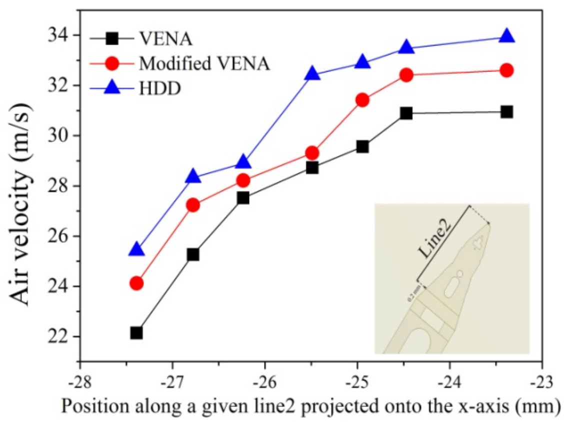

Fig. 11: Air velocity versus position along a given line1 projected onto the x-axis

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