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Using CFD to find the best placement of HDD production machinery for major renovation of factory clean room

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Abstract

HDD production needs to be done in a clean room that keeps particulate contamination to the minimum. In planning a renovation of a clean room in an HDD factory in Thailand, a question came up whether to put components of HDD production machinery on raised platforms or keep them on the floor level in order to better minimize contamination. This study was conducted to find the answer using computational fluid dynamics (CFD) simulation software, Ansys Fluent, combined with the real ventilation conditions planned for the clean zone. The simulated results showed that keeping the machinery in the same level with the floor is more effective.

Keywords: Computational fluid dynamics, CFD, Clean room, Airflow, Particle contamination

1. Introduction

Minute airborne particles lodging on small hard disk drive parts can render a hard disk drive (HDD) unusable. Therefore, HDDs need to be manufactured in a clean room that complies to US FED STD 209E standard [1], such as clean room class 1000 that is most widely used in HDD production industry. Clean room class 1000 allows not more than 1000 of 0.5 micron particles in one cubic foot of air. Although this class of clean room guarantees low particulate contamination in the room, in general, additional measures need to be taken to ensure that clean zones in the room are as free of contaminated particles as possible.

This study was born out of a collaboration between the authors and the researchers at an HDD factory in Thailand in an effort to plan out a major renovation of its clean room for it to be as effective as possible. Originally, the class 1000 clean room was built to the standard of its day and has been operating effectively. However, as time passed and more and more new machines were introduced into the room, the level of particulate contamination became higher, so a major renovation of the ventilation system was needed, not only for taking care of the immediate problem but also for supporting the operation of even more modern machines that would be introduced later.

To have an idea of what kind of air flow pattern and level of contamination in the to-be-renovated clean room would be, the computational fluid dynamics (CFD) simulation was employed. CFD can be used to simulate airflow in a clean room under conditions and with parameters that imitate those of the to-be-renovated room, such as its room plan, machine location, and ventilation system and operation parameters. To date, CFD has been widely applied to numerous problems and in many research studies. For example, CFD was successfully applied to reduce particulate contamination during production in clean rooms [2-3]. Lui et al.[4] used CFD to investigate the effects of medial lamp and thermal plume on the airflow in a medical operating room and were able to apply the results to reduce the number of infection incidents. Recently, authors, Thongsri and Pimsarn [5-6] has used CFD to simulate the air flow and particle trace over and around a piece of HDD machinery in an HDD factory in order to determine the best airflow setup later adopted by the factory.

Encouraged by the above successes, this study used CFD to simulate the airflow in a clean room in an HDD factory under conditions and with parameters that imitate those of the room in order to find the answers to the following questions: “Does it make any difference to the airflow if pieces of machinery are put on a raised platform versus if they are kept level with the ground? If so, how are the differences?” and “What are the most effective setup conditions and parameters of the ventilation system to minimize particulate contamination?”

2. Materials and methods

Mathematically, airflow pattern can be determined by a system of differential equations–conservation equations and turbulence equations [7]–while particle trace can be

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Table 1 Air outlet conditions and parameters

Outlet	Size (^{2}m)	Numbers	Percentage of total outflow (%)		
			Condition 1	Condition 2	Condition 3
Return air grille	1.2x0.6	18	45	43	39
Return air shaft, back side	1.1x0.4	12	18	16	14
Return air shaft, L1 and L2	1.1x0.4	2	8(6)	6(4)	5(3)
Return air shaft, R1 and R2	1.1x0.4	2	8(7)	6(5)	5(4)
Outflow Openings, L and R	40x3	2	2(2)	6(6)	8(8)
Outflow Opening, Center	20.4x3	1	4	8	14

determined by the following particle force balance equation [8],

$$du_p/dt = F_d(u_g - u_p) + g(\rho_p - \rho_g)/\rho_p + F_s \quad (1)$$

where p and g represent particle and fluid, respectively, F_d is drag force acting on the particle, F_s is another external force such as the Saffman lift force, and $\rho_p \gg \rho_g$ so only Saffman lift force is significant. u is velocity.

Inlet and outlet airflow conditions are according to a mass flow rate equation,

$$\text{mass flow rate (kg/s)} = \rho A v \quad (2)$$

where A is cross-sectional area that air flows through and v is velocity perpendicular to that area.

For particle trace investigation, we modeled the simulated particles as a stainless steel particle, the kind of particle most often found in the factory, whose diameter and density were 0.5 μm (which was considered very small) and 8,000 kg/m^3 (which was many folds higher than the density of air of 1.225 kg/m^3), respectively.

Airflow simulation was one-way, done with FLUENT 16.0 software. A shear stress transport turbulent model widely used in the industry [9] was used with mass flow rates and air outflow conditions that reflect the actual measured values obtained on site. After airflow simulation was completed, traces of particles simulated by a discrete phase model and released from selected places were determined. The simulation results were expected to be reliable and able to address the research questions adequately.

3. Methodology

We constructed a basic model of airflow in a clean room with conditions and parameters that imitated those of the real clean room in the HDD factory. Then, we constructed a fluid model out of it, shown in Figure 1, that included rectangular boxes representing pieces of machinery which were either raised on a platform 10 cm above the ground or kept level with the ground as well as locations of ventilation inlets from fan filter units (FFUs) and ultra-low particulate air (ULPA) filter and outlets to return air shafts and grilles. In addition, air could leak out from 3 sides of the clean zone to 3 neighboring zones. We called these sides 'outflow openings'.

3.1 Mesh model

Out of the fluid model shown in Figure 1, we constructed 6 mesh models with different numbers of tetrahedron elements (5.94-9.06 millions) and nodes (1. 14- 1. 68 millions). All of these mesh models were put through a mesh analysis and it was found that the mesh model, shown in Figure 2 that was constructed with 8.07 million elements and 1.42 million nodes was the best model in terms of the quality of the results and computation time.

3.2 Fluent settings

Fluent software was set up with certain mass flow rates and air inlet and outlet conditions and parameters listed in Table 1 and 2. Three air outlet conditions were investigated in order to find one that yielded the best airflow.

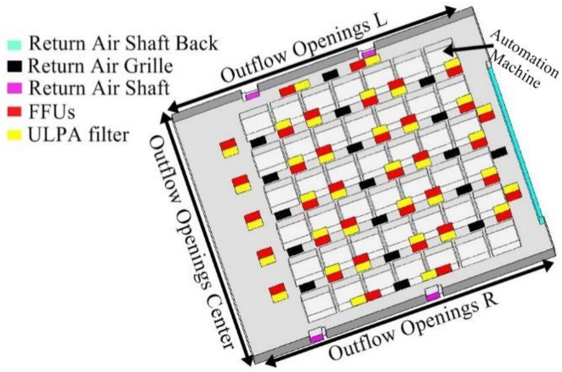

Figure 1 A model of the clean zone

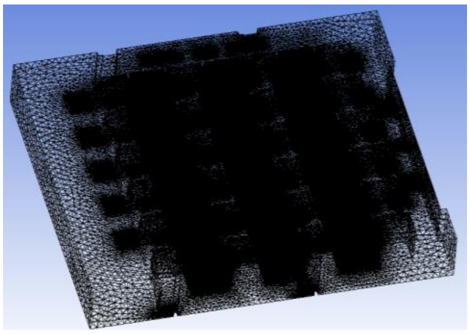

Figure 2 Mesh model

Table 2 Air inlet conditions and parameters

Inlet	Size (^{2}m)	Numbers	Temperature (℃)	Mass Flow Rate (kg/s)
FFUs	1.2x0.6	36	13	9.84
ULPA Filter	1.2x0.6	36	20.5	11.43

Other settings included 'coupling' for pressure-velocity option and 'second order upwind' for momentum, turbulence kinetic energy, and turbulence dissipation options, and 'steady state' for simulation option. The total number of iterations was set to 1000.

4. Validation

We validated the reliability of our model by comparing theoretical results of outflow air velocities at the return shafts according to Eq. (2) with simulation results under Condition 2 in Table 2. The comparison results are shown in Table 3.

Table 3 Comparison of outflow air velocities at return shafts between values obtained from theoretical calculation versus simulation

Shaft	Velocity (m/s)		Error
	Theoretical	Simulated	
Return shaft L1	2.40	2.48	3.33%
Return Shaft L2	1.58	1.62	2.53%
Return Shaft R1	2.40	2.47	2.92%
Return Shaft R2	1.97	2.02	2.54%

It can be seen there that the maximum discrepancy was only 3.33%. Moreover, the simulated airflow patterns from the FFUs and ULPA filter into the clean zone, over the pieces of machinery, and out of the zone through the return air shafts, grilles, and outflow openings were in agreement with the actual patterns observed on site. All of these suggested that our simulation results would be reliable.

5. Results and discussion

Regarding the answer to our first research question, the simulation results in Figure 3 showed that keeping the pieces of machinery on the same level with the floor is better than putting them on a raised platform because strong vortices formed around the machines and beneath the platform at the 7-cm high XY-plane as well as at 3 and 9-cm XY-planes but at lower air velocities. These kinds of vortices were not formed at all around machines that are kept on the same level with the floor.

Regarding the investigation of the amount of unpurged particles from the clean zone, we simulated releases of 6,000 stainless steel particles from pieces of machinery located in 3 areas–Area 1: the back of the clean zone, Area 2: the middle of the zone, and Area 3: the front of the zone. The simulation was done in one area at a time, and the illustrated results are shown in Figure 4.

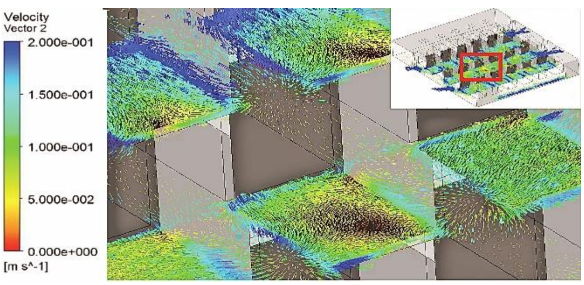

Figure 3 Air velocity vectors beneath raised platforms

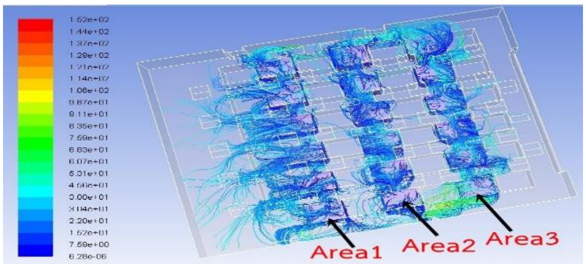

Figure 4 Traces of released particles

The trace of each particle in Figure 4 is color-coded according to its residence time in the clean zone. It can be seen that most of the particles in every area got purged out quickly through the return air shafts and grilles. Only a few stayed for a longer time which might be due to vortices and/or insufficient air velocities. To confirm these results, we repeated the simulation 50 times for each area with 150,000 released particles and counted the number of unpurged particles. The counts are shown in Figure 5.

Like the previous results, these results showed that most of the released particles got purged. Only fewer than 420 particles did not get purged. Moreover, they showed that the number of unpurged particles for the case of keeping the pieces of machinery on the same level with the floor was fewer than those for the case of putting the pieces of machinery on raised platforms. When we reported this finding to the researchers at the HDD factory, they were very pleased because not only can they have a fewer number of unpurged particle but they can also save a lot of investment money on expensive vibration stands for raised platforms.

Regarding the best air flow condition for minimizing contamination among the three listed in Table 2 (for the case of keeping the pieces of machinery on the same level with the floor), a particle trace simulation was done with each condition, and the numbers of unpurged particle counts under all of the conditions were obtained, shown in Figure 6.

It was found that the numbers of unpurged particles in the three areas varied, most likely due to the differences in relative locations of the return air shafts and grilles to each of the areas, but on average, Condition 3 yielded the fewest number of unpurged particles. This finding was also welcomed by the researchers at the factory because it agreed with a result of an empirical test that they had conducted.

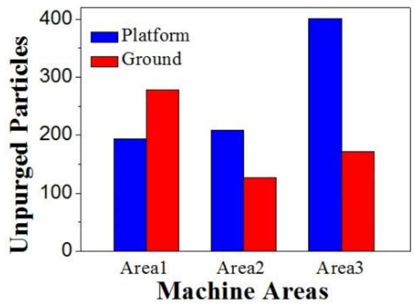

Figure 5 Numbers of unpurged particles

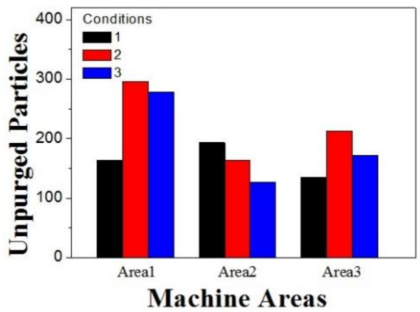

Figure 6 Numbers of unpurged particles under conditions 1-3

6. Conclusion

In this study, CFD was used to simulate airflow in a clean room in an HDD factory in order to find the best placement for HDD production machinery and the best air ventilation system's setup conditions and parameters for minimizing particulate contamination. The simulation results showed that placing pieces of machinery on the same level with the floor is better than placing them on raised platforms. Condition 3 is the most effective setup conditions to minimize particulate contamination.

7. Acknowledgements

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