

Airflow and Temperature Simulation in a Big Cleanroom to Reduce Contamination in an HDD Manufacturing Factory

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Abstract. Contamination is an important factor that must be well controlled at a stringent level of cleanliness. If it exceeds factory's specifications it shall contribute to poor quality products and product loss in the hard disk drive (HDD) manufacturing factory. This research used a CFD software, FLUENT to simulate the airflow pattern and temperature distribution in a big clean room to find the cause(s) of high contamination. The results of simulation revealed that there are areas in the production with vortex flow which caused high contamination similar to the actual measurement in that clean room. High air velocity that came out of the ULPA Filter at the ceiling above collided at the front of one Return grill nearby. It also caused high velocity vortex and high contamination in that area. To reduce the contamination, we closed one of the Return Grilled near that problematic area which could help reduce the vortex flow and the airflow pattern to be smoother than the previous clean room. Also, the contamination result showed a significant reduction in particle count. The temperature distribution after improvement action taken was unaffected and remained under the control. This research can help enhance a product quality and improve an efficacy of HDD manufacturing process

1. Introduction

Currently, all electronic devices or components are very small sized built in manufacturing in many industries. Small components need to be environmentally controlled in the production line, especially in the clean room area where the levels of cleanliness, temperature, and humidity must be controlled to ensure good quality for products in factory. Contamination is the one of factors controlled in the clean room in order to ensure the quality of the products to be up to the specifications and good per spec requirement. The experiment to study some complex of building and structure for understanding the whole production line is difficult. Therefore the one method that has been currently and successfully used is the Computational fluid dynamics (CFD) which is the method to simulate and validate our model easily. Many researches such as K. C.Noh et al. [1] successfully used CFD analysis based on particle concentration measurement and airflow by the study was carried out to look for the source of contamination and examine the route of contaminant transfer in the mini-environment applied in the LCD process clean room to improve results. J. Thongsri et al. [2-3] used CFD to simulate airflow and particle trace over and around a piece of hard disk drive (HDD) machine in factory to find the best airflow setup which was later deployed to the manufacturing process. The cause of the high particle counts was improper air-speed from the FFUs. Air speed was optimized to be in the suitable range which the airflow would block out nearby airborne particles and purge away particles generated by the



machine effectively. The temperature is the one factor studied to control the clean room such as J. Thongsri [4] used CFD to study the condensation in the factory which the recommendation from the study can be used in the factory to help save costs in the factory as well. CFD was also applied to the medical field such as in hospital rooms to reduce contamination in an operating room and to optimize rooms for efficient ventilation, as opening and closing doors can transfer contamination into other rooms in a hospital [5-7]. CFD is a fluid mechanics software that uses numerical analysis and algorithms to solve problems that involve fluid flows and display the solution data in colour graphics which makes it easy to analyse the model. The advantages of using CFD mainly are less time consumption and cost saving compared to conventional experimental methods that may be difficult to perform. Still, the accuracy of the results may be questionable. This research study HDD Manufacturing AAB clean room at Seagate Technology, Thailand (Korat plant), which manufactured HDD reader head. This paper studied the airflow pattern and temperature distribution in the big clean room which is scheduled for an environment big cleaning day every year. The environment will change after the big clean due to changes in the inlet and outlet. The scope of this study covers airflow pattern, temperature distribution and particle count by using experiment and ANSYS FLUENT. The purpose is to find the way to reduce contamination based on the experimental results. This research is different from the other research mentioned above as we consider the temperature of this clean room by using standard $k-\varepsilon$.

2. Theoretical

ANSYS Fluent [8] was used in this study by solving conservation equations that consist of mass, momentum and energy conservations, the equation for conservation of mass, or continuity equation, which can be written as follows,

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0. \quad (1)$$

The momentum and energy conservations can be written in (2) and (3)

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial P_i}{\partial x_i} + \mu \frac{\partial}{\partial x_j} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \rho g_i, \quad (2)$$

$$\frac{\partial (peT)}{\partial t} + \frac{\partial}{\partial x_j}(peT u_j) = pq + \frac{\partial}{\partial x_j} \left(k \frac{\partial T}{\partial x_j} \right) - \frac{\partial (p u_j)}{\partial x_j} + \frac{\partial (\tau_{ij} u_i)}{\partial x_j} + pg_i \quad (3)$$

This study selected a standard $k-\varepsilon$ model [9] which is a model based on model transport equations of turbulence kinetic energy (k) and dissipation rate (ε). The model transport equation for k derived from the exact equation, while the model transport equation for ε derived from physical reasoning and bears little resemblance to its exact mathematical counterpart. The standard $k-\varepsilon$ model in ANSYS FLUENT falls within this class of models and has become the workhorse of practical engineering flow calculations in the time proposed by Launder and Spalding [9]. The equations of turbulence kinetic energy (k) and dissipation rate (ε) are written as follows,

$$\frac{\partial (\rho k)}{\partial x_j} + \frac{\partial (\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] G_k - \rho \varepsilon, \quad (4)$$

$$\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{\varepsilon 1} \frac{\varepsilon}{k} G_k - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k}, \quad (5)$$

where $G_k = -\overline{\rho u'_i u'_j} \frac{\partial u_j}{\partial x_i}$, represents the generation of turbulence kinetic energy due to the mean velocity gradients. The model constants have been established to ensure that the model performs well for certain canonical flows. The model constants are;

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}, \quad C_\mu = 0.09, C_{\varepsilon 1} = 1.44, C_{\varepsilon 2} = 1.92, \sigma_k = 1.0, \sigma_\varepsilon = 1.33$$

ANSYS FLUENT solved a set of partial differential equations of (1) - (5) to determine the airflow pattern, temperature distribution and shown in graphic colour.

3. Research Method

3.1. Model Description

Our research studied the clean room where the reader heads of hard disk drives are manufactured. The clean room is classified to be class 6 with particles of size $0.3 \mu\text{m} < 102,000 \text{ part/m}^3$ and particles of size $0.5 \mu\text{m} < 35,200 \text{ part/m}^3$ [10]. When particle counts exceeded the specification, or we called “Contamination out of control limit”. The product quality would be poor or rejected. The level of cleanliness or contamination must be controlled in this clean room. Every year the factory will have a technical wipe down activity. The environment will be changed after the startup of the production line. The reason why we selected this clean room to study is to reduce or control contamination to be in the control level. Another purpose is to study the clean room whether it can be reused after an environmental change. The clean room layout shows in Fig.1. The environment was in operation during measuring all parameters such as air flow, pressure, temperature and particle count. The dimensions of this clean room were $26.81 \text{ m (L)} \times 27.1 \text{ m (W)} \times 3 \text{ m (H)}$. There are 3 smaller “service rooms” inside the clean room which machine engines are stored. The air inside the clean room will flow out to these service rooms. On the top of clean room wall, there are 25 return grilles and on the ceiling are 55 ULPA Filters with the size of $0.6 \text{ m} \times 1.21 \text{ m}$. Outlets are Return grilled and the panel on the wall. Inlets are ULPA filters. These inlet and outlet are filled in the fluid model with different colour. We constructed models with different numbers of tetrahedron elements and nodes. All of these mesh models were put through a mesh analysis, and it was found that the mesh model was constructed with 10.36 million elements and 1.95 million nodes were the best model in terms of the quality of the results and computation time.

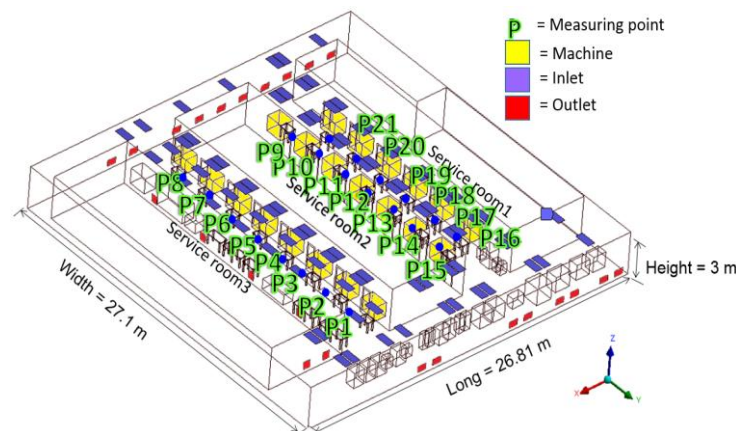


Figure 1. Clean room layout

3.2. ANSYS FLUENT Settings

There are 55 inlets (ULPA Filters) that are mass flow inlets of which boundary conditions around 0.1-1.4 kg/s and 47 outlets of which boundary conditions are 0.24% - 5.51%. All air velocity measurements are done with an airflow meter under actual operating conditions. The inlet velocities are measured under the ULPA filters at the center of each filter, and the outlet velocities are measured at the center of the return grille and the measuring time at each position is at least 10 s. Approximately 10 measurements are averaged at each point. The flow in the cleanroom is assumed to be steady. The standard $k-\varepsilon$ transport equations of turbulence model are used for the simulation. Fluent settings are as shown in Table 1.

Table 1. Fluent settings.

Parameters	Settings	Parameters	Settings
Solver	Pressure based	Algorithm	Pseudo Transient
Velocity Formulation	Absolute	Solution Initialization	Hybrid Initialization
Time	Steady	Convergence Criterion	1.00E-06
Model	k-epsilon	Thermal	On
Pressure-Velocity Coupling	Coupled	Energy	On

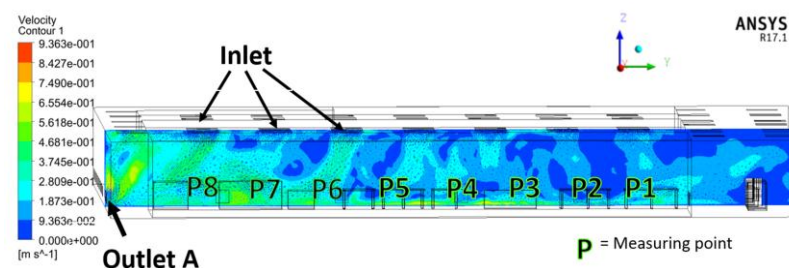
4. Result and Discussion

To verify the model and results of simulation, we measured the air velocity in the points P1-P21 shown in Fig. 1 which are compared with the results of simulation. We selected air velocities points in the area where the production parts are placed to verify the model whether similar with the real environment compared with CFD simulation. During the measurements, the operators and the machine were operating normally in the clean room. The air flow meter was activated for 1 minute for each measuring point. The positions along the x-axis of P1~P8 was X=17.45 m, of P9~P15 was X=8.49 m, and of P16~P21 was X=7.50 m. The height Z from the ground to the point where the airflow velocity was measured was 0.82 m for each point. The comparison result shows that the percentage error (%) of every point was less than 15% as Table 2. We concluded that our model from CFD was able to accurately reproduce the air velocities in the clean room

Table 2. shows the velocities of airflow at P1~P21.[11]

Machine Zone 1 X= 17.45 m					Machine Zone 2 X= 8.49 m					Machine Zone 3 X= 7.5 m				
Point	Y (m)	velocity (m/s)		% Error	Point	Y (m)	velocity (m/s)		% Error	Point	Y (m)	velocity (m/s)		% Error
		Experiment	CFD				Experiment	CFD				Experiment	CFD	
P1	21.3	0.219	0.206	5.89	P9	4.8	0.078	0.071	8.54	P16	19.0	0.085	0.079	6.18
P2	18.7	0.068	0.061	10.87	P10	7.3	0.089	0.081	6.31	P17	16.3	0.071	0.070	1.39
P3	16.2	0.134	0.143	7.03	P11	9.9	0.075	0.066	10.99	P18	13.8	0.091	0.090	8.45
P4	13.6	0.131	0.144	9.88	P12	12.5	0.067	0.060	9.66	P19	11.2	0.258	0.233	8.02
P5	11.1	0.030	0.029	5.19	P13	15.0	0.060	0.055	6.32	P20	8.7	0.100	0.088	11.30
P6	8.4	0.248	0.278	12.09	P14	16.9	0.064	0.060	5.55	P21	6.2	0.091	0.100	9.37
P7	5.8	0.338	0.344	1.78	P15	19.5	0.076	0.066	13.14					
P8	3.3	0.265	0.231	12.97										

We considered the graphic contour of velocities along the x-axis of P1~P8 was Plan X=17.45 m, of P9~P15 was Plane X=8.49 m, and of P16~P21 was Plan X=7.50 m where the production parts were placed and observed Plan X=17.45 m had higher velocity than other plan shown as Fig.2. This was probably shown as graphic colour result at P6-P8 higher air velocities than other measuring points. The observation is the air velocity flows out of the ULPA Filter at the ceiling above before colliding and returning to the grided causing high velocity vortex near P6-P8.

**Figure 2.** 2D YZ View of the Velocity of Air flow at Plan X =17.45 m

Temperature is one important factor which must be controlled. If it becomes out of specification or lower than the dew point, it may result in other problems such as condensation resulting in defects [4].

In this study, we simulated and measured the temperature distribution in the clean room. From the measurement and simulation, the temperature is around $19.7\text{ }^{\circ}\text{C}$ – $22.3\text{ }^{\circ}\text{C}$ which is within specification of this clean room by $18.3\text{ }^{\circ}\text{C}$ – $23.9\text{ }^{\circ}\text{C}$. The temperature distribution in the Plane $X=17.45$ shows in Fig. 4 of next section (before action). At a center of clean room, the temperature is around $21.27\text{ }^{\circ}\text{C}$ – $23.9\text{ }^{\circ}\text{C}$ but in the area near wall of clean room, the temperature is around $19.7\text{ }^{\circ}\text{C}$ – $21.27\text{ }^{\circ}\text{C}$ which is lower than that of the center.

4.1. Contamination control

We considered the contamination point to be the same as the velocity measurement in the previous section at points P1~P21 as shown in Fig.1. We used optical particle counter Lighthouse, Soliar 3100+ to measure particle for investigation. All measurements were measured under normal operating conditions. The particle counter was activated for 1 minute and 5 measurements were averaged at each point. We observed that the particle count at every point was within the specification except the point P6, P7 and P8 which were higher than those at other points related with the velocity data as shown in the previous section. We speculate that those point have higher particles from the vortex flow around that area from the simulation result. We considered to reduce the contamination at P8 which is highest.

We observed the P6, P7 and P8 from CFD simulation. The air velocity coming out of the ULPA Filter at the ceiling above P6, P7 and P8 were high and the airflow was not smooth due to air vortex at the in front of Outlet A. We were able to understand that the main contamination source near P8 was a vortex flow.

At first, we tried to reduce the vortex flow by adjusting the airflow rate coming out of the UPLA filter but it could not be done because the flow rate of all ULPA filters were centrally controlled and could not be adjusted individually. Moreover, the cabinet that obstructed around that area could not be moved away to another location. Therefore, we decided to close the Outlet A (flow rate = 0 kg/s) at the wall near these positions. The vortex flow and particle concentration were reduced from the measurement after the action was taken. We compared the before and after-action from CFD simulation in Fig.3. They showed that the airflow velocity at point P6, P7 and P8 improved significantly after the improvement. Also, the temperature after the action do not significantly impact nor change, therefore still landing within the specification as Fig.4. The study showed that after closing the one return grilled, this helped reduce vortex flow and did not impact the clean room temperature. This temperature simulation can be future improved for further study about this clean room since some reports showed this clean room was contaminated out of spec in the high temperature area in the simulation while some reports mentioned condensation problems on the machine around the lower temperature zone in the simulation area, related with the work of **J. Thongsri** [4]. If the temperature is lower than the dew point, water will condense. The research can help factory save costs from contaminated product, avoid water condensation problem and increase yield rate of the product.

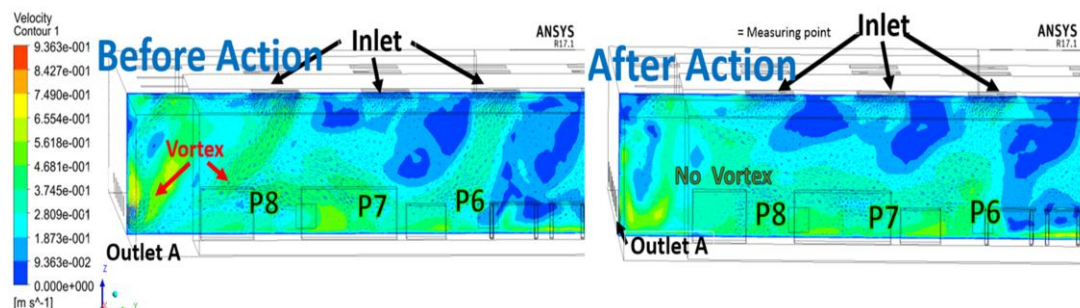


Figure 3. YZ View of the Velocity of Air flow at Plan $X = 17.45\text{ m}$ (Before- After Action).

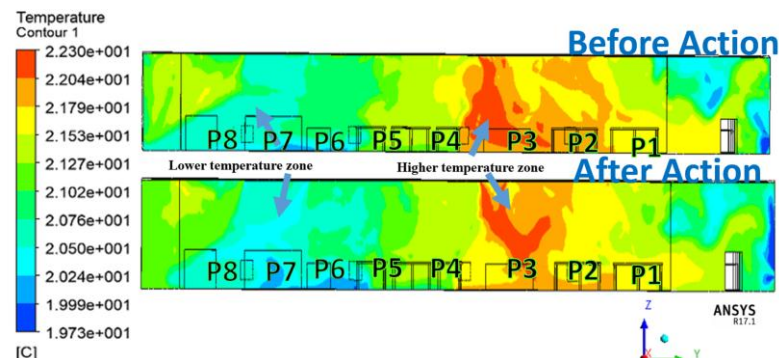


Figure 4. YZ View of the temperature After Action at Plan X =17.45 m (Before- After Action).

5. Conclusion

We studied the airflow inside a big clean room in a hard disk drive manufacturing factory in order to investigate the contamination, the airflow pattern, temperature distribution and particle count compared to an actual measurement. The CFD results show accurately simulated airflow pattern and high velocity with the vortex flow from return grilles which is related to the measurement data from the particle count. Areas of high particle which has vortex flow collecting the particles were found near the observed positions P8, P7 and P6 respectively. After the improvement action was taken by closing the Outlet A (one of return grilles) with flow rate = 0 kg/s at the wall near these positions, the vortex flow and contamination were reduced as Fig.5, and the temperature distribution of this clean room were left unaffected. This study confirms that CFD methodology can be utilized to predict the distribution of contaminated particles whenever an environmental change may take place. This model was submitted to the factory and was accepted to be used as information for clean room improvement.

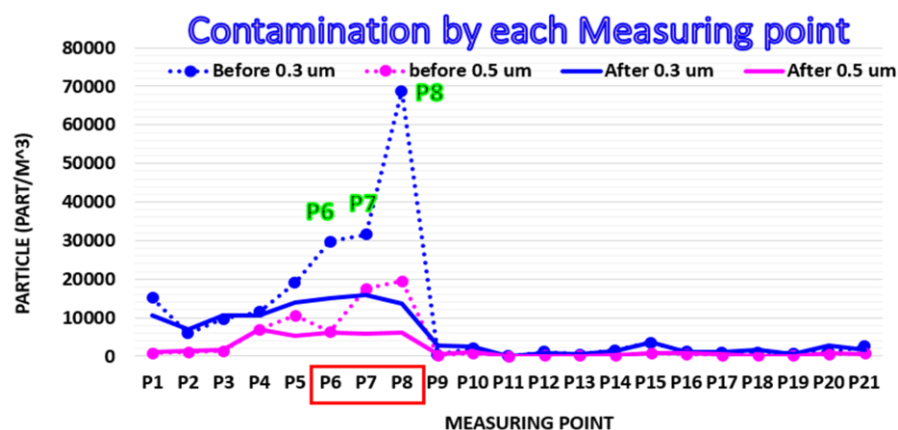


Figure 5. Contamination at P1-P21 Before-After the improvement

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