Numerical Investigation on the Performance of Suction Head in a Cleaning Process of Hard Disk Drive Factory

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ABSTRACT

The suction head is a component positioned at the vacuum cleaner's tip and used to control airflow to eliminate small particles, thus preventing contamination from occurring during the cleaning process at a hard disk drive (HDD) manufacturing factory. At the factory, 2 suction head types (bowl and straight) were used in the cleaning process. From an actual usage, the operators questioned the operating condition's performance and suitability. In order to seek an answer to the questions, the researchers used computational fluid dynamics (CFD) to simulate airflow and particle trace using the ANSYS Fluent software, the factory's actual conditions, and a suction distance ranging between 2.5–15 mm. CFD simulation results showed that the bowl type suction head performed better compared to the straight type in every suction range under the exact same operating conditions. Both suction heads performed well at a 5 mm distance between the suction head and cleaning area. Suction performance decreased when the head was positioned closer or farther than the mentioned distance. Apart from applying all results from this research to increase cleaning efficiency in the actual factory, the findings could also be used as basic information for designing new suction head models with higher efficiency than the original model.

Keywords: Airflow, ANSYS Fluent, Computational Fluid Dynamics, Cleaning Process, Particle Contamination, Suction Head

1. INTRODUCTION

The Hard Disk Drive (HDD) is a device used to store information in computers. Currently, the HDD industry's major manufacturing base is situated in Thailand. The HDDs are exported to countries over the world, generating many billion-baht income for the country. An HDD consists of over 2,000 tiny pieces of electronic parts. During the manufacturing and assembling process, all parts must be assembled within a clean room with a cleanliness level between class 100 and 1,000. Even a small amount of contamination onto an HDD part may negatively impact the HDD's performance, making it a defect which cannot be sold. Therefore, contamination in these processes were a major problem in the factory that must be urgently resolved. The problem also challenged the researchers as we had to develop new technology to overcome the obstacle and support the industry to produce higher quality HDDs.

To solve the contamination problem in an HDD factory's cleaning process, the operators would regularly clean the production line using a vacuum cleaner with a suction head installed at the tip to control airflow to facilitate effective particle suction. This factory used 2 suction head types: straight and bowl types as in Figs. 1(a) and 1(b) accordingly. The bowl type's angle and degree could be adjusted. Still, we only considered the case which the head was positioned vertically as shown in Fig. 1(b). Both suction heads were used under the same operating conditions; therefore, raising questions among the operators of both types' work efficiency and suitable operating condition, which eventually led to this research.

From our reviews of relevant research, we found that in the HDD manufacturing industry, Computational Fluid Dynamics (CFD) was widely used to design and develop devices and components to increase the efficiency of removing the small particles in the cleaning process, such as Yimsiriwatana and Jearsiripongkul [1] who used CFD to simulate airflow from a single probe vacuum. They discovered that the most suitable distance between the suction head and the designated cleaning area was 5 mm. Still, the single probe suction head in their research had a different design and operating condition from the suction head of interest in this research. Jai-Ngam and Tangchaichit [2] used CFD to study airflow in HDDs to improve the Impinging Air Jet Particle Detachment System used to efficiently clean head stack assemblies. Thongsri et al. [3–5] successfully used CFD to simulate the airflow in automated machines and in clean rooms to find the most suitable operat-

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(a)

(b)

Fig.1: *Suction heads for (a) straight type and (b) bowl type.*

ing conditions, which were later implemented at the actual factory and effectively decreased particle contamination. Most mentioned research consistently indicated that nozzle heads or suction heads were the devices that contributed to highly efficient vacuuming or spraying. Other examples of research which used CFD to design nozzle heads were Kumar et al. [6] and Reza and Arora [7]'s study, which used CFD to design and develop an aerospike nozzle head that was suitable for attaching to new rockets that sent satellites into space. Hyder and Hayat [8] used CFD to optimize a nozzle head with multiple air exit holes. Their research resulted in the creation of a nozzle head that could spray air at a high speed and large quantity within a short period of time. For developing air suction devices, Xi et al. [9] used CFD to check the particle suction performance of a reverse blowing pickup mouse. Their research led them to discover the design and operating conditions that were suitable for cleaning road surfaces. All this literature review confirmed that CFD and suction head design were major contributors to solutions for this problem.

In this article, we used the CFD to simulate airflow and the particle trace which occurred after using both straight and bowl suction head types under the factory's actual operating conditions. Simulation results from both suction head types were then compared with actual measurement to verify the credibility. Finally, the simulation results were analyzed to evaluate its performance and to find the most suitable operating condition for each suction head type.

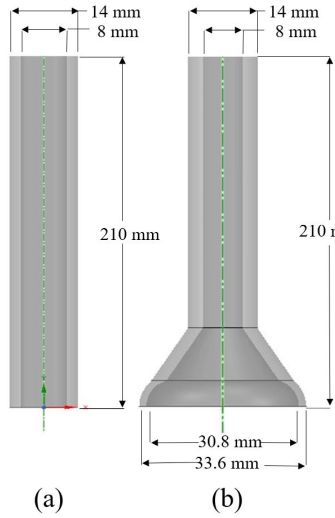

Fig.2: *Solid models and dimensions of (a) straight type and (b) bowl type.*

2. METHODOLOGY

2.1 Fluid and mesh models

We simplified both suction head types in Fig. 1 into a solid model as in Fig. 2 for both suction heads; (a) straight type, and (b) bowl type. To save computational time and the resources employed for calculation, we created a fluid model and mesh model for the air within the suction head and the air in the surrounding area. Only a half model was created as in Fig. 3 for the straight suction head type, and Fig. 4 for the bowl head type. The quantity of elements and nodes of the straight type were 0.59 million elements and 0.61 million nodes. As for the bowl suction head type, there were 0.40 million elements and 0.43 million nodes. All elements were the hexahedron type, created by the ICEM CFD software, with an average skewness value of 0.075.

2.2 Boundary conditions

Air from outside would flow into the suction head whenever the pressure in the pipe was lower than the pressure outside. After measuring the actual operating conditions in the factory, we found that the air pressure outside the suction head was 101,375 Pa, while the pressure inside the pipe was 92,800 Pa. Therefore, the air pressure outside was set as the pressure inlet while air pressure inside the pipe was set as the pressure outlet in the simulation. Fig. 5 shows the boundary conditions used in the bowl suction head type. The same conditions were applied with the straight suction head type, with only the design of the head as the difference. The symmetry was the area where airflows were exactly the same. The symmetry enabled the software to calculate faster. The air density was 1.255 kg/m^3. Convergent criterion was set as 10^{-4}. The turbulence model was shear stress

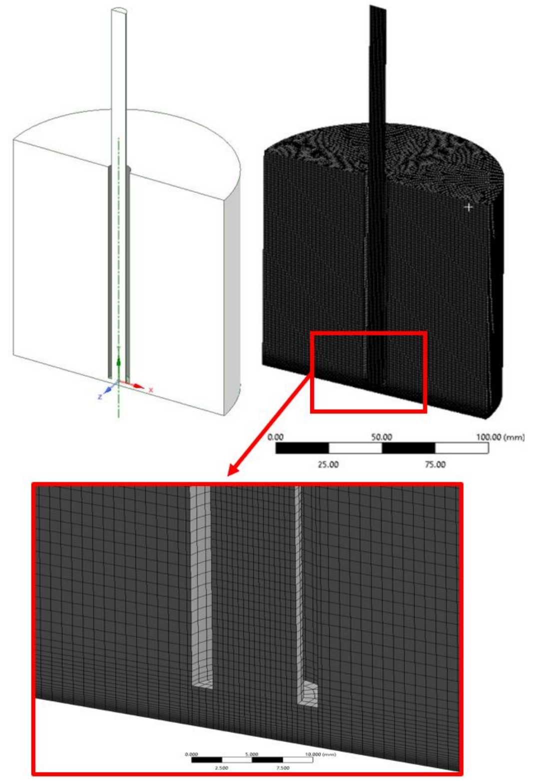

Fig.3: *Fluid and mesh models of straight type.*

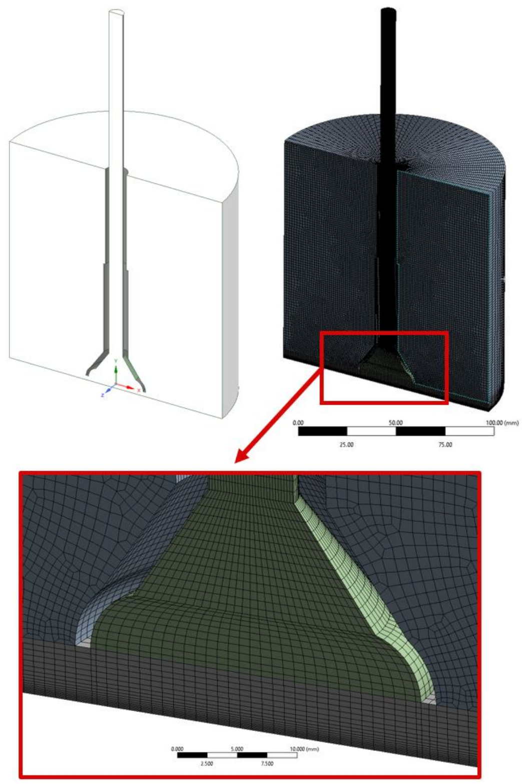

Fig.4: *Fluid and mesh models of bowl type.*

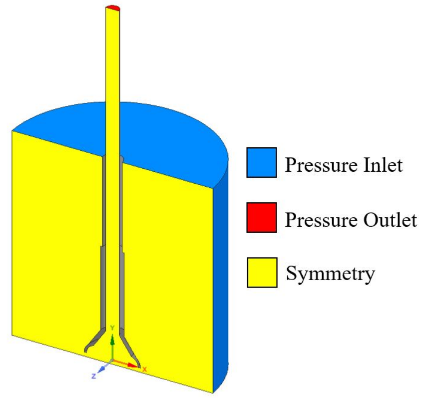

Fig.5: *Setting of boundary conditions.*

transport (SST) $k-\omega$. The reason of using SST $k-\omega$ was because of its widespread popularity in research relevant to industrial and medical applications [10–11]. This turbulence model combined the advantages of both $k-\omega$ and $k-\varepsilon$ turbulence models together, thus enabling us to simulate the fluid's flow behavior in the inner area of the boundary layer accurately, which is the $k-\omega$'s uniqueness. Moreover, it can also switch to correctly calculate the free shear flow, which is another distinctive property of $k-\varepsilon$. All simulations were calculated in a steady-state condition using the ANSYS Fluent software. We separated the simulation into 2 phases; phase 1 when the airflow was simulated and air velocity was criterion, and phase 2 when the particle trace was simulated, and number of the suctioned particles was criterion. Results from both phases were then analyzed to investigate both suction head types' performance. In phase 2, since the particles that must be eliminated are tiny in size but have greater density compared to the air, we used the Discrete Phase Model (DPM) with one-way simulation; we finished solving the flow before starting to solve the DPM. This technique enabled us to accurately predict particle traces [3, 12, 13]. The particles that would be suctioned were skin particles that were 0.5 micron in size, and 7,500 kg/m^3 in density. These particles were reported to be frequently found in factories, caused by the operators' activities [13–14].

2.3 Performance of suction head

As mentioned previously, we divided the criteria used to evaluate the suction heads' performance into 2 phases: using the suspension velocity as the criterion and using the suctioned particle count as the criterion. Details of using suspension velocity (v_s) as the criterion are as follows. When the vacuum cleaner is operating, the surrounding air is constantly suctioned into the device. Small particles are suctioned inwards when the velocity of the air where the particles are floating in are equal to or higher than v_s. If the particles that will be suctioned are spherical in shape and have a Reynold number for floating between 500–2×10^5, v_s can be expressed by [9]

$$v_s = 5.45\sqrt{\frac{d_p(\rho_p - \rho)}{\rho}} \tag{1}$$

where d_p stands for diameter of particle. ρ_p and ρ stand for density of particle and air, respectively. In this research, the Reynolds number was in a range of 5,000–10,000.

Therefore, for phase 1, we may consider the suction head's performance (P_1) from the suspension velocity which can be calculated from

$$P_1 = \left|\frac{A_s}{A_0}\right| \times 100\% \tag{2}$$

where A_s is cleaning area that has air velocity higher than v_s. A_0 is the circle area with radius 6 cm expected to be cleaned, totalling 1.13×10^{-2} m^2.

In phase 2, we calculated the suction head's performance from the suctioned particles count (P_2) using equation;

$$P_2 = \left|\frac{N_s}{N_0}\right| \times 100\% \tag{3}$$

where N_s is the number of suctioned particles from the simulation. N_0 is all particles expected to be sucked totalling 10,000 particles.

3. RESULTS AND DISCUSSION

3.1 Validation

To validate the used methodology and simulation results, we measured the air velocity from both suction heads at the distances of (h) 10, 15 and 20 mm in the vertical direction using hot-wire anemometer with ±0.03 m/s of accuracy. Each h was then divided horizontally into 9 positions; at –10, –7.5, –5, –2.5, 0, 2.5, 5, 7.5, and 10 mm. Negative positions meant positions on the left side of the central line, while positive positions meant positions on the right side of the central line. Number 0 meant the position at the center, exactly at the middle of the suction head. Each position was measured 10 times. Measured results were then compared with simulated results as in Figs. 6–7 for straight and bowl type suction heads, at distances of (a) h = 10 mm and (b) h = 20 mm. From Figs. 6 and 7, it is noticeable that the actual air velocity measurements were close to simulated results. The highest maximum error value was 16.41% at h = 10 mm of straight type; however, the simulated result was within the error bar. Therefore, the methodology used, and simulation results were credible. The results compared at h = 15 mm also gave consistent outcomes. However, due to the article length limitations, we couldn't include all the contents.

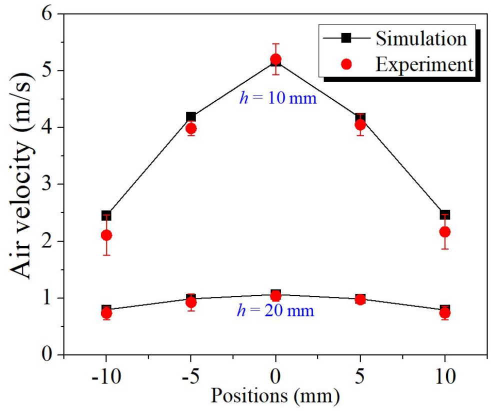

Fig.6: *Comparison between the simulated and measured air velocities for straight type.*

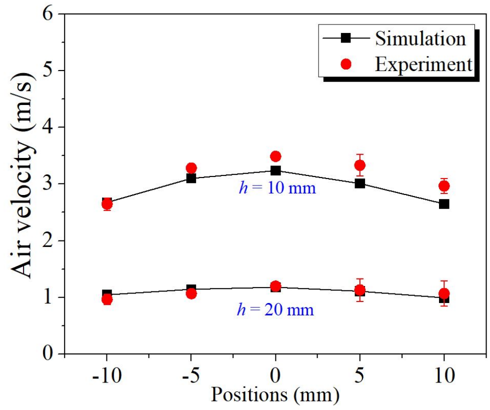

Fig.7: *Comparison between the simulated and measured air velocities for bowl type.*

3.2 Performance comparison

To compare the performance of both suction head types using suspension velocity as the criterion for consideration in phase 1, Fig. 8 represents the velocity contour generated by the simulation of (a) straight type and (b) bowl type suction heads. We also found that at the region near both suction heads, the velocity of the suctioned air was higher than the velocity of the air further away. This finding was consistent to actual measurements in Section 3.1. The calculation of v_s using Eq. (1) resulted in v_s = 0.092 m/s which assumed that at an air velocity of 0.092 m/s or more, the air could lift these particles up, enabling the head to suction the particles [9]. At h = 5 mm, the air moved faster than 0.092 m/s that gave $A_s = 3.47 \times 10^{-3}$ m^2 for the straight suction head type, and $A_s = 4.95 \times 10^{-3}$ m^2 for the bowl suction head type. $A_0 = 1.13 \times 10^{-2}$ m^2 was the circle area that we expected to clean. When the cleaning area was used to calculate suction performance using Eq. (2), the straight type suction head's performance was 30.69% while the bowl type suction head's performance was 43.83%. Fig. 9 shows velocity con-

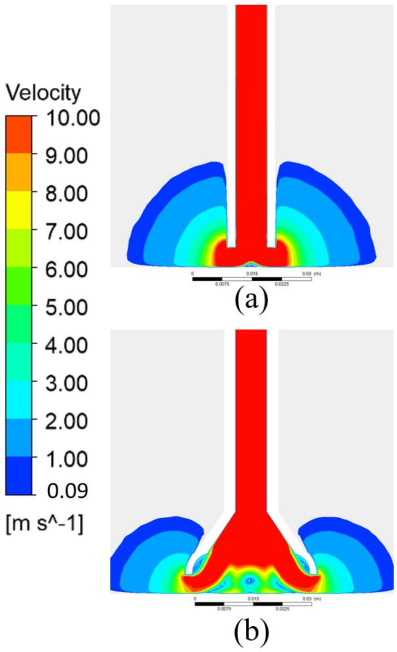

Fig.8: *Air velocity contour of suction heads at h = 5 mm for (a) straight type and (b) bowl type.*

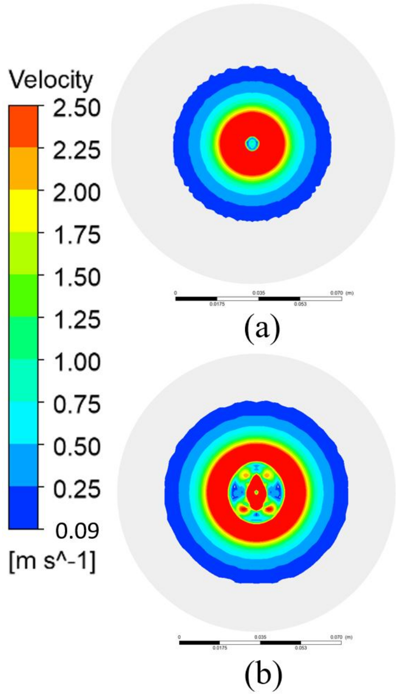

Fig.9: *Air velocity contour on cleaning area of suction heads for (a) straight type and (b) bowl type.*

tour of cleaning areas resulted from Fig. 8. The bowl type gave the cleaning area a diameter of 79.41 mm, while the straight type gave a diameter of 77.38 mm. Fig. 10 shows velocity vectors of both suction heads at $h = 5$ mm. Air from the outside will be suctioned into the suction head. The air volume with speeds higher than 0.092 m/s for the bowl type were higher than the straight type. When considering Figs. 8–10 along with Figs. 6–7, we analyzed that the most suitable suction distance was $h = 5$ mm, because the air had velocity higher than v_s once compared to other distance ranges. Apart from at this distance, the suctioned air will not have a velocity high enough to push the articles upwards to enter the suction head.

In phase 2, to evaluate the performance by using the number of suctioned particles as the criterion, we simulated the suction process using DPM in ANSYS Fluent software with a one-way simulation technique. We pretended that there were $N_0 = 10{,}000$ skin particles intended to be suctioned, placed at h of 2.5, 5, 7.5, 10 and 15 mm away from the suction head. The positions of particles were randomly distributed in a circle area with $A_0 = 1.13 \times 10^{-2}$ m^2, which was the same area mentioned in Eq. (2). The software would later count the quantity of particles that were successfully suctioned. Fig. 11 shows the example of particle traces of 500 particles. It was noticeable from Fig. 11 that the bowl type suctioned particles better than the straight type because there were more lines showing the particle traces. As for the bowl type, particles were suctioned into the head in 2 routes. The straight type, on the other hand, had only one route. The number of remaining particles in

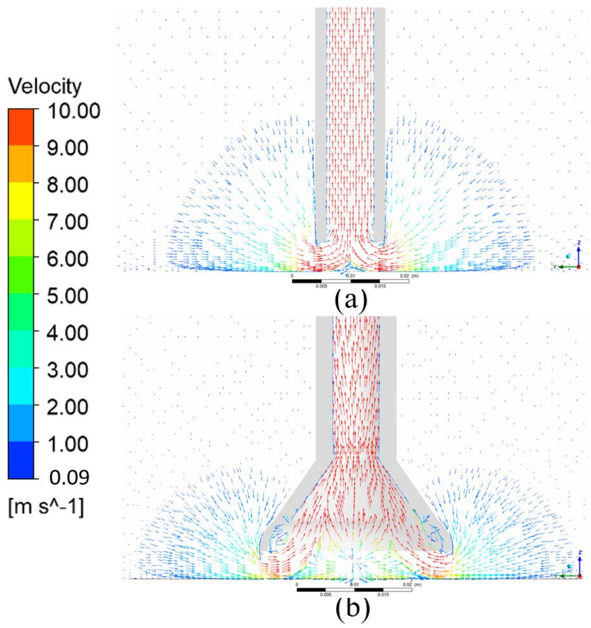

Fig.10: *Air velocity vector of suction heads at h = 5 mm for (a) straight type and (b) bowl type.*

Fig. 11(a) was greater than Fig. 11(b). Also, the velocities of the suctioned particles were faster. After the DPM was completely run, the number of suctioned particles were recorded for both head types. Fig. 12 shows the number of suctioned particles simulated by the software for varying h. The maximum number of suctioned particles was $h = 5$ mm with 6,408 particles for the bowl type and 4,383 particles

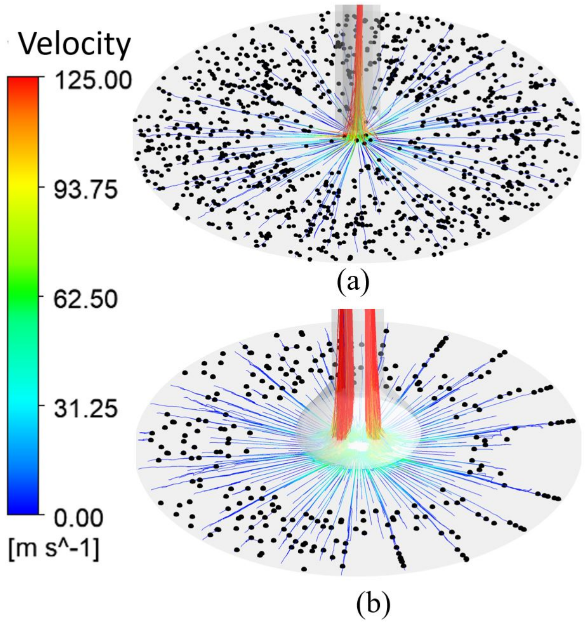

Fig.11: *Particle traces of suction heads at $h = 5$ mm for (a) straight type and (b) bowl type.*

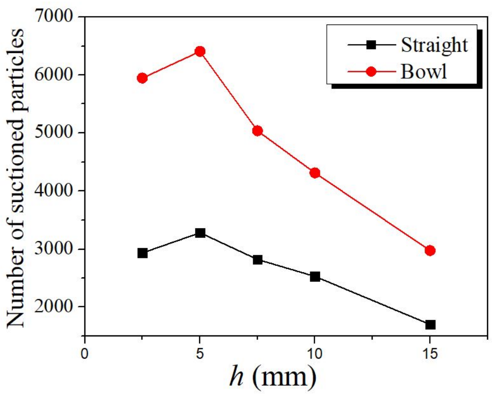

Fig.12: *Comparison of the number of suctioned particles between the straight and bowl types.*

for the straight type.

After the Fluent software recorded A_s and N_s, the performances P_1 and P_2 can be calculated by using Eqs. (2) and (3) at h between 2.5–15 mm; calculation results are presented in Table 1.

We found that the performance levels of bowl type were higher than the straight type for every h. The optimal suction performance was at $h = 5$ mm, which had $P_1 = 43.83\%$ and $P_2 = 64.08\%$ for bowl type, and $P_1 = 30.69\%$ and $P_2 = 32.82\%$ for straight type at the same h. When suctioned at $h = 15$ mm from the suction head, the performance level of both types decreased to $P_1 = 33.21\%$ and $P_2 = 29.73\%$ for the bowl type and $P_1 = 21.88\%$ and $P_2 = 17.00\%$ for the straight type. Therefore, from the measured results and simulated results presented in Figs. 6–12 including Table 1, the researchers were confident that the

Table 1: *Performance of suction heads.*

Type	h (mm)	P_1 (%)	P_2 (%)
Straight	2.5	29.72	29.33
	5	30.69	32.82
	7.5	29.65	28.21
	10	27.95	25.30
	15	21.88	17.00
Bowl	2.5	43.02	59.46
	5	43.83	64.08
	7.5	42.26	50.39
	10	39.30	43.14
	15	33.21	29.73

bowl type's particle suction performance was higher than the straight suction head. Both types had a suitable particle suction distance at 5 mm. All findings from this research were shared with the factory's engineers for further cleaning process optimization. Still, the bowl type's particle suction performance only had maximum particle suction performance of 64.08%, a rate lower than the factory's anticipation that their operating condition should exceed 80%. Designing a new suction head model with higher performance is therefore a challenging and interesting task for researchers.

4. CONCLUSION

We used FLUENT software to investigate the particle suction performance of both straight and bowl type suction heads which were used in the cleaning process of an HDD factory. We also studied to find the optimal suction distance for operations. Investigation on the performance were conducted using 2 criteria: suspension velocity and the quantity of particles for the suction distances ranging between 2.5–15 mm. When suspension velocity was used as the criterion, theoretically we found that the minimum air velocity for suctioning particles was $v_s = 0.092$ m/s. Using suspension velocity as criterion, simulation results of the velocity contour showed that the bowl type suction head enabled the cleaning area to have air velocities higher than v_s more than the straight type suction head at all suction ranges with a maximum performance rate at 43.83%, while the straight type suction head's performance rate was only 30.69% at a suction distance of 5 mm. The results could be analyzed to show that the performance of bowl type was higher than the straight type. When the number of particles for the suction distances was used as the criterion, we simulated the particle trace using DPM. We found that the bowl type suction head could suck the particles more than the straight type suction head at all suction ranges, with a maximum performance rate at 64.08% at a suction distance of 5 mm, while the straight type suction head's performance rate was only 32.82% at the same suction distance. Both criteria were credible and gave consistent results; the most suitable suction distance for both suction head types was 5 mm, since a distance closer or farther than that would not enable the device to suction the particles and decreased the performance of suction.

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