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DOE-Decision Support System for Optimizing Air Box Parameters in Air Shower

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Abstract *- Air flow of nozzles in an air shower (AS) can greatly enhance the cleanroom's performance by removing particles from humans and materials before entering to the cleanroom. After an installation, the air velocity of each nozzle was lower than all the customer requirements. The main problems are an air box and some defects from production and installation processes. The objective of this research was to find the optimal parameter levels for the production process of an air box in the AS via a decision support based on a design of experiment (DOE). The DOE was designed based on the 2k factorial design with four influential parameters. They consist of the width (W), length (L), and height (H) of an air box including a nozzle orifice diameter. The air velocity of nozzles from two replications were analyzed using the DOE-decision support. The results of all four parameters were statistically significant at the 95% confidence interval. The most appropriate levels of those four parameters could be achieved by setting the (W x L x H) dimension of an air box at (630 x 900 x 250) mm and the nozzle orifice diameter at 25 mm. This proposed setting for an air box are suggested to implement in a production design process for the Thai AS company.*

Keywords: *air velocity of nozzles, cleanroom, design of experiment.*

I. INTRODUCTION

Currently business operations were changed in economic conditions, causing reductions in domestic investments with subsequent effects causing lower employment. In addition, the number of business competitors increased, causing lack of work and higher production costs. Therefore, businesses or organizations must adapt to improve and increase capacity to become successful in business with product and knowledge development. Moreover, businesses or organizations must make efforts to cut costs and develop income-generating products to cover as much market share as possible. Current business competition capacity is an important factor for a business to survive. Businesses must have the competitive capacity in the areas of price, quality and businesses must use technology to improve performance in order to meet customer needs and create the highest satisfaction. Nowadays, the production technology has developed and progressed with a use of the advanced technology in various industries which require a clean environment. This reflects the production process to provide products that have good quality industries related to clean room. Clean rooms have become important in Thailand's leading industries such as food and beverage industries, pharmaceutical, biotechnology, hospital and lab industries, electronics and computer industries, packaging industries and industries with highly sensitive machines. Clean rooms have benefits in making products in a production system without dust and germs while complying with standards such as Federal STD. 109-1144(Clean Room Class 10-100000) [1] , Good Manufacturing Practice (GMP) [2], International Organization for Standardization (ISO)[3] and Hazard Analysis Critical Control Point (HACCP) [4].

In this study, the decision support system via the sequential procedures of the design of experiment was applied to develop the air box design parameters in the air showers. However, the method has limitation on the experimental runs according to levels of related parameters. At the beginning of the experimental design it is necessary to obtain suitable values for the air jet of nozzles to be the strongest possible under the condition of limited resources. Parameters consist of the (W x L x H) dimension of an air box and the nozzle orifice diameter as shown in fig 2. The main findings from the study consist of production designs and lists of suitable production and assembly materials for international clean room standards. The outcome can be applied to develop small and medium enterprises in industries such as electronics, food and automobiles which engage in businesses involving clean rooms. This development in forms of the DOE-decision support system can be applied to other products in the clean room industry effectively.

II. AIR BOX DESIGN OPTIMIZATION FOR CLEANROOM

Clean room equipment is designed and used to prevent and manage the dust and air quality. Generally, the air cleaning system uses a highly sensitive filter to screen germs and PM 2.5 at full efficiency by using a high efficiency particulate air or HEPA filters in the ventilations systems of sterile rooms. The cleanroom also uses air showers for disease control room entrances-exits as shown in Figure 1. Therefore, designing air showers with an air box set inside to have good wind pressure will remove dust and germs on the body more effective. Several researchers applied research related to clean rooms and air showers. In 1993, Whyte and McGeorge [5] conducted research on effects of air showers on dust removal from the body or clothing and prevention of air contamination between clean rooms and rooms with normal air conditions by experimenting to determine appropriate wind force at a suitable wind strength of 23-25 meters per second. Knotter and Wali [6] stated that the air shower efficiency was determined by differences in the particle size. Additionally, the main variables included the air pressure on human skin or work surfaces including a distance between contact surfaces and air nozzles. Effects from blowing metal and dust of different sizes showed the air pressure to have direct effects on the dust removal capacity. Research from Sadrizadeh et al. [7] showed the lamina vertical systems in operating rooms prevented a bacteria dispersion during surgery and found a HEPA filter size and wind speed to have direct effects on operating room cleaning efficiency. In 2020, Zhou et.al. stated sterile rooms with a dust caution could be used in industries of electronics, microchips, electrical appliances, computers, and smartphones. The dust on circuit boards may cause severe short circuits and damage. [8]

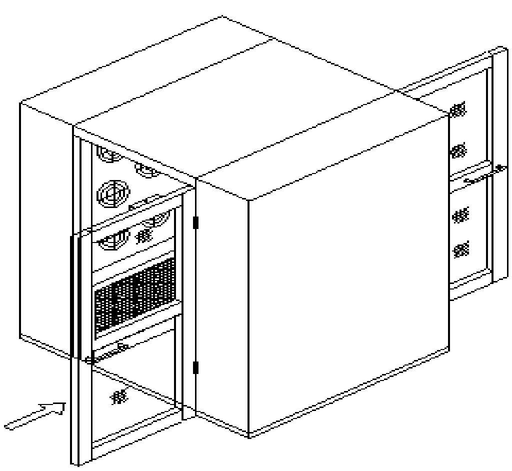

Fig. 1 Air shower size 1 M.

In industries producing paint, film or chemicals, dust may cause protruding and bring work pieces to be damaged. Clean rooms used in the industries have the positive pressure. Positive pressure is used for cleanliness controls such as packing rooms, raw material preparation rooms and high-risk areas to prevent particles such as dust, bacteria, yeast, mold, bacterial spores, and mold spores from entering. Differences in internal and external air pressure should be at 0.03 to 0.05 water inches. The room pressure must be maintained at a stable level when doors or openings are opened. The additional air control systems must be installed to provide air to replace outflows from doors opening. When positive pressure controls are in multiple areas, the cleanest room must have premium pressure and air pressure control systems present in each area. Prevention of particles or unclean items from entering rooms uses HEPA filters to filter air entering the room, maintains positive pressure in the room and uses air showers to clean bodies. These must be done before entering clean rooms along with wearing personal protective equipment such as masks, hair nets, static electricity prevention suits and gloves.

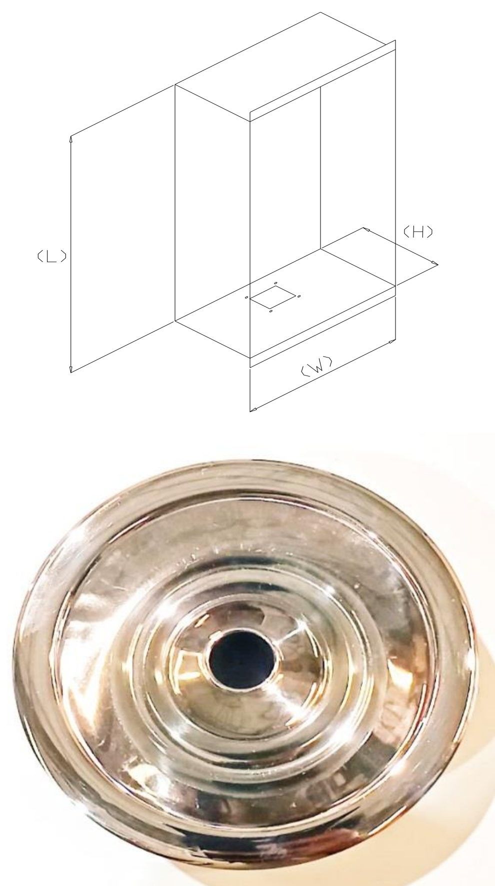

Fig. 2 Parameters of an air box and the nozzle orifice diameter.

III. DOE-DECISION SUPPORT SYSTEM

In various industries design and analysis of experiment (DOE) has become increasingly important for the system of data driven decision support. It is largely practical by the requirement for increased performance measures.[9] Parameters are divided into 2 groups consisting of the controllable group or “parameters which are controllable or parameters which can be designed” and the uncontrollable group or “parameters which disrupt the system”. Statistical design of experiment means the process of planning an experiment to obtain suitable data for use in analyses. In Montgomery’s statistical method [10], the 3 basic principles of design of experiment are replication, randomization and blocking. These principles have the goal to control changes of independent variables, called “parameters”, [11] in any process of interest and observing effects on the response variable of that process. The process is the combined function of machines, raw materials, people, work methods, environments, and measurements to create products or services. A process may have many parameters. Some parameters may be controllable and may not be controllable. In design of experiment, we call these parameters “noise” and use these parameters to select appropriate parameters in many problems such as hot press forming process parameters [12] , laser cutting [13], laser welding processes [14] and micro injection molding process [15]. The DOE-decision support system takes benefits from design plan reduction and mapping including the response surface (Fig.3). Design of experiment is one-time or continual testing by changing parameters or study processes in order to be able to observe and indicate causes of changes of outcomes or responses from that process or system.

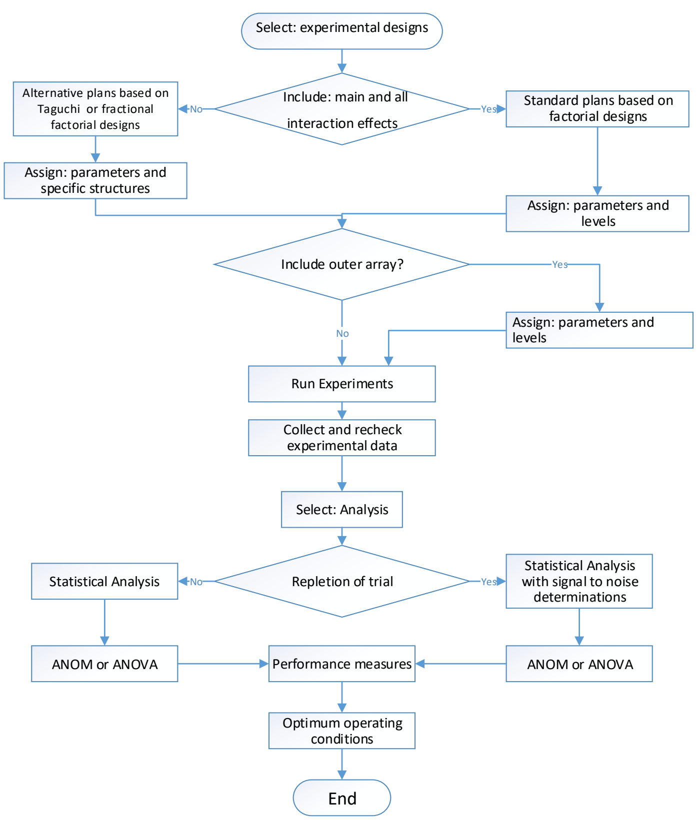

Fig. 3 DOE-decision Support System.

IV. NUMERICAL RESULTS

The experiment started by studying the method for air box in air showers from cleanroom factory. The objective was selecting controllable parameters affecting air velocity coming out from a nozzle. The expert determination concluded of influential parameters consist of the (W x L x H) dimension of an air box and the nozzle orifice diameter. The parameters and values used in the experiment design are shown in TABLE I. In this experiment, the 24 factorial design technique was used by repeating the experiment two times for a total of 16 experiments. The experimental results with 2 replications were shown in TABLE II.

TABLE I
EXPERIMENTEL FACTORS AND THEIR LEVELS

Parameter	**Level**		
	-1	**+1**	**Unit**
Air box width (A)	600	630	mm.
Air box length (B)	900	1000	mm.
Air box height (C)	250	300	mm.
Nozzle diameter (D)	25	27	mm.

TABLE II
EXPERIMENTAL DESIGNED OF AIR VELOCITY OF NOZZLES (2^4 FACTORIAL DESIGN)

Run Order	Air box width (A)	Air box length (B)	Air box height (C)	Nozzle diameter (D)	Response of air velocity
1	600	1000	250	25	28.25
2	600	900	350	27	26.57
3	600	900	350	25	26.12
4	600	1000	350	27	25.32
5	630	1000	350	25	27.62
6	600	1000	350	25	25.31
7	600	900	250	25	27.34
8	630	900	250	25	27.02
9	600	1000	250	27	25.43
10	600	900	350	25	26.35
11	600	1000	250	25	27.23
12	630	900	250	27	25.70
13	630	1000	250	27	26.10
14	600	900	250	27	25.53
15	630	900	350	25	26.81
16	630	1000	350	27	27.47
17	630	900	350	25	24.80
18	630	1000	350	25	26.23
19	630	900	250	27	26.87
20	600	1000	350	25	27.50
21	600	900	250	27	25.79
22	630	1000	250	27	26.21
23	600	1000	250	27	25.87
24	630	1000	250	25	27.12

25	600	1000	350	27	26.66
26	600	900	350	27	27.65
27	600	900	250	25	28.21
28	630	1000	350	27	26.30
29	630	900	250	25	26.85
30	630	1000	250	25	26.78
31	630	900	350	27	27.50
32	630	900	350	27	26.70

The data obtained from the experiment were analyzed using the Minitab Release 17 program. Normal plot of standardized effects and experimental accuracy of normal probability plot from the residual analysis is used to the ANOVA confirmation . The impact values of point CD (the interaction of air box height and nozzle orifice diameter) indicated that they were influenced responsive factors with statistical significance (0.05). A graphical representation of the analysis of variance and the main and interaction plots are shown in Fig. 4 and 5, respectively. From the analysis of variance in Fig. 5, significant parameters were air box height and nozzle orifice diameter. A parameter with p-value < 0.05 was considered statistically significant with a 95% confidence interval. Others are selected on the best so far sub-procedure on the DOE-decision support system. In case of maximization air velocity of nozzle, air box width (A) at 600 mm, air box length (B) 1000 mm, air box height (C) at 250 mm and nozzle orifice diameter (D) at 25 mm (Fig.6) should be set.

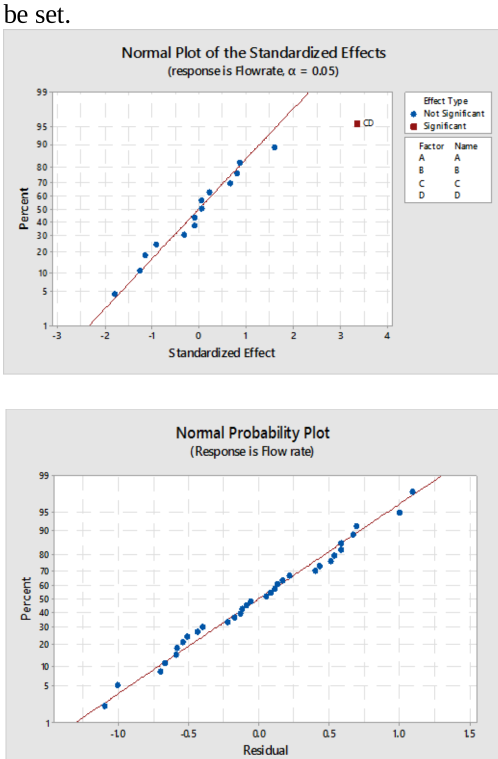

Fig. 4 Normal plots of all parameters and their interaction effect and the residuals on the nozzle air velocity

V. CONCLUSION AND FUTURE WORK

In this paper, the DOE-decision support system of the air box design optimization for a cleanroom has been presented. The numerical results of two from all four parameters were significant at level of 0.05. The most appropriate levels of those four f parameters could be achieved by setting the air box width (A), the air box length (B), the air box height and the nozzle orifice diameter (D) at 600 mm, 1000 mm, 250 mm and 25 mm, respectively. DOE is a valuable experimental strategy for designing and conducting an ample experimentation. DOE is a compromise tool for increasing performance of production process. The experiments can be used to improve the performance of the product design and product quality. The appropriate setting for an air box in the AS is suggested to use in production process for the AS company. As a future study, new experimental designed methods such as Taguchi design [16,17], response surface methodology (RSM) [18,19] and metaheuristic elements such as league championship algorithm[20] and horse herd optimization [21] were suggested. An aim is to automatically find suitable designed parameters via the DOE-decision support system for the product and process optimization.

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Source                DF   Adj SS   Adj MS  F-Value  P-Value
Model                 15  13.7366  0.91577     1.51    0.210
  Linear               4   2.0242  0.50605     0.84    0.522
    A                  1   0.0286  0.02864     0.05    0.831
    B                  1   0.0056  0.00555     0.01    0.925
    C                  1   0.0613  0.06134     0.10    0.754
    D                  1   1.9287  1.92867     3.19    0.093
  2-Way Interactions   6   9.9759  1.66264     2.75    0.050
    A*B                1   0.4009  0.40090     0.66    0.428
    A*C                1   0.2728  0.27278     0.45    0.511
    A*D                1   1.5725  1.57252     2.60    0.126
    B*C                1   0.0016  0.00156     0.00    0.960
    B*D                1   0.9437  0.94367     1.56    0.230
    C*D                1   6.7844  6.78443    11.21    0.004
  3-Way Interactions   4   1.7349  0.43373     0.72    0.593
    A*B*C              1   0.4654  0.46540     0.77    0.393
    A*B*D              1   0.0059  0.00595     0.01    0.922
    A*C*D              1   0.4837  0.48373     0.80    0.384
    B*C*D              1   0.7799  0.77986     1.29    0.273
  4-Way Interactions   1   0.0016  0.00160     0.00    0.960
    A*B*C*D            1   0.0016  0.00160     0.00    0.960
Error                 16   9.6795  0.60497
Total                 31  23.4161
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Fig. 5 Analysis of variance for an air box design optimization for a cleanroom

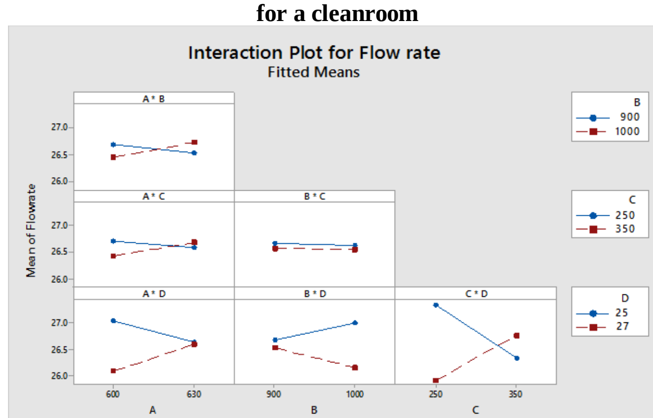

Fig. 6 Interaction effects plot for an air box design optimization for a cleanroom

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