

# The Design of Experiment to Determine the Optimum Parameters for Air Particles Control in the Head Gimbals Assembly (HGA) Washing Process

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**Abstract--** The aim of this research is to increase the quality of the Head Gimbals Assembly (HGA) by reducing the particle contamination of the washing process in the Cleanroom. Six factors have been identified and the experiments have been conducted. The six factors are 1) the air velocity of the fan filter, 2) the width of the air return, 3) the holes' diameter of the washing machine table, 4) the height of the air ionizer, and 6) the suction force of the exhaust. The Box-Behnken Experimental Design has been used to identify the significant effect of each factor. A Response Surface Methodology (RSM) technique was then applied to determine the proper configuration of each factor. The optimal setting obtained from the experiments are as follows: 1) the air velocity of the fan filter unit (FFU) should be 105 feet per minute (fpm), 2) the width of the Air Return should be 1 centimetre (cm), 3) the Holes' diameter of the washing machine table should be 3 millimetres (mm), 4) the effect of the height of the air ionizer is not significant, and 5) the suction force of the Exhaust should be 300 fpm. The mathematical analysis showed that the amounts of size 0.3 microns ( $\mu\text{m}$ ) particle are reduced from 4,392 to 57 Counts per cubic foot (Counts/ $\text{ft}^3$ ) and the amounts of size 0.5  $\mu\text{m}$  particle are reduced from 1,323 to 1 Counts/ $\text{ft}^3$ , respectively, which are conformed to the operating standard required by the US Federal Standard 209E. The confirmation production run then conducted and it's shown that the actual amounts of size 0.3 and 0.5  $\mu\text{m}$  particles obtained are 68 and 17 Counts/ $\text{ft}^3$ , respectively. This is expected to help reducing defect and increase quality in the production of components in the hard disk drive.

**Keywords—** Head Gimbals Assembly (HGA), Clean room, Box-Behnken Experimental Design, Response Surface Methodology (RSM)

## I. INTRODUCTION

The Hard Disk Drive (HDD), a computer-based digital storage, is one of the major components in the computer system. The main function of the HDD is to record data and information, so thus the quality of the HDD is important to every computer system. The Head Gimbals Assembly (HGA) is one of the most important components in the HDD Reader. The quality of the HGA is highly affected by the particles contaminated in the air during the production. It is thus necessary to control the airborne particle contaminants in the clean room [1]. The

issue aroused in the work area of the studied manufacturing plant due to the highly contamination of air. This research studied the airborne particles contamination at the HGA washing process to determine the factors that generate contaminants in the air, which cause damaged and scratches on the HGA as shown in Fig. 1. According to the US Federal standard 209E [2] requirements, the particles contamination in the air of the Class 100 clean room must be as follows: the particles size of 0.3 microns shall be less than 300 counts per cubic feet (counts/ $\text{ft}^3$ ) and the particles size of 0.5 microns shall be less than 100 counts per cubic feet (counts/ $\text{ft}^3$ ).

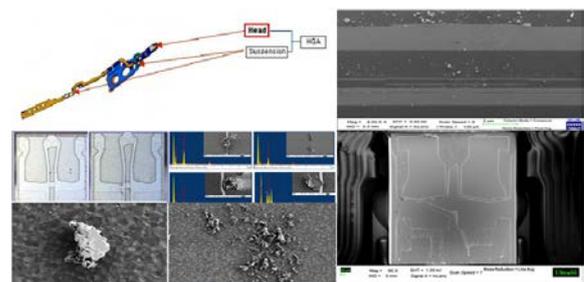


Fig. 1 A sample HGA damaged by the airborne particles contamination.

The airborne particle counts (APC) monitored at the unloading point of the washing process exhibited the non-conformance with the specification required by the US Federal Standard 209E as shown in Fig. 2 and Fig. 3.

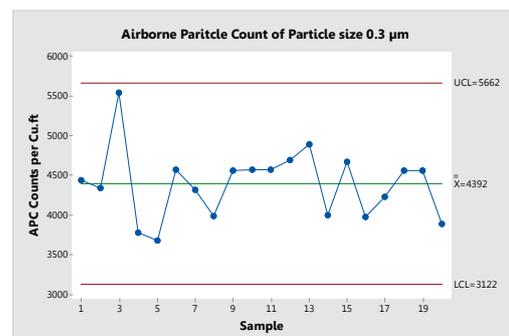


Fig. 2 APC monitoring chart of the particle size 0.3 microns

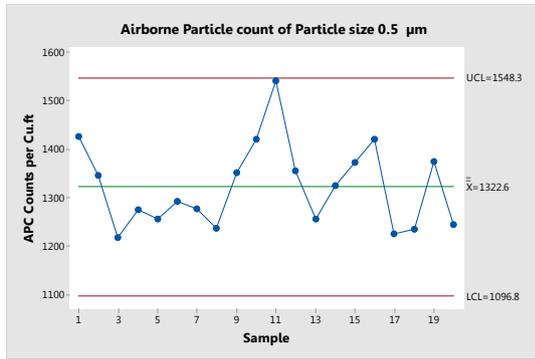


Fig. 3 APC monitoring chart of the particle size 0.5 microns

As shown in Fig. 2 and Fig. 3, the average APC of the particle size 0.3 microns and 0.5 microns are 4,392 Counts/ft<sup>3</sup> and 1,323 Counts/ft<sup>3</sup>, respectively.

## II. OBJECTIVES

The main objectives of this research are as follows:

- 1) To determine the appropriate parameters for controlling the amount of particles contamination in the air of the HGA washing process.
- 2) To achieve the capability of the US Federation Standard 209E class 100 clean room requirements.

## III. EXPERIMENTATION AND METHOD

### A. Introduction

**Problem definition** – the Air Particle contamination of the HGA washing process is higher than the specification required by the US Federal Standard 209E.

**Response Variable identification** – quantity of the Airborne Particle Counts (APC) on particle size 0.3 and 0.5 microns at the HGA washing process.

**Factors identification** – Five process parameters were selected as the controllable factors for the experimentation: these includes, A) the speed of the fan filter unit (FFU), B) the width of the air return duct, C) the hold size of the table at the unload washing process, D) the height of the air ionizer, and E) the exhaust suction fan's speed.

### B. Experimental Method

There are three steps as follows.

1) **Box-Behnken Designs:** The experiments are run at different factor values, called levels. Each run of an experiment involves a combination of the levels of the factors that are being investigated. The Box-Behnken design [3] is a response surface methodology (RSM) [4] design that requires only three levels to run an experiment. It is a special 3-level design since it does not contain any points at the vertices of the experiment region. This could be advantageous when the points on the corners of the cube represent level combinations that are prohibitively expensive or impossible to test because of physical process constraints. Fig. 4 shows an example of a Box-Behnken design with three factors.

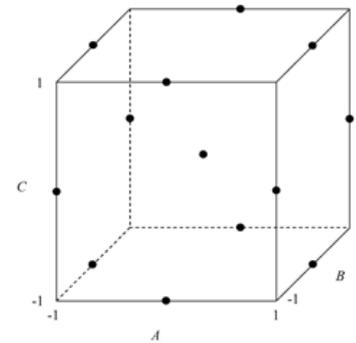


Fig. 4 Box-Behnken design for three factors

2) **Designed levels of factors:** Levels of each factors used in the experimental plan are summarized as shown in Table I.

TABLE I

THE DESIGNED LEVELS OF THE EXPERIMENTAL FACTORS

Factor	Unit	Levels		
		Low	Center	High
A: FFU speed	fpm.	70	90	110
B: Air return duct width	cm.	1	2	3
C: Hold size of table	mm.	3	4	5
D: Air ionizer height	cm.	60	65	70
E: Exhaust suction speed	fpm.	200	250	300

The location and configuration for each selected factor for controlling the airborne particle contamination in the air at the washing process is show in fig. 5.

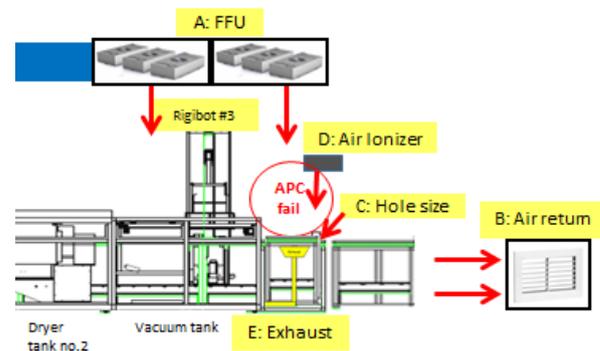


Fig. 5 Location and configuration of the controlled factors

The experimental plan was obtained by Minitab version 17 having the total runs of 46 as shown in Table II

TABLE II  
The experimental plan of the Box-Behnken designs from Minitab 17

StdOrder	RunOrde	PtType	Blocks	A	B	C	D	E
10	1	2	1	90	1	4	65	200
41	2	0	1	90	2	4	65	250
3	3	2	1	90	1	3	65	250
27	4	2	1	90	2	5	65	200
18	5	2	1	90	3	4	60	250
2	6	2	1	90	2	4	70	300
22	7	2	1	90	3	3	65	250
33	8	2	1	90	2	4	70	200
4	9	2	1	70	2	4	65	300
24	10	0	1	90	2	4	65	250
42	11	2	1	90	2	5	65	300
20	12	0	1	90	2	4	65	250
34	13	2	1	110	3	4	65	250
5	14	2	1	110	2	4	65	300
17	15	0	1	90	2	4	65	250
8	16	2	1	90	1	4	70	250
29	17	2	1	70	2	4	70	250
39	18	2	1	70	1	4	65	250
14	19	2	1	70	2	4	65	200
26	20	2	1	90	3	5	65	250
36	21	2	1	110	2	3	65	250
9	22	0	1	90	2	4	65	250
15	23	2	1	90	2	3	65	300
30	24	2	1	70	2	3	65	250
16	25	2	1	90	1	4	65	300
25	26	2	1	90	2	3	60	250
7	27	2	1	90	3	4	65	200
13	28	2	1	90	1	4	60	250
38	29	2	1	90	3	4	70	250
19	30	2	1	90	2	4	60	200
6	31	2	1	70	2	5	65	250
31	32	2	1	110	1	4	65	250
21	33	2	1	110	2	4	70	250
11	34	2	1	90	2	3	70	250
37	35	2	1	90	2	5	60	250
45	36	2	1	90	2	3	65	200
1	37	2	1	90	1	5	65	250
44	38	2	1	110	2	4	65	200
35	39	2	1	90	2	5	70	250
46	40	2	1	90	3	4	65	300
28	41	2	1	90	2	4	60	300
23	42	2	1	70	2	4	60	250
12	43	0	1	90	2	4	65	250
40	44	2	1	110	2	4	60	250
32	45	2	1	70	3	4	65	250
43	46	2	1	110	2	5	65	250

#### IV. RESULTS AND DISCUSSION

##### 1. Analysis of the results

**Model Adequacy Checking:** The experimental results of the APC have to be checked for statistically conformance, called residuals analysis. The residuals have to be i) normally distributed; the variances of the residuals should be ii) stable, and iii) independence.

**Normality of the residuals:** According to the probability plot of the residuals as shown in Fig. 6 and Fig 7, the P-Value for particle size 0.3 microns and 0.5 microns are 0.152 and 0.911, respectively. Thus the residuals for both particles sizes are normally distributed at a significance level of 0.05.

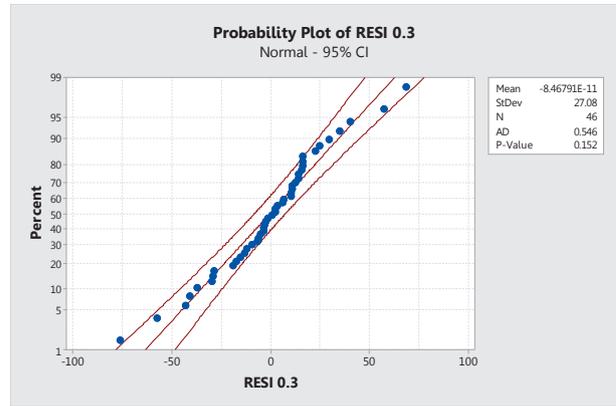


Fig. 6 Probability plot of the residuals for APC 0.3 microns

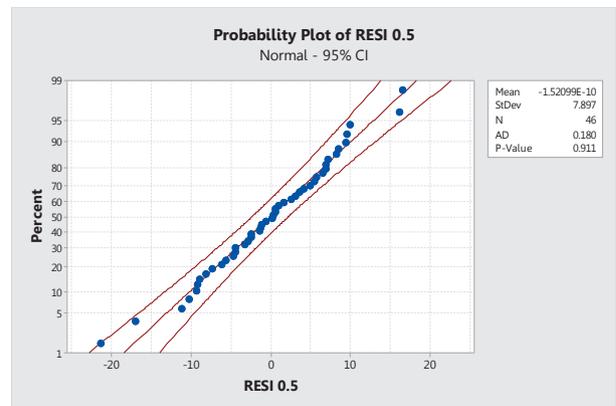


Fig. 7 Probability plot of the residuals for APC 0.5 microns

**Variance stability test:** The residuals versus fitted values plot are shown in Fig. 8 and Fig. 9 for particle size 0.3 microns and 0.5 microns, respectively. Since the residuals were randomly distributed without any particular pattern, therefore, the stability of variances was confirmed.

**Independence of the residuals:** Referring to the residuals plot versus observation orders as shown in Fig 8 and Fig 9, it is shown that the residuals were randomly distributed without any particular pattern. Therefore, the residuals were assumed to be independent.

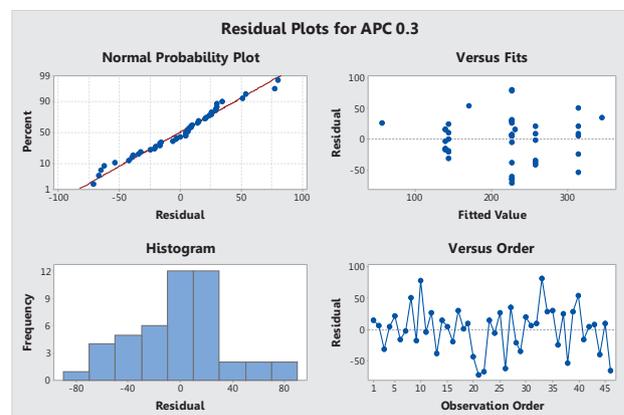


Fig. 8 Residual plot 4 in 1 of the residuals APC 0.3 microns

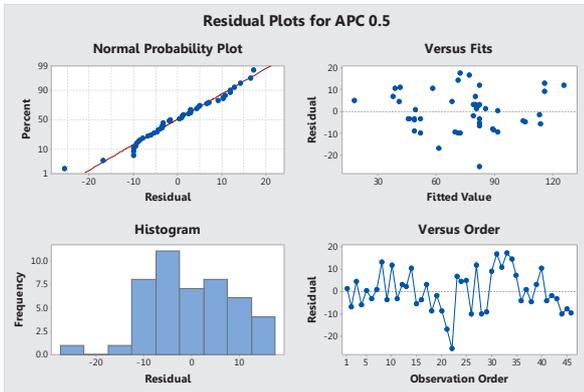


Fig. 9 Residual plot 4 in 1 of the residuals APC 0.5 microns

The experimental data were analyzed by Minitab R17. The Analysis of Variance (ANOVA) [4] for particle size 0.3 microns is shown in Fig. 10, while for particle size 0.5 microns is shown in Fig. 11. It's found that the factors and terms that have effect on the APC for both particles size 0.3 microns and 0.5 microns are the same. That is factor B, factor E, and the square of B\*B is significance at a level of 0.05.

## 2. Response Surface Methodology (RSM)

### A. Box-Behnken Design.

The results from Minitab R17 for Box-Behnken Design analysis with backward elimination stepwise algorithm are shown on Fig. 12 for particle size of 0.3 microns and Fig. 13 for particle size of 0.5 microns, respectively. The reduced regression models for APC of particle size 0.3 and 0.5 microns are shown in equation (1) and (2)

$$\text{APC } 0.3 = 446.8 + 162.4B - 1.755D - 26.4B*B \quad (1)$$

$$\text{APC } 0.5 = -72.9 + 2.77A + 62.4B + 58.0C - 0.6746E - 0.01636A*A - 10.54 B*B - 6.7C*C \quad (2)$$

Where:

A: FFU Speed (fpm)

B: Air Return width (cm)

C: Hold Size of Table (mm)

D: Exhaust Suction (fpm)

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	20	206136	10307	7.81	0.000
Linear	5	181577	36315	27.51	0.000
A	1	2475	2475	1.88	0.183
B	1	51832	51832	39.27	0.000
C	1	1202	1202	0.91	0.349
D	1	2809	2809	2.13	0.157
E	1	123260	123260	93.38	0.000
Square	5	13128	2626	1.99	0.115
A*A	1	1709	1709	1.29	0.266
B*B	1	7721	7721	5.85	0.023
C*C	1	2799	2799	2.12	0.158
D*D	1	112	112	0.09	0.773
E*E	1	303	303	0.23	0.636
2-Way Interaction	10	11431	1143	0.87	0.575
A*B	1	841	841	0.64	0.432
A*C	1	8	8	0.01	0.938
A*D	1	2209	2209	1.67	0.208
A*E	1	2272	2272	1.72	0.201
B*C	1	2336	2336	1.77	0.195
B*D	1	812	812	0.62	0.440
B*E	1	17	17	0.01	0.910
C*D	1	2116	2116	1.60	0.217
C*E	1	568	568	0.43	0.518
D*E	1	251	251	0.19	0.667
Error	25	32998	1320		
Lack-of-Fit	20	22193	1110	0.51	0.869
Pure Error	5	10805	2161		
Total	45	239134			

Fig. 10 The Analysis of Variance for APC 0.3 microns

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	20	27663.5	1383.2	12.32	0.000
Linear	5	25417.7	5083.5	45.28	0.000
A	1	200.7	200.7	1.79	0.193
B	1	6534.0	6534.0	58.20	0.000
C	1	300.4	300.4	2.68	0.114
D	1	180.0	180.0	1.60	0.217
E	1	18202.5	18202.5	162.15	0.000
Square	5	1721.3	344.3	3.07	0.027
A*A	1	210.4	210.4	1.87	0.183
B*B	1	692.8	692.8	6.17	0.020
C*C	1	224.9	224.9	2.00	0.169
D*D	1	73.2	73.2	0.65	0.427
E*E	1	195.2	195.2	1.74	0.199
2-Way Interaction	10	524.6	52.5	0.47	0.895
A*B	1	21.8	21.8	0.19	0.663
A*C	1	5.4	5.4	0.05	0.827
A*D	1	124.7	124.7	1.11	0.302
A*E	1	72.2	72.2	0.64	0.430
B*C	1	9.0	9.0	0.08	0.779
B*D	1	64.0	64.0	0.57	0.457
B*E	1	7.1	7.1	0.06	0.803
C*D	1	200.7	200.7	1.79	0.193
C*E	1	17.4	17.4	0.15	0.697
D*E	1	2.2	2.2	0.02	0.889
Error	25	2806.5	112.3		
Lack-of-Fit	20	2023.4	101.2	0.65	0.780
Pure Error	5	783.1	156.6		
Total	45	30470.0			

Fig. 11 The Analysis of Variance for APC 0.5 microns

### Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		227.26	6.71	33.85	0.000	
B	113.83	56.92	9.19	6.19	0.000	1.00
E	-175.54	-87.77	9.19	-9.55	0.000	1.00
B*B	-52.8	-26.4	11.4	-2.32	0.025	1.00

Fig. 12 Result of the RSM analysis for APC particle size 0.3 microns

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		82.36	2.65	31.10	0.000	
A	-7.08	-3.54	2.48	-1.43	0.161	1.00
B	40.42	20.21	2.48	8.16	0.000	1.00
C	8.67	4.33	2.48	1.75	0.088	1.00
E	-67.46	-33.73	2.48	-13.62	0.000	1.00
A*A	-13.09	-6.54	3.15	-2.08	0.045	1.06
B*B	-21.09	-10.54	3.15	-3.35	0.002	1.06
C*C	-13.42	-6.71	3.15	-2.13	0.040	1.06

Fig. 13 Result of the RSM Analysis for APC particle size 0.5 microns

B. Response Optimizer

To determine the optimal level of each factor, the response optimizer in Minitab was conducted with the setting of minimization. The target of zero counts/ft<sup>3</sup> of the APC was set for both particle size of 0.3 and 0.5 microns. The upper limits of 300 counts/ft<sup>3</sup> and 100 Counts/ft<sup>3</sup> for particle size 0.3 microns and 0.5 microns were set, respectively. The results obtained in Fig. 14. The minimum APC for particle size 0.3 microns is 56.1875 Counts/ft<sup>3</sup> and for particle size 0.5 microns is 0.1192 Counts/ft<sup>3</sup>.

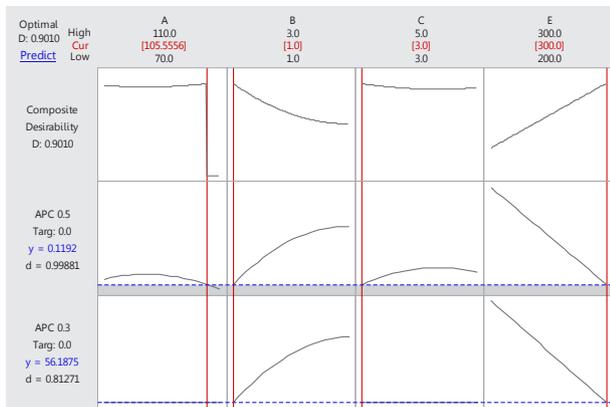


Fig. 14 Results of the RSM Response Optimization

V. CONCLUSION

The optimal setting for each factor that provide the lowest APC is shown in Table III

TABLE III  
OPTIMAL FACTORS LEVEL

Factor	Unit	Parameter
A: FFU Speed	fpm.	105
B: Air Return width	cm.	1
C: Hold Size of Table	mm.	3
D: Air ionizer height	cm.	set at convenience level
E: Exhaust Suction	fpm.	300

Then confirmation runs were then performed, the APC were compared as shown in Table IV.

TABLE IV

CONFIRMATION RUNS AND THE COMPARISON OF RESULTS BEFORE AND AFTER ADJUSTING THE PARAMETERS OF EACH FACTOR

Run Number	Before Parameters Adjustment		After Parameters Adjustment	
	0.3 μm	0.5 μm	0.3 μm	0.5 μm
1	4,435	1,427	59	10
2	4,345	1,347	63	11
3	5,543	1,217	66	18
4	3,781	1,276	61	13
5	3,678	1,256	79	19
6	4,567	1,292	89	21
7	4,321	1,277	58	12
8	3,982	1,236	68	21
9	4,563	1,352	64	16
10	4,567	1,421	66	14
11	4,576	1,542	84	22
12	4,689	1,356	56	16
13	4,897	1,256	78	22
14	4,003	1,324	76	20
15	4,673	1,372	60	18
16	3,974	1,421	61	15
17	4,231	1,226	78	21
18	4,564	1,234	56	12
19	4,566	1,375	76	26
20	3,891	1,244	65	19
Average	4,392	1,323	68	17

As shown in Table IV, from the confirmation runs it's found that the APC for both particle size 0.3 and 0.5 microns were drastically reduced. The average APC of particle size 0.3 microns was reduced from 4,392 counts/ft<sup>3</sup> to 68 counts/ft<sup>3</sup>. The average APC of particle size 0.5 microns was reduced from 1,323 counts/ft<sup>3</sup> to 17 counts/ft<sup>3</sup>. With the optimal setting of process parameters obtained from this research, the HGA washing process of the studied plant is now conformed to the class 100 clean room requirements specified by the US Federal Standard 209E.

VI. SUGGESTION

From the experimental results, it's found that the actual APC were a little bit deviated from the expected APC results that could have been obtained from the regression models. This might be caused by the noises or the uncontrollable factors in clean room, such as temperature, humidity, errors due to experiments, measurement instruments, and etc. Thus the carefully set up of experimentations with the same environmental conditions before and after the improvement are important.

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## REFERENCES

- [1] T. Lin, Y.-C. Tung, S.-C. Hu, and Y.-J. Chen, "Experimental study on airflow characteristics and temperature distribution in non-unidirectional cleanrooms for electronic industry," *Building and Environment*, vol. 46, no. 6, pp. 1235–1242, Jun. 2011.
- [2] "Cleanroom Classifications," *Data Recovery Salon*, 2015. [Online]. Available: <http://www.datarecoverytools.co.uk/data-recovery-vocabulary/vocabulary-a-e/clean-room>.
- [3] "Box-Behnken Designs for Optimizing Product Performance," *Reliability HotWire*, 2015. [Online]. Available: <http://www.weibull.com/hotwire/issue130/hottopics130.htm>.
- [4] D. A. Raj and T. Senthilvelan, "Empirical Modelling and Optimization of Process Parameters of machining Titanium alloy by Wire-EDM using RSM," *Materials Today: Proceedings*, vol. 2, no. 4, pp. 1682–1690, Jan. 2015.
- [5] J.-J. Chen, C.-H. Lan, M.-S. Jeng, and T. Xu, "The development of fan filter unit with flow rate feedback control in a cleanroom," *Building and Environment*, vol. 42, no. 10, pp. 3556–3561, Oct. 2007.
- [6] M. Ebrahimi, F. Mahboubi, and M. R. Naimi-Jamal, "RSM base study of the effect of deposition temperature and hydrogen flow on the wear behavior of DLC films," *Tribology International*, vol. 91, pp. 23–31, Nov. 2015.
- [7] C. Y. Khoo, C.-C. Lee, and S.-C. Hu, "An experimental study on the influences of air change rate and free area ratio of raised-floor on cleanroom particle concentrations," *Building and Environment*, vol. 48, pp. 84–88, Feb. 2012.
- [8] T. Xu, "Characterization of minienvironments in a clean room: Design characteristics and environmental performance," *Building and Environment*, vol. 42, no. 8, pp. 2993–3000, Aug. 2007.