Optimization of Parameters in Ultrasonic Cleaning Process for Hard Disk Drive Arm Using Taguchi Experimental Design Technique

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Abstract

In this paper, we describe an experimental study undertaken to investigate the most influenced factors on the surface cleanability of hard disk drive arm and provide the optimal settings to maximize surface cleanability or minimize liquid particle counting (LPC). This will lead to reduction in the operation cost and improvement in hard disk drive arm quality. The experimental design for the study was based on Taguchi technique. A 2 level and 4 factors orthogonal array was used for screening main factors. The results show the main factors and optimal setting of water temperature at 35 °C, ultrasonic frequency at 80 kHz, ultrasonic power level at 90 per cent of 2500 watts and cleaning time at 480 sec.

Keywords: Taguchi technique, design of experiment, ultrasonic, cleaning, hard disk drive arm

Introduction

Submicron particulate contamination is a leading cause of device failures and manufacturing process yield losses in many microelectronic industries, such as semiconductor devices, integrated circuits, hard disk drives, etc. As critical product dimensions shrink in an increasingly miniaturized market, the minimum size of particle that can cause defects continues to decrease as well, resulting in spiraling cleaning complexity and costs Nagarajan et al.,2006.

Ultrasonic cleaning process has been widely adopted in the hard disk drive industry according to its effectiveness. It can remove tough contaminants on the hard disk drive arm according to manufacturing, assembling and components. It is also able to reach internal areas which are not accessible using other cleaning means including spray and mechanical agitation. Cleanliness of parts and assemblies has always been an important factor for product yield in the hard disk drive industry. It spends on the efficiency of the final cleaning process. It is critical that this process be well optimized (Roman and G, 1997).

The optimization of an ultrasonic cleaning process for a given surface must be based on measurable surface cleanability. The optimum setting of ultrasonic cleaning must be identified in order to produce the minimum LPC of product.

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The LPC in this paper, which removes particles from a surface are defined by first suspends the product to be measured with cleanliness in a liquid medium, enables the indirect determination of surface cleanability. The LPC provides particle size as well as count information. These highly-sensitive techniques are more suited to the study and optimization of ultrasonic cleaning of hard disk drive arm and other high-precision assemblies and components (Antony and Kaye, 1995).

Taguchi's parameter design methodology (PD) has proved to be an effective approach for producing high-quality products at a relatively low cost. The objective of parameter design (also know as robust design) is to determine the best settings of the process parameters, thereby making the process functional performance insensitive to various sources of variation. In order to accomplish this objective, Taguchi advocates the use of statistical design of experiments (Nagarajan,1993). Many successful applications of PD have been reported in US and European manufacturing firms, especially over the last fifteen years (Taguchi and G,1986;Quinlan and J,1985;Ramberg and J.S., 1989;Pereira et al.,1993).

The Taguchi technique of experimental design was an immediate replacement of the traditional "one-factor-at-a-time" experiment, which did not provide any insight into the behavior of the system and the best levels identified were rather far from optimum. The results of improved and more consistent LPC will reduce the number of rejects and hence produce a more reliable and robust product. In order to apply Taguchi methods effectively in industry, one may require planning, engineering, communication, statistical and teamwork skills. Moreover, the participation of the right people, the commitment of top management, an awareness of Taguchi methods, reasonable statistical skills, etc. are essential ingredients for the successful implementation of Taguchi methods in any organization. Taguchi methodology is a powerful approach to understanding the process and then optimizing the performance of the process using the statistical design of experiments. Taguchi methods provide a systematic approach to a better understanding of the process and assist industrial engineers to discover the key process

Parameters (or variables) which affect the critical process /product characteristic(s) (Antonyet al., 2001.). Taguchi's philosophy is more relevant in terms of working towards a target performance of product/process, which essentially reflects the continuous improvement attitude (Miesel et al., 1991). Taguchi methods have numerous applications in manufacturing companies, particularly in automotive, plastics, process, semiconductors and metal fabrication (Antonyet al., 2001).

Experimental equipment

JCS/QUTN4531/2006 ultrasonic equipment at Lanna Thai Electronic Components Ltd [LTEC] has been used for the experiment of our study. The In-line washing machine consists of 9 processing tanks. They are namely ultrasonic cleaning (1 unit), Spray Rinsing, Ultrasonic Rinsing (3 units), Pre-Dry, conventional oven (2 units) and vacuum oven. The input power to the ultrasonic tank is a maximum of 2500 watts. Figure 1 illustrates the ultrasonic cleaning process. The Nighthawk 1H Arm-Coil (Aluminum material) product model was used to conduct the experiments.

Experimental data and analysis

The following steps are used for the experiment.

Step 1: set objective of the experiment

The objective was to identify those control factor settings which provided minimum LPC with minimum variation.

Step 2: identification of the control factors and their levels

The identification of production parameters (control factors) is crucial for the success of any industrial experiment (Antony, 1997.). A brain-storming session among senior design engineers, quality assurance engineers and operators identified a list of control factors which were thought to influence the LPC. Table 1 illustrates the list of control and noise factors.

Step 3: selection of most suitable response for the experiment

A "response" is an output performance characteristic of product or process critical to customers; these often reflect the quality of the finished product (Kolarik,1995). Antony recommended the choice of quantitative over quanlitative response (Antony et al., 2001.). For this paper, it was decided to measure LPC in 0.3 and 0.6 microns (µ).

Step 4: choice of orthogonal array (OA) design

The L_8 orthogonal array with 3 replication used in the experiment as shown in Table II. A batch of 224 pieces of hard disk drive parts were selected for cleaning process. After cleaning, a sample of 8 pieces were taken randomly for LPC test.

Step 5: preparation of experimental layout and run

In this step, the main task is to design the experimental layout and assign the factors to appropriate columns of the chosen OA. Table II illustrates the experimental layout.

Step 6: statistical analysis and interpretation of experimental results

In this paper, as we needed to minimize the LPC with minimum variation, the S/N ratio for "smaller-the-better" response was selected. The higher the S/N ratio, the better the product performance will be.

The S/N ratio for smaller-the-better response is given by the following equation:

$$S/N = -10\log \sum_{i=1}^{n} \frac{y_i^2}{n} \qquad (1)$$

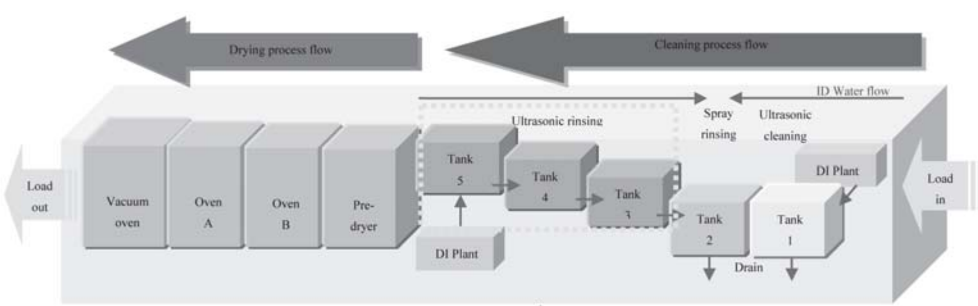

Figure 1. A simple illustration of the ultrasonic cleaning process

Using the above equation, the S/N ratio corresponding to each trail condition was computed. Having obtained the S/N ratio values, the next step was to calculate the average S/N ratio at each level of each factor. For interaction effect, it is important to analyse the S/N ratio corresponding to each factor level combination. Table III and IV provides the average S/N ratio of LPC 0.3 and LPC 0.6 for all factors and the interaction between water temperature and ultrasonic frequency (AxB), water temperature and ultrasonic power level (AxC), ultrasonic frequency and ultrasonic power level

(BxC). The figure 2 and 3 shows that main effects plot for S/N ratio of LPC 0.3 and 0.6. The figure 4 and 5 shows that interaction plot for S/N ratio of LPC 0.3 and LPC 0.6.

In order to determine which of the factor/interaction effects are statistically significant, a powerful statistical technique called analysis of variance (ANOVA) was used. Using ANOVA, one is able to identify the active and inactive factor/interaction effects with statistical confidence (Antonyet al., 2001.).

The ANOVA on the S/N ratio of LPC 0.3 and LPC 0.6 were conducted. The results of the ANOVA on the S/N ratio of LPC 0.3 and LPC 0.6 shown in Table V and VI shows that factors A, B, D and interaction factor BxC are statistically significant at 0.10 level are implying that factor C should be incorporated into the model.

The analysis based on Taguchi S/N ratio structure showed similar trends in terms of main effects and interactions for both the S/N ratio output and the results of ANOVA.

Table 1. List of control factors for the Taguchi experiment

Control factor	Level 1	Level 2
Water Temperature (A) (°C)	35	45
Ultrasonic Frequency of Tank1 (B) (kHz)	40	80
Ultrasonic Power Level (C) (per cent of 2500W)	70	90
Cleaning Time (D) (sec.)	240	480
Noise factor	**1**	**2**
Position of baskets (E)	Left	Right
Position of parts (F)	Lower	Upper

Determination of optimal condition

The optimal condition is the optimal factor settings which yield the optimum performance. In this case, it is the factor settings which provide the highest S/N ratio with minimum variation. The optimal condition is obtained by identifying the levels of significant control factors which yield the highest S/N ratio and minimum mean LPC. As 4 control factors have significant impact on the S/N ratio according to the concept of delta measure of Taguchi, it was important to determine the optimal levels of these factors. The optimal settings based on the S/N ratio are: $A_1B_2C_2D_2$. Similarly, the optimal settings base on the mean LPC 0.3 and 0.6 are: $A_1B_2C_2D_2$. It is obvious that there is no trade-off in the factor levels. Therefore the final optimal condition is given by: $A_1B_2C_2D_2$.

Estimation of predicted mean response at the optimal condition

Step 7: confirmation run

A confirmation run/trial is necessary in order to verify the results from the analysis (Antony and Kaye, 1995). For this study, a set of confirmation trials will been carried out in the future work.

Table 2. Experimental layout used for the study

Trail	A	B	A x B	C	A x C	B x C	D	Average S/N ratio	
								LPC 0.3	LPC 0.6
1	1	1	1	1	1	1	1	-96.71	-75.20
2	1	1	1	2	2	2	2	-96.86	-76.05
3	1	2	2	1	1	2	2	-95.47	-74.24
4	1	2	2	2	2	1	1	-94.83	-74.47
5	2	1	2	1	2	1	2	-96.83	-77.41
6	2	1	2	2	1	2	1	-99.05	-79.52
7	2	2	1	1	2	2	1	-98.20	-79.14
8	2	2	1	2	1	1	2	-94.84	-76.56

Table 3. Average S/N ratio of LPC 0.3

Level	A	B	AxB	C	AxC	BxC	D
1	-95.97	-97.36	-96.65	-96.81	-96.52	-95.80	-97.20
2	-97.23	-95.84	-96.55	-96.39	-96.68	-97.40	-96.00
Delta	1.26	1.53	0.10	0.41	0.16	1.59	1.20
Rank	3	2	7	5	6	1	4

Table 4. Average S/N ratio of LPC 0.6

Level	A	B	AxB	C	AxC	BxC	D
1	-74.99	-77.05	-76.74	-76.50	-76.38	-75.91	-77.08
2	-78.16	-76.10	-76.41	-76.65	-76.77	-77.24	-76.07
Delta	3.16	0.94	0.33	0.15	0.39	1.33	1.02
Rank	1	4	6	7	5	2	3

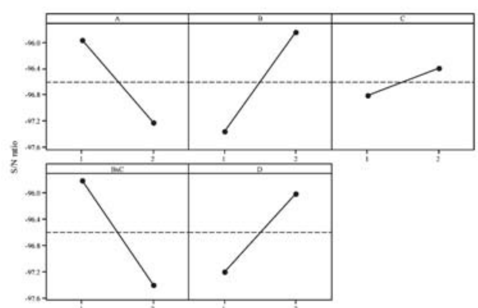

Figure 2. Main effects plot for S/N ratio of LPC 0.3

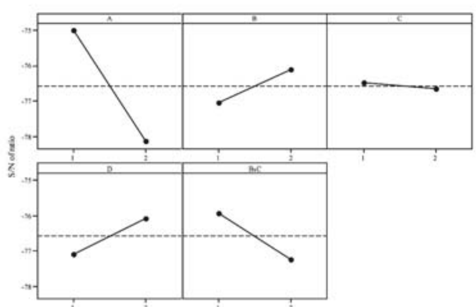

Figure 3. Main effects plot for S/N ratio of LPC 0.6

Conclusion

The paper presented the results of screening factors of a study on optimization of process parameter for ultrasonic cleaning process. It is important to bear in mind that the successful application of Taguchi technique of experimentaldesign requires planning, engineering, statistical, communication and team-work skills. The real benefits are achievable when the technique is used in conjunction with other tools and techniques such as statistical process control. As the LPC decreases with a decrease water temperature, increase ultrasonic frequency, ultrasonic power level and cleaning time, it was decided to perform a three level experiment with the aim of achieving greater optimization.

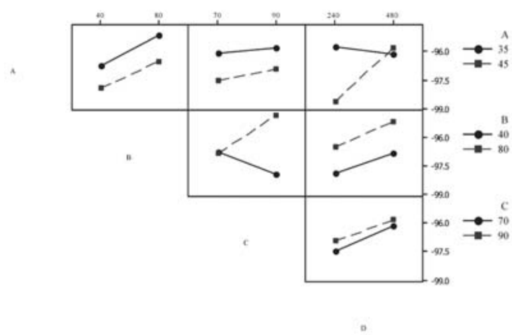

Figure 4. Interaction plot for S/N ratio of LPC 0.3

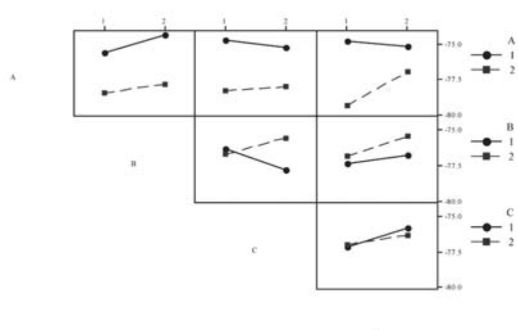

Figure 5. Interaction plot plot for S/N ratio of LPC 0.6

Table 5. Results of ANOVA on S/N ratio of LPC 0.3

Source of variation	Sum of Squares	DF	Mean Square	F-ratio	P-value
Model	16.21	6	2.70	123.88	0.0687
A	3.19	1	3.19	146.20	0.0525
B	4.67	1	4.67	214.12	0.0434
C	0.34	1	0.34	15.61	0.1578
AxC	0.053	1	0.053	2.41	0.3640
BxC	5.07	1	5.07	232.63	0.0417
D	2.89	1	2.89	132.29	0.0552
Residual	0.022	1	0.022		
Total	16.23	7			

Table 6. Results of ANOVA on S/N ratio of LPC 0.6

Source of variation	Sum of Squares	DF	Mean Square	F-ratio	P-value
Model	27.93	6	4.65	99.29	0.0767
A	20.03	1	20.03	427.27	0.0308
B	1.78	1	1.78	37.95	0.1024
AxB	0.21	1	0.21	4.52	0.2798
AxC	0.31	1	0.31	6.58	0.2367
BxC	3.53	1	3.53	75.28	0.0731
D	2.07	1	2.07	44.15	0.0951
Residual	0.047	1	0.047		
Total	27.97	7			

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