Thammasat Int. J. Sc. Tech., Vo.7, No.2, May-August 2002

Quality Improvement on the Slider Cutting Process

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Abstract

This paper discusses the study to improve the quality of sliders in the final cutting process of the harddisk drive production through the use of the design of experiment (DOE) technique. The objective of this study is to find a better cutting condition for the cutting process to reduce the number of chips and cracks. The method began with the consideration of influencing factors that cause chips and cracks on the slider. Using the cause and effect diagram, five promising parameters were selected. They are: spindle speed, depth of cut, feed rate, duration of dressing time, and direction of cut. These factors were subject to the screening experiments using one-half fractional of 2^k factorial design. The results showed that the significant parameters that affect the chips and cracks are the spindle speed and the direction of cut. Therefore, further analysis was conducted with the emphasis on the spindle speed and the direction of cut. The results suggested that the spindle speed be set at 8,500 rpm and the direction of cut be "pole to taper." Nevertheless, the field experiment failed to show the significant reduction of the number of chips and cracks. Additional analysis (single-factor experimental design) was then conducted on the frequency of inline-dressing using three frequency levels. It was found that setting the inline-dressing at its highest frequency yielded the best result. Performing the dressing in every cut could reduce the number of chips and cracks. The result was also confirmed by the field experiment.

Keywords: Chip and crack of the slider, one-half fractional factorial design, 2^k factorial design, harddisk drive production, quality improvement

1. Introduction

Harddisk drive is an important part of a personal computer. Its function is to store operating system, software, and data. Presently, harddisk drive has been developed with the objectives to improve reliability and quality, increase density and seek time, and reduce cost. The price of a harddisk drive tends to be decreased while the density is increased. Since customers do not want to lose important data that are saved in the harddisk, harddisk drive makers must try the best they can to reduce the number of defective products that will be delivered to the customers. A harddisk drive consists of many parts and requires several manufacturing processes to produce the final unit. It is essential that each process produce or assemble parts that are free of defects. If one part fails, it will affect workability of the harddisk drive.

The read/write head called slider is one significant part in the harddisk drive. In concept, harddisk heads are relatively simple. They transform electrical signals to magnetic signals, and magnetic signals back to electrical ones. The heads on a home stereo tapedeck perform a similar function, although using a different technology. The read/write heads are in essence tiny electromagnets that perform this conversion from electrical information to magnetic, and back again. Each bit of data to be stored is recorded onto the harddisk using a special encoding method that translates zeroes and ones into magnetic flux reversals.

The bit size of a harddisk has shrunk dramatically over time. Current high-end harddisks have exceeded 10 Gbit/in^2 in area density, but it has been only a few years when 1 Gbit/in^2 was state of the art. As the bit size drops and the bits are packed closer together, magnetic fields become weaker and more sensitive head electronics are required to properly detect and interpret the data signals. Because of the tight packing of data bits on the harddisk, it is important to make sure that the magnetic fields do not interfere with one another. Increasing the density of the harddisk means that the fields must be made even weaker, which means that the read/write heads must be faster and more sensitive so they can read the weaker filed and accurately figure out which bits are ones and which bits are zeroes.

Slider fabrication requires many processes to develop the read/write head part. The steps of the slider fabrication process are shown as follows.

1. Attach wafer to carbon lava.
2. Cut wafer to be rectangular stick called "Bar".
3. Release bars from carbon lava
4. Attach them onto transfer tool.
5. Rough lap on Air Bearing Surface (ABS)
6. Auto lap and measure the resistance until the specification is met.
7. Release bars from transfer tool
8. Attach it on pallet by using glue.
9. Glue curing.
10. Make cavity depth.
11. Make relief cut.
12. Dice through each bar. Slider will be obtainable in this process.
13. Debond sliders from pallet and pick them up by robot.
14. Relap
15. Diamond coating on ABS.

At present, the slider is shrunk to be a very tiny unit in order to reduce the unit cost of a harddisk. Therefore harddisk makers have to put more effort to control quality and reliability of the head. Because of very small head size, every process needs to have better (and tighter) process control. One wafer consists of many sliders and they have to be separated by the cutting process. Many defects were found in the cutting process. Currently, defects commonly found on the slider include chips, cracks, contamination and scratches on ABS.

The machining department of a major harddisk manufacturer has experienced quality problems in its production processes. The quality improvement program was set up to achieve better quality and to reduce loss from defective sliders. It was found that chips and cracks are major defects since their occurrence rate is at the highest level. Therefore, the improvement target is to decrease the number of chips and cracks. The current percentage of these defects is at 0.3%. To support the quality improvement effort of this harddisk manufacturer, the cutting process needs to be improved in order to reduce the chip and crack defects.

The design of experiment (DOE) was used as a tool to identify the cutting parameters that are potential causes of defects. (The wafer cutting theory is explained in [1]). DOE has been found to be an effective tool for the quality improvement effort. Phichatwattana [2] applied DOE to identify the causes of the pull strength problem of the read/write head. In IC manufacturing, the CSP singulation process was investigated and DOE was applied to determine better cutting conditions [3].

In this study, two experiments were needed to identify influencing parameters. Firstly, one-half fractional of 2^k of factorial design was used to search for potential causes of defects, but without success. The second search was then performed. A single factor analysis of variance was able to recommend cutting conditions that reduce chip and crack defects.

2. Search for Causes of Defects

A systematic procedure for applying DOE can be found in [4]. Briefly, the procedure consists of the following steps:

1. Recognition and statement of the problem.
2. Choice of factors, levels, and ranges.
3. Selection of response variables.
4. Choice of experimental design.
5. Performing the experiment.
6. Statistical analysis of the data.
7. Conclusion and recommendation.

2.1 Problem Analysis

In the cutting process, chips and cracks are the main defects that have to be improved.

Therefore, the objective of the first experiment is to determine the influencing parameters that cause chips and cracks in the cutting process and better cutting conditions that can reduce the number of defects. The target is to reduce the number of defects by half (or 50% reduction).

A cause and effect diagram is used to identify possible causes of chips and cracks on the slider. The concept of 4M (man, machine, method, and material) are mainly considered for finding potential causes. Five potential parameters are selected, i.e., spindle speed (A), depth of cut (B), feed rate (C), duration of dressing time (D), and direction of cut (E). Each parameter has two levels and possible ranges of the values are set as shown in Table 1.

Table 1 Potential parameters and levels

Parameters	Symbol	Levels	
		- (Low)	+ (High)
1. Spindle speed (rpm.)	A	8,500	11,000
2. Depth of cut (mil)	B	30	40
3. Feed rate (IPM)	C	4	6
4. Number of dressing time (time)	D	6	10
5. Direction of cut	E	Taper – Pole	Pole – Taper

2.2 Experimental Design

Normally, a 2^k factorial design is used for screening the factors. As the number of factors in the 2^k factorial design increases, the number of runs required for a complete replication of the experiment will usually outgrow the resources of the experiment. If it can be reasonably assumed that certain high-order interactions are negligible, the information on the main effects and low-order interactions may be obtained by running only a fraction of the complete factorial design. These fractional of 2^k factorial designs are especially useful in the early states of experiment when there are many factors to be investigated. Therefore, they are widely used for product and process design as well as for process improvement.

As stated earlier, a one-half fractional of a 2^k factorial design is selected for the first experiment. Since it consists of 5 factors (k=5), one-half fractional of 2^5 factorial design is called 2^{5-1} design. The generator is I = ABCDE. Thus, the design is as of resolution V. For more information, see Montgomery [4].

The construction of the 2^{5-1} design is shown in Table 2. All 16 runs (experiments) in Table 2 were performed in random order. The sample size in each run was kept constant. Therefore the number of defects can be used in the analysis of variance directly. The data are shown in the last column of Table 2.

Table2 A 2^{5-1} Design for Chip & Crack Defects

Run	Basic Design				E=ABCD	Treatment combination	Chip & Crack Defects
	A	B	C	D			
1	-1	-1	-1	-1	1	E	2
2	1	-1	-1	-1	-1	A	17
3	-1	1	-1	-1	-1	B	16
4	1	1	-1	-1	1	ABE	35
5	-1	-1	1	-1	-1	C	25
6	1	-1	1	-1	1	ACE	6
7	-1	1	1	-1	1	BCE	12
8	1	1	1	-1	-1	ABC	29
9	-1	-1	-1	1	-1	D	22
10	1	-1	-1	1	1	ADE	29
11	-1	1	-1	1	1	BDE	14
12	1	1	-1	1	-1	ABD	5
13	-1	-1	1	1	1	CDE	7
14	1	-1	1	1	-1	ACD	8
15	-1	1	1	1	-1	BCD	27
16	1	1	1	1	1	ABCDE	33

2.3 Statistical Analysis

Estimators for the parameters in one-half fractional of 2^5 factorial design are presented as following linear model.

$$\begin{aligned} y_{ijklm} &= \mu + \tau_i + \beta_j + \gamma_k + \omega_l + \theta_m + (\tau\beta)_{ij} \\ &+ (\tau\gamma)_{ik} + (\tau\omega)_{il} + (\tau\theta)_{im} + (\beta\gamma)_{jk} \\ &+ (\beta\omega)_{jl} + (\beta\theta)_{jm} + (\gamma\omega)_{kl} + (\gamma\theta)_{km} \\ &+ (\omega\theta)_{lm} + \epsilon_{ijklm} \end{aligned}$$

where possible values for *i*, *j*, *k*, *l*, and *m* are 1 and 2, y_{ijklm} is the (ijklm)th observation, μ is overall mean effect, τ_i is the effect of the i th level of the factor A, β_j is the effect of the j th level of the factor B, γ_k is the effect of the k th level of the factor C, ω_l is the effect of the l th level of the factor D, θ_m is the effect of the m th level of the factor E, $[(\tau\beta)_{ij}, (\tau\gamma)_{ik}, (\tau\omega)_{il}, (\tau\theta)_{im}, (\beta\gamma)_{jk}, (\beta\omega)_{jl}, (\beta\theta)_{jm}, (\gamma\omega)_{kl}, (\gamma\theta)_{km}$, and $(\omega\theta)_{lm}]$ are the effect of the two-order interaction between each pair of factors, and ϵ_{ijklm} is a random error component.

An example of the hypotheses for testing the factor A effect is shown below.

H_0 : $\tau_1 = \tau_2 = 0$

H_1 : At least one $\tau_i \neq 0$; $i = 1, 2$

where τ_i is the effect of factor A.

To check the adequacy of the model, the residuals of each effect are calculated. Figure 1 presents a normal probability plot of the residuals, Figure 2 presents a plot of residuals versus time, and Figure 3 is a plot of residuals versus predicted values. All plots are satisfactory. Thus, there is no reason to suspect any violation of the normality, independence, and constant variance assumptions.

Table 3 contains the estimated effects, sums of squares, contrasts, and model regression coefficients of the 15 effects from this experiment. It is seen that the main effect of B and the interaction effects of AE, BC, BE, CE, and DE are large. Therefore, they were further analysed using the analysis of variance (ANOVA). Table 4 shows the summary of the analysis of variance. The model sum of squares $SS_{model} = SS_A + SS_{AE} + SS_{BC} + SS_{BE} + SS_{CE} + SS_{DE}$ and is equal to 1455.36. This accounts for 83.21% of the total variation in the model. The AE interaction has the largest effects and its P-value is 0.0019. The result indicates that the AE interaction is significant at $\alpha = 1\%$.

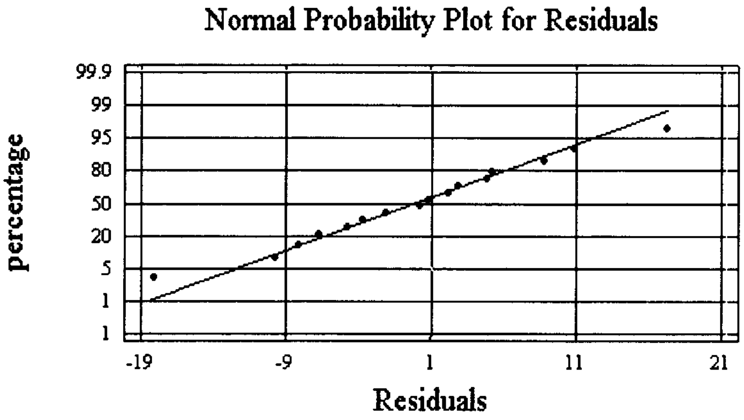
Normal Probability Plot for Residuals

Figure 1 Normal probability plot of residuals.

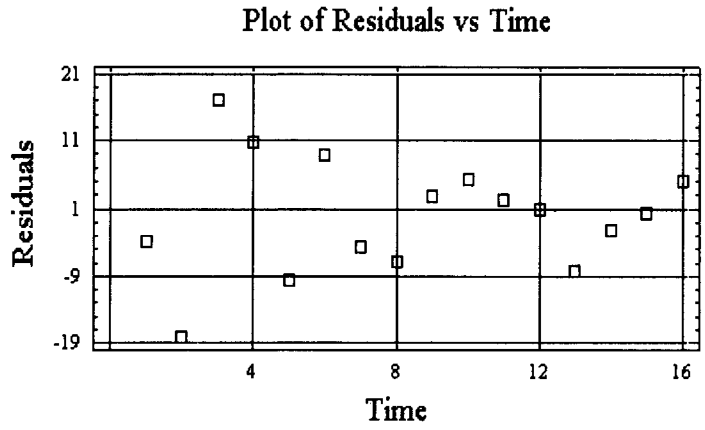
Plot of Residuals vs Time

Figure 2 Plot of residual versus time.

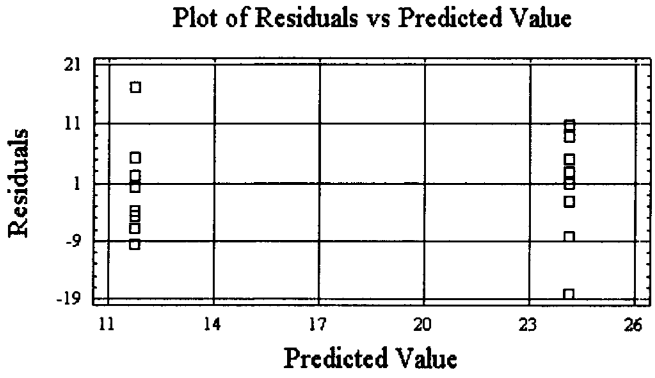
Plot of Residuals vs Predicted Value

Figure 3 Plot of residuals versus predicted chips and cracks.

Table 3 Effects, Regression Coefficients, and Sums of squares

Variable	Regression Coefficient	Estimated Effect	Sum of Squares	Contrast
Overall Average	17.938			
A	2.313	4.625	85.56	37
B	3.438	6.875	189.06	55
C	0.438	0.875	3.06	7
D	0.188	0.375	0.56	3
E	-0.688	-1.375	7.56	-11
AB	1.813	3.625	52.56	29
AC	-1.688	-3.375	45.56	-27
AD	-1.688	-3.375	45.56	-27
AE	6.188	12.375	612.56	99
BC	3.438	6.875	189.06	55
BD	-1.813	-3.625	52.56	-29
BE	2.813	5.625	126.56	45
CD	0.188	0.375	0.56	3
CE	-3.188	-6.375	162.56	-51
DE	3.313	6.625	175.56	53

Table 4 ANOVA table for the first experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_0	P-value
B	189.06	1	189.06	5.80	0.0394
AE	612.56	1	612.56	18.78	0.0019
BC	189.06	1	189.06	5.80	0.0394
BE	126.56	1	126.56	3.88	0.0804
CE	162.56	1	162.56	4.98	0.0525
DE	175.56	1	175.56	5.38	0.0455
Error	293.54	9	32.62		
Total	1748.90	15			

2.4 Interpretation of the Results

Table 4 shows the AE interaction has a significant effect on the chips and cracks on the slider. This means that the main factors A and E and their interaction factor AE should be further investigated. Table 5 shows the average response at each treatment combination of AE. The result confirms that chips and cracks were lower when both A (spindle speed) and E (direction of cut) were set at low level. The spindle speed of 8,500 rpm and the pole-taper direction are the preferable parameters for a new cutting condition while other parameters are set according to their initial settings.

The cutting condition shown in Table 6 was applied and the data showed that the average proportion of defects (p) was reduced from 0.0030 to 0.0027. Such reduction however is not significant. It was confirmed by the hypothesis test in defect proportion [5]. Other parameters that were not initially considered in the first experiment could have significant effects on the cutting process.

Therefore, the second experiment was set up in order to find new cutting parameters that have significant effects on the occurrence of chips and cracks.

Table 5 Average chip and crack defects when the AE interaction is significant

Direction of Cut	Spindle Speed (rpm.)	
	8,500	11,000
Taper - Pole	16.5	14.75
Pole – Taper	8.75	25.75

Table 6 New cutting conditions suggested by the first experiment

Factors or parameters	**Cutting condition**
1. Spindle speed (rpm.)	8,500 (rpm.)
2. Depth of cut (mil)	35 mil
3. Feed rate (IPM)	4 inch/min
4. Number of dressing time (time)	6 times
5. Direction of cut	Pole – Taper

3. Second Search for Causes of Defects

New cutting parameters were considered next. The frequency of inline-dressing was selected as a factor of the new experiment. Generally, Inline-dressing is performed in order to sharpen the blade. It is expected that a sharp blade should contribute to good quality in the cutting process. However, the production output would be reduced if the frequency of inline-dressing is increased.

3.1 Experimental Design

Since the frequency of inline-dressing was the only parameter to be investigated, a single factor analysis of the variance technique was employed. Three levels of the frequency of inline-dressing (shown in Table 7) were of interest. For each factor level, two replications of the experiment were performed. The data (numbers of cracks and chips) are also shown in Table 7.

3.2 Statistical Analysis

The estimated model parameters of a single factor experiment are according to the following linear model.

$$y_{ij} = \mu + \tau_i + \epsilon_{ij}$$

where $i = 1, 2$, and 3; $j = 1$ and 2, y_{ij} is the (ij)th observation, μ is a parameter common to all treatments, τ_i is the effect of i th treatment, and ϵ_{ij} is a random error component.

As a result, the hypotheses of this experiment can be written as:

H_0 : $\tau_1 = \tau_2 = \tau_3 = 0$

H_1 : At least one $\tau_i \neq 0$; $i = 1, 2$, and 3.

where τ_i is the treatment effect of factor level i.

3.3 Interpretation of the Results

The sums of squares, mean squares, and P-value are shown in Table 8. The P-value of this factor is 0.004, which indicates that the frequency of inline-dressing is a significant parameter. Therefore, it is concluded that the frequency of inline-dressing has a significant effect to on the number of chip and crack defects on the slider (significant at α = 1%).

Table 7 Experimental design for the second experiment

Frequency of inline-dressing	Amount of defects	
1. every 1 Column and 3 times	17	15
2. every 1/2 Column and 3 times	11	12
3. every 1 cut and 1 time	6	5

Table 8 ANOVA Table for the second experiment

Source of Variation	Sum of Squares	Df	Mean Square	F_0	P-value
Frequency of inline-dressing	111	2	55.5	55.5	0.004
Error	3	3	1		
Total	114	5			

4. Conclusion

Notice in Table 7 that the numbers of defects are lower when the frequency of inline-dressing is set at the highest frequency tested in this experiment. Thus the cutting condition in which inline-dressing was performed one time in every cut was implemented. The result of the implementation was positive, meaning that the quality has been improved. The proportion of defects was reduced from 0.003 to 0.001. The reduction is significant and meets the initial target. However, the economic justification of this implementation has to be analyzed because while the defects were decreased, the production output was also decreased.

5. Summary

This paper discusses the quality improvement of the slider cutting process in the harddisk drive production using the design of experiment (DOE) as an analysis tool. The objective of this study is to determine the influencing parameters that have significant effects on the number of chip and crack defects on the slider, and to find the better cutting condition. Initially, an experiment was conducted to gather the data based on one-half fractional of 2^k factorial design with single replicate. Five potential parameters, each having two setting levels, were investigated in this experiment. The analysis of variance showed that the effect of the AE interaction factor (where A = spindle speed and E = direction of cut) was significant. As a result, new cutting condition was set based on the spindle speed and the direction of cut. Although this cutting condition could reduce the number of defects, the percent reduction did not meet the target goal (50% reduction). Therefore the second experiment was conducted to search for a new parameter which will lead to greater improvement. The frequency of inline-dressing was tested to justify its potential. A single-factor analysis of variance was conducted with three factor levels. From the ANOVA table (Table 8), it is clear that the frequency of inline-dressing was a significant parameter. If the frequency of inline-dressing is set at its highest level tested in the experiment, the number of chips and cracks found on the slider will be at its minimum. When setting this parameter according to the result, the proportion of defects was found to decrease significantly (from 0.003 to 0.001, more than 50% reduction). However, setting the frequency of inline-dressing at a high level causes the productivity to decrease. It is thus necessary to compare the cost of productivity loss and the benefit of achieving better quality before implementing such cutting condition to all concerned machines.

6. Acknowledgments

The authors wish to express their gratitude to the harddisk drive manufacturer for allowing the experiments to be conducted. All members of the Machining Department are also thanked for their suggestions and collaborative efforts to make both experiments possible. Finally, the authors are also indebted to Associate Professor Dr. Suebsak Nanthavanij of Sirindhorn International Institute of Technology (SIIT), Thammasat University, for his encouragement to write this paper and providing invaluable suggestions.

7. References

[1] Levinson G., Process Optimization of Dicing Microelectronic Substrates, USA, Kulicke & Soffa Indutries Inc.

[2] Phichatwattana S., Apply of the Design of Experiment for Quality Improvement of Pull Strength of Read/write Head in Harddisk Drive, Thesis in Industrial Engineering, Chulalongkorn University, 1998.

[3] Vijchulata P., Blade Breakage Reduction in CSP Singulation Process, Thesis in Industrial Engineering, Chulalongkorn University, 2000.

[4] Montgomery, D.C., Design and Analysis of Experiments, 4th Edition, Wiley, New York, 1997.

[5] Montgomery, D. C. and G. C. Runger, Applied Statistic and Probability for Engineers, Wiley, New York, 1994.