The Development of Head Induced Crown Control in Hard Disk Drive Head Gimbal Assembly (HGA) Line

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Chesoh Saiyanee[1*], *Jaturonatee Jarumon* [2]

Abstract

The Fly Height Gap is the most important factor for Hard Disk Drive reliability because it is one of the key input process variables (KPIVs) for read-write process efficiency in terms of magnetic flux intensity. The Fly Height Gap is the distance between the slider or head and the magnetic surface of a disk while the Hard Disk Drive is operating. Many KPIVs have been studied and controlled in the Head Gimbals Assembly (HGA) process; Pitch-Roll Static Attitude, Slider Alignment and Induced Crown among others. Controlling the induced crown reduces the process variations from head to head and from hard drive to hard drive so that the Fly Height Gap and HGA crown variations can be reduced and controlled.

This research examines the potential KPIVs of induced crown, including the control limit of these variables. The Six Sigma methodology is employed to investigate the induced crown behavior in the HGA process. All key HGA processes are considered by following toolkits so as to find the potential KPIVs; Cause and Effect Diagram, Process Mapping, Prioritization. In totally, thirteen variables are considered in the experiment. The design of the experiment (DOE) methodology is employed to identify and optimize the potential KPIVs. The fraction factorial design model is employed to screen the potential KPIVs. The results indicate six variables which have a significant effect on the induced crown. Only three variables; Parameter C, E and K; are selected for process behavior study using the Full Factorial Design. The results indicate that two variables (C and E) have a significant effect on the induced crown. The Central Composite Design (CCD) experiment is employed as the final stage to identify the optimum machine set up points.

Keywords: Key input process variable (KPIV), Fly Height Gap, Pitch-Roll Static Attitude, Induced Crown, Fraction Factorial Design, Full Factorial Design and Central Composite Design

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[1] *Western Digital (Thailand) Co.,LTD, Bangpa-in Industrial Estate, Ayuthaya, Thailand*

[2] *Industrial Engineering Departments, Faculty of Engineering, Thammasat University, Pathumtanee, Thailand*

**corresponding author; e-mail: saiyanee.chesoh@wdc.com*

Introduction

The Hard Disk Drive is one of the most important components in a computer; whether it be a desktop or a notebook. Hard Disk Drive information capacity or area density is the main area of competition in this industry. Area density of the media is determined by the transducer's ability to read and write distinguishable transitions. An important factor affecting area density is the distance between the head and the recording surface, referred to as "fly height". Fly height stability is achieved through many factors such as the shape of the Air Bearing Surface (ABS) of the slider for desirable aerodynamic characteristics. The physical characteristic of the slider is its curvature along the length of the ABS from the leading end to the trailing end. The curvature is referred to as "crown".

Crown variation can be created by the slider fabrication process and Head Gimbals Assembly (HGA) process. The slider fabrication process results in crown variation from slider to slider. As is generally known, a positive crown will cause the slider to fly higher while a negative crown will cause the slider to fly lower, which is riskier for head-disk contact. Crown variation may be greater due to the HGA process.

The key HGA process is the slider-to-suspension bonding with epoxy which will be pre-cured by ultraviolet light. When a suspension flexure is epoxy bonded to a slider, the epoxy usually contracts as it cure, exerting a force along the slider's length. Slider-to-suspension circuits are connected with gold balls which will be bumped by a capillary tube. The last important process is the slider-to-suspension curing with Infrared ray. Since a suspension is normally formed from stainless steel, whereas the slider is comprised of a ceramic substrate, the suspension material has been observed to expand and contract at a different rate (different Thermal Expansion coefficient in response to temperature change).

The crown is one of the key process output variables (KPOV) of the HGA process which is controlled by the statistic process control (SPC). The HGA lines are shut down for process verification whenever a crown is out of the control limit. The ideal HGA process should maintain the crown of the slider, which is referred to as "slider crown". This means the induced crown in the HGA process should be zero.

The purpose of this research is to examine the KPIVs affecting the induced crown in the HGA process. Those potential KPIVs will be optimized through the Six Sigma tools for getting zero or least induced crown. The paper is organized as follows;

- HGA Process Overview
- Research Methodology
- Analysis and Key Findings
- Conclusion

HGA Process Overview

The HGA is the assembly part between the head or slider and the suspension. The assembly area on the suspension is called the Gimbals or Flexure.

The slider is the electrical component which converts the magnetic field into an electronic signal. It consists of a reader, a writer coil and an air bearing surface.

The suspension's function is to maintain the slider's angle, load force and the z-height of the head while the head is flying on the disk.

The HGA key processes are the following:

The Auto dispensing dispenses the adhesive, which consists of construct (UV) and conductive (silver) substances, and is added to the flexure area where the slider will be attached. See Figure 1.

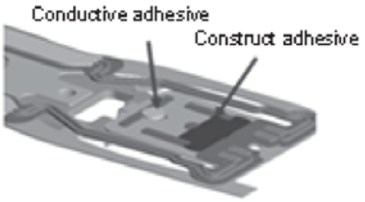


Figure 1. The adhesive is dispensed on the flexure.

The Auto slider bonding attaches the slider onto the flexure area which was dispensed during the auto adhesive dispensing operation and the adhesive pre-curing done using ultra-violet light. See Figure 2.

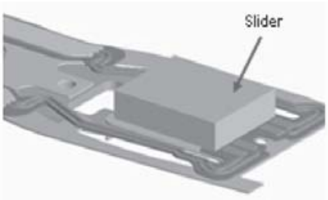


Figure 2. The slider is placed on the flexure and attached by the adhesive

The gold ball bonding uses the wire bond machine to do the gold ball bumping to connect the circuit between the slider and the suspension pads. See Figure 3.

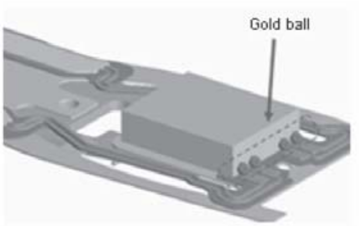


Figure 3. The gold balls are connected on the slider and the suspension circuit.

The infrared curing is used to cure the adhesive with infrared rays.

Fly Height Sensitivity

The fly height gap is the distance between the slider and the recording surface which is one of the KPIVs for the efficiency of the read-write process in terms of the magnetic flux intensity.

The electrical parameters which mainly relate to the fly height gap are the Pulse Width (PW), High Frequency Amplitude (HFA) and Low Frequency Amplitude (LFA).

The main KPIVs have been controlled to maintain the fly height gap at the designed target. The crown is one parameter which is relative to the fly height gap.

Research Methodology

The Six Sigma is a disciplined, data-driven approach and methodology for eliminating defects (driving towards six standard deviations between the mean and the nearest specification limit) in any process — from manufacturing to transactional and from product to service.

The statistical representation of the Six Sigma describes quantitatively how a process is performing. The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction through the Six Sigma tools. The key steps on the Six Sigma improvement framework are:

***D**efine* the process improvement goals that are consistent with customer demand and enterprise strategy.

***M**easure* the current process and collect relevant data for future comparison.

Analyze to verify the relationship and causality of the factors. Determine what the relationship is and attempt to ensure that all factors have been considered.

Improve or optimize the process based upon the analysis using techniques like DOE (Design of Experiments)

Control to ensure any variances are corrected before they result in defects. By setting up pilot runs to establish process capability and transfer to production. Then continuously measure the process, so that the control mechanisms are instituted.

A partial list of the specific tools used to support each of these steps is shown below.

Define

- Project Scope & Objective
- Base Line

Measure

- Data Collection
- Measurement System Analysis
- Cause and Effect Diagram
- Process Mapping

Analyze

- Prioritization Variables
- Capability Study
- Initial Failure Mode and Effect Analysis

Improve

- Design of Experiment

Control

- Capability Study
- Statistic Process Control
- Final Failure Mode and Effect Analysis

Key Metric

- ***Entitlement is 0.055 min*** which is calculated from 5% of the least HGA crown variation lines (4 lines).
- ***Base line is 0.094 min*** which is calculated from 95% of the remaining HGA lines (49 lines).
- ***Goal is 0.074 min*** which is set at 50% of the value between Entitlement and Base line.

Base Line / Data Collection

This research aims to reduce the induced crown variation in the HGA process through the prototype line. The prototype line is selected based on the downtime frequency due to crown out of control as per the Statistic Process Control (SPC) chart. The historical downtime frequency tracking report indicates line N is at the top of the Pareto chart as shown in Figure 4.

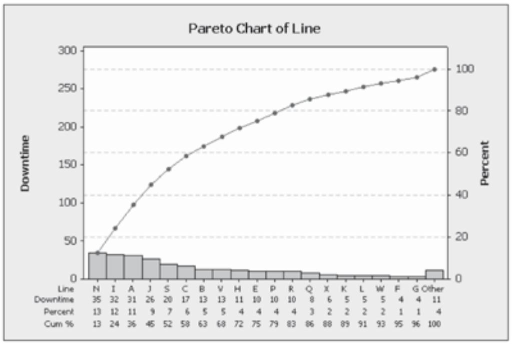


Figure 4. Crown Downtime Frequency Pareto

The descriptive induced crown statistical data of line N at the sampling plan 5 HGAs /shift/line is presented in Table 1.

Table 1. Descriptive Statistics of Induced Crown

Variables	**HGA**	**Slider**	**Induced** (minch)
Mean	1.2618	1.0911	0.1707
StDev	0.1020	0.0470	0.1184
Median	1.2293	1.0876	0.1306
Count	140	140	140

Cause and Effect Diagram

The Cause and Effect Diagram is used to explore all the potential KPIVs that result in a single effect to the induced crown (KPOV). It is used to search for the root cause, and identify the area where there may be problem causes. The cause & effect diagrams are arranged into four major categories; 4M – Manpower, Method, Material and Machinery.

Method

- Adhesive pattern
- Adhesive location : Y-dimension
- Adhesive size
  - UV adhesive curing
  - Gold ball bonding
  - Infrared adhesive curing

Machinery

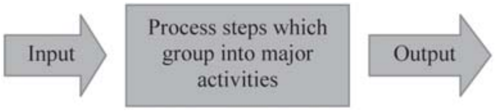
- Auto dispenser
  - Adhesive size (volume)
  - Adhesive pattern
- Slider bonding
  - Improper adhesive curing
- Gold ball bonding
  - Force controlling
- Infrared oven
  - Temperature un-constant

Material

- Suspension / Slider / Gold wire
- Adhesive

Process Mapping

The process map is used to analyze and understand the process. A high level enrolment process map is used in this research.



The processes, inputs and outputs (customer requirements) are identified, and the KPIVs are classified as process inputs which are controlled (C) or uncontrolled (U). The process map is linked to the prioritization matrix, FMEA, DOE and other the Six Sigma toolkits.

Prioritization Matrix

The prioritization matrix is used to compare the KPIV relative to the KPOV. It must be decided which of the KPIV are important to the induced crown. The prime source of information for the prioritization matrix comes from the process map. The key customer requirements (KPOV) from each process step are identified. Each KPOV is ranked in order and is assigned a priority factor on 1 to 10 scales. Then the correlation between each KPIV and KPOV is evaluated. The correlation scores cross multiplied with the priority factors and sums of each KPIV are shown in Table 2.

The funnel effect is the final step for the prioritization matrix and it indicates the potential KPIV for the initial FMEA analysis.

Table 2. Prioritized Scores

Potential KPIV	Score
Auto Adhesive Dispensing	
Parameter A	145
Parameter B	145
Parameter J	97
Auto Slider Bonding	
Parameter C	193
Parameter D	145
Parameter L	145
Parameter K	97
Gold Ball Bonding	
Parameter G	97
Parameter H	103
Infrared Curing	
Parameter F	147
Parameter E	147

Measurement System Analysis

The measurement system analysis (MSA) is an experimental and mathematical method of determining how much the variation within the measurement process contributes to overall process variability.

Repeatability is the inherent variation within the measurement instrument (gauge) and is represented by $\sigma_{\text{repeatability}}$, which is the standard deviation of the measurement instrument.

Reproducibility is the variation that results when different conditions are used to make the measurements of the same characteristic and is represented by $\sigma_{\text{reproducibility}}$.

The interference microscope (changed to the surface profile analyzer) is used as a measurement instrument. This instrument applies the interferometer theory by studying the interference (a light phenomena) between the front light wave beams which are coming from a single source but are divided into two beams by the interferometer (optical device). The parts are measured twice. First, the parts are measured at the HGA level. Then the same parts are torn down and measured at the slider level. The difference between the 1st and 2nd value is represented by the induced crown. The MSA is performed for both levels of measurements as shown in Table 3 below.

Table 3. Crown Measurement System Analysis

Parameter	HGA	Slider
% Study Variance (Gauge R&R)		
Total GR&R	4.64	4.62
Repeatability	4.51	3.97
Reproducibility	1.12	2.36
NDC (Number of Distinct Categories)	21	60

Based on the results, the measurement instrument is acceptable as per the AIAG standard criteria.

Design of Experiment

Design of Experiment (DOE) is a structured, organized method that is used to determine the relationship between the different factors (Xs) affecting a process and the output of that process (Y). It involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify the optimum conditions, the most and the least influential factors as well as other details such as the existence of interactions and synergies between factors.

The Design of Experiment is classified as 3 steps;

- *Fractional Factorial Design* is used to identify or screen only the important factors.
- *Full Factorial Design* is used to understand system or process behavior.
- *Central Composite Design* is used to optimize the process.

The KPIVs that were used in the experiment are listed in Table 2, including some interesting parameters which are observed with other products; process sequence (Parameter M) and adhesive pattern (Parameter N).

The part of the experiment that used the two level Fractional Factorial Design is listed in Table 4.

In total, there were sixteen experiments with thirteen parameters.

Table 4. Two Levels Fractional Factorial Design

Parameter	**-1**	**+1**	**Unit**
Auto Adhesive Dispensing			
Parameter A	5	13	mils
Parameter B	9	19	mils
Parameter J	400	490	kcPs
Auto Slider Bonding			
Parameter C	2.5	4.5	watts
Parameter D	0.5	2.0	sec
Parameter L	Remove	Install	-
Parameter K	0.5	5.0	mm
Gold Ball Bonding			
Parameter G	400	600	gram
Parameter H	70	85	gram
Infrared Curing			
Parameter F	15	20	min
Parameter E	110	135	C
Others			
Parameter M	Before	After	-
Parameter N	1line/1dot	1dot/1line	-

Table 5. ANOVA table for best model

Estimate Effects and Coefficient for Induced Crown

Term	**Effect**	**Coef**	**SE Coef**	**T**	**P**
Constant		0.09363	0.006918	13.53	0.000
C	-0.05100	-0.02550	0.006918	-3.69	0.005
E	0.02400	0.01200	0.006918	1.73	0.117
F	- 0.02525	-0.01263	0.006918	-1.82	0.101
K	-0.06375	-0.03188	0.006918	-4.61	0.001
L	-0.03550	-0.01775	0.006918	-2.57	0.030
M	-0.07925	-0.03962	0.006918	-5.73	0.000

S = 0.0276727 R-Sq = 89.95% R-Sq(adj) = 83.25%

Analysis of Variance for Induced Crown (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effect	6	0.061678	0.061678	0.0102796	13.42	0.000
Residual Err	9	0.006892	0.006892	0.0007658		
Total	15	0.068570				

Analysis and Key Findings

The experimental analysis identified only four parameters that influence induced crown. The significant parameters have a P-value less than 0.05 as shown in Table 5.

The main effects plot is used to understand the direction of the effect. Almost all of the parameters, except parameter E, show a lower response at the -1 level than at the +1 level. The main effects plot is shown in Figure 5.

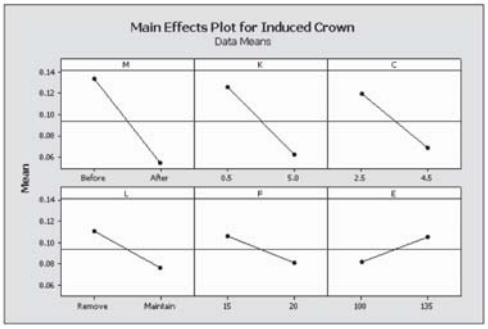


Figure 5. The Main Effects Plot for Induced crown

The General Linear Model is used to determine the practical significance of the term that we are interested in. This model provides the contribution percentage (proportion of the total Seq SS) for each variable as shown in Table 6.

Table 6. General Linear Model

Analysis of Variance for Induced Crown

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
C	1	0.010404	0.010404	0.010404	13.59	0.005
E	1	0.002304	0.002304	0.002304	3.01	0.117
F	1	0.002550	0.002550	0.002550	3.33	0.101
K	1	0.016256	0.016256	0.016256	21.23	0.001
L	1	0.005041	0.005041	0.005041	6.58	0.030
M	1	0.025122	0.025122	0.025122	32.81	0.000
Error	9	0.006892	0.006892	0.000766		
Total	15	0.068570				

Contribution Percentages

Source	**Seq SS**	**%Contribution**
C	0.010404	15.17
E	0.002304	3.36
F	0.002550	3.72
K	0.016256	23.71
L	0.005041	7.35
M	0.025122	36.64
Error	0.006892	10.05
Total	0.068570	100.00

Table 7. ANOVA table for best model

Estimate Effects and Coefficient for Induced Crown

Term	Effect	Coef	SE Coef	T	P
Constant		0.09665	0.004477	21.59	0.000
C	-0.04750	-0.02375	0.004477	-5.31	0.006
E	0.12105	0.06052	0.004477	13.52	0.000
C*E	-0.02195	-0.01098	0.004477	-2.45	0.070

S = 0.0126619 R-Sq = 98.19% R-Sq(adj) = 96.83%

Analysis of Variance for Induced Crown

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C	2	0.004512	0.004512	0.004512	28.15	0.006
E	1	0.029306	0.029306	0.029306	182.80	0.000
C*E	1	0.000964	0.000964	0.000964	6.01	0.070
Error	4	0.000641	0.000641	0.000160		
Total	7	0.035424				

Table 8. General Linear Model

Analysis of Variance for Induced Crown

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C	2	0.004512	0.004512	0.004512	28.15	0.006
E	1	0.029306	0.029306	0.029306	182.80	0.000
C*E	1	0.000964	0.000964	0.000964	6.01	0.070
Error	4	0.000641	0.000641	0.000160		
Total	7	0.035424				

Contribution Percentages

Source	Seq SS	%Contribution
C	0.029306	82.754
E	0.004512	12.742
C*E	0.000964	2.721
Error	0.000641	1.782
Total	0.035424	100.00

Since this HGA product was launched on the market several years ago, the process sequence was ignored in this research because the process must be optimized for other cross defects before implementation. The side light guide set up was also maintained since the experimental analysis indicated that the process provided a lower induced crown when the side light guide was installed.

The selected parameters for studying the process behavior via the Full Factorial Design were parameters C, E and K. There were 8 experiments with three parameters in total. The experimental analysis identified only two parameters that influenced the induced crown. The significant parameters with a P-value of less than 0.05 are shown in Table 7. The General Linear model indicated that parameter E was the most influential parameter for induced crown with a 82.75% contribution as shown in Table 8.

The main effects plot in Figure 6 shows that the response of parameter C at the +1 level is lower than at the -1 level while parameter E shows opposite results. The cube plot, in Figure 7, shows that the machine set ups which provided the least induced crown are low E and high C.

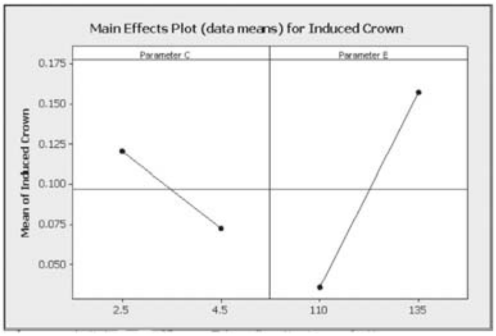


Figure 6. Main Effects Plot for Induced Crown

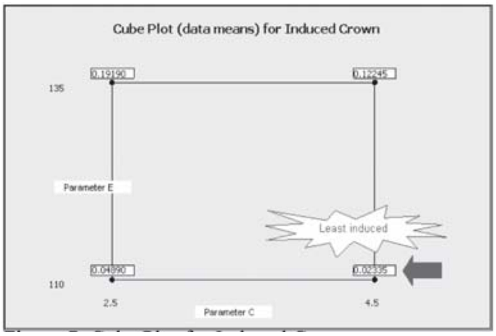


Figure 7. Cube Plot for Induced Crown

Finally, only parameters C and E are factors that influence the induced crown. The Central Composite Design was used at this stage to optimize these parameters to minimize the induced crown. In all, there were fourteen experiments with two parameters and three levels (-1, 0, +1). The statistical analysis indicates the relation between the induced crown and these parameters as per the following equation:

$$Y = 0.7221 + 0.2419C - 0.0225E + 0.0021C^2 + 0.0001E^2 - 0.0023CE$$

The contour plot for the induced crown is shown in Figure 8. The blue zones represent the machine set ups which provided an induced crown value lower than 0.15 min. Three machine set up points were considered to predict responses. The predicted results indicate that set up no.3 (C = 4.5, E = 125) provides the lowest induced crown. This set up was tested during the experiment before being implemented into the actual HGA process.

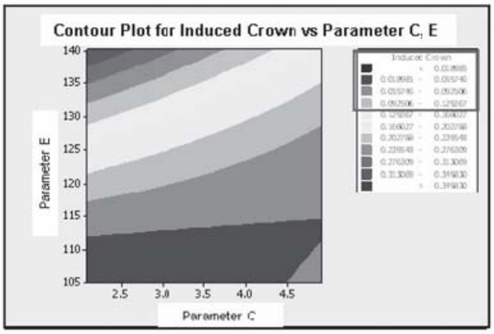


Figure 8. Contour Plots of Induced Crown vs Parameters C and E.

Conclusion

The Six Sigma toolkits of Measurement and Analysis Phase were used to find the potential parameters for the experimental design.

The Design of Experiment via Fractional Factorial was designed for thirteen potential parameters (sixteen replicates). The experimental analysis indicated that six out of the thirteen studied parameters (M, K, C, L, F and E) influence the induced crown. Three parameters (C, E and K) were selected for the process behavior study using the Full Factorial Design. The results indicated that two variables, C and E, had a significant effect on induced crown. The Central Composite Design experiment was used as a final stage to identify the optimum machine set up points.

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